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Enquiries relating to the contents should be addressed to the Honorary Editor: Professor Ronald Tylecote, Yew Tree House, East Hanney near Wantage, Oxford OX12 0HT.

Enquiries concerning subscriptions to the Society, back copies and publications sold by the Society, should be sent to Ian Standing, Rock House, Bowens Hill, Coleford, Gloucestershire GL16 8DH.

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The illustration on the Cover

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The production of wrought iron in Finery Hearths
Part 1: The Finery process and its development

Alex den Ouden

Introduction
When the bloomery was gradually superseded by the blast furnace, the iron produced could no longer be directly used in smithies. As this was at the time a very important application of iron, a solution had to be found.

The brittleness preventing the forging of blast furnace iron, called pig iron, is caused by its high carbon contents. This carbon has to be almost fully removed from pig iron to obtain wrought iron that is equivalent to the original bloomery iron. The process developed for this purpose, fining, was based on a mixture of a bloomery and the Catalan forge, already known at that time. In these iron ore was smelted to obtain a ball of almost pure iron, intermixed with slag. Charcoal here combined the roles of fuel – to obtain sufficient heat – and *reducing* agent – transforming the iron oxides of the ore to iron.

In the finery iron has to be stripped of surplus carbon, which is done by *oxidizing* the latter to carbon monoxide. Still, the same type of hearth could be used, by altering its mode of operation.

The fining process in a charcoal hearth[136]
The hearth proper of a charcoal fining hearth is formed by a well which is clad with cast iron plates. In and on top of the well a charcoal fire is built. At one side – in the Swedish Lancashire hearth at two sides – a tuyere, slightly down-tilted, is inserted directly above the iron side or tuyere plate.

Two zones can be distinguished in the hearth. Just in front of and above the tuyere lies the hottest zone; just below the tuyere a colder, oxidizing zone. Lower in the hearth the temperature decreases further.

At the beginning of the fining process pig iron is brought into the first, hottest, zone. It starts to melt, forming droplets of liquid pig iron. These fall through the charcoal and slag of the second, oxidizing zone. During this, the following processes take place:

- most of the Si present in the iron is oxidized into SiO_2;
- a part of Mn – if present – is oxidized into MnO;
- Fe is oxidized into FeO;
- a $FeO.MnO.SiO_2$ or $2FeO.SiO_2$ slag is formed;
- a small part of C is oxidized into CO;
- any graphitic C is transferred into combined C.

At the bottom of the hearth the iron droplets gather into lumps. These are semi-solid, since the temperature in that part of the hearth is lower and the melting point of the iron is increased by diminished C and Si. In the hearth the new-formed slag combines with slag intentionally left from previous fining. The described processes together form the so-called *Stage 1*, the refining or melting stage.

The finer now stirs and coalesces the lumps at the hearth bottom into a loup and lifts this in front of the tuyere. The combination of these two actions is called rabbling. In front of the tuyere the metal melts again and the droplets again fall through the slag in the oxidizing zone below the tuyere. Now the following processes take place:

$$C + MnO \longrightarrow CO\uparrow + Mn$$
$$C + FeO \longrightarrow CO\uparrow + Fe$$
$$Mn + O \longrightarrow MnO$$
$$Fe + O \longrightarrow FeO$$

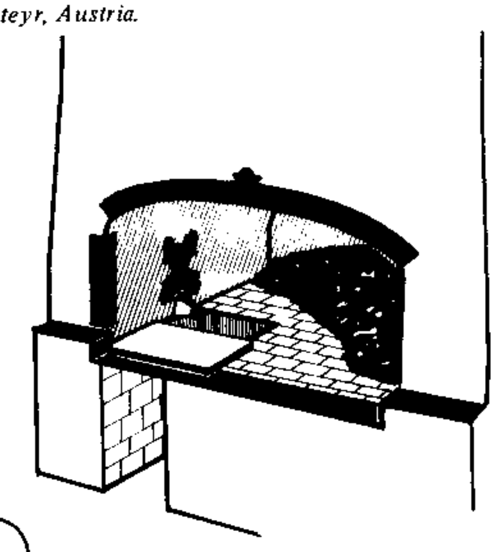
C is thus decreased with blast, via the slag. Rabbling is repeated a number of times. At each passage C is further decreased and the melting point accordingly rises. Finally the melting point becomes so high that melting down any part of the loup is no longer possible. Then blast is temporarily increased and a last melting and oxidation occurs. This, the repeated rabbling and melting, is the so-called *Stage 2*, the fining or rabbling stage.

Types of Finery Processes

The German forge

The construction of a German hearth resembles – in general terms – that of an ordinary blacksmith's hearth, see Figure 1. The sole is enclosed by three walls that carry the chimney. These parts are stone-or brick-built, usually with a cast iron lintel or with a brick vault. Thermal stresses are taken up by tie bars. The sole is covered in tiles. The hearth proper is let into the sole. It is a square well, covered on four sides and the bottom with cast iron plates. It lies adjacent to one of the side walls of the hearth. Through this wall, a tuyere is inserted. The fore (or front) plate of the hearth proper stands free from the sole. There are several holes in it[1], for slag tapping. On top of the front plate lies a work plate, also of cast iron.

German Hearth (Stuckofen-era) – General View, Steyr, Austria.



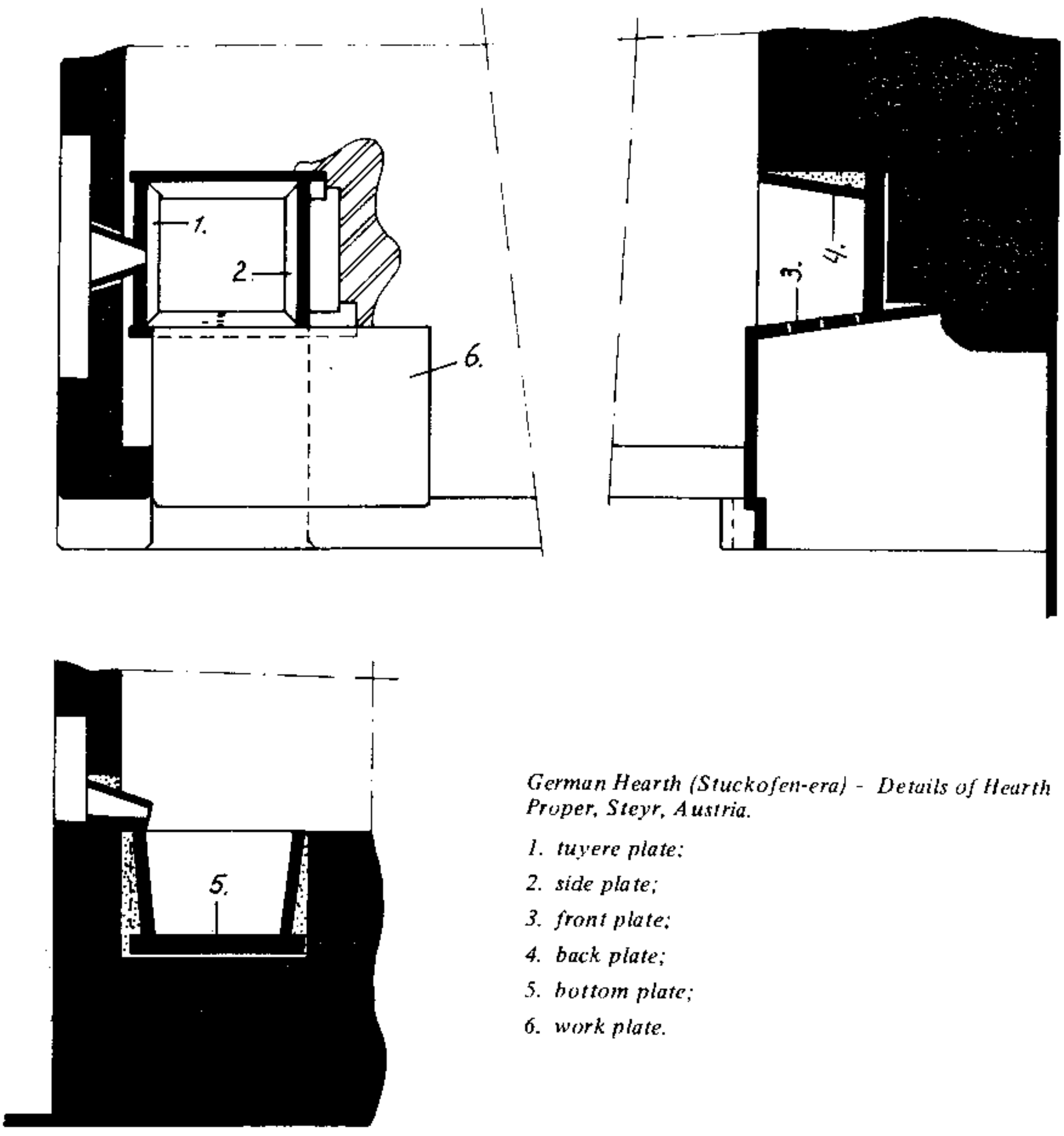
1

In the early German forges in Austria and Germany, 'Massl' and "Kraglach" from the "Stücköfen"[2] were used as raw material. The hearth proper used in fining and fagotting these, was quite deep, e.g. a depth of 0.3 m at a length and width of 0.4 m each, see Figure 2. The four side plates were set in loam, all tilted outwards. The bottom plate was not cooled. These early hearths were blown with two sets of single bellows. The mouth-pieces of these were inserted into a tuiron[3], set in loam. The fluctuations in air flow caused by the use of single bellows were considered to be advantageous to the iron quality[4]. The wall containing the tuiron was covered with thinner cast iron plates to protect the brick- or stone-work.

When the "Stücköfen" were replaced by blast furnaces around 1750, at first "Deutschhammer" were built[5]. These combined a blast furnace with two German hearths[6] side-to-side under one roof. From about 1775 however, blast furnaces and fineries generally were built as separate units, due to prevailing scarcity of charcoal.

The hearth of this independent finery – that was working pig iron exclusively – differs from the earlier German hearth in a number of ways, see Figure 3. The hearth sole is much lower, about 0.3m instead of 0.8m. The hearth has two walls instead of three. The chimney is carried on two cast iron lintels resting at the open corner on a cast iron, brick or stone pillar. The hearth proper is larger with a length and a width of 0.5 m[7]. The work plate is much narrower, almost a sill.

In Sweden, in the 1830s many improvements were made to the German hearth. In 1833 e.g., in Forsbacka, blast was heated in a separate wood fired stove[8]. Soon afterwards, waste gases from the German hearth itself were used for that purpose. A cast iron U-tube was laid across the chimney, see Figure 4[9]. Another improvement was to preheat pig iron before fining. In 1834, Morell used waste gases for this purpose, too[10]. The chimney was provided with a false bottom and a small door giving entrance to this (see Figure 4). Pigs of iron were piled on this bottom prior to fini



German Hearth (Stuckofen-era) - Details of Hearth Proper, Steyr, Austria.

1. *tuyere plate;*
2. *side plate;*
3. *front plate;*
4. *back plate;*
5. *bottom plate;*
6. *work plate.*

(2)

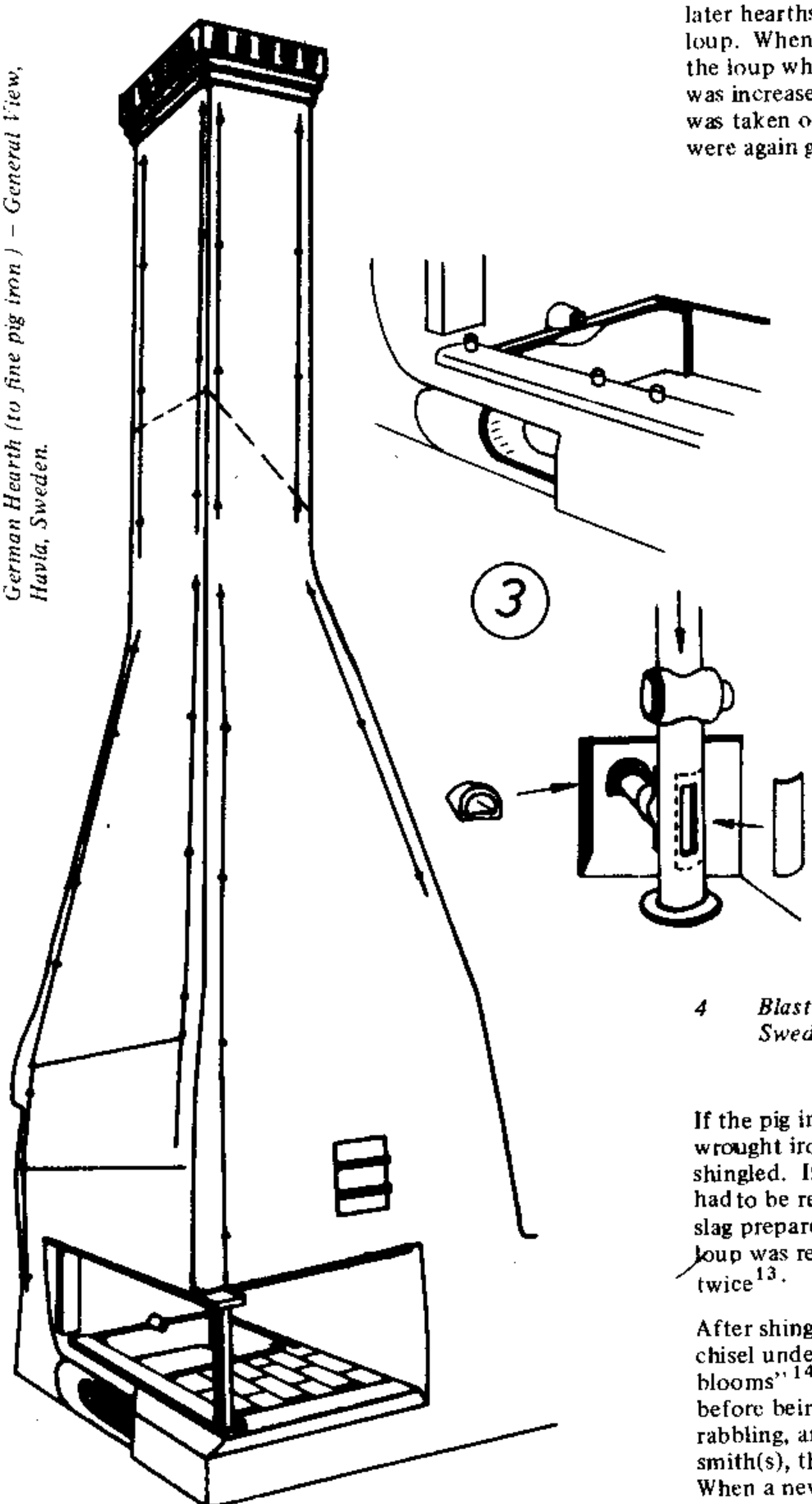
Of course, the hearth is not the only object in a German forge. At least a hammer and a set of bellows or a blowing engine were needed . A very small scale German forge of 1775 is shown in Figure 5. It has one tail helve hammer and a grinding wheel, necessary for regular regrinding of the hammerhead. The German hearth is blown by bellows. A small hearth for general repair and forging work has hand operated bellows. The anvil in front of the German hearth was used to remove (with hand hammers) charcoal and slag from the finished loup prior to consolidating this under the waterhammer.

