HIGH PURITY ELECTROLYTIC MANGANESE FROM LOW-GRADE ORE AS A SUBSTITUTE FOR VARIOUS FORMS OF MANGANESE NOW BEING USED IN METALLURGICAL INDUSTRIES

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Abstract

India produces about 1 million tons of high-grade manganese ores every year and about the same quantity of low-grade ores is being dumped in the mining areas. Besides high-grade ores she has abundant resources of low-grade ores for which there is practically no market. Investigations have already been undertaken in this country under the Five Year Plan to utilize these low-grade ores by different methods of beneficiation and also by the production of high purity electrolytic manganese.

The purpose of this article is to discuss in the light of the experiments carried out in U.S.A. that high purity electrolytic manganese from low-grade ores can be substituted for different forms of manganese specially ferro-manganese now being employed in metallurgical industries. The main disadvantage in using electrolytic manganese is its comparatively high cost of production. A substantial reduction in the price can be expected if the demand for electrolytic manganese increases with increasing use. The present price of electrolytic manganese is 31 cents per pound. It has been estimated by the U.S. Bureau of Mines that in a 40 ton per day electrolytic manganese plant, the total operating cost, exclusive of taxes, interest, ore, sales and plant insurance, comes to about 7·2 cents per pound.

Introduction

INDIA has vast deposits of manganese ore, which are among the most important minerals of the country. India produces about 1 million tons of high-grade ores every year. An approximately equal quantity of low-grade ores is being dumped in the mining area. High-grade ores are mostly being exported to foreign countries, although a portion is consumed for the manufacture of ferro-manganese by the local steel industries.

Investigations have already been undertaken in this country under the Five Year Plan for the utilization of these low-grade manganese ores by different methods of beneficiation and also by the production of high purity electrolytic manganese. A semi-pilot plant is already under construction in the National Metallurgical Laboratory for the production of pure electrolytic manganese metal. But the use of electro-manganese in industry is still limited. The Electro-Manganese Corporation of America is the only commercial producer of electrolytic manganese. It produces about 4·5 million pounds a year (5·5 tons per day). About one half of this goes to iron and steel manufacture and one half into non-ferrous alloys of copper, aluminium, magnesium, zinc and other metals and into chemicals. Consumers and research workers have developed new uses of electrolytic manganese for which the pure metal is indispensable, but the sum total of such uses is not very large and would not by itself sustain a commercial electrolytic manganese plant. While statistics are incomplete, about 96 per cent of manganese consumption in industries is in the form of standard ferro-manganese. The purpose of this article is to discuss how far the high purity electrolytic manganese produced from domestic low-grade manganese ore can be substituted for other forms of manganese, especially ferro-manganese, now being employed in practice. This will be done mainly on the basis of results secured by the U.S. Bureau of Mines (with whom the author was associated for a period in 1952-53 on a U.N.

TABLE 1 — TYPICAL ANALYSES OF ELECTROLYTIC AND OTHER MANGANESE AND FERRO-MANGANESE

ITEM	Mn, %	Fe, %	Si, %	P, %	C, %	SELLING PRICE IN CENTS PER LB. OF CONTAINED Mn, *CAR-LOADS (Nov. 1953)
Electrolytic manganese	99·98 min.	0·001 max.	Not found	Not found	0·004	31·50
Manganese metal (thermit process)	95-98	2·0-2·5	1·0-1·5	?	0·06-0·20	36·95
Low-carbon ferro-manganese (special grade)	Approx. 90	Balance	1·2	0·06 max.	0·07 max.	30·00
Low-carbon ferro-manganese (regular grade)	80-85	do	1-2	Approx. 0·18	0·10	28·00
Medium-carbon ferro-manganese	80-85	do	1·5-2·5	?	1·5 max.	21·35
Standard ferro-manganese	78-82	do	1·00 max.	0·35 max.	7·0	13·15

*Car-loads of 56,000 lb. (25 gross tons) except for electrolytic manganese, which are 36,000 lb.

Fellowship basis) in co-operation with the consuming industries.

Electro-manganese is supplied as chips or platelets, $\frac{1}{16}$-$\frac{1}{8}$ in. thick and about 1-2 in. in the greatest dimension. Typical analyses of electrolytic manganese and other forms of manganese are given, together with recent prices, in Table 1.

