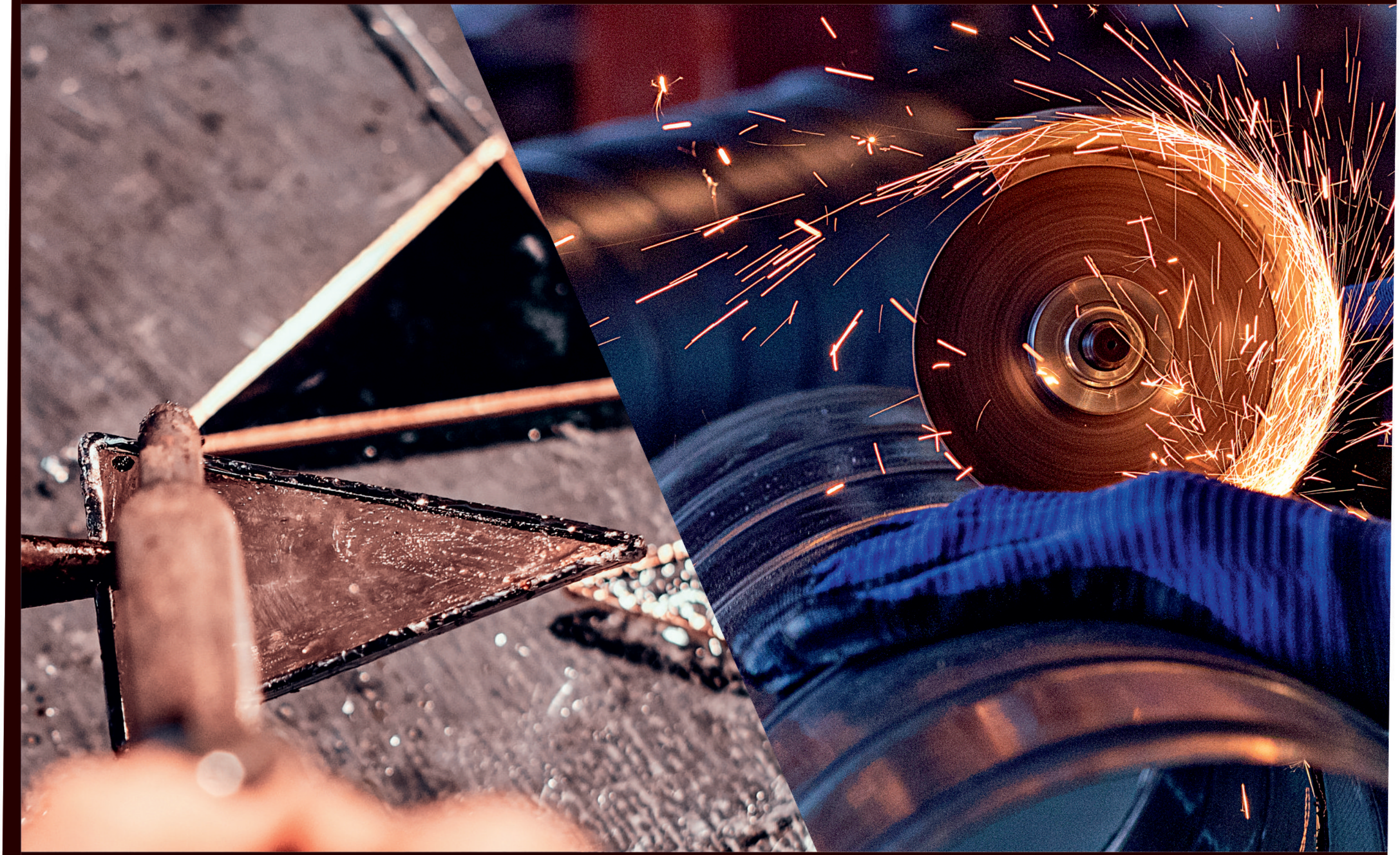
INTEGRATED

Iron- and Steelmaking

Krishna Kant Prasad / **Amit Chatterjee**



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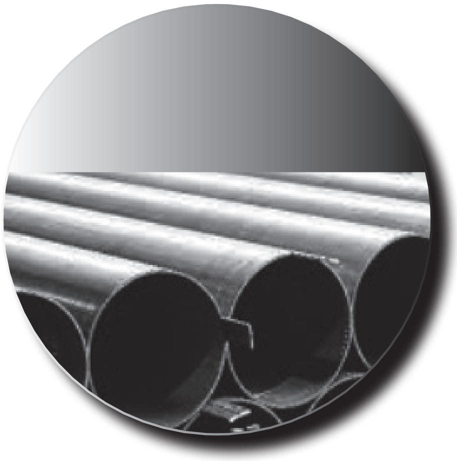

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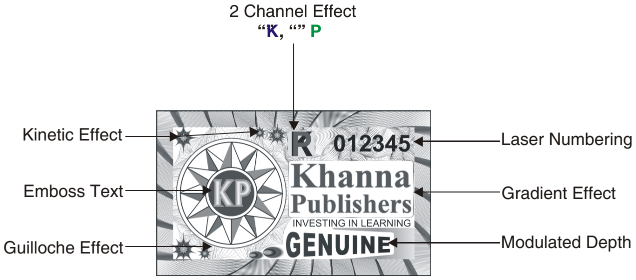

