Basics of

IRON MAKING

Theory and Practice

Arbind Kumar

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Theory & Practice

Arbind Kumar
M.Tech. (IIT Kharagpur)

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Operational Office :
4575/15, Onkar House, Opp. Happy School,
Ground Floor, Daryaganj, New Delhi 110 002
Phones : 011-45033819 • *Mob.* 09811541460
email : contactus@khannapublishers.in

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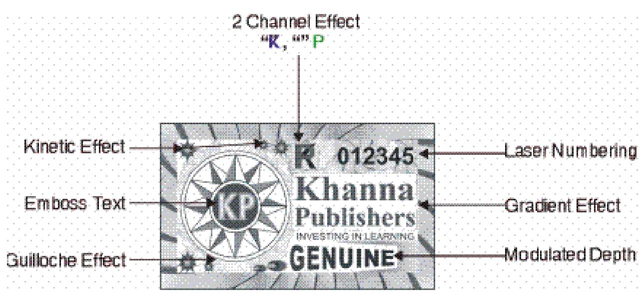

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Preface

I feel immense pleasure to publish the book Basics of Iron Making — Theory and Practice. I had an idea of writing this book, when I was working in Blast Furnace Department, as production incharge. That time I observed that there is huge gap between theory and practice of iron making. Technological developments in iron making include experiences of many technocrats working in this field.

Production of iron largely depends upon the technical knowledge and practical experiences of the furnace operator. It is observed that in a steel plant two similar blast furnaces do not behave in similar fashion, although same facility is provided to each furnace. This descripancy is tried to solve by both practical and technical skills.

In this book, I have tried to describe the basic technology of iron making as well as the practical aspects of the processes involved in the production.

This book covers the syllabus of B.Tech (Metallurgy). This book will be very helpful for A.M.I.E., A.I.I.M. and diploma students of metallurgy.

I am indebted to Sri Kratu Khanna and Sri Kumar Sandip of Khanna Publishers, who encouraged me a lot to write this book. I am also obliged to the entire team of Khanna Publishers for quality production of this book.

Bokaro Steel City Arbind Kumar

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History of Iron Making

1.1. INTRODUCTION

This is the age of technology based on metals and their alloys. Although some non-metals and materials have gained lot of importance, but without metals and alloys, we cannot imagine the present civilisation.

Most important among them are the ferrous metals and their alloys. The word ferrous have been derived from the Latin word "ferrum" meaning iron.

The development of iron making processes to the present level of efficiency has come largely by trial and error and by experience gained under production conditions. This practice continued till 1970. Now many research and development centres are working for the development and modifications in iron making processes. These modifications are coal dust injection, oxygen enrichment, bigger furnaces, BLT system of charging, tuyere dimensions, lime injection, hearth lining with carbon blocks etc.

1.2. HISTORY OF IRON MAKING

Iron objects were found in few countries like Mesopotania, Egypt and Turkey in ancient times. Archaeological notes believe that these objects were found between 3000 B.C. and 2000 B.C. Bronze age is the oldest one and it was used for weapons. Iron age followed the bronze age. Iron tools and weapons were used in the 1100 B.C. Melting point of copper is lower than that of Iron, that is why former was easy to smelt.

It is believed that smelting of iron was based on the heating of iron ore stones with charcoal, where bellows were used to force air. Burning of charcoal produced carbon monoxide, which reduced iron ore to metallic iron. But the temperature was not so high to melt iron, therefore iron produced was spongy mass or bloom. It was associated with ash and slag. The spongy mass was again heated to soften and beaten repeatedly to separate slag and impurities with it. The process becomes more laborious and time consuming. The product thus obtained is called wrought iron, which is a type of Malleable solid iron with little carbon.

Literature reveals that iron smelting was done in Greece, China, Egypt and India. The wrought iron was carburised to steel.

In India crucible steel making process was adopted in ancient times by 300 B.C., which was gradually modified and developed.

Iron making all over the world have tried to produce maximum, with the prevailing conditions around them. The prevailing conditions such as quality of raw materials, automation and trends in operations, vary from works to works. Sometimes the results obtained in blast furnaces differ from that of other, but the basic underlying principles remain unaltered.

