Newer methods of stainless steel production and their impact on ferroalloy consumption pattern

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ABSTRACT

The conventional method of stainless steel making through the electric arc furnace has got several limitations such as restricted use of low cost high carbon ferroalloys and lower productivity. In recent times a number of secondary steelmaking methods viz AOD, VOD etc. have been developed to overcome the shortcomings of the conventional method. The paper describes the various new secondary steel making processes for stainless steel making. All these new processes have a substantial flexibility regarding the input materials usage. As a result considerable scope exists in these processes for the use of low cost ferroalloys. Based on the material balance of these process, typical examples are given in the paper on the consumption pattern of the input materials. The situation in these context of the Indian stainless steelmaking industry has been reviewed.

Introduction

The production of stainless steel involves the use of a large quantity of ferroalloys, particularly of chromium and nickel. There are two major groups of stainless steels viz. ferritic and austenitic types. The ferritic type contains about 17% chromium and is classified under series 400 (AISI), whereas the austenitic variety contains about 18% chromium and 9% nickel and is classified under series 300 (AISI). In addition to iron, chromium and nickel, these steels contain manganese, silicon, and sometimes molybdenum and titanium.

Since the early twenties the production of stainless steel was through the electric arc furnace where the steel was melted, oxidized and refined completely in the furnace. This process requires expensive low carbon ferrochrome in the reduction and finishing period mainly, because the process is limited by an upper boundary for chromium and carbon content in the initial charge. Moreover, blowing down carbon to required low values, in presence of chromium necessitates operations at very high temperature regions. This makes the metallurgical and operational control difficult and also results in poor chromium and manganese recovery as well as badly eroded furnace lining.

In recent times, several developments have taken place in the field of application of secon-

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dary steelmaking processes, viz, AOD, VOD, CLU etc. for the production of stainless steels, in order to overcome the problems associated with the conventional arc furnace route. The use of the electric arc furnace for melting and the secondary refining vessel for decarburization as well as composition and temperature control gives high production rates and low product cost. Through the use of the secondary refining processes, the overall chromium yield is increased from 85% to about 94% and the manganese yield from 70% to about 80%. The low carbon ferrochrome usage is nearly eliminated and silicon usage is reduced substantially. In addition to the improved productivity, the secondary steelmaking route also excels in its ability to meet extra low carbon specification consistently at the same chromium level.

Consumption pattern for ferroalloys in stainless steel production

In the past two decades the production of stainless steel ingot in the world, excluding the communist countries, has increased by an average of 273,000 MT per year or at a 7.5% compound rate[1]. The stainless ingot production forecast as given in Table 1 shows slightly reduced growth to 407,000 MT yearly for the western world and 167000 MT yearly for USSR and eastern bloc countries from 1975 to 1985.

TABLE—1

Stainless steel ingot production in 1975 and projections for 1985 with percent growth rates (DMT X 1000)

Country	Growth rate%	Year 1975	Year 1985
USA and Canada	3.5	1126	2384
Japan	5.7	1645	3569
Total Europe	6.4	1767	3290
Balance Western World	8.6	280	641
Total Western World	5.5	4818	9884
USSR and Eastern Block	5.6	2280	3948
Total World	5.5	7098	13832

A detailed look at the production and supply position of ferrochrome, nickel and molybdenum shows a close link between ferroalloys and stainless steel production. About 60-70% of the chromite mined goes into the production of ferrochrome for metallurgical use and atleast 65% of this ferrochrome goes into stainless steel manufacture[2]. Of the order of 55% of all nickel produced goes into the steel industry of which about 45% goes to stainless steel production. An examination of molybdenum usage shows that about 80% goes into the steel industry of which about 20% is used in stainless steels. These few facts serve to illustrate the very close link between the stainless steel manufacturing industry and the ferroalloy industry. The various aspects of the use of the two principal elements viz. chromium and nickel, in the manufacture of stainless steel have been dealt within the paper.

TABLE – 2

Chromium required as ferro chromium in stainless steel (DMT X 1000)

(Source : Metal bulletin's first ferro alloys conference, Zurich, 1977)

Country	Year 1975	Year 1980	Year 1985
USA and Canada	123.9	220.2	257.1
Japan	189.1	318.4	400.7
Total Europe	205.7	310.5	374.9
Balance Western World	33.9	57.8	75.7
Total Western World	552.6	906.9	1108.7
USSR & Eastern Block	263.8	348.0	441.7
Total World	816.4	1254 9	1550.1

The chromium required to produce stainless steel for the principal consuming geographical areas is shown in Table 2. The western world's annual usage will increase from 552,000 tons in 1975 to 1.1 m tons in 1985 or about 56,600 tons per year. The eastern bloc's annual usage will increase from 263,000 tons to 441,000 tons during the same period or at the rate of 17,800 tons per year.

