CHARCOAL-FIRED BLAST FURNACES ; CONSTRUCTION AND OPERATION

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There are a number of blast furnace remains in the Forest of Dean and South Wales, but many of the older furnaces are in such a state of decay, that the untrained eye has difficulty in understanding how they once operated. True, there are books and papers to which the enthusiast can refer [2], but these give either too detailed an account of particular furnaces, or they are scattered through various journals.[3] The purpose of this paper is to convey a general idea of how iron was made in charcoal-fired blast furnaces, while at the same time providing more detailed references for those who require them.

Blast Furnace Chemistry

To understand the blast furnace process, it is necessary to consider, albeit in outline only, the chemistry of iron manufacture [4] The raw materials for smelting iron comprise iron ore, a carbon-bearing fuel, a flux, and air. The function of the blast furnace is so to work these materials that molten iron may be formed.

The main constituents of iron ore are iron oxide, and the earth-forming oxides of silica and alumina. The would-be ironmaker has therefore not only to extract the iron from the ore, but also to cope with the unwanted materials: these are known collectively as the'gangue'.

In the blast furnace, the iron oxide is reduced with carbon to give iron and carbon monoxide. But since this reaction absorbs heat - is endothermic - sufficient heat has to be generated to allow the reaction to proceed: the reduction of iron oxide with carbon will not take place at temperatures below 800^{0}C. To achieve such a temperature, most of the carbon charged to the furnace is burned, air being forced into the lower part of the furnace to assist in the combustion. The burning of the fuel's carbon together with the oxygen in the air blast forms carbon monoxide, and produces the heat necessary for the reduction of the ore: the process gives out heat, is exothermic.

At the same time, the gangue in the ore is fluxed, generally by limestone, to form a fluid and workable slag. Although the fluxing reactions are not essential to iron production, they do make life much easier for the ironmaker, since his non-gaseous waste products can be flushed from the furnace in a fluid state. The oxides silica and alumina both have very high melting points, and they will not fuse at the temperatures normally generated in a blast furnace. Before limestone was used as a flux, these cinders tended to collect in the bottom of the furnace, so that periodically the hearth had to be opened to allow the ash and clinkers to be cleared away. When limestone is used, the furnace heat calcines it to lime, and this forms various double and triple oxides with the silica and alumina. Such combined oxides have much lower melting points than do the single oxides, and in this combined state they can be melted to form a fluid slag.

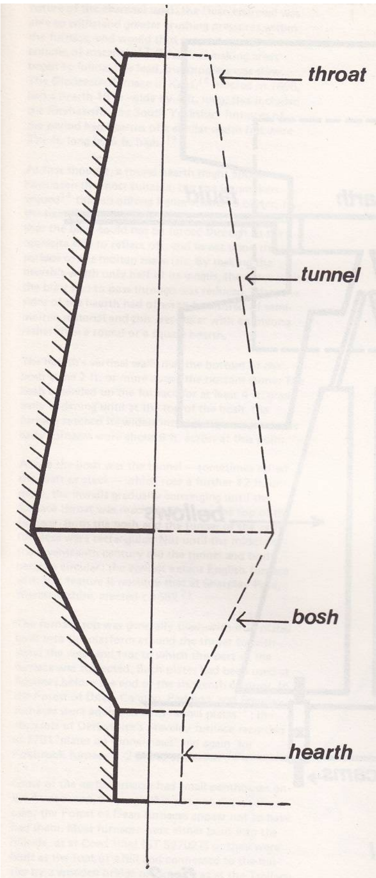
Three other elements merit attention: manganese, phosphorus, and sulphur. Generally, manganese is a desirable addition, whilst the other two are not. Phosphorus appears in the ore as phosphorus pentoxide, and manganese as manganous oxide. Phosphorus pentoxide has a stability similar to that of iron oxide, so that during smelting nearly all the phosphorus finds its way into the metal. On the other hand, manganese oxide is more stable than iron oxide, but not as stable as silica; hence the manganese divides itself between the metal and the slag.

Finally sulphur, which enters the furnace either in the ore, or more usually in the fuel. This unwanted element causes the iron to be brittle and weak, and its intrusion is always to be guarded against. Sulphur divides itself between the slag and the metal, although the presence of manganese will encourage it to enter the slag.

The Blast Furnace Shape

The chemical reactions within the blast furnace have also dictated the furnace's shape[5] Rather than use a simple, cylindrical furnace, ironmakers found it necessary to provide a furnace whose internal shape mirrored the physical changes that took place in the raw materials. The internal shape of the furnace thus came to have four clearly defined zones: the throat (tunnel head); the stack (tunnel); the bosh; and the hearth. (Fig. 1).

The furnace inwalls diverge from the throat downwards because the raw materials swell as they pass into the hotter regions of the furnace. At the bosh, the inwalls contract to restrict the descent of the stock, holding it until such time as the necessary gases have been given off - which in turn reduces the volume of the materials - and allowing the molten iron to filter into the hearth. Although furnace design depends essentially upon the nature of the materials being worked, the distinctive shape of the blast furnace is unmistakable. It is a shape it has kept since its introduction; but then the furnace's role and its manner of fulfilling this role have remained fundamentally unchanged.