Sometimes the behaviour of the furnaces becomes unpredictable. Different furnaces of similar dimensions and capacity, operated under similar conditions in an integrated steel plant may behave differently. Their productivity, coke rate, slag rate, energy consumptions etc. may differ from each other.

In our epic "vedas" manufacture of steel has been discussed. With the available technical reports and literatures, it is claimed that the Hindus have made the steel first. It is believed that obelisks of temples and pyramids of Egypt were made of steel, manufactured in India.

The famous book "Aine Akbari" of Mughal period also describes the manufacture of steel from iron ore. The Ashoka iron pillar near the world famous Kutubminar of B.C. 310, Iron pillar near Indore of 12th century, the beams used in Konark Sun Temple of 13th century, iron beams of Bhuveneshwar temple of Orissa of seventh century, prove the existence of articles made of iron.

The chemical composition of iron used in the pillar near Kutubminar of Delhi is as follows:

Fe – 99.72%, C – 0.08%, Si — 0.46%, S— 0.006%, P — 0.114%.

This composition of low S and low C provided anticorrosive property in the pillar. The wrought iron of same composition was used for the iron beams of temples of Orissa.

In Rigveda iron utensils have been mentioned. In ancient times the rods of chariots, tips of axes and arrows, iron chains were also used.

In Rigveda smelting or ion ore has been discussed. It is believed that blacksmiths of ancient India would have heated iron minerals with charcoal. They may be getting charcoal, after burning teak, babul or Shesham wood. Much of iron may be going with slag. That iron may be coming into plastic state instead of flowing into molten condition. This was heated repeatedly to remove iron ores and slag present in it. This iron was utilised for weapons, beams for temples, handlocks, agricultural tools, and building making.

According to Trining (1893), iron was being made in Monghyr of Bihar, Birbhum of West Bengal. Main products were chairs, cots and furnitures of iron.

Few iron objects and weapons have been excavated in Aditnathur of Tamil Nadu. It seems to be of 400 B.C. In Bodh Gaya temples of Bihar, iron clamps of 300 B.C. have been used. Thus we conclude that manufacturing of iron is not new for Indians. We are doing it since the down of civilization. Lot of developments have taken place since then.

1.3. HISTORY OF IRON MAKING PROCESSES

It is believed that around 400 B.C. iron smelters used bowl, placed in the ground to melt iron ore with charcoal. Bellows may have been used to force air to burn charcoal. This may have achieved the temperature up to 1130°C.

Iron is believed to collect as a spongy mass in the bottom. The product thus obtained is called bloom, containing ash and slag in its pores. This was heated to separate ash and slag to get wrought iron called bloom. The place where bloom was produced is called bloomery.

In Spain furnace of one metre tall called "Catalan Forge" was developed to melt about 150 kg iron a time or in a batch. Bellows were used to supply air.

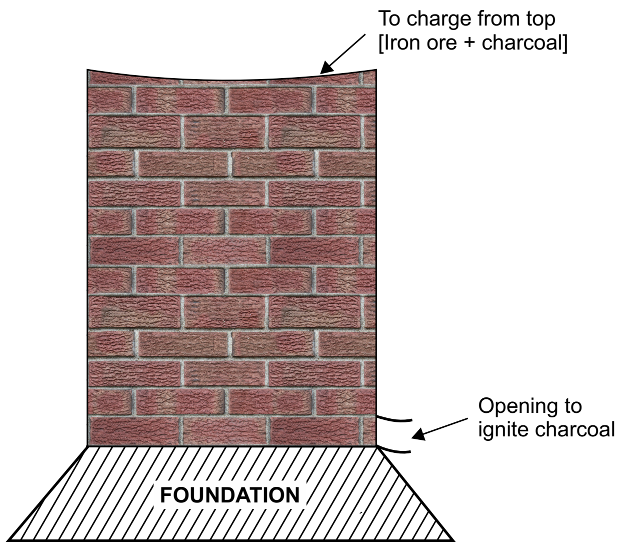


Fig. 1.1. Catalan Forge

Historian suspects that iron smelting Kiln may be of the type as shown in Fig. 1.1.

