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ELECTRIC ARC FURNACE STEELMAKING FOR DEVELOPING COUNTRIES 1/

by

T.V.S. Ratnam and R.D. Lalkaka
India

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ELECTRIC ARC FURNACE STEELMAKING FOR DEVELOPING COUNTRIES[1]

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T.V.S. Ratnam and R.D. Lalkaka,

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SUMMARY

The electric arc furnace is a versatile steelmaking unit. It is particularly suited for small-scale non-integrated operation and for alloy steelmaking. The paper reviews the recent technological developments which have further widened its scope and usefulness, until today it can economically produce even plain carbon steels in large tonnages. The advent of continuous casting has enabled the installation of electric furnace/concast plants to produce billets for re-rolling, which at favourable locations can well be competitive with billets produced by the large integrated steelworks using ingot practice and conventional primary rolling mills.

It is interesting to note that while there has been a major ferment in steel production technology with the oxygen converter (B.O.F.) rapidly outpacing the open-hearth as the major steel producer, the share of electric arc furnace steel continues to increase though at a slow rate. It is possible to visualise that in

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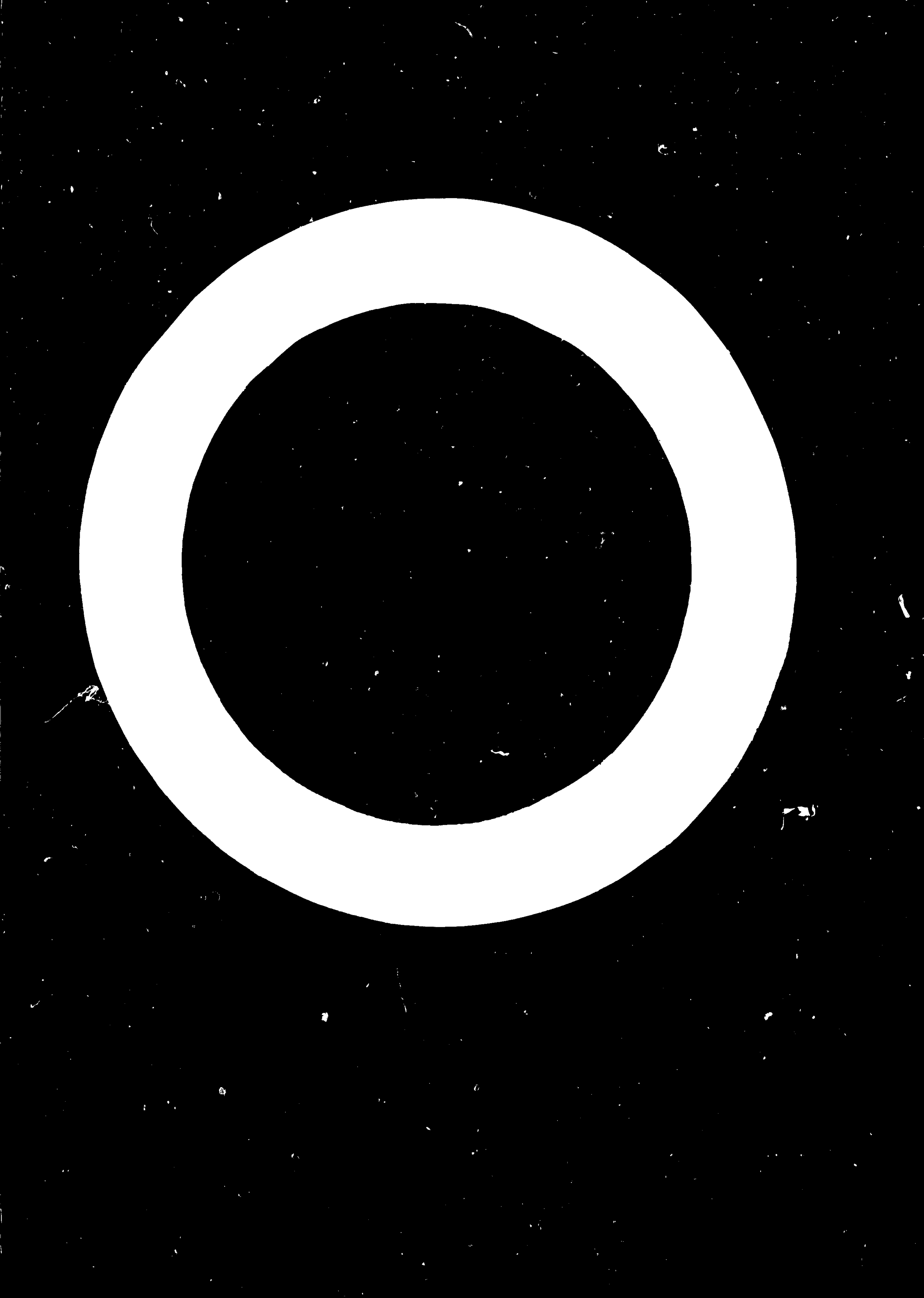


the next 15 to 20 years, the oxygen converter and the electric furnace would be the only two principal steelmaking processes in most countries - with the B.O.F. converting the bulk of liquid iron to steel, and the electric furnace taking care of the bulk of the scrap. In developing countries such a two-process situation would come even earlier, because they have the unique opportunity of straightaway starting with the oxygen converter for integrated operations or the arc furnace for scrap-based small-scale production, whereas the industrialized countries have the problem of retiring their existing open-hearths.

One of the major problems of the developing countries is shortage of capital, and the consequent necessity of utilizing resources with maximum effectiveness and producing steel at competitive costs, so that this industry can generate surpluses to plough back into the economy. This, in turn, calls for adoption of up-to-date technologies and of intensive efforts (on the part of the owner, generally the government in most developing countries) to cut down costs of new steelworks to the barest essentials. These countries also lack technological skills and machine building capacity, and therefore ultimately depend upon industrialized nations to supply the plant, often on "turn-key" arrangements. At times this prevents the developing country from securing the best process and the lowest cost, most efficient plant. First of all, "tied-aid" itself adds to the cost of imported equipment; then, the necessity of installing technology available with the donor rather than that best suited to the owner may further add to investment costs and to recurring operating costs. It would therefore be in the interest of developing countries to resist "turn-key" or "tied-aid" arrangements for such plants. Competition between suppliers, based upon well prepared specifications and plans by consultants, has the best chance of resulting in a viable electric arc furnace project.

Another major draw-back in developing countries is the shortage of steel scrap - the basic melting stock for the electric arc furnace. Without a strong industrial base, the generation of capital scrap as well as process scrap is inadequate. Further, if an integrated steel plant is already coming up in the country, more likely than not it is based on continuous casting so that plant return scrap is only say 10 per cent, and the steel plant itself may want to purchase scrap for its B.O.F.s from the open market - scrap which would otherwise go to electric furnaces.

The shortage of scrap need not be a serious handicap as alternative melting stock such as sponge iron can now be considered. The developing country which has a fair iron ore reserve may produce pre-reduced pellets to supplement the charge to the electric arc furnace. In most cases, however, this material may cost slightly more than good melting scrap and the cost of steel would also be somewhat higher. If the country already has blast furnace ironmaking (or the raw material and market conditions for installing a blast furnace), hot metal (say 50 per cent) and scrap (50 per cent) could also form the arc furnace charge. The paper makes estimates of the cost of production of liquid steel using alternative charges under assumed conditions.

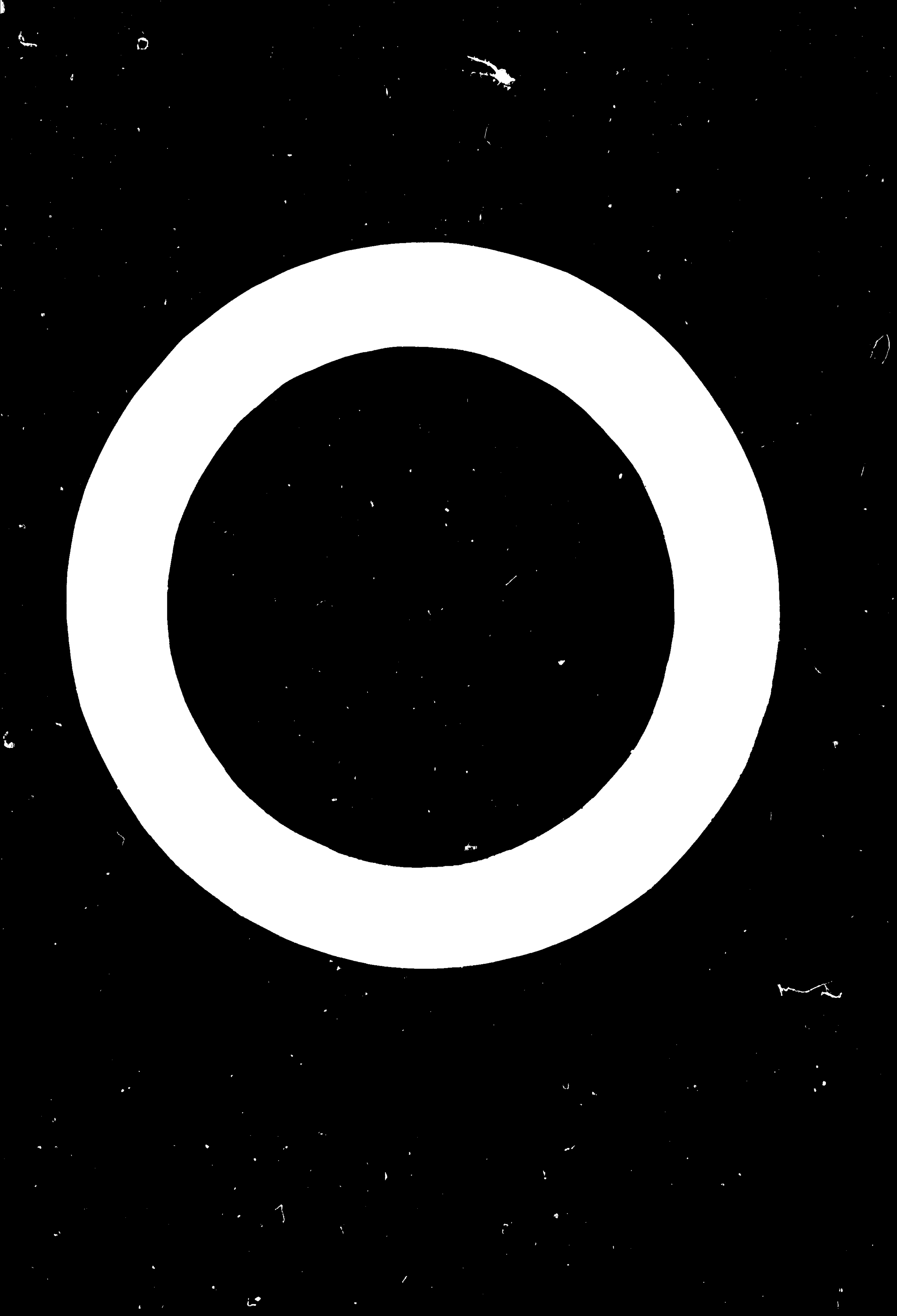
A third problem is that the electric power required for arc furnace steelmaking may not be abundantly available in developing countries. Where available, it is often argued that electricity could more effectively be utilized to light villages and install pumping sets for irrigation. Large electric furnaces are considered an undesirable load for an electricity grid because of the wide fluctuations in voltage they impose upon the system during meltdown. But for furnaces of up to say 20-25 tons - which provide an optimum initial size in most situations - such difficulties can now be effectively met. Further, the power consumption itself per ton of liquid steel can be brought down with such techniques as preheating of scrap.

A final factor pertinent to developing countries is the technical skills to install an electric furnace meltshop, and to operate and maintain it efficiently. Electric furnace installation and operation are relatively simple. A well-devised training programme could readily create the basic skills required.

The paper presents a case study of electric arc furnace steelmaking in India. Starting in 1922 with a 2-ton furnace in Calcutta, there are now a total of 126 units with a combined rated capacity of about 900,000 tons/year. Most of these furnaces are operating in steel foundries while some are also producing small tonnages of ingot steel. The largest units today are the 50-ton furnaces powered by 18,750 kVA transformers at Hindustan Steel's Alloy Steels Plant at Durgapur.

