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SMELTING FURNACES IN ANCIENT INDIA

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The advent of metals which has played a vital role in deciding the course of civilisation resulted in a collosal stride of human ingenuity. With metals man could mould,twist, shape, cast, recast, weld and forge objects of his choice to suit his needs and requirement. The present paper describes a few furnaces used in ancient times for different metals which brought about significant changes in contemporary life.

Copper being the first metal smelted from its ore, copper furnaces are first considered. Most of the ancient furnaces have been found near the old mine workings. Gold and silver are mostly available in natural form. However, crucibles have been used for smelting and melting for moulding purposes. The smelting of iron gave a new turn to the development of ancient civilization. Iron smelting furnaces of ancient time have been located in abundance. The important furnace types discussed are bowl shaped furnace, dome shaped furnace, shaft furnace etc. Metallurgy of zinc was the most complex process, as zinc was produced in vapour form during ancient times. The process of downward distillation of zinc vapour was developed. The working of furnaces and archaeometallurgical process of zinc are discussed.

Credit goes to India for developing the complex metallurgy and producing alloys of metals. This speaks legions of the metallurgical skill which the metal workers and artisans of ancient India possessed way back in the early centuries before Christ which have played a vital role in deciding the course of civilization .

Key words: Ancient, Archaeometallurgy, Copper, Furnaces, Gold, Iron. Silver, Smelting, Zinc.

INTRODUCTION

An ethno-archaeological approach for the proper understanding of a culture is of great significance, more so in the context of those cultural horizons which are not mentioned in treatises of history. Even today in the remote interiors of India, there are several ethnic groups involved in traditional technology who are still engaged in pursuing their age old craft of smelting ores for procuring metals. The present paper

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describes a few furnaces used in ancient times for different metals bringing in significant changes in contemporary life.

Although, it is an arduous task to trace the history of different metals from the earliest times, careful excavations provide sufficient clues for a reasonable reconstruction of furnaces/ forges. Archaeometallurgical researches on archaeological remains with laboratory experiments have successfully traced the furnace designs of the past. Several kinds of furnaces are discernible in different parts of the world[1]. During 400-200 BC high temperature furnaces were in vogue[2]. Vedic references to the use of draught to fan the flame indicate the use of some sort of bellows[3]. Right from the Harappan period down to the early Historic period, copper-bronze technology has continued. Furnaces capable of melting copper (1083° C), gold (1063° C) and making well fired pottery have been used during this period. As we know that an ordinary furnace cannot provide the high temperature expected, hence chimneys or bellows were used to provide high temperature as an open fire cannot give a temperature of more that 700 °C. It appears that the earliest furnace was a hollow or a depression in the ground in which charcoal and oxidised ores were placed for smelting.

Furnace for Copper smelting

The earliest kiln for copper smelting has been traced at Lothal. The kilns used for melting copper ingots in earthen bowls was a simple circular and brick structure (0.8m in diameter and 0.6m deep). The mud plaster on the inner face of the Lothal kiln was vitrified due to intense heat. Two types of kilns were used by copper smiths for melting copper ingots (i) circular and (ii) rectangular. The long mouth of the furnace suggests that a bellow was used for pumping air to increase the temperature to a high degree. The molten metal and a thick terracotta bowl - like crucible found nearby suggest that copper ingots were melted in the kiln[4].

Near all the ancient workings we find large heaps of broken stones. It seems that ore-bearing rock pieces were carried down to the valley, where they were roasted, crushed, concentrated and smelted. Small size furnaces, that were used for smelting copper ores, have been found near the Aravalli hills (Fig.1) that are near the mines of Rajpura - Dariba (Udaipur district). Most of the slag pieces showed clear cylindrical flow structure, suggesting that the furnace was used for smelting copper. The ancient Indian copper smelting furnace was small, barely 35cm in height, 18cm in diameter at rim, 14cm in diameter at mid level and 10cm diameter at the base[5].

A copper smelting furnace of the Aravalli hills was assembled by putting the three curved parts together. The small capacity of the furnace and the relatively high yield of the metal as represented by the weight of the ingot, enable us to infer that the ancient Indian copper smelting processes were very efficient. The evidence of tuyere luted to a segment of the furnace wall suggests that the smelting process in the furnace was carried out with the help of forced draught.

