18th-century ironfounding: coke iron, air furnaces and cupolas

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ABSTRACT: The foundry trade developed as a separate branch of the iron industry in the first half of the 18th century. It mostly used coke pig iron, which was produced at Coalbrookdale and in a small number of other furnaces. This was rendered possible by Sir Clement Clerke's development of the air furnace for remelting pig iron and of Abraham Darby's patented method of casting pots in green sand. This paper considers the spread of coke smelting and of foundries with air furnaces in the 18th century, which are closely related to each other. It ends by looking briefly at unresolved issues in the origins of the later foundry cupola.

Introduction

The Coalbrookdale furnace survives, because it was considered to be the first furnace where iron was successfully made with coke as fuel; it was certainly the first in Europe where coke was used successfully over any considerable period. Coalbrookdale's fame rests primarily on its role in the cast iron sector. A small amount of its pig iron was fined and forged into bar iron in the 1730s and probably beyond (King 2011a, 145–50), but when its owners began to supply coke pig iron to forges on a large scale in and after the 1750s, it was from Horsehay and Ketley, not from Coalbrookdale (SW a/c).

The rise of coke did not immediately bring the preceding charcoal industry to an end. Charcoal ironmaking continued far into the 19th century and even the early 20th (Hayman 2008), but it was dwarfed by the coke industry. However, Coalbrookdale and its coke-using peers rapidly took over the cast iron sector. That had hitherto been a small one, with a few furnaces making small quantities of cast iron goods such as cooking pots, and a few in the Weald producing substantial amounts of iron ordnance. The situation was changed not only by the introduction of coke as by two previous inventions. Firstly Sir Clement Clerk adapted the reverberatory furnace, which he had devised for smelting lead and copper, as an air furnace for remelting pig iron (Fig 1; King 2002). Secondly, while operating an air furnace at Cheese Lane, Bristol, Abraham Darby invented a method of casting pots in so-called 'green sand' and patented it in 1707. This involved the use of reusable patterns around which damp sand was packed (Raistrick 1953, 22). This made it much quicker to produce moulds than the previous method where a grass rope was wound around a core, and then a loam mould formed around that, after which the rope was pulled out to leave the void to be filled with iron (Evans 1958; Browne 1960). Darby's methods enabled him to make his pots thinner (and hence cheaper) than his predecessors. Nevertheless, coke pig iron, being more fluid than the purer charcoal pig iron, was particularly suitable for foundry work, which no doubt contributed to his success at Coalbrookdale (Cox 1990, 128–9).

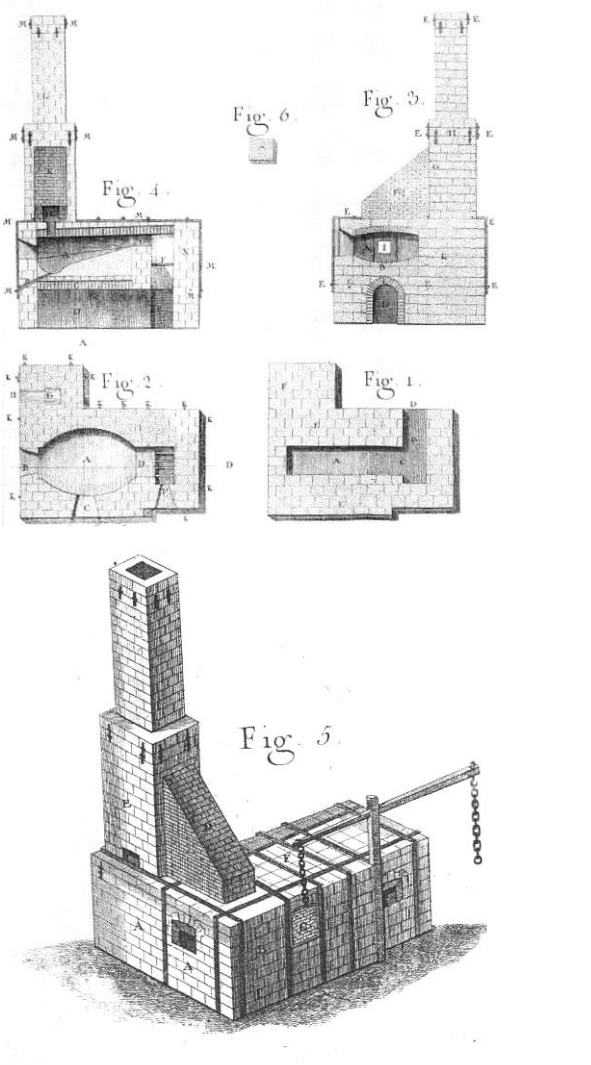

Figure 1: Foundry air furnace near Newcastle. The design is extremely similar to other varieties of reverberatory furnace. Those for smelting lead are normally known as cupolas (after Jars 1774).

