

# The application of electrolytic manganese as a substitute ferro alloy

B. C. KAR and T. BANERJEE

INDIA has got vast deposits of high grade and low grade manganese ores which are among the most important minerals of the country. High grade ores, which are mined annually to the extent of more than a million tons, are generally exported or utilised for the production of standard grade ferromanganese. Investigations have been undertaken in N.M.L. and other places in India to upgrade these low grade manganese ores by different methods of beneficiation<sup>1</sup> and to utilise them for producing standard grade ferromanganese. National Metallurgical Laboratory has also developed a method to produce electrolytic manganese from low grade ores.<sup>2-4</sup> Electromanganese is now being produced at the rate of 50 kg per day in one cell in the pilot plant set up in the laboratory. This manganese is being utilised for producing nickel-free stainless steel which has already been developed in N.M.L. and also for other experimental purposes, in addition to a portion of the same being supplied to defence and other industries.

In India, a top priority programme for alloy and other steels for defence requirements has been initiated by the Steel and Mines Ministry of the Government of India. Several alloys and special steel plants have already been set up both in the public and private sectors and started production and more are coming up with or without foreign collaboration in the Fourth Five-Year Plan.

With the development of so many alloys and special steel industries in India, she will have to produce or import low carbon and medium carbon ferromanganese.

The purposes of this article is to discuss how far electrolytic manganese can substitute low carbon, medium carbon and also high carbon ferromanganese in different steel industries in India. This will be done on the basis of the experimental results obtained by using electrolytic manganese in place of various grades of ferromanganese by the steel industries in overseas countries.

Manganese is essential for the manufacture of steel. Approximately thirteen pounds of manganese are necessary for the production of one ton of steel. It acts as a deoxidising and desulphurising agent in steel and

offers it the properties of resistance and ductility specially suitable for hot working. Manganese as an alloying element increases the toughness and strength of steel. It is added to steel as different grades of ferromanganese, spiegeleisen and silicomanganese.

Electromanganese is supplied as chips or platelets, 1/16 to 1/8" thick and about 1-2" in the greatest dimension. The analysis of electrolytic manganese is :

Sulphur as sulphide	0.018%	Max.
Sulphur as sulphate	0.006%	"
Iron	0.001%	"
Carbon	0.005%	"
Heavy Metals	0.005%	"
Phosphorus	Not detectable in 25 gm sample	
Silicon	Spectrographic traces only	
Hydrogen	0.015%	Max.
Manganese	99.9%	Min.

A special grade of electromanganese, classed as "hydrogen removed", which contains less than 0.00075% (7.5 parts per million) of hydrogen is available for a small premium over the base prices).

India produces standard ferromanganese conforming to IS : 1171-1964.

## Use of electrolytic manganese in place of ferromanganese in different steel industries

### *Stainless Steel*

The Rustless Iron and Steel Corporation<sup>5</sup> made a large number of heats of different types of stainless steels in basic electric furnace, in which low carbon ferromanganese was replaced by electrolytic manganese.

The log of preparing a heat using electrolytic manganese did not actually differ from that using ferromanganese. In both cases manganese was added in the furnace 5-10 min. before tap and the bath was stirred. The percentage recovery of manganese from the electrolytic manganese was invariably as high as from ferromanganese and was found to be satisfactory whether the addition was made in the furnace or in the ladle. Table I gives the recovery of manganese from electro-

Dr B. C. Kar and Dr T. Banerjee, Scientists, National Metallurgical Laboratory, Jamshedpur.

lytic manganese and low carbon ferromanganese added in the furnace or in the ladle.

TABLE I Recovery of manganese

	Furnace addition		Ladle addition	
	No. heats	Average Mn recovery %	No. heats	Average Mn recovery %
Electrolytic Manganese	63	87.8	6	89.9
Low carbon ferromanganese	63	84.0	15	72.7

The use of pure manganese in place of ferromanganese has not brought about any adverse change in the quality and hot workability of the steel.

The corporation has pointed out that the electrolytic manganese has the following advantages over ferromanganese in making stainless steel heats.