It is clear from the foregoing description that the ancient Indian copper smelting furnaces were small, crucible shaped, clay walled slag tapping furnace, worked on forced draught into it from bellow as described above. The furnace at Aravalli was a composite structure made of three moulded segments. Evidence found at the smelting site shows that it was set up on a brick platform and was surrounded with bricks and earth to keep the three segments of the furnace closely and in position. The arrangements helped to conserve the heat within the furnace. At many sites terracotta clamps that joined the tuyere and the nozzle of the bellow was found. This type of furnace is still used in many parts of India for smelting copper[5].

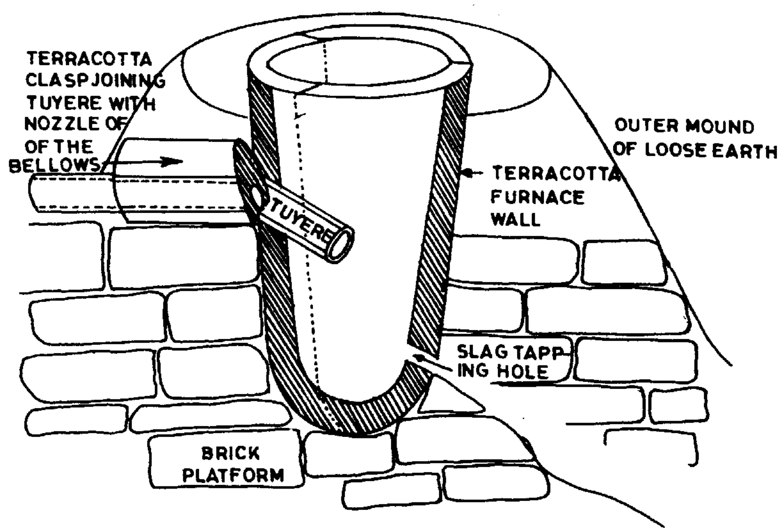

Fig. 1 Assembled copper smelting furnace from Aravalli

A number of furnaces which are more or less intact have been located at Chapri in the Singhbhum area (Fig.2) by the author [6&7]. These furnaces which lie abandoned today are dome shaped made of locally available mud and clay. The outer diameter of furnace at ground level is approximately 4 feet, the inner diameter is approximately 3.2 feet and it tapers slightly at the top. The height of the furnace is approximately 4 feet. The inner wall of the furnace shows deep impression of hot molten metal. There are two holes at the botom—one for slag tapping and the other was probably used for bellows. In a nearby raised ground about 1 km. from the furnace a large number of slag and impression of seals of terracotta have been found. A superfluous examination of the terracotta pieces suggest that it was actually a mould for casting coins. The extensive area and their exhaustive number suggests that it was a centre for casting coins during the Kushan period.

The other type of furnace as reported by Ball[8] was generally built with refractory clay, or was simply a deep hole in the ground with a clay rim at the sides and front. The inside was also plastered with refractory clay. The furnaces were 18 inches deep, a foot square at the top and tapering to the bottom where charcoal is rammed down so as to form a floor through which the molten metal cannot sink. There was no orifice at the base of the furnace. Two clay tuyeres dip into it vertically and were connected with simple skin bellows by horizontal tuyeres which are about a yard long. The furnace when filled with lighted charcoal is soon raised to its full heat by the alternate working of the bellows and the ore is then sprinkled on from time to time to entail a sufficient quantity of regulas. On the removal of charcoal the surface of slag was cooled with a wisp of wet straw and the solidified cakes of slag was removed in succession, leaving the heavy regulas behind. When it sets it was taken out,pounded and kneaded with cowdung and made into balls. These balls were dried in the sun and then roasted with free access of air in a shallow furance, formed of a ring of slag cakes placed on the edge. The last process of refining consists of treating the powder produced from these roasted balls in the same furnace and in precisely the same manner as was the original ore, the result being that fluid mass of copper was found at the bottom of the furnace which on cooling was removed. It had to be still further refined before it could be made available for ordinary purposes[8].

Crucibles for Gold and Silver Smelting

The archaeological and literary evidence reveals that crucibles in the Indian subcontinent were in regular use for pyrotechnological process for different metals right from the Neolithic period as evidenced from Mehragarh (Baluchistan). Crucibles (Fig.3) are heat resistant containers used for smelting and melting of metals. They are generally made of ordinary clay with admixture of organic material[9-12].

There is no direct evidence of the use of crucibles for smelting and melting gold, although it is one of the earliest metals used by man. A number of crucibles (pieces) have been excavated from Mohenjodaro which is thickly coated with mixture of clay and sand[13]. It could have been used for smelting gold. Although it cannot be ascertained as to the exact metal for which it was used.

