Changing trends in ferro-alloy consumption in an integrated steel plant

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Introduction

Ferro-alloy addition for the purpose of deoxidation or alloying, is an integral part of steelmaking. The grade of alloy used is influenced by technical, economic and availability considerations. In addition to ferro-alloys, requirements can also be met partly from plant return scrap.

Traditionally integrated steel plants produced tonnage steel, basically using manganese and silicon in the form of several ferro-alloys. With the change in steelmaking practice, particularly with the introduction of secondary steelmaking, the complexion of the product mix of the integrated steel plants is undergoing a significant change.

Micro alloyed steels are now common products of integrated steel plants. Many plants, particularly, Tata Steel, also produce large tonnages of plain carbon and low alloy forging quality steels. With the growth of automobile and engineering industry, the demand for such steels is steadily increasing.

The prices of ferro alloys had been very erratic, but even more erratic had been their availability. As a result the steelmakers have to stretch the limit of their ingenuity to maintain production. The physical metallurgist has to develop alternate analysis for providing the same properties in the finished steel. Changes are also initiated with a view to improve quality or to reduce the cost of production.

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Changes in steelmaking

Developments in steelmaking technology have influenced the grades of ferroalloys required and consequently there has been a decline in use of some grades and an increased demand for the others. Similarly certain developments have improved the alloy recoveries, thus reducing the specific requirements.

The influence of process developments on these aspects can be best illustrated[1] by following the basic reactions taking place while decarburising steel metals containing chromium. Manufacture of stainless steel is not a common product of integrated steel plants; nor any of the integrated steel plants in India produce stainless steel for sale. But this example is pertinent as it pinpoints, precisely, the dramatic effect of process developments on ferroalloys consumption.

On injection of oxygen in a molten steel bath containing both carbon and chromium, the relative portion of each element oxidised depends on composition of metal and its temperature, and the partial pressure of oxygen and its input rate. It is well known that chromium to carbon ratio in the bath can be increased by increasing the temperature or by reducing the partial pressure of oxygen or carbon monoxide. The high cost of production of low carbon ferrochrome, the economic necessity of having high recovery of chromium and the need for producing stainless steels with extremely low levels of carbon led to the development of the AOD and the VOD processes, where the beneficial effect of reduced partial pressure of oxygen or carbon monoxide could be exploited. This development resulted in a radical change in the consumption pattern of chromium alloys for steelmaking. The consumption of chromium alloys in U. S. A. during the last 10 years, as shown in Fig. 1[2],