This iron smelting unit may have been made of stone and clay. The charging of iron ore and charcoal is believed to do from the top.

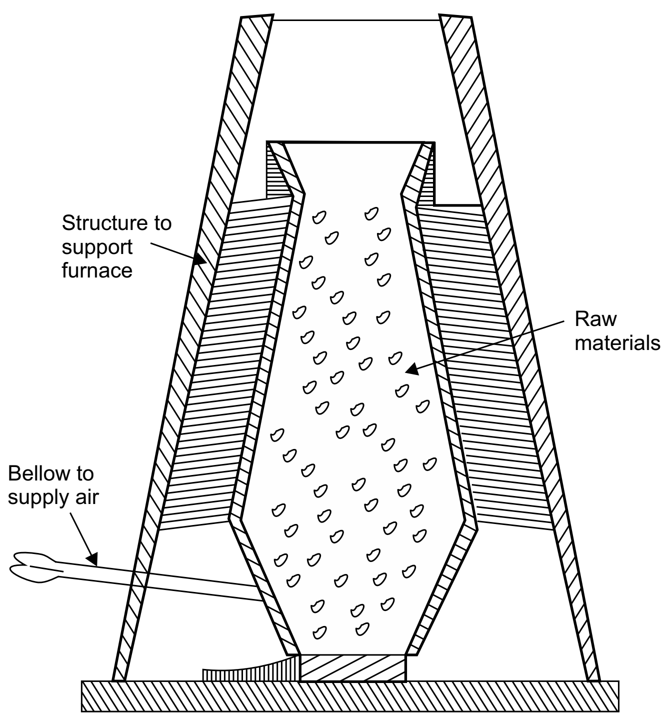


Fig. 1.2. Stukofen Furnace

After Spain "Stukofen Furnace" was developed in Germany. It was about (3.5–4.0) metres high and made of stone and clay with round cross-section and supported by outside structure.

This design may be the basis for the development of modern blast furnace. The production of German Stukofen Furnace was about 4 tons per month.

Bloomery furnace, Catalan Forge and Stukofen Furnace have smelting of iron per batch 60 kg, 150 kg and 800 kg respectively.

Major breakthrough took place, when Abraham Darby used coke for iron smelting in 1709. Coke having more strength than charcoal could sustain forceful blast of air. Such blast, caused better ignition of coke. The height of smelting furnace was also increased due to use of coke. Coke was are fined coal product and cheaper then charcoal. Iron produced from coke was of inferior quality than that of charcoal. The quality of iron improved, when coking process of coal was improved in 1750 and blast furnace using coke for iron smelting was used universally.

1.3.1. History of Iron and Steel Making in India

The effort to make iron in India was done by J. Marshal Heath around 1830. He commissioned a small plant at Port Novo, near coast of Madras. He used charcoal to produce pig iron. The process was too expensive to afford. The consumption rate of charcoal was 4 tons for producing one ton of hot metal (pig iron). The plant was closed in 1854.

In 1889, Bengal Iron and Steel Company was set up at Kulti (near Asansol) in West Bengal). Here coke was used for smelting iron ore. The plant was near coal field area. In the beginning Jharia coal was used to make coke. This plant was taken over Indian Iron and Steel Company (IISCO) in 1936. In 1974, it come under Hindustan Steel Ltd., a Government of India undertaking.

In Karnataka, Mysore Iron and Steel works was started at Bhadravati in 1918. That time, the furnace was operated with charcoal. The production was 60 tons per day in 1918. The electric arc furnace was commissioned in 1952 to produce pig iron. The furnace to produce iron with charcoal was stopped. Two more electric arc furnaces were commissioned.

The real development took place by Jamshed ji Tata. He established “Tata Iron and Steel Company (TISCO)” at Sakchi in August 1907. The place later on was named Jamshed Pur. That time it was in Bihar State but presently it falls in Jharkhand State and TISCO is renamed as “Tata Steel”.