The air furnace was a reverberatory furnace (fuelled with mineral coal) that was similar to the cupolas used for smelting lead and copper. This is a completely different technology from the modern foundry cupola which is a sort of small blast furnace. The term 'cupola' is thus a confusing one. The word is a diminutive of the Latin *cupa* – a barrel; a cupola is thus a little barrel. For reverberatory furnaces this seems to refer to the barrel vault over the top of the smelting (or melting) area; the notional barrel lies on its side. The modern foundry cupola seems to have originated as a portable furnace that could be taken to pieces like a barrel with the notional barrel standing on its end. This seems to have been popularised in Britain in the late 18th century (Tylecote 1991, 242–3) and is discussed below. To avoid confusion it is thus best not to refer to foundry air furnaces as cupolas, though this may have been a contemporary usage at Sheffield, a topic that is explored briefly below.

Coalbrookdale and its early competitors

Coalbrookdale had two blast furnaces and three air furnaces in the 1720s and 1730s, but normally only had the two blast furnaces and one of the air furnaces in use. A second air furnace was used when a blast furnace was silent. Presumably, due to the cost of heating pig iron to its melting point, producing cast iron goods in air furnaces was more expensive than using molten iron run (or ladled) direct from a blast furnace. However air furnaces could be useful because any dross would float to the surface and could be skimmed off. For instance, in gunfounding it was usual to cast a gunhead beyond the muzzle of the cannon barrel, into which the dross would float; this was subsequently cut off and used as feedstock for a forge. This would be unnecessary if the metal could be adequately skimmed before casting (Cleere and Crossley 1995, 201).

The Coalbrookdale Company marketed its pots to retailers in their own region in the 1720s and 1730s. William Jukes & Co of London and Leonard Fosbrooke of Gainsborough took substantial quantities, evidently as wholesalers. Thomas Goldney of Bristol seems to have managed sales there both of pots and coke pig iron (King 2011a, 142). It is not clear who operated the Cheese Lane Foundry after Darby moved to Coalbrookdale but in the 1770s it was run by John Jones & Co, also called Jones and Winwood (Ordce Min: 83–87; TNA: WO 47/97, 715; Torrens 1989, 197–8). Jones was one of the original partners in the Dowlais Works at Merthyr Tydfil (Jones 1987, 12). This was not the only foundry at Bristol. There was another, known by the 1730s as the Welch Ironfoundry, in Back Lane (now Jacob Street) behind Old Market which by then belonged to William Donne and partners. They built Bryn Coch Furnace near Neath which supplied it; hence the name. The foundry was bought from Charles Axford and others (BRO: 09458/26). Rent receipt records refer to Mr Dunn's pothouse from 1730 and previously to 'Axford pot-house'; earlier 'Mr Axford house and ironworks'; and in 1710–14 'Charles Axford workhouse' (BRO: PR/StP&J, 1711–41). Charles Axford's purchases of pig iron from the Foley Forest ironworks begin in the year 1709/10 (HRO: E12/VI/DFf/5-13) which was presumably when he built his foundry.

In the 1720s, Coalbrookdale suffered from competition in the Liverpool market from Cookson & Co's Little Clifton Furnace near Whitehaven (SRO: 6001/3190, 18 August 1733). This had been built in 1723 just after Darby's patent expired. This, like most of the other

blast furnaces mentioned in this article as supplying the foundry trade, was coke-fuelled. The leading partner John Cookson was Newcastle-based and involved in a variety of coal-using businesses there. The managing partner at Little Clifton was John Williams, previously of Stourbridge; the important ironmaster Edward Kendall of Stourbridge was also a partner. The firm made cast iron goods at Little Clifton, but were presumably supplying pig iron to their foundry on Old Trunk Quay at Gateshead (Anon 1908, 170–1; Wood 1988, 32 & 36). In the 1740s the owners built a furnace nearer at hand, Whitehall Furnace at Chester le Street (Riden 1993, 126–8). Both at Newcastle and at Bristol 'plantation pig iron' seems to have been mixed with coke pig iron as foundry feedstock (LL: 78, 3 March 1737/8; Somerset RO, D/DN/424, 17 June 1730).