1. Electrolytic manganese can be stored in less space and weighing can be done more easily.
2. The recovery of manganese in the case of electrolytic manganese is more uniform from heat to heat and the average recovery is higher.
3. For equivalent manganese additions, 20 per cent less weight is necessary in the case of electrolytic manganese, with a corresponding decrease in chilling of the heat.
4. Less time is required to prepare a heat with electrolytic manganese owing to easy handling, weighing and shovelling of the product. Electrolytic manganese melts more quickly than ferromanganese.
5. By using electrolytic manganese chips, the carbon and phosphorus content of heats do not change appreciably, so that the heats can be made according to specifications more easily and greater proportions of scrap may be used.

Electrolytic manganese is superior to low carbon ferromanganese in the production of stainless steels and the company has switched over entirely to the use of pure manganese chips in alloy steels in place of ferromanganese, the price of electrolytic manganese coming down to the level of low carbon ferromanganese with its increase in production.

Universal Cyclops Steel Corporation<sup>5</sup> used electrolytic manganese in making 310 and 307 modified stainless welding wire to very low phosphorus maximum specification used by the Navy and Army for welding combat ships and tanks. The specification of these two types are given in Table II

These specifications require low percentage of C and P. Experiments were, therefore, made with electrolytic manganese which is virtually free from C and P. Electrolytic manganese addition was made in the basic electric furnace in exactly the same manner as the low carbon ferromanganese having the average composition 83 per cent manganese, 0.09 per cent carbon and 0.18 per cent phosphorus.

The conclusion drawn by the company from more than 100 heats in which electrolytic manganese was used in place of low carbon ferromanganese may be stated as follows :

TABLE III Manganese recoveries on type 310 modified steel

Electrolytic manganese		Ferromanganese	
Heat no.	Recovery per cent	Heat no.	Recovery per cent
A-1018	84.2	A-1019	91.9
A-1020	89.0	A-1039	95.6
A-1056	100.0	A-1057	77.7
A-1212	93.1	A-1225	78.2
A-1224	94.9	A-1396	100.0
A-1226	83.6	A-1397	94.0
A-1388	88.2	A-1398	84.7
Average	90.0	Average	88.8

TABLE II Chemical specification of 310 and 307 modified types of steel

Element	C %	Mn %	Si %	S(max.) %	P(max.) %	Cr %	Ni %
Type 310 (modified)	0.07/ 0.15	1.50/ 2.00	0.25/ 0.60	0.025	0.025	26.5 min.	21.00 min.
Type 307 (modified)	0.07/ 0.15	3.75/ 4.75	0.25/ 0.60	0.030	0.050	19.50/ 21.50	9.0/ 10.5

The use of electrolytic manganese in place of low carbon ferromanganese results in obtaining appreciable lower phosphorus and carbon contents in the finished steel. Though the difference may not appear to be great, there are many instances in which it represents the difference between meeting and missing the specifications.

The recoveries of manganese are almost the same in both cases as shown by Table III

Macroetching showed no apparent difference in quality resulting from the form of manganese used and there is no appreciable difference in the hot workability of steels made with pure manganese and with ferromanganese.

From the operational point of view, electrolytic manganese is definitely superior to ferromanganese. Electrolytic manganese goes into solution faster than ferro and the heat is prepared in a shorter time compared to ferromanganese.

On consideration of these advantages, Universal Cyclops Steel Corporation is now taking part of their manganese requirement as electrolytic manganese.

The Timken Roller Bearing Co.<sup>6</sup> made in the basic electric furnace five types of stainless steel of the com-

position given in Table IV using electrolytic manganese.

In 81 heats producing 2146 tons of steel, 50,738 pounds of electrolytic manganese were used in place of low carbon ferromanganese. When using pure manganese in place of ferromanganese, it was concluded that electrolytic manganese had certain advantages over the ferro grades and no disadvantages: the advantages are:

Electrolytic manganese is easy to store, handle, calculate and weigh. In melting 347 type, the absence of C in electrolytic manganese is a distinct advantage.

Electrolytic product does not cause any change in hot-workability, etch quality and surface condition of the steel.

