The role of charge materials in alternative routes to steel

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Introduction

New steelmaking technologies being developed presently are likely to have a significant impact on the future competitive structure of the steel industry. These technologies would not only lower costs but could greatly reduce the size requirement for efficient operations as well as eliminate several processing steps. Such technological developments always influence the structure of any industry. Development of oxygen steelmaking for example, offered lower scrap consumption compared to open hearth steelmaking, and this helped electric furnace steelmaking to grow by releasing scrap. Meanwhile, the developments of continuous billet casting allowed small steel electric furnace based plants to produce long products economically. The new technologies being developed today have the potential of causing even greater structural changes. Technologies such as smelting reduction, direct reduction, direct steelmaking from iron ore and near net shape casting are so revolutionary that they may change the complete rules of the game for steelmaking.

A survey of the developments in the steel industry through out the world gives an impression that after immense growth during the thirty years of prosperity and stability following the Second World War, there was stagnation and loss of growth as shown in Fig. 1. This impression is perhaps unfounded and actually conceals certain significant developments which are illustrated below:

- o Quantitatively, by very marked growth in consumption and production of finished steel and not just raw steel.
- o Qualitatively, by the development and marketing of new grades of quality steel products.
- o Technically, by the development of second generation continuous casting such as near net shape casting. Presently, the emphasis is on units with a capacity ranging between 0.3 to 1.5 mtpa (instead of having larger integrated units with 3-10 mtpa) for virtually all steel products.

All these factors have brought about profound changes in steel production processes and routes, Fig. 2. in order to arrive at a proper appreciation of technical developments in the steel industry and consequent gains in productivity achieved over the last twenty years, it is important to distinguish between the two basic routes viz. BF-BOF and scrap based EAF and the other emerging routes shown in Fig. 3.

Two important routes of steelmaking :

Fig. 4 illustrates the two basic routes of steelmaking which are :

- o The integrated route based on the use of iron ore and coking coal for blast furnaces, where the hot metal produced is converted into steel through an oxygen process.

- o The mini-mill route based on scrap which is melted and converted into steel in an electric arc furnace.

The essential features of both these steel production routes are summarised in Table-1. It can be seen that the principal raw material used in the conventional blast furnace ironmaking are iron ore and coal while scrap and electricity are the essential inputs in EAFs. The relative change in the share of these two routes is shown in Table-2 for the industrialised countries from which it is clear that while raw steel production in this group of countries has hardly changed over the last twenty years, developments in rolling and continuous casting have undoubtedly led to an increase in the production of finished steel from 300 to almost 340 mtpa.

In addition to the disappearance of older steelmaking processes (OH and Thomas converter), Table-2, the processes competing with each other now are :

- o The oxygen converter which, after substantial growth between 1960 and 1980, is now beginning to recede slightly from 68 to 66%.

- o The electric arc furnace which is continuing to develop, with its production having doubled between 1970 and 1990 and its relative share of production having expanded from 16 to 33%.

It is to be noted that the "short route" based on the electric furnace involving direct reduction using cheap natural gas is of greater importance for the 'Third World' but it is of less importance for the industrialised countries. In the latter, the growth of scrap resources has encouraged the development of the short route.

Tables -3 and 4 indicate the major trends in development over the last twenty years for each of the two routes, the salient features of which are presented below :

- o For ferrous raw materials, there has been no quantitative change. About 1030 to 1050 kg. of iron is still required for each tonne of steel produced and marketed.

- o As far as energy sources are concerned, no major changes have occurred in the conventional route except the direct injection of coal through the tuyeres for conserving coking coal and decreasing the coking capacity. However, there has been a major change in the energy sources for EAF steelmaking involving:

a) Improved thermal and electrical efficiency

b) The use of oxygen injection

c) As far as productivity is concerned, although there have been hardly any changes in the conventional route, there has been a marked improvement in the EAF. Form 2000 heats annually with tap-to-tap times of 3-4 hours, the productivity has increased to 6000-7000 heats per year with a tap-to-tap time of less than 1 hour.

Important developments in EAF steelmaking

Size and capacity

The world wide trend in the capacity of EAFs is illustrated in Fig. 5. Just as in the case of the conventional BF-BOF route, there has been no significant increase in the capacity and only a limited number of furnaces with a capacity exceeding 300 tonnes were actually built earlier on. Later on, the trend rapidly returned to capacities ranging between 100-150 tonnes due to emergence of mini steel plants and a remarkable increase in productivity. For 'micro-plants' which spread considerably throughout developing countries like India, many of the furnaces has a capacity of 30-60 tonnes. At this juncture, three important points are to be emphasised :

- o The philosophy underlying mini or micro-plants is very compact and simple production units concentrating on a single product, high productivity and reduced manpower.

- o Advantages associated with continuous casting have provided the necessary 'missing link' between the production of liquid steel and the rolling mill. In this regard, continuous billet casting has been integrated quite naturally with sizeable advantages into the mini steel plant system which was not so easy to achieve for continuous slab casting.

- o New methods of continuous thin slab casting have given yet another advantage to the mini plants.

Productivity

The most significant developments resulting in increased productivity include :

- The use of ultra high power furnaces with ratings ranging between 500 to 1000 KV/t.
- Improved electrical features with the use of direct current and plasmas.
- The role played by foaming slag.
- The use of oxy-fuel burners.
- Improved automation and process control.
- Scrap preheating.
- The recycling of energy, gases, etc.

The results of the above developments have been spectacular with regard to the reduction in tap-to-tap time to less than 1 hour, Fig. 6, and the corresponding increase in the number of heats per year almost equal to that of basic oxygen furnaces as shown in Fig. 7. It is clear that for production levels sought in the most modern "mini plants" (0.5-1.5 mtpa), it is not necessary to have larger capacity electric furnaces. A unit of approximately 100 t has now become the norm, whereby a production level of 0.6-1.2 mtpa can be achieved with a single furnace.