While the electric furnace has hitherto been used primarily for alloy steels and castings in India, its share in carbon steel is now expected to increase in conjunction with continuous casting installations for billet production. The 25-ton arc furnace at Mukand, Kalwe, and the 25-ton furnace under construction at Arkonam (Madras Government project) are instances in this direction. The Indian Government is also thinking in terms of electric furnace/continuous casting installations at favourable locations to supply billets to the re-rolling industry.

The paper concludes that for developing countries, arc furnace/continuous casting plants could well be considered initially for small-scale steel production as the capital required will be low, operating costs can be competitive, technology is well established and the necessary operating skill could be readily developed. Provision needs to be made in the initial layout for expanding the meltshop and also for installing new techniques such as vacuum degassing. Depending on resources, such a plant may be subsequently integrated with other facilities. Where substantial steel tonnages are envisaged because of favourable iron ore and coking coal reserves as well as market conditions, integrated steel plants with blast furnaces and oxygen converters would be the answer.



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Though not spectacular in its growth as the recent oxygen steelmaking process, the electric arc furnace has steadily increased its share in the total steel production over the century. It received an impetus during world war II and established itself as a versatile unit for alloy and special steels. Thereafter, with advancing technology, it has made sizeable inroads into tonnage steel with larger and larger units. It has also demonstrated its flexibility in accepting hot metal, pre-refined metal and sponge iron in the charge. Its favourable economics in situations where there is availability of cheap scrap and power has now made it a close competitor to even oxygen steel. Along with continuous casting, it has become even more attractive for developing countries.

Changing Pattern in Steelmaking

Throughout the history of steelmaking, processes offering the optimum technical and economic advantages have successively dominated production at any given time, from the ancient cementation process through the crucible, Bessemer, open-hearth and oxygen converter. Since the coming of the open-hearth in 1865, it has been the principal producer, accounting for over 80 percent of world steel production till only 10 years ago.

A real challenge to the open-hearth emerged in the early 1950s with the introduction of the oxygen converter process, which has revolutionised steelmaking technology today. In spite of the tremendous efforts being made by the open-hearth for survival by the adoption of intensive production methods (such as high firing rates, basic roof, oxygen lancing and dual-hearth), the 100 to 120 ton per hour productivity of even the largest furnaces (500 to 700 tons capacity) cannot compete with the over-300-tons-per-hour output of large 300-ton LD converters.

The decisively favourable economics of LD operation is steadily pushing the open-hearth out from its preponderant position. While the LD process has made substantial inroads into the open hearths' domain, it is interesting that the electric arc furnace has in many countries expanded its share of steel production.

At the beginning of this century, when the electric arc furnace made its debut, it was used mainly in the foundry industry, and then for production of tool steels, largely replacing the crucible process. Its development in the years between world war I and world war II was primarily in the field of alloy steel production.

The size of furnaces increased and 20-feet diameter furnaces with capacities of upto 90 tons were introduced during world war II.

The electric furnace has entered the field of plain carbon steels only in the last two decades. About 62 percent of the electric furnace production in the United States is currently in such steels. In Japan, of the total electric steel production of 9.24 million tons in 1966, plain carbon steels (in ingots and castings) constitute 5.92 million tons (that is, 64 percent).

Output by Processes

The crude steel production by processes in some of the developed countries (USA, USSR, Japan, UK) is shown in Table 1. The tonnage figures upto 1965 are compiled from statistics published by various agencies; the projections for 1970 and 1975 have been based on available forecasts for the countries, suitably modified by us to take into account current trends(1),(2),(3),(4),(5),(6),(7),(8). These trends are of interest to countries which are now only on the threshold of large scale industrialisation.

In a fast changing field such as steelmaking technology, it is perhaps hazardous to make forecasts. Nevertheless, all countries need to look ahead 10 years, 15 years, 20 years, so as to anticipate changes and plan a strategy to meet them.

TABLE 1 - CRUDE STEEL PRODUCTION BY PROCESSES, 1955, 1960, 1965 AND FORECASTS FOR 1970 & 1975
(All figures in metric tons)

		Actual Outputs			Forecasts	
		1955 mill t	1960 mill t	1965 mill t	1970 mill t	1975 mill t
USA						
Open-hearth	..	95.80	78.35	85.45	54.00	50.00
Bessemer	..	3.00	1.08	0.53	-	-
Oxygen Steel (LD)	..	0.27	3.04	20.76	54.00	62.00
Electric	..	7.27	7.60	12.52	17.00	23.00
Total	..	106.34	90.07	119.26	125.00	135.00
USSR						
Open-hearth	..	39.85	55.11	76.28	95.00	83.00
Bessemer	..	2.01	1.87	1.90	-	-
Oxygen Steel (LD)	..	-	2.50	3.82	20.00	52.00
Electric	..	3.41	5.82	9.00	12.00	15.00
Total	..	45.27	65.30	91.00	127.00	150.00
JAPAN						
Open-hearth	..	8.22	15.05	10.16	8.00	5.00
Oxygen Steel (LD)	..	-	2.63	22.63	50.00	62.00
Electric	..	1.19	4.46	8.37	12.00	13.00
Total	..	9.42	22.14	41.16	70.00	80.00
UK						
Open-hearth	..	17.53	20.86	17.49	14.00	7.00
Oxygen Steel (LD)	..	1.46	2.12	6.46	12.00	21.00
Electric	..	1.12	1.71	3.49	5.00	7.00
Total	..	20.11	24.69	27.44	31.00	35.00

In the United States, the share of the electric arc furnace increased from 2.5 percent of the total ingot production in 1940 to 11.5 percent in 1967. While there was a two-fold increase in total U.S. ingot production, electric furnace output registered almost a ten-fold increase. By 1975, the share of the electric furnace is expected to be around 17 percent.

In USSR and UK also the production of electric furnace steel is rising. In Japan open-hearth steel has steadily declined from 87 percent in 1955 till it is only 24 percent of total in 1965 (18% in 1966), whereas LD has registered a dramatic increase from nothing to 55 percent in 1965 (62.5% in 1966); the electric furnace continues to maintain its position without any inroads from the LD process. In countries such as Sweden and Norway which have abundant sources of electric energy, electric furnace steel is over 50 percent.

Trend in World Steel Production

In Table 2 the world crude steel production for 1955, 1960 and 1965 by processes, and our estimates for 1970 and 1975, based on current trends, are set out and shown in Fig. 1.

TABLE 2 - WORLD STEEL PRODUCTION BY PROCESSES, 1955, 1960, 1965 & FORECASTS FOR 1970 & 1975

	Actual Outputs			Forecasts	
	1955	1960	1965	1970	1975
	mill t	mill t	mill t	mill t	mill t
Open-hearth ..	201.47	256.52	269.30	250.00	215.00
Bessemer & others	47.65	61.06	57.50	33.00	15.00
Oxygen Steel (LD)	-	12.19	74.90	220.00	369.00
Electric ..	20.83	35.15	54.60	67.00	101.00
Total ..	269.95	344.92	456.30	570.00	700.00

The world production of electric steel in 1966 rose to 62 million tons, out of total output of about 474 million tons. By 1975, we estimate it will rise to over 100 million tons out of an anticipated total world crude steel production of 700 million tons.

According to present trends, it appears that all new steel production capacity being installed will be divided mainly between LD and electric furnace, and as always the supremacy between them will be resolved in terms of investment, operating cost and product quality for specific installations. For the production of quality steels including stainless steels, the electric furnace will remain paramount for some time to come, although the LD process is attempting a break-through even in this direction. As for steel foundries, it would today be difficult indeed to find justification for a steel-making process other than the electric furnace.

In the next 15 to 20 years, the oxygen converter and the electric furnace may be the only two principal steelmaking processes in most countries - with the LD converting the bulk of liquid iron to steel, and the electric furnace taking care of the bulk of the scrap. In developing countries such a two-process situation would come even earlier, because they have the unique opportunity of straightaway starting with the oxygen converter for integrated operations or the arc furnace for scrap-based small scale production, whereas the industrialised countries have the problem of retiring their existing open-hearths.

Technological Developments

The technological revolution in steelmaking in the last decade is also having a significant effect on the future role of the electric furnace. At various plants, where the price and availability of electric power and steel scrap were favourable, the electric furnace based on cold scrap melting practice has displaced the cold-charge open-hearth. A development which has favoured the growth of arc furnace steelmaking in recent years is the continuous casting of steel which can readily be scheduled to match the operating cycle of an electric furnace. Further, the limited scrap melting capability of the LD process makes available larger tonnages of scrap for the electric furnace.

Scrap Allocation: Efforts towards increasing the scrap proportion in the LD charge are made by the use of auxiliary fuel, calcium carbide, etc. While it may appear that additional steel is being produced by using more scrap, the overall economics of steelmaking has to be examined closely. A comparison of scrap plus hot metal in the LD vis-a-vis ore plus hot metal in the LD and all the scrap in electric furnace indicates that there is little difference in the overall cost of steel(9); if the higher productivity of the LD while using no scrap is taken into account, the cost advantage would be towards using hot metal in the LD and all the scrap in the electric furnace. Thus, as noted earlier, future practice may well be that the LD concentrates on using hot metal and the arc furnace takes care of all the scrap.

As regards scrap availability for steelmaking, this is expected to be adequate in the foreseeable future. According to an United Nations study, the availability of scrap in 1972-75 has been estimated at around 289.5 million tons based on a world crude steel production of about 650 million tons(2). On similar basis, it is roughly estimated that the scrap availability in 1975 would be about 322 million tons when the crude steel production is expected to reach 700 million tons as foreseen in this paper.

Against the above availability, the scrap requirement for steelmaking in 1975 is estimated at 315 million tons, based on the process pattern given in Table 2 and assuming specific scrap consumption for the different processes on current trends particularly in USA and Japan where the shifting pattern in steelmaking is more pronounced.

While on a worldwide basis, the scrap availability would be satisfactory, there can be shortage in less developed countries engaged on steel expansion programmes. This is because they cannot draw on a potential supply of capital scrap as the steel consumption in the earlier period was low. Also, the process scrap arising in a developing country would be lower, since substantial proportion of finished steel goes into construction as compared to advanced countries where manufactured products such as automobiles, consumer durables and industrial machinery give rise to relatively more process scrap.

Further growth in the share of electric furnace steel is expected to be favoured by a possible shift in the scrap from LD to arc furnace, as explained earlier, for reasons of overall economy. The use of sponge iron under favourable situations would add to the melting stock for arc furnace steel.

Furnace Size: Today there are several 200-ton furnaces with shell diameters of 22 to 26 feet and transformer ratings of upto 70,000 kVA, such as those at Republic Steel at Canton, Ohio, and Laclede Steel Co at Alton, Illinois. At the Chubu Steel Plate Co in Japan, there is a 200-ton electric furnace with 40,000 kVA transformer, and similar furnaces are being planned in the USSR. Electrics of 26 feet dia and with 100,000 kVA transformers now being planned are expected to operate at 2½ to 3 hour heat cycles, which means a rate of 100 tons per hour(10).

For arc furnaces larger than 200-ton capacity, renewed consideration is being given to the six-electrode elliptical shell design, to overcome problems of power input and furnace wall maintenance(11). Lower secondary voltages and lower current values could be used. With six energy liberating points the power is better utilised in the steel bath, with less radiation to roof and walls thereby minimising refractory wear. Also, the elliptical shape facilitates back wall maintenance. Interest is also shown in the replaceable or interchangeable furnace shell concept. The advantages are greater operating flexibility, elimination of contamination from one quality steel to another, and higher furnace availability.

Some of the other methods being used to increase production and reduce costs are operation with very high power inputs, intensive oxygen injection with adequate fume removal system, scrap pre-heating, continuous charging of sponge iron, and linear programming methods to optimise furnace charge.

High Power Operation: This is economically attractive in many situations. For instance, Northwestern Steel & Wire Co connected a 85,000 kVA capacity transformer to a 150-ton furnace and is obtaining a productivity of over 70 tons per hour with cold scrap.

