OXYGEN IN FOUNDRY STEEL-MAKING

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THIS paper is presented with the intention to examine some of the steel production problems in Indian steel foundries that may be faced due to shortage of steel scrap or due to increased cost of scrap in the future.

Even now in many parts of India, foundries are forced to use highly oxidized and very light steel scrap in electric furnaces, thereby creating metallurgical problems.

It is, therefore, necessary that this problem of production created by unsuitable raw materials, such as steel scrap, coke, etc., should be examined carefully from now, and practices determined which will make foundry iron and steel-making flexible enough to utilize the raw material easily and economically available.

In recent times considerable attention has been drawn to the direct use of oxygen as a tool to increase iron and steel production, and from the results so far available it appears that by adopting some of the applications, the necessary flexibility in production may be achieved.

The oxidation processes in iron and steel, as you are aware, are:

(1) Oxidation of metalloids (C, Si, Mn and P) from molten iron, such as in Bessemer and Tropenas converters, electric furnaces, open-hearth furnaces and ladles.

(2) Flame enrichment, e.g. combustion of flames in the open-hearth furnaces, partial combustion to produce reheating furnace atmosphere.

(3) Blast enrichment in solid fuel combustion, such as combustion of fuels in blast furnace, producer gas furnace and cupolas.

In steel foundries, the possible use of oxygen with benefit should be for the oxidation of metalloids in ladles and Tropenas converters, electric furnace, enriched air blast in cupolas, and should help to make foundry steel-making flexible.

It will, therefore, be interesting to discuss the applications mentioned above and the conditions of use.

Oxygen in Ladle

In ladles, provided the scale of operation is not too small so that it is possible to gain sufficient temperature in the melt against the heat losses, the process is quite simple. From experience it appears that about 10 cwt. in an open ladle is the minimum practicable amount. Smaller amounts than 10 cwt. would be practicable employing a converter-shaped ladle and insulating the lining from the shell, in order to reduce the heat losses.

With regard to the operation of the process on iron containing appreciable amount of phosphorus, it is possible to consistently reduce the phosphorus content to finished steel levels by the use of limestone/iron ore or soda ash slags in dolomite-lined ladles in a foundry on a small scale. The following two examples are given to indicate the typical results that have been obtained:

Lining: Tar-dolomite mixture.

Dolomite used in the mixture was burnt, stabilized and was of roughly $\frac{3}{8}$ to $\frac{1}{8}$ in. grading.

With regard to the life of the lining on this small scale, blowing pig iron to semi-steel and using limestone/iron ore or soda ash slag making additions, a life of 30 blows on a 3 in. lining was obtained. Provided the metal is not overblown with excessive iron oxide formation, a life of 15-20 blows is estimated for making steel, but this will depend largely on the experience and the conditions at different places and also on the quality of dolomite available (*see* Table 1).

There is very little doubt that, had the latter melt been continued, the final phosphorus would have been in the region of 0·04-0·05 per cent.

Whilst it has been found that soda ash is slightly more efficient in phosphorus removal, and under basic conditions the experience is that there is not much lining attack with soda ash, it is, however, much more unpleasant and considerably more expensive to use. In general, it is recommended that the limestone/iron ore slag be added to the extent of about 100/25 lb. per ton. The iron ore can be omitted without much deleterious effect, although in theory it assists the rapid solution of limestone and conserves oxygen.

It appears that the efficiency of oxygen usage increases with the scale of operation and, therefore, oxygen consumption is slightly lower than those above on the larger scale.

Tropenas or Side-blown Converters

In Tropenas converter, enrichment of the blast with oxygen enables steel for the foundry to be produced at a higher temperature giving castings of superior quality and at a higher rate.

Heat is derived by the oxidation of silicon, and by using oxygen less silicon need be present. The necessity of addition of ferro-silicon or high-silicon pig iron is reduced depending on the size of the converter and the starting silicon.

The degree of enrichment varies with the local conditions, but in general the oxygen content of the blast is increased to between 25-30 per cent at a consumption of approximately 400-900 cu.ft./ton. Higher enrichment may occasionally be employed.

