LIME KILNS
and the manufacture of quicklime

Lime kilns on Victoria Street, Burnley. The very substantial lower support structure remains. The kilns are located adjacent to a wharf on the Leeds and Liverpool Canal.

Peter del Strother - revised December 2017
The manufacture of quicklime in lime kilns – an explanation

These notes have been prepared for those who are not chemists. Chemical symbols are used sparsely, and only as additional information for chemistry buffs. This account does not cover the manufacture and use of dolomitic lime, which is quite a different story.

1 Quicklime and lime mortar

If lumps of limestone are heated to a temperature in excess of about 800°C, carbon dioxide is driven off and what remains is quicklime, calcium oxide.

\[
\text{limestone decomposes into quicklime and carbon dioxide} \\
\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \\
\text{by weight} \quad 100 \rightarrow \quad 56 \quad + \quad 44
\]

The process is called ‘calcination’. If calcination is carried out correctly then the lumps of quicklime are approximately the same size as the original lumps of limestone but much less dense, because of the weight loss of 44% arising from the removal of carbon dioxide.

If a precisely controlled amount of water is added to quicklime, a (violent) reaction ensues with much evolution of heat. Do not under any circumstances get quicklime in your eyes! If you do, flush them with copious amounts of water and consult a doctor. The lumps break down to a dry fine white powder known as hydrated lime or lime hydrate.

\[
\text{quicklime} + \text{(a controlled amount of) water} \rightarrow \text{hydrated lime} \quad \text{(also called lime hydrate)} \\
\text{CaO} + \quad \text{H}_2\text{O} \rightarrow \quad \text{Ca(OH)}_2
\]

If excess water is added then the lime is said to have been slaked and the outcome is a slurry or paste of hydrated lime, such as might be used for lime-washing a wall or for spreading on acid ground to reduce acidity and improve soil structure. Quicklime was also spread on the ground directly and in the eighteenth century its use was often a requirement set down in farm leases. Modern uses of quicklime and hydrated lime are outlined in section 4.

Lime mortar consists of a mixture of hydrated lime, sand (and/or other fine grained material such as coal ash) and sufficient water to make a workable paste. It hardens through the reaction of hydrated lime with atmospheric carbon dioxide.
hydrated lime $+$ (atmospheric) carbon dioxide react together to produce calcite and water

$$\text{Ca(OH)}_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O}$$

The formation of calcite, which is the principal mineral constituent of limestone, is the outcome of this reaction. As a result, hardened lime mortar can be considered to be man-made sandstone with a limestone binder.

Without access to atmospheric carbon dioxide the lime mortar paste will not harden. Lime mortar used in foundations would not have access to atmospheric carbon dioxide so, prior to the invention of Portland cement, foundations were often built without a binder to hold the stones together. Lack of sound foundations has been the cause of structural problems with many medieval cathedrals. Portland cement, reinvented in the 19th century, is quite different as it achieves its strength through a chemical reaction with water and is eminently suitable for use in permanently damp conditions.

You can purchase ‘lime putty’, which is a mixture of hydrated lime and water, in an airtight container to prevent premature hardening by reaction with atmospheric carbon dioxide. You could also make your own by mixing hydrated lime, purchased from a builder’s merchant, with water. Dry hydrated lime in a paper sack reacts only very slowly with atmospheric carbon dioxide and so has a long shelf life. Lime mortar was used extensively for plastering, often mixed with horse air for added strength. Lime wash, which is slaked lime of paint consistency, is very effective as a paint, and can be coloured by the use of pigments. It is still used today, although only for specialist applications.

In the quicklime manufacturing industry the word ‘lime’ is used to mean quicklime, CaO. The word ‘lime’ is also used in the building trade to mean hydrated lime, Ca(OH)$_2$. Unfortunately you have to interpret what is meant by ‘lime’ from the context. It is important to get it right, because quicklime is very much more hazardous than hydrated lime. Except in the expression 'lime kiln', the word quicklime will not be abbreviated to ‘lime’ in this account.
2 Early kiln types

The earliest kilns produced quicklime in batches. A hollow was made in the ground and a rudimentary wall built to line the hole. A typical size would have been about 3 metres in diameter. Heights of early kilns are not known with any certainty, but the top would probably be conical and partially covered in turves, both to control the fire and to minimise heat loss. An opening in the base would face towards the prevailing wind in order to increase the draft through the kiln. The same principle was used for smelting lead in a ‘boles’, which were usually located on hill tops. In the kiln the limestone and fuel were stacked in layers and the fuel at the base ignited. It seems likely that it took more than two days for the fuel to burn out. David Johnson, in his book on Limestone Industries of the Yorkshire Dales, describes how he has identified kilns of this type in the Craven area dating between 1440 and 1700.