FURNACE ZONES fig 1

Early Blast Furnace Construction

The early furnaces were of rectangular section, and built of stone, the outer walls being given a batter such that the area of the furnace top was less than that of its base. (Fig. 4). But at some furnaces, the builders went too far, and provided too great a slope for the furnace's walls. The result was that the stonework weathered quicker, the rain and frosts taking a greater toll, and the direction of the furnace's weight was thrown upon the inside of the hearth, causing it to give way, and sometimes breaking the furnace apart.[6]

Many furnace casings cracked during a first heating, but this did not necessarily prevent their being successfully worked. Some furnaces were surrounded by a framework of timber to preserve the casing, and to prevent the stones moving out of alignment[7]. This was an expedient that had been adopted at least since the sixteenth century. The furnace at Panningridge, Sussex, was reputed to have been so constructed in 1549,[8] and a report on the Forest of Dean's Parkend furnace in 1635[9] noted that 'the furnace and the binding beams thereof' were cracked and not fit to work.

Possibly the greatest enemy of the masonry furnace was moisture. The facts that the early furnaces were blown by water-activated bellows, and were often built into a hillside for ease of charging, both increased the problem.[10] Furnacemen had early learnt that a furnace tended to draw moisture from the ground beneath it. If these 'damps' were allowed to enter the hearth, then the whole structure was in danger of being destroyed. Originally, a series of trenches were dug under the hearth to guard against moisture encroachment,[11] and by the seventeenth century furnaces were constructed with a stone-lined moisture chamber under the hearth. This chamber was covered either by a large stone, or, as at Darvel furnace, Sussex (erected c. 1649) by an iron slab.[12]

On top of this was placed a layer of sand to carry
the hearthstone. This formed the basis of the furnace's interior. So that the moisture could be led away from the danger zone, a pipe or vent was constructed, allowing fresh air to circulate under the furnace.[13] Care was taken to keep this chamber clear at all times. (Fig. 4, page 13).

Parkend furnace, built in 1612, had a 'penthouse' under the hearth to collect ground moisture, [14] and the accounts of the 1710 campaign at Foxbrook furnace, Derbyshire, recorded 'taking up soughs in furnace, and false bottom'. [15]

The hearth, built of fire resistant sandstone,[16] was of a rectangular shape, its dimensions varying with the furnace size. The Forest of Dean hearths measuring 4 ft. high and 2 ft. across, began to give way to larger dimensions from the mid-seventeenth 2 century, an improvement made possible by the nature of the charcoal used: the Dean charcoal was able to withstand greater crushing pressures within the furnace, and would thus support a greater column of materials.[17] Other ironmaking areas began to follow this lead, but progress was slow. The Gloucester furnace in Kent,[18] erected in 1695, had a hearth 18 in. wide by 4 ft. long; this included the forehearth. The South Yorkshire furnaces of the period had hearths of a similar width but were 2$^1/_3$ ft. long by 5 ft, high.[19]

At first thought, a round hearth might appear to have been the most suitable, but the ironmakers argued [20] that an oblong figure answered better. If the hearth were round or square, they maintained that the blast could not be forced through to the opposite side to reflect off, and to act upon the surface of the molten materials. By making the hearth's width only half of its length, the space which the blast had to pass through was reduced. Also, the sides of the hearth had often to be cleared of semi-molten material and this was easier with an oblong rather than a round or a square hearth.

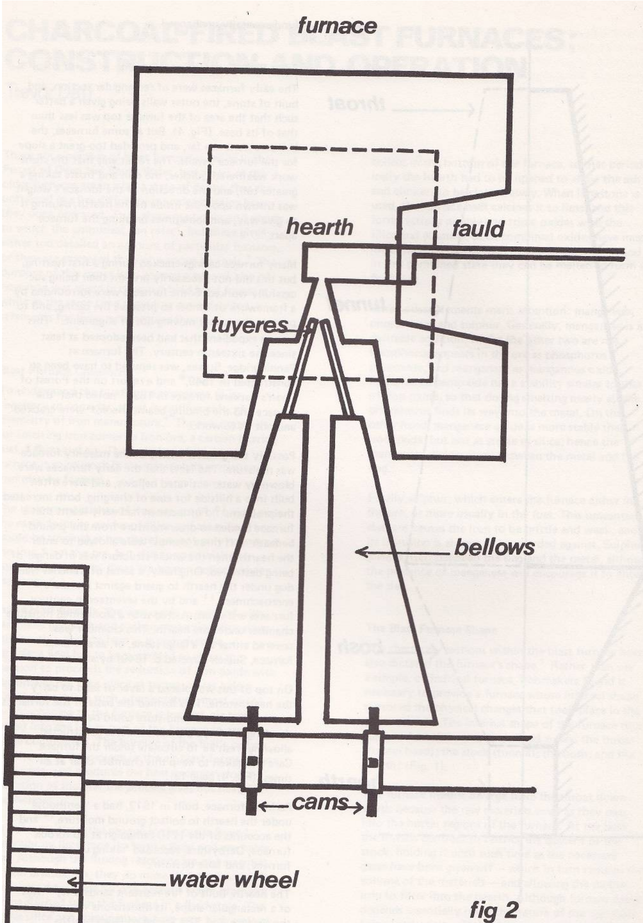


fig 2
HEARTH ARRANGEMENT PLAN

The hearth's vertical walls met the bottom of the bosh some 2 ft. or more above the bottom stone. The bosh extended up the furnace for at least 4 ft. gradually widening until at the top of the bosh, the furnace reached its widest internal measurement; the early furnaces were about 6 ft. across at this point.