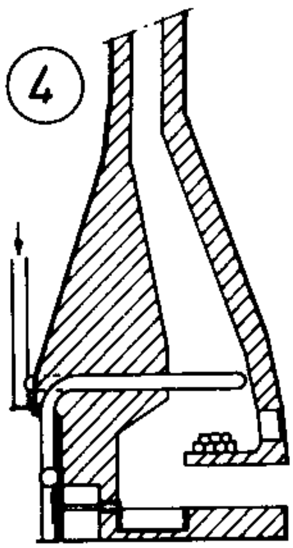
A larger scale German forge of 1808 is shown in Figure 6. This has a tilt of three tail helves, a grinding wheel and a very peculiar semi-circular hearth with just one (back) wall containing the tuyere [11]. This hearth is blown with cold air by a Widholm blowing engine[12] with two bellows.

These two examples show tail helve hammers, but of course the more powerful, though less versatile, belly helve hammers were employed as well.

Pig iron was fed into the German hearth batchwise, in small pigs. As soon as the pig iron was covered with charcoal, blast was turned on, and the fining process started. During rabbling, the smith used the work plate (or the sill, in later hearths) to support his rabbling bar when lifting the loup. When finally molten iron would no longer exude from the loup when it was lifted in front of the tuyere, the blast was increased to obtain a last melting down. Then the blast was taken off and the fined lumps at the bottom of the hearth were again gathered into a loup. This was taken out by tongs.

German Hearth (to fine pig iron) – General View, Havla, Sweden.





4 *Blast Heating and Pig Preheating Arrangements in A Swedish German Hearth.*

If the pig iron was not very impure, or if no very high quality wrought iron was wanted, the loup would then be cleaned and shingled. If a higher quality was required, the fining process had to be repeated. First the old slag was tapped and a new slag prepared (e.g. with sand and hammer scale). Then the loup was remelted and fined in this fresh fire, once or even twice[13].

After shingling the bloom was divided by means of a hand-held chisel under the shingling hammer, usually into 4 – 7 "half-blooms"[14]. These were reheated in the German hearth before being hammered out into bar. Since both fining, ie rabbling, and bar drawing were performed by the same smith(s), the division of the necessary tasks had to be strict. When a new batch of pig iron was melting down, no rabbling took place [15] and the smith could draw out half-blooms of

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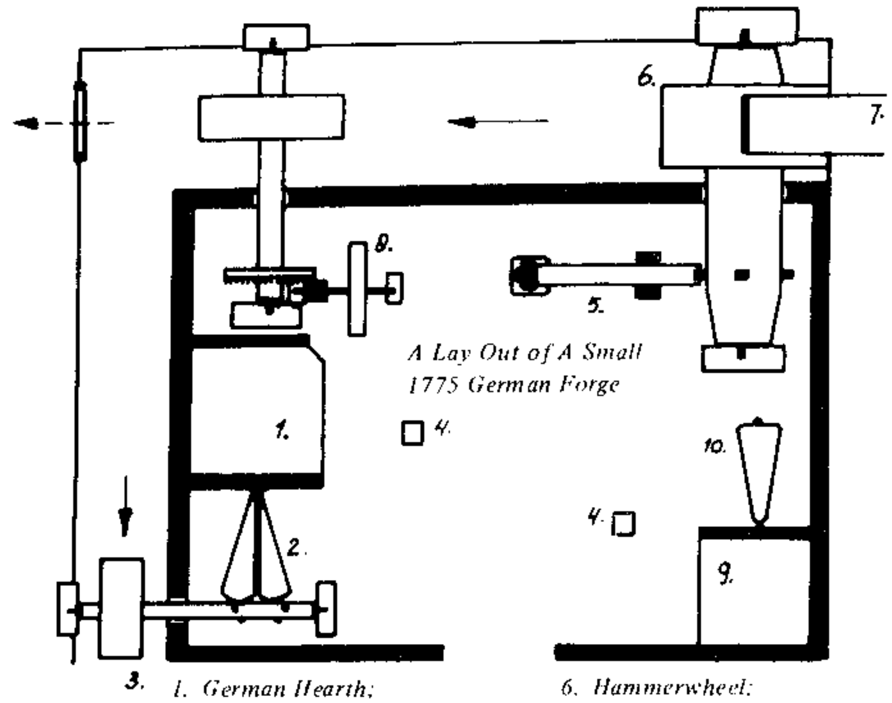
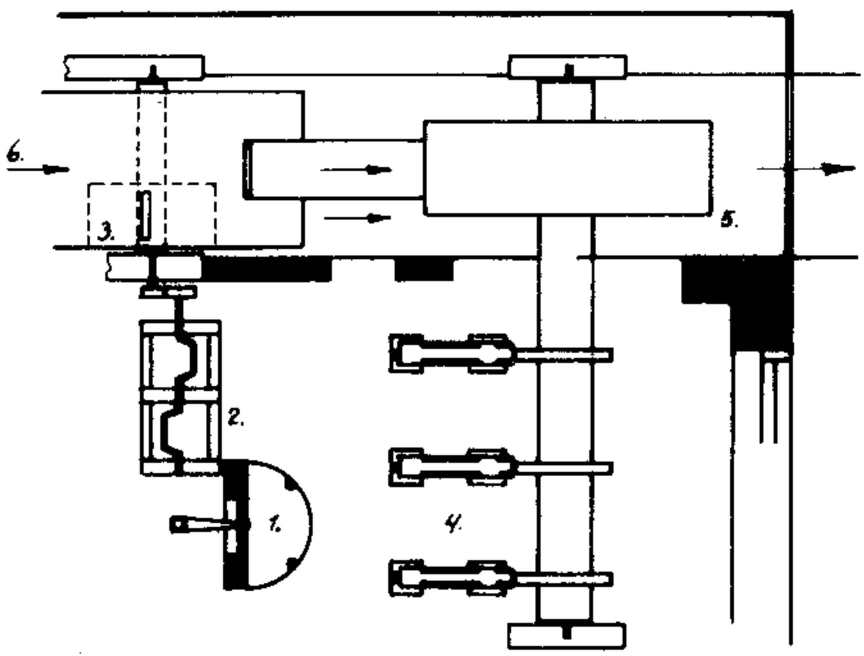


1. German Hearth;
2. Bellows;
3. Bellows Waterwheel;
4. Anvils;
5. Tail Helve Hammer;
6. Hammerwheel;
7. Leat;
8. Grinding Wheel;
9. Auxiliary Hearth;
10. Hand-operated Bellows.

6



6 A Lay Out of A Larger 1808 German Forge:

1. German Hearth;
2. Widholm Blowing Engine;
3. Blower Waterwheel;
4. Tilt;
5. Hammerwheel;
6. Leat.

a previous batch. Drawing had to be in two passes. First a half bar with butt was made, and then, after a (second) reheating, now of the butt, the bar was finished [16]. During rabbling, no drawing could take place.

Many variations of this procedure were in existence. One was the "Osemund-Schmiede"[17]. In this forge very tough and homogeneous wrought iron was made, mainly for wire drawing. The hearth dimensions and the inclination of the tuyere slightly differed from those of an ordinary German hearth. The fined iron lumps were not gathered into a loup to be lifted in front of the tuyere, but wound on a rod and rotated in front of the tuyere to melt down again. When fining was finished, the iron was again wound on the rod to be hammered. To increase toughness and homogeneity the blooms were divided into small half-blooms and these were fagotted. The quality realised was high, but so was the charcoal consumption. Still, the last Osemund forge in Germany, that at Bruninghausen, was laid down only in 1858, ie some time after the introduction of the puddling process.

A German hearth was operated by three men[18], a smith, an apprentice and a charcoal hand. Smith and apprentice performed in rotation the tasks of rabbling plus drawing or fetching pig iron, (if necessary) breaking this, controlling the waterhammer during shingling or drawing, weighing iron and all other tasks except carriage of charcoal.

It took about 4 hours to fine one batch of 100 kg of pig iron into 85 kg of half-blooms [19]. These could be drawn into about 72 kg of bar. The specific charcoal consumption was:

cold blast, cold pig:	about 200 hl/ton bar [20]
hot blast, heated pig:	about 100 hl/ton bar [21]

Each shift at one hearth could produce up to 45 tons of bar iron a year. Usually a hearth was worked 24 hours a day (6 days a week) and its maximum production then was 135 tons of bar iron a year.

The Walloon forge

In the Walloon forge two separate hearths are used in the production of wrought iron bar. Pig iron is fined in a finery hearth; reheating of blooms takes place in a chafery hearth. The finery hearth – in general terms resembles a pig iron German hearth, compare the Figures 3, 7 and 8. Both types of hearth have a low brick or stone hearth sole with the hearth proper clad in cast iron plates; two walls and a pillar carrying the chimney. There are several differences, though.

The most striking difference is related to the pig iron supply. In a Walloon finery hearth iron is fed in the form of "gueuses" or sows, instead of batchwise in pigs. A normal sow would weigh about 500 kg. It has a length of about 4 m and a half-circular section. It was laid – face down – on wooden rollers (tree trunks). These had been drilled cross-wise with two holes perpendicular to their axis (see Figure 14). With a hand-spoke, the roller was slowly rotated to feed the sow gradually into the finery hearth. The end of the sow was thus pushed into the burning mound of charcoal in front of the tuyere, to melt down continuously. In this way 35 – 100 kg of pig iron [22] were melted for each fining.

In most countries using the Walloon forge [23], the sow was fed from the rear of the finery hearth, necessitating a "pig hole" in the back wall, see the Figures 7-9. The hearth sole in front of the pig hole was covered with a cast iron hare or back plate. In some localities however the sow was fed – on rollers – from the open side of the finery hearth [24] (see Figure 10).

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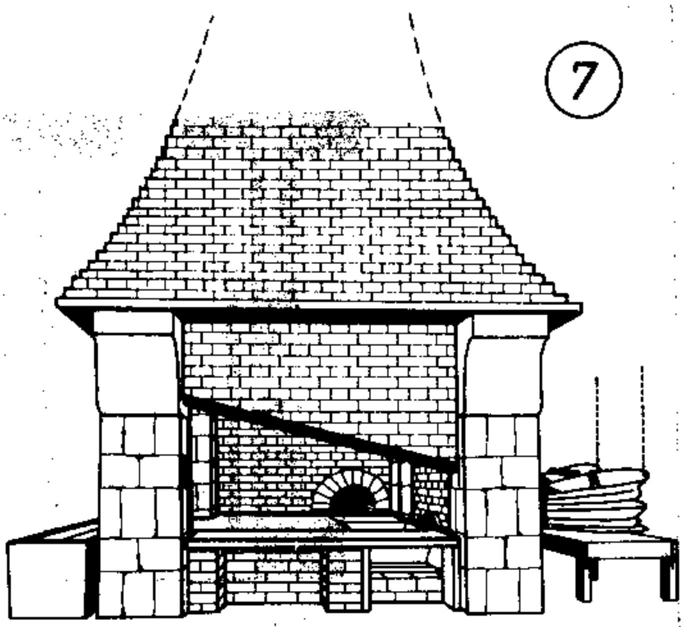

Walloon Finery Hearth – General View, Liege, Belgium.

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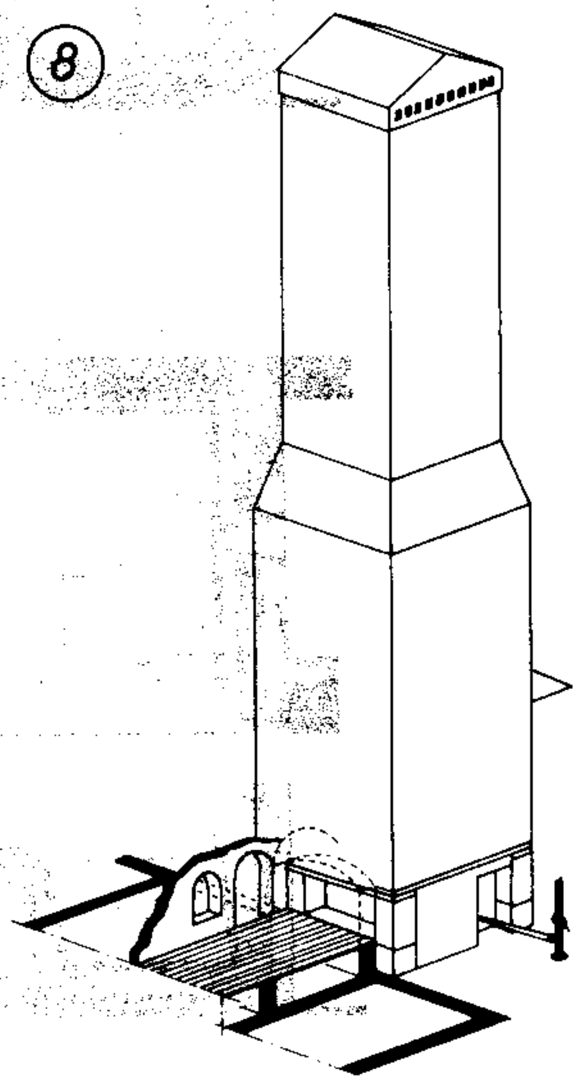
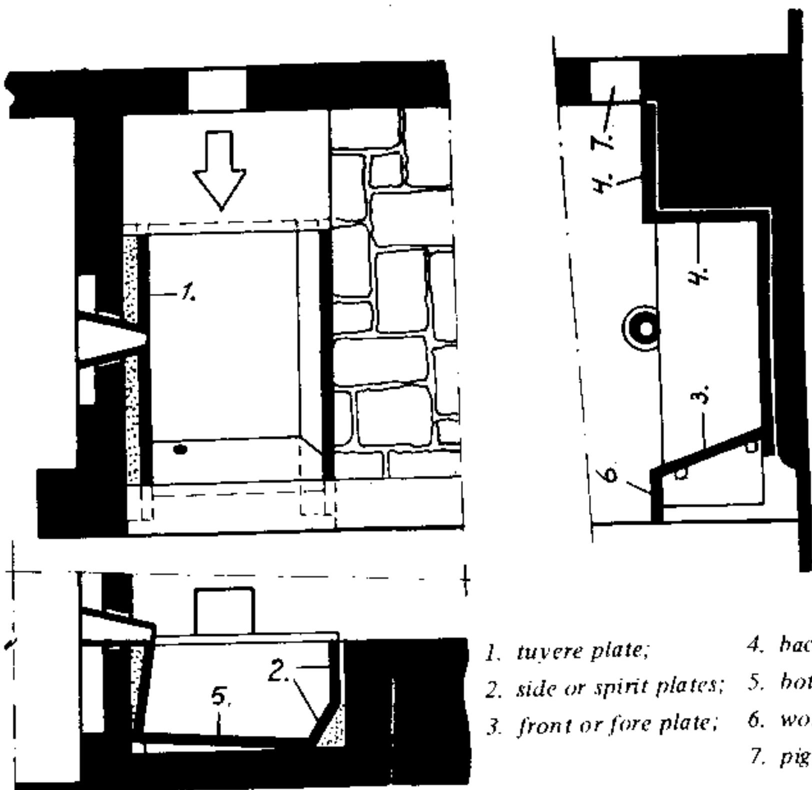