Over the past 30 years the free world production of refined nickel (both class-I and class-II products) has shown an annual growth rate of 5·6% and has increased as shown in Table 3 from 120,000 tons in 1950 to 544,000 tons in 1980[3]. Classification of nickel products according to grade can be done in the following manner : Products which are essentially 100% nickel i.e. briquettes, pellets and cathodes form class I, while products with lower nickel levels i.e. Ferronickel and nickel oxide sinter form the class II group.

TABLE—3

Production of refined nickel

	1950	1960	1970	1978
Productin in '000 M tons	120	265	455	420
Production of Class-I product	95	85	65	51
Production of Class-II product	5	15	35	49

Main characteristics of the major ferro-alloys/alloying elements used in stainless steel-making are given[4] in Table 4.

TABLE—4

Main Characteristics of some ferro-alloys

Alloying Element		Chemical Analysis (%)					Usual Sizes
Met	Grade	Main Element	C	S (Max)	P (Max)	Others	mm
Silicon	Ferro Silicon	Si					
	FeSi D (★)	65/70	0.1 max	0 025	0.120	Al 1.25 max	300 max
	FeSi C (★)	74/79	0.1 max	0.025	0.120	Al 1.25 max	-do-
	(★) ASTM						
Manganese	Ferro Manganese	Mn					
	High C FeMn	76/78	6/7	0.03	0.25	Si 1.5 max	300 max
	Medium C FeMn	75/85	1 max	0.03	0.25	Si 1.5 max	-do-
	Low C FeMn	75/85	0.1 max	0.03	0.25	Si 1.5 max	-do-
Chromium	Ferro Chromium	Cr					
	Charge Chrome	50/60	8 max	0.05	0.04	Si—3/10	
	High C FeCr	55/72	6/8	0.05	0.04	Si 3 max	200 max
	Medium C FeCr	55/75	2/4	0.05	0.04	Si 1.5 max	100 max
	Low C FeCr	55/75	0.5/1.0	0.05	0.04	Si 1.5 max	
	Extra L C FeCr	58/76	0.5 max	0.05	0.04	N_2 0.05/0.15	-do-
Nickel	Pure Nickel	Ni+Co More than —99	0.05 max	—	—	Co-1.5 max	Shots, Granules Briquettes etc
	Ferro Nickel						
	F N 1	24/30	0.04 max	0.02	0.04	Si-0.4 max	Pigs or Granules
	F N 2	22/28	1.2/1.8	0.02	0.04	Si-0.5/2	
	F N 3	22/28	1.2/1.8	0.02	0.04	Si-0·25/0.5	
	F N 4	22/28	1.2 1.9	0.02	0.3	Si 1/3	
	Sinter Oxide						
	NiO	75/95	—	—	—	—	Powder or Granules
Molybdenum	Ferro Molybdenum	Mo					
	Fe Mo	48/52	0.07 max	0.1	0.05	Si 1 max	5 to 30
	Fe Mo	60/65	0.07 max	0.1	0.05	Si 1 max	5 to 30
	Oxide						
	MoO_3	52	—	—	—	Oxygen	Powder or Pellets

Production of stainless steel by electric arc furnace route

The process consists of melting the charge mix comprising stainless steel and other scraps, high carbon ferrochrome, nickel and high carbon ferromanganese. The melt down bath containing about 0.35-0.40% carbon, 12-13% chromium, 0.80–1.00% manganese and 10-11% nickel is then decarburized to carbon levels of about 0.06-0.07% and simultaneous oxidation of chromium to about 6-7%, resulting in bath temperature in excess of 1800°C. This is followed by addition of cooling scrap to bring down the bath temperature, addition of the balance amount of chromium in the form of low carbon ferrochrome and ferrochrome-silicon. At this stage the slag is reduced by means of ferrosilicon to recover the chromium and manganese. Final trimming additions are then made for the desired chemistry. The process flow diagram and the specific consumption of the various inputs for this route for the production of AISI 304 grade of stainless steel are shown in Fig. 1.