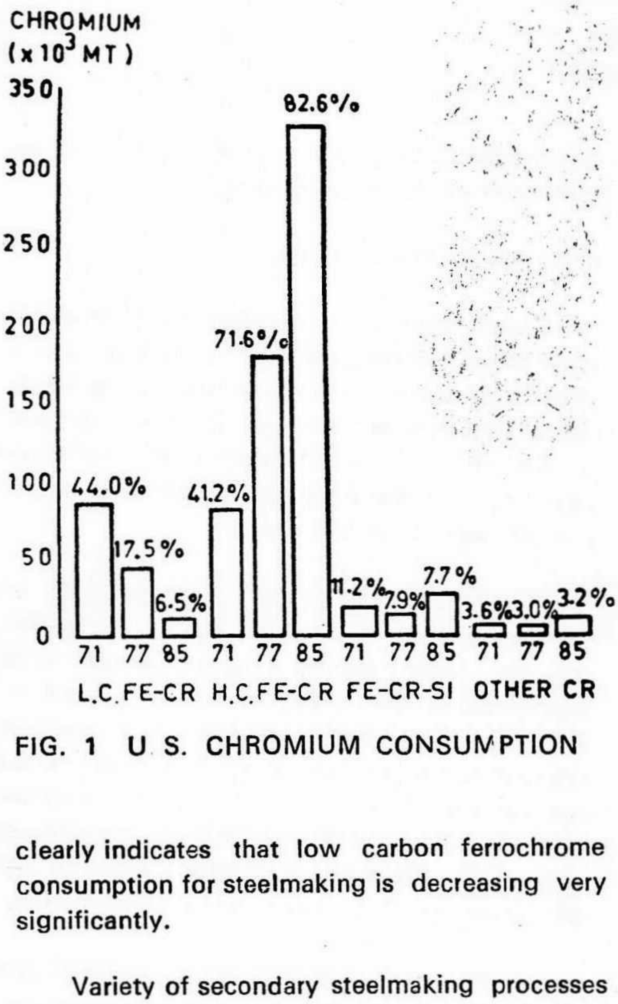

FIG. 1 U. S. CHROMIUM CONSUMPTION

clearly indicates that low carbon ferrochrome consumption for steelmaking is decreasing very significantly.

Variety of secondary steelmaking processes like ladle injection, ladle furnaces (L. F.), vacuum arc degassing and refining (VADR) are now widely used in the integrated steel plants. Use of calcium for desulphurisation and deoxidation was known to steelmakers for quite sometime. However due to its high vapour pressure, the addition of calcium presented a problem of inconsistent recoveries. Injection of powdered calcium alloys deep in the steel bath could solve this problem. As a result, wide scale use of calcium alloys for desulphurisation, deoxidation and inclusion morphology control has been adopted. Consequent to the development of injection techniques, consumption of powered ferroalloys has gone up.

The introduction of ladle furnace and VAD has further opened the avenues for optimising the alloy consumption. Steelmakers have been aware that readily oxidisable alloying elements should be added as late as possible in the ladle. However due to limitations of operating practice this was not always possible. These refining processes allow late addition with reliable and consistent recovery. The steel sample collected during secondary refining determines alloy requirements. The composition control that can be achieved with these processes is shown in Table-1[3] The economical benefit of the close composition control can be illustrated by an example of a common grade of carburising steel SAE 8620. The aim molybdenum and nickel is 0.20% and 0.50% respectively, for production through normal steelmaking processes. With VADR process, the aim additions can be 0.16% Mo and 0.42% Ni. The same set of properties can be obtained by maximising the level of the less expensive and indigenously produced alloy, manganese. Such flexibility, as possible with secondary steelmaking processes will naturally bring about optimum utilisation of ferro-alloys, in terms of consumption of indigenous alloys and cost of production.

With the development of various process control techniques, faster analysis aids and wider use of computers. the standardisation of steelmaking process is improving day by day. Such standardised process now leads to reproducible bath conditions, and therefore, optimum alloy recoveries. As a result considerable ferroalloy saving is possible by operating within a

TABLE — 1

Composition & temperature control performance for ASEA-SKP, Finkl-Mohr (VADR) and L. F. Process with B. O. S. (95% confidence limits for 0.16C-1.5 Mn steel[1]

Process	Composition Control Weight %			Carbon equivalent	Hydrogen PPn	Temperature OK
	Carbon	Manganese	Aluminium			
ASEA-SKF	± 0.015	± 0.08	± 0.008	± 0.03	2	± 4
Finkle-Mohr(VADR)	± 0.015	± 0.05	± 0.010	± 0.025	2	± 5
Ladle furnace	± 0.014	± 0.04	± 0.010	± 0.020	2.5	± 8.5

narrow range of specified hardenability band as illustrated in Fig. 2 [4].

Changes in steelmaking technology and compositions of various grades of alloy steels have not only led to saving of costly alloys like, Ni, Mo etc. but also the consumption of the most commonly used ferro-alloys. The world consumption of maganese in steelmaking has dropped from about 18 kg/t to less than 10 kg/t [5]. This reduction has mainly been possible through

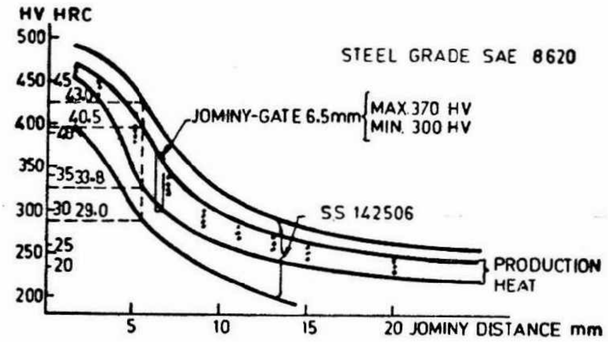

FIG. — 2

NORMAL AND STRICT HARDENABILITY SPECIFICATION

(a) maintaining high level of bath manganese (b) maintaining low level of Mn in the steel by use of microalloying elements and control rolling/heat treatment and (c) improvement in yield from liquid to finished steel by wider adoption of continuous casting.