Above the bosh was the tunnel - sometimes called the shaft or stack - which rose a further 12 ft. or more, the inwalls gradually converging until the furnace throat was reached. This was the top of the furnace. Both the bosh and the tunnel of the early furnaces were rectangular. Not until the middle of the seventeenth century did the tunnel and bosh become circular: the earliest extant English furnace with this feature is possibly that at Sharpley Pool, Worcestershire, erected c.1652.[Z1]

The furnace top was generally tiled, with iron plates built into the platform around the throat to withstand the wear and tear to which this part of the furnace was subjected. Such plates had been used at furnaces before the end of the sixteenth century. In the Forest of Dean, Cannop, Parkend, and Soudley furnaces were equipped with tunnel plates [14] ; the accounts of Derbyshire's Staveley furnace recorded in 1701 'plates on tunnel head' and again 'for Foxbrook furnace ... 2 plates on tunnel'.' s

Some of the early furnaces had small penthouses on the furnace top, although this was not always the case: the Forest of Dean furnaces appear not to have had them. Most furnaces were either built into the hillside, as at Coed Ithel (ST 527027) or they were built at the foot of a hill and connected to the hilltop by a wooden bridge or ramp," as at the Trellech (Woolpitch Wood) furnace (ST 486046) and Gunns Mill (SO 675159). Such an arrangement made charging easier. On the hill behind the furnace stood the bridgehouse in which the raw materials could be stored ready for charging.

The throat dimensions were very small, and they remained so until the closing years of the eighteenth century. The South Yorkshire furnaces, standing 20-25 ft, high had tunnel mouths of little more than 20 ins across.[22] Even when furnaces of 28 ft. high were being worked, the throats remained only 1$_1$/2-2 ft. wide.[23] The justification for this practice was the conservation of furnace heat,[24] but adherence to small throats was to cause trouble during the early nineteenth century.[25]

The furnace lining was of either stone or brick. The Derbyshire furnaces at the beginning of the eighteenth century were stone-lined: Foxbrook (1700) 'getting stone for mending tunnel'; Staveley (1708) 'stone for mending tunnel'.' s In 1739, it was intended to reline the tunnel of the Barnby furnace, Barnsley, with stone.[26] The Forest of Dean furnaces had stone linings, [27] as also did the furnace at Coed Ithe1.[28]

The furnaces in Sussex were brick-lined '[29] the Waldron furnace paying £4. 10. 0 in 1704-5 'for bricks to build the tunnel .'[30] Bricks were used at Staveley for the 1710 campaign.' s The late seventeenth century Midland furnaces were also lined with brick,[31] the easily obtainable Stourbridge Clay being used for furnace repairs.

Between the primary and secondary lining was a 2-3 in. gap filled with earth, sand[32] small stones,[33] or fuel dust.[34] This was to allow the inner casing to expand without damaging the rest of the fabric. Thus, if the filling materials were rammed too tight, this could lead to steam generation, and would certainly have placed expansion strains upon the outer stonework as the furnace shell became hotter. The result could have been the rupturing of the furnace casing, and the weakening of the furnace structure.

Standing behind the primary lining, the secondary lining did not have to withstand the same rigorous treatment, so it was possible to use for it a less refractory stone. The space between the secondary lining and the outer casing was filled with rubble.[35]

The primary lining was essentially expendable. During a campaign it tended to wear outwards, resulting in an unsafe and often unworkable furnace. A new hearth and bosh was put into the furnace after each campaign [36]; the tunnel lining tended to last longer than one blast. To enable the lining to be repaired without disturbing the rest of the masonry, the lining of the shaft was often accompanied by inbuilt iron bars which supported the upper lining during hearth repairs, or allowed the primary lining to be renewed without disturbing the secondary lining.