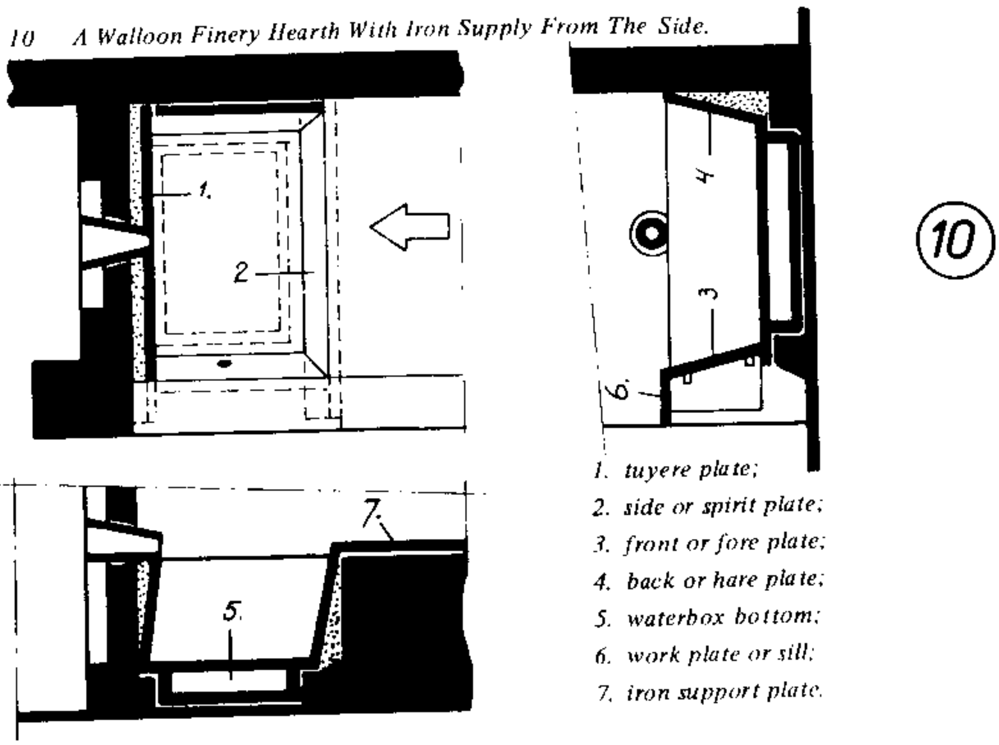
Walloon Finery Hearth and Iron Supply, Osterby, Sweden.



1. tuyere plate;
2. side or spirit plates;
3. front or fore plate;
4. back or hare plates;
5. bottom plate;
6. work plate or sill;
7. pig hole.

9 A Walloon Finery Hearth With Iron Supply From The Rear:

10 A Walloon Finery Hearth With Iron Supply From The Side.



1. tuyere plate;
2. side or spirit plate;
3. front or fore plate;
4. back or hare plate;
5. waterbox bottom;
6. work plate or sill;
7. iron support plate.

A second difference between a Walloon finery hearth and a German hearth is in the hearth proper. In a Walloon finery this is rectangular with a length of 0.65 m and a width of 0.45 m[7]. The hearth sole is also a bit higher than that of a German hearth, at 0.4-0.5 m. The cast iron plates covering the walls of the hearth proper were generally tilted slightly. In the German hearth all four plates leaned outwards. In a Swedish Walloon finery hearth this was also the case[25]. In other countries the Walloon tuyere plate, ie the plate standing just below the mouth of the tuyere, leaned inwards[26]. Comparison of the Figures 9 and 10 shows that further variations did occur in other side plates. These differences were related to the degree of impurity of pig iron, and they had a significant effect on the quality and quantity of fined iron. The correct setting of the hearth plates thus was an important task of the finer.

A third difference between a Walloon finery hearth and a German hearth is in the cooling of the bottom plate. In a Walloon finery hearth this is inclined slightly by inserting small pieces of iron under its corners. In the resulting interstice water was poured, to cool the bottom plate[25,27]. From some date in the 18th century, water-box bottoms were used[28] (see Figure 10).

At the start of a new fining the sow was pushed into the burning charcoal mound in the finery hearth and the blast was turned on. As soon as pig iron began to melt, the finer started rabbling[29] with a rabbling bar[30]. Thus, as opposed to German forge practice, the iron was worked not only during *Stage 2* of the fining process, but also during *Stage 1*[31]. To lift the loup in front of the tuyere, the finer used a second, lighter bar[32]. The hearth has a sill or workplate to lever this bar on. When sufficient iron was melted, the sow was pulled back but the finer proceeded with rabbling until his iron "had come to nature", ie was fully fined. As in German hearth practice, a final melting down of the loup with increased blast concluded the fining. One fining sufficed.

The loup was taken out with tongs. Adhering slag and charcoal were cleaned away with a hand hammer on an anvil or cast iron plate in front of the finery hearth. Then the loup was dragged with tongs towards the waterhammer. To this purpose the floor was covered with iron plates. A loup was first hammered into a bloom, this was divided with a chisel under the waterhammer and the parts were hammered into half-blooms, all without reheating. These half-blooms were about 0.4-0.6 m long and about 0.1 m square.

The further working of the half-blooms in Sweden was confined to the chafery. The half-blooms were reheated in this hearth, drawn out into a half bar with a butt, reheated again in the chafery hearth and finally drawn out into "råskenor", rough bars, eg of 70 mm width, 20 mm thickness and 3.6 m length.

In England a somewhat more complex process was used. The half-blooms were reheated in the *finery* hearth during the next fining. When the loup of this fining had been shingled and hammered into half-blooms the - now reheated - half-blooms of the prior fining were hammered into "anconies" ie their middle parts were drawn out to the dimensions of the bar to be produced. The length of an ancony would be about 0.9 m and the two knobs left at the ends had different dimensions. The small one was called "ancony end" and the large one "mocket head". These anconies were reheated in a chafery hearth, first the ancony end, which could be drawn out in one heat, and then the mocket head which needed an intermediate reheating.

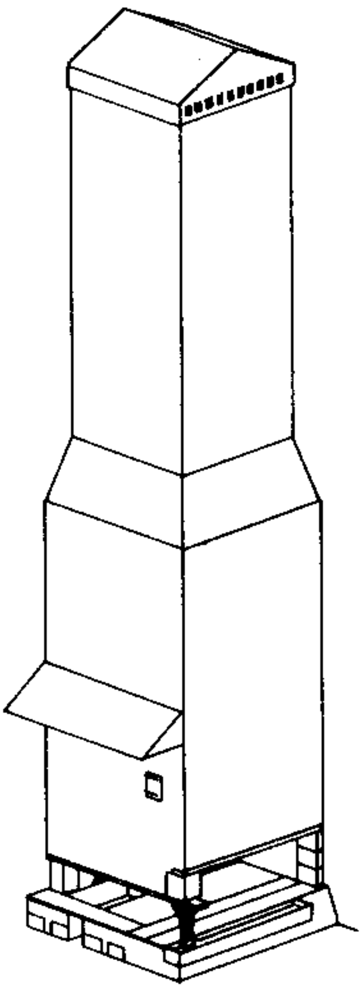
The chafery hearth, see Figure 11, in general construction resembled the finery hearth. The hearth proper is larger than that of a finery hearth, with a length of 0.9 m and a width of 0.6 m[7]. Also, the hearth sole of a chafery is fully covered in cast iron plates.

A large beehive shaped fire is built in and over the hearth well, against the side wall, amply covering the tuyere. The mound consists of small lumps of fuel, slag and ash. Pieces to be reheated, ie half-blooms and half bars with butts, are slid into this mound over the covering plates of the hearth sole and/or over the sill of the hearth[33].

A Walloon forge at least had to contain the two hearths, a hammer and either 2 sets of bellows or a blowing engine. Figure 12 shows the layout of a later Swedish Walloon forge. The painting in Figure 13 refers to this kind of layout[34]. In such a forge eight men were working each shift: two smiths, two apprentices, two labourers and two charcoal hands. Some of the hand tools used are shown in Figure 14.

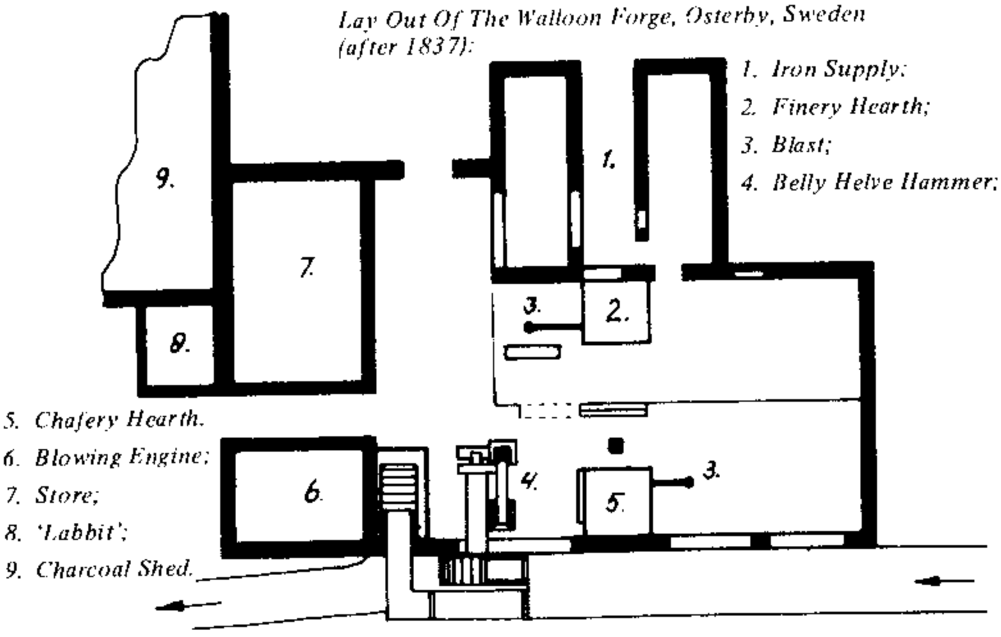
It took about 1.5 hours to fine one melt of 100 kg pig iron into 85 kg half-blooms. Chafery oxidation losses were about 12%. The 85 kg half-blooms could thus be drawn out into about 75 kg bar. Each shift at a one finery-one chafery forge could produce up to 125 tons of bar iron a year. As such a forge was usually worked 24 hours a day and 6 days a week, its maximum production was 375 tons of bar iron a year.

11



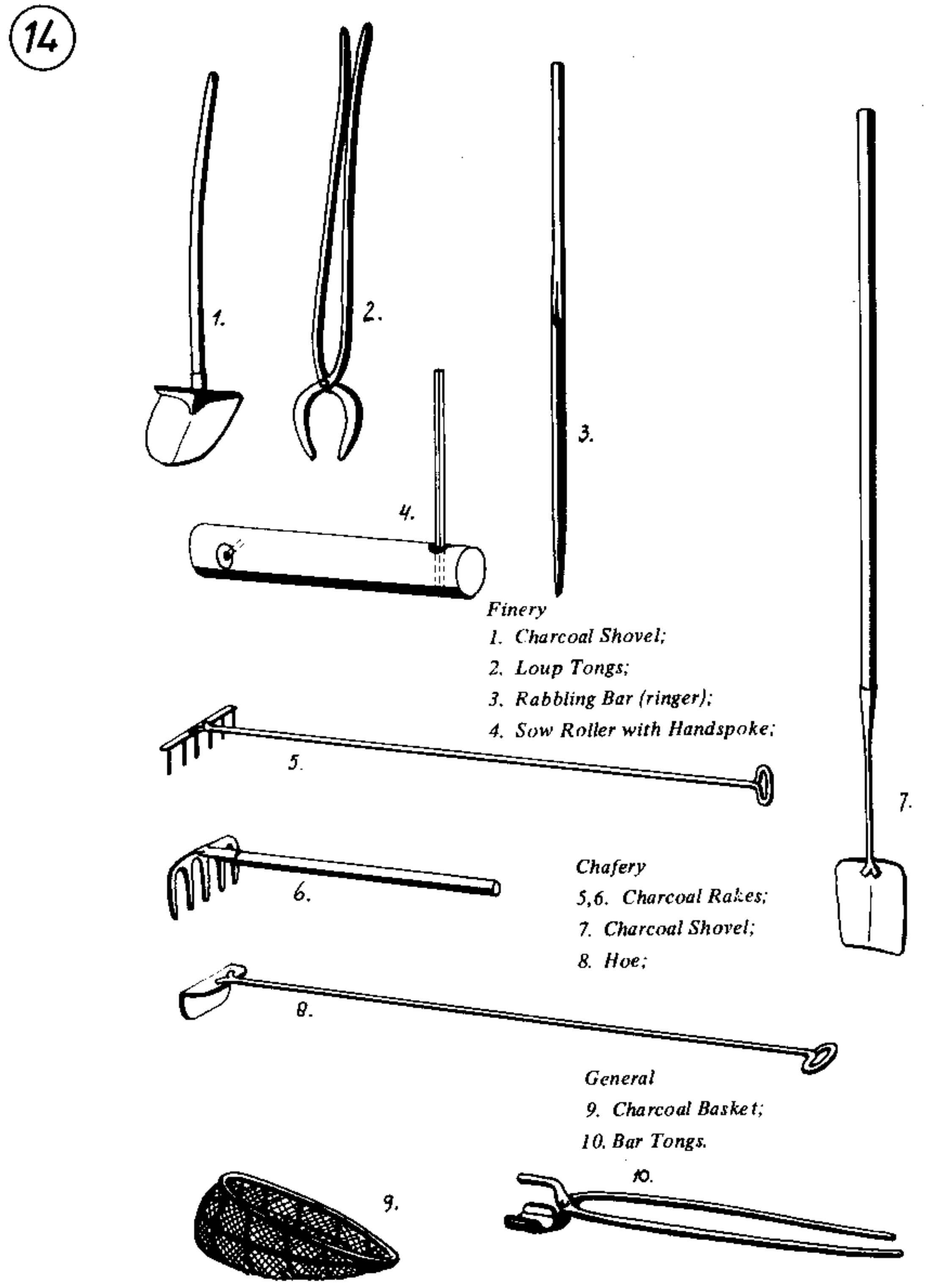
Walloon Chafery Hearth, Osterby, Sweden (drawn in the right position with regard to the finery hearth in figure 8, see also the lay out of figure 12).