Changes in the Product mix

The demand for high quality steels for applications in hot and cold forging, automobile, wire drawing, pipe lines, power generation and structural engineering is increasing world over. Upto 1970, majority of these steels were produced through either electric arc furnace (EAF) or through EAF followed by vacum degassing. Production of these grades, if possible, by the basic oxygen processes could effect distinct advantages of high productivity and low energy consumption. The developments in secondary steelmaking technology helped in switching over the process route from EAF to basic oxygen process. As a result, majority of these grades are now made in the integrated steel plants.

Better understanding of quantitative relationship between microstructure and mechanical properties and innovations in hot rolling technology, have contributed to the maturity of micro-alloyed steels as a new class of structural engineering materials. In the advanced countries, the projected growth rate of high strength low alloy (HSLA) steels is almost three times higher than that of carbon steels. The requirement of alloys like vanadium and columbium, which are the main micro-alloying elements, have been going up steadily for last twenty years and the expected demand pattern for last twenty years and the expected demand pattern for these alloys upto 1990 is projected in Fig. 3 [6].

Availability and prices of ferro-alloys in our country

While the basic ferro-alloys like Mn, Si, Cr and special alloys like Ti & V are available indigenously, our country has to depend on imports

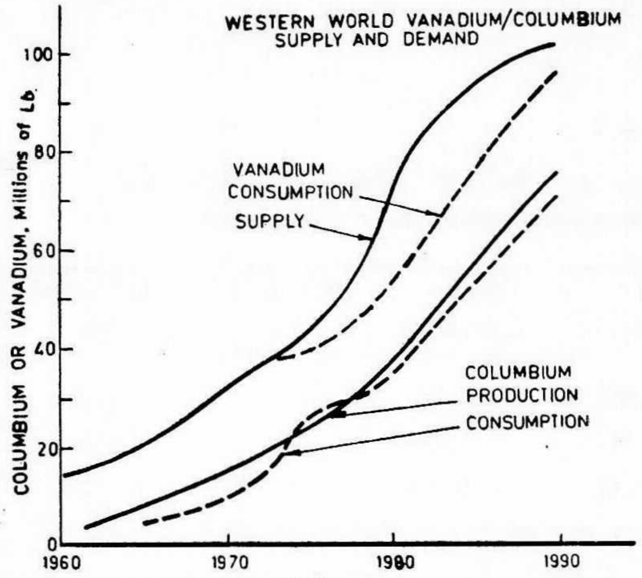

FIG. — 3

for alloys of calcium, nickel, molybdenum and columbium. The availability and prices of indigenous alloys were fairly steady till 1979. However, due to crippling power shortage and abnormal increase in the power tariff, after this period, the availability and price structure of ferro-alloys has been quite uncertain. Indicative prices of various alloys, during the last four years is shown in Table - 2. The rapid increase in the prices of alloys of silicon, chromium and molybdenum, after 1979, is quite revealing.

TABLE — 2

Indicative Prices of ferroalloys, Rs/T

	1978	1979	1981	1982
Fe-Si	4700	5600	9800	9200
Fe-Cr-LC	9900	12000	20000	22300
Fe-Mo	150000	450000	200000	160000
Niekel	60000	70000	110000	85000

While supply position of ferro-alloys produced indigenously with indigenous raw materials had been erratic for reasons like power shortage, flood etc., the import of ferro-alloys or raw materials for ferro-alloy manufacture had its ups and downs because of major strikes and/or political upheavals. The acute shortage of nickel in the late sixties due to the strike at Sudbury mines of International Nickel and the shortage of molybdenum in the late seventies due to low production in Zambia are classic examples.