Electrolytic Manganese in Stainless Steels, Tool Steels, Low-alloy Steels made in the Basic Electric Furnace

Stainless Steels — In the commercial production of stainless steel, low-carbon ferro-manganese having the composition 80-85 per cent manganese, 0·1-0·75 per cent carbon, 0·17-0·22 per cent phosphorus is generally used.

The Rustless Iron & Steel Corpn., the Universal Cyclops Steel Corpn., Timken Roller Bearing Co., Jessop Steel Co. and Rotary Electric Steel Co. made a large number of heats of different types of stainless steel in which low-carbon ferro-manganese was replaced by electrolytic manganese.

The Rustless Iron & Steel Corpn.[1] used 403,085 lb. of electrolytic manganese in place of low-carbon ferro-manganese in making 22 different types of stainless steels, to the extent of 1596 heats producing 22,124 tons of steel. The log of preparing a heat using electrolytic manganese did not actually differ from that using ferro-manganese. 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 product was invariably at least as high as from ferro-manganese. In 63 trial heats of each kind, the average recovery from electrolytic manganese was 87·8 per cent whereas the corresponding figure from ferro-manganese was 84 per cent. In the case of ladle additions, the electrolytic manganese figure was 89·9 per cent in 6 heats and the ferro-manganese figure was 72·7 per cent in 15 heats. According to the firm concerned, the use of pure manganese in place of ferro-manganese has not brought about any change in the quality and hot-workability of the steel, but the electrolytic metal has a definite advantage in allowing close control over carbon and phosphorus.

The producers have pointed out that the electrolytic manganese has the following advantages over ferro-manganese in making stainless steel heats:

1. By using electrolytic manganese chips, the carbon and phosphorus content of the heats do not change appreciably, so the heats can be made according to specifications more easily and greater proportions of scrap may be used.

2. Electrolytic manganese can be stored in less space and also weighing can be done more easily.

3. The recovery of manganese in the case of electrolytic manganese is more uniform from heat to heat and the average recovery is higher.

4. 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.

5. Less time is required to prepare a heat with electrolytic manganese owing to easy handling, weighing and shovelling of the product.

Electrolytic manganese has been proved to be definitely superior to low-carbon ferro-manganese in the production of stainless steels and in spite of the higher cost of electrolytic product per pound of manganese content, the Company has switched over entirely to the use of pure manganese chips in alloy steels in place of ferro-manganese.

Universal Cyclops Steel Corpn.[1] is principally interested in making a substantial amount of types 310 and 307 modified stainless welding wire used by the Navy and Army for welding ships and tanks. The specifications for these two types are given in Table 2.

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 furnace in the same way as the ferro-manganese normally employed.

The conclusions drawn by the Company from more than 100 heats in which electrolytic manganese were used in place of ferro-manganese may be stated as follows:

By using electrolytic manganese instead of low-carbon ferro-manganese, lower C and P contents in the steel can be easily obtained.

The recoveries of manganese is almost the same in both cases.

There is no appreciable difference in the workability of steels made with pure manganese and with ferro-manganese.

From the operational point of view, electrolytic manganese is definitely superior to ferro-manganese.

No disadvantages were observed in the case of electrolytic manganese and the furnace operators preferred pure manganese to ferro-manganese.

On consideration of these advantages, Universal Cyclops Steel Corpn. is now taking part of their manganese requirements in electrolytic manganese.

The Timken Roller Bearing Co.[2] made five types of stainless steel of the composition given in Table 3, using electrolytic manganese.