Providing the Blast

The blast was provided by a pair of leather bellows activated by cams from a water wheel shaft. (Figs. 2 & 4). The size of the wheels and of the bellows varied with the furnace size. The early plants were equipped with wheels of some 15 ft. diameter, operating bellows some 12 ft. long by 3 ft. wide at the broadest end.[37] These dimensions gradually increased, so that by the seventeenth century the Lydbrook furnace was worked by a wheel ft. high, and the other

Forest of Dean furnaces - Cannop, Parkend, Soudley - reputedly had wheels 22 ft. in diameter.'[a] The bellows in the Forest by this time had become 18 ft. long and 4 ft. wide at the breech,[38] dimensions similar to those at Backbarrow in 1711.[39] The South Yorkshire furnaces had smaller bellows, 15 ft. long and 3'/z ft. in the breech 40

To obtain the maximum power from the water, the furnace wheel was generally overshot. In the Forest of Dean, the wheels were fed by troughs cut from pieces of solid timber, and caulked with pitch, tar, and oakum.[41]

The water wheel shaft turned on cast iron gudgeons. Usually, as at Parkend and Cannop *42* the shaft was hooped with iron bands for added strength. A series of cams mounted on a collar rotated with the shaft and pressed down on pieces of timber (firketts in the Forest of Dean) specially placed on the upper bellows boards to take the force of the wheel [43]

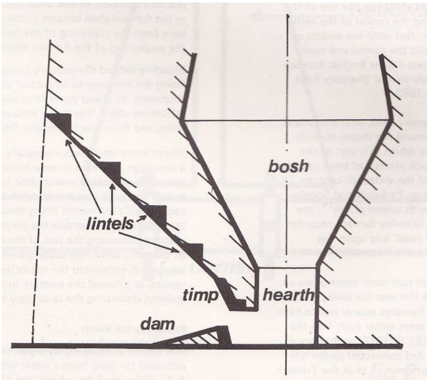
The top and bottom boards of the bellows were made of thick ashwood planks; in 1703, Staveley paid for 'squaring ashwood and sawing it into bellows boards'." The boards were lined on the inside with hide, tinplate, or sheet lead, and later with iron plates. The accounts for Staveley in 1705 recorded the purchase of a 'plating hide' possibly cow hide. 15

The South Yorkshire blast accounts made frequent reference to such purchases. Sheepskins were used for the air valves. The bellows head was packed with wool, hair, or moss. The bellows skins themselves were of bulls' hides, well lubricated on the inside with butter, tallow, or other grease.

After each depression, the bellows were forced open again by a counterpoise. This was either a long, springy branch or sapling, anchored to the ground by heavy stones [44] ; or a set of planks with counterweights on one end. At Cannop, 3'/z cwts. of iron was used to weight the counterpoise.'[a] Attached to the back of the bellows was a frame to prevent the skins' straining during the return stroke.

As the water sheel rotated cams on the shaft depressed the belows, forcing the air into the furnace; the counterweights then pulled them open again ready for the next blow.[45] Usually, two sets of bellows were employed so that while one was blowing into the furnace, the other could be taking in air. In this way, a reasonably constant blast could be maintained.

But the blasts were very weak. It was estimated that as much as half of the air escaped through the bellows boards, the stitches, or rents in the skins. In fact, the bellows were a source of constant trouble; the skins had to be kept well greased, and any punctures had to be patched over as well as might be. It was not unknown for the air valves to jam, causing the bellows to draw in air from the furnace, with the result that the skins were scorched, or even set alight.46



SECTION THROUGH FOREPART fig 3

Issuing from the front end of each of the bellows was an iron pipe, the orifice of which was about 3 in. diameter; this pipe extended some 3'/z ft. towards the furnace, and reached back 6 in. inside the bellows. Two feet of the nozzles' length was inserted into the tuiron in the furnace wall, the nozzles converging until they were only about 6 in. apart. From the end of the nozzles to the hearth was a further 1'/a ft. The nozzles were rarely taken closer to the hearth, the ironmakers affirming that to do so would impair the blast. By leaving the tuyere open in this way, problems of blast recoil were also reduced.[47]

The tuiron was a quadrangular canal, wide at the outer end near the bellows, but contracting sonically towards the hearth, the bottom of the tuiron being level. The tuiron was made of stone and slag, set in sand and clay. Its bottom was covered by a triangular iron plate [48]which sloped inwards at the angle thought necessary for successful working. The purpose of this plate was to carry the nozzles and to keep them blowing into the hearth at the required angle.

The tuyere hole, through which the blast entered,
was a foot or more above the base of the hearth, the space below the tuyere often being called the 'crucible'. This connected laterally with the forepart, the roof of which, as with that of the tuyere arch, was strengthened by a number of inbuilt iron lintels: (Fig. 3). The furnace at Gunns Mill shows this pattern of construction quite plainly. Wooden beams were sometimes used, but often with little success. The weight carried by the lintels was so great that even cast iron lintels were known to fail under the strain; and wooden lintels were also liable to catch fire .49

The taphole was situated on the side of the furnace adjacent to the tuyere wall. The corner of the furnace between the two apertures was called the furnace pillar. The roof of the forepart sloped downwards from the furnace exterior to the taphole. Immediately above the taphole was the timp stone, protected by an iron plate - the timp plate[50] - set into the masonry. On the ground beneath this, set a little further out from that taphole was the dam stone, and this too was usually protected by a plate - the dam plate[s]' The vertical distance between the top of the dam and the timp was about 6 in. (Fig. 3). On each side of the aperture between the timp stone and the floor, the masonry was protected by vertical iron plates called buckstaves.[52] Each of these items appears in the accounts of the Forest of Dean furnaces, [14] and they are recorded in the books of Backbarrow[53] and Invergarry,[sa]

The lower part of the furnace, and certainly the expensive bellows, was usually enclosed in a furnace house, a stone-built structure originally covered with thatch, but later with wood and tiles. The furnace house also covered the pig beds in front of the taphole.