Changing trends at Tata Steel

The product mix of Tata steel, has undergone a dramatic change in the last 10 years. Simultaneously efforts were also made to optimise the deoxidation practice to improve steel cleanliness and the ingot to finished steel yield. The increase in the proportion of special steel production and the improvement in yield achieved during this period is shown in Table - 3 (a) & (b) & Fig. 4. The introduction of high silicon ferro manganese (HiSiMn), as a regular ferro-alloy, from 1979, has resulted in the reduced consumption of FeSi and FeMn in the subsequent years. The major changes introduced during the last ten years and their impact on the consumption of various ferro-alloys need elaboration.

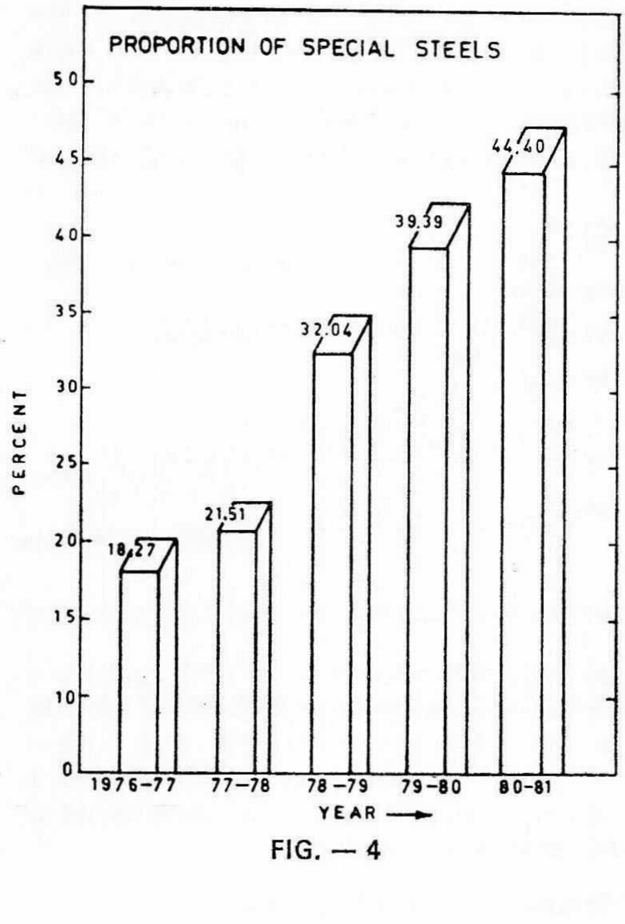

FIG. — 4

TABLE — 3 (a)

		1971-72	1975-76	1980-81
a)	Special steel despatch (T)	302905	278663	677962
b)	Special steel despatch as % of total steel production	21.83	13.75	44.00
c)	% yield ingot to finished steel	78.57	78.89	80.71
d)	Despatch of microalloyed steels	—	3019	139682
e)	Despatch of alloy seamless bars	192	160	2013
f)	Despatch of forging quality steels	10,230	19,760	37,130

TABLE — 3 (b)

Ingot to finish steel yield of special steels

Grade	1981-82	1980-81	1979-80	1978-79	1977-78
Forging quality	72.91	70.64	63.73	56.91	57.36
Seamless	60.06	58.69	57.82	56.81	40.90

Quality Improvement

To improve the quality of killed steels, the cleanliness of these steels have to be improved. The alumina inclusions tend to float up faster and therefore, it is possible to achieve better cleanliness in aluminium killed steels. However, there are many steels, where aluminium killing is undesirable and therefore, manganese and silicon additions and sequence has to be adjusted to obtain cleaner steel. It is well known, [7] that deoxidation by silicon is more effective than that by manganese, yet simultaneous deoxidation by these two elements gives much lower oxygen[8]. Though the additions of these elements is governed by the final specifications, adjustments were done, wherever possible to apply these basic principles of deoxidation. The following can be cited as an example

	C	Mn	Si	Mn/Si ratio	Al
Specified	0.10-0.14	0.40-0.70	0.10-0.35	1.1-7.0	Not specified
Preferred	0.10-0.14	0.60-0.70	0.10-0.15	4 to 7	Around 0.02

As a result, the steel quality has improved, there is an increase in manganese and aluminium consumption and decrease in the silicon consumption for the production of these steels.