Field kilns are those built as permanent structures and made entirely of stone. Field kilns, in a simple form, appeared in the north in the seventeenth century. Only in the mid to late nineteenth century did this design go out of use.

It is difficult to assess the fuel efficiency of early kilns; a reasonable estimate would be that more than 250 kg of coal were required to produce 1000 kg of quicklime.

Kilns were operated on a semi-continuous basis, with alternate layers of limestone and fuel fed to the top and quicklime drawn out from the base.

The inner shell of a field kiln was a separate construction from the outer ‘visible’ structure. This design improved insulation and reduced the opportunity for rain water ingress, which could have had disastrous consequences.

Diagrams and a picture of various kiln types are shown in Figures 1 to 3.

**Fig 1:** Sketch by Titus Thornber of a bee-hive lime kiln at Shedden Clough (near Burnley)
An early kiln, like that shown in Figure 3, would have been operated on an intermittent basis. Alternate layers of limestone and fuel would have been stacked in the kiln and the fuel set alight. After about 60 hours the lime would be removed from the base of the kiln. It would be very wasteful on fuel to fire the kiln from cold on every occasion, so it likely that repeat batches were produced one immediately after another. Most of the quicklime produced from these early kilns was consumed locally.

An example of a more advanced kiln design is shown in Figure 4.
Fig 4: The well-preserved base of a field kiln at Cow Ark, probably of an early 19th century date. Like many such kilns, it was built into a slope so that the limestone could be transported downhill en route to the kiln.

Not all lime kilns are found where you might expect. Because of the source of the limestone, the arrangements at Shedden Clough, south east of Burnley, were unusual but they are of special interest and will be described in some detail.

In Shedden Clough are the remains of a large number of relatively primitive kilns. Field kilns, up to about 6 metres high, were operated over a period of hundreds of years. That is not to say that any of these kilns operated for more than a few months per year; some may have operated for one summer only. Titus Thornber spent a great deal of time documenting the kilns in this locality; his work is preserved in the local history section of Burnley Public Library.

At first sight, Shedden Clough is a very unlikely location for lime kilns. There is no bedrock exposure of limestone within many miles, so the limestone could not be won by conventional quarrying. At Shedden, boulders of limestone from the Carboniferous period, about 350 million years ago, are found within a deposit of boulder clay (properly described as ‘till’). Boulders were eroded by glaciers in upper Ribblesdale and the Yorkshire dales, transported within the ice to Shedden and deposited there towards the end of the last ice age between 24,000 and 10,000 years ago. Separating boulders of limestone from the till must have involved considerable effort as they were separated by a process called ‘hushing’. Between Shedden and Skipton there were at least twenty localities where hushing was carried out.

Hushing is the process whereby water is dammed at the top of a slope, the ground surface below the dam is broken up with picks and shovels and the dam broken. The resulting surge of water entrains the loose surface material and washes it down the slope. Whoosh! This process was not confined to Shedden. At Roughton Gill, near Caldbeck in the Lake District, the process was extensively used for exposing veins of mineral ore in the valley sides. At Shedden each boulder would have been coated with boulder clay, so each boulder would have had to be at least partly washed to identify whether it was...
limestone or not. The limestone boulders would probably have been fully washed as a coating of clay on the surface was likely to cause lumps of quicklime to fuse together in the kiln and block the extraction point.

The Burnley Geological Memoir describes a four feet thick (1.2m) seam of the ‘Gannister Coal’ cropping out in Shedden Clough so, although limestone extraction was not straight forward, a fuel supply was available close by. In 1978 a new coal mining adit broke into the old coal workings where coal had been extracted for lime burning.