From the excavation at Harappa 16 furnaces have been located, but only one jar furnace associated with Stratum II seems to have been used for smelting gold. The furnace consisted of a round pottery jar with its lower part embedded in the earth. It contained ash, and on the inside showed marks of frequent contact with fire. The fuel used seems to have been, at least partly, cowdung cakes of which calcined lumps

Fig. 2 A copper furnace from Singhbhum

Fig. 5a and 5b : An iron smelting furance of the Agarias

Fig. 8 Zinc smelting furnace—Zawarmala

Fig.9 View of the interior of the zinc smelting furnace

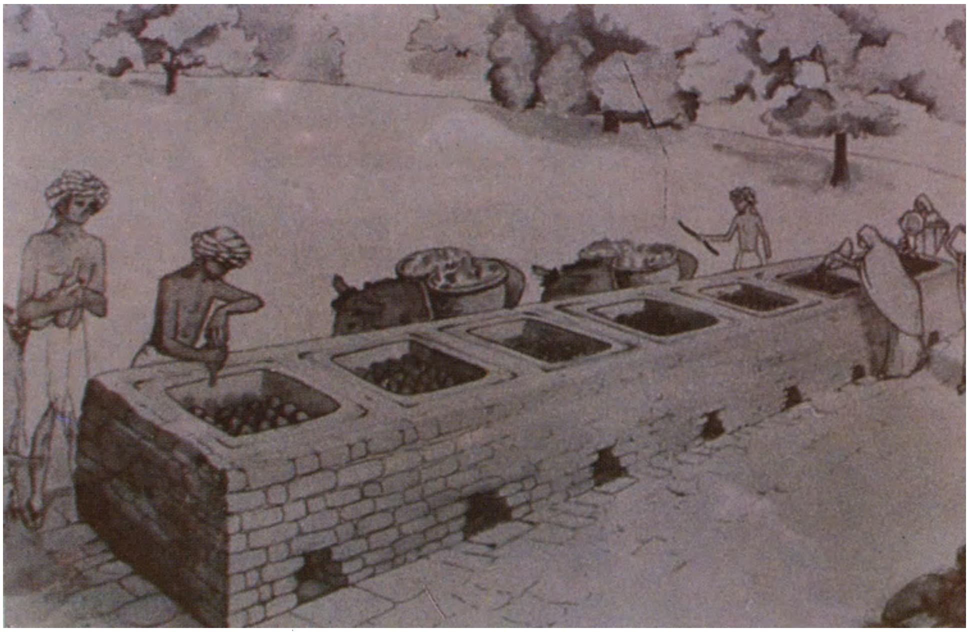

Fig. 10 An artist's view of the working of the process of zinc smelting furnace

containing burnt pieces of straw was recovered in the ashes. This kind of furnace, with charcoal as fuel, is still used by gold and silversmiths in India[14].

From the N.B.P. phase five terracotta crucibles were excavated at Taxila[15]. These crucibles are generally cup shaped vessels with rounded bottom. Some are more splayed at the mouth in comparison to the others. These crucibles are made of coarse sandy clay, grey in colour with evidence of excessive heating and were used for the melting operations for coppper and gold.

Terracotta crucibles belonging to the early historic period have been found from Nagarjunakonda from a goldsmiths's workshop[16]. This means that it was used for smelting gold. Although a number of crucibles from various cultures have been located at different sites, we do not have concrete evidence to prove that it was used for gold.

Literary evidence attests to the use of cupel which is a special type of crucible made of clay with heavy admixture of bone ash. These were used for extraction and purification of silver around 4th century BC. Indian alchemical literature also throws light on the nature and types of crucibles and cupels used in ancient India. The earliest evidence of cupels so far comes from the excavations at Kausambi which have yielded a number of crucibles belonging to the 4th century BC to 4th century AD[17]. Out of these crucibles one had the shape of a boat and was possibly used as a cupel.

On the basis of the use of bone ash in the preparation of crucibles, it can be said that Indians were very much familiar with the cupellation process. Heating silver with lead in a bone crucible i.e., cupel which has a lining of calcium phosphate, practically resembles modern cupellation. This type of cupel has been in use in India since 4th century BC as attested by Kautilya's *Arthaśātra.* This is also corroborated by the high purity of Indian silver coinage.

Although, a number of crucibles have been found at different sites it needs to be analysed to throw light on the purpose for which these crucibles had been used by man during ancient times.