The production of pig iron started in 1908 with capacity to produce 1,20,000 tons of pig iron.

Developments in iron and steel production took place during second five year plan. Hindustan Steel Limited was set up by India Government to produce iron and steel.

Immediately after the independence our country realised the future requirement of iron and steel and hence the need for setting up steel plants. Feasibility studies were initiated by foreign consultants for the establishment of iron and steel works. As per the recommendation of the consultants two sites were selected in the beginning. One was selected in Madhya Pradesh and other in Orissa.

The third site was considered as the government in either Durgapur in West Bengal or Sindri/Bokaro in Bihar. But Durgapur was selected because, Bokaro was not so developed.

In 1955, the government decided to develop the Bokaro site for the possible location of a future steel plant. Thus Bokaro Steel Plant became the fourth steel plant in the public sector. Bokaro Steel Plant started iron production in 1972.

Thus we had the following steel plant till then –

1. Indian Iron and Steel Company, Burnpur (West Bengal)

2. Tata Iron and Steel Company, Jamshed Pur (Bihar) now called Tata Steel, Jamshed Pur (now in Jharkhand)
3. Mysore Iron and Steel works, Bhadravati (Karnataka)
4. Rourkela Steel Plant, Rourkela (Orissa)
5. Bhilai Steel Plant, Bhilai (now in Chattisgarh)
6. Bokaro Steel Plant, Bokaro Steel City (Jharkhand)

Mysore iron and steel works was renamed as Visvesvaraya Iron and Steel Limited.

Hindustan Steel Ltd. was renamed as "Steel Authority of India Limited" by government of India in 1970.

Bhilai Steel Plant and Bokaro Steel Plant were commissioned under Russian collaboration. Rourkela Steel Plant was set up under German collaboration. Durga Pur Steel Plant was set up under British collaboration.

The decision to set up a steel plant in Visakhapatnam by government was taken in April 1970 with assistance of USSR. It was named as Vizag Steel Plant under SAIL. In 1982 it was separated from SAIL and was renamed as "Rashtriya Ispat Nigam Ltd. RINL)". It is only shore-based steel plant. In the beginning it was installed with capacity of 3.6 M.T. Now it is running with capacity of 6.3 M.T.

Due to the policy of decontrol of iron and steel production in India, lot of industries were commissioned in public sectors. Various small medium and integrated steel plants were set up after the beginning of 1990. Hot metal production was even started with mini blast furnace or sponge iron units. The coal based DRI (Direct Reduced Iron) plant was also installed.

The Ispat Industries Ltd. Delvi, Vikram Ispat and Essar Steel utilised midrex process for DRI production. Many industries having induction steel furnace plants developed for the production of construction grade steels like bars, angles and channels. Such furnaces were set up all over India. But such furnaces lost their existences, because refining is not possible in such furnaces. Basic oxygen steel making furnaces (BOF) and Electric Arc Furnaces (EAF) dominates for producing quality steels.

Electric Arc Furnaces were set up at many places. These were set up at Sandur (Bellary district) of Karnataka, Maharastra. Electrosmelt at Chandrapur (now under SAIL) for production of pig iron.

Mini blast furnace was set up at Barbil (Orissa) in Kalinga Iron Works Ltd. There were three small blast furnaces (Shaft furnaces) of 100 m^3 working volume. Then Mini blast furnaces were set up at Goa (175 m^3 capacity) in 1992, Tata Metaliks Limited (TML) in 1994. Mini Blast furnace of TML is presently working with 2.2 ton/m^3/day productivity.

Jindal Steel Works and Essar Steel have commissioned corex DRI units. Each has two 2000 tons per day corex units at their plants.

Iron making by blast, furnace route has its own importance and still dominates for production of iron in an integrated steel plant.