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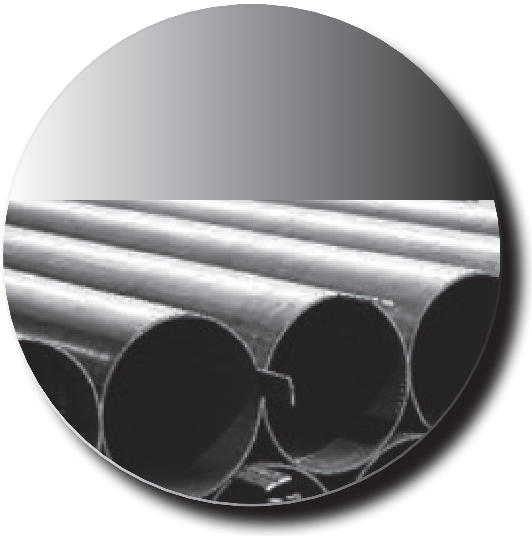

Preface

Steel, the key material for economic development, is made available in bulk quantities by large Integrated Steelworks. Making it in bulk quantities is one way of making it available at affordable prices. Those who make it in smaller quantities keep themselves viable by limiting their inputs, process parameters, outputs, etc. thus catering to a very narrow segment of market and also they do not have flexibility in their inputs. Forward and backward integration employed in an integrated steelworks help them in developing flexibility in all aspects without compromising in profitability. But integration of operations brings with it much higher complexities requiring a large number of complex and intricate technologies. It also requires higher levels of managerial and management skills, which we are not attempting to describe in this book. Thus the aspects of Financial Management, Production Management (including Production Planning and Scheduling), Operations Management, Marketing management, etc have not been covered here and we are limiting ourselves to the description of technologies and techniques required in operation. These, in themselves, are massive in number and we have attempted to give only an overview of the more important ones.

And the number and complexities of technologies keep increasing day by day. By the name ‘Integrated Steelworks’ we meant, not many years ago, a coke oven—blast furnace—basic open hearth furnace—ingot casting—soaking pit and rolling mill complex. It changed to a coke oven—blast furnace—basic oxygen furnace—continuous casting—soaking furnaces and rolling mill complex. But we now have integrated steelworks of different kinds. First we had electric arc furnace for scrap melting, continuous caster and rolling mill complex. Then we had sponge iron, induction furnace, continuous caster and rolling mill complex. Now we are seeing a combination of mini blast furnace, sponge iron making, basic oxygen/Conarc furnace, ladle refining, thin slab caster and flat rolling (compact strip casting and rolling) mill. There are many other variations.

With these variations, the number of technologies employed has also increased. No wonder it is not possible to do full justice to these technologies in a single write up and no attempt has been made to make the present exercise a comprehensive one. Instead we have attempted to give an overview, just to give an idea of the enormity of number and complexities of the technologies employed and, thereby also give an idea of the steps required in attempting to build an enterprise of this type.

We, as students in the mid 1960’s, had failed to get the complete picture of integrated steel plants by reading books. We only got an idea of not only the enormity of operation until we saw one; and even then we failed to get even a reasonable idea of the vast number of technologies involved therein. Only one book was existing, and exists even today in an updated version, published by an organisation which we now know by the name of Association of Iron and Steel Engineers or AISE. This has been a comprehensive compilation, prepared like an epic with full details, and is a well compiled reference book. But both students and entrepreneurs get lost while going through it for the purpose of getting an overall idea of an integrated steel works and its operation. We had long felt the need for a book which gives a shorter summary about the technicalities of a steel plant. This book is the outcome of that long felt thought.

In addition to the above, we have observed that, the development of operational technologies has been slightly different over the years in iron- and steelmaking in India compared to the rest of the world. These have come up due to the typical inputs as well as opportunities available in India. Some of these aspects are included here which, naturally, cannot be found in the AISE publication. We consider these information as unique to this book.

In the introductory chapter of this book, we have indicated the history of evolution of modern iron and steel making and in what steps these complexities developed. We have presented the various operating steps and arranged the chapters likewise, roughly following the flow of materials, indicating the technologies involved in these steps. We have emphasised the importance of maintenance, automation and the impact on environment due to the process steps and the ways to minimise it. Towards the end, we have tried to crystal-gaze and have tried to describe what a steel plant of twenty second century would look like.

Overall we have tried to present a gross reference book for readers who would like to have an overall and relatively superficial idea of technologies required to run an integrated steelworks.

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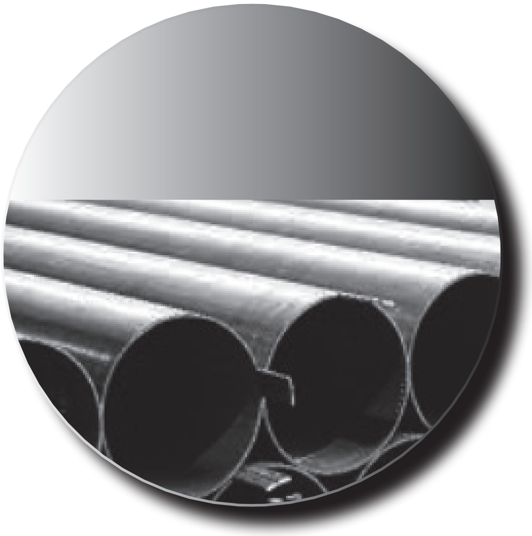
August 2013



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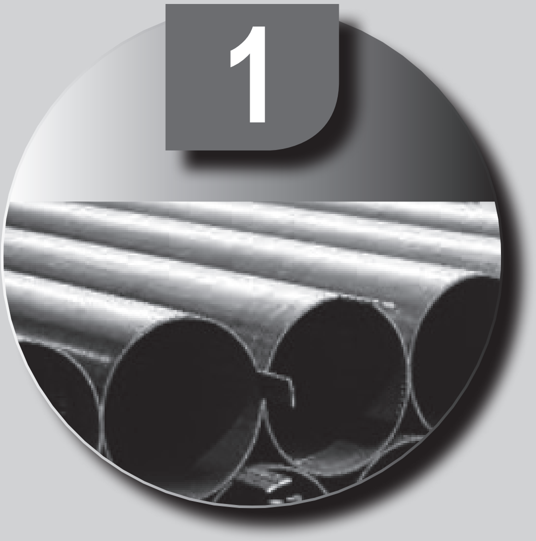

1

The Journey to Integrated Iron and Steel Works

1.1. INTRODUCTION

Over the ages, iron and steel have played a critical role in the sustenance and development of human society. This is mainly because of the unique combination of properties of strength, ductility and toughness exhibited by steel, which is an alloy of iron and carbon. Thus, steel has become the barometer of progress in society. The per capita consumption of steel—and its pattern of consumption (explained in Chapter 12)—are among the key economic indicators which the economists use for assessing the state of development of a nation.