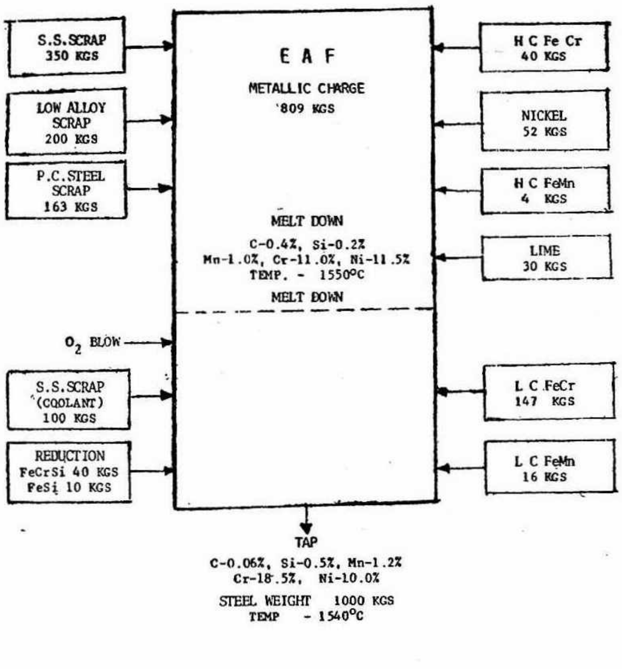

FIG. 1 : PROCESS FLOW DIAGRAM AND MATERIAL BALANCE FOR A TYPICAL AISI 304 HEAT (45% S. S. SCRAP) BY EAF ROUTE

The conventional electric furnace route for stainless steelmaking suffers from the following drawbacks :

i) The use of low cost high carbon ferroalloys is restricted due to the limited process capability.

ii) The recovery of chromium and manganese are low (85% and 70% respectively).

iii) The high temperatures achieved during decarburization severely damage the refractory.

iv) The productivity is poor.

Newer methods of stainless steel production

In the late 1960's the methods for production of stainless steel underwent dramatic changes resulting from the successful development of processes which were able to decarburize chromium bearing melts with oxygen at low partial pressures. The success of these processes lay in their ability to remove carbon to low levels at reasonable temperatures without excessive oxidation of chromium and the other oxidizable metals in the melt viz. iron and manganese. The first process exploiting such a technique was Vacuum Oxygen Decarburization (VOD) developed at Witten in 1968 and the second process was Argon Oxygen Decarburization (AOD) which was developed commercially in 1969. Another process developed on the same principle was Creusot Loire Uddeholm (CLU). These processes achieve their results by reducing the partial pressure of CO through the use of vacuum, an inert gas, and steam respectively. In all these processes the electric furnace is used primarily as a melting unit, with the secondary vessel being utilized for the refining and finishing operations. In this paper discussion has beed restricted to the two principal processes of stainless steelmaking practiced presently viz. AOD and VOD.

Argon Oxygen Decarburization Process (AOD)

The AOD system consists of a bottom blown tilting converter utilizing oxygen and argon (sometime nitrogen) in which the principle of reducing the partial pressure of CO by the inert gas is utilised. The AOD process has continued to make major technological progress in the recent times. The size continues to increase with heat times compatible to the requirements of continuous casters. Within only ten years after its introduction 80 vessels had been installed in the steel industry. Something like 65% of the free world's stainless steel production is now through the AOD vessels and in the USA and UK, this figure is about 85-90% of the total production[2].

Whereas in the conventional arc furnace steelmaking upto 45% of chromium charged is oxidized to the slag during decarburization, in AOD vessel this is normally not more than about 10% of the chromium charged. Decarburization is extremely efficient and as a result of the reduced oxidation of metals less heat is generated during the blow, compared with the extremely high temperatures of conventional decarburization.