The manganese recovery in the case of electrolytic manganese was slightly higher, 99.6 per cent in type 304 and 96.9 per cent in type 347 whereas the corresponding figures in the case of low carbon ferromanganese were 96.8 and 95.1 per cent respectively.

From the results of tests with electrolytic manganese it is evident that electrolytic manganese is entirely satisfactory as a substitute for low carbon ferromanganese.

TABLE IV Types of stainless steel made by the Timken Roller Bearing Company

Type	C %	Mn %	P %	S %	Si %	Cr %
303	0.08 max.	0.80/ 1.00	0.12/ 0.15	0.025 max.	0.35 min.	17.50/18.50
304	0.05/ 0.07	0.40/ 0.50	0.025 max.	0.025 max.	0.40/ 0.50	18.50/19.25
347	0.07 max.	1.50/ 1.75	0.030 max.	0.030 max.	0.50/ 0.65	18.00/19.00
416	0.09/ 0.11	0.70/ 0.80	0.025 max.	0.24/ 0.26	0.35 max.	12.50/13.50
Timken alloy						
16-25-6	0.12 max.	2.00 max.	0.030 max.	0.030 max.	1.00	15.00/17.50
Type	Ni %	Mo %	Cb %	Sc %	Cu %	N <sub>2</sub> %
303	9.00/9.50	—	—	0.22/0.25	0.50 max.	—
304	9.25/9.75	—	—	—	—	—
347	12.25/12.75	—	0.60/0.80	—	—	—
416	0.25	0.30/0.40	—	—	—	—
Timken alloy						
16-25-6	24.00/27.00	5.50/7.00	—	—	—	0.10/0.20

Similar results were obtained by the Jessop Steel Co., Rotary Electric Steel Co. and other companies using electrolytic manganese in place of low carbon ferromanganese in different types of stainless steel industries.

### Tool steels

Henry Disston and Sons Inc.<sup>7</sup> produced in basic electric furnace different grades of steel ranging from structural steels of the S.A.E. specifications to various grades of tool steels including high speed steel. Electrolytic manganese was used by them in place of standard 80% ferromanganese normally used and the steels produced contained manganese from 0.25/0.35% to 11.5/14.0 per cent. They made a series of tests using electrolytic manganese in place of ferromanganese in the following grades of steel: alloy saw steel, alloy die steel, low alloy structural steel, Hadfield manganese steel and modified 18/8 stainless steel. The steels made with electrolytic manganese and with ferromanganese were identical with respect to hot and cold workability, macrostructure and other physical properties developed by standard heat treatments.

There is no appreciable difference in the recovery of manganese between the electrolytic product and the ferromanganese.

For pure manganese, efficiencies of recovery were almost 100 per cent in the case of alloy saw steel (0.75 C, 0.30/0.40 Mn), alloy chisel steel (0.34 C, 0.35/0.50 Mn); and low alloy structural steel (0.43 C, 1.00/1.30 Mn); close to 100 per cent in the case of Hadfield manganese steel (1.30 C, 11.50/14.0 Mn); 89 per cent in the case of modified 18-8 stainless steel (0.08 C, 1.30/1.65 Mn) and 93 per cent in the case of alloy die steel (1.00 C, 11.00/11.25 Mn).

### Low alloys steel

Babcock and Wilcox Co.<sup>8</sup> produced grades of steel ranging from low-alloy steel of the SAE types through intermediate alloy steels for high temperature service up to austenitic grades.

A trial heat in which pure manganese was used was of a modified 52100 steel for high duty ball bearings made in an electric furnace having the following chemical analysis per cent.

C. — 0.92/1.02; Mn—0.95/1.25; P—0.025 (max.)  
S. — 0.025(max.); Si 0.50/0.70; Cr—0.90/1.15;  
Ni — 0.25(max.); Mo—0.08 (max.) and Cu—0.25 (max.)

The efficiency of manganese recovery was 100 per cent.

From the experimental heats the plant metallurgist concluded that there was essentially no difference between the two products obtained by pure manganese and ferromanganese in the hot working or deep-etch characteristics. It was stated that because of the purity of electrolytic manganese the material was more attractive.