Furnace Operation

The first job with any new furnace - or new lining - was to dry the masonry. The bottom and sides of the hearth were lined with common bricks set on edge; their purpose was to prevent the stone from splintering when the initial heat was applied.[55] A temporary fireplace was built in front of the furnace, with side walls high enough to reach under the side of the timp plate. A fire was kindled on the bars, and fed with fuel until the furnace had dried out - a period of up to two weeks. [56] The empty stack acted as a chimney to draw the fire.

In the blast account of Foxbrook for 1714-15 was recorded the payment of a shilling for 'tending fire to neat the hearth." [s] Thomas Cope wrote to William Spencer during November, 1740, that he had been to Barnby furnace where 'fire has been in a week, and they begin to blow tonight.' 57

When the furnace had been thoroughly dried out, the fireplace and the protective brick lining were removed. Charcoal was placed in the hearth, and ignited well. Gradually, the furnace was filled with fuel, and once filled a small quantity of ore was added to the charge. Slag, too, was sometimes added to provide a protective cover for the new hearth stones.[58] As matters progressed, so the amount of ore charged was increased.

Two or three times each day, iron bars were inserted through the taphole to support the charge whilst the cinder was removed.[59] As the iron melted, it passed through the bars to the hearth. Once the cinders had been removed, the burning fuel was allowed to fall, and was brought forward with iron bars to a level nearly of the dam. The space between the surface of the hot fuel and the bottom of the timp plate was rammed with strong, binding sand and charcoal, and covered with charcoal dust. [60]

When the iron was seen trickling down in front of the tuyere, the tuyere hole was lined with fire clay and loam, [61] and the bellows made ready to blow. Initially, only a very light blast was used, the amount of water falling onto the wheel being kept small, and a narrow discharge pipe being fitted to the bellows. Later, as more normal working was achieved, the blast was increased.

Slowly, the slag level rose to the notch in the dam plate, and passed over it to the slag pits: At the commencement of operations, the slag contained much carbon, and was a black colour: the iron, short of carbon, was white. Much of this iron was later recharged. As the furnace temperature increased, and more ironstone was charged, the slag became white, and the metal became grey.

The molten iron, being heavier than the slag, accumulated underneath it. When the iron was nearly over the dam, the blast was turned off, and the sand fauld (fold) that had closed the gap between the furnace side wall and the dam stone, was broken down, allowing the metal to run out.

In preparation for this, some 15-30 minutes before the iron was cast, the moulds were made ready. The ground in front of the furnace was covered with coarse sand 8-9 in. deep. Water was thrown on the sand to moisten it, and to make it hold together, although care had to be taken not to add too much water, since this would cause the molten iron to boil, and even to explode. Where the iron seemed likely to do this, moist sand was thrown over it to form a crust on the metal, and thereby to avoid an accident.

The sand was worked with a spade to form a trench leading from the furnace; further, shorter trenches were prepared running at right angles to this main one. The sides and bottom of the trenches were smoothed with burnt sand or ashes, and each trench possibly stamped with the maker's mark.[62] The main trench was to hold the sow iron, and the smaller ones the pig iron, the analogy being that of a sow suckling her young.

When the molten metal had filled a mould, moist sand was sometimes thrown upon the pigs where they joined the main runner; this made the iron easier to break when cool. Even when in full blast, the early furnaces made only about 50-60 cwt. of iron each 24 hours.[63]

After the iron had been taken out, the slag which had floated on top of the metal began to run from the furnace. Every effort was made to prevent the slag running onto the pigs. The entrance to the iron runner was blocked with sand, forcing the slag into the slag pits, and protecting the iron pigs.

The hole that had been made in the fauld was not made at the bottom of the hearth, so that there was always some slag and metal left in the furnace. This slag tended to be less fluid than that obtained earlier. In order to drag it from the hearth, a larger opening was made in the dam, and the workmen used iron bars called ringers (ringards)[64] and hooks to guide the material out. At many furnaces, this slag was reworked to extract the high proportion of iron it contained.

The furnace was then cleaned of any pasty material that adhered to the hearth walls. Every wall and corner was scraped by iron bars being introduced through the taphole. Iron bars were also inserted through the tuyere to dislodge any slag that might impair the blast. The materials fell into the molten bath where they were melted when the air was reintroduced.

This completed, the space between the dam and the timp was filled with charcoal, sand, and clay, the furnace heat baking this to form a protective wall against the furnace reactions. The bellows were then set going, and the furnace charging resumed. After a couple of hours, some furnacemasters again took off the blast, opened a hole above the dam, and endeavoured to remove such slag as had earlier proved too difficult; the increased amount of iron in the hearth had by this time raised the level of the molten slag, and made it easier to drag the pasty materials clear. The hole was afterwards stopped up, and the furnace set going again.