12



13

A Walloon Forge (painting ca. 1800).



Tools, Used in A Walloon Forge:

The Lancashire forges

The general need to decrease the charcoal consumption of a Walloon finery hearth led in England to the emergence of the Lancashire hearth. Details of its construction are available from a Swedish travel report, dated 1828[35]. The finery hearth, see Figure 15, was fully enclosed but for a working arch. A sow of iron, which was fed from the rear, was pushed through a brick chamber acting as a reverberatory furnace heated by the exhaust gases of the hearth. There was one watercooled tuyere[36]. Although this is not clear from the sketches, the text of the report mentions the use of a waterbox bottom[37]. A damper flap on top of the chimney could reduce natural draught – and thus charcoal consumption during shingling, etc.

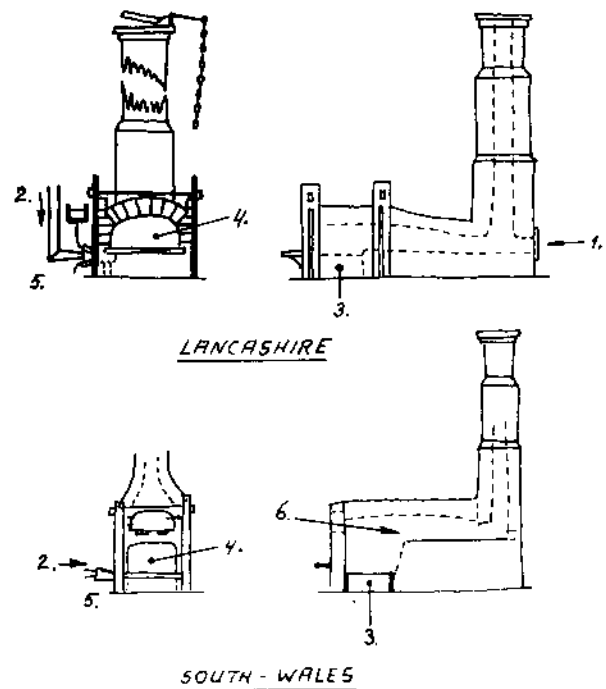
In this hearth, charcoal pig iron was fined in the customary Walloon way, ie rabbling was started as soon as the sow began to melt. Reheating of half-blooms was performed in a separate – coal-fired – reheating furnace[38]. The hot half-blooms were rolled into bars.

The Lancashire hearth was quite successful. In 1828 it was also used in tin-plate works in South Wales. The travel report referred to above gives some details of the process applied there, and of the hearth construction (see Figure 15). The South Wales works used coke-smelted pig iron. This was first refined in a run-out hearth. Fine-metal from this hearth was fed into the finery hearth either in pigs or broken-up lumps. These were stacked on the bridge in the flue behind the hearth to be preheated before fining. A door on the front of the hearth gave admission to this bridge. Below the door lay the working arch of the hearth[39].

It is interesting to see how in the earliest Swedish Lancashire finery hearths parts of these two English hearths are combined (see Figure 16)[40]. Iron was fed in pigs and stacked on an iron-clad bridge to preheat, but there was no separate charging door, just the working opening. The hearth was provided with a chimney of about 8 m high, with a damper flap on top. The hearth had a single tuyere. Presumably blast was heated in a separate stove. The tuyere would in that case be watercooled[41]. The brickwork of the hearth was enclosed in three large iron castings, held together by eight tie bars. In the brickwork a well of about 1 m long, 0.65 m wide and 0.4 m deep contained the hearth proper. A waterbox bottom was used. Presumably the hearth proper, of which details are lacking, would measure approximately 0.9 m by 0.55 m and be 0.3 m deep[41]. No information is available on the hearth plates, either, so it is not known whether slag was tapped through the fore plate or through the tuyere plate[42]. In the very first experimental model of the hearth the backplate leaned inwards[43]. It is not however known whether this special setting was applied in later experimental hearths.

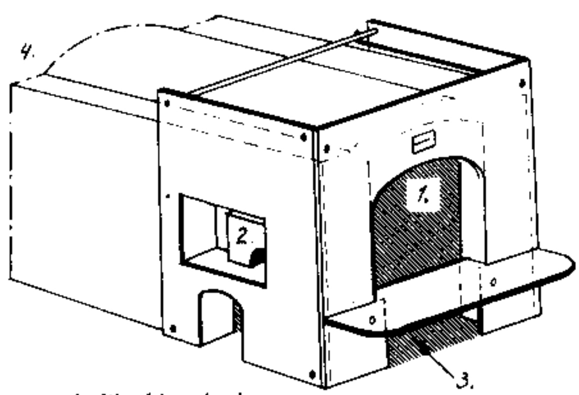
Later Swedish Lancashire hearths were constructed according to the same principle[44] (see Figures 17 and 18). Two – adjustable – tuyeres were used, one at each side wall. Blast was heated with combustion gases of the hearth itself, by conducting it through a cast iron U-tube in the flue behind the pig iron bridge. The hearth was bolted together from castings. The structure was lined with fire brick internally and the back side of the hearth and the flue were also built in brick. The flue ends in a spark-catching chamber, which usually served several hearths. The chimney rises from this chamber.

The hearth proper has four side plates and a watercooled bottom box. There is no slaghole. Part of the slag from fining was removed with a shovel after each fining. The



1. Sow Supply; 4. Working Arch;
2. Blast; 5. Tuyere;
3. Hearth Proper; 6. Pig Supply.

15 *Sketches Of English Lancashire Finery Hearths From A Travel Diary (1828) By Gustaf Ekman.*



1. Working Arch;
2. Single Tuyere;
3. Hearth Proper;
4. Chimney.

16 *One Of The Earliest Swedish Lancashire Hearths (Furudal, 1831):*

remaining slag was used as a basis for the next fining. When a hearth had so been prepared, the pig iron stacked on the bridge was pulled into the hearth with a hook and buried in the charcoal. New charcoal was added with a shovel. Then the blast was turned on and fining began (see Figure 19).

Rabbling started – as in Walloon practice – as soon as the pigs began to melt. Two bars were used in rabbling, a stirring bar and a lifting bar[45]. From time to time the tuyeres had to be cleaned of adhering matter. This was done by tapping them with a third, lighter bar. In the final gathering of the loup prior to taking it out, a fourth, longer and heavier bar was used[46]. Two men took out the loup with a pair of tongs and a lifting bar and put it on a ball-bogie. With this the loup was brought to the shingling hammer where it was tipped off the bogie on to the anvil to be manoeuvred under the hammerhead by tongs. The bloom was divided with a very large chisel into 5 to 7 parts. These were – without reheating – hammered and/or rolled into half-blooms or even rough bar.

The number of men working in a Lancashire forge depended on the scale of operation. In a forge with 5 hearths and 2 reheating furnaces, a shift of 34 men was necessary, including the manager and two foremen. This shift further comprised five smiths, ten apprentices, four reheating furnace stokers and four bar drawers. The remaining eight men took care of the transport of pig iron, half-blooms, half bars, bars, charcoal etc. In Figure 20 some of the hand tools are shown.

In the early 1890s just prior to the introduction of the Lagerwall rabbling device, it took about 1.1 hours to fine one batch of 125 kg pig iron into 110 kg half-blooms. Reheating furnace losses were about 10.5%. The 110 kg half-blooms could thus be drawn out into about 98.5 kg bar. The charcoal consumption of the Lancashire hearth was about 38 hl/ton of half-blooms[47]. If a charcoal fired reheating furnace was used, this would consume about 40 hl/ton of bar iron[48]. Total charcoal consumption was about 83 hl/ton of bar iron[49]. Each shift at one hearth could make a sufficient number of half-blooms to produce up to 225 tons of bar iron a year. Usually a hearth was worked 24 hours a day (6 days a week) and its maximum production then was 675 tons of bar iron a year.

After the introduction of the Lagerwall rabbling device, in the late 1890s, these data were as follows: 1.08 hours for a batch of 135 kg pig iron, drawn out into 108 kg bar. Charcoal consumption of the Lancashire hearth: 35 hl/ton of half-blooms[47]. One shift at one hearth could make a sufficient number of half-blooms to produce up to 250 tons of bar iron a year.

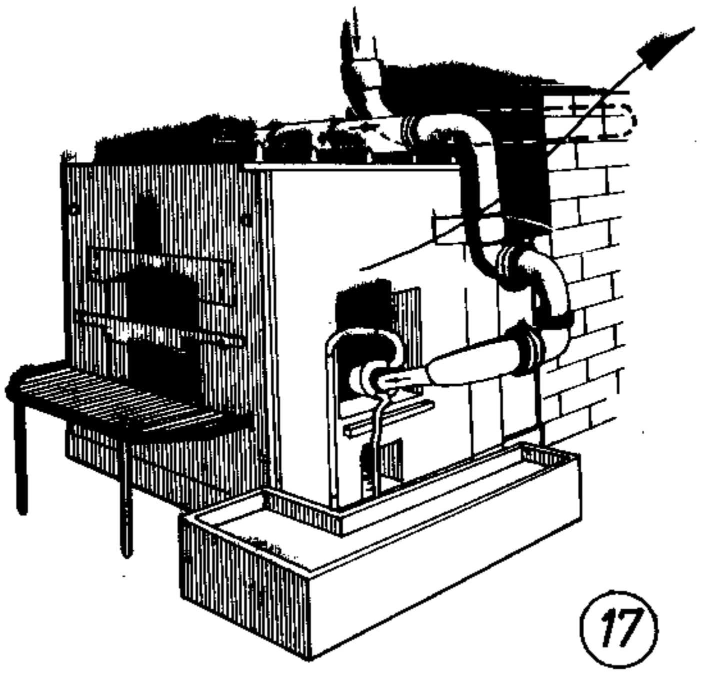
Forges producing these amounts of iron are no longer comparable to the small industrial establishments that German and Walloon forges were. This can clearly be seen from the Figures 21 and 22, that show the lay-outs of works with 5 and 6 hearths, respectively.

Development of hearth fining of wrought iron

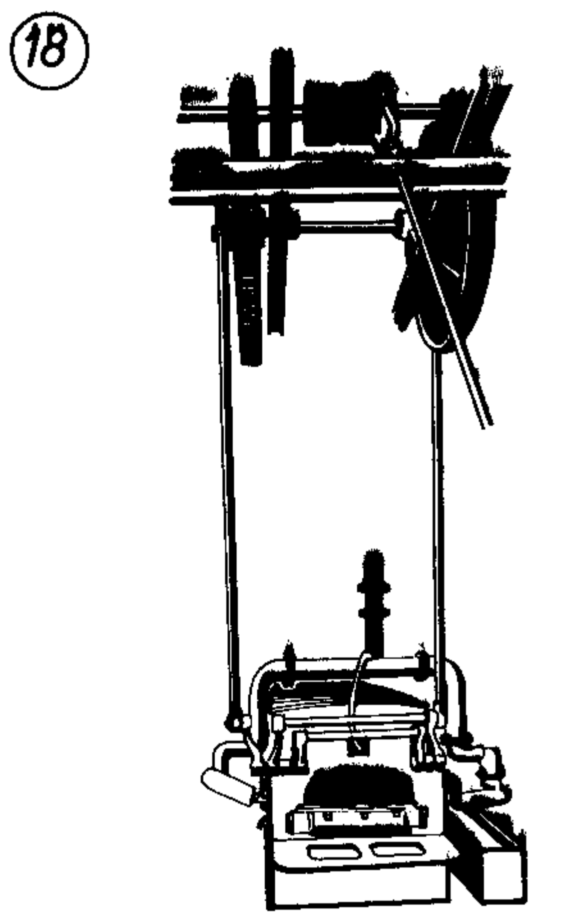
In the period before 1750, two main manufacturing processes for wrought iron bar existed in Europe: the Walloon and the German forge method. The former was used in conjunction with charcoal[50] blast furnaces only; primarily in France, the Low Countries and England[51]. The second method was in use in Germany, Austria, Italy[52] and Sweden[51].

The German forge

It is important to realise that the German forge produced not only wrought iron but also steel – from several kinds of raw material.

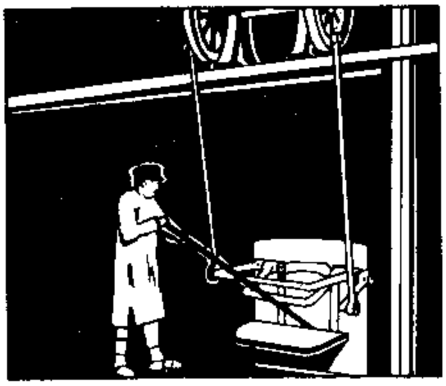


A Swedish Lancashire Finery Hearth.



A Swedish Lancashire Finery Hearth With Lagerwall Rabbling Device.

(19) *Operations In A Lancashire Forge:*



Rabbling With A Lagerwall Device; 1.

Taking Out A Loup; 2.