### Low carbon rimmed and killed steels

The Stanley Works<sup>9</sup> used electrolytic manganese in place of ferromanganese on basic open hearth in the manufacture of low carbon rimmed and killed steels. The specifications of the steels selected for experimental work are given in Table V.

TABLE V Specifications of steels for experimental heats

Type	C	Chemical analysis per cent		
		Mn	P. max.	S. max.
Rimmed	0.07/0.10	0.32/0.40	0.012	0.040
Rimmed	0.05/0.08	0.25/0.35	0.012	0.040
Killed	0.12/0.16	0.70/0.90	0.020	0.035

In the case of the 0.07/0.10 C, 0.32/0.40 Mn steel, it has been the practice to add standard ferromanganese to the ladle. With 0.05/0.08 C, 0.25/0.35 Mn steels, the practice has been to add medium carbon ferromanganese to the ladle. For 0.12/0.16 C, 0.70/0.90 Mn killed steel it is customary to add part of the manganese to the furnace as standard ferromanganese and the balance to the ladle as medium carbon ferromanganese together with 50 per cent ferrosilicon. In the experimental heats for all the above mentioned steels, electrolytic manganese was substituted for the ladle addition, the chips being shovelled into the steam.

### Rimmed heats

Rimming heats were made with electrolytic manganese and were compared with ferromanganese. Table VI summarises the results obtained.

The average efficiency of recovery of electrolytic manganese was 66 per cent, as compared with 51 per cent for ferromanganese. The explanation for the superior efficiency of recovery of the electrolytic manganese may be due to its fine state of division and high purity with greater ease of solution.

The distribution of manganese through the heat was about the same for the electrolytic and ferromanganese.

The steel treated with standard ferromanganese averaged 1 point higher in carbon than the steel treated with electrolytic manganese.

Two experimental heats were made to the lower carbon and manganese specification (0.05/0.08 C, 0.25/0.35 Mn) using electrolytic manganese and compared with two heats made according to regular practice using medium carbon ferromanganese. The average recovery of manganese was 56 per cent in each case and final carbon was lower by 2 points in the steel treated with electrolytic manganese.

### Killed heats

Two heats of SAE X 1015 killed steel (0.12/0.16 C,

TABLE VI Efficiency of recovery of manganese in rimming heats

(a) Electrolytic manganese

Heat No.	Chemical analysis per cent						Steel made lb	Manganese added		Manganese recovered points	Manganese recovery per cent
	C	Mn	P	S	Cu	Ni		lb	points		
Specified	0.07/0.10	0.32/0.40	0.012	0.040	—	—					
25122	0.08 0.08	0.40 0.39	0.009	0.027	0.19	0.08	122 800	500	41	28	68
15142	0.08 0.09	0.39 0.38	0.010	0.036	0.15	0.08	120 900	400	33	25	76
15149	0.09 0.09	0.36 0.36	0.009	0.027	0.14	0.10	135 850	500	40	26	65
15152	0.08 0.08	0.36 0.34	0.009	0.036	0.14	0.08	121 000	450	37	23	62
15153	0.10 0.10	0.34 0.32	0.009	0.034	0.14	0.12	124 000	350	28	17	61
15162	0.10 0.10	0.36 0.34	0.008	0.028	0.17	0.10	119 650	400	33	23	70
15164	0.08 0.07	0.37 0.37	0.009	0.035	0.20	0.16	125 300	400	32	20	62
Average	0.09		0.009				124 214	428	35	23	66

(b) Standard ferromanganese

25126	0.10 0.10	0.40 0.38	0.009	0.035	0.14	0.08	123 300	675	44	26	59
25144	0.10 0.10	0.34 0.32	0.010	0.035	0.19	—	123 800	650	42	20	48
15139	0.09 0.08	0.35 0.33	0.009	0.036	0.17	0.12	121 000	700	46	20	44
15147	0.10 0.10	0.38 0.36	0.009	0.039	0.15	0.09	122 600	650	42	19	45
15150	0.11 0.10	0.42 0.40	0.010	0.036	0.15	0.10	122 000	650	43	25	58
151154	0.10 0.10	0.42 0.40	0.101	0.040	0.18	0.09	129 000	700	43	25	58
15155	0.10 0.10	0.34 0.34	0.011	0.034	0.18	0.22	119 800	650	43	20	47
15156	0.10 0.10	0.38 0.39	0.029	0.027	0.11	0.08	122 700	700	46	24	52
15158	0.10	0.38	0.008	0.038	0.17	0.08	122 650	650	42	22	52
Average	0.10		0.009				122 980	669	43	22	51