The effect of calcium, zirconium and misch metal on inclusion morphology control and its effeot on improving the steel properties has been well established of late [9,10,11]. Accordingly, these alloying elements are being used in certain grades, especially those rolled into flat products, to improve their through thickness properties.

Titanium is an indigenously produced ferro-alloy and it had hardly any use in integrated steel plants. However, consumption of titanium in Tata Steel has gone up, as it is used for deoxidation and micro-alloying.

Development of steels with indigenous raw materials

Hardenable grades of forging quality low alloy steels presently being used in India, were developed in Europe & U. S. A., using ferro-alloys abundant in these countries. Grades developed with indigenous alloys are expected to be more economical than equivalent existing grades of these steels. With this in view, studies are being carried out to develop equivalent grades for 42CrMo4, EN.19, En. 24 etc., with guaranteed identical physical properties.

For many applications molybdenum is used for improving hardenability and for avoiding temper embrittlement. The first point can be taken care of by adding alloying elements like Ni, Cr, V, Mn. The second point is not so important for applications where welding is not involved or for components which can be cooled fast after tempering and would not be used in the temper brittle temperature region. In any case Mo required to avoid temper embrittlement can be reduced from normal range of 0.20% to around 0.10%. Thus after thorough trials by the customers, % Mo in many grades has been reduced to mutually agreed standards and the balance replaced by other alloys, like vanadium.

Improvement in the yield

The semi killed steels constitute a significant part of the total steel production in the integrated steel plants of India. Surveys of practices followed for the production of semi-killed steels show that Mn, Si & Al. are the only elements which are used for deoxidation[12]. The comparative deoxidising power of these elements is shown in Fig. 5 [13]. It can be seen from this figure that Mn alone cannot be used as a deoxidiser as prohibitively large precentages would be required to suppress the carbon-oxygen reaction. On the other hand aluminium is such a strong deoxidizer that any excess addition will lead to complete suppression of gas forming reaction, resulting in pipe in the solidifying ingot. Silicon therefore, is a very popular deoxidiser for the production of semi-killed (balanced) steels.

Various deoxidation practices followed world over indicate that there is no universal practice for any specific grade, which is due to variation in the operating practices of the individual plants. At Tata Steel the earlier deoxidation practice for balanced steels used to be addition of 450 kg of FeSi in the ladle. In many instances this practice led to overdeoxidation of the

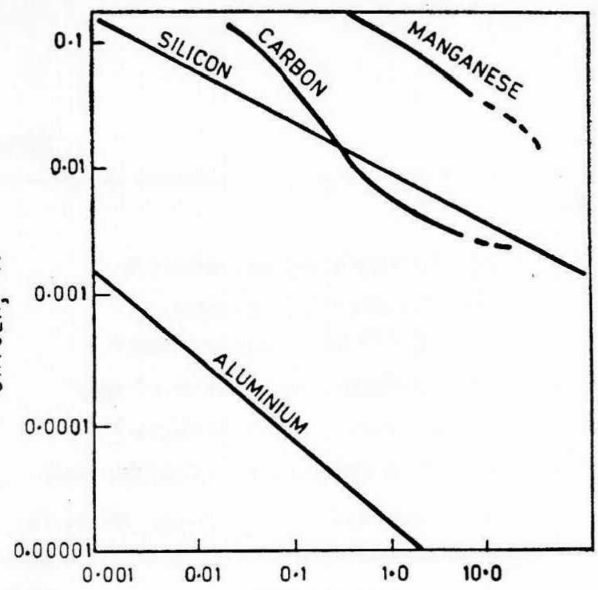

FIG. — 5

COMPARISON OF DEOXIDIZING POWER OF CARBON MANGANESE, SILICON AND ALUMINIUM AT 1600°C

steel. The quantity was gradually reduced to 300 kg per heat. This change helped the efforts being made to improve the surface quality of rolled products and the blooming mill yields.