In the late 1730s, cast iron wagon wheels (Fig 2) were supplied to Sir James Lowther of Whitehaven both from Little Clifton and Backbarrow (LL: 76–8 and 96–7 *passim*). Backbarrow Furnace was unusual for its time in being a charcoal furnace with a significant foundry trade. From 1735 (when its foundry was built) until 1748 (when he was poached by a newly established neighbour, the Low Wood Company), the Backbarrow Company employed the potfounder Isaac Wilkinson, father of the more famous John. Isaac had previously been at

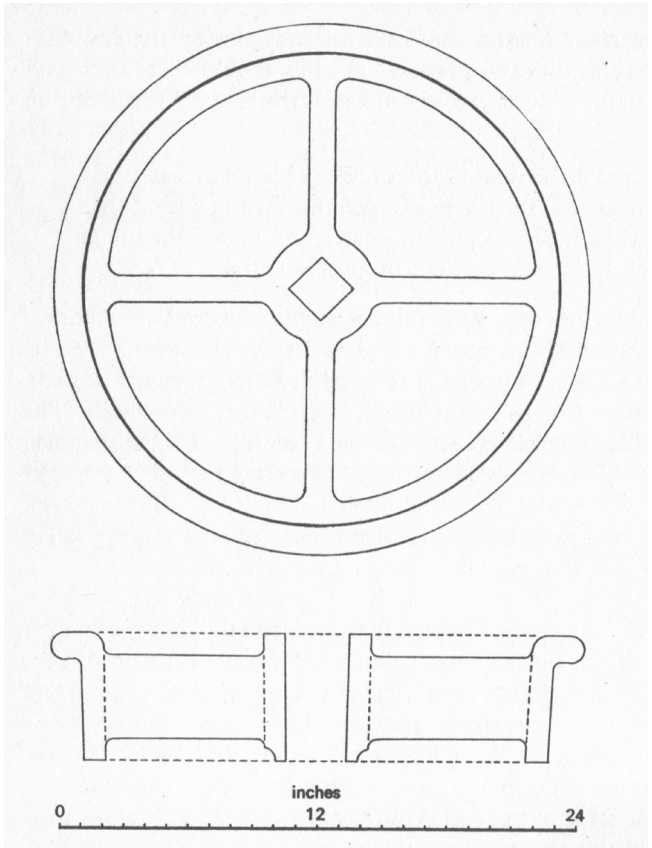

Figure 2: Iron waggon wheel, as used at Whitehaven in 1735 (after Lewis 1970, 196).

Little Clifton (Cranstone 1991). From 1753, Isaac Wilkinson rented Bersham Furnace (Grentner 1992, 177), from which time it was probably mainly engaged in the production of cast iron goods. Bersham Furnace had been built in 1718 by Charles Lloyd of Dolobran (Montgomeryshire) in partnership with William Wood and Co (Lloyd 1975, 52–3; King 2011b, 70). On occasions in the 1720s, it 'ceased blowing with charcoal and went over to coke for potting' (Lloyd 1975, 54–5). Wood and Co were also concerned in Ruabon furnace, which was associated with Thomas Harvey's Garthen [Gardden] Potworks, and various other ironworks in the 1720s (King 2011b, 70–1). However in the succeeding period it was associated with Joshua Gee's charcoal forges in Shropshire (King 2011b, 77–8). Bersham is likely to have become purely a coke furnace making cast iron goods only from Isaac Wilkinson's arrival in 1751. A series of chimney bases at Bersham, in the foundry building adjoining the furnace, are the remains of air furnaces (Grentner 1992, 180 & 187). These must be what Marchant de la Houlière saw being used to cast large cannon in 1775 (Chaloner 1948–9), not the octagonal building further from the furnace.