Furnaces for Iron Smelting

It may be apparent from the available details that very little data is available by way of exact designs etc. of iron smelting furnaces. Some reconstruction has been attempted on the basis of archaeological evidence by Hegde[5], Banerjee[18], Gogte[19] and Tripathi[20]. A real breakthrough in understanding technology and more specifically furnace designs comes through a close observation of ethnological data. The pre-industrial working still continues in remote parts of the country even today. Attempt is made to have an idea of earlier furnace designs in some detail.

Remains of furnace structure discovered by Banerjee[18] at Ujjain and Gogte[19] and Deo[21] at Naikund (Fig.4) are similar to the iron smelting furnace that was in use until the forties of the present century by the pre-industrial iron working communities in

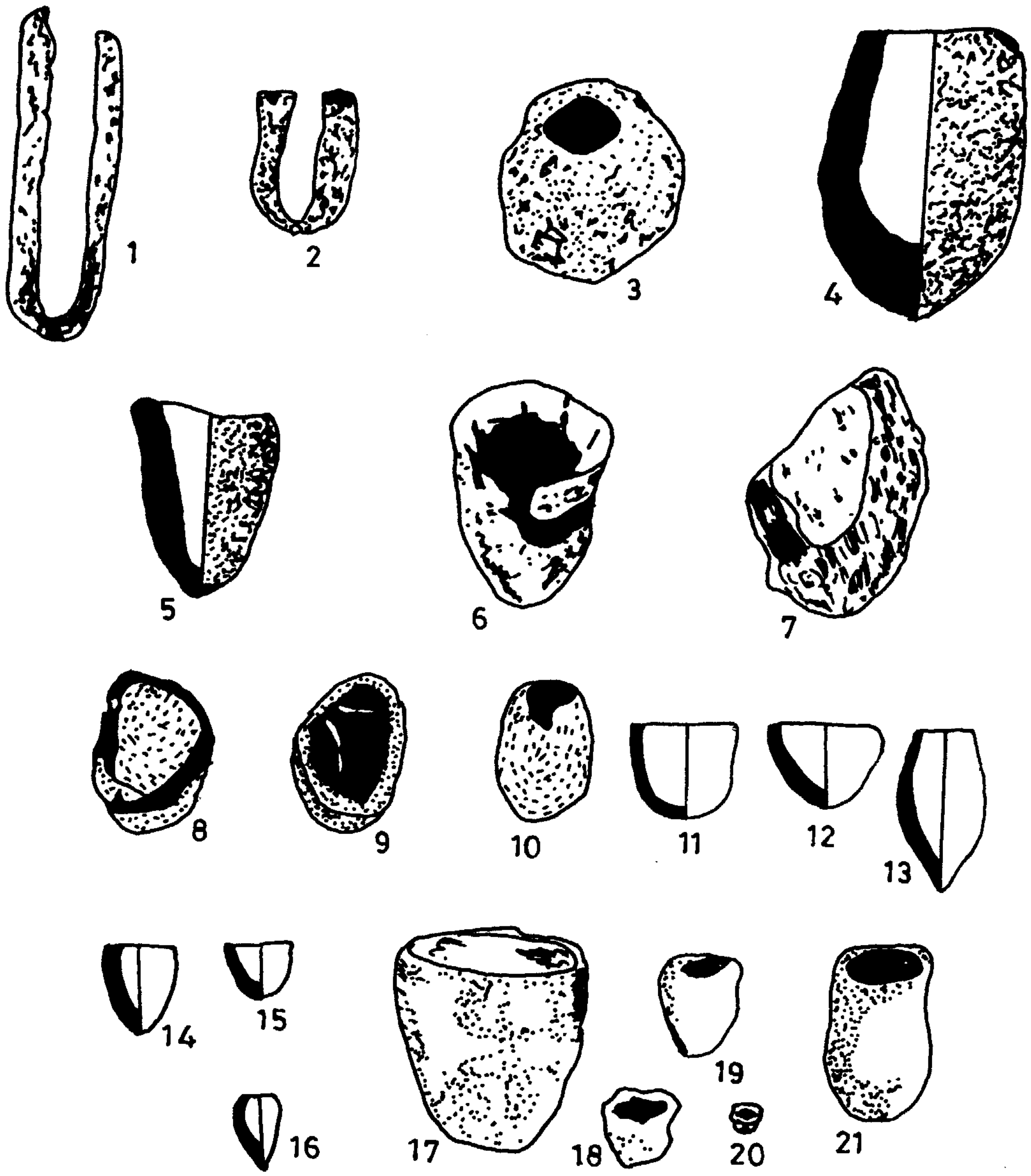

Fig. 3 Crucibles found in different sites in ancient India
1 & 2. Terracota crucibles in Lothal; 3. Stone crucibles from Lothal; 4&5. Terracota crucibles from chalcolithic phase of Ahar; 6&7. Crucibles from N.B.P. phase of Atranjikhera; 8-10. Crucibles from N.B.P. phase of Rajghat; 11-16. Crucibles from N.B.P. phase of Taxila; 17-21. Crucibles from early historic period of Bhokardan .