TABLE 1

Per cent					Stage in O_2 delivery, cu.ft./ton	Flux
C	Si	Mn	P	S		
		Single Soda Ash Slag — Melt Lanced				
3·44	1·43	0·38	0·41	0·064	0	Approximately 150 lb./ton of soda ash powder was employed, additions being made regularly throughout the blow. No slag was removed until the end.
3·36	0·62	0·21	0·37	0·050	376	
3·16	0·21	0·11	0·28	0·047	753	
2·78	0·02	0·05	0·17	0·043	1077	
2·21	0·02	0·04	0·07	0·035	1436	
1·46	0·01	0·03	0·04	0·034	1795	
0·77	0·05	0·03	0·03	0·039	2064	
		Single Limestone/Iron Ore Slag — Melt Lanced				
3·56	1·74	0·40	0·41	0·053	0	The iron ore used was in small lump form. The limestone was not previously calcined. Approximately 100 lb./ton of limestone and 25 lb./ton of iron ore were employed.
3·44	0·78	0·22	0·40	0·050	398	
3·17	0·13	0·08	0·30	0·046	796	
2·63	0·01	0·03	0·18	0·048	1194	
2·03	0·01	0·02	0·08	0·042	1592	
1·18	0·02	0·02	0·06	0·055	1991	

In many foundries oxygen is normally added during the first 5 to 6 min. of the blow when the air rate is reduced by 20 per cent and an enrichment of 5 per cent is employed. The early heats of the day are treated, but as the iron temperature improves, the use of oxygen is discontinued unless multiple heats are required. No troubles are encountered from converter lining wear.

Electric Arc Furnaces

Arc furnaces are developing so as to be competitive in the bulk steel-making field where conditions are favourable, e.g. cheap power or for the manufacture of high grade steel and special alloys which are difficult or impossible to make in other ways. Oxygen lancing has been introduced in a number of works with the object of oxidizing a proportion of the charge and utilizing the heat generated to melt the remainder. The charge is melted in the normal way until a small pool has formed at the bottom of the furnace, after which lancing into this pool at the base of the scrap is performed until the whole becomes molten. Ferro-silicon or carbon may be added to generate additional heat, but usually the oxidation of the iron alone is sufficient to give the desired result. This is of particular interest from the economic point of view since the melting-down period involves by far the heaviest power costs.

Comparison of working in a furnace with and without oxygen during melt-down is given in Table 2.

The oxygen lance is most frequently used in refining. Oxygen is introduced by a lance which is a consumable steel tube of ½-1 in. internal diameter capable of passing up to 500 cu. ft. of oxygen per minute. The end of the tube is inserted just below the slag metal interface. The life of the lance depends largely on the extent to which the open end is cooled by adiabatic expansion as well as protected by refractory coatings, such as slags or ceramic sleeves. Lance consumption is of the order of ½-1 ft. per minute with refractory coverings and may be as high as 5 ft. per minute for bare lances in alloy steel melts at a temperature over 1800°C.

It is now more or less a standard practice in the refining period to record the results as a curve showing the specific oxygen consumption against the carbon content (FIG. 1), since the main interest is carbon reduction. The specific oxygen consumption is the cu. ft. of oxygen at 20°C. and 760 mm. Hg needed to remove 1 point of carbon as carbon

TABLE 2

	WITHOUT O_2	WITH O_2	REMARKS
Power consumption/ton (in kWh.)	748	630	
Time — tap-to-tap (average)	4 hr. 45 min.	4 hr. 5 min.	
Melting rate per ton	50 min.	40-43 min.	
O_2 consumption (cu. ft./ton)	—	250-275	Press: 25-35 p.s.i.
Scrap charged	Heavy melt quality, e.g. steel blooms	Heavy melt quality, e.g. steel blooms, etc.	No effect on lining, bank, bottom and roof. Condition remained normal.
Quality of steel	Medium carbon	Medium carbon	

REMARKS — Lancing started after 1 hr. 10 min. to 1 hr. 20 min. of power on. Increase in the rate of output is approximately 15 per cent. Approximate melting time: 2 hr. 10 min. with oxygen lancing.