0.70/0.90 Mn) were made, in which electrolytic manganese was substituted for medium carbon ferromanganese in the ladle. These were compared with the two heats made according to regular practice as shown in Table VII.

Unlike the heats made with ferromanganese heat time can be reduced when electrolytic manganese is used, there being no carbon pick up in this case. A considerable time is expended in eliminations of the final points of carbon necessary in the case of ferromanganese addition due to carbon pick up.

Steel castings

Atlas Steel Casting Co.<sup>10</sup> made in acid electric and acid open hearth furnaces, plain carbon steel in the low and medium carbon ranges with an occasional heat of alloy steel. Nickel, vanadium and molybdenum were the alloying metals ordinarily used. All the steels produced were used in the foundry for casting for the Navy. The usual furnace charge was scrap having low phosphorus and sulphur content.

Standard ferromanganese was normally used to pro-

TABLE VII Efficiency of recovery of manganese in killed heats

Heat no.	Chemical analysis per cent*		Steel made lb	Manganese added				Total points	Manga-nese reco-very point	Manga-nese reco-very per cent
	C	Mn		Furnace lb points	Ladle lb points					
Specified	0.12/0.16	0.70/0.90		Standard ferro (80 per cent)		Electrolytic (99.95 per cent)				
75176	0.12	0.81	129,200	800	50	600	46	96	63	66
75193	0.12	0.79	134,385	800	48	600	44	92	57	62
Average	0.12	0.78	131,792	800	49	600	45	94	60	64
				Standard ferro (80 per cent)		Medium carbon ferro (82 per cent)				
65111	0.16	0.94	122,940	800	52	800	53	105	70	67
75121	0.15	0.90	131,385	1100	67	800	50	117	75	64
Average	0.15	0.91	127,162	950	60	800	51	111	72	65

\*Elements other than C and Mn are omitted here. All were within specification.

vide the specified manganese content and recarburise the steel. As in the acid practice phosphorus cannot be removed and the specification of phosphorus is low, the use of electrolytic manganese in place of ferromanganese being desirable. Metallurgists in the Atlas Steel Co. were interested in the possibilities of obtaining improved physical properties with electrolytic manganese. Table VIII gives the chemical and physical recovery of manganese and other data of the acid open hearth heats with electrolytic manganese. According to the company all heats using electrolytic manganese have good physical properties.

Electrolytic manganese was added in the ladle for open hearth heats and in either ladle or on top of the slag for electric furnace heats. Manganese recovery was at least as good as that obtained from ferromanganese. When electrolytic manganese was added either in the furnace or in the ladle in paper bags, efficiency appeared to increase. In the production of low carbon steels, electrolytic manganese when added to the ladle had a definite advantage over low and medium carbon ferromanganese. In some cases steel made with electrolytic manganese was found to possess superior physical properties to the product made with ferromanganese.

When the electrolytic manganese was added in the ladle, there was no evidence of the undue chilling of the metals or of hard spots in the castings owing to manganese segregation. The melter in the open hearth considers it a great advantage over the ferro.

After making a number of acid open hearth and

acid electric furnace heats in which electrolytic manganese was used in place of standard ferromanganese, the technical and operating man of Atlas Steel Casting Co. concluded that electrolytic manganese is entirely acceptable as a substitute for ferromanganese.