Costs

The total costs of EAF steelmaking is comprised of processing as well as capital costs. The processing costs amounting to approximately 50% of the total costs, consist of inputs like scrap and other raw materials including pig iron and DRI together with ferro-alloys and fluxes. it also includes the cost of energy in the form of electric power and solid, liquid or geaseous fuels. The trend in electrical power consumption is shown in Fig. 8. The consumption of fossil fuels such as coal amounts to 10-15 kg/t of steel. Substantial increase in the productivity has been achieved together with significant savings in electrodes, Fig. 9, or refractories. Environmental protection is one of the most important considerations which is promoted by the recycling and reutilisation of scrap. Dust emission either through the preparation of scrap or due to the electric arc furnace is being collected and the corresponding product used or treated in the best possible manner.

As far as the capital costs are concerned, these are not largely influenced by economics of scale because consideration is usually given to units of a similar size. What is more important is the actual design of the installation which may be more or less'conventional'. This means that for a given production capacity, equipment and ancilliary facilities may be more or less over-sized in order to take account of possible future developments. Table - 5 indicates a possible range of values for these capital costs.

Impact of new processes and new routes

Direct ironmaking/smelting reduction

Blast furnace productivity and energy efficiency have improved significantly over the past twenty years, and coal injection with oxygen enrichment will continue to reduce the blast furnace requirements of coke. Nevertheless, coke oven/blast furnace iron production is highly capital intensive and has continuing environmental problems. Consequently, efforts are under way to develop a process which can use coal directly and, in some cases, use ore directly.

Table 6 lists the direct ironmaking processes being developed, along with their current status, smelting or production intensity, fuel rate, capital costs and the possible time frame for commercialisation. The new processes can be commercialised only if they are tested in a demonstration unit of at least 25,000 tpa size. However, commercialisation not only depends upon the process being proven technically, but the technology having a significant potential economic advantage over the coke oven/blast furnace route. Commercialisation also is contingent upon the demand for new iron production.

The only direct ironmaking process that is reasonably well proven is COREX, which uses coal directly. However, this process has a high fuel rate, generates excess rich gas, has a relatively low productivity per unit reactor volume and a high capital cost.

Other processes that may be more energy efficient and require less capital are the American Iron and Steel Institute (AISI) and US Department of Energy (DOE) direct ironmaking, the direct ore smelting, (DIOS) and HIsmelt. These three processes, however, require further evaluation since they have only been proven on a small scale. HIsmlet and DIOS have built pilot plants and AISI-DOE is planning to build a demonstration plant. All are at about the same stage of development and will not be commercialised before 1998-2000.

The ROMELT process has been under development in Russia for over ten years. It is similar to the other bath smelting processes, but does not use a pre-reducer. The process uses ore or waste oxide and its coal consumption and productivity have been reported to be 650 to 900 kg/t of iron produced and 2-2.5/m^2/d respectively.

The implementation of direct ironmaking processes could result in incremental increases in hot metal production or several direct ironmaking units could replace blast furnaces. Also, these processes could serve as possible suppliers of clean iron units for an EAFD ro EOF. Direct ironmaking processes, potentially have lower operating and capital costs and could be considered for implementation in existing plants where the blast furnaces and coke plants have to be rebuilt. Of course there are factors like reduced requirement of ironmaking capacity and coal injection that may dampen the implementation of direct ironmaking processes. Therefore, the implementation of direct ironmaking technologies, including COREX, in existing integrated steel plants would be relatively small and less than 5 million tonnes by the year 2005. In the long term, however, even with coal injection in blast furnaces, these processes may have significant advantages over the coke oven/blast furnace route and may grow to 10 million tonnes by the year 2015. These processes may also be implemented effectively in developing countries like India - this trend is appearing already.

If used as an alternative iron source for a scrap based process, direct iron could find an attractive application in units like EOFs, which can run effectively using 40-60% hot metal. The smelter/EOF route could also be linked with a thin slab caster to produce higher quality steel products than those normally produced in an EAF.

Since the implementation of direct ironmaking technology will be slow and incremental, its immediate impact on competitiveness will be small. However, in the long term, the technology could make integrated production more competitive with scrap based production. It could also lead to the establishment of "mini-integrated mills" operating at 1 mtpa or less.

Direct reduction

The impact of near net shape casting and its influence on the growth of EAF production is dependent upon steelmakers being able to produce the liquid steel quality required. The metallic charge would be limited to high quality scrap as some form of clean iron containing minimum residuals (Cu, Ni, Cr, Hs, Sb, Su, etc.) and nitrogen contents. While the demand for quality scrap will increase significantly with more EAFs, the supply will decrease due to more efficient manufacturing industries such as the automotive sector. Therefore, the need for alternative iron sources, such as DRI and HBI, will increase significantly. Many flat rolled and special bar quality steels can be produced using a charge comprised of 10-30% alternate iron sources and a reasonable scrap-mix. If the price of the alternate iron is competitive, the amount used could be even greater.

The alternative iron source could be liquid hot metal supplied by one of the smelting reduction processes. Another possibility is that it could be pig iron, which is low in residuals and has a high carbon content that can be oxidised to supply energy and flush out nitrogen. Most likely, however, the best economic solution is DRI/HBI or iron carbide. While the processes for producing DRI and HBI are reasonably well developed, the iron carbide making process is under commercialisation. The major possible alternate iron sources are listed in Table-7, along with a range of their selling price, cost of production and capital cost.