Although the type and extent of usage of steel may have changed over the years, it cannot be denied that iron and steel were essential items even in primitive human society. Almost no human society could do without iron and/or steel after about 500 BC. In isolated instances, human societies existing from even 2500 BC were known to use some form of iron and steel, mainly obtained from meteorites.

In the Indian sub-continent, primitive methods of iron extraction were developed and adopted in five different regions—possibly independent of each other—probably from 2000 BC, but more definitely between 1300 BC and 1000 BC. Mud/clay furnaces were initially used in all such cases [*Prakash*, 1991].

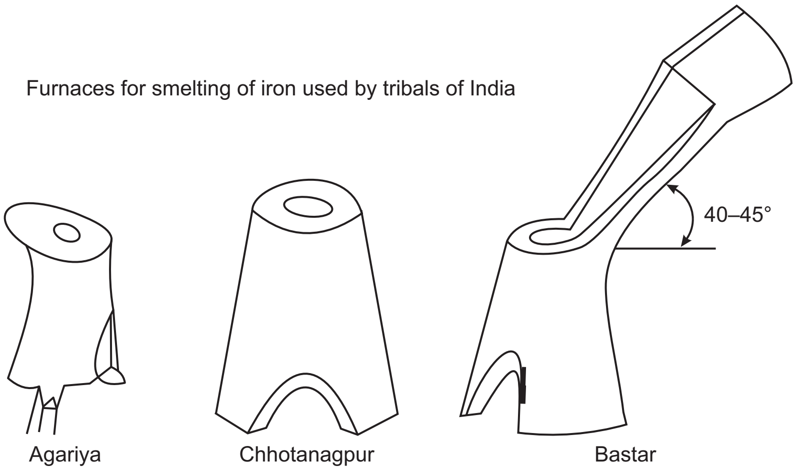

Fig. 1.1. Remnants of primitive iron making furnaces.

Just before the Industrial Revolution, India was one of the world leaders in making and trading iron and steel. Wootz iron ingots (commonly referred to as Wootz steel, probably erroneously) were exported from Indian ports to West Asia for making quality swords (Bulat, Damascus Sword), for meeting the requirement of the entire world. Iron was extracted in India using the primitive mud/clay furnaces (Fig. 1.1) until 1875, when the first blast furnace was blown in, at Kulti (WB), in Eastern India. At present, the per capita steel consumption in India is only about 90 kg compared with the world average of 240–250 kg and about 800 kg for China. This is mainly on account of the fact that steel is not commonly used in rural India comprising over 70% of the country. China dominates by producing and consuming over half the world steel production. India is the second largest producer of steel, and is expected to make big strides, even though presently it produces only a little over one ninth of China.

1.2. IMPORTANCE OF IRON AND STEEL IN PRIMITIVE SOCIETY

Primitive human beings depended on hunting for their subsistence. They developed tools for more efficient hunting. At the beginning, these were limited to stone-tipped wooden spears. The stone-tip was made sharp and pointed by breaking a large piece of stone along strategic points and across visible cleavage planes. Primeval society was constantly looking for materials to upgrade their tools. Some were fortunate in locating the remains of meteorites. In most such cases, it was their first exposure to a metallic material and that too, a ferruginous (iron containing) material.

The first instance of extraction of iron was probably an accident. If a Chhattisgarh folklore is to be believed, one such "accident" took place in the Bastar region. A termite mound (anthill) is generally hollow from inside. In many cases, it is formed over a tree stub. A hunter saw a rat entering such an anthill from an opening on the top. He covered the top opening with a red rock (!) as he was busy and wanted to catch the rat later. In his free time, he made an additional opening at the base, in a direction where the wind was favourable. He lit a fire with dry leaves and stoked the fire. The suffocating rat tried to escape and the hunter caught it. But during the night, the favourable wind intensified the fire and the next day, a thin strip was found, which was far superior for hunting weapons than anything that had been used earlier [Prasad *et al.*, 1995, Das *et al.*, 2005].

Since there are evidences of development of iron extraction in different locations independent of each other, most probably similar "accidents" took place in many locations (Fig. 1.1) and at different times.

Historians credit the ancient Egyptians with the first extraction of iron but this conclusion appears to be erroneous. There is stronger logic to suggest that the iron objects found buried with the Pharaohs were obtained from India by trading through the land route. In any case, there is no denying the fact that in the latter part of the ancient era, Indian iron and steel dominated the civilised world. Along with other parts of the world, North African tribes also started extracting iron and making steel. Later on, they upgraded their techniques and made superior quality steel; but for getting a premium in return, they started calling it "Indian steel". This fact should be considered a tremendous tribute to early Indian steel makers.

1.3. EMERGENCE OF STEEL

An "accident" might have yielded liquid iron, but it was found that better quality implements could be made from agglomerated sponge iron lumps (*i.e.*, with practically no melting). Attempts were made to perfect the techniques of blowing to get consistent properties in the product. Whenever, over-burnt sponge iron lumps were used, it was found that the properties of the final product were not consistent. Very often, they were more brittle than the material from normally smelted sponge. If these products were reheated and beaten a large number of times, the product became stronger and more durable than the normal wrought (*i.e.*, "worked") iron implements. Steel was thus "discovered" and it was realised that over-association with charcoal had something to do with it. Later on, similar and more consistent results could be achieved by exposing already prepared wrought iron implements to charcoal over long periods. This process is now known as the "cementation process" of making steel. This became a more popular method of making steel than the more logical route of making and using over-burnt sponge iron, possibly because of higher toughness of case-hardened steel, which was obtained by the cementation process—*i.e.*, a harder and stronger surface with a soft and tough interior.