The superior performance of high power operation is evident from the results of recent work done at Hojalata y Lemina S.A., Monterrey, Mexico (HYLSA) on application of ultra high power on their electric arc furnaces(12). In November 1965 the 7,500 kVA transformer on a 35-ton 13 feet dia furnace was replaced by a 20,000 kVA transformer. Initially only three of the four groups of transformer coils were connected, giving a capacity of 15,000 kVA. Subsequently, the fourth group of coils was also connected to give even higher transformer ratings. The original operation at 265 kW per ton of liquid steel was progressively raised to 477 kW per ton of liquid steel. Furnace output increased from 3,440 tons per month to 5,150 tons, that is by 50 percent. The overall effect on production costs was a decrease of about 12 percent as compared to costs using the original 7,500 kVA transformer. The effect of ultra high power operation on production and costs is shown in Fig. 2. The work done at HYLSA demonstrates that when electric energy tariffs are favourable, a fair increase in production can be achieved from the same furnace equipment by operation at high power.

As regards electric power, this is often not available in abundance for electric furnace operation in some of the developing countries. Large electric furnaces are considered an undesirable load for an electricity grid because of the heavy fluctuations in the load and the frequent voltage dips they impose upon the system during melt down. But for furnaces of upto say 20 to 25 tons - which provide an optimum initial size in most situations in developing countries - such difficulties do not generally arise as the power grid systems are sufficiently rigid. Further, the power consumption itself per ton of liquid steel can be brought down with such techniques as pre-heating of scrap and with improvements in the size, construction and performance of electric furnaces.

In this context, it should be mentioned that while the unit price of fuels such as coal and oil has been showing constant increase, there has been a decline in the relative price of electricity[13]. With the advent of nuclear powered plants, it will now be possible to build such units even where other types of fuel are not available. The importance of this trend has to be kept in view, as the cost of power will become increasingly competitive with other fuels and would favour the economics of arc furnace steelmaking in future.

Further, technological developments are under way to make electrodes of higher strength and greater conductivity which will reduce the consumption of electrode. High tensity graphite electrodes with grain orientation as well as graphite fibre composites are being developed to produce low resistivity, high strength electrodes.

Pre-heating of Scrap: Another interesting development is the use of pre-heated scrap which has been successfully tried out and regularly practised in some plants. As early as 1959, the Christiania

Spigerverk in Norway introduced scrap pre-heating in their arc furnace plant. With an average pre-heating temperature of 350°C the melting time was reduced by about 13% and the production increased by about 10%. There were also other advantages such as lower electrode consumption and longer lining life.

A Swedish meltshop with 50-ton arc furnaces employing a scrap pre-heat temperature of 400°C reports a net saving of about $ 0.70 per ton of steel. Recently, pre-heated scrap has also been regularly practised at the Campana plant of Dalmina Siderca[14] as well as in TAMSA plant at Veracruz in Mexico.

The operating results of using cold charge and pre-heated charge (500°C) as obtained at Campana in their 54-ton furnace with 13,400 kVA transformer are indicated below:

		Avg. of 2 months with cold charge	Use of pre-heated scrap	Variation %
Production rate	- t/hr	13.32	15.96	+ 19.78
Power consumption	- kWh/t	556.00	455.10	- 18.15
Natural gas	- Nm^3/t	-	22.25	
Electrode consumption	- kg/t	5.56	4.24	- 23.70

The effect of higher pre-heat temperature on production rate and power consumption for this 54-ton capacity furnace is given in Fig. 3. It is expected that with at 850°C pre-heat temperature production rate would be about 18 tons/hour with a gas consumption of 82 Nm^3/ton and power consumption of 366 kWh/ton.

This process is gaining importance because of the inherent advantages of increased productivity and better quality of steel produced by using dry scrap. The application of this technique will be of considerable economic advantage for areas where electric power is limited and comparatively costlier than fuel.

FOS and Spray Steelmaking Processes: Mention should also be made here of the fuel oxygen scrap (FOS) and spray steelmaking processes, both developed by BISRA. Under specific conditions where fuel and oxygen are available at reasonable prices, the FOS process could be considered. It is of interest to note that in the FOS process fumes are not generated during melting; on the other hand, fume extraction and cleaning which are increasingly adopted in arc furnaces, add to their investment costs.

The spray steelmaking process is attracting attention for its low investment cost as well as the possibility of continuous steelmaking. Emerging from the BISRA laboratory and the experimental plant at Millom Hematite Ore & Company, UK, in 1966, the first commercial unit recently went into operation at the Lancashire Steel Manufacturing Co Ltd (capacity of 50 tons/hour). A second installation is presently under construction at the Shelton Iron & Steel Co., Stoke-on-Trent. These processes are still in the early stages of development. Their growth by 1975 will be relatively slow and is not expected to materially alter the pattern of steelmaking.

Vacuum Degassing: Vacuum degassing was developed in the 1950s for upgrading the quality of high-cost alloy and special forging steels by producing a cleaner steel with less gas and non-metallic inclusion content. Beginning with stream degassing of large ingots, the subsequent development of non-stream degassing methods such as the D-H and R-H systems gave a spurt to the installation of degassing units. Several basic oxygen and electric furnaces have degassing facilities (or provision for adding in future) for the production of higher quality steel as well as for the production of continuously cast rimming steel which is considered possible with degassing. At present the number of installations are estimated to be over 250 with an aggregate capacity of around 14,000 to 15,000 tons.

Other technological developments are in the fields of vacuum melting (by both induction melting and arc melting) electron-beam furnace, and electro-slag melting. These operations will largely be confined to achieve ultimate properties in high strength steels, super alloys and speciality products.

Economics of Electric Furnace Steel

Various studies have been made in regard to the cost aspects of the electric furnace vis-a-vis open hearth and LD. The conclusions of a recent typical study by Battelle Memorial Institute[3] indicate that the investment cost per annual ton in a large electric arc furnace shop ($ 18 to 19) is only slightly higher than that ($ 17 to 18) of an LD shop, while the cost of both electric and LD is considerably lower (approximately half) than that of the open-hearth ($ 33 to 34). These costs refer to a 1.5 million ton capacity plant. The studies also confirm that, as is to be expected, there is substantial reduction in investment per annual ingot ton as plant capacity increases for a given process.

In regard to production cost, the electric furnace 'cost above' ($ 17 to 18) is higher than that of the LD ($ 12 to 13) but due to low cost of metallic charge, the total electric furnace production cost ($ 48 to 49) including fixed charges is lower than that of LD steel ($ 53 to 54). In other words, the electric furnace can produce cheaper steel compared even to LD at locations where abundant scrap is available.

A study was recently completed by Dastur & Company on the economies of scale at integrated steel plants in Latin America[15]. Among various alternatives, this study examined the economies of alternative processes for a small hypothetical plant with an annual liquid steel capacity of 50,000 tons per year. The electric furnace was considered with alternative charges, namely using 50 percent iron from a blast furnace, 50 percent iron from an electric smelting furnace without pre-reduction, 50 percent iron from an electric smelting furnace with pre-reduction, and 100 percent cold scrap. This again shows (Table 5) that under the specific conditions of the study, the investment and production costs of arc furnace operating on 100 percent

TABLE 5 - COMPARATIVE INVESTMENT AND PRODUCTION COSTS
(50,000 metric tons per year liquid steel)

Particulars	Investment Cost US $/annual ton	Production Cost (incl fixed charges) US $/annual ton	Production Cost Index
LD Converter (1-6 t vessel) (75% iron from blast fce plus 25% scrap)	83.80	102.76	100.00
Electric Arc Furnace (1-25 t) (50% iron from blast fce plus 50% scrap)	73.50	92.24	89.80
Electric Arc Furnace (1-25 t) (50% iron from electric smelting furnace using pre-reduced charge plus 50% scrap)	73.50	96.25	93.70
Electric Arc Furnace (1-25 t) (50% iron from electric smelting furnace without pre-reduced charge plus 50% scrap)	73.50	101.64	98.90
Electric Arc Furnace (100% cold scrap)	73.50	74.26	72.30

Notes:
Assumed Unit Costs:

Steel Scrap	..	US $ 30 per ton
Electric Power	..	US $ 0.016 per kWh
Hot metal		
from blast furnace	..	US $ 48 per ton
from elec smelting with pre-reduction	..	US $ 68 per ton
from elec smelting without pre-reduction	..	US $ 80 per ton

cold scrap charge are the lowest. This low cost arises, first, due to the difference in cost of charge metallics, second, the greater yield in the electric furnace and third, due to lower fixed charges on investment.

Alternative Metallic Charges for Electric Furnace

The charge for the electric furnace may consist entirely of cold scrap, or comprise partly liquid iron and partly scrap. There is also the alternative of varying proportions of sponge iron and scrap, as well as the possibility of duplexing with LD steel. The relative merits of alternative charges are briefly reviewed below:

i) 100% Scrap Charge

This is the conventional practice followed in most plants. Proper selection and preparation of scrap are receiving greater attention. As mentioned earlier, scrap pre-heating increases productivity and reduces power consumption. The use of oxygen for melting and refining has become attractive in many situations for achieving higher productivity.

ii) Part Liquid Iron Charge

The ability of the electric furnace to use hot metal (liquid iron) in limited proportions has been recognised and utilised at some plants. At the Brymbo Steelworks in United Kingdom about 50 percent pre-refined hot metal and 50 percent scrap are used in 40-ton arc furnaces(16). The hot metal is pre-refined with oxygen in a special oil-fired furnace. By this treatment the silicon is almost wholly oxidised, phosphorous is reduced from 0.4–0.8 percent to between 0.05 and 0.1 percent, carbon is burned down to between 1 percent and 2.5 percent depending on the carbon content required in the finished steel, and the metal temperature is raised by about 300°C. With such a practice, arc furnace power consumption varies from 240 to 340 kWh per ton. The total heat time is reported to be 2 to 3 hours, with a production rate of 15 to 25 tons per hour.

The new steelmaking shop at Pompey in Lorraine, France, with two 60-ton LD vessels and one 60-ton arc furnace practises duplexing of LD steel in the arc furnace, to produce special and low alloy steels for automotive and aviation industries(17). Average hourly output of the arc furnace is 30 tons and the power consumption varies from 90 to 230 kWh per ton. Electrode consumption is around 1.5 kg per ton of steel. Similar practice has been envisaged at the Mysore Iron & Steel Works in India for the production of alloy steels by duplexing LD and electric furnace operations.

Extensive tests conducted in 12-ton and 40-ton arc furnaces using ore as the main refining agent at the Von Roll Plant in Switzerland indicate that the power consumption for the melting down period with 50 percent scrap : 50 percent hot metal charge is

29 percent and 25 percent lower respectively for low phosphorous and high phosphorous hot metal charges, compared to 100 percent cold charges[18]. The total power consumption was less than 500 kWh per ton of ingot for most of the heats, and the electrode consumption around 5 kg per ton. Trials with 70 to 80 percent hot metal in the charge have been conducted and the possibility of using successfully such high proportion of hot metal exists.

It is understood that Armco's two 175-ton electric furnaces at the Houston plant operate with upto 40 percent hot metal charge at a sustained production rate of 60 tons per hour[19]. At the Chimbote Steelworks in Peru, direct hot metal is used to the extent of 45 to 55 percent of the charge in 25-ton arc furnace[20].

iii) Sponge Iron

Several pre-reduction processes have been developed and some of them have reached operation on commercial scale. Presently considerable interest is being shown on pre-reduced material for ironmaking and steelmaking. One basic reason for this is the relative availability and cost of scrap, iron ore and energy, particularly in developing countries with plans for installing steelmaking facilities. Direct reduction also assumes importance in countries with large deposits of natural gas. Further, if adequate capital is not available for installing integrated steelworks with conventional iron and steelmaking facilities, the sponge iron/electric arc furnace combination provides a starting basis for small plants in emergent countries. For these reasons, direct reduction has been employed in South America, and plants are being installed in South Korea, Brazil and New Zealand.

In regard to the use of sponge iron in electric furnace steelmaking, this has several advantages. Sponge iron can be produced with uniform characteristics and chemical analysis. Its contribution can be significant in the field of high quality steel production as it can provide a dependable supply of melting stock with low residuals such as copper, nickel and harmful contaminants. The demand made by continuous casting on steel quality is even more severe than with conventional ingot casting. It, therefore, becomes increasingly important to pay attention to the quality of melting stock to the arc furnace. Other advantages of sponge iron are its amenability to mechanised handling and continuous charging into the arc furnace.