Charges of roasted ore, fuel, and fluxes, each material having been screened to remove the smaller particles, were constantly tipped into the furnace throat, the fillers measuring the depth of the stock-line periodically by dropping an iron rod into the furnace top. This rod was fastened to a wooden handle, and looked very much like a flail.[65] When the stock had fallen sufficiently, further baskets of material were added, the charcoal being thrown in first, followed by the flux and the ore. So long as the furnace remained free of trouble, the sequence of charging and casting continued unabated, the cycle between casts being one of 12 hours.

But furnace campaigns tended not to be very long, traditionally the furnaces were blown-in during the late autumn, and were worked through the winter. The summer stand-down was used to replace the furnace hearth, to renew the bellows, to clear the water courses, and to carry off the slag. The time was also spent in gathering wood, and converting it into charcoal ready for the following campaign.

In reality, the situation was not as simple as this. Many furnaces were prevented from summer working, not by lack of fuel, but through lack of water. Talking of the Wealden iron works at the beginning of the seventeenth century, Norden noted that 'they work not all, all the year; for many of them lack water in the summer to blow their bellows.'[66] And in August, 1653, several Sussex ironmakers said they had no water, and could not promise to deliver ordnance until March.[67]

During 1696-97, the Vale Royal furnace was blown out because of lack of water, after labourers had been paid to drain pools in the Forest of Dean to keep the furnace supplied.[68] In 1725, the Backbarrow furnace was kept in blast by men using the wheel as a treadmill, and pumps were used regularly to pump back the water over the wheel so that it could do service again. [69]

But the story of summer shortages was not the same everywhere. Johnson has noted that the Foley records made no mention of the water wheels being turned by men or horses, and his evidence does not indicate that the furnace campaigns were restricted to the winter.[70] Neither did the Coed Ithel furnace in Monmouthshire, in blast c.1651 to c.1717, appear to suffer from lack of water. In discussing this furnace Dr. Tylecote pointed to the lengths of the campaigns - 61-62 weeks - to support his argument. [71]

Where the campaign was not restricted by fuel or water shortages, it was limited by the length of hearth life. The hearth gradually wore thinner as the campaign continued, so that if the furnace were not blown-out, the molten iron and slag would soon come upon stones that were little capable of resisting the heat. This limit was rarely reached, since beyond a certain stage, the hearth became so much enlarged, that the smelting operations were hampered.[72]

Large masses of semi-molten material began to form in the hearth such that the weak blast could not melt them. These masses were sometimes called 'foxes', 'bears' or 'deadmen'. The most common cause of these was the splintering-off of pieces of the hearth's lining; this was more likely to occur with a worn hearth. These pieces could not be melted in the fire and they floated on the slag, gradually collecting semi-molten material. They might also be formed if the hearth bottom was cooled by moisture collecting on the stone's underside; in this case, semi-molten materials began to build up from the base of the furnace. The cooling of molten slag at the tuyere could also form such obstructions. It was thus very important that the hearth be properly cleaned after each cast.73

If these masses were allowed to remain, they grew to such a size that they became too big to draw through the furnace front, and it was necessary then to knock down the furnace wall. These masses also took up valuable space in the hearth, leading to a cooling of the furnace, and a reduction in output. With the weak blasts in use, any obstruction in the hearth was likely to cause problems. When this occurred, it was time to blow out, and to clear and renew the hearth. And so the sequence of events was repeated.

ACKNOWLEDGEMENTS

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5	G.D. Elliot and J.A. Bond op cit. 1-7.	17	17 D. Mushet, op cit. 47; H.R. Schubert, 1957, op cit. 206-7.
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8	H. R. Schubert, 1957, op cit. 196 n.7.		See also A. Raistrick and E. Allen, 'The South Yorkshire Ironmasters, 1690-1750' *Economic History Review (9)* 1938-39, 168-85.
9	The most famous illustration of this type of arrangement is possibly the Richard Lenard fireback of 1636 depicting the Brede or Sackville furnace, Sussex. Negative No. 42/58 Science Mus. London. On Parkend, see below, note 14.	20	20 Swedenborg in W. Lewis, op cit. (4) f 118e.
10	Swedenborg in W. Lewis, op cit. (4) f 11 8a. 11 H.R. Schubert, 1957, op cit. 197.	21	21 M.M. Hallett and G.R. Morton, 'Yarranton's Blast Furnace at Sharpley Pool, Worcestershire' *Iron & Steel Inst. Journ.* (206) 1968, 689-93.
11	H. R. Schubert, 1957, op cit. 197.	22	22 A. Raistrick, op cit. 62.
12	12 The slab, now in Hastings Museum, measures 4 ft. by 2 ft. by 5 in. deep.	23	23 C. Leigh, 'The Natural History of Lancashire, Cheshire, and the Peak in Derbyshire' Oxford, 1700, 82.