When choosing an alternate iron source, steelmakers must consider its impact on steelmaking costs, as well as its capital and production. For example, the use of DRI with lower metallisation (less than 88%) and higher gangue content (more than 5%) increases energy consumption and can significantly affect the steelmaking cost. Thus, the development of alternate iron sources is not as important as the economics of quality steel production using these alternate sources of iron. As stated earlier, their impact is linked to the development of near net shape casting and the necessity for the continuing implementation of that technology.

Alternative iron technology will impact the steel industry in the following manner:

- o The United States alone will require 2 to 4 million tonnes of alternate iron by the year 2000. This range may drop if exports of quality scrap are significantly reduced.
- o Implementation of alternate iron technology requires traditional mini mills to integrate back in to the over all steelmaking process. Meanwhile, thin slab casting and flat rolling represent forward integration for integrated mills. Therefore, the traditional mini-mill is approaching the same type of processing as the integrated producer. The cost of adding alternate iron to the charge does not require as much capital as traditional integrated production, but it is considerably higher than that for an electric furnace shop that melts scrap for producing bars.
- o As alternate iron source processes become more complex, mini mills run the risk of loosing their focus and responsive cultures.
- o Even under the best conditions, the use of DRI, iron carbide and any other alternative iron source increases the cost of producing steels. This also will narrow the cost gap between the ore and scrap based producers.

Near net shape casting

This new field is developing for flat products with the continuous casting of this slabs having 30-60 mm thickness. The familiar example of the NUCOR Group in the United States points to the three-fold advantages of this technology as summarised below:

- o It eliminates part of the rolling process (i.e., roughing stands) enabling savings in capital and processing costs.
- o It encourages the casting-rolling link which had appeared in mini-plants for long products.
- o It is a key component in the design of mini-plants for flat products with a capacity of 0.2 to 2.0 mtpa.

Comparison of various steel manufacturing routes

The salient features which need evaluation for the comparison of the two basic routes of steelmkaing are presented below:

- o Production costs for liquid steel in the two routes and the analysis of their structures.
- o Possible developments according to varying economic conditions.
- o Flexibility of the two routes in technical as well as economic terms.
- o Adaptability of the two routes for manufacturing various steel products.

Production costs

Comparison of the production costs comprising the cost of raw materials, energy, manpower, processing including environmental protection are shown in Table - 8. The scrap-EAF route is approximately 12% less expansive than the conventional BF-BOF route in USA/Europe - this is also illustrated in Fig. 10. The important point to note is that the energy consumption, manpower and depreciation in case of the BF-BOF route is quite high because of the following structural differences :

- o Investments and their consequences such as depreciation, financial expenditure as well as the return on investments (ROI). If a new integrated plant is to be built today, costs related to investment would be almost impossible to bear and this is the reason why not many new plants are being built.
- o In most countries, labour and energy costs are far lower for the "short" route based on the electric furnace.
- o The cost of scrap or ferrous raw materials in general is of vital importance for the "short" EAF route and accounts for approximately half of steel production costs.

Probable trends according to economic conditions

For the short route based on the EAF, the cost of scrap has played and will continue to play a vital role. In the past, the price of scrap was an indicator of economic conditions, and a rise usually coincided with a period of favourable economic circumstances, i.e., increase in the cost of steel products. In case of the conventional BF-BOF route, variations in most of the production cost items are negligible. Coal and iron ore prices are relatively stable unlike scrap prices. While these conditions may vary probably very little in future, for major conventional plants, it is difficult to foresee what is likely to happen to scrap. As regards the current situation, the following points are to be noted:

- o The quantity of obsolete scrap which can be recycled is increasing throughout the world.
- o Encouragement to recycling is also increasing.
- o The means of recycling are improving continuously but their costs are likely to rise.

Relative flexibility

This is a significant advantage of the EAF route which, in technical terms, can operate at practically any market rate as the arc furnace with its continuous casting unit can be utilised according to need. Conversely, the blast furnace and coke ovens require continuous operation that virtually exclude any flexibility.

Relative adaptibility

This is the most significant advantage of the conventional route which can produce virtually all types of steel with the exception of highly alloyed varieties. Conversely, the arc furnace is well adapted to manufacturing alloyed steels as well as the opposite extreme of this range - reinforced steel and the most common long or even flat products. The fundamental problem with EAF route is the manufacture of varieties of carbon steels with very low contents of metalloids. The two complementary solutions to this problem are:

- o Very sophisticated selection and preparation of scrap.
- o Use of DRI, HBI and hot metal produced through one of the alternative routes to substitute scrap.

Counties having considerable resources of natural gas and suitable non coking coals can go in for direct reduction (coal as well as gas based) and electric steelmaking in order to produce virtually every type of steel.

Conclusions

In summary, it can be stated that the world steel industry is undergoing a structural transformation. New technologies are emerging, which substantially lower overall investment costs in a highly capital-intensive industry, reduce production costs, avoid certain processing steps which have hitherto been regarded as essential, and reduce environmental impact.

These developments are leading to a decrease in the size requirements of an efficient operation and acting as a spur to the introduction and expansion of mini-mills. By far the greatest influence has been near net shape casting technologies, which enable the mini-mills to compete directly with conventional integrated steel producers. The increasing demands on the quality of input materials for products from technologies such as thin slab casting require a substantial substitution of contaminated scrap by pure iron units.

Such technological revolutions in the steel industry are changing the structure and the relative competitiveness of this industry. The three technologies central to this revolution are smelting reduction, near net shape casting and direct reduction for the EAF as detailed below :

- Direct ironmaking through smelting reduction could offer incremental increases in production, replace older/smaller blast furnaces, or serve as the feed material for an EAF. This technology will be implemented at the modest pace, and its impact on competitiveness in the short term will be minimal. However, in the long term, it will make ore based steel production more competitive and could lead to an ore-based mini-mill.