The use of sponge iron for steelmaking is not new. Swedish plants have been using sponge iron produced by the Wieberg-Soderfors and Hoganas processes as a replacement for scrap for some years.

The HyL process at the Hojalata y Lamina Plant at Monterrey, Mexico, is now an established practice(21). The first experimental 50 tons/day unit was commissioned in 1955 and two pilot plants of 250 and 550 tons/day operated since 1956/57. The annual sponge iron capacity is 225,000 tons which is used for steelmaking in electric arc furnaces along with scrap. The meltshop facilities (1-28 ton electric arc furnace, 2-55 ton and 1-66 ton) have a rated capacity of 330,000 tons per year. The average proportion of sponge in the charge is 58 percent. The metallisation of the sponge iron is 85 percent and the total gangue is about 11 percent. The phosphorous content averages 0.45 percent and sulphur content 0.035 percent.

With this long operating experience, in 1967 a new 500-tons-per-day plant has been recently installed in Tubos de Acerode Mexico S.A. (TAMSA), Veracruz. Hojalata y Lamina is planning to construct a new plant near Puebla in Mexico. In Brazil, Usina Siderugica de Bahia S.A. (USIBA) is planning a 500 tons/day plant. Also other companies in South America and Asia are seriously considering this process[22].

Another process in which there is growing interest is the SL/RN process (Steel Company of Canada, Lurgi, Republic Steel Corporation, National Lead Company). As a result of the 100-tons-per-day pilot plant operation at Stelco's Hamilton Works since 1962, three commercial plants are now under construction: a 235,000 tons plant for Inchon Ironworks, South Korea (reduction degree 75%), 150,000 ton plant for New Zealand Steel Ltd (sponge iron with a reduction degree of greater than 90%) and four

250,000 ton units for Highveld Steel and Vanadium Corporation Ltd, South Africa (reduction 45%)[22].

Extensive tests have been conducted in Canada on the use of sponge iron in electric arc furnace. Sponge iron produced by the SL (Stelco-Lurgi) process at Hamilton Works of the Steel Company of Canada has been used upto 80 percent in the charge in a 4,700 kVA 15-ton electric arc furnace. No increase in power consumption is reported by increasing the sponge iron in the charge upto about 50 percent. The quality of steel produced confirmed the superior properties of the sponge iron and also resulted in a decrease in the residual copper content of the steel.

Tests have been run recently by the Steel Company of Canada at its Premier Works in Edmonton with continuous feeding of SL sponge iron in amounts varying from 15 to 100 percent of the charge in 15-ton, 25-ton and 75-ton arc furnaces[23]. The sponge iron is fed through the furnace roof direct into the region of the arc of each electrode between the side wall and the electrode. The charging system consists of a hopper, weigh feeder and feed pipes. The feeding rate is upto 700 lbs/minute. The production rate increased by as much as 45 percent compared with all scrap heats. The heat time was reduced from 3 hours charge-to-tap for all scrap heat to about 2 hours for high percentage of sponge iron charge. Continuous charging of sponge iron in a pilot plant 6-ton arc furnace has been investigated by IRSID in France[24]. It seems that this process may enable automation of the electric furnace, and even enable continuous steelmaking to be achieved.

It is reported that in USA, Gilmore Steel will be constructing a fully integrated plant at the Rivergate Industrial Complex at Portland, Oregon, based on metallised pellet facility (95 percent Fe) followed by an electric furnace complex with an initial capacity of 300,000 tons annually[25].

Investigations have been conducted on production of sponge iron from the Kanjamalai ore near Salem in India in connection with the proposed Neyveli-Salem Steel Project[26]. The magnetite ore containing about 35 percent iron has been found amenable to magnetic concentration producing a rich concentrate containing about 65 to 70 percent iron. This concentrate has been pelletised and used with Neyveli lignite and char as reductant for the production of sponge iron. Laboratory and pilot plant tests carried out at Frankfurt in West Germany indicate that good quality sponge iron with a high degree of metallisation (upto 97 percent) could be produced by the SL process. The iron content of the sponge iron is 93 to 94 percent. However, the sulphur content of the sponge was somewhat high during the tests, primarily due to the high sulphur content of about 1.3 percent in the Neyveli lignite and 1.4 percent in the char. It will be possible to produce low sulphur (below

0.05 percent) sponge iron by using Indian coal (which contains about 0.6 percent sulphur) as reductant. Rich Indian iron ore with upto 68 percent Fe content also can be directly used in the SL process for production of sponge iron.

Liquid Steel Cost with Alternative Charges

The cost of production of liquid steel using alternative charges of 50 percent hot metal and 50 percent scrap, 50 percent sponge iron and 50 percent scrap, and 100 percent scrap have been estimated for Indian conditions to evaluate the relative economics. Casting into ingot or continuously cast semis has not been considered as this will be common to all alternatives. For this exercise, one 25-ton arc furnace with a 10,000 kVA transformer, and necessary equipment and facilities including scrap yard but excluding casting facilities have been assumed. The investment on this arc furnace plant is estimated at Rs 12.0 million.

As regards sponge iron, while there are a number of processes for its production, the SL/RN process has been considered here because some Indian raw materials have already been tested for this process. We have considered a 30,000 tons per year plant to meet the material requirements for a 25-ton electric furnace using 50 percent sponge iron in the charge. The raw materials comprise sized high grade ore with about 66 percent iron content, non-metallurgical coal as reductant, and dolomite to take care of sulphur. The sponge iron is expected to analyse about 90 percent Fe, less than 0.06 percent phosphorous and less than 0.05 percent sulphur.

The sponge iron plant cost is estimated at approximately Rs 14.5 million (about Rs 480 per annual ton). In arriving at the production cost of sponge iron, the following unit costs at a hypothetical plant site are assumed:

Sized iron ore	..	Rs 25 per ton (incl Rs 10 for transport)
Coal	..	Rs 60 per ton (incl Rs 20 for transport)
Dolomite	..	Rs 40 per ton (incl Rs 20 for transport)
Fuel oil	..	Rs 200 per ton
Power	..	Rs 0.10/kWh

On this basis, the production cost of sponge iron is estimated at about Rs 190 per ton, as follows:

		Production Cost of Sponge Iron Rs/ton
Ore and flux	..	40.00
Reductant and fuel	..	52.00
Cost above	..	26.00
Fixed charges (at 15% of capital cost)	..	72.00
Total	..	Rs 190.00

The comparative production cost of liquid steel is given in Table 4. It should be appreciated that the production costs are only indicative of the comparative economics of the alternative charges for plain carbon steel production with single slag practice and the assumed unit costs.

TABLE 4 - COMPARISON OF PRODUCTION COST OF LIQUID STEEL BY ELECTRIC FURNACE USING DIFFERENT METALLIC CHARGES
(Basis: One 25-ton 10,000 kVA electric arc furnace)

	Alt-I 100% Scrap	Alt-II 50% Scrap 50% Hot Metal	Alt-III 50% Scrap 50% Sponge Iron
Basis:			
Yield metallics/liquid steel ..	95%	93%	92%
Power consumption ..	650 kWh/t	500 kWh/t	600 kWh/t
Production ..	45,000 t/yr	54,000 t/yr	50,000 t/yr
	Production Cost of Liquid Steel		
	Rs/ton	Rs/ton	Rs/ton
Production Cost:			
Metallics ..	218.50	256.20	223.80
Other materials ..	10.40	13.20	10.10
Power ..	65.00	50.00	60.00
Cost above ..	80.00	81.90	76.50
Fixed charges @ 15% of capital cost ..	40.00	33.00	36.00
Total Cost ..	413.90	434.30	406.40

Notes:

Unit costs assumed:

Scrap ..	Rs 200/ton
Hot metal ..	Rs 250/ton
Sponge iron ..	Rs 190/ton
Electric power	Rs 0.10/kWh

The Electric Furnace in the Indian Steel Industry

Having discussed the possible future role of arc furnaces, particularly in developing countries, it may be of interest to review the experience in the Indian steel industry.

Annexure I gives a survey of the bulk of the electric furnace installations in India today and Fig. 4 shows a plot of transformer capacity vs shell diameter for the furnaces[27]. Rated furnace holding capacity is also indicated alongside. It is interesting to note that the curve closely follows the calculated transformer sizes for different furnace ratings as recommended for general adoption[28].

Most of the electric furnaces in India are operating in steel foundries, while some are also producing small tonnages of ingot steel. The largest units in operation today in the country are the two 50-ton furnaces powered by 18,750 kVA transformers at Hindustan Steel's Alloy Steel Plant, Durgapur, commissioned in November 1967. According to present thinking, 80-ton furnaces will be installed at this plant during expansion.

While the electric furnace has hitherto been used primarily for alloy steels and castings in this country, its share in carbon steel is now expected to increase in conjunction with continuous casting installations for billet production. The 25-ton Kalwe arc furnace commissioned in December 1965 and the 25-ton furnace under construction at Arkonam (Madras Government project) are instances in this direction. The Indian Government is also thinking in terms of electric furnace-continuous casting installations at favourable locations to supply billets to the re-rolling industry.

It would be interesting to project the probable future 'process-mix' of Indian steelmaking. Taking current trends into account, an estimate of the probable share of electric furnace steel output in India is given in Table 5 and Fig. 5.

TABLE 5 - STEELMAKING PATTERN IN INDIA, 1955, 1960, 1965 & FORECASTS FOR 1970 & 1975

	Actual Output			Forecasts	
	1955 mill ingot t	1960 mill ingot t	1965 mill ingot t	1970 mill ingot t	1975 mill ingot t
Open-hearth ..	1.63	3.12	5.64	7.40	7.70
Oxygen steel (LD) ..	-	0.10	0.77	1.50	9.40
Electric ..	0.10	0.12	0.23	0.60	1.40
Total (incl metal for castings)	1.73	3.34	6.64	9.50	18.50

It is expected that in the 1965 to 1975 period, the current low proportion of electric steel (about 3.5%) will more than double to about 7.3 percent. LD will continue to record a steep increase, and overtake open-hearth output by 1975.

Recent Arc Furnace Installations in India

Two typical examples of recent arc furnace installations in India are briefly described below - one for making alloy steels, and the other working with continuous casting facilities for production of wire rods.

Durgapur Alloy Steels Plant: Hindustan Steel Limited's Alloy Steels Plant at Durgapur has two meltshops - one (SMS No.1) with two 50-ton electric arc furnaces of Daido-Lectromelt design for production of ingots in stainless and constructional alloy steels, and the other (SMS No.2) with 10-ton arc furnaces and induction furnace for making high alloy steels. Furnace shell diameter of the 50-ton furnaces is 5,182 mm and transformer rating 18,750 kVA.

The layout of the Steelmelt Shop No.1 is shown in Fig. 6. The overall size of the building is 130 m long and 83.7 m wide consisting of 3 aisles - scrap, charging and pouring aisles. The scrap aisle is of 30.3 m wide and the charging and pouring aisles are each of 26.7 m wide. The scrap aisle is served by two 10/5-ton EOT magnet cranes having a span of 28 m. The charging aisle is equipped with two 50/15-ton EOT cranes with a span of 24 m. The pouring aisle is equipped with two 100/30/20-ton EOT cranes having a span of 24 m. The gantry rail levels are 12 m in the scrap aisle and 21 m in the charging and pouring aisles.

A charging platform 100 m long is provided in the charging aisle at an elevation of 6 m. Openings have been provided at points where scrap buckets are brought from scrap aisle.

Two scrap transfer cars fitted with weighing scales are provided for transferring scrap from scrap aisle to furnace aisle.

Clamshell type charging buckets are used for charging scrap into the furnaces. Two 2.5-ton mobile chargers are provided for charging ferro-alloys and additions into the furnace. Two heating furnaces are installed on the charging platform for reheating the ferro-alloys and additions before charging them into the furnaces. One 50-ton hot metal transfer car is provided for transferring of hot metal from pouring aisle to charging aisle for reladling. In the pouring aisle, one stopper rod drying oven and three ladle heaters are installed. Slag from each furnace is collected into 2 cu m slag pots carried on self-propelled cars.