The installed capacity of few Indian Steel Plants are as follows :

S. No.	*Plant*	*Commissioned with initial capacity (MT)*	*Present capacity (MT)*
1.	IISCO	0.35	2.5
2.	TISCO Jamshed Pur (now Tata Steel)	1	13
3.	Visvesvaraya Iron and Steel Ltd.	0.06	0.15
4.	Rourkela Steel Plant, Rourkela	1	3.9
5.	Bhilai Steel Plant, Bhilai	1	4.0
6.	Durga Pur Steel Plant, Durga Pur	1	2.2
7.	Bokaro Steel Plant, Bokaro Steel City	1.7	4
8.	Rastriya Ispat Nigam Ltd.	2.5	7.3
9.	Jindal Steel Power Ltd. (JSPL, Raigarh)	—	3.25
10.	JSW Steel, Dalvi	—	4.2

There are many small and medium steel plants in our nation. These steel plants produce pig iron or hot metal through DRI process or mini blast furnace route. Few of them are Hospet Steel, Karnataka, Usha Martin, Jamshed Pur, Vardhaman Special Steels, Ludhiana, Jai Bala Ji Limited, Durga Pur, (W.B.), Jindal Stainless, Hissar (Haryana), Mukund Steel, Thane (Maharastra).

It is important to note that Rourkela Steel Plant was the first to incorporate LD technology of steel making in our country.

In the eastern part of the country, we have lot of coal mines. This is the cause of installation of coal based DRI units in the eastern part of the country, whereas western part of the country possesses gas based DRI units. In the western coast of the nation, natural gas is available.

1.4. DEVELOPMENTS IN IRON MAKING

The development of blast furnace iron making was encouraged all over the world and gradually it has reached to this stage. In the beginning "Catalan Forge" used in Spain was of about one metre height. "Stukofen Furnace" of Germany was of about (3.5 to 4) metres height. In these furnaces charcoal was used as fuel and reducing agent. The charcoal did not possess much strength and abraison resistance. Major breakthrough took place, when Abrahm Darby used coke for ion smelting in 1709. Coke was superior to coal in many respect, as far as physical and chemical properties are concerned like chemical composition, reactivity, thermal stability, strength and abraison resistance. The gradual increase in the size of blast furnace took place.

The taller blast furnace could be commissioned which in turn used increased blast volume. Productivity increased due to various modifications, like oxygen enrichment in blast, fuel injection, humidified blast, high top pressure, burden preparation, lower slag volume, modernised charging devices etc. The small bell and big bell has been replaced by bell-less top arrangement for charging, which has many advantages.

Now furnace has usually more than 3000 m^3 of useful volume and of hearth diameter more than 12 metres. Now hot blast temperature is maintained about (1100–1200°C) and B.F. productivity about 2 ton/m^3/day. With increasing price of coke and its scarcity, people also think of alternative methods of iron production. Various processes have been developed and many countries are adopting it.

1.5. ALTERNATIVE METHODS OF IRON PRODUCTION

There is shortage of coking coal. The price of coke is also high. At the same time, coke manufacturing in an integrated steel plant is not environment friendly. All these factors have raised questions marks about the future of coke making. Although blast furnace iron making accounts for the main hot metal production method now-a-days, but there is huge demand of alternative method of iron production.

Besides integrated steel plants, hot metal is also required in small scale mills, using electric arc furnace. Adoption of mini blast furnaces, coal or gas based direct reduction (DR) processes, smelting reduction (SR) processes are also in increasing trends.

The cost of commissioning mini blast furnace is very less than that of conventional blast furnace. It is also beneficial for foundries. Countries like Brazil, Russia, China, Bulgaria, Germany and India have adopted this process for manufacturing iron. First mini blast furnace in India was installed in Kalinga Iron Works in Orissa in 1960. In 1992, other mini blast furnace was set up in SESA GOA of Goa. The size of blast furnace was 175 m^3.

Conventional blast furnace requires good quality metallurgical coke. The commissioning of blast furnace requires huge amount. These points led to the discovery of low shaft furnace or charcoal blast furnace. Low shaft blast furnace uses the coke fraction, which is not used in normal blast furnace *i.e.*, nut coke of (+5 and –30 mm) size. Low shaft furnace utilises low grade ore or its fines. Poor quality metallurgical coal (lignite) can also be utilised. But low shaft furnace and charcoal furnaces are not widely used. Electric arc furnace for smelting iron is used, where electric power is cheap. The Tysland Hole electric furnace is used for this purpose. In this process anthracite, charcoal, coke breeze etc. may be used as reducing agent.