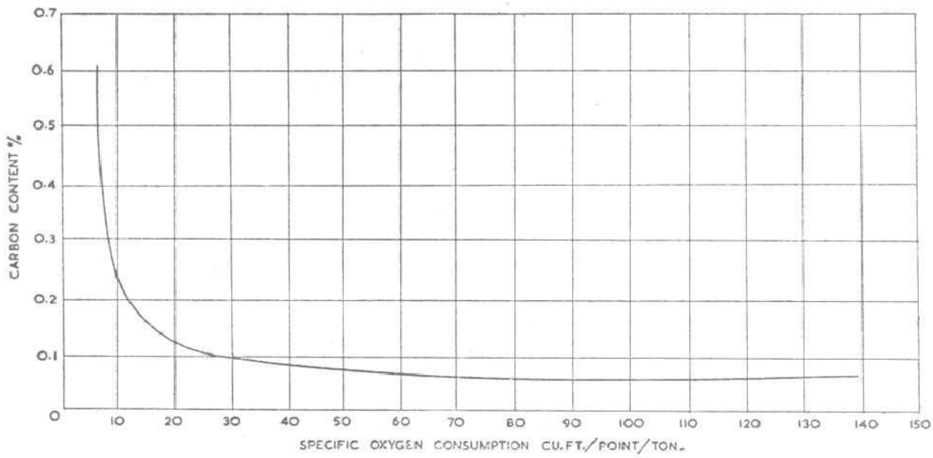

FIG. 1 — ELECTRIC FURNACE REFINING (CARBON REMOVAL) — CARBON STEELS. SPECIFIC OXYGEN CONSUMPTION AT VARIOUS CARBON LEVELS (CU. FT./POINT — 0·01 PER CENT C/TON)

monoxide per ton of steel. Theoretically, the figures are:

TABLE 3

ELEMENT	CU. FT. O_2 /POINT/TON
Carbon	3·60
Silicon	3·08
Manganese	0·79
Sulphur	2·70
Phosphorus	3·48
Chromium	0·83
Iron	0·77

From this it has also been possible to work out the total oxygen consumption per ton for a given carbon range and draw a curve. It is possible to read the total oxygen consumption per ton directly from this curve (FIG. 2).

With regard to the rate of flow of oxygen per minute in a furnace, it appears that for plain carbon 60 cu.ft./min./ton is satisfactory, i.e. if oxygen is required for a 3-ton furnace, the rate of injection should be 180 cu.ft./min. Therefore, from the theoretical consideration already mentioned, it is possible to determine the requirement of oxygen and the duration of blow in a furnace; for example, if carbon

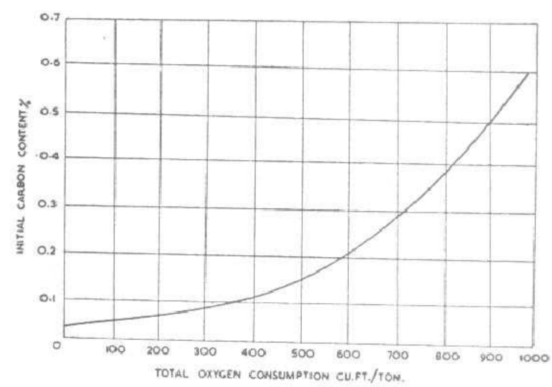

FIG. 2 — ELECTRIC FURNACE REFINING (CARBON REMOVAL) — CARBON STEELS. TOTAL OXYGEN REQUIRED PER TON TO REDUCE CARBON CONTENT FROM AN INITIAL VALUE TO 0·05 PER CENT

is required to be reduced for, say, 0·4 to 0·1 per cent in a 3-ton furnace, the total quantity of oxygen required will be

$$350 \text{ cu.ft.} \times 3 \text{ ton} = 1050 \text{ cu.ft.}$$

and the total duration of blow will be

$$\frac{1050}{180} = \text{approx. } 6 \text{ min.}$$

In the case of stainless steel and high grade alloy steel, the flow rate is increased to 100 cu. ft. per minute per ton and the specific oxygen consumption at various carbon levels and total oxygen consumption for carbon removal in stainless steel are indicated in Figs. 3 and 4.

In the case of stainless steel, the addition of oxygen in the bath should not be started below the temperature of 1580°C. because above 1600°C. carbon is preferentially oxidized, and below that chromium is reacted. Therefore, the idea here is to choke the chromium and attack the carbon. Loss of chromium is 4 per cent and less if it is started at higher temperature. Eighty-five per cent of the chromium in slag can be recovered by adding reducing agent.

