Bulletin of the Historical Metallurgy Group

Refining silver. Agricola Book X

volume 2
number 2
1968

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A treatise on iron ore as found in the bogs and swamps of Norway and the process of turning it into iron and steel

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A prize dissertation which won the 2nd Gold Medal of the Royal Danish Agricultural Society in 1782

Preface

I am not going to describe Norway as a country of immense stretches of mountains filled with wretched and desolate bogs, in contrast to the rich cornfields and vineyards of the warmer countries. I would rather wish that competent persons would examine Norway which indeed has forests and bogs that are natural resources equivalent to those of other fertile countries. But the capacity of my knowledge loses itself in ignorance. The disadvantages on one side and the advantages on the other make it difficult to produce a balanced picture. I will not therefore go beyond my primary purpose of showing that the cultivation of certain natural resources is neglected in Norway.

There are many different metals and ores – iron ore is the poorest but there are rich deposits. What an advantage when wrought into usable iron! Owners of ironworks for their part can ship iron from the country in exchange for goods.

Ore is found in the mountains, bogs, and lakes. Its quality differs and it must be treated in different ways. That in the mountains needs large ironworks, the latter (bog ore) only a bloomery furnace, a smithy furnace, and tools. Bog iron ore is what the countryman should take advantage of. Also, I myself have made many experiments with it, and the Agricultural Society exists to disseminate such knowledge.

1. Concerning some characteristics that usually show that bogs have iron ore in them

When the bogs have a supply of water which either filters through the earth or an efficient brook and overgrown hillocks like mounds, they contain ore and one would expect the following test to be rarely used in vain to find it.

2. Searching for ore and the tools required

Use an iron rod of "Ore-spit" which is a forged piece of iron ½ ell long* and 3-4 lines† diameter and octagonal with a pointed end. The top end should have a loop for the hand. (Plate I, Fig. VI).

The ore spit is used by pushing it into the bog, at the edges where there are trees, and in swamps. If the spit goes down easily there is no ore, but if it is difficult ore is present. Then the spit should be pushed down and turned before being pulled up. The granular ore will stick to the spit and will increase its weight. From the way in which the ore clings, one can judge whether it is satisfactory. There is usually peat and iron pan above the ore, but this is rarely more than 5-6 in thick. All this should first be removed with a fork or a pick and spade. The ore is different in colour from the earth. That which is coarse like sand, or gravel mixed with concretions like hens' eggs (round or flat), is good. That with sharp edges is bad. Both have some reservations.

3. Quality of bog ores – colour, shape etc.

Looking for the ore and by various experiments determining its quality. Judging by colour one can divide them into:

(1) That ore which is of an even black colour right through the layer and mixed with lumps which shine like silver when broken. This is rich in iron and has too little gangue in it and must be mixed with fluxes.

(2) That which is black, coarse, and fine with brown streaks and sharp edges, with splinters, needles, and spirals. This produces brittle iron when cold, i.e. cold-short iron.

(3) Red and yellow ore. Flat pieces of ore in thick and thin layers. A mixture of round and flat, but no sharp-edged concretions. After weathering, this material shows itself to be good and not in need of fluxing. It often contains particles of a grey gangue. This is sand that must be separated before weathering or else it will consume iron and make it brittle and bad.

(4) Dark and light brown mixed produces good iron. By itself (light brown ore) it produces hot-short iron.

(5) Grey and coarse rich ore. By itself it gives a fluid [slag?].

(6) Blue iron ore. Rare, but by itself is good when there is good material above.

(7) Verdigris – Useless. This has too big a copper and pyrite content. It is both cold and hot-short. Usually found by itself, but also often present a little below the red ores. When this happens it occurs in layers and streaks and must be separated or it will ruin the iron.

(8) Bog ore of no particular colour and having sharp-edged granules of copper or pyrite is rare. When broken it shows splinters and is useless.