- Thin slab casting is having, and will countinue to have, a major impact on the steel industry. In the United States, where this technology is being implemented widely, thin slab casting will force several ore-based plants to close and other to concentrate on the production of higher quality products. It will continue to eliminate processes across the board. Meanwhile, strip casting still is a few years away from commercialisation for carbon steel production and the major impact of this technology may be felt in developing countries.

- The continued growth of EAF steelmaking and thin-slab casting, is contingent upon the availability of clean iron sources. This will require increased production of DRI or other scrap substitutes like iron carbide.

Acknowledgement

The author acknowledges the assistance of Mr. B.D Pandey and Dr. U.S Yadav in the preparation of this paper, at very short notice.

Table - 1

Data for the two basic steel-making routes

	Blast Furnace (BF) +Basic Oxygen Furnace (BOF)	Electric Arc Furnace (EAF)
Ferrous raw materials	Iron ore + possibly some scrap	Scrap + possibly reduced ores & pig iron
Energy	Coal	Electricity + possibly solid, liquid or gaseous fuels
Usual size of units	BF up to 4000 to 5000 m³, BOF up to 380 t.	Apart from micro-plants (EAF of 10-20 t), average size increased slightly from 50-60 t to 100-150 t

Table - 2

Relative changes in the two routes for developed countries (mtpa)

	1970	1980	1990	1991
Total production of raw steel, including	397.1	407.0	391.2	380.4
o Open hearth furnace	98.6	24.2	4.6	3.1
o Basic Oxygen Furnace	200.3	276.8	257.4	251.1
o Electric Furnace	63.3	105.7	128.3	125.1
o Misscellaneous (mostly erstwhile Thomas converters)	34.9	0.3	0.9	0.1

Table - 3

Changes over the last twenty years in the two routes
(All data are given per tonne of finished steel, i.e., hot rolled)
Technical Data

	Blast Furnace (BF) + Basic Oxygen Furnace (BOF)	Electric Arc Furnace (EAF)
Energy : Coal (or fossil fuels)	Usually 750 to 800 kg of coal (i.e. approx. 25GJ). The main feature has been the development of the injection of coal into the tuyeres, which reduces consumption of coke and coking coal	Slight growth in the use of coal, natural gas or oil (1 to 2 GJ)
Electric power	Approximately 100 to 150kWh (including agglomeration, coking, injection and blowers, etc.)	Reduction from 600 kWh to 450 without additon & to 300 with injection of fossil fuels and preheating
Oxygen	55 Nm^3 in steel plant & 25 Nm^3 in BF	Rise from 20 to 40/50Nm^3
Productivity	For BOF, usually 2 to 2.5 t pig iron/m^3 per day approximately 10,000 heats per year (records, comparatively rare and usually for small units, have been achieved amounting to 12,000 to 15,000)	For EAFs, heats have risen from 2,000 to 5,000 per year. Today, the figure stands at around 6,000 to 7500

Table - 4
Changes over the last twenty years in the two routes
(All data are given per tonne of finished steel, i.e., hot rolled)
Economic Data

	Blast Furnace (BF) + Basic Oxygen Furnace (BOF)	Electric Arc Furnace (EAF)
Manpower : i.e. t/person & per year i.e. hour/t	Decrease from 10,000 to 5,000 for 5 Mt overall 500 ---> 1,000 3,2 ---> 1,6	Decrease from 600 to 500 for a unit rising from 0.3 Mt to 1 Mt. 500 ---> 2,000 3,2 --- 0,8
Production costs* (excluding ferrous raw materials, energy & manpower)	30 to 40$/t	35 to 45 $/t
Investment* (up to semi-products from continuous casting)	500 to 600 $/t per year	200, could now decrease to 100 $/t per year

* in US dollars 1993

Table - 5
Capital costs

	Simplified installation	Conventional installation
Capacity	0.6 to 0.8 Mt/yr of steel	
Scrap yard & infrastructure	US $ 30 M	US $ 70 M
Electric arc furnace M US$ Secondary metallurgy & continuous casting billets	US $ 40 M US $ 10 M	US $ 80 M US $ 10 M
Total	US $ 80 M	US $ 160 M
i.e. US$ per tonne of steel per year	for 0.6 Mt/.yr $ 130/t/yr	for 0.8 Mt/.yr $ 200/t/yr

Table - 6

Process Potential & States for Direct Ironmaking

Process	Smelting Intensity (mt/m^2 day)	Coal Consump. (kgt/mt)	Capital Cost ($/annual mt)	Status	Potential Commercial-ization (time frame)
Coke oven/BF	0.9-1.2	750-900	243	Mature technology	Current
Corex	0.9-1.1	1,000-1,200	210	300,000 annual mt - ISCOR, 750,000 annual mt - POSCO(1994)	Current
AISI-DOE	4.0-6.0	700-800	160	8-10 mt/hr pilot planned, 400,000 annual mt demo planned	1998-2000
DIOS	*	*	*	500 mt/day pilot NKK Keihin Works (1993)	1998-2000
Hlsmelt	*	*	*	250 mt/day pilo, Kwinana, Western Australia (1993)	1998-2000
ROMELT	8.0-12	650-900	*	500-1,000 mt/day pilot, Novolipetsk, Russia, has produced over 300,000 mt.	1995-2000

* Not available, However coal consumption and intensity should be similar to the AISI-DOE process.
Smelting intensity-BF/coke oven includes volume of coke plant, while the AISI estimate includes the volume of the prereducer.
Coal consumption depends significicantly on the type of coal employed, in this case, middle volume coals were used for comparison.