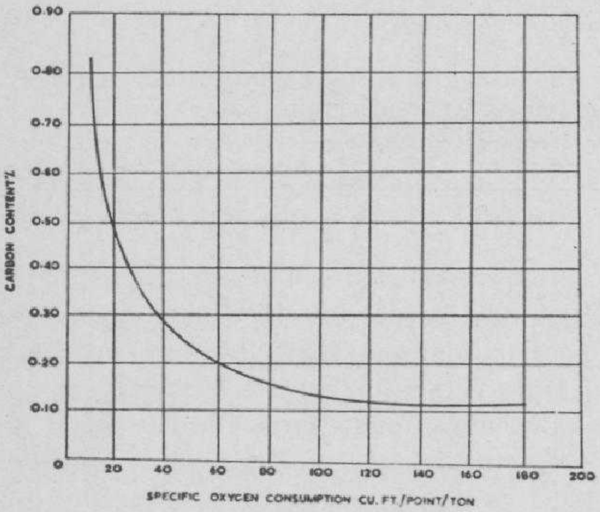

FIG. 3 — ELECTRIC FURNACE REFINING (CARBON REMOVAL) — STAINLESS STEEL (Cr, 18; Ni, 8 PER CENT). SPECIFIC OXYGEN CONSUMPTION AT VARIOUS CARBON LEVELS (CU. FT./POINT — 0·01 PER CENT C/TON)

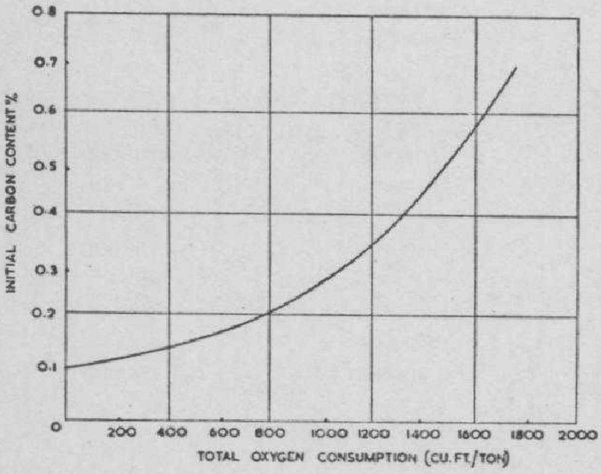

FIG. 4 — ELECTRIC FURNACE REFINING (CARBON REMOVAL) — STAINLESS STEEL. TOTAL OXYGEN REQUIRED PER TON TO REDUCE CARBON CONTENT FROM AN INITIAL VALUE TO 0·10 PER CENT C

For carbon steel, the minimum temperature is 1540°C. to start oxygen blowing.

Most of the cupolas in foundries in India are without any hot blast arrangement and, in any case, it requires heavy capital expense to install a complete unit for this purpose. The enrichment of blast with oxygen is the alternative to overcome the difficulties of temperature due to the use of inferior coke which is usually available. In many cases the blower capacity is on the low side and the enrichment of air with oxygen should overcome this difficulty of short supply.

In cupolas, enrichment from 1 to 3 per cent is employed and the quantity of oxygen may vary from 300 to 800 cu. ft. per ton of metal tapped. The enrichment is kept at higher level at the initial stage and then gradually reduced, depending on the metal temperature.

It appears that with enriched air blast coke with 22-24 per cent ash could be used without detriment to quality and metal temperature.

From the experience of trials carried out, it appears that considerable improvement in the consumption of oxygen per ton may be made by modifying the operation as well as the design of the hearth. The results with a 39 in. cupola over a period show about 11 per cent increase in the working rate, 40°-50°C. increase in temperature with 1·5-2·0 per cent of oxygen enrichment, increase in the fluidity of minimum 50 per cent, achieved in half an hour, decrease in porosity and improvement in mechanical properties of the castings. Some of the comparative data, given in Table 4, may be of interest.