There are two other general characteristics: (a) all good ores have a base of stone or clay – a soft base is no good; (b) the taste of good ore is sweet and sticky to the teeth. If it has no taste it is good but not rich; if acid it is useless. Also if it has shining granules of silver or lead colour and no sharp edges it is equal to good quality. Coppery and pyritic components must be separated and discarded. If the best ore be found mixed with sand it is very harmful and it must be left to purify itself by being put in a dry flat place after roasting. (Wooden boards 12 ells long by 6 ells wide will do). The ore must be thrown like corn after grinding. The ore will fly furthest and the sand nearest to the thrower. Sand from the moor is not harmful. Bog ore grows in the ground, no doubt due to the water. A constant supply increases it. It is best in exposed bogs facing the sun.

If the ore is flooded, first test it by placing it on a lattice of large stick 3 to 3½ hands apart on which is placed chopped dry wood and more lattices. Place the pieces of ore in a circle so that there is an opening in the centre for air. Make it red-hot, and when it is cold it should be like the rest. Figure V, Plate I describes this hearth for roasting.

If in doubt, put it in a smithing furnace, in the embers at the bottom, and make it shallower under the tuyere. Make the hollow firm and place a flagstone under the tuyere in such a

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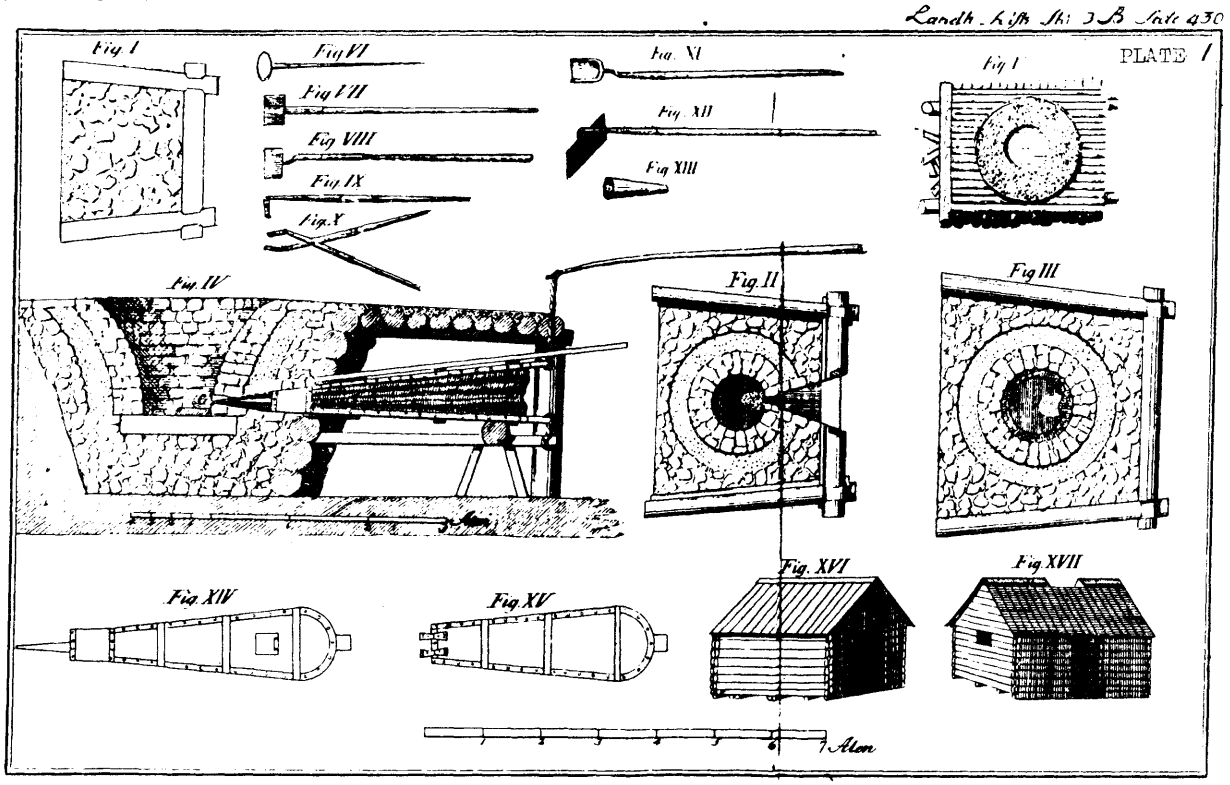
A slightly abridged version of a translation from the Danish kindly made by Niels L. Jensen of the University of East Anglia.