20 *Tools, Used In A Lancashire Forge:*

Hearth Preparation

1. Charcoal Shovel;
2. Charcoal Rake;
3,4. Slag Shovels;
5. Pig Tongs;
6. Pig Loading Shovel;
7. Pig Hook;

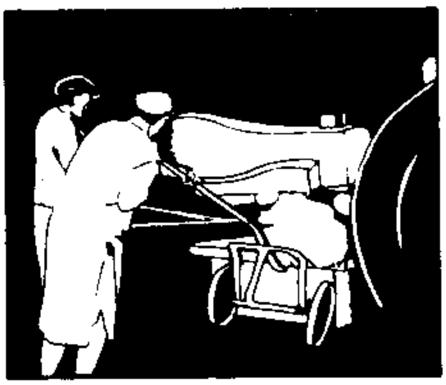
Fining

8. Stirring Bar;
9. Lifting Bar;
10. Compacting Bar;

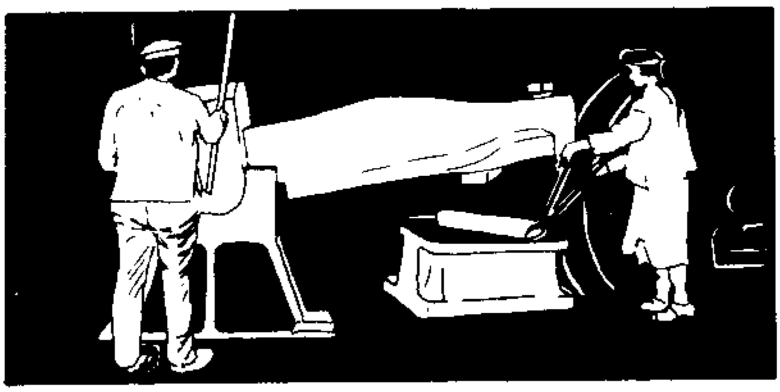
Shingling

11. Ball Barrow;
12. Loup Tongs;
13. Bloom Tongs;
14. Half-bloom Tongs;
15. Half-bloom Lifting Tongs;
16. Half-bloom Barrow;

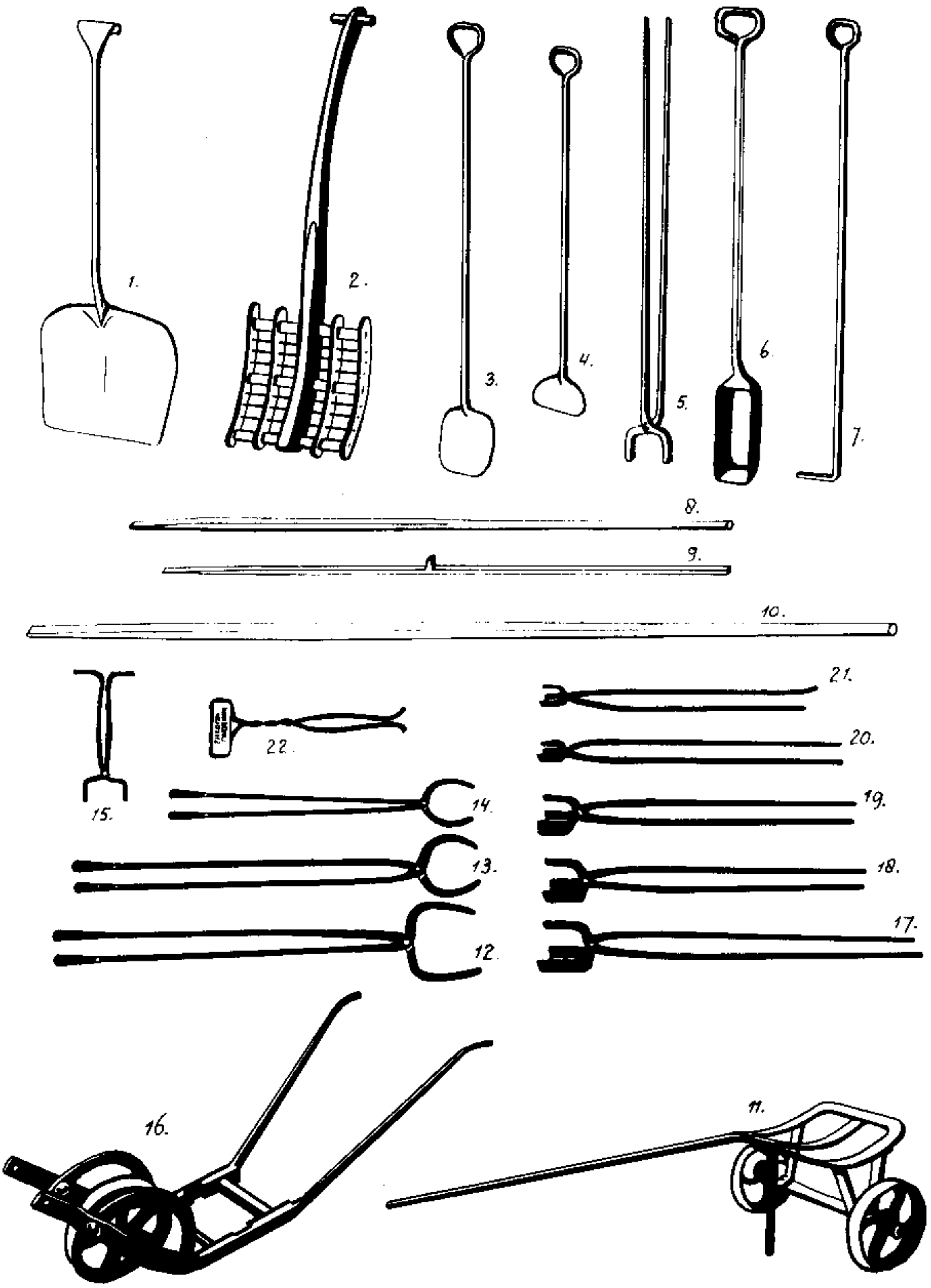
3. Bringing The Loup Under The Shingling Hammer;



3.

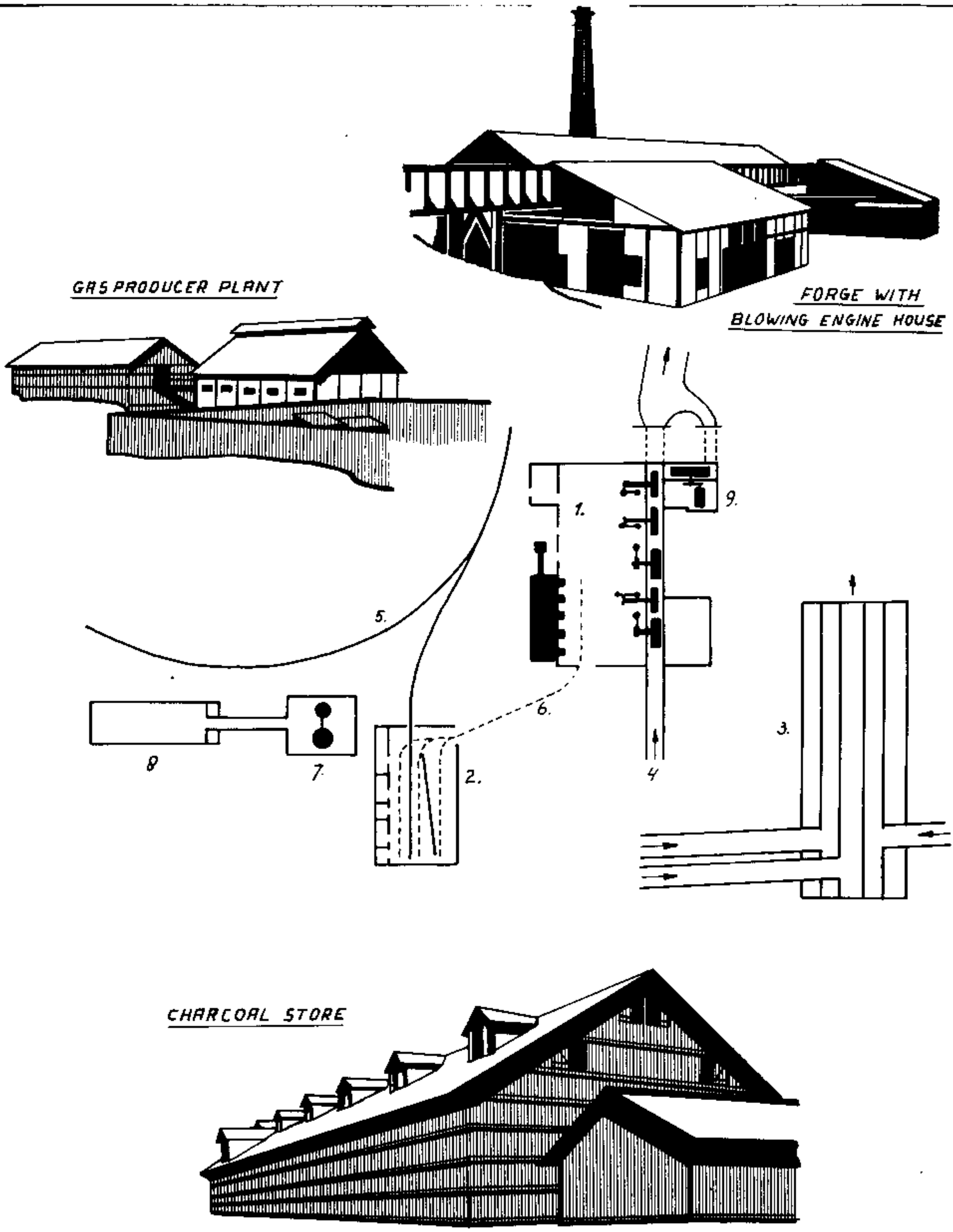


Half-bloom Hammering. 4.



Bar Drawing
17-21. Bar Tongs;
22. 'Stampel'.

20



1. Forge;
2. Iron Store;
3. Charcoal Shed;
4. Leat;
5. Horse Tramway;
6. Overheat Conveyor;
7. Gasproducer Plant For The Lundin Reheating Furnaces;
8. Sawdust Store;
9. Blowing Engine House.

21 Lay Out Of The Lancashire Forge (type 4), Korsa, Sweden:

Before 1750 in Austria and to some extent also in Germany, the raw material mainly consisted of parts of "Massl' or 'Stucke'[2] from 'Stuckofen'[2] . In this case relatively little fining is necessary, as this raw material has an analysis comparable to steel. Forging in the German hearth mainly served to enhance quality and homogeneity by "Garben" or fagotting[53].

In "Stücköfen" some liquid pig iron ("Kraglach") is also formed. This must truly be fined in the German hearth. "Kraglach" was usually fined down fully to become wrought iron[54].

In Sweden, on the contrary, straight from its introduction in the early 1600s the German forge was fed with charcoal pig iron and it produced wrought iron bar[55] and steel[56].

After 1750, the "Stücköfen" in Germany and Austria were quickly replaced by charcoal blast furnaces. The indirect process needs more charcoal – to fine pig iron into wrought iron or steel; still, the much larger productivity of the blast furnace made the change-over advantageous[57]. Both wrought iron[58] and steel[59] were then made directly in German hearths from charcoal pig[60] in these countries also.

But even after about 1750 when pig iron is used exclusively in the German hearth, many modes of operation remain, differing in details.

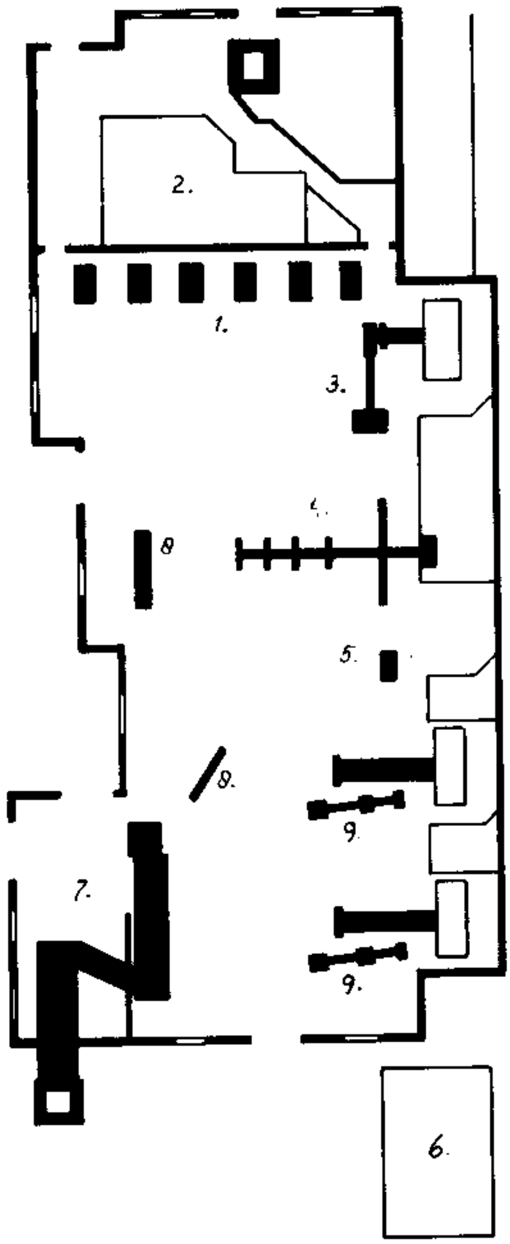
The Walloon forge and its derivatives

In the Walloon forge two separate hearths are used: a finery for fining of pig iron and a chafery for reheating before hammering into bars (Figure 13). Scarcity of charcoal and the availability of coal led, before 1700, to the application of the latter fuel in the *chafery* hearth. At least, it did so in France, the Low Countries and England[61]. In Sweden, circumstances were quite different. Charcoal was not scarce – and coal supplies near the orefields non-existent[62], while transport of coal to the forges was much too expensive to make this a competitive fuel, at least not before 1850[63]. Thus charcoal remained in use in the Swedish chafery hearth, even right up to the mid-1940s[64] (Figure 25).

In the search for a reduction of the charcoal consumption of a Walloon forge, experiments with coal or coke as a fuel in the *finery* hearth were also made, but as any sulphur in the fuel was quickly taken up in the iron, making this red short and unworkable in the forge, these were not successful.

One possible action was to retain a hearth but reduce its charcoal consumption . This method was chosen for example in Lancashire. The Lancashire (finery) hearth was designed for maximum efficiency with heated blast, pre-heated pig and damping of natural draught in the chimney, etc. In this latter form the Lancashire hearth was still in use at Ulverston in 1828[65].