Table - 7
Cost and Status of Alternate Iron Production Processes

Product	Reductant Energy	Investment Cost ($/mt 1993)	Investment Cost ($/annual mt)	Investment Cost ($/annual mt)	Status and Yearly Production
Pig Iron	Coke	120-140	-	-	Not readily available at a reasonable cost
Midrex DRI	Gas	110-125	95-115	160-180	Proven process, 13 million mt
HYI,DRI	Gas	110-125	95-115	160-180	Proven process, 6 million mt
HBI	Gas	110-125	90-120	160-180	Proven process, 1 million mt
Iron Carbide	Gas	Not available	95-110*	150-180	Nucor plant being built, 0.4 million mt
FASTMENT	Gas	Not available	95-110*	125-150	Demonstration plant planned

* Projected cost

Table - 8
Current schematic situation as regards production costs
(in US dollars per tonne of liquid steel)

	Conventional route Blast Furnace + Basic Oxygen Furnace	Short route Scrap + Electric Arc Furnace
raw material o Iron ore o scrap	 39 	 90
energy o coal o kWh o oxygen, miscellaneous	 50 7	 23 4
manpower	30	15
other processing costs environmental proctection	30	40
total	156	172
depreciation at 10% of	(600$/t) 60	(200$/t) 20
Total	216	192