In the late Ancient and early Medieval era (about tenth to third century BCE), the focus on the use of iron and steel shifted from hunting and agricultural implements to war-time applications—swords, shields, armour—and later to guns and cannons. It was in the making of swords that the best quality steels were required. The best of swords were carburised by the cementation process, and thereafter suitably heat treated – quenched and tempered – to get a very hard surface along with a tough core. Then came the Indian Wootz iron ingots using which, by some accident not yet fully understood, the Syrians could produce the best-ever sword – the "Damascus Sword" (Russians called it "The Bulat"). Prof. Thelma Lowe [1993] of Pennsylvania State University found references in Dutch documents, available in the museum of Hyderabad (Deccan) of the export of huge quantities of Wootz iron ingots from Masulipatnam port on the Andhra coast off the Bay of Bengal, apparently headed for Damascus. It appears that making of Wootz iron ingots, which are high carbon (2 to 2.5%) iron made by melting wrought iron with carbonaceous material in a closed crucible by firing from outside, remained a secret with the Indians. Similarly, the Syrians kept to themselves their technique of forging Wootz iron in a super-plastic temperature zone to make swords, not only of the highest quality, but also exhibiting "damask", or a regular and interesting pattern over the entire length (very likely, the name of the place 'Damishq'—what we know as Damascus, emerged from this pattern). Some decarburisation also occurred during forging so that the composition of the sword was finally in the very high carbon steel range, 1.6 to 2.0% C.

Wootz iron and Damascus swords (Bulat) are a rare example of iron composition in the cast iron range being in great demand, but it was steel of various compositions which gained in popularity as a material of construction, engineering and in various other applications.

With the advent of 'alloying'—*i.e.*, mixing with other elements—newer types of steel evolved. Strictly, steel itself is an alloy, since here iron is alloyed with carbon. But addition of other elements—invariably accompanied with higher costs—gave rise to a new group called 'alloy steels.' A very important and popular example in this group is the 'stainless steel' which has chromium and nickel as the main alloying elements. They are highly stain resistant and very suitable for kitchen-wares but not cost effective for high load bearing applications. It is the normal steel—called carbon steel to distinguish itself from alloy steels—which is in maximum demand for such applications. The current write-up would be concentrating mostly on this carbon steel while making a passing reference to stainless steel. Making and processing stainless and other alloy steels require techniques which, although not difficult to install within an integrated steelworks, but is not philosophically compatible with the tonnage production mindset. Integrated steel plants generally avoid going into the production of stainless and alloy steels.

Steel is now defined as an alloy of iron with carbon so that the carbon content is within 2.0% (austenitic range in the iron-carbon phase diagram)—and if carbon is beyond this range it is labelled variously as pig iron or cast iron depending on its history of making. Pig iron is the iron obtained in liquid form from iron making furnaces. Initially, blast furnace was the only unit which made liquid iron. Later, electric units and smelting reduction (SR) units also started producing liquid pig iron or hot metal. Use of the term ‘pig’ is explained in the next section. When pig iron was cast into desired shapes in moulds, it acquired the name ‘cast iron.’

Most of steel grades—either deliberately or otherwise—have manganese up to 0.8% (or even slightly higher) and silicon up to 0.4%—but presence of these elements do not qualify it to be called alloy steel and they exist as providing assistance to carbon. Such steels continue to be called normal or carbon steels. If carbon is within 0.35%, it is called ‘mild steel.’ Some would like to make a sub-category within mild steel of ‘soft steel’ containing carbon up to 0.15%. From above 0.35 up to 0.65% carbon, the steel is referred to as medium carbon steel and beyond this range it is high carbon steel. Although Damascus sword is an example of a very high carbon steel (about 1.75% carbon), there is hardly any industrial grade of steel which contains more than 1.1% carbon.

1.4. EVOLUTION OF BLAST FURNACE IRON MAKING

The primitive mud or clay furnaces were the forerunners of modern-day blast furnaces (BFs). Intensification of the process led to higher temperatures, resulting in melting of reduced iron, which then picked-up carbon and ended up as higher carbon containing ‘hot metal.’ The origin of the term ‘hot metal’ for the liquid iron coming out of the blast furnace is uncertain. Probably, when it was first tapped, it was the hottest metal seen in liquid form. Liquid steel was seen much latter and was hotter. But it is not referred to as hot metal, probably since that name was already taken by liquid pig iron.

It was convenient to cast the first hot metal in open sand moulds in front of the tap hole of blast furnace in a particular pattern. The main runner trapped any accompanying slag through the use of weirs (inverted dams or skimmer plates) on to the side openings, leading the liquid to the final crevices for solidification. The solids thus formed—devoid of any slag on top—remained red hot for long periods, while the main runner having slag at the top turned black in colour very quickly. This presented an appearance as though mother sow were feeding about a dozen litter of pigs and that is how it got the name ‘pig iron.’

Some of the important stages of development of iron making can be listed as follows:

- Manual blowing was replaced by using power for blowing (first water power and later electrical),
- Size of the furnaces was steadily increased,
- Mud and stone were replaced by suitable refractory and back-up structure,
- The furnace top was sealed,
- Cup-cone and later bell-hopper arrangement were introduced (now replaced by the bell-less system) to facilitate charging without breaking the gas seal,
- Gas was collected, cleaned and used as fuel,
- The air blast was pre-heated,
- There was a tendency to use prepared burden,
- Charcoal was gradually replaced by coke.