In 81 heats producing 2146 tons of steel, 50,768 pounds of electrolytic manganese were used in place of low-carbon ferro-manganese. When using pure manganese in place of ferro-manganese, they concluded that electrolytic manganese had certain advantages over the ferro grade and no disadvantages. The advantages are:

TABLE 2 — CHEMICAL SPECIFICATION OF 310 AND 307 MODIFIED TYPES OF STEEL

ELEMENT	C, %	Mn, %	Si, %	S (max.), %	P (max.), %	Cr, %	Ni, %
Type 310	0·07/0·15	1·50/2·00	0·25/0·60	0·025	0·025	26·5 min.	21·0 min.
Type 307 modified	0·07/0·15	3·75/4·75	0·25/0·60	0·030	0·050	19·5/21·5	9·0/10·5

TABLE 3 — TYPES OF STEEL MADE

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 16-25-6 alloy	0·12 max.	2·00 max.	0·030 max.	0·030 max.	1·00	15·00/17·50

TYPE	Ni, %	Mo, %	Cb, %	Se, %	Cu, %	N_2, %
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 16-25-6 alloy	24·00/27·00	5·50/7·00	—	—	—	0·10/0·20

TABLE 4 — COMPOSITION OF STEELS MADE BY JESSOP STEEL CO.

GRADE	CHEMICAL ANALYSIS, PER CENT				
	C	Mn	P (max.)	S (max.)	Si
E9	0·32/0·38	12·04/12·75	0·090	0·040	0·40/0·60
E200	0·25/0·40	10·50/12·00	0·080	0·060	0·60
321	0·10 max.	2·00 max.	0·030	0·024	1·00 max.
304	0·08 max.	2·00 max.	0·024	—	1·00 max.
316	0·10 max.	2·00 max.	0·030	—	1·00 max.
347	0·07 max.	2·00 max.	0·030	—	1·00 max.

GRADE	CHEMICAL ANALYSIS, PER CENT				
	Ni	Cr	Mo	Ti	Cb
E9	3·10/3·40	4·00/4·25	0·40/0·80	—	—
E200	7·00/8·50	—	—	—	—
321	8·00/11·00	17·00/19·00	—	4·00	—
304	8·00/10·00	18·00/20·00	—	—	—
316	10·00/14·00	16·00/18·00	2·00	2·50	—
347	9·00/17·00	17·00/19·00	—	—	—

The average manganese recovery was higher with the same furnace practice, 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 ferro-manganese are 96·8 and 95·1 per cent respectively.

In melting 347 type (18-10 + Cb), the absence of C in electrolytic manganese is a distinct advantage.

Electrolytic manganese is easy to store, handle, calculate and weigh.

Further, electrolytic product does not cause any change in hot-workability, etch quality, surface condition or performance of the steel.

In view of the higher cost of electrolytic manganese, the Company was, however, not in favour of using electrolytic manganese in any of its stainless types except 18-10 + Cb.

Jessop Steel Co.[3] manufactured 6 different types of stainless steel in the basic electric furnace of compositions given in Table 4.

The quality of stainless steel made with electrolytic manganese was just as good and perhaps a little better than the product obtained with ferro-manganese. High-manganese steel such as E9 and E200 grades performed decidedly better when made with electrolytic manganese than with ferro-manganese.

Similarly Rotary Electric Steel Co.[3], in making 18-8 + Cb stainless steel, containing 1·5 per cent electrolytic manganese, stated that corrosion resistance of the stainless steel made with electrolytic manganese was equally as good as the product obtained by using other forms of manganese and manganese recovery was excellent. As a consequence of these tests, they have replaced low-carbon ferro-manganese by electrolytic manganese.

Tool Steels — Henry Disston & Sons Inc.[3] made a series of tests using electrolytic manganese in place of ferro-manganese in the following grades of steel: alloy saw steel, alloy chisel steel, alloy die steel, unalloyed iron, unalloyed structural steel, low-alloy structural steel, Hadfield manganese steel and modified 18-8 stainless steel. The steels made with electrolytic manganese and with ferro-manganese 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 ferro-manganese. For pure manganese, efficiencies of recovery were almost 100 per cent in the case of alloy saw steel, alloy chisel steel, unalloyed structural steel and low-alloy structural steel, close to 100 per cent in the case of Hadfield manganese steel, 93 per cent in the case of alloy die steel, 87 per cent in the case of unalloyed iron and 89 per cent in the case of modified 18-8 stainless steel.

Low-alloy Steel — Babcock & Wilcox Co.[4] produces 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 type 52100 steel made in a basic furnace having the following composition: C, 1·01; Mn, 1·16; P, 0·014; S, 0·014; Si, 0·55; Cr, 1·07; Ni, 0·20; Mo, 0·06 and Cu, 0·08 per cent. 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 ferro-manganese in the hot-working or deep-etch characteristics. He stated that because of the purity of electrolytic manganese the material was attractive and could be used if the price came down.