London and around

Coalbrookdale must also have suffered competition in London, as there were at least two ironfoundries in Southwark. A manuscript from the 1700s refers to a 'work or two' in use at Southwark, and that there had been others at Woolwich, 'Fox-hall' [Vauxhall, in Lambeth], and Corborow Deal [Coalbrookdale]. The Fox-hall air furnace was only short-lived, but it was 'the first of these and built by direction of Sir Clement Clerke' (King 2002, 41 & 45); Thomas Fox used it to cast grenado shells for William III. The mention of Coalbrookdale as disused indicates firstly that there was an air furnace there before Abraham Darby arrived and secondly that the manuscript (quoted) predates his arrival there in 1709. His predecessor there, Shadrach Fox (Thomas' brother), is known to have supplied shot to the Board of Ordnance which he delivered at Bristol, evidently from Coalbrookdale (King 2002, 40). After Coalbrookdale furnace blew up, which was probably before April 1703, the Fox Brothers restored and used Wombridge Furnace in 1701, but Thomas died in debt in 1704 (TNA: E 112/833/957; TNA: C 11/1379/19; Mott 1957, 85; King 2002, 40).[1] After leaving Wombridge, Shadrach worked as a founder in London. He was employed by Richard Tolson and James Puckle making grenado shells, at least some of which were sold to the East India Company. In April 1707 he was recruited by a Russia merchant called Thomas Styles to go to Russia

to work for the Tsar. He had reached Moscow by the following January, but unfortunately he died less than two months later (TNA: C 6/357/34; SP 91/5/167).

One of the works at Southwark is probably the foundry that existed at Bankside, in the parish of St Saviour, later known as the Falcon Foundry. This was the subject of claims from rival creditors. after Peter Ellers in 1701 contracted to sell the works and his stock to one Henry Glover. The claimants included John Neale whose factor Roger Foster (an ironmonger) claimed to have bought the stock of old metal (TNA: E 112/827/215; TNA: E 133/74/64). The outcome of this litigation is unclear but Thomas Bowen (a witness) was a founder at Bankside – presumably here (TNA: E 134/3 Anne/East 26). The foundry probably passed to Richard Jones. He was authorised to set up a furnace in the Saltpetre House at Woolwich Arsenal in 1706 for casting shot from old ordnance (Hogg 1963, 238; Ordce Min: 22–5), presumably to increase his productive capacity. In 1723, John Wood advertised that he was making various iron goods 'at the ironfoundry late Mr Richard Jones at the Faulcon in Southwark' (Flinn 1961–2, 56). John Wood was one of the sons of William Wood (already mentioned), but the fate of this branch of the enterprise after Wood's empire collapsed in the early 1730s is unclear (King 2011b, 70–1; King 2014, 177). Nevertheless, Joseph Wright & Co were casting shot and shells at the Falcon Foundry for the Board of Ordnance from 1759. The firm became Wright and Prickett by 1771 and then Prickett and Handasyde about 1780 (Ordce Min: 53–120; King 2002, 41; King 2011b, 70–1).

William Bowen renewed a 1722 lease in 1748 for a brass foundry at Marigold steps, Upper Ground in Christchurch parish, Southwark. He had a Navy Board contract in 1728 to produce cast iron ballast, the first such contract awarded, under which he took old ordnance, iron ballast, or shells in part payment. This clearly indicates that his foundry was dealing with iron as well as brass (Southwark Local Studies Library, MS 8287; King 1995, 17). He bought guns that had failed proof in 1729, again pointing to his having an ironfoundry. At that time he owned Barden furnace near Tonbridge and in 1741 bought Cowden Furnace (also in the Weald). Sir James Lowther referred to him as 'the great ironfounder with charcoal'; It is not known what happened to the foundry after his death in 1771 (Hodgkinson 1993, 97–8; Cleere and Crossley 1995, 325 & 385; LL: 101, 13 November 1740).

Cast iron goods sold in London were also made in the Weald. When Sir James Lowther needed steam and pump cylinders for the engines to pump out his Whitehaven mines he obtained them in London from William Harrison the gunfounder who had them made in the Weald (LL: 91–100 *passim*), perhaps at Gloucester Furnace near Lamberhurst. Later in the 18th century, two foundries at Rotherhithe and one at 8, New Square (now New Street Square), Fetter Lane, London were among the suppliers of shells and shot to the Ordnance Board. The latter belonged to Kinmain and Co who bought 182 tons pig iron from Snedshill Furnace in Shropshire in 1782 (Ordce Min, *passim*; cf various London directories; TNA: C 12/211/5, Snedshill a/c in schedule to Answer).

