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AN EIGHTEENTH CENTURY RED LEAD PRODUCTION RECORD

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Abstract: A manuscript record of the production of red lead in the 1720s, probably at the Wingerworth mill, is described and analysed. The record comprises details of deliveries and furnace charges of pig lead, weights of barrels of red lead, and deliveries and dispatch of barrels. The mill operated continuously, with twice-weekly 'meltings', between April 1724 and July 1728, producing about 280 tons of red lead during that period.

A small manuscript book has kindly been lent to the author by a Wingerworth resident, in whose family it has long been kept. In part, it contains what is obviously a record of the production of red lead at a local mill between 1724 and 1728. The book measures c.15 x 10 x 2 cm and has a parchment cover with a clasped flap protecting the outer edge. Some writing on the cover is now practically illegible, and there is no definite clue inside as to the identity of the compiler of the record; although the name 'Mr. Joseph Smith' is written inside the front cover, it may not be contemporary with the record, since the remainder of the book has later been used for notes of payments in the 1730s and 1740s to an unidentified person for making red lead, and later still for miscellaneous jottings, mainly relating to husbandry. Nor is the name of the red lead mill explicitly stated, but in the table recording the carriage of barrels from the mill by various named carters, there is a single entry reading 'Wingerworth Carts 6'. This implies that these were very local carts and therefore that the production record is for Wingerworth red lead mill. It is not clear whether the entries were made at the actual dates stated or were written up at some later date, but at least two different handwriting styles appear to be discernible.

What has hitherto been known about Wingerworth red lead mill has been well summarised by Crossley and Kiernan (1992 p.34). It existed through most or all of the 18th century, but of course may not have been in continuous operation. It was owned by the Hunloke family, of Wingerworth Hall, but was not directly operated by them. In 1717 the tenant of the mill was John Bright, a known local lead merchant; he was mayor of Chesterfield five times between 1707 and 1732. He did not die until 1734, so it is quite likely that he was still running the mill in 1724-8 (Porter 1920-4 p.178; Chesterfield Parish Register, card index at Chesterfield Public Library). The paucity of surviving family papers of the Hunlokes does not allow us to be any more definite.

The present author provided the basic information for Crossley and Kiernan's description referred to above, and may have been responsible for two small errors: the National Grid reference is more accurately SK 38856660 (to the nearest 50 metres), and John Bright did not have a *lease* of the mill in 1717, but apparently only an annual tenancy. A few other points may also be added: (i) the mill is believed to have been on the site of a 17th century forge associated with Wingerworth charcoal blast furnace (Riden 1993 pp. 95-7), since an adjacent field was long known as Hammer Dam; (ii) the breach about halfway along the surviving dam of the millpond is, according to the 1758 map (Derbyshire Record Office, D1306A/PP1), actually where water was released to flow downstream and power the mill; (iii) the woodland, Hanging Banks Plantation, that now obscures the site from view from Derby Road (the A61) did not exist until about 1800 (Edwards 1976 p.3); and (iv) the tenants of the mill also leased or rented an adjacent farm from the Hunlokes, and not until an estate survey of 1779 (Chesterfield Public Library, Hunloke Collection) do we find a separate rent quoted (or calculable, rather) for the mill itself - the rather odd sum of £6 1s. 1d. per annum.

THE FORM OF THE RECORD

The book contains four sets of tables, headed 'Barrells brought to mill', 'Barrels Caryed from mill', 'Meltings at the Old oven', and 'Lead brought to mill', in order of appearance. In the following account, the page numbers - except in (1) - have been assigned mentally by the author, ignoring remnants of leaves torn out (none of which has disturbed the red lead record).

(1) *Barrels brought* (pp. 1-3). This table lists dates and corresponding numbers of barrels, with occasionally other items such as hoops or kits. The dates run from 15 May 1724 to 22 July 1728. A balance at one point shows that these were empty casks: B[arrels] 166, F[illed] 165 B [series - see below], R[emainde]r 1'. On nearly all dates, which were at intervals of between about a fortnight and a month, ten barrels were delivered, and the total number was 708.