Electrolytic Manganese in Carbon Steels, Low-alloy Steel, Silicon Electrical Steels made in the Basic Open-hearth Furnace

Kaiser Steel Corpn., Fontana, Calif.[3], Jones & Laughlin Steel Corpn., Pittsburgh, Pa.[5], Republic Steel Corpn., Cleveland, Ohio[3], the Stanley Works, Bridgeport, Conn.[6], and 10 other companies have made a large number of heats of carbon steels, low-alloy steels and silicon electrical steels using high purity electrolytic manganese in place of ferro grades. The recoveries of manganese are given in Table 5.

It has been shown definitely that electrolytic manganese can be substituted for other

TABLE 5 — MANGANESE RECOVERIES WITH RESPECT TO TYPE OF STEEL

TYPE OF STEEL	RIMMED OR KILLED	MANGANESE RECOVERY, PER CENT			
		Furnace		Ladle	
		Electrolytic	Ferro	Electrolytic	Ferro
Low-carbon	Rimmed	—	—	59	55
	Killed	—	—	73	73
Medium-carbon	Rimmed	—	—	49	51
	Killed	43	48	84	79
Silicon electrical	do	—	—	76	74

forms of manganese used in regular basic open-hearth furnace practice of manufacturing steels. Better results are obtained when manganese is added in the ladle. The main advantages of using pure manganese are: (i) easy controlling of the carbon control and (ii) permitting a shorter heat time. Physical properties of steels are, however, affected to some extent using pure electrolytic manganese. For instance, in the case of SAE 1035 steel slightly higher elongation and lower tensile strength resulted using electrolytic manganese. Izod impact values on steel submitted in varying degrees of cold-work did not reveal any particular difference between pure manganese and ferro grade. In quenched and tempered steel, tensile strength, yield strength and Brinell hardness number increased slightly in case of ferro-manganese, but elongation and reduction in area almost remained constant in both the cases. Hardenability test results were practically independent of the type of manganese used. Surface quality of sheets made with the two types of manganese were found to be almost the same. In many cases, no difference in the rolling properties of steels made with the two types of manganese could be noticed, but for cold-rolling of killed extra-deep drawing sheet steel, electrolytic manganese gave better physical properties, specially hardness, to the material than obtained in the regular practice. Better and more consistent results from the metallurgical standpoint on extra-deep drawing killed steel were obtained in the case of electrolytic manganese than medium-carbon ferro-manganese.

Electrolytic Manganese in Steel Castings made in the Acid Electric Furnace

Eleven co-operating companies[3] used acid electric furnace steel practice to make a large number of trial heats of carbon steel and alloy steel with electrolytic manganese, most of the steel produced being used for casting.

It has been proved beyond doubt that electrolytic manganese is quite satisfactory in acid electric furnace practice. Manganese recoveries are unaltered, but operators prefer to use electrolytic manganese and it would surely be used if the price of electrolytic manganese would be anywhere near in line with the standard ferro-manganese. In some cases steel made with electrolytic manganese was found to possess superior physical properties to the product made with ferro-manganese.

Electrolytic Manganese in Steel Castings made by Acid Open-hearth Furnace

Four companies[3] made experiments on the use of electrolytic manganese in the acid open-hearth furnace to produce steel for castings. In using electrolytic manganese in both alloy and carbon heats for castings and ingots they found that electrolytic manganese can be successfully substituted for ferro-manganese. Efficiencies of recovery of electrolytic manganese from ladle additions averaged 85 per cent whereas from furnace additions it was 66 per cent. Efficiency of recovery of manganese is slightly better with ferro-manganese than with electrolytic manganese when furnace additions are made, but in the case of ladle additions efficiency is better with electrolytic manganese.

When electrolytic manganese is added either to the furnace or ladle in paper bags, efficiency appears 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 ferro-manganese.