Oxygen lancing facilities are available for both the furnaces. Pneumatic tube system is provided for sending the samples to the laboratory and getting back the results. Fume extraction system is provided for collecting fumes directly from the furnace roofs, and after cooling the gas is discharged into the atmosphere.

The steelmelt shop has a 50-ton capacity RH vacuum degassing unit located in the pitside.

Mukand Wire Rod Plant: The steelmelt shop in Mukand Wire Rod Plant at Kalwe, Maharashtra, is provided with one 25-ton electric arc furnace and a 2-strand continuous casting machine for casting 80 mm sq billets. The ASEA make furnace has a shell diameter of 4,300 mm powered by a 10,000 kVA transformer. The annual production from this shop is expected to be 45,000 to 50,000 tons liquid steel of wire rod quality.

The meltshop layout is shown in Fig. 7. The shop building is of single stage and consists of 3 aisles - scrap aisle, transformer aisle and furnace aisle. The scrap aisle is of 36 m long and is served by a 10-ton magnet crane of 20 m span. The transformer aisle is of 72 m long and 15 m wide. Besides the furnace transformer, auxiliaries for continuous casting machine, laboratory and office building, storages for refractories etc are located in this aisle. The furnace aisle is 72 m long with 20 m crane span and houses the arc furnace and continuous casting machine. This bay is served by a 50/10-ton EOT crane. The crane rail height in the scrap aisle is 10.5 m and that for furnace aisle is 14.5 m.

Scrap is brought into the furnace aisle from the scrap aisle with the help of a scrap transfer car and weighed by press-ductor fitted on the 50/10-ton crane. Scrap is charged into the furnace from the top.

Ferro-alloys and additions are manually charged into the furnace from the portable storage bunkers located in front of the furnace. Slag is collected into slag box and is removed periodically from the pit by the overhead crane. After sufficient cooling of slag, this is removed from the box and taken away by trucks.

Ladle heating facilities are provided on the ground floor, whereas the launder and tundish heating facilities are located on the working platform of the continuous casting machine. One jib crane is installed near the concast machine for handling of launders, tundish etc during reladling.

Liquid steel from the furnace is tapped in a syphon type ladle held in the ladle pit. The heat is transferred to a ladle stand in the continuous casting machine. Here one burner is provided on the ladle for maintaining the hot liquid steel temperature. Liquid steel is cast into billets by the 2-strand continuous casting machine. The billets are cut to the proper lengths and discharged onto the discharging table. At the end of the billet discharging table a cooling bed is provided.

Conditioned billets are fed to a fast, modern Morgardshammer wire rod mill which has a capacity of 100,000 tons per year.

Skill Development: The paucity of necessary skills in developing countries to meet the requirements of steel plant operation has often been held as an impediment to rapid growth in steel capacity. This may, to some extent, be valid, for instance, in case of open-hearth furnace where the necessary skill to make steel has to be gained over several years of experience. The melter's experience and his personal judgment are still dominating open-hearth steelmaking despite technological improvements. The demand of the oxygen converter on skills is to a lesser extent. But in case of arc furnace operation the crew can be readily trained in a short period by setting out a well-designed training programme. Similarly, the development of skilled personnel required for continuous casting as compared to those for soaking pits and primary mills is relatively simple.

This has been the experience in India where, for instance, the personnel for Mukand Iron & Steel's arc furnace and continuous casting facilities could be trained without difficulty. From the first cast, the Indian personnel could confidently handle the Concast machine.

Similarly the start-up of the arc furnace facilities of the Alloy Steels Plant at Durgapur went off smoothly. The management on operation of arc furnace facilities has not posed any problem in India.

<u>Conclusion</u>

Within a decade the LD process has retired the open-hearth from its undisputed position for almost a century. At the same time, the electric furnace, in addition to its special role for the production of alloy steels, has made substantial inroads in the field of plain carbon steel. Its full potential however is yet to be exploited, and the present trend towards large furnaces of over 200 tons with high power operations indicates that the arc furnace will continue to grow. In the foreseeable future, LD and arc furnace will be the two major processes sharing the steel production. Arc furnace-continuous casting installations are attractive for developing countries which do not possess major resources.

Sponge iron as melting stock is of special interest to developing countries for non-integrated steel plant operation as well as for meeting the scrap shortage. The superior characteristics of sponge iron due to very low residual contaminants, amenability to mechanical handling and continuous charging are expected to enhance its importance as melting stock for steelmaking. The use of hot metal and continuous charging of sponge iron would further increase production rates.

A number of new developments have entered the steelmaking process 'race'. The open-hearth and the dual hearth have taken to intensive application of oxygen to gain advantage of the speed of the oxygen converter. The oxygen converter is experimenting with auxiliary firing to attain the flexibility of the open-hearth in scrap melting. The fuel oxygen scrap process (FOS) is making a bid to compete with the arc furnace. The latest in the field is spray steelmaking and the concept of continuous steelmaking. This trend may perhaps converge towards a single economic steelmaking unit in future, an electro-oxy-fuel hearth, seeking to optimise the scrap melting flexibility of the open-hearth, the speed of the oxygen converter, and the high quality product of the electric furnace.

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Figure 1

World crude steel production by processes

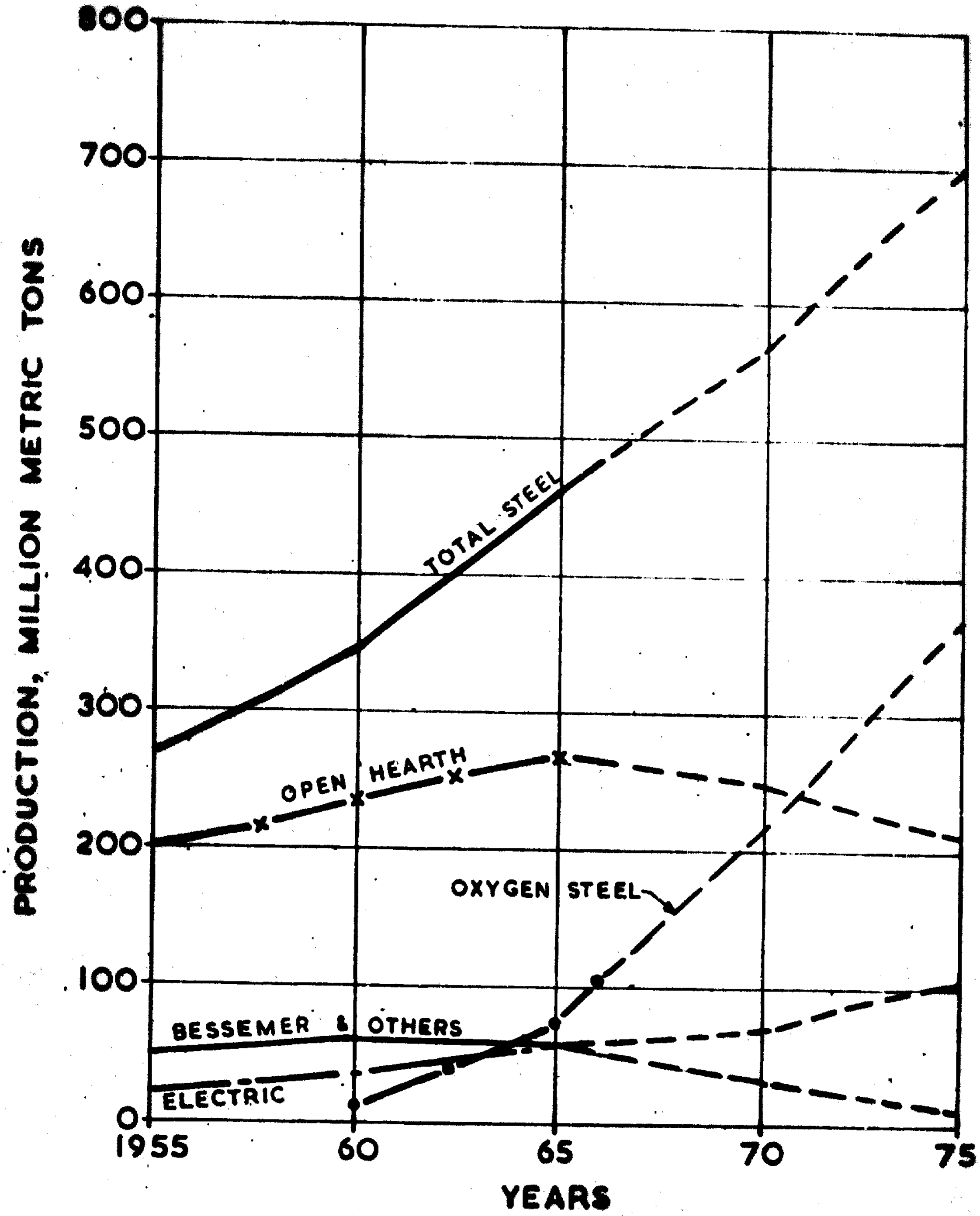
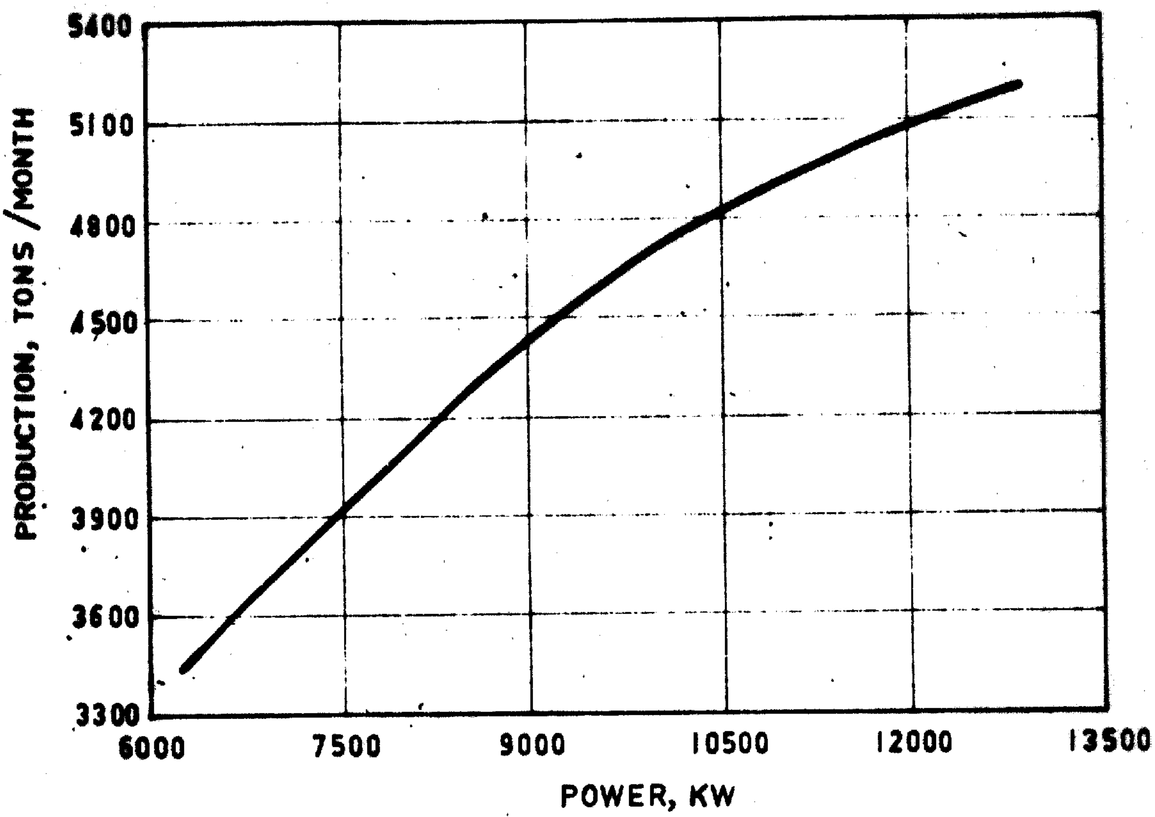