1.5. EVOLUTION OF MODERN STEELMAKING

During reduction of iron ore in blast furnaces, it is not possible to control the pick-up of carbon in the liquid metal in such a manner that steel (normally with less than 1.5–2.0% C) could be made in one operation. At the same time, steel being a more useful product because of its higher ductility and superior strength properties, was in greater demand than pig or cast iron obtained from blast furnaces.

In the middle of the 19th Century, Henry Bessemer made a successful attempt to decarburise liquid pig iron by blowing air from the bottom of a furnace called a converter (which "converted" iron to steel). Very soon thereafter, Siemens and Martin brothers developed the open hearth process for decarburising liquid pig iron to make steel in a totally different manner in which larger amounts of re-circulated steel in the form of steel scrap could be melted along with some amount of high grade iron ore. With these developments, steel could be made much faster, and on a much larger scale than the earlier method of first making sponge iron, then wrought iron and finally carburising the same to make steel. The traditional method was a more relatively direct means of making steel and this route was given the name 'direct reduction.' Blast furnace route was termed 'indirect' since ore was reduced by carbon much more than what is necessary and had to be oxidised thereafter to get steel.

When tonnage oxygen became available in the early fifties, it brought about another revolution in steelmaking. The basic oxygen furnace (BOF also called LD) using pure oxygen blown from the top of the converter to make the process of making steel much faster and more thermally efficient became the most predominant method of steelmaking. For steelmaking from iron ore, though many variations have since been attempted, the BF-BOF route remains the dominant method of making steel even today. The name LD is said to have emanated from the names of the two places, Linz and Donawitz, in Austria, where the first two commercial units of the world were commissioned. Another opinion is that LD stands for Linzer Duesen Verfahren meaning 'the lance process of Linz.' Prof. Duhrer of Germany was the brain behind this process, while VOEST—acronym for United Austrian Iron and Steel Works (Vereinigte Österreichische Eisen und Stahlwerke) was the company which adopted it first.

Recycling of scrapped iron and steel implements was recognised as an economical alternative available for supplementing steel requirements. This was carried out by melting and refining scrap in an electric arc furnace (EAF). With higher steel consumption, and passage of time, larger quantities of obsolete iron and steel items became available. The scrap-based EAF route of making steel is, worldwide, the second most popular method of steelmaking at present.

1.6. INTRODUCTION OF NEWER AND IMPROVED TECHNOLOGIES

Iron and steelmaking processes had to introduce a large number of improvements to meet the challenges posed by other materials with which it had to remain competitive. This has been one of the main reasons why in blast furnace iron making, the consumption of coke per tonne of hot metal has been steadily decreasing, the reactor capacity continuously increasing and the overall operation becoming more efficient by partly performing operations outside, such as by using a prepared burden, etc. Cokemaking technology has also gone through many changes so that coke of the proper quality can be produced from inferior and hence less expensive grades of coals. Alternative energy sources are also being used in blast furnaces such as usage of pre-heated air blast, injection of auxiliary fuels through the tuyeres, etc. However, coke still remains the primary reductant in blast furnace iron making and coke accounts for almost half of the cost of hot metal. To make coke of the proper quality, coking coal, which is both scarce and expensive, has to be used—in spite of the many innovations adopted.

Similarly, in the steelmaking area, innovations have been made to produce better steel, which can be utilised for making consumer products like automobiles and white goods that require superior quality steels with enhanced properties. Combined blowing (use of an inert gas from the converter bottom along with pure oxygen injection from the top), vacuum treatment for degassing, ladle treatment, incorporation of features like use of hot metal in EAFs, improved refractory and lining design, slag splashing, etc. are some of the newer techniques that have been adopted. Thermo-mechanical treatment of rolled products, incorporation of different coatings, micro-alloying, etc. have enhanced the range of application of steel.

All such technologies—with further innovations all the time—are needed in an integrated iron and steel plant of today. An overview of these techniques is included in this book.

1.7. ALTERNATIVE IRON MAKING PROCESSES

The problems with the dependence on coke in blast furnace iron making have led to the development of new iron and steelmaking processes. Some of these are actually a resurrection of older processes (like DR processes), while others (SR processes like Corex, Finex, Ausmelt, HIsmelt, HIsarna, etc.—explained in Chapter 12) have tried to split the operations of blast furnaces in such a way, that coke is no longer required to produce hot metal.

Two units of Corex have been operating very successfully in Southern India for many years and two more have been commissioned in Western region. Two larger Corex units have been commissioned in China; and South Korea is operating two units, one of which is a further development of the original process. Indian coals having high volatile matter and high ash are only suitable for those SR processes which incorporate a high degree of post combustion (for example, HIsmelt). Therefore, the Indian Corex units, which practice negligible post combustion, are operating with 100% imported coal supplemented by some amount of coke.

1.8. RESURRECTION OF DIRECT REDUCTION

While iron and steelmaking by the blast furnace-based route was gaining ground, sponge iron makers did not give up. They tried rotary kilns, which could perform multiple functions of oxidation, mixing, reduction, heating, etc., while being able to handle heavily dust-laden gases. Germany's Krupp-Renn process could make partially fused sponge iron called 'Luppen', which made a significant contribution towards supplementing Germany's iron and steel production during the World Wars. However, the process was plagued with the problem of heavy deposition of fines within the reactor and was later abandoned.

From the remnants of 'Krupp-Renn' emerged the 'Krupp-Codir' process, which dispensed with the idea of fusing sponge iron within the kiln. Almost parallelly, the Steel Company of Canada (Stelco), Lurgi Chemie, Republic Steel and National Lead joined hands to develop the SL/RN process with similar features. Thereafter, a number of other processes were evolved using rotary kilns (DRC, TDR, Jindal, etc.), which are all very similar.