Other early coke furnaces

A few other coke furnaces can be identified in the early 18th century. After Abraham Darby's death, his widow transferred his lease of Vale Royal Furnace in Cheshire to his partner Thomas Baylies. By this means Baylies seems to have considered himself entitled to use Darby's potfounding patent, but Vale Royal was hardly suitable for coke ironmaking as it was remote from any source of coal. It was well placed for making charcoal pig iron, blending Staffordshire ironstone with Furness redmine (haematite). Faced with this dilemma of mixed objectives the new Vale Royal Company built a coke furnace at Sutton near St Helens near another partner's coal mine. The business was not a success and collapsed in a mass of debt in 1731. Sutton Furnace may possibly have survived a few more years (King 1993, 8 & 13). Coke seems to have been used at Rushall Furnace near Walsall, as George Sparrow, the Midland coalmaster, told Sir James Lowther in 1738 that he and his partners had about 20 years before made pig iron with pitcoal and from the pigs made bar iron with pitcoal, but they could not make as much as with wood charcoal, but this and squabbles made them give it up (LL: 99, 5 December 1738; *cf* BCA: Galton 84).

The 1714 lease of Kemberton Furnace in Shropshire provided for a supply of coke, but no evidence is known that it actually used coke. The 1714 lessees included the charcoal ironmaster Edward Kendall (Trinder 2000, 25; SRO: 796/192–6). In 1725 and 1726, the furnace supplied pig iron to Coalbrookdale Forge at a period when the forge's feedstock was charcoal pig iron (SRO: 6001/328, 381 & 424). Nevertheless, Kendall was concerned at Little Clifton (as described above) and in a potwork in New Street, Stourbridge, built by William Stripling and others in 1717, which Kendall took over in 1723. Kendall settled the site on trustees in 1743, apparently to build a Presbyterian manse, by which time the foundry must have closed (WRO: BA 8441/6/iii).

Confusing terminology and the importance of coke iron

At Sheffield, ironfounding seems to have been a relatively late arrival. The Walker Brothers of Grenoside began casting pots at their nail smithy in 1741, and built an 'air furnace' in 1744 (John 1951, 1–2; Hey 1971, 31-4). This location is referred to as 'cupola' in contemporary documents (SA: ACM/S.157; SA: ACM/S.158, Ecclesfield; SA: ACM/S.870/95). In 1747, Samuel Walker bought land at Masbrough in Rotherham and built a 'casting house with two air furnaces' there. In 1755, this is referred to as a 'foundry or cupola' (SA: WC 2725, p.1–5; *cf* John 1951, 2). Unsigned articles of employment survive for William Holden to work as an ironfounder for Samuel Walker for 10 years from 1746 (SA: TC 684). The final version may have been for only five years, as William Bingley, Thomas Holden and William Holden mortgaged buildings in a small street just north of the centre of Sheffield in 1751 (WDR: AD/705/906). Two years later they sold the property, including an 'iron foundry or building for melting and casting iron', to Joseph Parkin and Joseph Dearden (WDR: AH/432/572). They in turn sold it in 1755 to Joseph Clay, John Fell, Thomas Cotton and Joseph Broadbent (WDR: AK/638/847). The purchasers comprised most of the contemporary Yorkshire ironmasters' firms. It is referred to as the 'cupola' in rate books from 1757 (SA: Rate books, Sheffield lower). Rotherham and Sheffield Foundry is mentioned in the ledger of John Fell & Co but its operations were recorded in separate account books that do not survive (SA: SIR/24, 220 and related journal entries in SIR/10). The street where it stood is still called Cupola. As the Walkers built air furnaces at Grenoside (also in Sheffield) in 1744, it is likely all these 'cupolas' were air furnaces, rather than the small blast furnaces of the kind used for re-melting iron today. Despite both being foundries and being called 'cupolas', they were a completely different species from the modern 'foundry cupola'. Dickinson (1914, 53) stated that this kind of 'English cupola' existed by 1764, and suggested (perhaps wrongly) that it had a German origin.