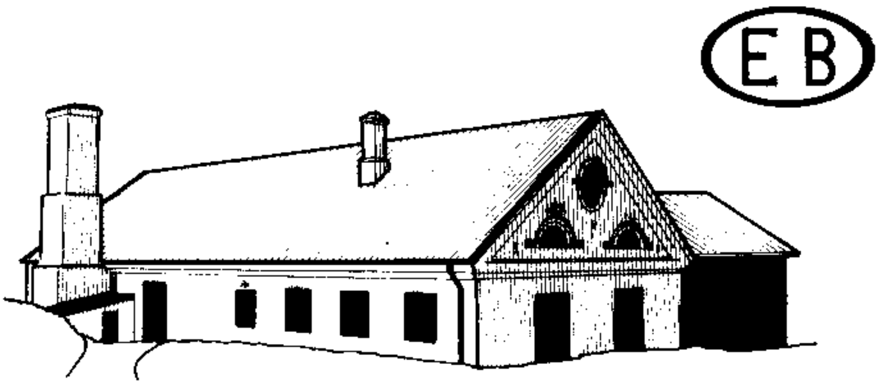
A second possibility for decreasing the charcoal consumption was to use a reverberatory furnace with natural draught for fining instead of a hearth. The strict separation of iron and fuel made it possible to use coal without sulphur contamination problems, but the oxidizing atmosphere in an air furnace caused new problems. To solve these and protect the iron from over-oxidation, it was "potted"[66]. This process was used in 1775 by Jesson and Wright[67] and even as late as 1796 at Coalbrookdale[68]. Of course this "stamping-and-potting" method culminated in Cort's puddling furnace, where strict control of the slag covering an iron bath made satisfactory metallurgical control of the fining process possible, without having to make recourse to pots.



1. *Lancashire Hearths;*
2. *Waste Gas Boilers;*
3. *Nose Helve Shingling Hammer;*
4. *Rolling Mill;*
5. *Shears;*
6. *Store For Half-blooms And Rough Bars;*
7. *Ekman Reheating Furnace;*
8. *Steam Hammers;*
9. *Belly Helve Bar Drawing Hammers.*

Lay Out Of The Lancashire Forge (type 5), Karlholm Sweden: 22

23



Engelsberg Estate Forge, Angelsberg, Sweden.

Further, another method that was tried to alleviate the scarcity of charcoal was by using coke in the *smelting* of iron. Coke smelting was gradually perfected in England[69] in the period 1750[70] to 1800[71]. It should be stressed, though, that in the north-west of England and in Scotland charcoal smelting continued far into the 19th century[72]. The Lancashire finery hearths, in use at Ulverston, referred to above, were fining local charcoal smelted pig iron[65].

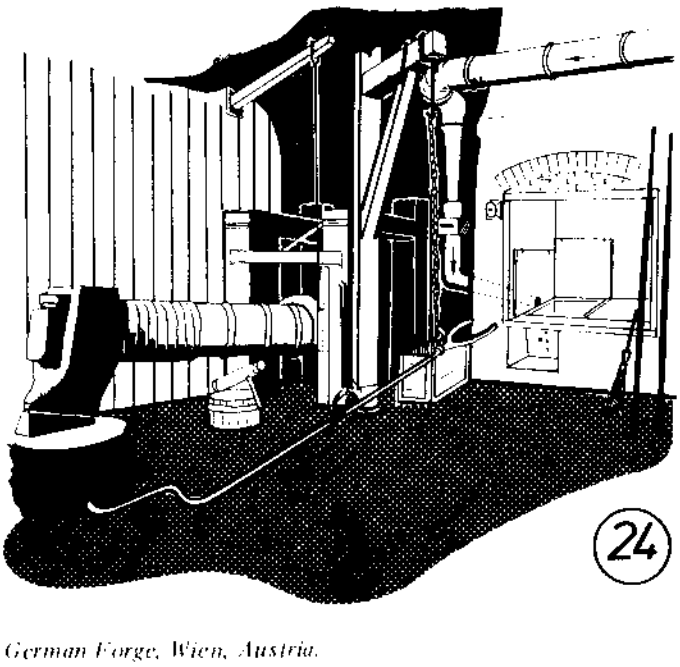
In iron smelting with coke, the biggest stumbling block of course was sulphur, introduced with the fuel. And when this problem was solved, the high silicon of the coke based pig iron[73] became the next problem. A Walloon finery hearth is not very well suited to pig irons with high silicon, due to the rather large slag volumes these cause. It was found necessary to precede the finery operation with a "refining" operation when using coke based pig iron.

"Refining" of the pig iron was performed in a separate hearth called a run-out hearth[74]. Up to at least 1770 the run-out hearth was charcoal fired, although the pig iron could be pre-heated in a (coal fired) reverberatory furnace[75]. In this way no charcoal was necessary for smelting . . . but extra charcoal was consumed in the forge. Later, very low sulphur coke was used in the run-out hearth, to bring the specific charcoal consumption in the forge back to the accustomed level[76].

This type of process:

coke smelted pig iron
↓
coke fired run-out hearth
↓
charcoal fired Lancashire finery hearth
↓
coke fired hollow fire chafery

did apparently work quite well, it was still in use at Pontymoils tin-plate works in South Wales in 1828[77].



German Forge, Wien, Austria.

Double Bullet Walloon Forge, Osterby, Sweden.

Puddling

From the 1790s onwards, the Walloon process was replaced in England with one in which no finery hearth was used at all[78, 79].

coke smelted (white) pig iron (No 3)

- coke smelted (grey or mottled) pig iron (Nos 1,2)
- coke fired run-out hearth
- coal fired puddling furnace
- coal or coke fired reheating furnace
- rolling for working into bars instead of shingling[80].

Due to the Napoleonic Wars and their blockades the puddling process was not introduced before the mid 1820s on the Continent. By then, wet puddling was available and between 1825 and 1840 this process quickly spread all over Europe, superseding the old German and Walloon methods.

The puddling process itself is outside the scope of this article as it uses no finery hearth, but its very quick adoption both in England and abroad caused some very special problems in Sweden. These could only be overcome by the development of a specific Swedish hearth fining process.

The Swedish situation up to the 1810s

Sweden has large amounts of iron ore – of high quality – and is quite rich in wood. In the 18th century these facts made for an advantageous position. The charcoal scarcity in other countries caused relatively high iron production costs. Swedish iron could thus – despite the sometimes very long transport route – very well compete with home-produced iron in most other countries, especially as its quality was relatively high.

During most of the 18th century the following rough statistics held:

- counted in money, half Sweden's export was bar iron[81].
- counted in iron 90% of Sweden's iron production was exported[82].
- of Sweden's iron export, 50% went to England[83].
- Swedish iron was made in German forges (90%) and in Walloon forges (10%).

The adoption of the puddling process in England caused a spectacular reduction in its iron imports. In the period 1815 – 25 only 15000 t/year were imported as compared with 45 - 50000 t/year around 1800[83]. This caused a decrease of some 20% in the Swedish export to England[83]. The emerging new markets of the USA quite easily took up this amount – and even more – but a *structural* problem remained:

> English puddled iron was cheaper and of a better quality than Swedish German forge iron[84, 85].

A full analysis of this problem revealed several causes:

price – coke as a fuel in iron smelting is cheaper than Swedish charcoal;

– coal fired puddling and balling (-reheating[79]) furnaces produce more cheaply than a charcoal fired German hearth;

– pig iron is pre-heated with combustion gases before puddling, a practice not yet employed in the Swedish forges[86];

– the iron efficiency of a wet puddling furnace is fully comparable to that of a German forge[87].

– rolling of loups into blooms then into bars is cheaper than shingling and bar hammering by hand under water hammers.

– the productivity of a puddling forge (around 1830) is more than 15 times that of a German forge[88];

– the puddling process is adopted in many other countries in Europe.

quality – the wet puddling process can be kept under control much better than the German forge process, thus enhancing the consistency of the iron quality;

– rolling (if from a high reheating temperature) improves homogeneity and toughness.

Two facts played a role in finding possible solutions for this problem of non-competitiveness.

Swedish iron production was strictly governed by royal "privilegier"[89]. For every forge the amounts of charcoal and pig iron to be used each year were stipulated; the origin of the pig iron was laid down; the amount of bar iron to be made was fixed; a minimum quality was standardized[90]. This inflexible and small-scale structure caused relatively high prices (no competition) and it did not make for maximum quality either (almost any forge had to operate with a mixture of pig irons from several blast furnaces fed with ores from several mines[91].

A much more important – whilst at the moment unalterable – factor was the lack of coal in the orefields[62]. Cheap bulk transport was not possible, before the 1850s[63].

It is clear that due to the scarcity of coal for forges Sweden had to find its own unique answer to the standard puddling process.

Sweden's options

The *first* option was of course to find a fuel cheaper than meiler charcoal which was used exclusively at that time. Charcoal, made in retorts, costs less in labour than meiler charcoal[92], but the cost of transport of wood to the retorts is much higher than that of charcoal due to the much larger volume[93]. Experiments were technically successful[94], but over-all retort charcoal did not offer any cost reduction[95].

Wood and peat – in their natural form[96] - were the only available replacements for coal in reverberatory furnaces, ie in puddling furnaces.

The *second* option then, was a modified puddling furnace, suited to wood or peat as fuel.

The *third* option was to find a cheaper charcoal hearth fining method, by reducing the specific charcoal consumption and/or increasing the iron efficiency. This problem had been encountered before, in England. The Lancashire finery hearth, mentioned above, was developed for just this purpose.

The *fourth* option was to decrease bar iron costs or increase efficiency by better hammers and/or by rolling. Reheating in hearths is not feasible with rolling [97], so a reheating furnace suited to Swedish circumstances – again no coal – must be found before rolling can be advantageously introduced. Of course a reliable and not too precarious power source is necessary to realise all the benefits of rolling.

Swedish developments 1810-50

In 1812 at Klosters Bruk and in 1816 at Bispberg experimental puddling furnaces (wood fired?) were built [98]. In 1819, at Skebo Bruk, an experimental puddling furnace and reheating furnace, both wood fired, together with a rolling mill were constructed [98, 99]. This was the first attempt to introduce full puddling plant technology.

The wood fired reheating furnace does not reach sufficiently high pre-rolling temperatures without inadmissibly high oxidation losses, and the iron quality is disappointing [100]. That this was indeed caused by the use of wood as fuel in the reheating reverberatory furnace is adequately demonstrated in 1825 by rolling experiments in England with Swedish iron [98]: excellent bar was obtained after reheating with coal.

The wood-fired puddling furnace itself was satisfactory. High transport costs of wood however, together with the extra costs of having to hammer bar [101] – failing a reheating furnace suited to Swedish fuels and rolling – are the reasons why the puddling process never caught on very much in Sweden.

In 1829-30 the first charcoal fining hearths of an improved design were built. These were based on the Lancashire finery hearth.

Waern installed a South Wales forge in Backefors Bruk. As mentioned previously, South Wales tin plate works did use – at that time – a run-out hearth (on coke), a Lancashire finery (on charcoal) and a hollow fire chafery (on coke). As Waern was going to use charcoal-smelted pig iron, with an analysis comparable to that of refined metal emerging from the South Wales run-out hearth [103], he could dispense with the latter. As he had no coke, he could not use a hollow fire [104]. But the rest, hearths, blower, hammers, smiths, know-how: all were imported from South Wales [105]. Buying technology usually only works when the methods are further developed and adapted to local circumstances [106] and the Waern method never found widespread use, as this necessary evolution was neglected.

At the same time as – but independent of – Waern, Ekman built new finery hearths, at Dormsjö and Söderfors [107]. These were clearly copies from the Lancashire hearths that Ekman had seen 1828 at Ulverston [108], although some changes were made [109]. The results were encouraging: [110]

- the wrought iron was excellently suited to cementation and was of better quality than German forge iron;
- the specific charcoal consumption of the finery was low, even for very low carbon iron;
- the iron efficiency of the finery was high, unless very low carbon iron was made.

In the period up to 1834 the Lancashire finery hearth was introduced in several other works [111]. Of course some teething problems occurred. Pig iron quality varied considerably [112]; blowing engines could not meet the requirements of the new hearths [113]; smiths, accustomed to the slow German process only gradually picked up the required technology. But there were two much larger problems to overcome.

As could be expected, many experiments were done to increase the efficiency of the German forge, and this work, eg by Morell [114], comes to fruition in the early 1830s. In fact the improvements are similar to those of the Lancashire hearth: an enclosed hearth, use of combustion gases, etc. The resulting decrease in specific charcoal consumption is not as spectacular as that of the Lancashire hearth; but in the latter case reheating before hammering into bars needs extra fuel, something which in a German forge is unnecessary as reheating is done in the same hearth as fining. If a charcoal chafery hearth is used in conjunction with the Lancashire finery hearth, about 5% more charcoal is consumed than in the improved German forge. Both methods still cannot compete with the English puddling process. Clearly, rolling is necessary to come anywhere near competition with puddling plants. A reheating furnace, suitable for Swedish fuels, reaching a sufficiently high temperature was not yet available. Failing this, the Lancashire finery hearth could only be coupled with a chafery hearth and hammering of bars. The German process intrinsically could never be adapted to rolling [97]. Narrow thinking and the need for even small savings steered production towards improved German forges and thus hindered the evolution of the new process: in 1840 only 3-4 works really used their Lancashire hearths [115].

The second problem is one of scale. When combining the Lancashire finery hearth with a chafery hearth, two fineries were needed to keep the chafery fully occupied. Shifts of seven men then produced about 360 t/year [114]. Of the 510 iron-works registered in 1834, only 74 had "privilegier" exceeding that amount [116].

It is quite clear, that the original problem of non-competitiveness could not be solved before an efficient reheating furnace, suited to Swedish fuels, was developed.

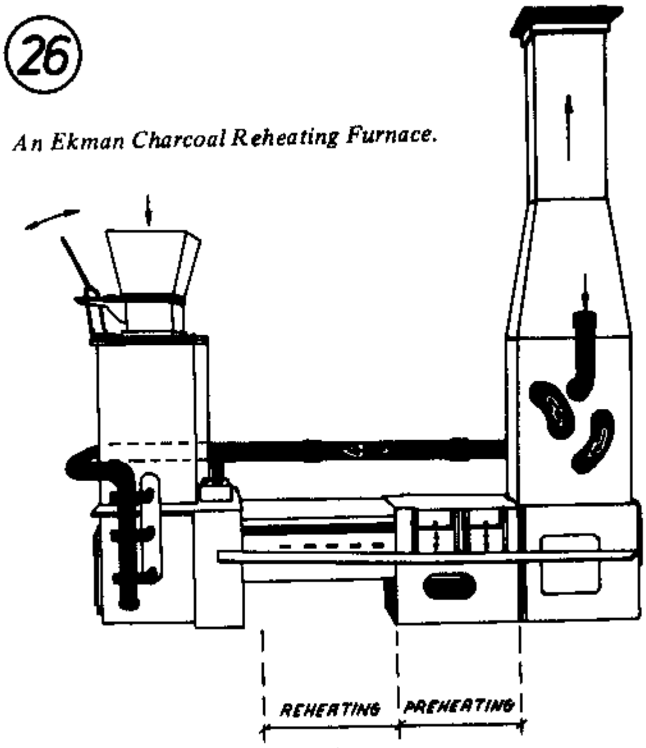
In 1842-4 Ekman succeeded with the application of a new concept. He used a separate hearth as a gas producer in which, by means of hot blast and added water, carbon-monoxide and hydrogen are formed from charcoal. These are fired in the furnace chamber. The atmosphere there could at wish be made oxidizing, neutral or reducing by changing the blast and water supply. Combustion gases emerging from the furnace chamber were used to preheat the blooms and then to heat the blast [117] (see Figure 26).