Figure 2

Effect of ultra high power on production and costs



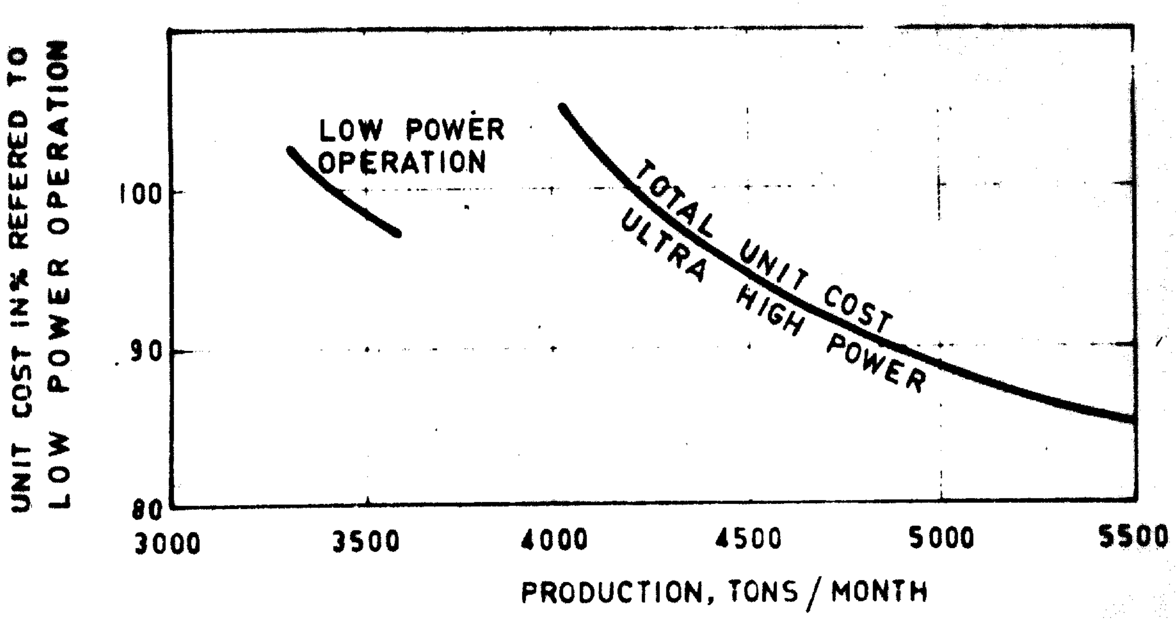


Figure 3

Effect of pre-heat temperature of scrap on production rate and power consumption of electric arc furnace

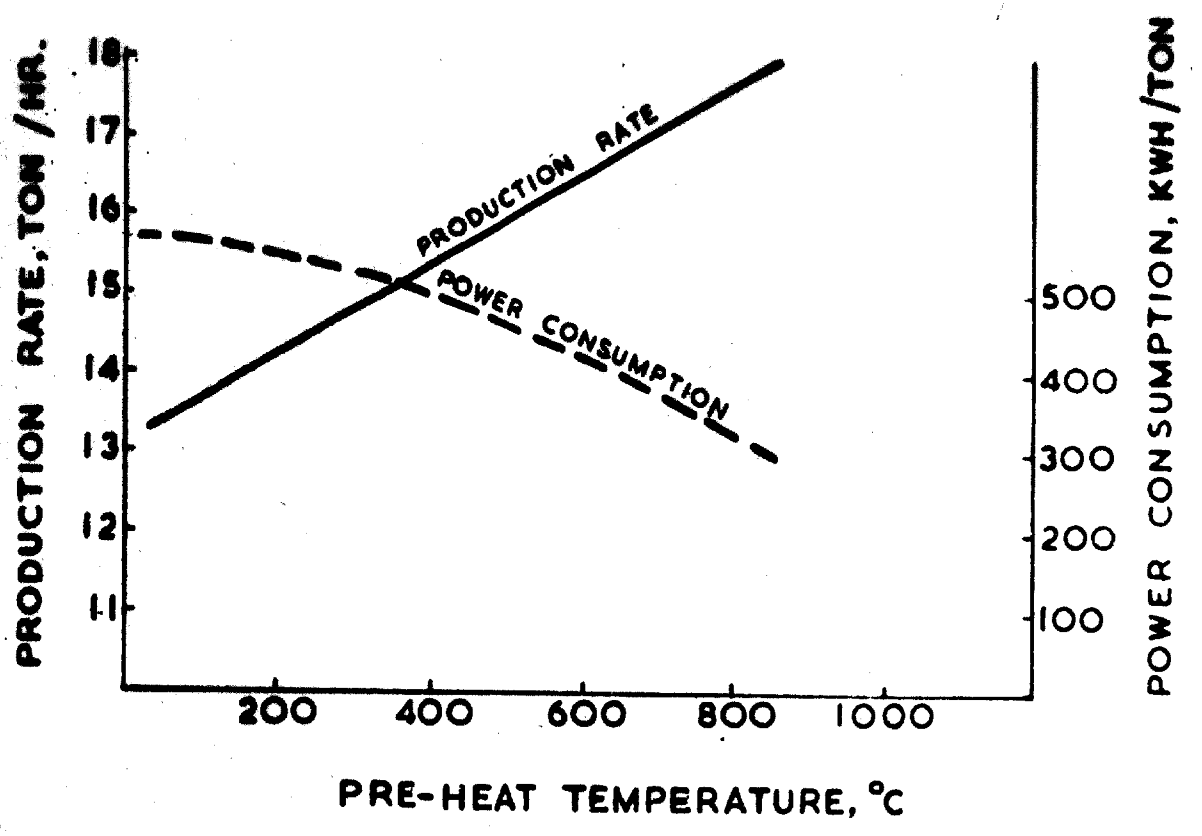


Figure 4

Shell dia. vs transformer capacity of arc furnaces in India

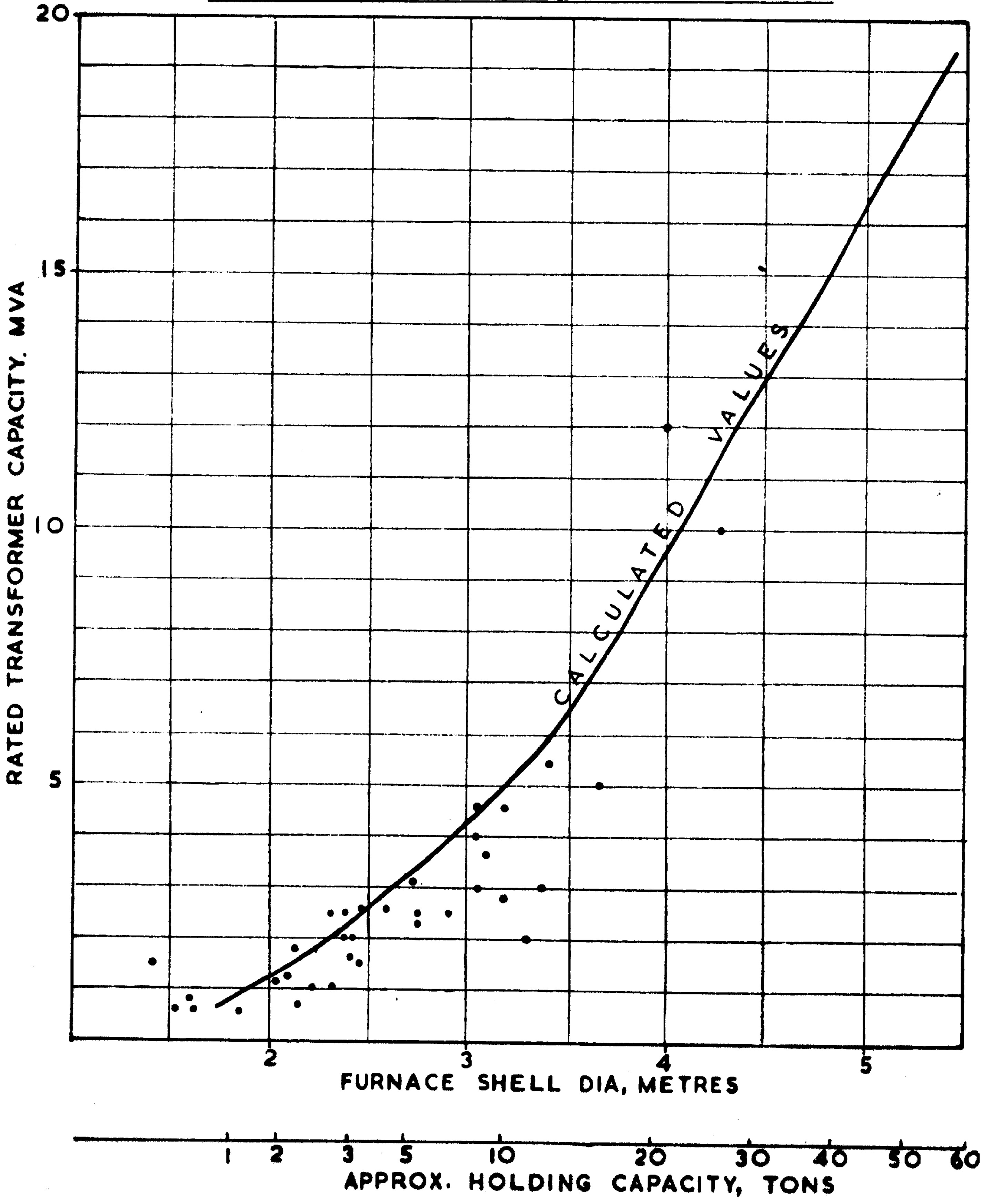


Figure 5

Crude steel production by processes in India

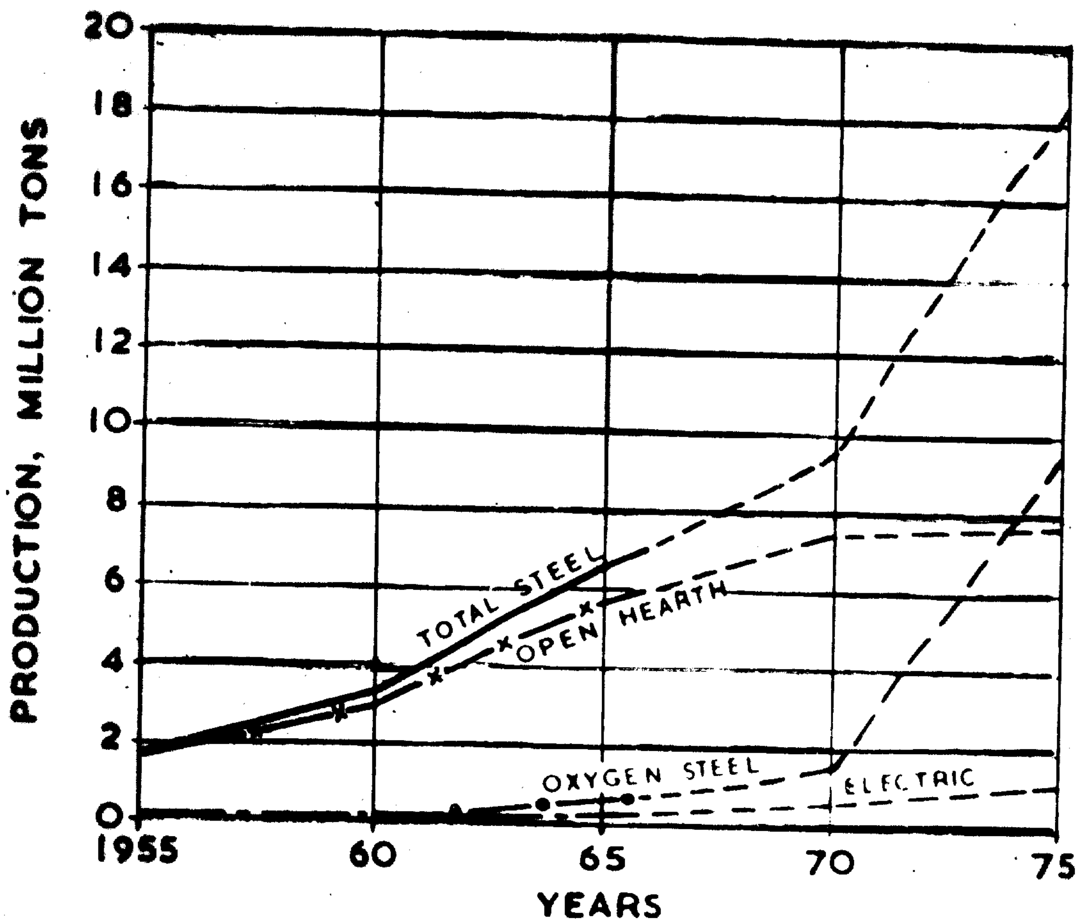


Figure 6

Layout of arc-furnace meltshop at Hindustan Steel Ltd's Alloy Steels Plant, Durgapur, India