Electrolytic Manganese in Screw Steels made in the Acid Bessemer Converter

Jones & Laughlin Steel Corpn., Pittsburgh, Pa.[3], made eleven blows of screw steel using electrolytic manganese and standard ferro-manganese. Efficiency of recovery of electrolytic manganese is equivalent to that of ferro-manganese 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 ferro-manganese.

Electrolytic manganese gave a product with excellent rolling properties.

Electrolytic Manganese in Cast Iron made in the Cupola

Five companies[3] participated in testing the use of electrolytic manganese in cupola practice. Columbian Iron Works was supplied with 250 lb. of pure manganese by the U.S. Bureau of Mines for testing the manufacture of grey cast iron valves for water and steam lines. The analysis of iron in cupola practice was: C, 3·26; Mn, 0·73; P, 0·63; S, 0·015 and Si, 1·70. Satisfactory results were obtained.

Skinner Engine Co., Erie, Pa.[3], was supplied with 100 lb. of pure manganese for testing as a ladle addition for the production of a special alloy cast iron containing Ni, Cr and Mo. With electrolytic manganese chips close control of manganese was obtained whereas considerable variation was observed using ferro-manganese.

Electrolytic Manganese in Malleable Iron made in the Air Furnace

Three companies[3] carried out experiments in the manufacture of malleable iron using electrolytic manganese in place of spiegel. The results obtained from 22 heats were found to be good and the physical tests were also satisfactory.

Electrolytic Manganese in Welding Rod Industries[3]

Electrolytic manganese was found preferable to ferro-manganese in welding rod coatings for stainless steel electrodes, carbon steel electrodes and other non-ferrous electrodes. This is due to the fact that electrolytic manganese is virtually free from phosphorus. One company has actually substituted electrolytic manganese for ferro-manganese in regular practice.

Aluminium Alloys

In aluminium alloys, electro-manganese competes with special low-iron, high-manganese, ferro-alloys and appreciable quantities are used for 2S, 25S and similar products.

Electrolytic Manganese as a Substitute of Nickel in the Regular Nickel-chromium Stainless Steel

In this connection it may be pointed out that a substitute stainless steel known as TRC using pure manganese in place of Ni and having the chemical composition Cr, 15·00 per cent min.; C, 0·10 per cent max.; Ni, 1·00 per cent max.; Mn, 16·5 per cent nominal; and N, 0·15 per cent nominal, was produced by Budd Co.[7] during the Korean War. Commercial performance of such steels in which manganese has been substituted in whole or in part for nickel has been so promising that they are now being produced in tonnage quantities. Chromium-manganese stainless steels have a pleasing appearance and compares favourably with conventional types of stainless steel as regards physical properties and resistance to atmospheric corrosion. The successful development of chromium-manganese stainless steels is attributable in no small degree to the utilization of high-purity electro-manganese.

Some question had been raised in regard to hydrogen content in electrolytic manganese. It has not been established with certainty that occasional wildness in heats or poor arc stability in welding experiments were due to hydrogen in the electrolytic manganese. Normally electromanganese contains 150 parts of hydrogen per million. This is no problem for ordinary uses in the melting process. Where needed the metal is available with hydrogen content of about 5 p.p.m. with a small premium over the regular prices.

Conclusions

From the tests recorded in this paper, it is evident that electrolytic manganese can often be substituted satisfactorily for ferro-manganese. Further experiments with the object of establishing the use of electrolytic manganese in India may be undertaken in the National Metallurgical Laboratory in co-operation with industry using the electrolytic manganese produced in the semi-pilot plant. Practically the only objection in using electrolytic manganese in place of ferro-manganese is its comparatively high price. There is probably no consumer who would not use electrolytic manganese in preference to ferro-manganese if prices were equal. Although at the moment there seems to remain a slight preference based on habit for thermal manganese for application where the ferro-alloy has been found unsuitable, thermit manganese is an inherently expensive product. The survey has revealed incidentally certain fields in which electrolytic manganese might find extended commercial application even while a considerable price margin remains between this material and ferro-manganese. This is particularly the case where high-manganese steels are required to have low carbon contents, e.g. manganese welding steels and case hardening steels. Another field is that of Hadfield manganese steel in which there is great difficulty in India in meeting the B.S. specification when using indigenous ferro-manganese. These fields, important as they are, are of course small when compared with the overall field of use of ferro-manganese.