The concept proved very successful: within one year nine of these furnaces were in use [118] and on an average one furnace was fed by three Lancashire finery hearths.

Clearly, this development did not fit within the strict framework of the "privilegier", as the optimum use of a reheating furnace would mean:

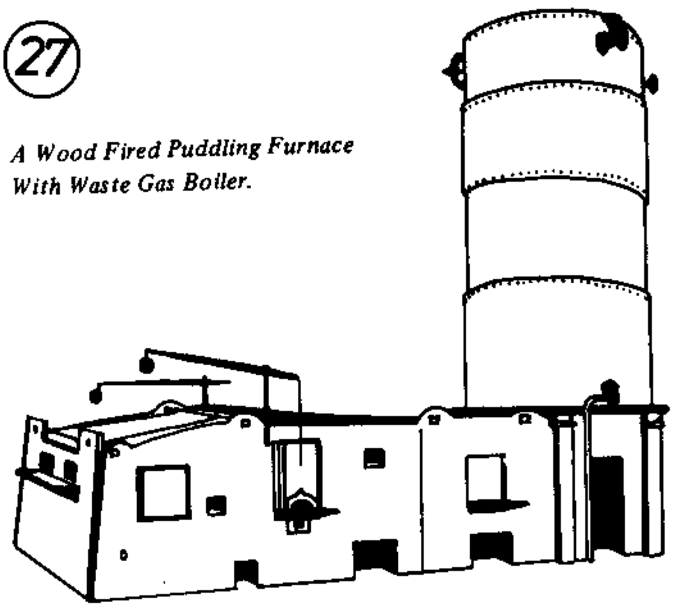
- a large flow of uniform pig iron [112];
- several finery hearths;
- rolling of bar.

26



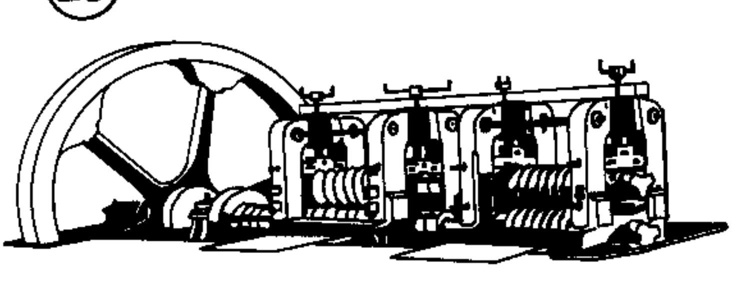
An Ekman Charcoal Reheating Furnace.

27



A Wood Fired Puddling Furnace With Waste Gas Boiler.

28



A Waterdriven Rolling Mill.

The large investment involved was really only justified in large scale works. The system of "privilegier" was abolished in 1846[119]. The first works using Lancashire finery hearths, an Ekman reheating furnace and a rolling mill was Lesjöfors – owned by Ekman[120] – in 1850[121] (see Figure 17). Of course, the reheating furnace could as well be used in conjunction with a wood fired puddling furnace (Figure 27). The first works to use this combination, ie a puddling furnace, an Ekman reheating furnace and a rolling mill was Surahammer – in 1851[122] (Figure 28).

In 1847 Ekman introduced a wood fired reheating furnace.[123] This is similar to the charcoal version, mainly with changes in the gas producer hearth. The wood has to be thoroughly dried in an oven to obtain a sufficiently high temperature in the furnace[124]. Usually combustion gases are used for this purpose. The consequent higher investment and – again – the higher wood transport costs however prevented a general adoption of this method.

Swedish wrought iron production after 1850

The Ekman reheating furnace finally made the application of rolling mills feasible, and Swedish bar iron prices again became competitive. In the mid-1850s the first Swedish railways were constructed[63], with home-produced rolled rails. The increased transport potential caused lower coal prices in the ore fields and higher charcoal prices, due to the now arising competition of other industries[125]. Furthermore, the demand for iron increased, due to lower transport costs. Gradually, coal became the main reheating furnace fuel. Only small changes to the gas producer hearth were necessary to adapt the existing furnaces to coal. The ironic fact remains that after a search of almost 30 years for a charcoal fired reheating furnace, this became obsolete in about the same time due to its own efficiency!

Lundin constructed in 1860-4 a furnace with a gas producer capable of burning sawdust, peat, splitwood, charcoal and mixtures of these. This furnace was the first to use the regenerative principle[126] and a condenser in the gas supply[127], but its main claim to fame is that it became – with minor alterations – the first Swedish open hearth furnace in 1867[128].

After the introduction of the tandem Lancashire finery hearth + Ekman reheating furnace, the German forge could no longer produce competitively. The former process however only works on a large scale. Many small forges had to look for a cheaper small scale process than the German method – or close. They found the Franche-Comté method. This is a mixture of the original Walloon and German methods, in that one hearth is used with two separate tuyeres, one for fining and one for reheating. There is no chafery so fuel for this is saved[129]. The fining operation in a Franche-Comté hearth is very similar to that in a Lancashire finery hearth.

Many small forges were reconstructed in the years 1845-50[130] simply by changing the German hearth to the new pattern. The last German forge in Sweden was presumably that of Rossberga, By, which was blown out in 1894. The Franche-Comté hearth remained in use until the 1880s, although the last one, at Woxna Bruk, was blown out only in 1920[129].

In 1851 the first steam hammer was bought from England (Figure 29). Increasing power demand on restricted sites, the logical effect of concentration, often led to water shortage[131] and difficulties in production. Steam, generated with waste heat gas cost little extra (apart from depreciation of the installations) and was a much more reliable power

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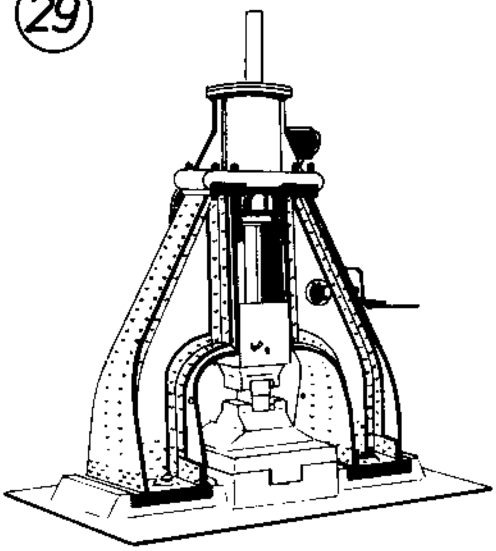
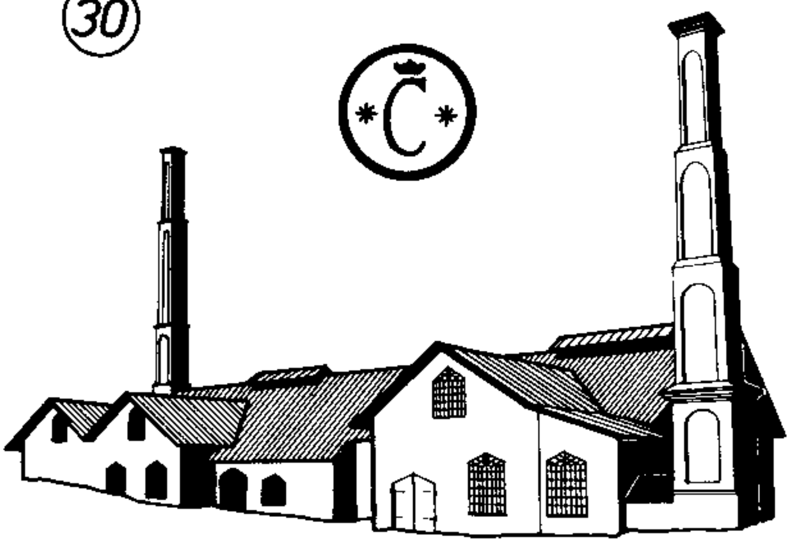


A Bar Drawing Steam Hammer.

30



Lancashire Forge (type 5), Karlholm, Sweden.

source. Steam hammers were considered unsuitable for shingling, though.

All these developments led to a gradually emerging pattern with six types of wrought iron production forges. These are:

1. Small scale forge – one hearth.

   Franche-Comté hearth; a water driven hammer, usually belly-helve.

   Producing bar for sale.

2. Small scale forge – one hearth.

   Lancashire finery hearth; a water-driven hammer, usually belly helve.

   Producing blooms for further working elsewhere.

3. Small scale forge – two hearths.

   Lancashire finery hearth; charcoal chafery hearth[132]; one or two water-driven hammer(s), usually belly helve.

   Producing bar for sale.

4. Medium scale forge.

   Lancashire finery hearths; water-driven – nose helve – shingling hammer; warehouse for blooms[133]; reheating furnace(s); water-driven – occasionally nose helve, usually belly helve – bar drawing and finishing hammers.

   Producing bar for sale.

5. Large scale forge – bar exclusively.

   Lancashire finery hearths or puddling furnaces; water-driven – nose helve – shingling hammer; roughing mill; warehouse for blooms[133]; reheating furnace(s); steam hammers for bar drawing and finishing (Figure 30)

   Producing bar for sale.

6. Large scale forge – universal.

   Lancashire finery hearths or puddling furnaces; water-driven – nose helve – shingling hammer; roughing mill; warehouse for blooms[133]; reheating furnace(s); rolling mills for bars, large and small sections, plate, sheet etc.

   Producing all kinds of wrought iron product.

The general trends are:

– type 1 forges evolve into type 2;

– type 3 forges fade away;

– type 4 forges become manufacturers of blooms or evolve into type 5;

– type 5 forges evolve into type 6.

The influence of liquid steel-making on the hearth fining of wrought iron

The puddling process had virtually wiped out all hearth-made wrought iron by 1850, except for the unique Swedish implementations described. These had gained a very strong hold at the time liquid steel production in Sweden got underway[134].

In 1887 eg 406 Lancashire hearths produced 201500 t/year of blooms[129], and it took to 1895 before total wrought iron production (of forges type 1 to 6 inclusive) was equalled by total liquid steel production (of both acid and basic pneumatic and open hearth methods)[129].

In 1895, a mechanical rabbling device for Lancashire hearths was designed by Lägerwall[135]. This proved very successful, increasing the iron efficiency and the throughput while decreasing charcoal consumption[47] – at the same time lightening the smiths' work (Figure 18)

But the tide was running out, and wrought iron came to be gradually replaced by steel. Still, in 1937, a count of forges gave the results [129] :

Lancashire	41 fineries	24800 t/year
Walloon	7 fineries + chaferies	1600 t/year
German	none	
Franche-Comté	none	
puddling	none	

In the mid 1940s the last Walloon forge was laid down, and in 1964 the last Lancashire forge, at Ramnäs[129].

Part II will be a Survey of the Remains.

Notes and References

NB **Sources: Roman numbers refer to items in the bibliography; arabic numbers to pages.**

1 "Kotlucken" or cinderholes: V,75; XXV,65.

2 In a "Stückofen", a loup of steely consistency – with carbon varying throughout the loup – and some liquid pig iron are produced. The former is called "Massl" or "Stück", the latter "Kraglach" or "Graglach". The "Stückofen" is charged at the top with alternate layers of charcoal and ore. There is just one tuyere, which from time to time during a melt is reset at a higher level to accommodate the growing loup at the furnace bottom. The loup was dragged out after removal of the tuyere wall. A total cycle took about 20 hrs, of which the effective blowing time was 15 hrs. The maximum weight of the loup was about 1000 kg.

3 The tuiron was generally made of copper. It had a circular section, as opposed to the tuiron of a similar hearth used for scythe making, which was oval (long axis horizontal).

4 IV,68.

5 VIII,148.

6 Occasionally one-such works was called "halbe Hammer"; VIII,149.

7 The depth of the hearth proper is about 0.3 m.

8 IV,73.

9 This drawing is based on on-site evidence of the German hearth at Hävla, Sweden (see "Survey of remains").

10 IV,47-8.

11 The plan refers to Storfors, Sweden (XXII,177). It would be very interesting to know whether this hearth worked satisfactorily – it certainly is an unusual design!

12 A Widholm blowing engine consists of a vertical wooden frame with 2 or 3 sets of single wooden bellows on top and an iron crankshaft in bearings at the bottom. The engine is powered by a waterwheel. There is no windchamber; the blast tube is square in section and made from wooden boards.
In the 1830s the wooden bellows were replaced with cylindrical cast iron pistons and cylinders by Ekman (see note 113). He used cast iron tubes; a very small windchamber (about ¼ of the stroke-volume of one cylinder for a 3-cylinder engine and a horizontal offset of the crankshaft of half a crankradius). This – in a single-acting engine – causes a decrease of the wear of the piston seals due to smaller lateral forces during the compression stroke of the cycle.
Fluctuations in flow and pressure of the blast were only partly eliminated by the small windchamber, but this was considered to be advantageous to the iron quality.
Still in the 1830s Bagge modified this engine by using a cast iron frame and – a more important distinction – a much larger windchamber, laid on top across the cylinders (over 7 times the stroke-volume of one cylinder for a 3-cylinder engine). In this form the engine has been used extensively for blast furnaces – and forges also.

13 VI,110.

14 After division the parts of the bloom were first hammered into uniform half-blooms without reheating: III,32.

15 This is generally held to be the cause of the superiority of Walloon iron, since in the Walloon method reheating and hammering was not done by the fining smith at all, so that he could give all his attention to rabbling during melting down: IV,36.

16 IV,33-7.

17 XXVI,19; XXVII,5-6.

18 XII,17; IV,48.

19 XII,17.

20 XI,849.

21 IV,109.

22 England: (1674) 35kg; (1760) 50 kg.

Sweden: (1800) 100 kg.

23 England, Sweden, France: XXV, 67.

24 Siegen in German Westfalen: XXV,67.
It is interesting to note that the restored finery hearth at Liège, Belgium, see Figure 7, has a pig hole, while in a book on the nearby Luxembourg Walloon forges, (XXVIII) a hearth with side supply is shown.