* An ell is about 24 in. (Ed.)

† A line would appear to be about 2 mm, 1/12 in. (Ed.)



way that it has a forward slope. Place around it a wall of small flat stones without clay and widening at the top. The smithy furnace is then filled with coals and lit. When well kindled it is then blown up with bellows. About half of the previously roasted ore is sprinkled fairly evenly on to the charcoal fire around the walls and not in the middle in order to leave a space for the rest of the ore. Keep it at a red heat by blowing gently. Afterwards press the coal gently together. The coal and the crust which has formed from the ore are pushed into the central hole and the ore slowly disappears into the coals. Then more ore is sprinkled on and the process is repeated. When the coals are almost burnt, the crust of the mould is pushed off with a flat bar and blowing is continued until all the coal is used up. The iron bloom lies close to the tuyere and the slag lies all around the sides like molten lead. The iron is taken out with the tongs and cleaned by hammering. This test is definite.

4. Roasting

Remove the ore from the bog and place in heaps. It may lie as long as you like but roasting must be done when it is not freezing. Clean the ore and free it from earth, or you will get slag on smelting. The ore is deposited in the bogs in different ways. The ore layer may be 2-3 in to 2 ells in thickness or more. The layers may be large in circumference. It is not possible to calculate the quantity until excavated. The ore should be roasted as soon as it is ready as one cannot keep interrupting the work of the bloomery furnace. Roasting reduces the water content and the impurities. Look for a place on dry ground, a sandy moor or a mound. First remove the heather and then place trees 10 ells long and 10-13 in thick alongside each other with 8 ells between. Across them place another layer of the same size to form a lattice. Half of these two layers should be dry wood. On the top layer place 10-12 loads of ore $^3/_4$ ell thick, making sure that air gets to the fire. Under the second layer place chopped dry twigs to fill the space. It is easiest to fill with chopped wood before the top layer is put on. When burnt, rake a little with an axe so that the ore falls through the embers (Fig. XII, Plate I). When cold, separate the charcoal from the ore and keep the latter. Plate II, Fig. I, illustrates the technique of roasting.

This method of roasting is the best that I have tried. The ore is now far more easily reduced than the unroasted ore and does not demand such a strong fire. It is difficult to crush the fine ore if it is overburnt. If too little burnt, it is bad and produces steam and more slag. It is certain that unevenly roasted ore gives a lower yield and much care is therefore required.

Further observations.

(1) The sticks can be made smaller or larger according to the amount of ore roasted.

(2) When bog ore is too soft or if it is difficult to roast, wait until it freezes.

(3) If the wood is damp, chop it early so that it has a chance to dry. Two men can roast and dig enough ore in two weeks for 4-5 weeks smelting.

How to preserve the ore. After roasting keep it dry. Build a hut near the furnace, 5-6 ells square. The walls, roof, and floor must be moisture-tight, and 1-1$^1/_2$ ell from the ground. Under these conditions the ore will keep for years. Alternatively, cover with boards in the open. Do not roast too much at any one time. Plate I, Fig. XVI shows the hut.

5. The Furnace

In the choice of place one must,

(1) Keep the forest near.

(2) Be near the bogs.

(3) Keep far from a farm on small slope south or west, on dry sandy gravel or even ground.