24.	W. Lewis, op cit. (4) 109.	46.	John Cockshutt's letter, 1 June, 1763, f. 9,
25.	D. Mushet, op cit. 255-56.		Egerton MSS 1941, Brit. Mus. London.
26.	W.S. Spencer to John Hall, 12 June, 1739,	47.	Swedenborg in W. Lewis, op cit. (4) f. 118e-
	Letter Book of William Spencer I, 1738-43,	48.	G. Wyrrall in Nicholls, 1858, op cit. 279;
	60505 (1) Spencer Stanhope (Cannon Hall)		1866, op cit. 39.
	Muniments, Sheffield Central Library.	49.	Swedenborg in W. Lewis, op cit. (4) f 1 18b:
27.	H. Powle, 'An Account of the Iron Works in	50.	G. Wyrrall in Nicholls, 1858, op cit. 279;
	the Forest of Dean' *Phil. Trans.* (12) 1677-78, 931-35, 933-34; reproduced in H.R. Schubert,	51.	Idem, 1866, op cit. 39. Ibid. 1858, 277; 1866, 38.
	1957, op cit. 418-20: T. Rudge, 'The History	52.	Ibid. 1858, 278; 1866, 39.
	of the County of Gloucester' 2 vols. (2)	53.	'Journal of Backbarrow Iron Co. 1746-53'
28.	Gloucester, 1803, 18. R.F. Tylecote, 'Blast Furnace at Coed Ithel,	**54.**	MS Z.192, Barrow-in-Furness Public Library. 'Account Book of Invergarry Iron Works,
	Llandogo, Monmouthshire' *Iron & Steel Inst. Journ.* (204) 1966, 314-19, 317.		1726-28' GD 1/168/1, Invergarry Iron Works Records, Scottish Record Office, Edinburgh.
29.	J. Ray, 'A Collection of English Words Not	**55.**	D. Mushet, op cit. 259-63.
	Generally Used' London, 1674, 126.	56.	J. Ray, op cit. 126; H.R. Schubert, 1957, op
30.	'Accounts of Waldron Furnace, 1628-57, and		cit. 234.
	1704-16' f. 36, Add. MSS. 33,154, Brit. Mus.	57.	14 November, 1740, William Spencer's
	London. General details of furnaces in the South East can be found in E. Straker,		Correspondence, Letters from Thomas Cope re. Wortley Forge, 1739-44'60513 (1-69)
31.	'Wealden Iron' London, 1931. B.L.C. Johnson, 'The Charcoal Iron Trade in		Spencer Stanhope (Cannon Hall) Muniments, Sheffield Central Library.
	the Midlands: 1690-1750' MA thesis,	58.	D. Mushet, op cit. 271.
	Birmingham, 1950, 13.	59.	Supplement to Fourth, Fifth, and Sixth
32.	J.M. Good, O. Gregory and N. Bosworth,		Editions of Encyclopaedia Britannica, (5)
33.	'Pantologia' (6) London, 1813, article 'Iron'. A. Raistrick, op cit. 62.	60.	Edinburgh 1824, 118. D. Mushet, op cit. 271. W. Lewis, op cit. (4)
34.	D. Mushet, op cit. 253.		147.
35.	Swedenborg in W. Lewis, op cit. (4) f 1 18a-b.	61.	'For digging and leading 2 load of clay for the
36.	'All below the top of the boshings requires to		tuyere, 2/-' Waldron Furnace, 1705-6, f. 50,
37.	be replaced with new stones' Cockshutt in W. Lewis, op cit. (4) 103. H. R. Schubert, 1957, op cit. 199.		Add. MSS. 33, 154, Brit. Mus. London; 'Getting clay for tuyere' Staveley, 1706, see note 15 above.
38.	H.G. Nicholls, 'Ironmaking In Olden Times'	62.	W. Lewis op cit. (4) 144-45.
	London, 1866 (Newton Abbott, 1966) 32.	63.	H.R. Schubert, 1953, op cit. 161-62.

39. A. Fell, 'The Early Iron Industry of Furness and District' Ulverston, 1908, 226.

40. A. Raistrick, op cit. 65.

41. Lydney Furnace's Account Summary, 11 September, 1699- 6 May, 1700, D 421/E9, Gloucester Record Office.

42. See note 14 above.

43. G. Wyrrall in Nicholls 1858, op cit. 279; Idem 1866, op cit. 40.

44. T. Daff, 'Introduction of Furnace Blowing Cylinders' *Steel Times* (201) 1973, 401-2. There is a mistake in the heading to this paper: Smeaton advised on the introduction of blow ing cylinders at Carron in 1766, and not 1776.

45. G. Wyrrall in Nicholls 1858, op cit. 279; Idem 1866, op cit. 40. Swedenborg in W. Lewis, op cit. (4) f 118e.

64. G. Wyrrall in Nicholls, 1858, op cit. 278; 1866, op cit. 39. See illustration in H.R. Schubert, 1957, op cit. 239.

65. W. Lewis, op cit. (4); G. Wyrrall in Nicholls, 1858, op cit. 279; Idem, 1866, op cit. 40.

66. J. Norden, 'The Surveyor's Dialogue' London, 1607, 215.

67. SPD 1653, vol. 39, no. 31.

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69. A. Fell, op cit. 234-35.