Central India. In India, iron working has been traced in Chalcolithic milieu from sites of eastern and central India. The earliest furnaces (circa 1100/1000 BC - 800 BC) are generally circular pits. At Pandu Rajar Dhibi (Distt. Burdwan, W. Bengal) a Chalcolithic site, slags and couple of objects of iron have been found with ash pits identified as iron smelting furnaces.

Rarely as stated earlier no complete furnace has come up in any of the excavation sites either because of the destructive technique of iron working or due to the reason of superstructure of the furnace which was the most vulnerable part exposed to natural calamities after the desertion of a site. The fragmentary remains make the task of reconstruction pretty arduous, although archaeometallurgists all over the world have tried to work out the design and shape of furnaces used in the antiquity.

According to Percy there were only three types of furnaces but we find different types of furnaces from Kamarjoda, Single Becha and Jiragora which show that there were more than three types of furnaces used by the primitive smelters. Several kinds of furnace, discernible in different parts of the world, used for iron ore smelting may be classified as given below:

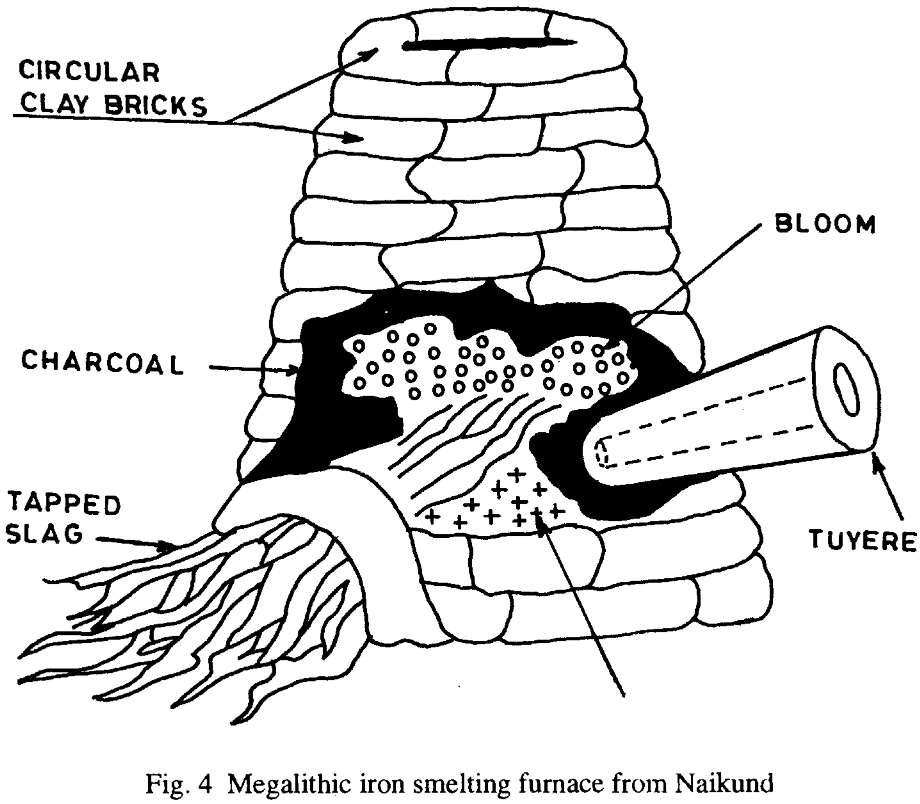

Fig. 4 Megalithic iron smelting furnace from Naikund

(1) Bowl shaped furnace.

(2) Dome shaped furnace.

(3) Shaft furnace: (a) furnace with a channel for slag tapping, (b) slag pit furnace.