At the end of 1979, there was an unprecedented shortage of FeSi, coupled with a staggering price rise from Rs. 5600 per T to Rs. 10,000 per T. Efforts were therefore made to replace part of the FeSi with aluminium, silicon metal (98.5% Si) and high silicon ferro manganese (16 % Si). FeSi addition in each and every grade was critically examined and optimised wherever possible. As the supply position of the FeSi improved, addition of silicon metal and aluminium was discontinued. However the use of Hi. SiMn was continued due to its inherent advantages as a complex deoxidiser and economics. All these efforts led to the realisation that total addition of silicon in the form of different alloys could be further reduced without affecting the yield. Table 4 shows the equivalent silicon consumption in the semi-killed heats of the steel melting shops of Tata Steel. The silicon in the ladle samples which used to analyse around

TABLE — 4

Consumption of equivalent ferrosilicon (Including all silicon alloys) in semikilled steels.

Year	SMS - 2 (Duplex shop) Kg/T	SMS III Kg/T
1974-75	2.15	1.95
75-76	1.83	1.76
76-77	1.88	1.56
77-78	1.85	1.47
78-79	1.86	1.49
79-80	1.60	1.31
80-81	1.32	0.95
81-82	1.28	0.90

0.10% in 1975 or earlier, around 0.05 to 0.07% between 1976-1979, has now come down to the range of 0.03 to 0.07%. The changes in the deoxidation practice contributed significantly in improving the surface quality of the rolled products which in turn resulted in higher ingot to finished steel yield.

Moulds used in the integrated steel plants in our country are narrow end up type and production of killed steels through these moulds sometimes leads to internal unsoundness in the rolled products. With this in view semi killing practice was extended to many grades hitherto killed e g. certain grades of high tensile plates, strips etc. Changing over from killed steel practice to semi killing practice, wherever technically possible, resulted in the following improvements :

i) Increase in the yield to the extent of 5%
ii) Saving in ferro-alloys
iii) Improved product quality.

Cost reduction

The effect of the various steps taken during the past few years led to considerable savings in the cost of ferro-alloys. Table-5 compares the deoxidation practice for a typical semikilled steel, TISCON, over the past ten years and its impact on the cost of the ferro-alloys.

TABLE — 5

Comparative cost of typical Deoxidation practice.

Grade : TISCON :
0.19-0.23% Carbon, 0.70-0.90% Mang.

Year	Ladle additions (kg) FeMn	High Si FeMn	FeSi	Unit cost
1970 to 76	2700	nil	400	100
1977 to 79	2500	nil	225	83
1980 to 82	1700	1000	nil	66

In case of high silicon steels, the aim carbon and silicon levels were 0.06 to 0.08% and 1.2 to 1.4% respectively. It is known that silicon percentage can be lowered if the carbon is also lowered, to maintain the same magnetic characteristics. Accordingly attempts were made primarily in Steel Melting Shop No. 2, wherein a duplex process used to be followed, to lower the carbon and silicon in the steel. The frequency distribution of silicon and carbon for electrical sheet steels from this shop where bulk of this steel used to be produced, for last few years is shown in Table - 6. With the introduction of L. D. Steelmaking process at Tata Steel, it will be possible to ensure further reduction in carbon content, which will help in reducing the ferrosilicon consumption for this grade.

TABLE — 6

Carbon and silicon levels in high silicon heats

Distribution of carbon	1981-82	1980-81	1979-80	1978-79
< 0.06	93.91	93.38	70.47	27.37
0.061 - 0.080	5.89	6.37	28.53	65.64
> 0.08	0.20	0.25	1.00	6.99
Distribution of Silicon				
< 1 00	12.81	9.16	2.23	3.35
1.01 - 1.20	70.73	76.08	43.18	31.56
1.21 - 1.40	16.26	14.76	43.42	47.49
1.41 - 1.60	0.20	—	9.93	14.53
> 1.60	nil	nil	1.24	3.07