25 XXV,64.

26 XXV,66.

27 XIII,196.

28 XXV,69-70.

29 IV,34; XXV.67.

30 Called "ringer" or "ringard".

31 This is generally held to be the cause of the superiority of Walloon iron over German forge iron: IV,36.

32 Called "furgon" or "fourgeon".

33 Presumably half-blooms were entered from the front, being short; while half bars were entered from the side as they were over 1.5 m long.

34 Although the artist has taken some licence with the laws of perspective, especially in the case of the finery at the right side of the figure.

35 Cited in IV.

36 IV,42. This indicates hot blast, but the report does not make clear how blast was heated. The tuyere is cooled according to the method described in an English encyclopaedia in 1811: XIII,203.

37 IV,44.

38 IV,12.

39 The loups from this hearth were hammered into "stamped cakes" The cakes were divided by chisel and waterhammer into smaller parts that were fagotted after reheating in a coke fired hollow fire (IV,34:44). The billets obtained were drawn out by hammer into bar (30 x 13 mm section), cut into lengths of 28 cm), reheated and rolled into sheets. This process is described in an English encyclopaedia under the entry "Rolling Mill" (XV,328), published 1815. In the same encyclopaedia under the entry "Tin plate" (VII,266), published 1817, a different and rather faulty description is given!

40 IV,38-43.

41 Details of this part are lacking.

42 Though it would seem probable that slag was tapped through the fore plate, leaving the opening under the tuyere-hole free for the connections of the waterbox bottom. This would nicely combine the cooling implements of tuyere and bottom.

43 As opposed to both German and Walloon practice.

44 III,29-31.

45 In the Lagerwall rabbling device it is the latter bar which is moved mechanically.

46 No last melting down with increased blast was performed.

47

		by hand	mechanically
Iron efficiency of Lancashire hearth (no reheating)	%	88.1	89.2
Throughput	t/week	14.4	16
Specific charcoal consumption	hl/t bloom	38	35

48 IV,108-110.

49 With 11% oxidation losses at reheating.

50 Before 1750 only charcoal pig iron was fined in a forge: I,93.

51 II,86.

52 In this period about 90% of Swedish iron came as bar from German forges: 10% came as rough bar (raskenor) from Walloon forges: III,29; IV,35.

53 The fagotted steel is called "Raffinier-Stahl" in German. This term does slightly confuse the issue: no refining takes place!

NB Not only new "Massl" are used in the preparation of "Raffinier-Stahl". Steel scrap can be re-used too (Zerrennen von Schrott). Source: V,109; VI,112.

54 V,84.

55 IV,33.

56 An excellent description of steelmaking in a Swedish German hearth is given by Swedenborg. This is cited in VII,249-50.

57 Although strict regulation of charcoal production and allocation was necessary and forges and mines and blast furnaces had to be separated by rather long distances: VIII,148.

58 V,110.

59 The steel is known under the names of Natural or German Steel: VII,158,248.

NB Using the term German Steel also for Shear Steel (made by fagotting blister bars, ie without melting in crucibles), as in VII,159, is confusing.

60 This pig iron seems to have been grey – not white! : V,85.

61 I,93.

62 IX,76.

63 X,33.

64 This certainly was also partly caused by the facts that:

1 Almost all Swedish Walloon forges were working on pig iron smelted from Dannemora ore – this very high quality wrought iron remained in high demand for cementation kilns and/or crucible furnaces (mainly in England) for steel production far into the 19th century; XI,856,859; IV,33.

2 The Swedish Walloon forges produced mainly "råskenor", ie rough bar (IV,35) ..... thus the chafery charcoal consumption is low compared with bar producing chaferies.

65 IV,25.

66 On the analogy of the cementation kilns . . . although the pots were much smaller!

67 II,110.

68 I,94.

69 See II,105-7 for an excellent description.

70 About 1750 the first charcoal furnaces ceased production: I,93.

71 About 1800 only 10% of English pig iron was still charcoal-smelted: XII,18.

72 Eg Bonawe (Lorn) furnace 1874
Duddon Bridge furnace 1866-7.

73 Heated blast was not available before 1828.

74 In XIII,188 (1811) the hearth is called a run-out furnace; later (XIV,49), in 1873, the name is further corrupted to running-out fire.

75 II,111.

76 Ie to the level normal for fining of charcoal pig.

77 IV,24,44.

78 I,96.

79 XIII,188.

80 XV,328.

81 X,17.

82 XI,849.

83 X,25.

84 IV,10.

85 IV,24.

NB It is interesting to note that, although in the 1820s the Swedish Walloon forges are considered to be rather old-fashioned, the export of Walloon iron – mainly to England for use in cementation and/or crucible steel production – never dropped. The combination of the outstanding Dannemora ore, the French-type blast furnaces (geared specifically to the needs of the Walloon forges) and the long experience with Walloon forges made for highest quality iron, warranting prices almost twice as high as those of Best puddled iron: XVI,35.

86 IV,26.

87

	wrought/ pig iron	
German forge	0.71-0.77	VI,110,111.
Walloon forge	0.77	II,89; XVII,58; I,95.
Dry puddling	0.50-0.56	XVIII,12; I,95.
Wet puddling	0.77	XVIII,12.

88 VI,133.

89 IV,7-8.

90 The thought behind this restrictive policy was to maintain quality, to raise tax, to prevent over-consumption, to obtain well-spread employment and to prevent killing competition.

91 IV,31.

92 About 1:3 : VI,98.

93 About 3:1 : VI,99.

94 IV,15.

95 XI,850.

96 Though dried, usually with the combustion gases of the fining and/or reheating hearths or furnaces: IV,89.

97 Due to insufficient homogeneity of temperature: IV,11.

98 XI,850-1.

99 IV,10.

100 IV,23.

101 Even the newly-introduced types of hammer from England could not compete with rolling; these are:

1830 The nose helve shingling hammer: formerly both shingling and bar drawing were performed under belly helve hammers;

1836 The belly or tail helve with a detachable T-piece: with this hammer both "räckning" or drawing and "slätning" or finishing could be performed from the same position without changing the hammer insert.

The latter hammer made a higher throughput possible, while the minimum bar dimensions that could be made in one heat became smaller: IV,70.

NB The T-insert for a hammer is already described in an English encyclopaedia, in 1811: XIII,197.

102 IV,11-2.

103 IV,46.

104 Waern first used a charcoal chafery, but afterwards discovered that his cost price was 25% higher than his selling price: IV,45. A suitable reheating furnace was not yet available, so rolling was impossible. Waern thus had to sell his iron as "råskenor", rough bars for cementation, to England, though its quality and in consequence, its proceeds were in no way comparable to those of Swedish Walloon iron. See note 85.

105 Waern's agents in England were Cowie and Brändström, Hull: IV,45,60.

Smiths: foreman Sam Houlder, with 3 sons and his son-in-law Whittington and their families came from Garnderis and Abergavenny, Monmouthshire: IV,45,50,60.

106 In the early 1600s the Walloon process was introduced in Sweden in a similar manner: both technique, gear and labour were imported. In this case a complete technology, from blast furnace to forge inclusive, was brought to the Uppland area around Dannemora. It is interesting to note, that this resulted in a more-or-less closed iron community, into this century, even, and that the technology did not spread to other places. In the case of Bäckefors, only part of the South-Wales process technology was used, thus making final success dependent on adaption.

107 IV,37-9.

108 IV,25.

109 In the Söderfors hearth, eg, pig iron was not – as in Ulverston(e) – fed a la Walloon in "gueuses" but in small pigs à la German: IV,39; XI,853.

110 IV,40-58.

111 1830 Dormsjö – drops the process very quickly again
Söderfors

1831 Ferna
Furudal
Dådran – drops the process very quickly again
Lesjöfors

1833 Mackmyra

1834 Liljendal
Fagersta
Hammarby
Forsbacka
Engelsfors

112 Better homogeneity and constant quality of pig iron are gradually obtained by:

– improved ore roasting techniques;

– higher blast pressure and larger blast flow;

– hot blast.

Significant improvements are not realised before the 1840s.

113 Ekman did design a new blowing engine for the new hearth in Ferna Bruk, which truly is a predecessor of the very well-known Bagge 3 cylinder blowing engine. The extra investment of a new blowing engine often was not authorized and the change-over to the Lancashire finery hearth then just consisted of a reconstruction of the existing German hearth.

114 IV,48.

115 Amongst others Lesjoförs and Munkfors: IV,58.

116 Amongst which 2 puddling works and 6 Walloon forges.

117 It is interesting to compare this description and the date – 1842 – with those of the Siemens patent for a gas producer!

118 Naes (N).
Horle Bruk
Finspång
Munkfors
Geijersholm
Gustafsfors
Uvanå
Likanå
Fentå

119 IV,112-8.

120 XIX,40-65.

121 IV,94.

122 XX,8.

123 IV,89.

124 The same type of wood fired furnace is also used to heat iron in the production of forgings. In this case a lower temperature suffices, and air-dried wood can be used.

125 Glass, eg.

126 Patented by Siemens, but according to Lundin he was mainly inspired by John Ericson's hot air engine of the 1830s: XXI,55.

127 Lundin's own invention.

128 It is claimed that the Martins in France were guided by Lundin's experiments of 1864 and that Lundin really was the first to successfully melt low carbon steel in an open hearth. As he had to replace the furnace lining after each melt, his hardly was a feasible furnace. The Lundin furnace was improved 1867-8, after his sudden death, by Rinman who had previously visited the Martins' works and obtained details of their furnace lining. The successful implementation of the open hearth furnace method thus seems to have been a case of interaction of French and Swedish developments, rather: XXII,216-23

129 XI,856.

130 This method is certainly older, eg it was observed by Ekman in the Low Countries in 1828 (IV,35). The introduction in Sweden depended on two factors:

1 the economic need to replace the German hearth;
2 the creation of necessary technique.

It is interesting to see that only when the Lancashire hearth method had matured, smiths migrating from the larger forges to smaller ones spread the necessary (fining) technique – the small forges never could afford research of their own, or import technological knowledge.

131 It was quite usual that in a "bad" year a forge had to cope with serious water shortages for half the year; XXIII,3.

132 Usually the former German hearth, reconstructed.

133 In contrast with the forges type 1 and 3, the hammered blooms are kept in store – often to be supplemented by blooms from a forge type 2 – and pre- and reheated before further working. The loss of heat from the finery is amply compensated for by the much increased flexibility in production.

134 Bessemer blowing from 1858;
acid open hearth from 1867-8;
basic processes from 1890;
electric furnaces from 1900.

135 XXIII,11.

136 XXIX,25-8.

Bibliography

I Morton, G R: The wrought iron trade of the West Midlands; JISI; Feb.1973; 93-105.

II Tylecote, R F: A history of metallurgy; The Metals Society, London; 1976.

III Nisser, M: Engelsberg Bruk – en vägledning; published by: Johnsonkoncernens Centralarkiv, Engelsberg Bruk, Sweden; 1976.

IV Ekman, G: Gustaf Ekman – Svenska järnhanteringens nydanare för 100 år sedan; Jernkontorets Berghistoriska Skriftserie No.12; Jernkontoret, Stockholm; 1944.

V Zeitlinger, J: Sensen, Sensenschmiede und ihre Technik; Jahrbuch des Vereines für Landeskunde und Heimatpflege im Gau Oberdonau, 91. Bd.; J. Wimmer, Linz, Austria; 1944; 13-178.

VI Hinz, F L: Die Geschichte der Wocklumer Eisenhütte 1758-1864; Altenaer Beiträge, Bd.12; 1977.

VII Rees, A: The Cyclopaedia; 1819-20. Reprint of those entries related to the manufacturing industries; Cossons, N (Ed.); David & Charles, Newton Abbot, England; 1972. Part V: Slate - Zinc.

VIII Wehdorn, M: Die Baudenkmaler des Eisenhüttenwesens in Österreich; VDI, Düsseldorf; 1977.

IX Nisser, M (Ed): Industriminnen; Liber Forlag, Stockholm; 1979.

X Sveriges Industriförbund; Sveriges Industri; Esselte A.B.; Stockholm; 1967.

XI Wibert, M: Järn- och ståltillverkningens utveckling i Sverige under åren 1817-1967; Jernkontorets Annalers Jubileumshäfte; Vol. 150 (1966); 849-890.

XII Saager, H: Zweieinhalbjahrtausende Eisengewinnung in Westfalen; Technische Kulturdenkmale; Vol.11 (1978); 9-19.

XIII As VII, Part III: Forge – Molosses.

XIV Bloxham, C L: Metals, their properties and treatment; Longmans, Green & Co., London; 3rd ed. 1873.

XV As VII, Part IV: Montgomeryshire – Silver.

XVI Barraclough, K C: Sheffield Steel; Moorland Pub. Co. Hartington, England; 1976.

XVII vanLaun, J: 17th c. ironmaking in S W Herefordshire; JHMS; Vol.13.2 (1979); 55-68.

XVIII Gale, W K V: Iron and Steel; Moorland Pub. Co. Hartington, England; 1977.

XIX de Geer, G: När järnet bröt bygd; Bonniers, Stockholm; 1975.

XX A brochure of Surahammars Bruksmuseum, Surahammar, Sweden.

XXI Hellgren, O: J F Lundin och hans ugnskonstruktioner; Daedalus; Tekniska Museet, Stockholm; 1946; 52-63.

XXII Andersson, I: Uddeholms historia; Norstedt & Söners Förlag, Stockholm; 1960.

XXIII Lindh, R: Åtgärder vidtagna vid Korså Bruk för att öka produktionen och stabilisera driften; 1965

XXIV Sahlin, C: Det 100-åriga ölet i Dannemora Bergslag; Daedalus; Tekniska Museet, Stockholm; 1935; 88-94.

XXV Schubert, H R: Early refining of pig iron in England; lecture at the Iron and Steel institute, 9/1/1952.

XXVI Sanger, H: Ein Platz in der Geschichte der Technik; Technische Kulturdenkmale; Vol.4 (1972); 18-23.

XXVII Sonnenschein, F H: Die Entwicklung der Technik im "Markischen Raum"; Technische Kulturdenkmale; Vol.7 (1974); 3-11.

XXVIII Wagner, J: La siderurgie Luxembourgeoise.

XXIX Morton, G R: & Wingrove, J: The charcoal finery and chafery forge; BHMG; 5.1 (1971); 24-9.

Alex den Ouden is a Netherlands industrial archaeological consultant who specialises in Iron and Steel primarily of the last 300 years. He is a very active member of the HMS and recently has put forward a project for a museum of steel.