Bowl furnace—The Bowl furnaces are the earliest reminiscent of copper working. They are simple pits in earth which must have been covered with fuel mixed with other combustible material as the top layer. It must have had a clay super structure of dome shape[22]. A tuyere was inserted into it and the bloom settled at the bottom resting above the slag. The capacity of smelting in this type of furnace was very small. The furnaces reported from Chalcolithic sites like Pandu-Rajar-Dhibi in Bengal [23] dated to 1045 + 55 BC—950 + 50 BC may be classified under this category.

At Jodhpur in district Jaipur (Rajasthan) pits, slags and ashes were noticed during the Painted Grey Ware Period[24]. A similar evidence is corroborated from Noh in Bharatpur district (Rajasthan). It also has provision for bellows. At Atranjikhera, a pear shaped fire pit was noticed. It contained tapering clay lumps and finished iron tools with a provision of nozzle for bellows. A pair of tongs and iron slag was found nearby. These are some examples of furnaces belonging to the Bowl type furnace.

Dome shaped furnace—The design of the dome shaped furnace is much better than the bowl shaped furnace. In this type of furnace there is provision for tapping slag from the pit. In these furnaces a cylindrical cavity was made in the bank of clay. At the bottom there are two openings facing each other and through one of which the tuyeres were inserted. This design was more suitable for maintaining reducing condition. Inside the furnace, an opening was provided at the top for intermittent feeding of fuel and ore during the process of smelting. According to Cleere[25], in Europe many such examples were found where a tunnel was provided for slag in Europe. This type of furnace could generate temperature up to 1200°C with the help of bellows. Many times pits encountered during excavations could represent these furnaces, like the one noted at Atranjikhera or Noh.

Shaft furnace—With the development of technology, higher furnaces were designed with a shaft, though small in size (25-30 cm in diameter and 35-40 cm high). These furnaces were much more efficient[26-29]. With a few variations this type of furnace remained in use till the advent of British pig iron.

The Naikund furnace of Megalithic Vidarbha[19] and the NBP furnace at Kairadih in Ballia district[30], are shaft type furnaces which fall in this category. The Naikund furnace dated to 700-400 BC had a diameter of 30 cm and height of 25 cm. The base of the furnace was broad and it tapers at its opening on the top. Two tuyeres made of clay with a length of 16 cm and diameter of 2.5 cm was also recovered. These were obviously to pass air into the furnace from the bellows. A model of this furnace has been reconstructed at Deccan college, Pune by Gogte.

Three furnaces positioned side by side are seen at Kairadih[26]. These furnaces are partially underground with their superstructure above the surface. It seems that clay mixed with sand, straw and husk was used for the furnace walls. Though, no tuyere was found in *situ* a charred bamboo was recovered, indicating the use of plastered bamboo for tuyere as practised elsewhere on copper furnaces[5]. The slag that dropped as drippings at the lower level of the pit, have been excavated from these furnaces. The large amount of slag (nearly 30 kg.) indicates a fairly heavy iron working practice, with rows of furnaces being used simultaneously.

The furnaces near Netarhat Plateau[31] and the furnaces worked by the Agaria's in Sarguja district[32] of Mådhya Pradesh are shaft type furnace that are in use even today by tribals (Fig. 5a&5b). The Asur Birjia tribe of Garhar Harup village on Netarhat plateau (near Bishunpur) practising the ancient process of iron making was witnessed by Agrawal[31] as well as the author herself[7]. Here vertical shaft type furnace are used. Lump iron ore and charcoal from *Sal* wood are the only raw materials used. The furnaces have two holes: one for bellows; and the other for tapping the molten metal.

The natives of Ghatgaon near Jashpur of Bastar region used shaft type furnaces made of locally available mud. It is heated with charcoal (of *Sal* wood) and then iron ores is pushed into the furnace from the top along with some more charcoal. The end product is a sintered sponge iron and some liquid slag.

A survey of pre-industrial working was done of the Agaria tribe, in Wadraffnagar and Pratappur block (Fig.6) of Sarguja district (Madhya Pradesh), who even today are smelting iron in shaft type (open shaped) furnaces[33]. The furnace is made with clay mixed with pieces of straw. Before making the furnace a pit of 10 cm in diameter is dug. In this pit, a 2 feet long piece of wood is fixed. Around the pit, a furnace made of clay mixed with straw is made. The thickness of the furnace is 5 inches. at the bottom the diameter is approximately 20-22 inches and at the top it is 16-18 inches. At one side of the furnace at the bottom a 6 inch semicircular hole is made connected to the middle of the pit for tapping iron slag. There is another hole at the bottom connnected to the pit for the use of bellows. In one operation 18-20 kg of charcoal along with 15-18 kg of iron ore is used. The process lasts for about 2 1/2 hours and produce around 5-6 kg of iron.