It should be built 6-7 ells into the hill and 2$^1/_2$ ells deep. In this way you will avoid the timber on one side as the uppermost edge of the furnace becomes level with the surface of the hill and the work is eased. It is even better if we can use a stream for the bellows. In this way you will save one man's labour. Use raw logs 9-10 in thick for the three walls. The inside of the bottom of the three walls measure 2 ells long. The earthern wall is 2$^1/_2$ ells so you must make the two side walls come together slightly (Plate I, Fig. I).

The walls must slant outwards. The height should be 2$^1/_2$ ells and the inside length 3$^1/_4$ ells on each side. It will be somewhat wider adjoining the earth wall. The total length of the sides will be 8-9 ells long since both ends overlap. At each end fix a pole into the ground and put a platform on both sides with one end on the earth surface (Plate II, Fig. II (A)). Dig a hole 1 ell from the earth (front) end, 1$^1/_4$ ell wide, and 12-14 in high. Fill the inside with stone $^3/_4$ ell deep. Place a flat stone $^1/_4$ ell thick and 1$^1/_2$ ell diameter on top; place it level and in the middle close to the back (wood) wall. This is the bottom stone of the furnace. Around it tightly pack stone and sand. Then erect a circular wall of flat stones and clay around the bottom stone, 10-12 in thick and 22-23 in inside diameter. At the back of the furnace, the wall comes in 2 in from the circle, thereby producing a small protruding

curve (Plate I, Fig. III). When 4 in high, the tuyere arch is then put in horizontally with a spirit level on top of the protrusion in the tuyere wall. Build up the wall to 18 in and slope it slightly outwards. During the erection see that the wall on the tuyere side 3 in from the top is circular with the rest of wall. Start the next (outer) wall of dry stone leaving space between. Fill this with sand and leave an opening coinciding with the tuyere arch the same width as the internal arch and narrowing towards the tuyere; cover with a flat stone at the top to retain the sand. One must not be closer than 8-10 in to the inner wall above the bottom flagstone.

The exterior edge of the tuyere arch stone must be bonded tightly to the outer walls and to the innermost edge of the opening in the outer wall and narrow inwards to the tuyere. Plate I, Fig. IV shows this. When the outer stone wall and the sand filling has reached the height of the innermost wall, start the inner wall again so that it has an internal width of $2\frac{1}{2}$ ells at the top where it is $1\frac{1}{2}$ ell high from the bottom stone. Gradually, as the inner wall is erected, build up the outer wall and fill in the sand as well. The outer wall must be a little lower so that, when the sand filling has been covered with flat stones, these stones slope outwards. The platform must also be slanting away on all sides. Then cover it with earth and turf after filling the space between the wall and the hillside. Line the inside of the furnace with good clay so that it stands neat and stays firm. Make a loose furnace bottom from clay 10 in x 11 in or 12 in, and 1 in thick, and lay it on the bottom stone against the tuyere side of the wall (Plate II, Fig. II (C)). On this the iron is collected and the slag flows downwards around the side. When the loose bottom breaks, replace it.

Tools: (1, 2) Two identical bellows. Bottom wood – 2 in thick; boards $3\frac{1}{4}$ ell x 9-10 in wide at neck where the hinges are, and 22-23 in wide at the back and there rounded. The bottom is divided into three by pieces of wood. In the middle of the end space is the 8 in square hole for the valve. The neck is $1\frac{1}{2}$ ells long. The pipe is $\frac{3}{4}$ ell long x 3 in wide, made of iron welded to form a taper. Both pipes should be parallel, since it is harmful if the air is blown crosswise into the tuyere of the furnace. Therefore, both pipes must have a twist, right to right and left to left, so that the ends of both pipes are parallel to each other and blow the air straight away from them. The hole must be narrow at the front and wider at the back. Each pipe reaches 6 in into the neck and is fastened by driving wedges at both sides. The remaining 12 in will project (Fig. XIV, Plate I). The upper wooden board is made from the same wood and is like the bottom except that it will be $\frac{1}{2}$ ell shorter (Fig. XV, Plate I). It should be made of well tanned horse leather, oiled. The height when filled should be 12-13 in for ease of treading. A trestle is made for the bellows and fired at a suitable height. The bellows should be clear of the tuyere by 2-3 in and firmly fixed. Spruce or fir rods 15 ells long by 3 in thick are used as springs. A bench is placed loosely on the ground about the middle of the rods. The bellows are foot-operated with rods for returning them. They are adjusted by moving the bench upon which they rest, back and forward (Plate II, Fig. II, F. G. H. I. K.). There should be a roof over the bellows (E, Fig. II, Plate II).