(2) *Barrels despatched* (pp. 13-25). This table comprises dates and corresponding names of men who were evidently carters, and numbers of barrels (obviously full ones), together with periodic totals, balances and indications of code letters with which consecutive series of casks were marked. In order of appearance, these letters were L, R, L again, A, B, and C; the first and last were short series, presumably incompletely recorded. Possibly the letters denoted consignments for different customers, but there is no indication of the ultimate destination of the red lead; as will be seen below, each completed series comprised almost a year's output, totalling between 162 and 173 barrels. The dates run from 20 May 1724 to 29 July 1728. The barrels were taken away every few days, in loads of usually two to four. The grand total recorded is 725. The frequent collection obviously provided regular work for the carters and avoided the accumulation of a large stock at the mill.

The carters' names were as follows, in order of first appearance:

Henry Steele	George Doman	Thomas Babb
Peter Shipston	Thomas Hilton	Christopher Stones
Widow Wadkinson	John Stones	Thomas Charlesworth
Thomas Harvey	John Fisher	Henry Bywater
Henry Fern	Christopher ?Reynard	
Joseph Brown	John Fidler	

These persons have yet to be identified, but some of them may

have been Wingerworth villagers; for instance, a Henry Fern and a John Fidler were tenants of the Hunlokes in 1717 (DRO, Registers of Papists' Estates, M6).

(3) *Meltings* (pp. 26-71). This is the production record proper, and comprises two types of entry. On each verso page are listed the dates (presumably of the start) of the 'meltings' and the corresponding numbers and sources of the lead pigs used. The number was always four, but pigs from two different sources were sometimes used together , and in one instance from three sources. Although the word 'pig' is not explicitly used in this part of the record, it is obvious that pigs were meant; that they were full pigs and not 'pieces' or half-pigs is shown by the entries on the recto pages (see below). The dates run from 27 April 1724 to 16 July 1728, and are every three or four days, usually Mondays and Thursdays but occasionally Sundays and Wednesdays. On nearly every verso page there are twenty entries, divided into two tens by a horizontal line.

This division corresponds to a vertical division on the recto pages, on each side of which are similar sets of entries. Each set comprises a list of serial barrel numbers headed by the relevant code letter (as mentioned above), the corresponding weights in cwt, qr and lb (to the nearest 7 lb only) and, written along the margin, some such statement as ' the first five fooder at the old oven' - 'first', 'second' etc. referring to the order within the relevant code-lettered series. Each five fothers is obviously the 40 pigs listed on each half of the facing verso page. The recto pages almost always list 16 or 17 barrels on each side of the division, as well as the total number and weight for each side. These data are discussed under 'The process' below.

(4) *Lead delivered* (pp. 143-149). There are two parallel sets of entries on each of these pages, with the dates of delivery, the numbers of pigs, and their provenance. The dates - every few days, but irregularly spaced - run from 29 April 1724 to 9 July 1728. The number of pigs in each delivery is usually between two and ten, but occasionally more. Totals and/or balances appear in places, at two of which the word 'piggs' is in fact used. Sometimes lines are drawn, dividing-off groups of five fothers. The smelting mills - naturally, the same as those recorded in (3) above - and the total numbers of pigs that they supplied are as follows:

'Lumms'	996	Shacklow	40
'Olermill'	476	Barbrook	36
Rowsley	124	Bowers	8
Beeley	76		
		Total	1756

'Lumms' is evidently Lumsdale (Matlock), and 'Olermill' Owler mill at Holymoorside; Bowers mill was at Ashover. For the locations and histories of these smelting mills, see Crossley and Kiernan (1992 pp. 14-16, 18, 33, 38, 40). The Lumsdale and Owler mills were evidently the normal sources of pigs for the Wingerworth red lead mill: the list includes long uninterrupted series of consignments from one or the other, more or less over the whole period of the record. The other mills were no doubt called upon when supplies from those two failed for some reason. The Rowsley and Barbrook deliveries were also distributed over most of the period, but the Shacklow and Beeley deliveries were confined to short intervals in 1725 and 1728 respectively, whilst the eight Bowers pigs all came on a single day. Of the seven smelting mills, Owler was nearest to the Wingerworth mill (c. 3.5 miles as the crow flies), and Lumsdale was also reasonably near (6 miles), so it seems rational that these rather than the more distant ones should have been the main sources. Unfortunately there seems to be no information as to whether John Bright had an interest in Owler or Lumsdale at that time (Crossley and Kiernan 1992 p.33, 38).