Early coke smelting and the foundry trade were thus closely related. The exceptions where charcoal iron was used in foundry work in the 18th century are few. Backbarrow Furnace where Isaac Wilkinson worked between 1735 and 1748 is one, while foundries in or near London used pig iron from Wealden furnaces, together with old cannon and cannon that failed proof. Only in the 1750s did coke furnaces begin significantly to supply forges making bar iron. Even then, the industry was split to some extent into forge and foundry sectors. Coalbrookdale, Willey and Madeley Wood of the early Shropshire coke furnaces do not (or hardly) feature among the suppliers of Edward Knight & Co's forges in the Stour valley. John Wilkinson's Bradley Furnace in Staffordshire only started supplying pig iron in 1769 to their Bromford Forge, in what is now east Birmingham (SW a/c), but that furnace was built in about 1757 (HRO: E12/S/378, 20 October 1784).[2] New coke furnaces elsewhere can similarly be identified as principally concerned in the foundry trade. Maling and Co built a new coke furnace at Bedlington (Northumberland) in about 1759, the partners including William Dockwray then late of Backbarrow. There was also an air furnace, and products in 1769 consisted of cast iron goods, ballast iron and pig iron (TNA: E 112/1895/20; E 134/12 Geo. 3/Hil. 10–11). Despite its proximity to Bebside Slitting Mill, its initial history is completely unrelated (Evans 1992, 181–3 & 190–1). Carr Mill Furnace near Wigan (hitherto a charcoal furnace) was leased to George Perry of Coalbrookdale with partners in 1759 (Awty 1957, 115). Neither of these furnaces is obviously associated with any forge, suggesting that both were mainly engaged in foundry work.

Origins of the foundry cupola

The modern foundry cupola has (since at least 1914) been widely attributed to John Wilkinson (Isaac's son), and to a patent specification of his dated 1794 (Fig 3; GB1993; Dickinson 1914, 32 & 53; *eg* Riley and Niehoff 2013, 525). In France it is called a *fourneau à la Wilkinson*, no doubt referring to his younger brother William who worked in France in the 1780s. This has led to the suggestion that William was the inventor (Dickinson 1914, 53; Ashton 1963, 102; Chrimes 2002, 755). Yet the specification (always cited) is for a furnace for smelting iron ore, 10 foot high (rather than the usual 30–70 feet) in a cast-iron casting and with multiple tuyeres (GB1993). Certainly, John's furnace at Brymbo (dated 1796), though much higher, is an early one to have multiple tuyeres. However, the patented design could still be related to the foundry cupola, the basis of the frequent statements about the patent. John had ironworks at Bersham (until he closed it in 1794). In the bank adjacent to the octagonal foundry building (existing by *c*1780) there is an enigmatic heavily slag-encrusted shaft (Grenter 1992, 182 & 190–1), evidently some kind of furnace. Was this the original foundry cupola? Or is it an experimental furnace? Or again, could drawing No 2 (Fig 3) actually be a sort of prototype for the multi-tuyere blast furnaces that began to be built in this period? But, if so, it would be a misleading specification, perhaps improbable at that period.

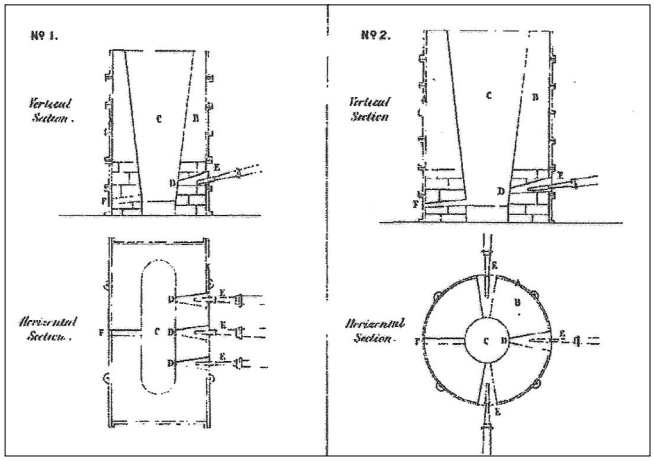

Figure 3: John Wilkinson's patent iron smelting furnaces of 1794. It is widely believed that No 2 (to the right) is a precursor of the foundry cupola (after GB1993).