Detroit Steel Casting Co.<sup>10</sup> made plain carbon and low alloy steel in acid open hearth and acid electric furnace for casting into rollers, die blocks and a variety of other materials. The specification of the alloy steel was C-0.30-0.35, Mn-1.00, Si-0.45-0.50, Cu-0.55-0.65, Ni-0.50-0.55 and Mo-0.10 and the specification of plain carbon steel was C-0.24-0.28, Mn-0.65-0.70 and Si-0.30-0.35, phosphorus and sulphur content of all heats were within the specified 0.05% maximum for each element.

The charge in the electric furnace was high quality scrap, low in phosphorus and sulphur. Standard ferro was used, part in the furnace and part in the ladle, to deoxidise, recarburise and to provide manganese according to specification.

From the different heats prepared for low alloy steel and plain carbon steel with ferromanganese and electrolytic manganese it was observed that there was practically no difference in the recovery of manganese with ferromanganese and electrolytic manganese, 77.4% in the case of electrolytic manganese and 77.7% in the case of ferromanganese. The two alloy heats, one made with electrolytic manganese and other with ferromanganese behaved similarly in pouring, fluidity and soundness. Pouring characteristics and soundness for all the four carbon steel heats were normal. After various heat

TABLE VIII Acid open hearth heats with electrolytic manganese

Heat no.	Chemical analysis, per cent					Heat time hr. min.	Electro- lytic Mn added lb	Mn reco- very, per cent	Tensile strength lb/sq. in	Yield point lb/sq. in	Elen- gation in 2 in %	Reduc- tion in area %
	C	Mn	Si	P	S							
Specified *	0.20/ 0.25	0.60/ 0.80	0.30/ 0.45	0.05 max.	0.05 max.				60 000 min.	30 000 min.	24 min.	35 min.
1806	0.21	0.76	0.34	0.026	0.032	5 25	313	91.2	70 500	38 700	35.0	57.1
1807	0.23	0.78	0.35	Not determined		5 35	313	93.2	70 250	36 600	28.5	39.7
2212	0.17	0.72	0.34	0.027	0.037	4 55	290	96.0	67 000	35 450	31.5	41.9
2213	0.16	0.70	0.35	0.027	0.037	5 15	290	95.1	66 000	37 000	33.0	49.4
2216	0.20	0.73	0.40	0.029	0.032	5 00	290	89.4	72 150	38 050	34.0	55.2
2217	0.20	0.74	0.47	0.029	0.032	5 00	290	98.6	71 700	41 600	29.0	39.7
Average	0.20	0.74	0.38	0.028	0.034	5 12	298	93.9	69 600	38 400	31.8	47.2
Specified	0.40/ 0.45	0.60/ 0.80	0.30/ 0.45	0.05 max.	0.05 max.							
2147 †	0.47	0.64	0.40	0.030	0.035	4 55	250	91.5	92 400	46 250	18.5	24.5

\* All heats to this specification fully annealed at 1650°F for 5 hours and drawn at 1100°F for 4 hours.

† Same heat treatment as\*

Chemical specifications are plant specifications. The physical specifications given are for US Navy class B Steel, they are the minimum aimed at in the plant.

treatments the two alloy heats show very little difference in properties such as ultimate strength, yield strength, elongation, reduction in area and Rockwell B hardness. The physical properties of carbon steel heats using electrolytic manganese and ferromanganese also compared closely ; however electrolytic manganese heats showed consistently higher ductility and a quicker response to heat treatment. This higher and more quickly attained ductility was also reflected in the consistently higher quality factor for the electrolytic manganese heats. Quality factor was calculated for each test bar according to the formula.

$$\text{(Ultimate strength + yield strength)} \times \text{per cent}$$

$$Q.F. = \frac{\text{Elongation}}{2 \text{ (100 per cent reduction on area)}}$$

The micro-examination of test bars obtained from electrolytic manganese and ferromanganese heat for alloy and carbon steels showed the structure to be very similar, regardless of the form of manganese used particularly after heat treatment.

The shape, size and distribution of inclusions in the carbon steels were similar. In the alloy steel, the sample treated with electrolytic manganese contained both large and small rounded inclusions of mixed type predominantly elongated and in chain formation. The

rounded inclusions were within the ferrite grains and the chains followed the grain boundaries. In the alloy steel the difference in the inclusion type is probably due to the fact that in the electrolytic manganese heat, no Alsifer addition was made whereas the ferromanganese heat was typical of the acid steel overkilled with aluminium or its equivalent.