(3) Rake spade. Flat iron with short square shaft of iron with wooden shaft 4-5 ells long inserted (Plate I, Fig. VIII). The blast spade is $1\frac{1}{2}$ in thick with a heavy iron shaft and a bigger socket than the rake spade (Plate I, Fig. VIII).

(4) A square iron hook, pointed and bent near the end with iron shaft and socket (Plate I, Fig. IX).

(5) Tongs of iron as used in smithies but longer. Wooden shafts (Fig. X).

(6) Shovel, 10 in x 8 in of bent iron plate. Iron shaft and socket $\frac{3}{4}$ ell and shaft bent at right-angles near blade with wooden shaft (Plate I, Fig. XI).

(7) The tuyere is made from iron 1 in thick x 3 in flattened out and thinned to give a width of 15-16 in at one end and 8 in long. The ends are bent together and welded so that it is 1 in diameter internally at the narrow end and elliptical at the wide end (Plate I, Fig. XIII).

(8) Ore iron rake. Blade, iron, 4-5 x 15 in. Very thin at one end of edge; iron socket and wood shaft. Slight bend near blade (Plate I, Fig. XII).

(9) To the tools also belongs the apparatus by which the bellows may be water-driven. This requires local knowledge. The wood is not important; it is all local at no cost.

If there is found about the furnace dry tails (fir trees not rotted), these are most serviceable for smelting. When the dry tails have been felled they may be carted uncut to the furnace and the three men doing the smelting can chop it. If men are lacking, chop it into fathoms in the spring since dry wood is necessary. The consumption of wood depends on the ore. One quarter of the wood must be $1\frac{3}{4}$ ells long, the rest $1\frac{1}{4}$ long. Chopped so small as to be 2 in thick either way. If not too far away take trees uncut and chop at furnace, as chips are very useful. The use of charcoal should ease the work considerably, but since a lot of prepared charcoal is needed and since burning costs a lot and the furnace will not bear such a heat, would turn iron to steel and would have to stand idle to cool. So there is no advantage unless bellows are driven by water power as one man could then do the smelting or make the charcoal.

6. The mixing of various sorts of bog ore and the method of smelting roasted ore to raw iron

In Section 3 the types that need blending are described. Rules for blending – This should take place on the smelting site. In order to be brief I will refer to the numbers given to the ores in Section 3. The coarse ores are rich and dry but the fine ores are lean and wet (fluid). The coarse ores are easier to smelt.

Coarse rich dry ores (1) need to be mixed with fine and fluid ore (3). Red and yellow are the most suitable for this; hard iron needs only one-third. If ductile irons are wanted, a different proportion has to be used.

The ore is mixed at the furnace and the "wet" ore used as a flux. No. 2 gives cold-short iron and No. 4 gives hot-short iron; if these are mixed 50/50 they produce good iron. For cold-short iron first add half of the cold-short ore, then the hot-short, and finally the rest of the cold-short ore. No. 4 may also be blended with No. 3. The mixing is done as described for No. 2. No. 5 is similar to No. 1 and is mixed with red or yellow ore. No. 6 alone is too coarse and dry, therefore add it to No. 3; this also fluxes other coarser ores. Fluid ores are more or less fine.

Rich ore by itself is difficult to smelt and it is impossible to resmelt raw iron in order to mix the iron from two different types of ore together. Rich ores need very strong heat and tend to give steel, and strong heat gives lower yields. Therefore, mix fine and fluid ore to dissolve coarse and dry ore. To obtain a mixed hard and soft iron by resmelting would be harmful; the hard would melt and burn before the soft has been dissolved. One notices that converting a hard raw iron to steel gives a high loss; use instead a softer raw iron. Mixing ores before smelting is the only way that is any good; they cannot be mixed in the furnace.