Huge amount of heat is produced due to resistance of the charge to the passage of current between the electrodes. There is common tap hole for taking out slag and molten iron.

When iron is produced in solid form, it is called sponge iron. Sponge iron can be produced by solid reducing agent like coal, coke or combination of the two in proper ratio. This process is called "Direct Reduced Iron (DRI)" sponge iron thus produced is major raw material for electric arc furnace. The gaseous reductent (hydrocarbon) is also used for producing iron. These processes are HYL process, Armco process, Purofer process, Midrex process, Hi-iron process, Nu-iron process, SL/RN process, Krupp-Renn process etc.

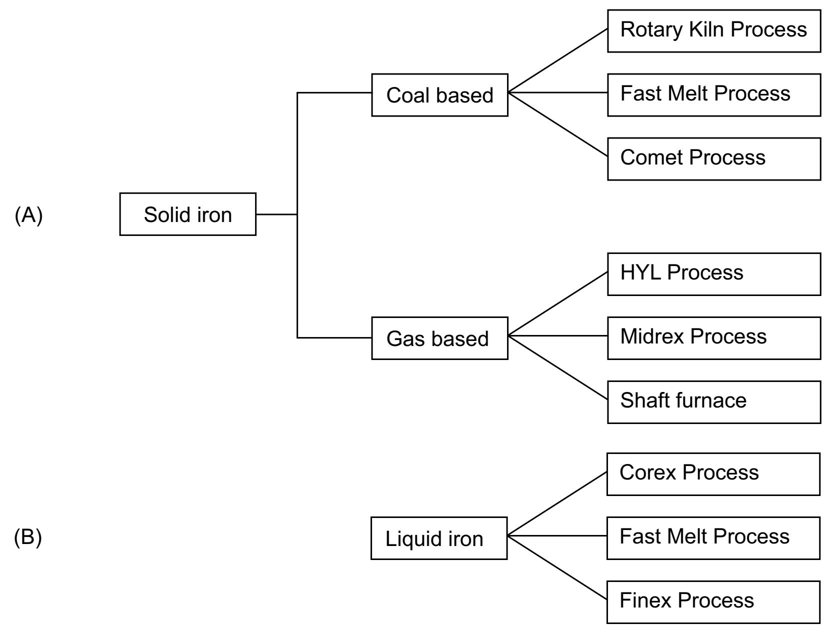
There are processes, where iron is produced in liquid state as hot metal. One of the such processes is Corex.

Midrex is other process, in which natural gas is used. In this process iron oxide is used in the form of pellets or ore lump, which is converted to direct reduced iron (DRI). Direct reduced iron in hot form is charged to electric arc furnace (EAF).

Midrex process works like counter current flow reactor. In this process solid iron oxide comes downward and reducing gas carbon monoxide and hydrogen move upward like blast furnace process. The iron produced may be discharged hot, directly to Electric Arc Furnace.

Few smelting reduction processes are as follows : Corex, Finex, Hismelt, Ausmelt, Romelt, Combismelt, Plasmasmelt, Inred, Tecnored HYL and Midrex processes.

Main alternative iron making processes may be summarised in tabular form as follows :



This processes will be discussed in separate chapter of alternative routes of iron making.

1.6. CONCLUDING REMARKS

Indians were knowing the iron making from prehistoric age. Iron making through blast furnace route dominates for larger production. Iron is an important raw material for steel making.

Conventional blast furnace requires good quality metallurgical coke. Alternative method of iron production called DRI utilised iron ore lump, coal or reformed natural gas (as reductant).

SR (Smelting Reduction) technology processes utilised ore fines, ore lump, non-coking coal or electricity.

In our nation few steel plants are adopting DRI and SR processes for iron making.

Molten iron from electric arc furnace is produced with ore lump and low grade coal (as reductant). But this process is preferrable, where electricity is cheap.