In 1979, where there was acute shortage of ferro-silicon, all round efforts had to be made to locate alternate sources of silicon. It was realised that certain percentage of FeSi purchased was being accumulated as silicon powder and about 250 T of silicon powder was readily available. As silicon could not be used in the powder form, trials were conducted by briquetting this powder. The properties of briquettes required was such that they should sustain the requisite handling inside the plant and the silicon recovery obtained was comparable to that obtained by ferro-silicon lumps. A specification for the briquettes was developed, the details of which are given in Table - 7. The recovery of silicon obtained from these briquettes is similar to that of lumps. The success of this development can be judged by the fact that during last two years about 300 T of silicon powder has been salvaged as briquettes.

TABLE — 7

Specification of Ferro silicon briquettes

% Si.	....	70 to 75
% Moisture	....	0.75 max.
Crushing strength	....	150 kg/cm^2 minimum

Special grade ferro-manganese is produced by the captive ferro alloy plant at Joda. The economics of its use is therefore very attractive and the saving accrued compared to equivalent quantities of purchased FeMn and FeSi is substantial. Apart from economics this being a complex deoxidiser, has its own inherent advantages[14]. However the Steel Melting Shops were basically designed to use only two ferro-alloys viz. Mn & Si, for wide scale use and the introduction of a third ferro-alloy, vis. special grade FeMn, presented a very difficult problem After thorough study of the handling problems and the individual shop logistics a suitable method was evolved to use this ferro-alloy regularly. The consumption of special grade Ferro-manganese which was around 1000 T per annum in 1976, has now gone up to around 7000 T per annum during last two years.

With change in the product mix, the production of nickel and molybdenum bearing steel has gone up considerably in the last few years. To conserve these costly alloys and to save valuable foreign exchange, a study was conducted to find out ways and means to collect the alloy bearing scrap, stock it seperately and then to remelt it in the steel melting shops. A special drive was also made to collect rejected castings, rolls etc. having recoverable alloys. A suitable method of alloy bearing scrap segregation, collection and remelting was then developed and as a result increasing amounts of alloys are being recovered from the scrap.

In the past, aluminium shots were used as mould additions, to control the ingot structure in the semi-killed and rimming quality steels. Due to their small size and method of handling it was observed that a considerable wastage was taking place. To eliminate this wastage, these shots were replaced by cubes, each weighing about 25 grams. The reduction in aluminium consumption due to this change was about 5%. Due to ease of addition, the control over ingot structure also improved.

Certain alloys, when added in the mould, yield higher and consistent recoveries. Trials were therefore conducted with addition of columbium in the mould instead of ladle for some HSLA grades. This led to the saving of ferro-columbium consumption to the extent of 25 kg in a 90 T open hearth heat.

Conclusions

i) Due developments in the steel making and processing in the last few years, the product mix of integrated steel plants has undergone a significant change. This has led to a change in the alloy consumption pattern.

ii) Tremendous growth in the use of HSLA steels for structurals, pipe lines and other applications have resulted in increased demand of alloys of vanadium, columbium and titanium. Consumption of misch metal or alloys of calcium and zirconium has gone up significantly in recent years for the production of steel with improved formability and isotropic properties.

iii) The rising cost of energy and production have forced the steel plants to optimise the deoxidation practices and alloy consumption.

iv) Though the final specification, limits the choice of alloys to be used, various means and ways have been found to reduce the cost of alloys. Cost of alloys have also been lowered by developing new specifications, without impairing the end product quality by replacing the costly ferro-alloys partly or fully by cheaper ones.

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Concluding remarks on the key note session .... — Dr. B. Panda*

Distinguished key-note speakers, fellow delegates, Ladies and Gentlemen,

It is my proud privilege to chair the first Technical Session of the Seminar today. In this Session, the Key-note Speakers have presented very interesting papers, which are in the field of beneficiation by Dr. S. R. Pramanik; energy conservation by Mr. C. N. Harman; ferro-nickel production by Mr. Erik Svana and changing trends in ferro-alloy consumption by Dr. T. Mukherjee. Instead of summarising and analysing their speeches, I will rather point out that all these aspects, which were presented this morning in the Technical Session as well as earlier, in the Inaugural Session by very eminent speakers including the Hon'ble Minister of Steel & Mines, amount to in one single phrase "Productivity in its Totality". It is productivity of the capital, productivity of man-power, productivity of energy, productivity of raw-materials. It is very difficult to put any of these in particular order. If you can have the highest productivity i.e. if you can squeeze out the most, for each unit of inputs, in the items I just now mentioned, whether it is ferro-alloy industry or any other industry, it need not worry even during the recessionary period like the one which the world is passing through for sometime now.