There were parallel developments in the area of reforming of hydrocarbons, specifically natural gas, to yield a mixture of hydrogen and carbon monoxide. This gas mixture was ideally suited for iron oxide reduction. Further, iron ore fines could be agglomerated into uniform sized iron ore pellets. Midland Ross in U.S.A. and Hojalata ya Lamina in Mexico developed the Midrex and the HyL (now renamed "Energiron") processes respectively of sponge iron making using predominantly iron ore pellets in a shaft reactor. The original HyL process used a static bed reactor for reduction, but later on, like the Midrex process, a continuous reduction reactor was evolved. These processes can produce sponge iron with higher carbon content and with no contamination with char that is normal in coal-based DR processes.

However, gas-based processes require reformation (partial oxidation) of natural gas, costly inputs like pellets, and therefore were viable only in locations where natural gas was available in abundance and at relatively low cost (Iran, Mexico, Saudi Arabia, Venezuela etc). In India, three such plants are operating on the western coast, but rising gas prices and lower or uncertain availability of natural gas have discouraged new installations. On the other hand, coal-based rotary kiln plants, mostly small, have flourished in India, mainly because of the lower capital cost along with the ability to install such units in different locations.

As a result, India has emerged as the largest producer of sponge iron, more than 75% of which is based on non-coking coal. However, on a global scale, coal-based sponge iron, in which India is the leader by far, contributes more than 30% of global sponge iron production, the rest is centred around natural gas-rich countries like Iran, Russia, Saudi Arabia, Mexico and Venezuela. At present about 120 million tonnes (Mt) of sponge iron is produced in the world, while the steel production globally is about 1950 Mt.

1.9. EVOLUTION OF INTEGRATED IRON AND STEEL WORKS

Iron and steelmaking is an energy intensive operation involving a large number of separate unit processes, some of which have been highlighted already. Further, it involves handling and transportation of large tonnages of materials. The economic viability of such a system could only be improved by placing the different processing units in close proximity to each other. This minimised transportation costs, as also allowed hot products of one unit being transferred downstream to the next processing unit, thereby resulting in substantial energy saving. This gave rise to the concept of an integrated iron and steel works.

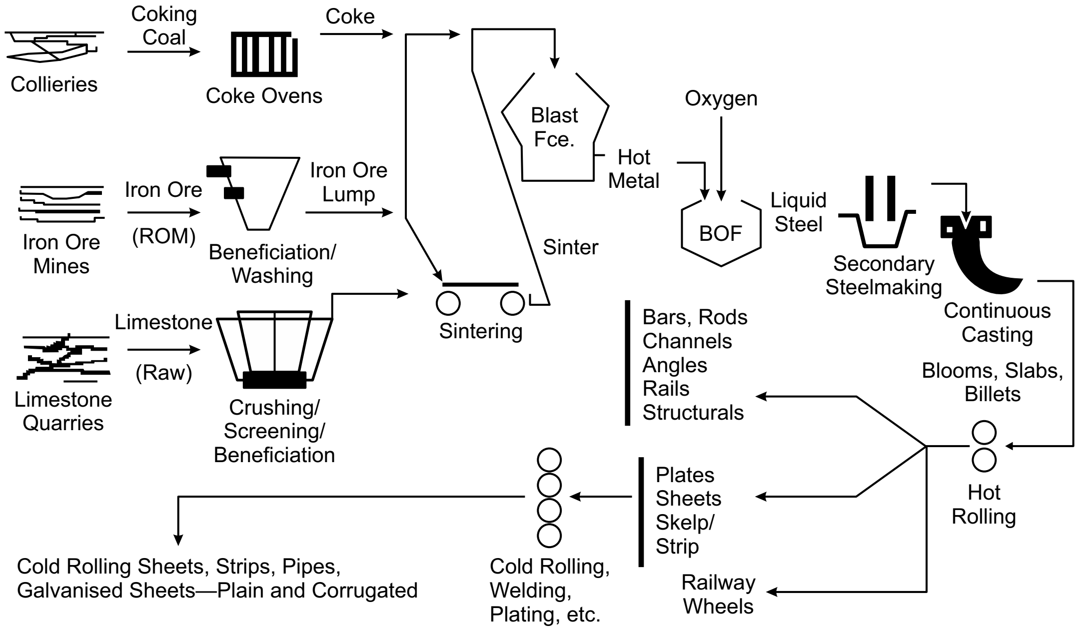

Fig. 1.2. Present day integrated iron and steel works.

Figure 1.2 shows the typical process steps that are adopted and the principal products made in integrated iron and steel plants of the conventional type.

Figure 1.3 shows the variation in the oxygen content (oxygen potential) when iron ore is converted to finished (rolled or forged) steel. Economic factors have been responsible for the adoption of this rather tortuous route.