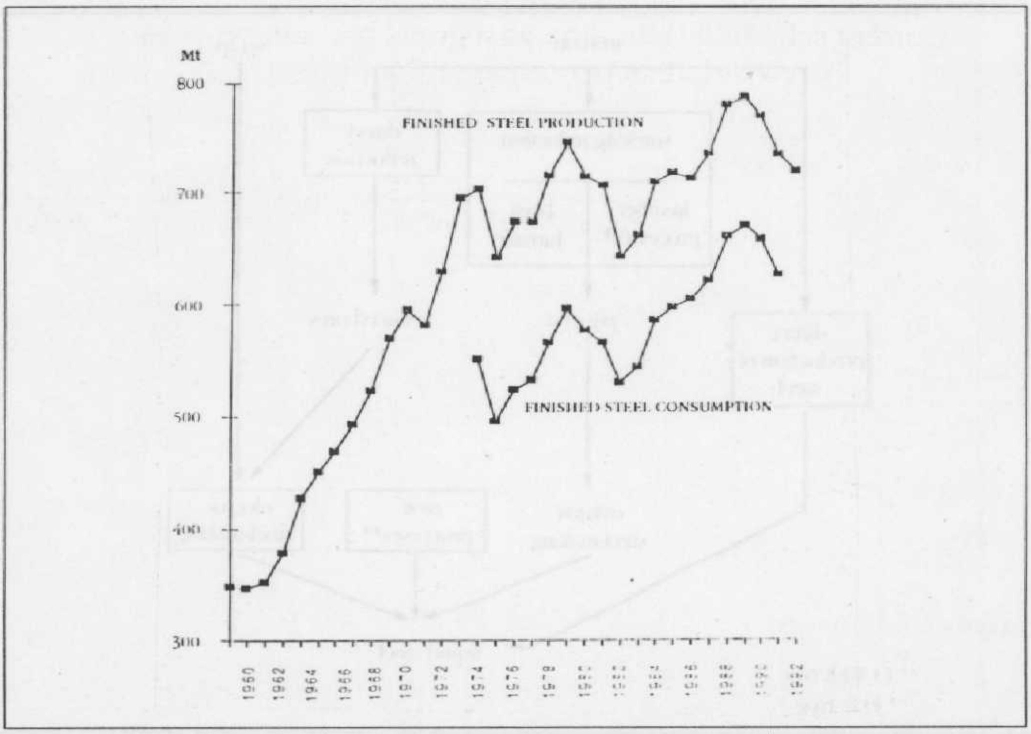


Fig. 1. Developments in world production of raw steel and finished products

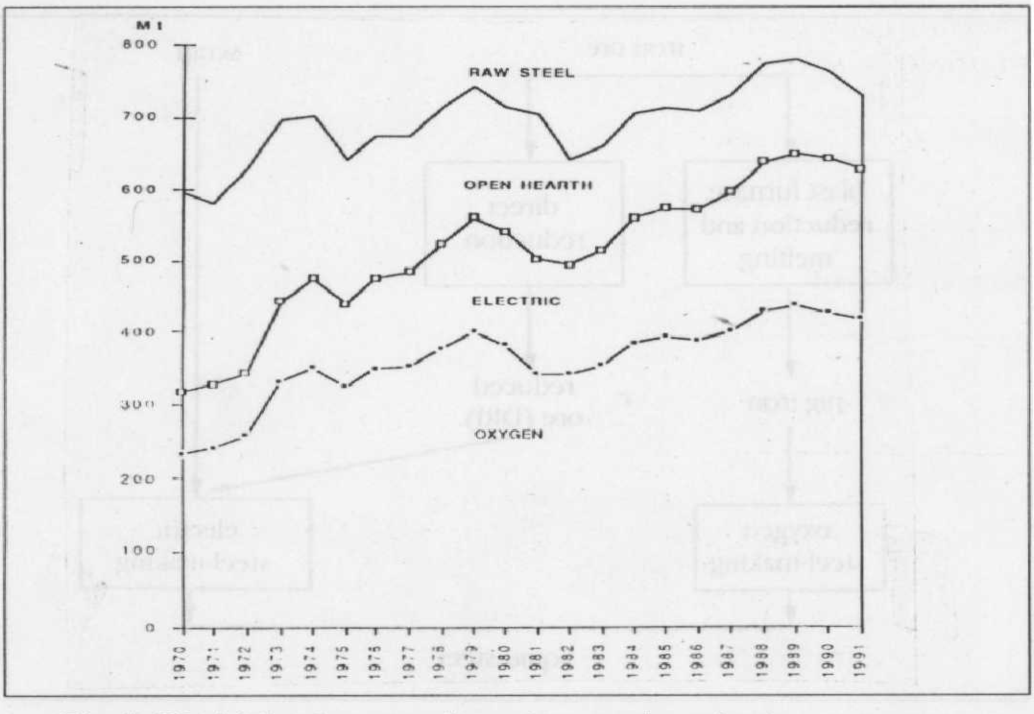


Fig. 2. World developments in various steel production processes

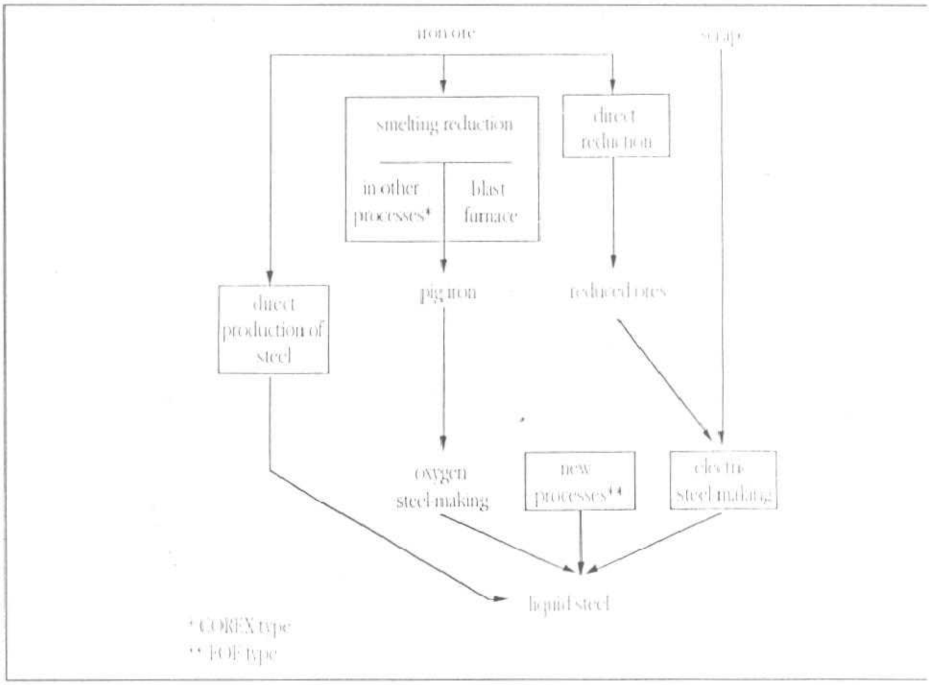


Fig. 3. Various possible routes in steel production