National Malleable and Steel Casting Co., carried out a large number of experiments dealing with the application of electrolytic manganese to steel foundry practice with the object of establishing the technological acceptability of electrolytic manganese in iron and steel industries.

They used electrolytic manganese in acid electric steel foundry practice particularly with reference to the effect of hydrogen present in electromanganese.

Their observations may be briefly stated as follows :

The effect of electrolytic manganese upon higher critical medium manganese steel casting was satisfactory. The castings were acceptable from every point of view.

Tempering of normalised test bars at 200°C improved the ductility of the castings, may be due to the fact that the effect of such treatment removes hydrogen or other gas.

Although the castings made with electrolytic manganese were prone to retain slightly more hydrogen than castings made with ferromanganese, the hydrogen

content was still within the permissible range and had no deleterious effect upon the finished castings.

Efficiencies of the recovery of manganese depend upon the technique of adding the material to the furnace. Manganese was added in burlap bags so that it may pass under the slag as quickly as possible. When electrolytic manganese was added in the ladle, the efficiency of recovery was increased.

Thus it is shown that electrolytic manganese can be used successfully in place of ferromanganese in acid practice, the quality of steel and recovery of manganese, both being satisfactory.

Jones and Laughlin Steel Corporation<sup>7</sup> made eleven blows of screw steel using electrolytic manganese and standard ferromanganese in acid Bessemer converter; efficiency of recovery of electrolytic manganese is equivalent to that of ferromanganese when coal is added ahead of pure manganese as the stream of blown metal flows into the ladle. Using this practice recovery with electrolytic manganese was 61.3 per cent as compared with 62.5 per cent in the case of standard ferromanganese. Electrolytic manganese gave a product with excellent rolling properties.

Five companies<sup>7</sup> participated in testing the use of electrolytic manganese in cupola practice. Electrolytic manganese was used for testing the manufacture of gray cast iron valves for water and steam lines. Tests showed that the valves in which electrolytic manganese was used were found to be satisfactory.

Skinner Engine Company made alloy cast iron containing nickel, chromium and molybdenum for engines operating at a temperature of 650°F and higher. By using electrolytic manganese, close control of manganese was obtained whereas considerable variation was observed using ferromanganese.

Electrolytic manganese can also be used successfully in the making of malleable iron in the air furnace.

#### Cost comparison

The present prices of standard ferromanganese, medium carbon ferromanganese, low carbon ferromanganese and electrolytic manganese metal in U.S.A. as on December 13, 1965 are as follows :

The price for standard 78 per cent lump ferromanganese (C-7% approx.) is \$ 181 per gross ton. A gradual increase in price is allowed for successively finer crushed sizes, reaching a maximum for 150 to 200 mesh material. The price per lb of contained manganese would be 10.4 cents (Rs 0.49) (1 \$ = 100 cents = Rs 4.726).

The price for carload (25 gross tons), lump medium carbon ferromanganese (Mn 80-85%, C-1.25-1.5% max.) is 15.8 cents (Rs 0.75) per pound of contained manganese f.o.b. producing plant. The price increases from lump to finer crushed sizes.

The price for regular grade low carbon ferromanganese (Mn 85-90%, C-0.10% max.) in lump, 30 000 lb lot and packed, is 27.70 cents (Rs 1.31) per lb of contained manganese, f.o.b. producing plant. The price increases with decreasing carbon maximum specification and by about 3-4 cents in passing from lump to finer size material.

The price for special grade low carbon ferromanganese (Mn-90% min. C-0.10% max. P-0.06% max.) is 30.70 cents (Rs 1.45) per lb of contained manganese under the same condition as the regular grade.

Electrolytic manganese having a purity of at least 99.9% has a price of 30.25 cents (Rs 1.43) in 30 000 lb quantities in pallet boxes f.o.b. producing plant. The price of electrolytic manganese will gradually decrease as the capacity and number of producing plant increases.