Slag pit furnaces— The slag pit furnaces are more or less similar in shape to the above type but without a channel. They could be shaped with straight walls or with tapering sides. In these furnaces slag along with the bloom gets deposited at the base in the shape of a block, Generally, the superstructure had to be broken for the retrievel of the bloom[34].

FURNACES FOR ZINC SMELTING

Zinc was and is still extensively used with copper in the production of brass. Before the advent of modern high pressure reduction technology, zinc had to be produced as

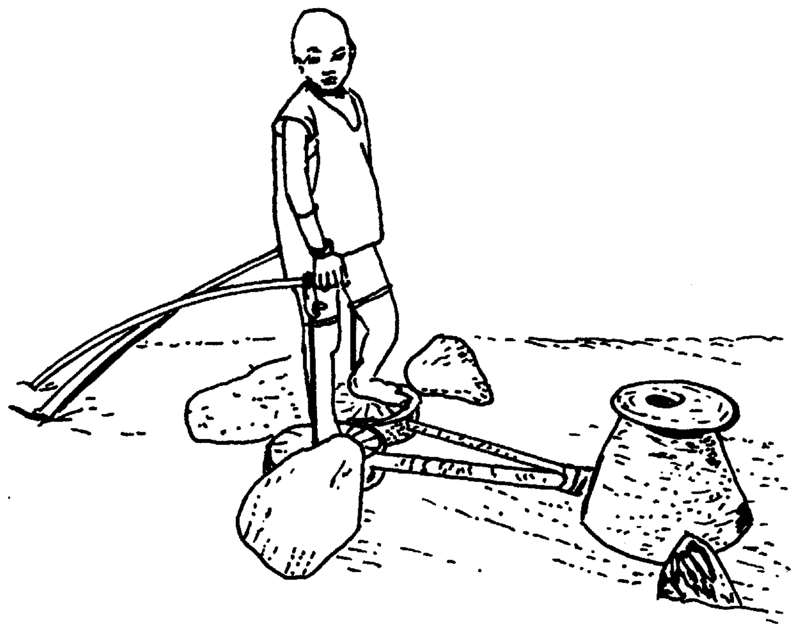

Fig. 6 Iron smelting furnaces of Agaria(after Elwin)

vapour. In an ordinary metal smelting furnace, this vapour would promptly reoxidize to light white, smoky zinc oxide. This light oxide would be carried up to the furnace and get lost, thus the principle of downward distillation of zinc vapour was developed.

Excavation at Zawar in 1983 brought to light two groups of impressive nearly intact structural remains of furnaces which were used for the distillation of zinc in antiquity (Fig. 7,8,9). These intact furnaces, containing their final charge include both large and small retorts each consisting of an array of thirty six retorts (6 x 6) inverted over a perforated grate or support made of ceramic bricks[35]. The condition of the retorts leave no doubt that the fuel was stacked around them and heated directly.

The furnaces at Zawar were in two parts (Fig.10). The bottom of the furnace consists of a zinc vapour condensation chamber and there was a furnace chamber at the top. Both these chambers were separated by a perforated plate. Up above the perforated terracotta plate in the furnace chamber, 36 charged retorts were arranged vertically: it may be presumed that these 36 vessels were placed, one underneath each retort, to collect the condensed zinc vapour. This arrangement of the retorts in the furnace at Zawar is strikingly similar to the arrangement of retorts in the "distillation per descensum"zinc distillation process[36] patented by William Champion in 1748. The retorts found at Zawar were of two principal sizes with a capacity of 750cc or 1200cc.

The *Rasaratnasamuccaya* describes both the retorts and condenser in great detail and are clearly identical to those found at Zawar[37].

The condensation chamber at the bottom of the furnace measures 45cm by 65cm and is 20cm in height The perforated terracotta plate that separates the two chambers is a composite unit made of four equal 35cm segments. It is 4cm thick, well baked and sturdy. Its perforations include circular holes of two sizes. The large ones are 4cm in diameter, each of which are surrounded by a number of smaller holes of 2.5cm diameter. Within the furnace the composite terracotta plate was found to be supported on a ledge in the furnace wall on all four sides and a single solid terracotta pillar placed below the junction of its segments[5].