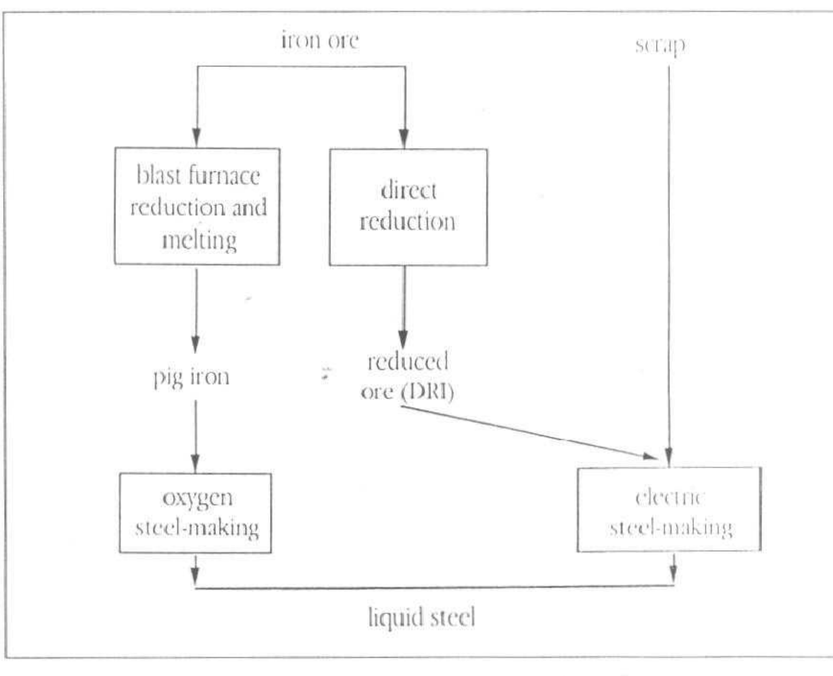


Fig. 4. Two conventional routes in steel production

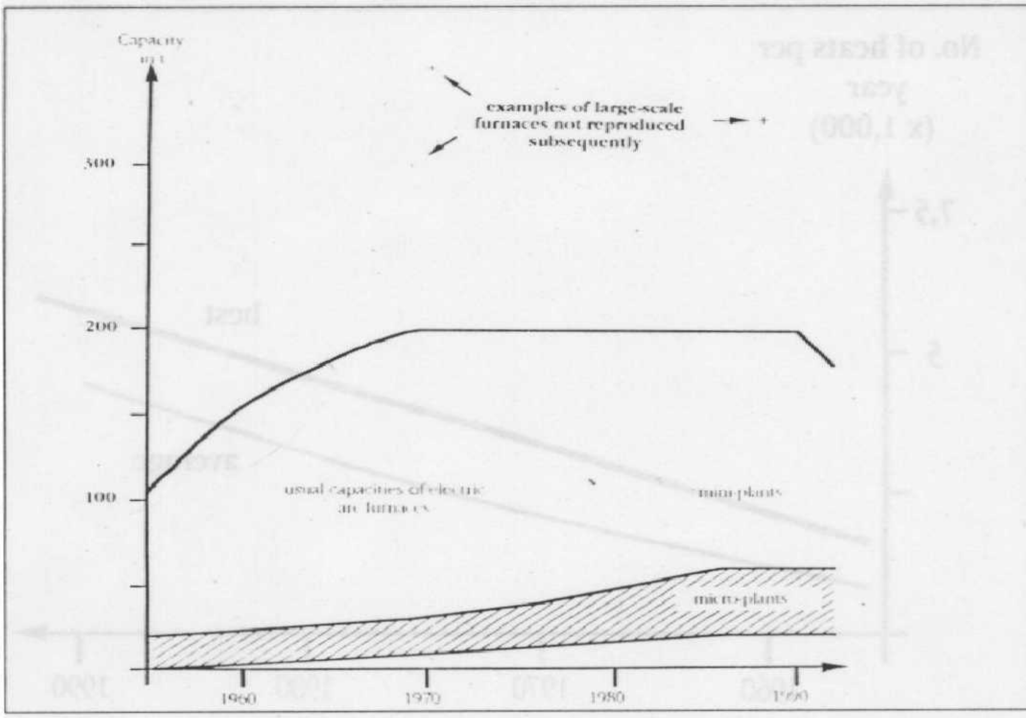
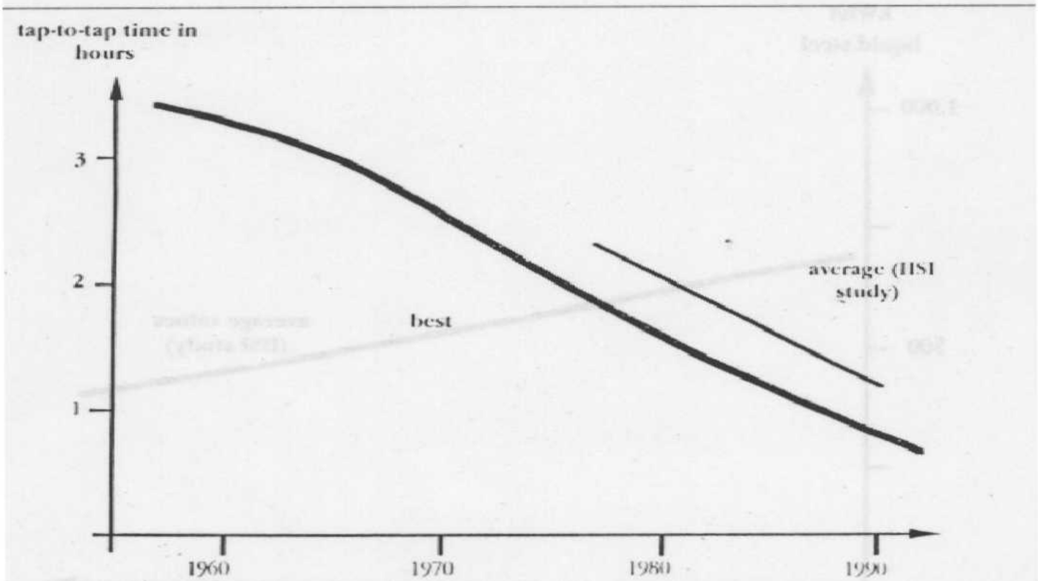


Fig. 5. Worldwide trends in the capacity of electric arc furnaces



SOURCE : IISI Electric Arc Furnace, 1990, p.73.