When ore has been roasted and before it is smelted, crush it to a sand grade. Take one fathom of chopped wood; one quarter of this wood is placed in the furnace diagonally. In the middle make a large opening for air. The wood is kindled at once and the rest of the wood is placed in the furnace until it is full. Make it more open at the middle than at the sides. The long logs will reach above the furnace and will be longer than the short logs, so some of the latter are placed around the sides of the long logs. Keep open so as to maintain the fire which must burn the wood to charcoal. Fill up with wood $1\frac{1}{2}$ ells above the furnace and sloping outwards. After the fire is lit, while putting in the long logs you need two men to put the rest of the wood into the furnace quickly before it is too late. When holes appear between the logs, fill them. There must be no ashes – all must go only to charcoal. One can use the coarse chips to fill the holes. When the wood is all coaled, press it together and then place a firebrand on top of coals here and there. Sprinkle 12 parts of granulated ore gently on top of the charcoal fire, leaving an opening in the middle for ore. When the iron ore is red-hot, rake the coal and iron ore towards the middle so that it forms a mound, after which add another 8 parts of fine ore round the periphery. When the ore has turned red, one man starts the bellows gently, the coals start to be consumed, and a hole is produced. Press coal and ore gently into this hole so that it is full. The man now steps on the bel-

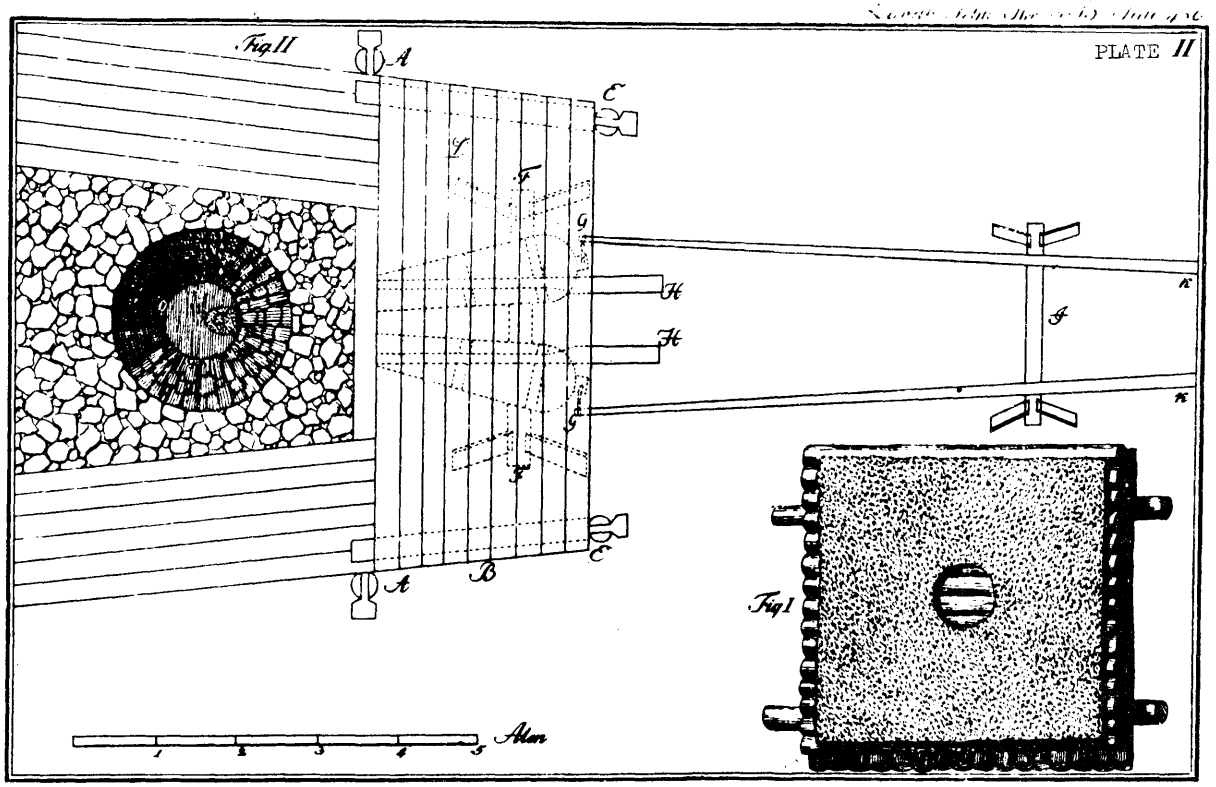
lows and blows strongly. When another hole has been made, one man takes the rake-spade and puts it into the coal near the furnace wall, first at the tuyere side, and by this means coal and ore will be pushed into the hole. As soon as it clears and drops into the middle, more coal and ore are pushed into it from the other side of the furnace. One proceeds thus every time until one has pushed the material from all four sides into the middle, making a mound. When it is half burnt, sprinkle ore (four parts) for the third and last time.