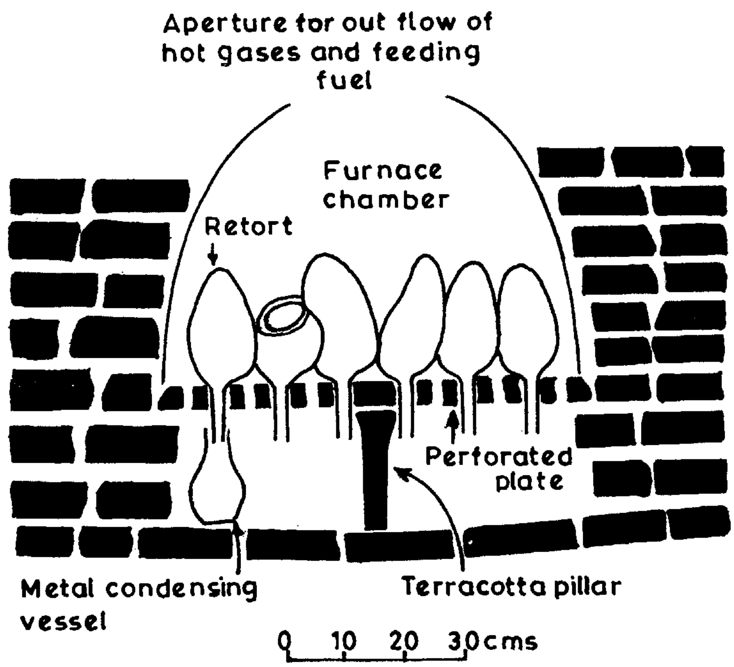

Fig. 7 A cross section of ancient zinc distillation furnace excavated from Zawar

Working of the Furnace

The open retorts had to be filled with calcined ore, charcoal,salt and other reagents. A stick had to be set in the middle of the retorts, and a funnel like condenser fitted of the end and sealed in to place with clay. The constriction and operation of these furnace have been described in detail by Hegde[5] and Craddock[38].

Once the furnace is set on fire, hot gases formed within the furnace rises up and passes out through the top outlet inducing a natural draught of air. Fresh air goes into the furnace through the front opening in the condensation chamber and small holes in the perforated terracotta plate separating the furnace chamber from the condensation chamber. During this time a number of chemical reaction takes place inside the retort.

When the temperature is below 1000°C, PbO and Ag_2O which is present in the ore gets reduced by the carbon and produces liquid Pb-Ag alloy and CO gas.At the same time the reed plug of 1.5cm diameter which was luted to the retort gets charred and burnt and releases CO gas inside the condenser where it expels the air from the chamber and creates a reducing atmosphere. During the same time the liquid alloy of Pb-Ag trickles out through the vacuum created by the burnt reed and gets collected inside the condenser vessel.This happens due to the reduction of ZnO to Zn vapour and CO gas at 1200°C - 1300°C. Due to few actions the Zn vapour and carbon turns into Zn metal when the Zn vapour and carbon is forced through the condenser tube:

(1) The reason for this is that there is a sudden volume expansion which leads to lowering of vapour temperature.
(2) Due to the low temperature in the condenser the Pb-Ag alloy gets chilled.
(3) At the bottom chamber the cooling action of the air draft takes place.

The fire had to be carefully controlled. Zinc melts at 420°C and boils at 906°C so it was crucial to keep the temperature in the condenser between those limits. Zinc oxide reduces to Zinc metal most efficiently at around 1100°C and the clay walls of retorts found at Zawar suggests that this temperature was reached[39].

The metallurgical material from Zawar has contributed significantly to our understanding of the smelting remains. The raw materials have helped us to infer the smelting process and the condition of smelting. The line of evidence and field data help us in getting a picture of how zinc smelting began on a fairly small and dispersed scale but became extremely organised by the 17th - 18th century.

Conclusions

Thus the credit goes to India for developing the complex metallurgy and producing alloys of metals. This speaks legions of the metallurgical skill which the metal workers and artisans of ancient India possessed way back in the early centuries before Christ. Such a good understanding of metallurgical processess as involved in metallurgy of zinc may also be a pointer to the overall expertise which the Indian artisan possessed of the fine behaviour of specific minerals in the antiquity. It was almost at this point of time that the famous Damascus steel was being exported to other parts ofthe world from India, The extraction of zinc may be taken as the culmination of this art (or science).

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