Fortunately the trend in the price of electrolytic manganese has been generally downwards. In 1942, when it was first produced commercially, price was 40 cents a pound and in 1949 it came down to 28 cents. This reduction took place during a period when general costs of American production were strongly upwards as measured by the U.S. Department of Labour Index. For example, the increase according to this index from 1942 to 1949 was 101 per cent for non-ferrous metals and 74 per cent for iron and steel. Due to increased costs the price has increased slightly and is now 31 cents. It has been estimated by the U.S. Bureau of Mines that the operating cost of a 10-ton per day plant located near the mines supplying the ore would be 11·3 cents per pound of manganese produced exclusive of ore cost, interest, taxes, sales and plant insurance. The operating cost of a 40-ton plant would be 7·2 cents per pound of manganese produced exclusive of taxes, interest, ore, sales and plant insurance. These estimates are based on 3 years' operation of a 1-ton per day pilot plant at Boulder City, Nev., using Three Kids ore (20 per cent Mn)[8]. The more obvious savings in the process have perhaps by this time been accomplished and are allowed for in the U.S. Bureau of Mines estimates, still there remains many interesting possibilities for further progress which research and engineering may translate into action, thus reducing the cost. Some reduction in price can be expected with increased production, i.e. if more and more metal producers use electrolytic manganese. Electrolytic manganese acceptance is slowly growing up in competition with all the lower-priced forms of manganese. Over 40 million pounds of high purity electrolytic manganese has reached the market since 1940.

Manganese has recently found favour as a nickel substitute in austenitic steels and has opened a whole new field of manganese alloys and permitted higher manganese contents in existing alloys. In these circumstances the production of electrolytic manganese in India justifies consideration.

U.S.A. is now the only country producing electrolytic manganese. Although small-scale German and Japanese production was reported during the last war, these plants operated for only a short period with a short deposition cycle and the metal was of an impure grade. Compared to U.S.A., India is in greatly advantageous position with regard to manganese minerals and labour. With the execution of hydro-electric schemes according to the Five Year Plan, power in India is expected to be plentiful. Domestic low-grade ores will be available at a very low price. If the regeneration of the electrolyte from electrolytic manganese bath by the saw dust method as developed in N.M.L. on a laboratory scale with Indian ores can be applied on the commercial process, the cost of operation of the plant is likely to come down appreciably as compared with the cost of the present method of regeneration adopted in America. Further, the 'poor' Indian ores are of better grade than those of U.S.A. and contain higher percentage of manganese: lower the percentage of manganese in the ore, the larger will be the electrolytic plant to tackle the residue and greater will be the cost of production as the overall recovery of manganese will be less. Moreover, some of the Indian-high grade manganese ores are rather high in phosphorus and are not very suitable for making ferro-manganese by the usual blast furnace practice, especially as most Indian coking coal contains high percentage of phosphorus. These high-phosphorus ores can be blended with poorer ores for producing electrolytic manganese as the process is not affected by the presence of phosphorus. Thus the raw material in India, namely the ore, is far better than the U.S. low-grade ores which forms the starting place of the American electrolytic manganese industry.

From these considerations it is not unlikely that a time will come when high purity electrolytic manganese from low grade Indian ores will compete with standard ferro-manganese in steel industry.

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Discussion

DR. A. N. GHOSH (Director, Government Test House, Calcutta)

The lecturer referred very briefly on the use of electrolytic manganese in the non-ferrous industry. Could the author give us information on the possibility of replacing nickel in nickel-containing brass or cupro-nickels? This is particularly important for India in view of the non-occurrence of nickel and abundance of manganese in India.

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It seems possible to replace nickel wholly or partly in Ni-containing brass and cupro-nickel by pure electrolytic manganese. Alloy of copper, zinc and manganese, that is, nickel silver, in which manganese is substituted for the entire amount of nickel, compares favourably with the standard properties of Ni silver. The ternary alloy of copper, nickel and manganese when made with pure manganese retains its ductility and has got commercial application.

So far as the author is aware the change in properties by replacing Ni with pure manganese partly or wholly in nickel-containing brass and cupro-nickel has not been thoroughly studied so far.