Exercises

[A] Mention True/False against each statement. Write correct statement in case of false one.

1. Bronze age preceded the iron age.
2. In bloomery, iron was produced in the form of spongy mass containing its pores with ash and slag, which was beaten to remove.
3. Hindustan Steel P. Ltd. was changed to Steel Authority of India Ltd., in 1960.
4. All steel plants of Steel Authority of India Ltd. was commissioned under the collaboration of Russia.
5. Rastriya Ispat Nigam Ltd. is situated at Visakhapatnam.

6. Small shaft furnaces were commissioned in Kalinga Iron Works at Barbil in Karnataka.
7. Blast furnace pig iron is the major source of steel production in India.
8. In alternative method of iron production, we mainly use coke as fuel.
9. Durgapur Steel Plant (SAIL) was started with British Collaboration.
10. Pig iron and Wrought iron were produced from Catalan Forge and Stukofen Furnace.
11. The working height of a blast furnace is the height between tuyere level to throat of the furnace.

[B] Fill up the blanks with suitable word/words.

1. Bronze age preceded the iron age, because smelting of copper ore/bronze required .... fuel, to achieve .... temperature.
2. Ashoka pillar near Kutub Minar in Delhi is made of ....
3. Abrahm Darby produced iron by smelting iron ore with ....
4. Bloomery, Catalan Forge and Stukofen Furnace were used to produce .... in ancient times.
5. The first iron works in India was successfully started by .... at Port Novo, Madras.
6. Bengal Iron Works was started at .... in West Bengal.
7. In Mini blast furnace, Air blast temperature is around ....
8. The production of iron started in Tata Iron and Steel Company (presented named as Tata Steel) in ....
9. The need for the development of alternative method of iron production was mainly due to shortage of ....
10. Mysore Iron and Steel Works at Bhadravati (Karnataka) initially started with .... as a fuel for iron making.
11. Indian steel industry was decontrolled in ....

[C] Answer in brief with suitable equations or figures if required.

1. In ancient times, it was difficult to produce iron in molten state.
2. What are the evidences that prove that Indians were knowing iron making from prehistoric age.
3. What was the specialty of Stukofen furnace? Where was it developed first?
4. The benefits of iron making, when coke making was invented?
5. What was the contribution of J.M. Heath (1830) to the development of iron making in India?
6. What is the contribution of Sri J.N. Tata in iron making?
7. The use of charcoal restricted the increase in height of furnace. How this problem was solved?
8. Define DRI.
9. "Production of iron through B.F. Route increased in the nineteenth century". Explain.
10. "The technology of B.F. iron making is in fully matured stage". Explain.
11. Describe the limitations of conventional B.F.

Answers

[A]

1. T	2. T	3. T	4. F	5. T
6. F	7. T	8. F	9. T	10. T
11. T				

[B]

1. less, lower	2. iron	3. coke	4. iron	5. J.M. Heath
6. Kulti	7. 800°C	8. 1912	9. Coking coal	
10. Charcoal	11. 1990–91			

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About the Book

- This book describes the Technology of Iron Making as well as the practical aspects of the processes involved in the production.
- This book includes Blast Furnace Plant and Processes, Hot Blast Stores, Raw Materials for Iron Making, Fuel, Burden Distribution and Preparation, Properties of Blast Furnace Charge Materials, Operations, Refractories and Accessories, DRI, EAF and SR processes.
- This book covers the syllabus of B. Tech (Metallurgy) and will be very helpful for AMIE, AIIM, Diploma students of Metallurgy and other competitions.

About the Author

Author is M.Tech from IIT Kharagpur. He is pioneer in the field of Iron Technology. During his service tenure, he has tackled various problems related to iron making. He has published papers in technical magazines and produced technical papers in seminars. He is a regular faculty member in HRD programmes for graduate engineers and Skill Development Courses conducted by Central Governments.

His first book in metallurgy for competitive test was published forty years back from this publication. Author has written two books in Hindi to promote Rastrabhasa in technical field. Author is recipient of several awards for record production and quality product.

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