THE PROCESS

The method of manufacturing red lead as observed by Gabriel Jars in 1765 (Jars 1780) and summarised by Willies (1972 pp.37-8; Smythe 1928 pp. 236-7 has a similar account), is not likely to have been much different at Wingerworth in the 1720s. The furnaces that he saw were of the reverberatory type with a fire chamber each side of a hearth some 9 ft square on which the material was processed, all three sections being open to the air at the front and communicating with a chimney to disperse the fumes. Possibly, however, the 'old oven' at Wingerworth had only one fire chamber.

The process was conducted in two stages: (a) the oxidation of lead metal to litharge or massicot, PbO; (b) the further oxidation of that product to red lead (minium), Pb_3O_4. The terms litharge and massicot were used interchangeably in the 18th century to describe the product of stage (a) (Rowe 1983 p.16 n.22), but in modern chemistry they are the tetragonal (red) and orthorhombic (yellow) crystalline forms of PbO respectively; red lead is a mixed-valency oxide, of spinel crystal structure (Greenwood and Earnshaw 1984 pp. 448, 450; Greininger et al. 1975 pp. 70-2). Stage (a) took something like 28 hours, after which the product was watered and ground in a mill to make it more suitable for stage (b), which took even longer, up to 48 hours. The final product was sieved into casks. The operation was very laborious, involving threefold handling of over half a ton of material as well as continual raking of the hearth of the furnace, particularly in stage (a) to draw the initial 'calx' away from the remaining molten lead and then to expose the calx to air in the furnace; 24-hour supervision seems to have been required.

In the first stage, little control of furnace conditions beyond the maintenance of a temperature above the melting point of lead (327°C) was needed to convert the metal to PbO; Smythe (1923 p.236) quotes a figure of 340°C, but Jars (1780 p.570) stated that the heat was a very dark cherry-red (*d'un rouge de cerise tres-fonce*), suggesting a temperature of at least 550°C and possibly as high as 700-800°C, which would be more in line with the 600°C or higher temperature used in more modern processes for making litharge (Smythe 1923 p.232; Greenwood and Earnshaw 1984 p. 448). However, the bulk of the material on the hearth may not have been as hot as the walls of the furnace. In the second stage, as is now known, quite a narrow temperature range was needed, since below 450°C the reaction is too slow, and above 500°C Pb_3O_4 becomes unstable, rapidly reverting to PbO beyond 550°C, at which temperature its dissociation pressure equals the partial pressure of the oxygen in air (Greininger et al. 1975 p.73). How such control was achieved in the days before accurate pyrometry is a source of wonder, especially since 500°C is below the first visible red-heat. Jars (1780 p.572) stated that the fire was continued in the same way as in the first stage, but in view of the considerations just mentioned this seems rather hard to accept. There was evidently some secret in the art.

Jars's revelation that the whole operation took a good 3 days to complete is in line with the twice-weekly frequency of 'meltings' in the present case - which seems to confirm that it was indeed red lead that was being made, even though that is not explicitly stated anywhere in the four parts of the record. It is also obvious from the continuity of the dates that the manufacture of red lead was not a seasonal operation like that of water-powered charcoal ironmaking: not a great deal of water would have been needed to drive the grinding mill for a few hours in each 3-day procedure, and none for working any bellows or hammers, and the fuel - if coal - was also not a seasonal product. On the other hand, the slowness of the process meant that productivity was low: each year only about 65 tons of red lead was manufactured.