Others point to the origin of the foundry cupola in small furnaces in France, described by Réaumur in 1722 (Sésco 1955, 275–92). He described three kinds of furnace. The first used a simple crucible as for brass founding. He called the second 'ladle melting': the ladle – a pot or kettle lined with sandy clay – had a removable stack, also lined with clay (Fig 4). It was heated from the outside using small charcoal with a blast from bellows. For casting, the stack was lifted off and the ladle tipped in the usual way. The third was devised by Réaumur himself, as a variation of the same idea, but the stack was clamped to the ladle and mounted on trunnions (Fig 5). When ready, the whole furnace was tipped, so that iron was poured from the top of the furnace. This had the advantage that the stack did not cool between successive meltings. The whole furnace with its bellows was mounted on wheels, so that it could be moved from place to place. Something like Réaumur's second furnace could well have been a precursor for the foundry cupola, if that is indeed to be attributed to William Wilkinson.

Rhys Jenkins (1933a, 75) said that the earliest reference he had come across to the foundry cupola was in the description of the Carron Works in the 1792 *Statistical Account of Scotland*, but on another occasion (Jenkins 1933b, 167) he quoted from Farey (1811, 405) who wrote:

> 'The small cupolas, or hells as they are called, which are used in foundries here, were introduced about 30 years ago, which are used for heating pig-iron, instead of air or reverberatory furnaces, which, as I am told, answer well for cannon balls and some other purposes,

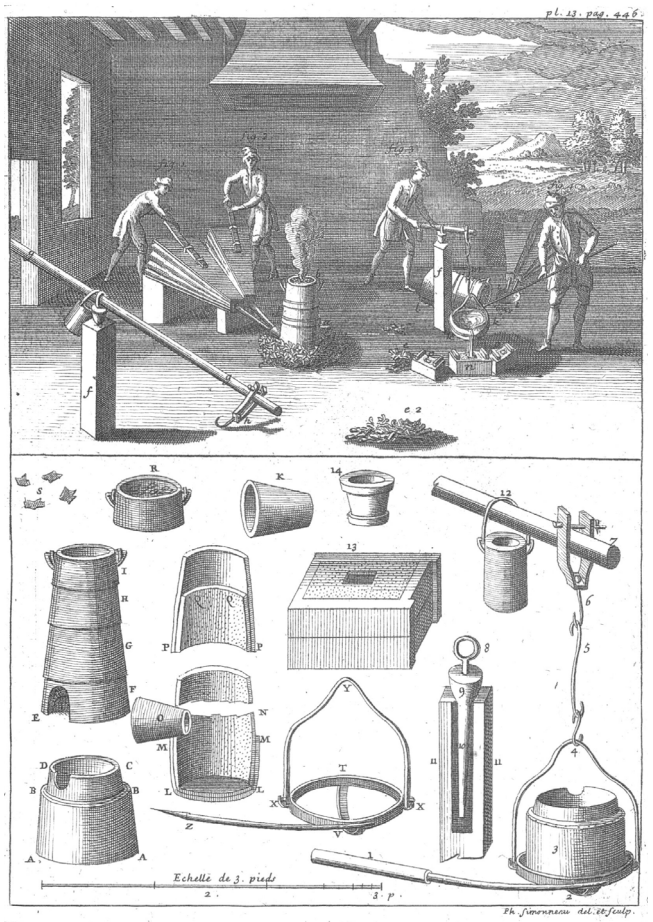

Figure 4: Réaumur's plate showing a furnace for ladle melting.