The use of enrichment in a cupola at the starting appears to be most beneficial. In a 26 in. diameter cupola, which normally runs for a short period every day, before the oxygen introduction the first tap normally could

TABLE 4

	With O_2	Without O_2
No. of days worked	10	10
Production time (hr.)	36	39·5
Weight of metal (tapped) (tons)	105	104
Melting rate (tons/hr.)	2·92	2·63
Average oxygen used/ton (cu. ft.)	417	—
Average tapping temp.	1430°C.	1390°C.
Quality of metal tapped	White iron	White iron
Increase in melting rate	+10·8%	—

not be cast and the metal temperature ranged between 1290° and 1300°C.; but with approximately 2½ per cent oxygen enrichment, it is now possible to regularly tap the first heat about 1320°C. and get a good metal for casting. The production shows about 15-20 per cent increase. It is also possible to reduce or stop the oxygen during later heats and maintain easy run of the cupola. The consumption is approximately 700 cu. ft. per ton.

The results with or without oxygen are given below:

TABLE 5

	With O_2	Without O_2
Melting rate, cu.ft./hr.	32	26·3
Cu. ft. oxygen used/ton	700	—
Tapping temperature (average)	1339·5°C.	1320°C.
Enrichment	2·3-1·2%	—
Quality of metal tapped	Grey iron	Grey iron
Increase in melting rate	21·6%	—

Remarks — 80 per cent of the first tap could only be utilized as scrap for subsequent charges due to low tapping temperatures (1290°C.).

From the above it will be seen that perhaps it will now be possible for Indian foundries to obtain iron from cupola, pretreat the metal in ladle, either to get steel directly or to remove silicon and charge the hot metal in the electric furnace, to enable the operation of the electric furnace with less quantity of

TABLE 6 — CAPITAL COSTS

Capacity of plant, tons/annum	250000	500000	1000000
Furnace size and number	3×18 ft.	4×20 ft.	8×20 ft.
Transformer size	20000 kVA.	25000 kVA.	25000 kVA.
	$	$	$
1. Buildings and foundations	1500000	2500000	3500000
2. Furnaces and auxiliaries	1250000	2000000	4000000
3. Scrap handling equipment	750000	1250000	1750000
4. Pitside equipment (cranes, ladles, etc.)	1250000	1750000	2750000
5. Stripper facilities (cranes, locos, tracks, etc.)	1000000	1500000	1750000
6. Moulds and mould conditioning plant	500000	750000	1000000
7. Storage facilities for refractories	150000	250000	400000
8. Utilities (power lines, water pumps, etc.)	350000	500000	750000
Total	$ 6750000	$ 10500000	$ 15900000
Depreciation per ton — 12% of capital charge, i.e. fixed charge	3·24	2·52	1·91

TABLE 7 — COST ABOVE OR 'ON-COSTS' PER INGOT TON

Annual production	250000 T.P.A.	500000 T.P.A.		1000000 T.P.A.	
Type of charge	Cold	Cold	50% HM	Cold	50% HM
1. Power ($ 0·009/kWh.)	4·70	4·70	4·25	4·70	4·25
2. Electrodes ($ 0·18/lb.)	2·15	2·15	1·80	2·15	1·80
3. Fluxes (*see* below)	0·62	0·62	0·67	0·62	0·67
4. Furnace refractories (*see* below)	0·60	0·50	0·45	0·50	0·45
5. Ladle refractories	0·15	0·15	0·15	0·15	0·15
6. Ingot moulds and replacements	0·85	0·85	0·85	0·85	0·85
7. Furnace repairs (bricks + labour)	1·20	1·30	1·20	1·30	1·20
8. Production labour ($ 2.00/man hr.)	1·70	1·35	1·25	1·35	1·25
9. Maintenance (labour and materials)	0·95	0·80	0·70	0·65	0·55
10. Indirect labour	0·35	0·25	0·25	0·20	0·20
11. Oxygen and compressed air	0·28	0·28	0·28	0·28	0·28
12. Supplies, tools, etc.	0·20	0·20	0·20	0·20	0·20
13. Water and utilities	0·35	0·35	0·35	0·35	0·35
14. Yard switching	0·25	0·20	0·20	0·20	0·20
15. Slag disposal	0·20	0·20	0·20	0·20	0·20
16. Employee benefits	0·30	0·25	0·23	0·25	0·23
17. General expenses	0·50	0·40	0·40	0·40	0·40
Total	15·35	14·55	13·43	14·35	13·23
Depreciation	3·24	2·52	2·52	1·91	1·91
Total/ton steel	18·59	17·07	15·95	16·26	15·14