It is not in a Technical Session of this kind that we should cover the various intricacies of capital productivity, which the economists call as "capital output ratio". Even today, as correctly pointed out by Dr. Dastur earlier, although

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India claims, as the 10th largest industrialised nation in the world, our capital output ratio is far below than that of South Korea or Singapore. This is very important particularly for the ferro-alloy industry where the capital investment per unit production is far in excess than even steel mills or aluminium or any other industry. But India has the skill, the expertise, the knowledge both in financial analysis and technical ability to keep this capital output ratio the best that we need. We in our own way have shown in ferro-alloy industry, like the Charge Chrome Plant we have put up recently, that it is less than 1/4th the cost anywhere else in the world for the same capacity with the latest equipment including computerisation. I am sure, the efforts can be continued and this is the most important aspect we must tackle first otherwise we would be starting with the wrong foot. Once the capital investment is too high, all other efforts will be in vain, we can never compete with the rest of the world.

Similarly, man-power, I would very much like to pay much more wages and salary to the man-power with high productivity, than even zero wages with no productivity at all because it does not pay to have low productivity. Next to capital productivity the beneficiation of raw-materials, which formed the subject matter of the first paper presented, is very important. In raw-materials, of course, India has been unfortunate in some aspects but fortunate in many other aspects; unfortunate in the sense we don't have the right type of reductant or sometimes the right type of ore even in the major tonnage alloys. Beneficiation is the right direction as the Key-note speaker has highlighted and we are proceeding in the right direction.

As far as the energy is concerned, I am sorry to say that we are not very well situated for ferro-alloy industry. Once you have controlled the capital output ratio, in other words minimum capital invested per unit of production, the next important question is cheap energy input. One does not have to depend on hydel power alone to compete in ferro-alloy industry. South Africa, has proven by converting their vast coal resources into thermal electricity and virtually dominating in the field of ferro-alloys in the whole world today. In India, we may not have metallurgical coal for our reductant purposes or for blending but the high ash or high abrasive coal available is quite feasible for power generation. Orissa State alone for example has 30,000 million tonnes of coal reserves and yet the State suffers from one of the severest power shortage in the country. This is a very anomalous situation. The coal, I am talking about which may not be very suitable for metallurgical purposes. but eminently suitable for power generation, is the cheapest in the whole world, much cheaper than the South African coal and fabulously cheaper than the normal coal available anywhere else in the world. Sometimes it is 1/10th of the cost of coal available anywhere else in the world. Even then neither we have the energy nor we have the productivity in energy, in other words, cheap energy, we have not been able to produce.

Once these problems are tackled earnestly and quickly, I am sure, India can again start in a new path of progress and rapid development in the field of ferro-alloys irrespective of the steel development programme on which ferro alloys naturally depend. India could still be a very large exporter of these raw-materials provided we tackle the central problem of productivity in all its aspects.

As far as the problems faced by the ferro-alloy industry today, it is a world phenomenon. It has been a very long one this time. Being an optimist, I would still like to highlight some virtues out of the recession. There are many problems, of course, I do not have the time nor there is a need for, as you are already aware what problems any economy faces during recessionary trends. One thing is however, certain, that if you like to achieve the highest possible productivity in the fields I just mentioned, recession could be a blessing in disguise. Few years ago, we didn't care what amount of energy we spent, what type of raw-materials we spent, what wastage whether in gaseous form or in solid form, but today the user, the producer and the planner everyone of us are aware of these. Thanks for recession. Keeping this in mind and with an optimistic note, I conclude this Technical Session for today. Thank you.