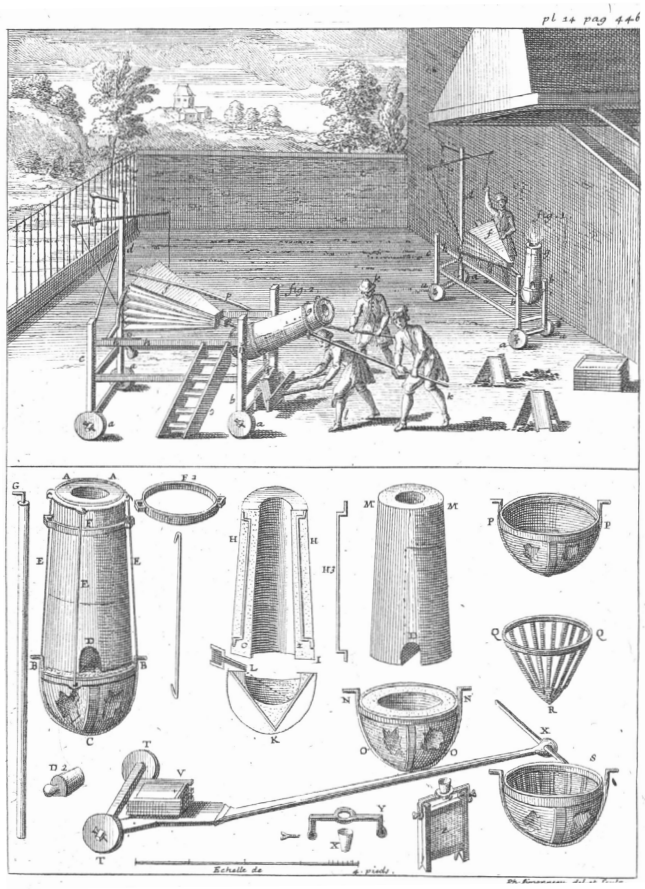

Figure 5: Réaumur's plate showing his portable furnace..

making very solid castings, yet the iron becomes whiter and nearer the quality of bar iron in infusibility every time it is melted in such furnaces.'

Farey's 'hells' (introduced *c*1780) evidently decarburised the iron. That is something that would not happen in the standard foundry cupola, where the metal is in contact with the fuel. This could refer to the Griffin Foundry at Brampton near Chesterfield, built before the lease was granted in 1775 (Robinson 1957, 10–11).[3]

Several questions remain undetermined concerning early cupola furnaces. Abraham Darby III acquired Madeley Wood Furnaces in 1776 (Trinder 1973, 66), just before building the Iron Bridge. It is not clear how or precisely where he made the large castings needed for the bridge. The Old Blast Furnace at Coalbrookdale was apparently enlarged at that time, as indicated by the dates cast into the lintels, but Madeley Wood Furnaces were presumably also used. There is a 'snapper furnace' close to the Old Furnace, which is said to have been built in the 1790s for re-melting pig iron (but never used). Is this another early cupola or something slightly different? Snapper furnaces could handle 10–15 tons of iron at a time (Belford 2012, 36), much more than an air furnace. The origin of the foundry cupola is not entirely clear, but the use of the term cupola for two completely different kinds of furnace will certainly not make finding an answer any easier.

Acknowledgements

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Notes

1 Mott's account of this period is based on the recollections of Hannah Rose (Friends Meeting House, Euston Road, London: Norris MSS). These recollections are useful, but prove to be inaccurate in detail.

2 There has been confusion of the date of the first Bradley Furnace. This seems to result from the work of Smith in 1966 on the rescue recording of Hallfields Furnace at Bradley, which was probably built in (or soon after) 1768, as he stated (Smith 1966; Morton and Smith 1966). However, other documentary evidence clearly indicates that Wilkinson had works at Lower Bradley earlier. Various older works about Wilkinson concur on the earlier date, but do not cite their sources.

3 Subsequent work suggests that is this is the most likely foundry for Farey to have been referring to. The source is a history of the works; 'could have' is my comment.

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Abbreviations for manuscript sources

BCA: Birmingham City Archives.

BRO: Bristol Record Office.

GB1993: British Patent GB1993 of 1794, John Wilkinson 'Manufacture of Iron'.

HRO: Herefordshire Record Office.

LL: Lowther letters: Carlisle RO, D/Lons/W2/ [cited by bundle and date].

Ordce Min: Minutes of the Board of Ordnance, TNA: WO 47 [cited by volume, with original pagination]. Most references are to several volumes, *passim*. The entries alluded to can be located from the abstract (usually at the front of each volume) under 'gunfounders' or 'founders'.

SA: Sheffield Archives.

SRO: Shropshire Record Office

SW a/c: Knight Stour Works accounts, *passim*. WRO: b899:310 BA 10570/3.

TNA: The National Archives.

WDR: Wakefield Deeds Registry: West Yorkshire Archives Service, Wakefield.

WRO: Worcestershire Record Office.

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