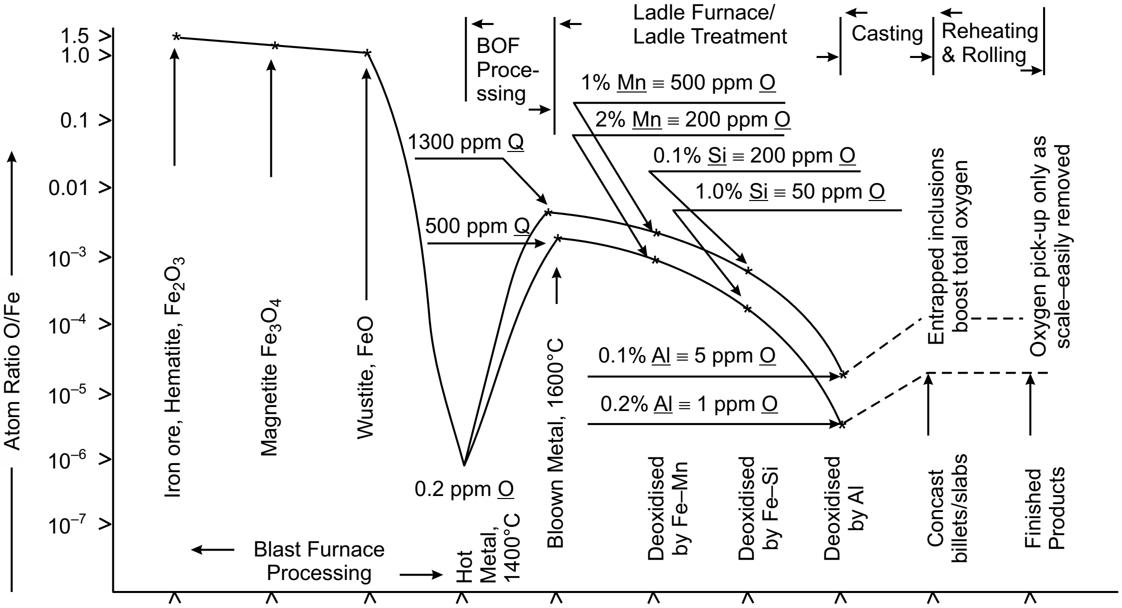

Fig. 1.3. Oxygen-to-iron ratio during iron and steelmaking.

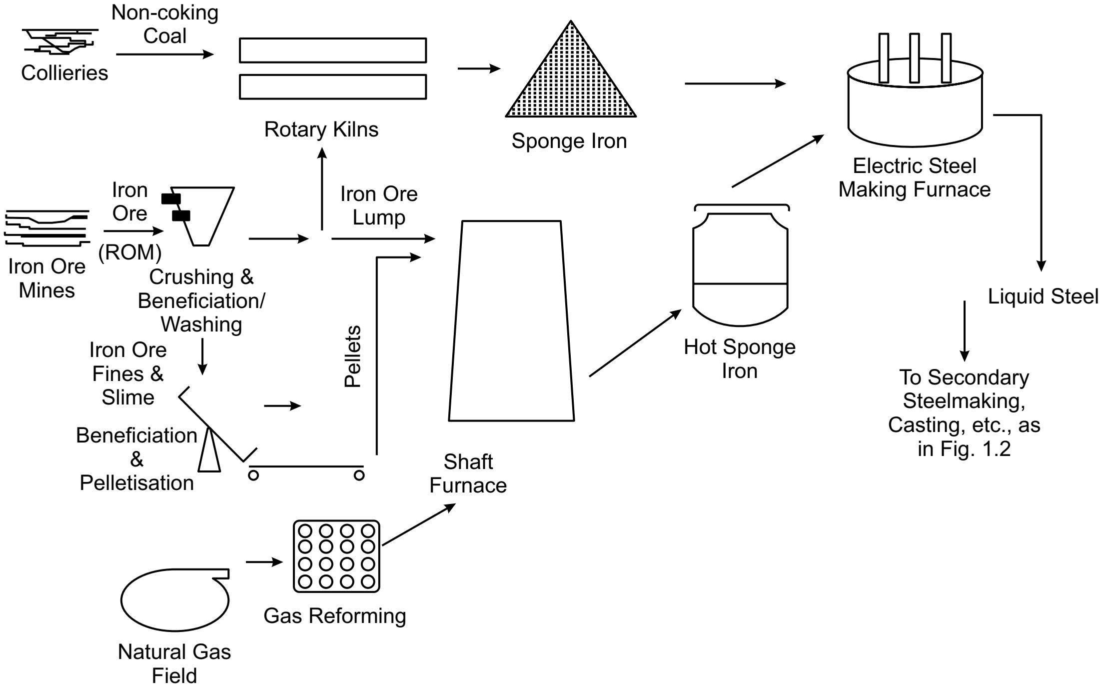

Fig. 1.4. Steel plant based on sponge iron.

The primitive method via sponge iron was a more gradual approach in the reduction of the oxygen potential of iron ore and therefore, did not need an oxidation step in making steel, as is essential in the case of the BF-BOF combination. Now, the same economic factors, particularly in terms of the limited availability and high cost of coking coal required for making blast furnace grade coke, are once again encouraging the adoption of different sponge iron making processes. The net result is that a much smoother line than that seen in Fig. 1.3, would be obtained, indicating lesser variation in the oxygen potential in producing steel through this route.

This has triggered interest in steelmaking based on sponge iron. Figure 1.4 represents the operations in such a steelmaking facility up to the liquid steel stage. The downstream facilities in such a plant, from secondary steelmaking onwards, would be the same as that given in Fig. 1.2.

Figure 1.5 represents another type of steel plant, often not of very large capacity, which is now emerging to take advantage of both hot metal and sponge iron. These materials are used together to make steel in an efficient manner. One particular advantage that has accrued is that the carbon content in hot metal and its sensible heat, assist in reducing the electricity consumption in the EAF and also help in reducing the small quantities of oxides of iron that come along with sponge iron. The induction furnace in such a plant set-up is an optional facility. It can be used for small tonnages of steel demand and also for consuming the fines of sponge iron (below 3 mm) that are invariably generated (to the extent of 20–30%) when iron oxide is reduced to sponge iron in a rotary kiln using coal as the reductant.