70. Idem, thesis, op cit. 18, 24.

71. R.F. Tylecote, op cit. 317.

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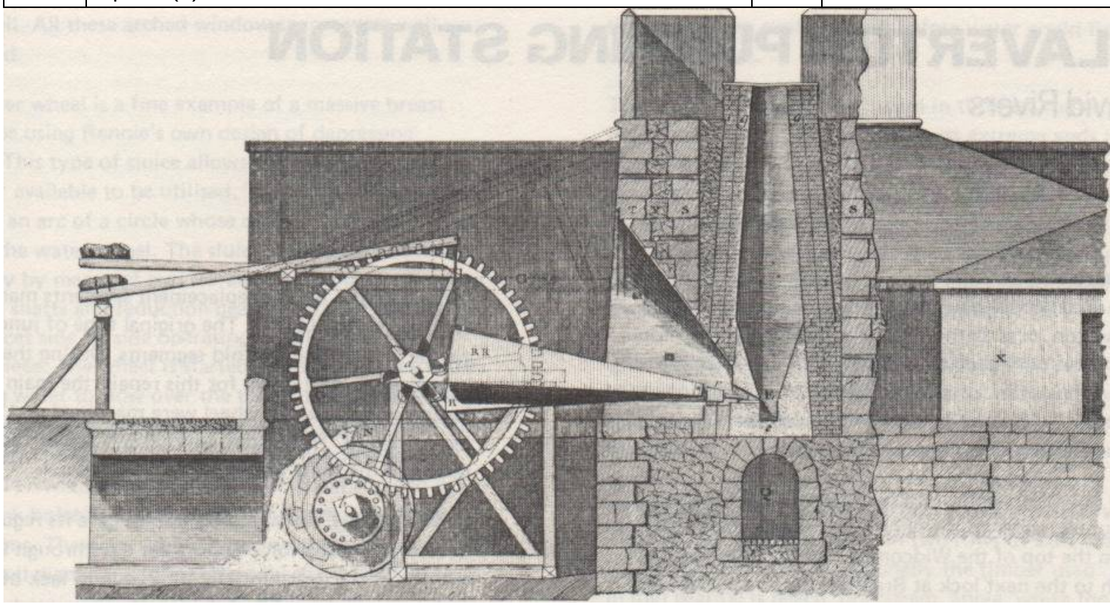
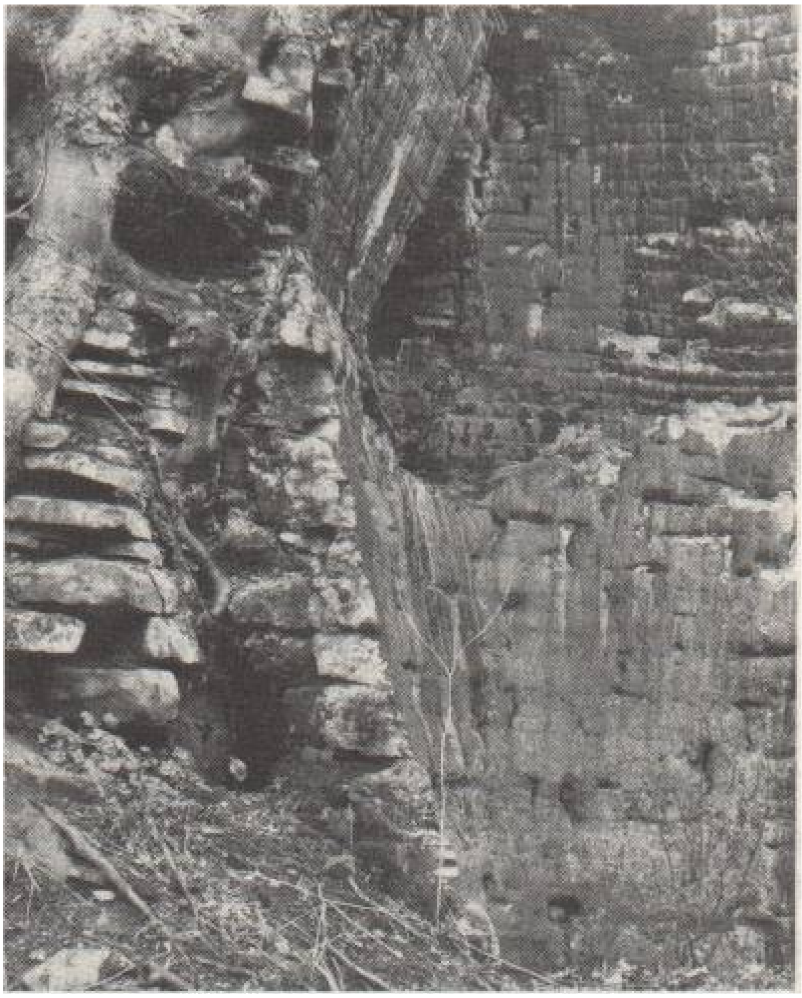
73. Ibid. 147-49.



Charcoal blast furnace (fig. 4) Science Museum


Coed Ithel furnace
R. Day