The precise significance of the term 'the old oven' can only be guessed at, but perhaps a new furnace came into use at the end of the period covered by the record. Since each five fothers referred to on the recto pages of part (3) of the record corresponded to 40 units on the verso pages (ten 'meltings' of four units each), it is clear that each batch charged to the furnace comprised four full pigs of lead, or 1350 lb. Here the Wirksworth fother is assumed: 22.5 cwt of 120 lb each (Willies 1990); as shown below, this results in a more sensible percentage yield of red lead than does a fother of 22.5 cwt of 112 lb each. This was a rather smaller charge than the ten half-pigs of 150 lb each that were used in the furnaces that Jars saw. The four pigs need not have been charged as such, of course; it is probable that they were cut up beforehand to make handling easier. Jars (1780 p.570) stated that one of the half-pigs had to be the product of slag-hearth smelting, otherwise the charge was too 'hot' to make red lead. Smythe (1923 p.237) and Kiernan (1989 p.160) imply that this was because antimony present in the slag lead facilitated the 'drossing' of the lead to oxide, although whether this was fully appreciated in the 18th century seems doubtful. However, there is no indication that this was done at Wingerworth in the 1720s, and in fact antimony oxide retards the second stage of the process (Greininger *et al.* p.73). Of the charges for the whole period, 81% were of four pigs all from the same smelting-mill, 16% of three from one mill plus one from another, and 3% of two plus two - so there was no regular attempt to blend lead from different sources.

The figures on the recto pages of the production record proper do not state the output from each 'melting': that output (c. 12.5 cwt) did not correspond to a whole number of full casks. The product from each batch of five fothers of lead filled 16 or 17 barrels. The total output over the whole period covered by the record was roughly 280 tons of red lead from 220 fothers (265 tons) of lead. At the sort of prices indicated by Willies (1969) for pig and by Jars (1780 p.573) for red lead - say £13 per fother and £0.70 per cwt respectively - this might have corresponded to 35-40% in value-added, but of course not so much in profit. For analysis of the figures in more detail, it is more convenient to take just the campaign to fill the 162 barrels labelled R, which ran from 27 April 1724 to 8 April 1725; 50 weeks, consuming 50 fothers of lead and producing 1270 cwt 3 qr 21 lb of read lead. (It is evident from the figures 7, 14 and 21 in the 'pounds' column of the barrel weights that here the hundredweight was one of 112, not 120, lb.) The total weights of red lead in the other three full series of barrels were 1353, 1360 and 1287 cwt in series L, A and B respectively, produced from 53, 53 and 50 fothers of lead respectively.

In series R, therefore, 63.55 tons of red lead were produced from 60.27 tons of pig lead. This represents a yield of 105.4%, compared with a theoretical figure of 110.3% (calculated from the atomic weights of lead, 207.2, and oxygen, 16.0: Pb_3O_4 /Pb = 685.6/621.6). A yield lower than theoretical could have been expected, if only because of incomplete conversion of the litharge or massicot to red lead (even the modern product can be as low as 70% purity for some commercial uses) and various losses such as that of lead by vaporisation in the first stage; in fact, according to Percy (1870 p.516, as quoted in Kiernan 1989 p.160), in the 19th century the yield in practice was about 108%. It must be noted, however, that the calculated yield in the present case is strongly influenced by the figure assumed as the mass of a fother; for instance, the use of 2520 instead of 2700 lb (22.5 cwt of 112 instead of 120 lb each) would have given a yield figure of 113%, an excess which might have been difficult to explain unless as a result of weighing error and/or contamination or adulteration (e.g. with water) of the product - further sources of inaccuracy that have to be borne in mind anyway.

The average weight per barrel in the R series was 7 cwt 3 qr 7 lb, but individual weights of for example the first 33 barrels varied from 7 cwt 1 qr to 8 cwt. In the 18th century, 8 cwt barrels of red lead were apparently the norm (Rowe 1983, p.43). The total weights resulting from each five fothers of lead also varied quite widely, from 121 cwt 2 qr 7 lb (16 barrels-full) to 135 cwt 0 qr 7 lb (17 barrels-full). The 50 fothers used for the R series comprised the following pigs:

Olermill	191	Barbrook	36
Lumms	125	Bowers	8
Rowsley	40		
		Total	400

As an example of the schedule of deliveries, processing and despatch, two months of the R period in 1724 may be quoted:

Date[a]	In[b]	Out[c]	Date	In	Out
July			August		
1	8P		3 M	3P	
2 M			6 M		3,HS
3		3,HS	7	3P	3,HS
6 M			8	3P	
7	2P	3,HS	10 M		
9 M	6P		11	4P	
10	10B		13 M		
11		3,PS	14		3,HS
13 M			16	4P	
16 M			17 M		
20 M	2P	3,HS	20 M	8P	
21		3,PS	22	10B	
23 M	6P		24 M		
24		3,PS	27 M	4P	
27 M	6B		28	8P	
30 M	3P		30 M		

[a]M = 'melting' that day.
[b]P = pigs (all from Olermill, except on July 7 and 9 from Barbrook);
B = Barrels. [c]Barrels;
HS = Henry Steele; PS = Peter Shipston (carters).

The frequent deliveries of small numbers of pigs suggest that no great advance stock of lead was kept at the mill. A comparison of pig deliveries in part (4) of the record with usage in part (3) seems to bear this out in some instances. For example, the eight Bowers pigs were delivered on 10 March 1725 and were all used in the 'meltings' of 11 and 15 March. Furthermore, the first four Shacklow pigs, delivered on 7 May 1725, were used on 10, 13 and 17 May. However, the last batch of Shacklow pigs, fifteen received on 27 June 1725, was used only gradually in ones or twos up to the beginning of October. Perhaps in any case the individual smelting-mills were able to supply pigs at only a low rate; the annual consumption of the Wingerworth red lead mill, 53 fothers, was something like one-third to one-quarter of the annual output of a typical ore hearth smelter, 180 fothers (Crossley and Kiernan 1992 p.8). However, it is obvious that deliveries of both pigs and empty barrels were organised well enough to maintain sufficient stocks to allow uninterrupted operation for more than 4 years. It is also obvious that the mill's operator had a steady market for the product, whether in his own vertically integrated business or elsewhere.

One remaining point of interest is that although 'meltings' for the R series of barrels were begun on 27 April 1724, the first full barrel in that series was not despatched until 1 June, when ten meltings had taken place, and the last not until 21 May 1725, over a month after the last melting for that series. In other words, the full barrels from any one group of ten meltings (five fothers of lead) seem to have been stockpiled at the mill

before despatch. Possible reasons for this are: (a) the barrels may not actually have been weighed until the sixteen or seventeen from each five fothers had accumulated, or (b) the existence of a small stock ensured that barrels were always available for collection when a carter turned up at the mill.

CONCLUDING COMMENTS

Although the present record provides some valuable information on the method of operation and output of a red lead mill in the early 18th century, it still leaves several questions unanswered:

(i) How were the deliveries of pigs to the mill organised, and who transported the pigs? Were orders perhaps communicated by carrier pigeon?

(ii) How many men were employed at the mill, and in what capacities?

(iii) Were the named carters who collected the full barrels employees of the mill operator (John Bright, or whoever), or were they independent?

(iv) What was the ultimate destination of the red lead? Red lead had long been used as a pigment, so at least some of the product may have been sold, and very possibly exported for this purpose. However, it may be suggested that the red lead works at Wingerworth was started up primarily to take advantage of a rising demand for the manufacture of lead crystal glass (flint glass). In England the technique had been developed by George Ravenscroft in the last quarter of the 17th century, and by the end of that century there were eleven glasshouses in London making lead glass, four in Bristol, five in Stourbridge and an important one in Newcastle upon Tyne (Douglas and Frank 1972 pp.14-18). Almost half the weight of a typical batch of raw material for clear flint glass was made up of red lead (Douglas and Frank 1972 p.63), so this could have been a major market for the Wingerworth product.

(v) What was the fuel used in the furnace, and how much was consumed? According to Jars (1780 p.572) it was coal, consumed at the rate of 1 ton per week, and it was not allowed to burn down to ash in the fire chambers but was withdrawn in the coked state and replenished - so what was the subsequent use of the partly burnt coke?

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