Fluxes

Cold charge:	75 lb. burnt lime ($ 16·75/ton)	
	30 lb. limestone ($ 4/ton)	
50% Hot metal:	80 lb. burnt lime	
	35 lb. limestone	

Furnace Refractories

Cold charge:	53 lb. burnt lime ($ 16·75/ton)
	5 lb. magnesite ($ 62/ton)
50% Hot metal:	41 lb. burnt dolomite
	5 lb. magnesite

steel scraps or with 100 per cent hot metal charge.

With regard to the question of using oxygen to pretreat iron for finishing in electric furnaces, there is no doubt that such a practice would increase the steel productivity. A certain degree of phosphorus removal could be achieved simultaneously with desiliconization if required by the use of basic slags and basic lined ladles. The heat gained should enable some scrap to be melted where available without the use of electric power.

Hot metal practice in electric furnaces is now becoming fairly common in the United States, and we would expect the application to spread to this country where at present the use of hot metal is rare.

We have not yet considered the cost aspect of treating hot metal in the electric furnace, or investigated the effect of preliminary desiliconization. However, in the U.S.A. a comprehensive publication was issued in 1953 by the Bituminous Coal Research Inc. entitled *Comprehensive Economics of Open*

TABLE 8 — TOTAL PRODUCTIVE COST

The work is based on a metal yield of 91 per cent for a cold (mainly scrap) charge and 88 per cent for a 50 per cent hot metal charge

ANNUAL PRODUCTION	250000		500000				1000000			
TYPE OF CHARGE	Cold 92% scrap 8% pig		Cold 92% scrap 8% pig		HM 50% HM 50% scrap		Cold 92% scrap 8% pig		HM 50% HM 50% scrap	
	lb./ton	cost	lb./ton	cost	lb./ton	cost	lb./ton	cost	lb./ton	cost
Steel scrap, $ 43/ton	1985	38·10	1985	38·10	1103	21·18	1985	38·10	1103	21·18
Pig iron (cold), $ 58/ton	173	4·50	173	4·50	—	—	173	4·50	—	—
Iron ore, $ 14/ton	50	0·30	50	0·30	120	0·75	50	0·30	120	0·75
80% FeMn ($ 225/ton) (in FeSi and Al)	12	1·20	12	1·20	12	1·20	12	1·20	12	1·20
Hot metal, $ 33/ton	—	—	—	—	1103	18·20	—	—	1103	18·20
Total metallics cost	$ 44·10		$ 44·10		$ 41·33		$ 44·10		$ 41·33	
Cost above	$ 18·59		$ 17·07		$ 15·95		$ 16·26		$ 15·14	
Gross cost	$ 62·69		$ 61·17		$ 57·28		$ 60·36		$ 56·47	
Credit 60 lb. works scrap	$ 1·15		$ 1·15		$ 1·15		$ 1·15		$ 1·15	
Net production cost	$ 61·54		$ 60·02		$ 56·13		$ 59·21		$ 55·32	
Cost less depreciation	$ 58·30		$ 57·50		$ 53·61		$ 57·30		$ 53·41	

Hearth and Electric Furnaces for Production of Low Carbon Steel. Among the various cases treated was the use of 100 per cent cold charge or a 50 per cent hot metal - 50 per cent scrap charge in the electric furnace. The costs quoted in the book are probably known to many of you, but I am giving the details (*see* Tables 6, 7 and 8). All tons are short tons of 2000 lb., and costs are based on 1952 levels.

Thus from these figures it appears to be more economic to make steel in the electric furnace from a 50 per cent hot metal charge than from an all-cold charge. This should apply in India also where the relative scrap and hot metal prices are the same as in the U.S.A. In the U.K., on the other hand, scrap is cheaper than hot metal so that the metallics cost in the 50 per cent hot metal charge will be higher, and there may be then no advantage in using hot metal in the electric furnace.

I hope the details given above will enable these foundries to work out their economics and find out how far the whole operation in a foundry may be made flexible to suit the availability of the raw materials.

In conclusion, I acknowledge the help received from the Research Centre of the British Oxygen Co. Ltd., London.