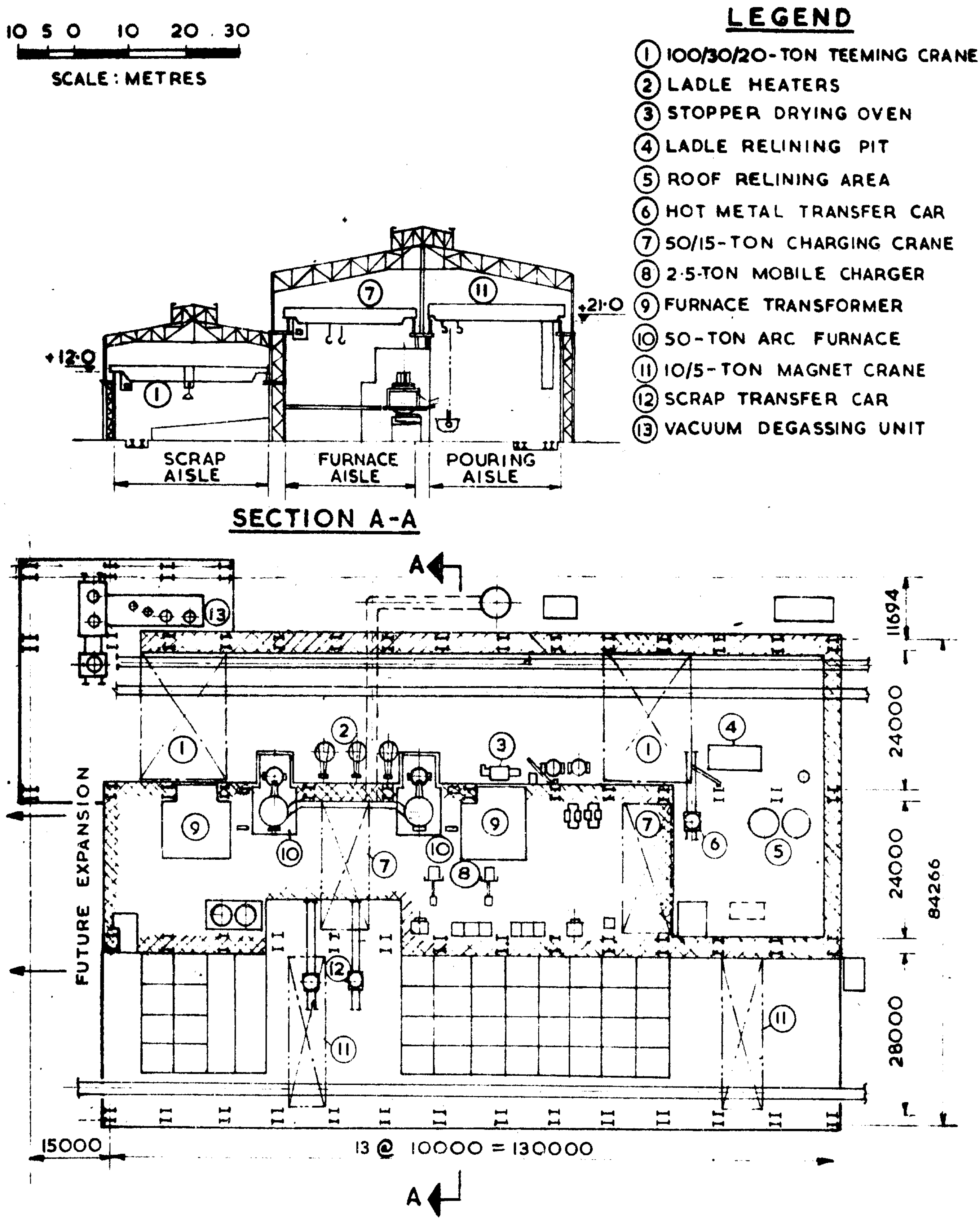
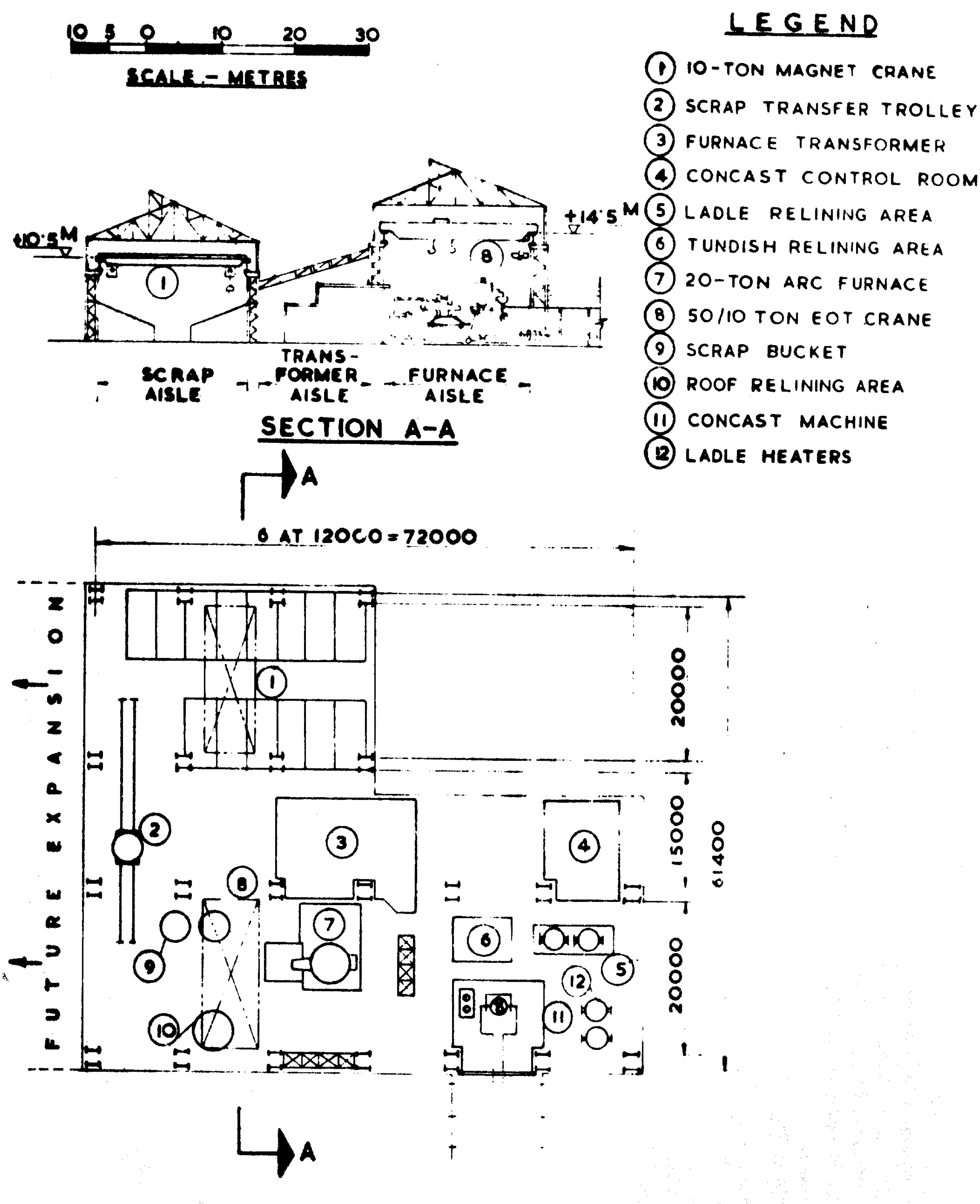
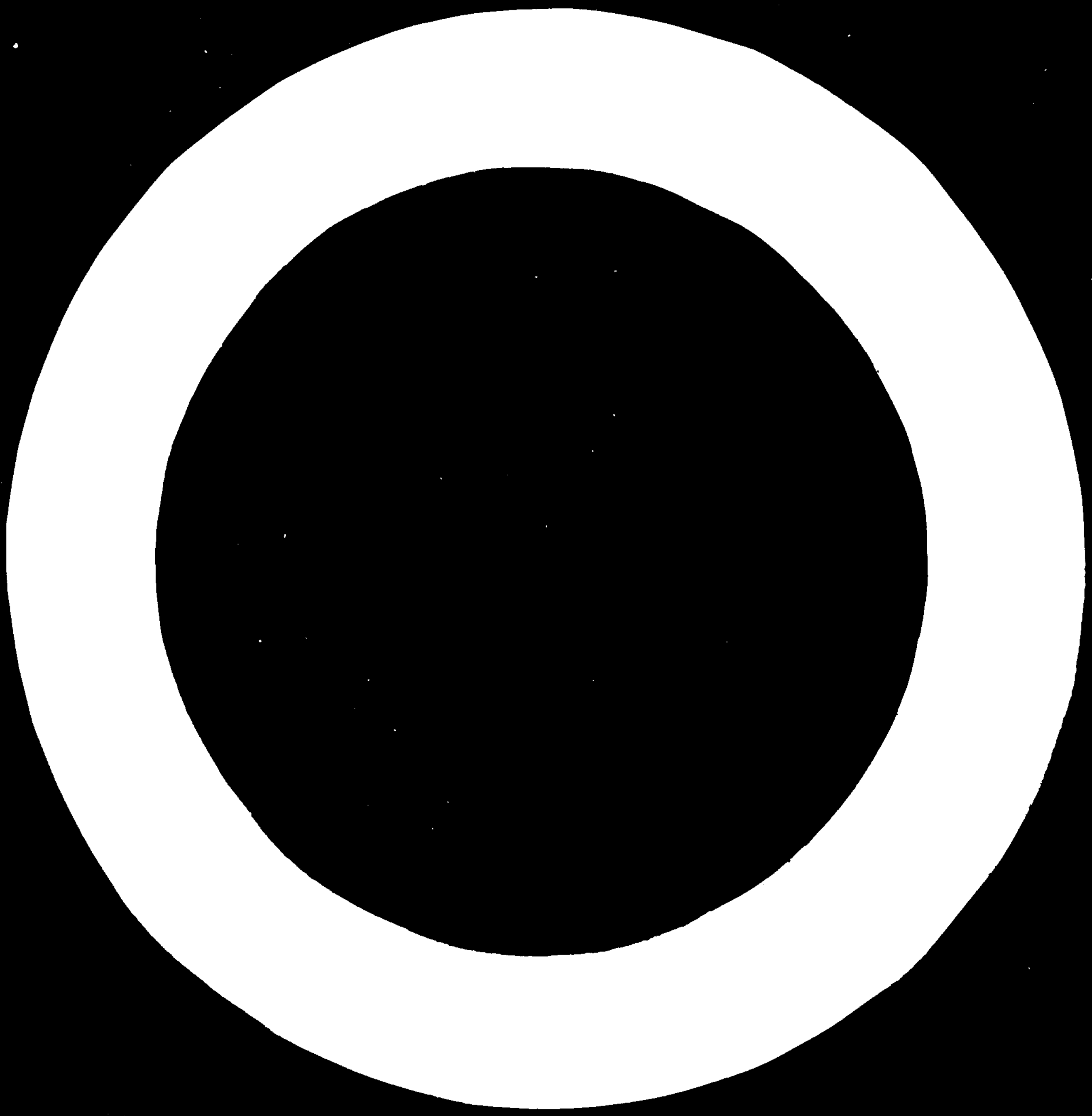


Figure 7

Layout of arc-furnace meltshop with concast machine at Mukand Iron and Steel Works, Bombay, India