Now blow gently until the fire clears in the middle, and with the back of the spade coal and ore are pushed in from all four sides. Now blow strongly and when the hole clears in the middle shovel in more ore. Keep doing this. Blow gently and remove the coals from the tuyere and then push off the sleeve of ore from the tuyere and put it on top of the bloom. The coal from the other side of the furnace and the ore from the walls should also be put on to the bloom after the coal has been taken from the top of the sides. The bloom is now turned with the aid of the furnace hook so that it can be handled and taken up from the furnace with tongs. With a big stone place the bloom on edge and cut it almost into two parts. After the furnace is cleaned out of slag and the remaining coal with the tools, more wood is placed in it and a new smelt starts as soon as possible. Three men can do 5-6 smelts a day, and when wood is ready two men can do 5 smelts. Do not use too much ore at one time, for a good deal of ore will be wasted by falling into the slag and thus producing bad iron from good ore. Judge the quality from the shape of the bloom. When the iron is ductile, the bloom is thin and flake-like; when hard, it is thick and porous. Hardness is due to a mistake in the mixture. Holes are due to a mistake in the smelting. Iron will become more ductile by being remelted.

The first day will be difficult but keep the furnace going. Using charcoal instead of wood use 3 to 3½ barrels of coal. On the bottom of the furnace place small dry wooden logs to make the coal burn quicker. Put half the coal into the furnace and place small dry sticks with it. Otherwise the heat becomes too strong and steel will be made. About half the ore is sprinkled on as previously, then blow gently, and then faster until a hole appears in the middle, when coal and ore must be pushed into it. When the fire has cleared a hole a second time, add half a barrel of coal and then more ore (see previous description). Continue until all the coal and ore have been used. After this the treatment of the ore sleeve and the bloom is as before. When charcoal and water-powered bellows are used, use slow and even blowing or else steel will be produced.