Practically the only hurdle in using electrolytic manganese in place of medium and standard ferromanganese is its comparatively high price. There is probably no consumer who would not use electrolytic manganese in preference to ferromanganese if prices were competitive.

Fortunately the trend in the price of the electrolytic manganese has been gradually downward and its production is gradually increasing. Commercial production, begun in U.S.A. in 1939, was very small, of the order of 1 000 lb a day. Production and consumption in 1962 were estimated as approaching 100 tons per day. Production and consumption are rapidly increasing. In 1942 the price was 40 cents (Rs 1.81) a lb and presently it is 30 cents (Rs 1.41) a lb. In India estimations of the cost of electrolytic manganese have been carried out in the National Metallurgical Laboratory on the basis of operating data from its pilot plant for the production of electrolytic manganese from low grade Indian ores. On a 10-ton per day basis the cost of production in India comes to Rs 1301.00 (Rs 0.58/lb). A substantial reduction in the price of electrolytic manganese can be expected when the metal is produced on a large enough scale, to attain minimum production costs.

Owing to the high cost of electrolytic manganese it has not yet been able to replace standard and medium carbon ferromanganese in steel production in spite of some of its distinct advantages. On a price basis, it is with grades other than standard and medium carbon ferromanganese that electrolytic manganese competes.

Electrolytic manganese is now invariably used in place of low carbon ferromanganese, particularly those of 0.06, 0.1% carbon content where the price is comparable. On a performance basis it is being used gradually in greater volume to compete with medium carbon ferromanganese.

#### Conclusions

From the tests recorded in this paper it is evident that electrolytic manganese cannot only be substituted satisfactorily for different grades of ferromanganese in steel industries, but also in many cases it is advantageous to use electrolytic manganese as the form of manganese addition to steel instead of ferromanganese normally used in different steel practices.

For the manufacture of steels and alloy steels with rigid specifications for low carbon and phosphorus, specially for defence purposes, the use of electrolytic manganese is gradually becoming a "must".

India with her abundant resources of low grade man-



ganesse ores, cheap labour and high priced standard ferromanganese, is in a favourable position to take to electrolytic manganese for her steel industries. With the development of power generation and transmission, cost of electricity is likely to be cheap in India which will further lower the cost of production of electrolytic manganese. In view of this it is quite likely that in foreseeable future, high purity electrolytic manganese utilising the low grade Indian ores may even compete with medium carbon ferromanganese in steel industries.

#### Acknowledgement

The authors' grateful thanks are due to Dr B. R. Nijhawan, Director, National Metallurgical Laboratory, for his many valuable suggestions and helpful criticism of this paper.

#### References

1. Narayan, P. I. A. and Subramanyan, N. N. : 'Beneficiation of Low grade manganese ores of India' - C. S. I. R., New Delhi.
2. Dhananjayan, N., Chakraborty, H. K. and Banerjee, T. : J.S.I.R. 13B (1954) 136.
3. Banerjee, T., Chakraborty, H. K. and Dhananjayan, N. : Indian Pat. No. 49355 dated 10-4-53 to CSIR, India.
4. Aitkenhead, W. C. and Kar, B. C. : J.S.I.R., 13B (1954) 778.
5. Rasmussen, R. T. C. : U. S. Bureau of Mines, R. I. 3829 (1954)
6. Sillers, F. (Jr.) and Rasmussen, R. T. C. : U.S. Bureau of Mines R. I. 4078 (1947).
7. Sillers, F. (Jr.) : U. S. Bureau of Mines, R. I. 4861 (1952).
8. Sillers, F. (Jr.), Rasmussen, R. T. C. and Jacob, J. H. : U. S. Bureau of Mines, R. I. 4157 (1947).
9. Sillers, F. (Jr.) and Rasmussen, R. T. C. : U. S. Bureau of Mines, R. I., 3911 (1946).
10. Rasmussen, R. T. C., U. S. Bureau of Mines, R. I., 3830 (1945).
11. Sillers, F. (Jr.) : U. S. Bureau of Mines, R. I., 4482, (1949).
12. Steel December 13, 1965.