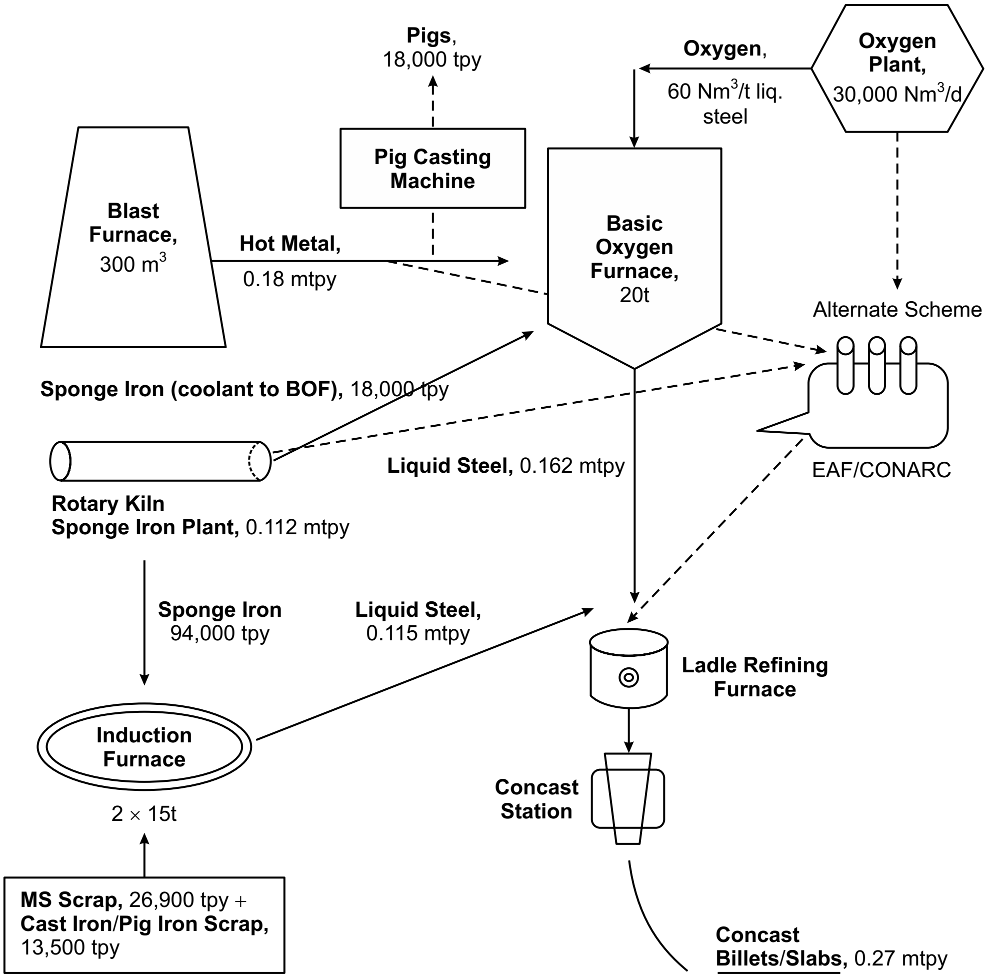

Fig. 1.5. Schematic of a typical Mini/Midi Steel Plant of India

1.10. TECHNOLOGIES IN IRON MAKING AND STEELMAKING

There is little doubt that the technologies used for iron making as well as steelmaking have become more complex over the years. This tendency is likely to continue in future. Integration of operation has necessitated the adoption of many auxiliary technologies within most iron and steel plants. Technologies related to preparation and pre-treatment of inputs, fine tuning of outputs, scheduling of material movement, preventing breakdown of equipment, preventing or reducing damage to the environment, etc., have become a part and parcel of steel plants. Such facilities would need to be adopted to a greater extent in future. Any new entrepreneur would need to have an idea of such technologies before venturing into it. The present book, though not comprehensive, attempts to provide glimpses of a few such important technologies.

1.11. CONCLUDING REMARKS

Iron and steelmaking processes have gone through extensive development over many years. While steel remains the key factor catalysing industrial production and economic growth, the integrated iron and steel works of today, despite being under threat from competitors, remain the focal point of manufacturing activity. Integrated steel plants have been successfully warding off challenges by adopting newer and improved technologies in all areas of its operation. Protection of the environment is the latest buzz word in such units and large sums of money are being expended for sustainable methods of steel production.

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INTEGRATED
Iron- and Steelmaking

About the Book

In the introductory chapter of this book, we have indicated the history of evolution of Integrated Iron-and Steelmaking and in what steps these complexities developed. We have presented the various operating steps and arranged the chapters likewise, roughly following the flow of materials, indicating the technologies involved in these steps. We have emphasised the importance of maintenance, automation and the impact on environment due to the process steps and the ways to minimise it. Towards the end, we have tried to crystal-gaze and have tried to describe what a steel plant of twenty second century would look like.

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Dr. Krishna Kant Prasad completed B.Sc. Hons. (Chem.) from Bhagalpur University and secured a merit scholarship. He then did his B.E., M.E. and Ph.D. in Metallurgical Engineering from Indian Institute of Science, Bangalore. After brief teaching stints at Banaras Hindu University and MR Engineering College, Jaipur he joined R&D Division of Tata Iron & Steel Co. Ltd. (Tata Steel), Jamshedpur in 1972. He moved to RDCIS, SAIL, Ranchi in 1981 as the in-charge of R&D activities in the Sponge Iron Pilot Plant Complex. He was actively involved in steering R&D activities both in Sponge Iron Making and Alternate Iron Making areas. He joined as a full time Visiting Professor in the Metallurgical Engineering Department of the Banaras Hindu University (BHU) at Varanasi, he joined the National Institute of Technology Karnataka (NITK) in the Department of Metallurgical and Materials Engineering as the Ministry of Steel Chair Professor. He holds three patents on sponge iron making – two have been granted and one is in process. He has also edited two books published by R&D Centre for Iron and Steel (RDCIS). He was instrumental in getting RDCIS SAIL registered as a publisher of technical books. His work related to Ironmaking by Tribals of India has won acclaim at technical meetings of the Indian Institute of Metals which included a Best Technical Poster Award.

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