7. How roasted ore is smelted to make steel

First, it is necessary for the furnace to have been in use for four to five days making iron. Try making steel towards evening after having made iron during the day. Get a hot furnace, then as fast as possible clear the furnace of all slag. Throw dry sand under the tuyere, otherwise during steel smelting the strong heat will dissolve the loose bottom. Place and kindle the dry wood as with iron, but use more charcoal. Move the firebrands as close as possible to the wall. After, when the charcoal is packed hard, eight parts of ore are sprinkled on to it. Then four to five parts when the charcoal is red. Take a piece of iron like a spit but quite round in section and pointed; place the pointed end in the tuyere so that the thick end protrudes into the furnace. Blow hard until the charcoal and iron ore are evenly heated and then remove the iron from the tuyere and blow hard and fast. The fire cuts a hole in the charcoal and ore in the middle of the furnace, so then press the charge as before into the hole. Do not shovel charcoal and ore into the hole from both sides. This goes on until half the charcoal is consumed. Then the coal and ore are pushed to the middle from all sides so that it will be the same height all round, and then put two parts of ore around the sides. A strong blast is needed now. The rest follows as with iron. Throw in a handful of dry sand every time the charcoal and ore are put in, to make the slag fluid. Ore and slag must be pushed off the tuyere into the middle. Take care that smelted ore is not deposited above the tuyere so that it blocks the flow of air. If it does, try to push it up from below and flux with sand. All smelted iron from the vicinity of the tuyere must be chopped off the steel bloom when it is removed from the furnace. Continue to shovel the charge to the middle as long as any charcoal is left. When all the charcoal has been burned, one removes the bloom afloat in molten slag carefully so as not to break it. Sprinkle dry sand on it, then hammer and cut it with an axe into narrow pieces or bars. It must be forged in a clean forge with a strong charcoal fire and, when hot enough for welding, taken out and turned and cooled off a little and then put into the fire until whitish-hot. One blows constantly, then stops for 6-8 minutes so that the heat will purify the steel, leaving little holes in it. Repeat this operation and then take the bloom out, sand it, and hammer and compact it. The steel will not stand too long at this heat, so that the whole product cannot be heated and purified at one and the same time. Take it bar by bar as individually cut. If it is wanted all in one piece, weld it together at the end of the process. Such a smelt in which fifteen parts ore give eighteen pounds of steel is suitable for axes. If more steel is to be smelted, as soon as the steel



bloom is removed, clean out the slag and start at once. If iron is required, make a new loose bottom, in which case the furnace may stand idle and get cold.

8. Working up the iron

To remove slag to make it weldable etc. Experts find it difficult to judge whether the best iron has been made or not. Use the smithing furnace, but the hole must not be so deep. Air is supplied from the tuyere as before. The fire is now 11-12 in high and 12 in wide. The charcoal is compacted, flat, and level at the bottom. The bellows and tuyere are placed so that air has a straight passage. The forge is filled with coal and, when well aglow, the bloom or the total quantity of iron is placed upon it. When sparkling, grip with tongs and keep near the air hole until melted. Add dry sand and granulated (smithy) slag to it. The slag that falls from the iron when it is cut is most suitable. When the bloom is finished and the slag has melted and fallen into the bottom, the iron becomes a flat lump. It is removed with tongs and placed on a stone and cut into pieces. Then it is finished. Part is lost in this process but the addition of the slag minimises this loss. It is advantageous to make as many forgings as possible at one time. Build a hut with a hammer and bellows driven by water.

9. Converting iron into steel

To convert iron into steel, use a smithy forge. It will take a full day and must be hot. Clean out and remove any previously smithed iron. Make a space 2 in deep under the tuyere so that the air does not touch the steel when it has fallen into the forge during melting. Fill high with charcoal over the edges. Take forged iron, cut it into two pieces, heat and weld them, and then hammer them into a square iron bar. Place it on the charcoal and, when hot, keep charcoal close to the hole of the tuyere so that air does not touch the iron. Make a strong fire and blow. The iron will fall into the forge and become steel. During melting, throw sand on to the fire two or three times until the steel has formed. Remove and weld with the hammer and then cut it into small bars, which should be hammered out and welded where they are porous. The yield will be half the weight of iron from which it came. The furnace bellows are best for re-melting.

Conclusion

Profit and labour costs. Smelting 24 parts of ore gives 36 lb of raw iron (500 gr = 1 lb.), but mediocre iron ore gives only 30 lb. Output should be 150 lb per day. The cutting of timber almost stopped smelting 60 years ago, but I have now revived it. There are many advantages; even if costs rise by one-third, there are still great advantages to be had. The work can be done in winter when the people can do nothing else. Three men can do 5 smelts per day. [Probably in 12 hours; Ed].

Acknowledgment

The translation was prepared from a microfilm copy of the original in the Danish National Library, Copenhagen, which was provided through the kindness of Olfert Voss.