The unique feature of the AOD process lies in its ability to refine a wide compositional range of chromium bearing melts. This provides the chance of scanning the full range of available nickel and chromium bearing raw materials and thereby minimizing the cost of inputs through the selection and use with the minimum of technical restraints of an optimized steelmaking charge. Both operational AOD vessels at Panteg and Stocksbridge, British Steel Corporation, proved themselves against charges containing as much as 3.0-3.5% carbon on occasions and generally within 1.5-2% carbon range[5]. Only in exceptional circumstances the decarburization is started in the furnace. The only justification for this is to increase productivity in those shops where the AOD cycle time, rather than the arc furnace cycle time dictates the steelmaking productivity. The coincidental high silicon content of certain charge materials may as a consequence be turned to profitable use. Normal silicon content at metal transfer to the AOD is 0.20 to 0.30%, sufficient to protect the furnace chromium from oxidation. It has been reported by Hodge[6] that no difficulties are encountered in processing charges with 0.20-2.0% carbon 0.03 to 0.50% silicon, upto 0.15% sulphur, and upto 0.10% lead. In contrast the opening carbon in the conventional arc furnace steelmaking before blow is limited to about 0.60% maximum, due to excessive chromium oxidation, temperature build up and flame evolution above this level.

Usage of input Materials and Ferroalloys in AOD

The cost of each unit of the two most important alloying elements viz. chromium and nickel being lowest in stainless steel scrap, it is a natural tendency for the stainless steelmakers to use as much return stainless scrap as possible. However, the steelmaker cannot normally expect more than 40-50% return scrap in his furnace charge. With the advent of processes where yield of products is improved significantly, the amount of return scrap available goes down further. In the absence of stainless scrap the steelmaker turns to the cheapest sources of ferroalloy/alloying elements. The flexibility of the AOD process in terms of its capability to process high carbon melts, has made possible significant use of the high carbon bearing reduction products of chromite ore, viz. charge chrome and high carbon ferrochrome. Due to this reason the use of costly low carbon ferrochrome in the AOD process has been restricted to only finishing additions for the purpose of trimming of the composition. Whereas British Steel Corporation in the early 1970's used to purchase 60% of the ferroalloy chromium units for stainless steel making in the low carbon form, towards the early 1980's these alloys represented only 2% of their intake[2]. The trend of change in the USA on the use of various chromium bearing ferroalloys since the advent of AOD process, as reported by Bureau of Mines, US is shown in Fig. 2. In addition to the use of high carbon bearing chromium inputs, there has also been a change to a greater usage of high carbon ferromanaganese. The consumption of silicon for reduction is lowered substantially in AOD (about 10 kg/t), as compared with the electric furnace route (about 20 kg/t).

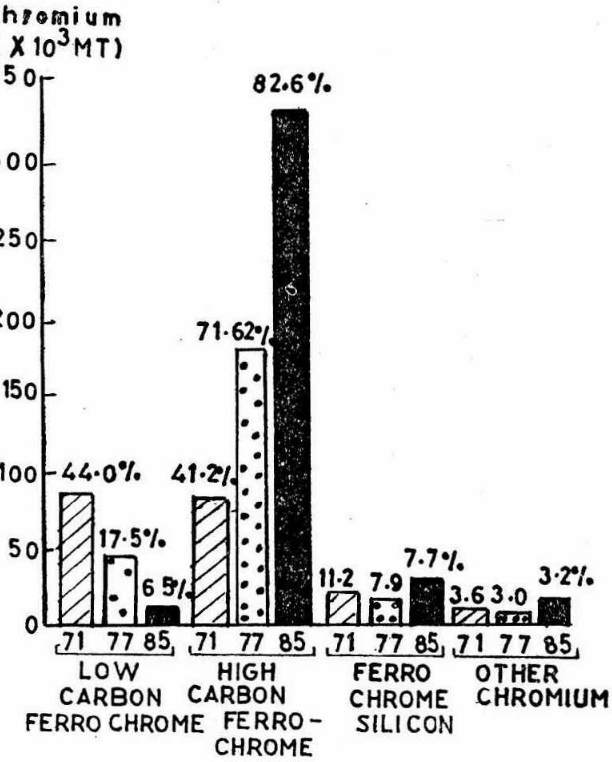

FIG. 2 : UNITED STATES CHROMIUM CONSUMPTION PATTERN

Previously most of the stainless steel was produced only with a small proportion of the required nickel in the form of ferronickel or nickel oxide. The high sulphur and carbon content of certain grades of ferro nickel was an inhibiting factor in their usage in the conventional electric arc furnace practice. However, due to its ability to decarburize and desulphurize from high levels, the AOD process can operate successfully with addition of carbon and sulphur containing ferronickels. These have the additional advantage of being an attractive coolant material for use in temperature control during blowing of the AOD vessel and at the same time contributing valuable iron units. The use of nickel oxide sinter also helps in reducing silicon to the desired level (about 0.30%) before transferring the molten metal to the refining vessel. NOS 75 developed by M/s Inco Metals Co. (Ni+CO =76/77 %, oxygen = 22%), used in conjunction with chargechrome, is reported to remove silicon to this level without the need for oxygen lancing[7].