Fig. 6. Trends in the tap to tap time in electric arc furnaces

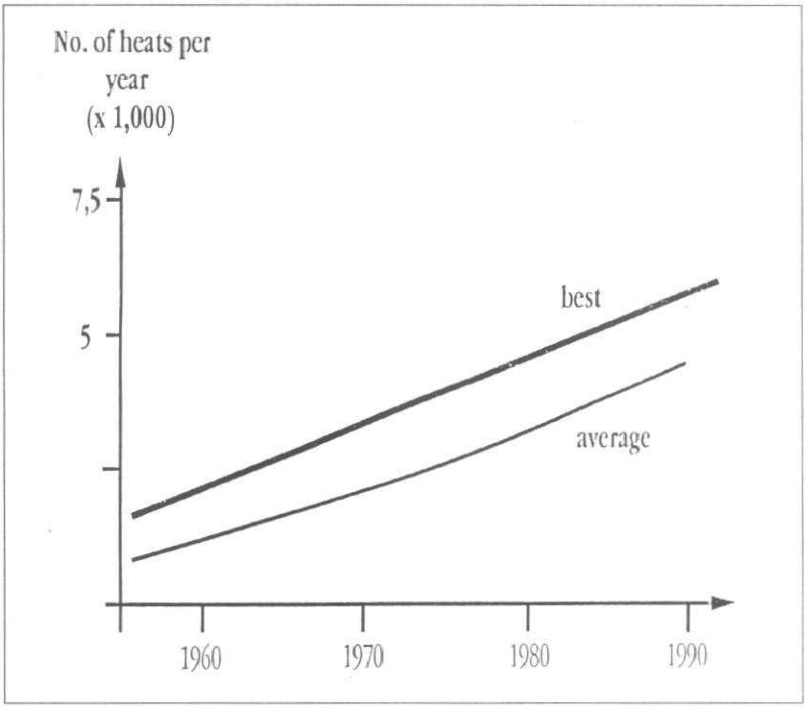


Fig. 7. Trends in the number of heats per year with electric arc furnaces

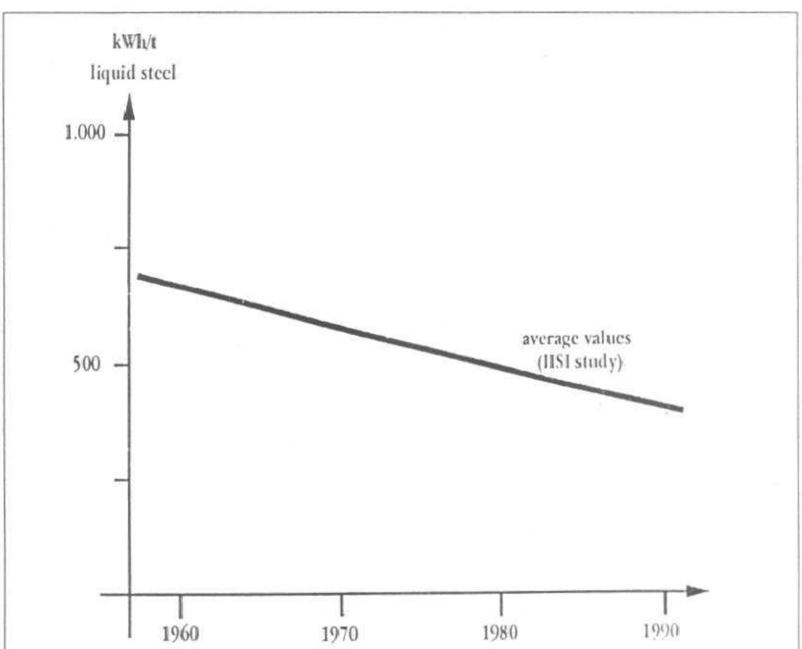


Fig. 8. Trends in electric power consumption for electric arc furnaces

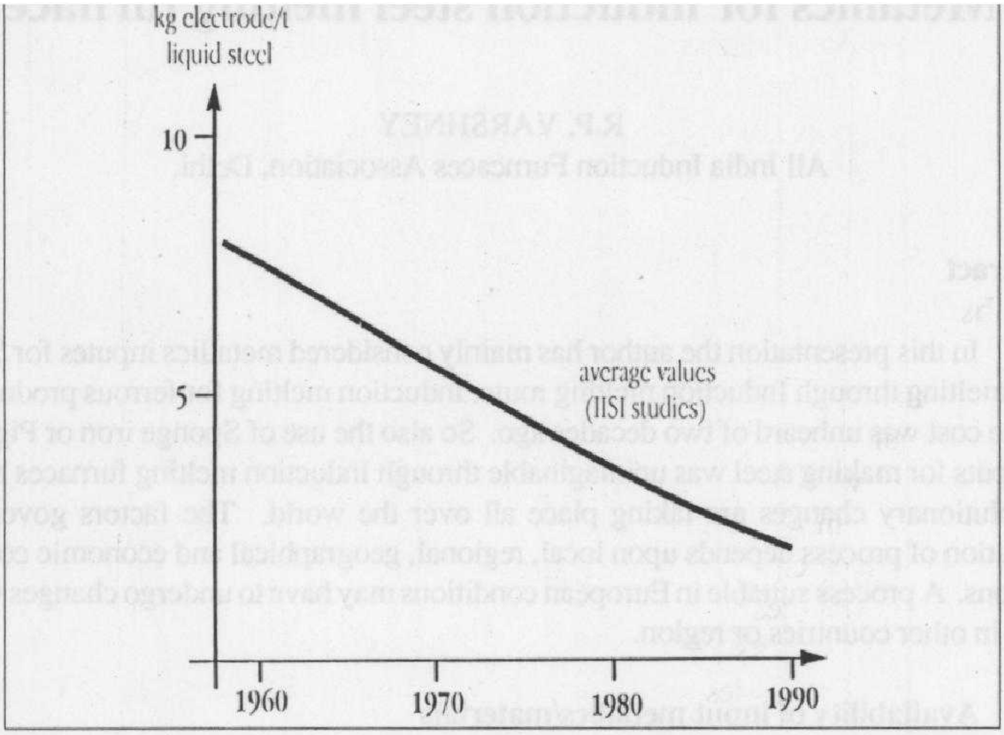


*Fig. 9. Trends in the consumption of electrodes with electric arc furnaces**

***The use of direct current does of course provide a slight saving as regards the consumption of electrodes**

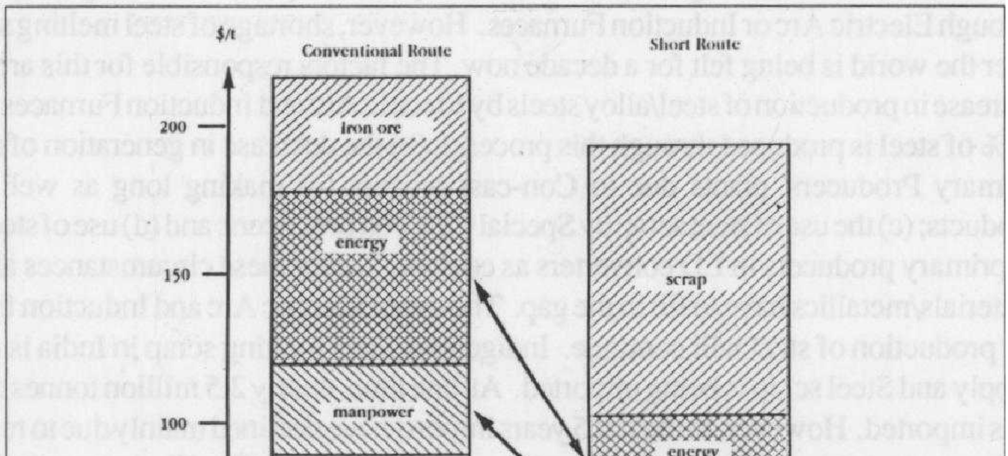


Fig. 10. Typical break-up of cost of production