ANNEX I

STEELMAKING ARC FURNACES INSTALLED IN INDIA

Sl. No.	Name of the Company	No. of furnaces		Year of installation	Manufacturer	Shell dia mm	Nominal Fce capacity tons	Rated Transformer Cap. kVA	Electrode dia mm
1.	Alloy Steels Plant, Durgapur ..	3	I	1965	Daido-Lectromelt	3658	10	5,000	355
			II	1967	Daido-Lectromelt	5182	50	18,750	457
			III	1967	Daido-Lectromelt	5182	50	18,750	457
2.	Amin Chand Payarelal, Bombay ..	1			AEL-Birlec	2130	3	1,500	203
3.	Amin Chand Payarelal, Jullundur ..	1			AEL-Birlec	2130	3	1,500	203
4.	Ashoka Cement Ltd, Dalmianagar ..	1		1954	AEL-Birlec	2130	3	1,500	203
5.	Bhartia Electric Steel Co., Calcutta ..	4	I	1922	Stobie	2130	2	650	178
			II	1922	Stobie	2130	2	650	178
			III	1938	Stobie	3200	5	2,500	228
			IV	1964	AEL-Birlec	2440	4	2,000	203
6.	Bhilai Steel Plant, Bhilai ..	1			USSR		6	2,500	
7.	Binod Steel Ltd, Indore ..	1		1963	Brown-Bovery	2290	2.3	900	180
8.	Britania Engg Co Ltd, Titagarh ..	1		1964	AEL-Birlec	2440	4	2,000	203
9.	Burn & Co Ltd, Howrah ..	2	I	1954	AEL-Birlec	2440	4	2,000	203
			II	1964	AEL-Birlec	2130	3	1,500	203
10.	Canara Workshops Ltd, Mangalore ..	1		1965	AEL-Birlec	2740	5	2,500	254
11.	Central India Machinery Mfg Co., Birlanagar	1		1965	AEL-Birlec	2440	4	2,000	203
12.	Chittaranjan Locomotive Works, Chittaranjan	3	I	1964	Brown-Boveri	3100	8	3,600	350
			II	1965	Brown-Boveri	3100	8	3,600	350
			III		AEL-Birlec	2740	5	2,500	254
13.	Dalmia Cement (Bharat) Ltd, Dalmianagar	1		1956	AEL-Birlec	2130	3	1,500	203
14.	Dalmia Iron & Steel ..	3	I	1957	AEL-Birlec	2130	3	1,500	203
			II		AEL-Birlec	2440	4	2,000	203
			III		AEL-Birlec	2440	4	2,000	203
15.	D.G.S. & D., New Delhi ..	1			AEL-Birlec	2440	4	2,000	203
16.	Durgapur Steel Plant, Durgapur ..	1			British Make	2900	6	2,500	228
17.	Ennore Foundries Ltd, Madras ..	2	I		AEL-Birlec	2440	4	2,000	203
			II	1965	AEL-Birlec	2440	4	2,000	203
18.	Godrej & Boyce Mfg Co Pvt Ltd, Vikhroli	1		1966	G.W.B. Furnaces	2740	5	3,125	254
19.	Globe Steels, Ballabgarh ..	2	I	1962	Brown-Boveri	2200	3	1,100	180
			II	1964	Brown-Boveri	2600	5	2,500	230

Sl No.	Name of the Company		No. of furnaces		Year of installation	Manufacturer	Shell dia mm	Nominal Fce capacity tons	Rated Transformer Cap. kVA	Electrode dia mm
20.	Globe Steels, New Delhi	..	1		1962	AEI-Birlec	2440	4	2,000	203
21.	Grand Smithy, Belur	..	1			AEI-Birlec	2130	3	1,500	203
22.	Guest Keen Williams, Calcutta	..	3	I	1952	Tagliaferri	2740	5	2,500	254
				II	1956	Tagliaferri	2740	5	2,500	354
				III	1965	AEI-Birlec	3660	14	6,500	305
23.	Heavy Electricals (India) Ltd, Bhopal	..	1			AEI-Birlec	2130	3	1,500	203
24.	Heavy Engineering Corpn, Durgapur	..	1		1964	AEI-Birlec	2440	4	2,000	203
25.	Heavy Engineering Corpn, Ranchi	..	4	I	1966	AEI-Birlec	2740	5	2,500	254
				II	1967	AEI-Birlec	4270	20	7,500	406
				III	1963	Demag	3960	20	7,500	406
				IV	1967	Brown-Boveri	3200	10	4,560	250
26.	Herman & Mohatta, Bombay	..	1		1959	AEI-Birlec	2130	3	1,500	203
27.	Himmat Steel Foundry, Raipur	..	1			AEI-Birlec	2130	3	1,500	203
28.	Hindustan Aircrafts Ltd, Bangalore	..	1			AEI-Birlec	1830	1½	1,000	150
29.	Hindustan Iron & Steel Co., Calcutta	..	2	I		AEI-Birlec	2440	4	2,000	203
				II	1955	AEI-Birlec	2130	3	1,500	203
30.	Hindustan Machine Tools Ltd, Bangalore	..	1			AEI-Birlec	2130	3	1,500	203
31.	Hindustan Malleables & Forgings Ltd, Dhanbad		1			AEI-Birlec	2130	3	1,500	203
32.	Hindustan Motors Limited, Uttarpara	..	4	I	1965	Brown-Boveri	2600	5	2,500	230
				II	1966	Brown-Boveri	2600	5	2,500	230
				III		AEI-Birlec	2740	5	3,000	254
				IV		AEI-Birlec	2740	5	3,000	254
33.	Howrah Iron & Steelworks, Howrah	..	1		1964	AEI-Birlec	2130	3	1,500	203
34.	Indian Institute of Science, Bangalore	..	1			AEI-Birlec				
35.	Indian Iron & Steel Co Ltd, Kulti	..	1		1956	AEI-Birlec	2440	4	2,000	203
36.	Indian Naval Dockyard, Bombay	..	1		1957	AEI-Birlec	2440	4	2,000	203
37.	Indian Steel Rolling Mills Ltd, Nagapatam	..	2	I		Demag	2670	5	2,000	230
				II		Demag	2670	5	2,000	230
38.	Jamshedpur Engg. & Mfg., Jamshedpur	..	1		1953	AEI-Birlec	2440	4	2,000	203
39.	JK Iron & Steel Co Ltd, Kanpur	..	1		1939	Brown-Boveri	3300	6	2,000	254

Sl. No.	Name of the Company		No. of furnaces		Year of installation	Manufacturer	Shell dia mm	Nominal Fce capacity tons	Rated Trans-former Cap. kVA	Electrode dia mm
40.	Kay Steel, Patiala	..	1		1965	AEI-Birlec	2440	4	2,000	203
41.	Kolay Iron & Steel Co., Calcutta	..	1		1966	Brown-Boveri	2400	4	2,000	200
42.	Kumardhubi Engg Works Ltd, Kumardhubi	..	3	I	1966	AEI-Birlec	3050	7½	4,000	254
				II	1952	Brown-Boveri	2210	1.6	1,000	178
				III	1959	Brown-Boveri	2790	5	2,200	228
43.	Kusum Engineering Co Ltd, Calcutta	..	1		1959	Brown-Boveri	1600	1	800	150
44.	Man Industrial Corporation	..	1			AEI-Birlec	2440	4	2,000	203
45.	Metal & Steel Factory, Ishapur	..	3	I	1931	Stobie	2130	2	650	176
				II	1944	Stobie		3½		
				III	1959	AEI-Birlec	3660	12	6,250	
46.	Modi Steel, Modinagar	..	3	I	1963	Brown-Boveri	2600	5	2,500	230
				II	1966	Brown-Boveri	2600	5	2,500	230
				III	1966	Brown-Boveri	2600	5	2,500	230
47.	Motilal Padampat Sugar Mills Co Pvt Ltd, Kanpur		1		1966	Brown-Boveri	2600	5	2,500	230
48.	Mukand Iron & Steel, Kalwe	..	1		1965	ASEA	4270	26	10,000	406
49.	Mukand Iron & Steel, Kurla	..	3	I	1939	Efco	2440	5	2,000	203
				II	1951	Brown-Boveri	2130	4	1,800	203
				III	1961		2440	5.2	2,500	203
50.	Musco, Khopoli	..	2	I	1966	Brown-Boveri	4000	20	12,000	400
				II	1966	Brown-Boveri	2300	5	1,000	250
51.	Mysore Iron & Steel Ltd, Bhadrawati	..	4	I	1961	Demag	3810	18	6,000	356
				II	1961	Demag	2670	5	2,000	230
				III	1965	Demag	3960	20	7,500	406
				IV	1965	Demag	3350	10	4,000	305
52.	National Engineering Industry, Jaipur	..	1		1966	AEI-Birlec	2740	5	3,000	254
53.	National Iron & Steel Co Ltd, Belur	..	3	I	1937	Demag	3350	10	3,000	305
				II	1939	Efco	2740	6	2,300	228
				III	1957	AEI-Birlec	1520	1	600	130
54.	National Metallurgical Laboratory, Jamshedpur		1		1960	Brown-Boveri	1600	0.8	550	130
55.	Northern India Iron & Steel Co Ltd, Delhi		1			AEI-Birlec	2440	4	2,000	203
56.	Ordnance Factory, Kanpur	..	2	I	1957	Metal Electric		3		
				II	1961	Brown-Boveri	2600	5	2,500	230
57.	Ordnance Factory, Muradnagar	..	1			AEI-Birlec	2440	4	2,000	203

Sl No.	Name of the Company	No. of furnaces		Year of installation	Manufacturer	Shell dia mm	Nominal Fce capacity tons	Rated Transformer Cap. kVA	Electrode dia mm
58.	Orient Steel & Wire Products, Calcutta ..	1		1965	AEI-Birlec	2130	3	1,500	203
59.	Orissa Alloy & Steel Casting Co Ltd, Calcutta	1		1962	Brown-Boveri	2200	3	1,000	180
60.	Ramkrishna Steel Industries Ltd ..	1		1966	AEI-Birlec	2440	4	2,000	203
61.	Satna Cement, Satna ..	1			AEI-Birlec	2130	3	1,500	203
62.	Shree Shree Ram Chokhani & Co ..	1			AEI-Birlec	2130	3	1,500	203
63.	Singh Engineering Works, Kanpur ..	1		1957	AEI-Birlec	2440	4	2,000	203
64.	Sivananda Steels Ltd, Madras ..	1		1967	AEI-Birlec	2440	4	2,000	203
65.	Steel Cast Corporation, Bhavnagar ..	2	I	1961	Tagliaferri	1500	0.5	540	100
			II	1966	Nikex	2050	1½	1,300	150
66.	Steel Rolling Mills of Hindustan P Ltd, Calcutta	3	I	1963	Daido-Lectromelt	2070	4	1,250	250
			II	1964	Tagliaferri	1410	2½	1,500	200
			III	1965	USSR	3200	5	2,800	300
67.	Tata Engg & Locomotive Co Ltd, Jamshedpur ..	8	I	1954	AEI-Birlec	2440	4	2,000	203
			II	1954	AEI-Birlec	2440	4	2,000	203
			III	1954	AEI-Birlec	3050	7	3,000	254
			IV	1954	AEI-Birlec	3050	7	3,000	254
			V	1954	AEI-Birlec	2440	4	2,000	203
			VI	1964	AEI-Birlec	3350	10	3,000	254
			VII	1965	AEI-Birlec	3350	10	3,000	254
			VIII	1966	AEI-Birlec	3350	10	3,000	254
68.	Tata Iron & Steel Co Ltd, Jamshedpur ..	3	I	1936	Demag	2440	5	1,500	203
			II	1940	Demag	2440	5	1,500	203
			III			2440	5	1,500	203
69.	Texmaco, Belghoria ..	2	I	1956	Demag	2130	3	1,800	178
			II	1967	Nikex		6	3,500	254
70.	Textool Company Ltd, Coimbatore ..	4	I		Textool	1830	1	500	130
			II		Textool	1830	1	500	130
			III		Textool	1830	1	500	130
			IV		Textool	1830	1	500	130
71.	Upper India Steel Mfg Co Pvt Ltd, Ludhiana ..	1		1962	Brown-Boveri	2400	4	1,650	200
72.	U.P. Steels Ltd, Muzaffarnagar ..	1		1967	AEI-Birlec	3050	5	3,000	254
73.	Watkins Mayor & Co Ltd, Jullundur ..	1		1965	Brown-Boveri	2400	4	2,000	200

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