The process flow diagram for the EAF-AOD route for the production of AISI-304 grade of stainless steel, based on the estimated material balance is given in Fig. 3.

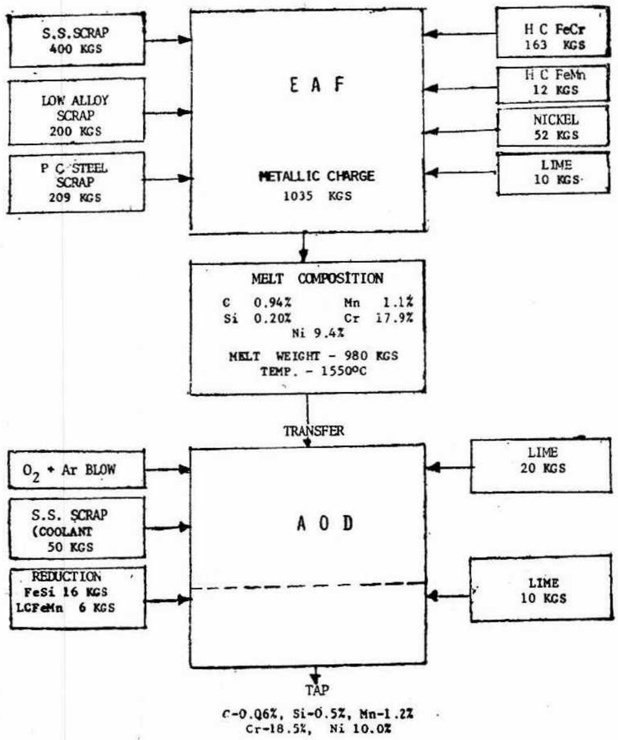

FIG. 3 : PROCESS FLOW DIAGRAM AND ESTIMATED MATERIAL BALANCE FOR EAF-AOD ROUTE (45% S. S. SCRAP) OF AISI 304 PRODUCTION

Vacuum Oxygen Decarburization Process (VOD)

The VOD system consists of a stationary top blown ladle with a large free board in which refining operations are carried out under vacuum. Lowering of partial pressure of carbon monoxide for improved refining operations is done through the vacuum. The process also requires stirring of the bath by argon introduced through a porous plug in the bottom of the ladle. Though the growth of the VOD process was very rapid till the early seventies, the AOD process, because of its additional advantages, took over in the production of stainless steel in most countries. Till the end of 1976 the number of operating AOD units rose to 59 against 25 VOD units[8].

Oxidation of elements for a given final carbon level is a little lower in the VOD process than in the AOD. However, the process has got lesser flexibility in terms of the carbon content of the transfer metal. Normally the carbon content at transfer to VOD is restricted to 0.80%. Therefore the scope of using low cost high carbon ferroalloys is somewhat restricted in the VOD process. While attempting to use higher proportion of high carbon ferroalloys in the charge, it is necessary to give a predecarburization in the electric arc furnace, so that the carbon content of the transfer metal is within the desirable level. Even then the charging is so designed as never to exceed 1.5% carbon and it is necessary even from 1.0% to use special procedures such as a very careful deslagging, before blowing. It is also fairly difficult to desulphurize during treatment in VOD. It is therefore preferable that the metal should already have a low sulphur content.

In addition to the advantage of using higher proportions high carbon bearing ferrochrome and ferromanganese, as compared to the conventional electric furnace route for stainless steel making, the VOD process is also suitable for using cheaper forms of nickel viz oxide or ferronickel like the AOD process.

The process flow diagram for the EAF-VOD route for the production of AISI-304 grade of stainless steel, based on the estimated material balance is given in Fig. 4.

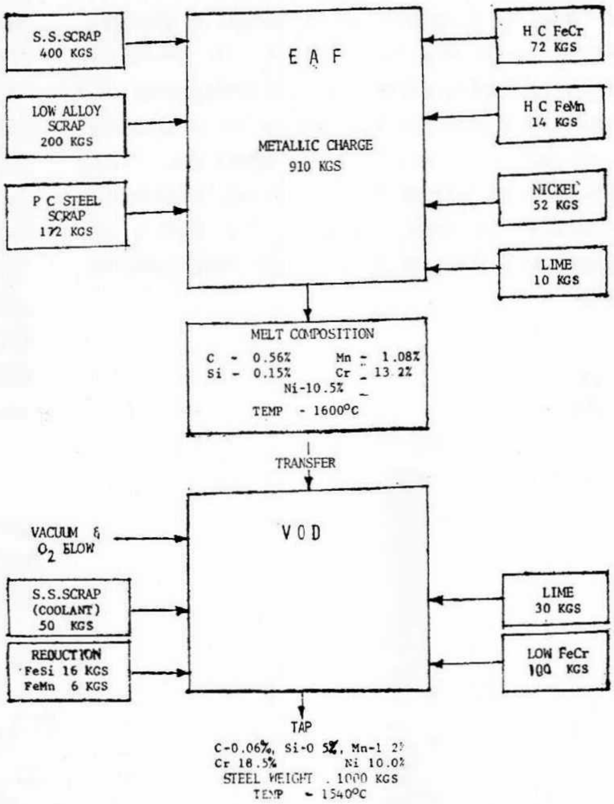

FIG. 4 : PROCESS FLOW DIAGRAM AND ESTIMATED MATERIAL BALANCE FOR EAF-VOD ROUTE (45% S. S. SCRAP) OF AISI 304 PRODUCTION

THE INDIAN SCENE

Status of production of ferroalloys

In India chromium bearing ferroalloys (high carbon ferrochrome, low carbon ferrochrome and ferrochrome silicon) are produced by three companies viz. FACOR, Andhra Pradesh, IDC, Orissa and VISL, Karnataka. VISL produces ferrochrome for the consumption of its own alloy steel plant. The other two companies together have an installed capacity of 20,000 tonnes/year for high and low carbon ferrochrome. The domestic demand for ferrochrome by 1983-84 is estimated to be 22000 tonnes and to meet this requirement and export requirements an additional production capacity of 50,000 tonnes/year of charge chrome is being generated in FACOR's plant in Orissa[9].

The installed capacity of eight plants producing ferromanganese in India is 241,000 tonnes per year[9]. All the varieties of ferromanganese viz. high carbon, medium carbon as well as low carbon are produced indigenously and the production is sufficient to meet the domestic requirements as well as to export a large quantity. The status of availability of electrolytic manganese as well as extra low carbon ferrochrome, from indigenous suppliers is not known. These are very critical items for the production of ELC variety of stainless steels by the conventional process. However, for the newer methods of stainless steel production their use is likely to be minimal.

The entire quantity of nickel in various forms used for steelmaking processes is imported.

Status of stainless steelmaking in India

Most of the stainless steel made in India, presently, is through the conventional electric arc furnace route, the major producers being Alloy Steel Plant, Durgapur and Visesvaraya Iron and Steel Ltd., Bhadrawati. A few mini steel plants are however, reported to produce stainless steels through the secondary refining vessel.

The secondary steelmaking route has already made a dent in Indian Stainless Steelmaking scene. VISL Bhadravati have already commissioned their VOD unit for the processing of stainless and other special steels. Alloy Steel Plant Durgapur is also in the process of carrying out its expansion programme through increasing the stainless steelmaking capacity by the EAF-VOD route to 90,000 tonnes per year.

As already discussed, there is a close link between the method of stainless steel manufacture and the usage of ferro-alloys. It will be seen from the process flow diagrams given in Figs. 1, 3 and 4, the salient features of whose ferro-alloy consumption pattern have been summarised in Table 5, the consumption of high carbon bearing ferro-alloys will increase substantially with the introduction of the secondary steelmaking routes for stainless steels in India. The steelmaking industry is expected to benefit substantially through the use of cheaper graeds of ferro-alloys and improved productivity by the newer process routes.

TABLE—5

Consumption pattern of input materials in EAF, EAF-AOD and EAF-VOD routes for AISI 304 stainless steel

Material	S. P. Consumption (KG/T Steel)		
	EAF	EAF-AOD	EAF-VOD
Stainless Scrap	450	450	450
Low Alloy Scrap	200	200	200
Plain Carbon Steel Scrap	163	209	172
Nickel	52	52	52
High C Fe Cr	40	163	72
Low C Fe Cr	147	10	100
High C Fe Mn	4	12	14
Low C Fe Mn	16	6	6
Fe Si	10	16	16
Fe Cr Si	40	—	—

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