Titus Thornber produced a detailed map of Shedden Clough, incorporating hushes, limekilns and pack horse tracks. The increase in building activity associated with the industrial revolution would have provided a local market for quicklime and it seems likely that a large amount of money was made, at least by the landowners. Thornber’s map is reproduced in Figure 5 below.
**Fig 5:** Map of the area around Shedden Clough, reproduced from Thornber. Note that the leat (otherwise described as goit or goyt) bringing water from Black Clough (top right) is about a mile long.
3 The evolution of kiln design

The next step in the evolution of lime burning technology was the development of the ‘industrial’ kiln, with its output destined for a wider market. Figure 6 shows the principles of operation of a continuous-operation lime kiln. Modern versions, manufactured from steel with a refractory lining, are described as shaft kilns. The diagram shows a kiln rail-fed out of jubilee trucks but obviously the earlier kilns, of similar shape, would have been fed manually. In later, more efficient, designs the fuel would be fed directly into the hottest part of the kiln and limestone alone would be fed to the top.

![Early continuous operation lime kiln](image)

**Fig 6:** Principles of operation of a continuous process lime kiln. Relatively early kilns would be filled with alternate layers of fuel and limestone as shown here. In this diagram the fuel is described as coke; coal and charcoal were also used. [see also Appendix 1]

The great benefit of the design of an industrial kiln was the considerable improvement in fuel efficiency. Air for combustion was preheated, by passing through the quicklime en route to the hottest part of the kiln, with the additional benefit of cooling the quicklime at the same time. Exhaust gas from combustion also dried and preheated the limestone.

Industrial scale lime shaft kilns were certainly in operation by the mid nineteenth century. The bank of kilns shown in Figures 7 to 9 is located near Bellman quarry, Clitheroe. The kilns are located on privately owned land and there is no safe access. The structure may not be entirely sound either. The kilns were probably built very soon after the completion of the railway in 1850.
Fig 7: Bank of four industrial scale lime kilns, with a rail siding (not shown but underneath the kilns) for despatch of quicklime.

Fig 8: Photograph of the Bellman lime kilns in operation. The long bridge-like structure supported an endless chain conveyor which carried limestone and fuel to the top of the kilns (located to the left of the chimney).

The Bellman lime kilns, like many others, were strategically placed so that quicklime could be loaded directly into full sized railway wagons.
In the early design of continuous-process kilns the fuel was put into the top with the limestone. This may not have mattered much if the fuel was coke, but it did not make good use of coal. Coal typically contains between 20 and 30% by weight of methane gas and other volatile matter. As the coal was heated the volatile matter was evaporated before the temperature was high enough for it to burn. Consequently much of the heat value of the coal was wasted. After the mid nineteenth century more modern designs incorporated fuel chutes into the hottest (calcining) part of the kiln, as shown in Figure 10. Most kilns of this design were of quite small diameter because of the difficulty of introducing coal into the centre of the kiln.
**Fig 10:** Diagrammatic representation of a lime kiln with coal chutes, designed to introduce coal into the hottest part of the kiln and therefore to make more efficient use of the coal. [see also Appendix 2]

Figure 10 is a picture of a lime kiln at Slite, on the Swedish island of Gotland. Note that the ports for fuel input lead into the calcining zone, quite low down in the kiln.

**Fig 11:** Kiln with separate coal chute (the square hole) in the calcining zone. The quicklime draw arch is at the base. The limestone feed conveyor has been removed. This kiln is located at Slite on the island of Gotland in the Baltic Sea.

The motive power for drawing air and gas through the kiln was initially provided by convection, in earlier designs sometimes supported by orientation of the quicklime withdrawal arch towards the prevailing
wind. In modern kilns the motive power comes from an induced draught fan whose suction side is connected to the top of the kiln. Then, of course, a gas tight seal is required at the limestone input point. In older kilns a chimney was sometimes used to maximise the benefit from convection. Figure 12 shows such a kiln, located at Toft Gate near Greenhow in north Yorkshire. The chimney is on higher ground, joined to the limekiln by a flue.

Fig 12:
(left) The remains of the chimney stack at Toft Gate and, in the near ground, the flue from the lime kiln. (right) Toft Gate kiln with coal feeding ports at ground level. The quicklime withdrawal arch is lower down at the back. The start of the flue is just visible on the right. Except when limestone was being loaded to the kiln an iron plate, or something similar, was used to seal the top of the kiln.

Fig 13: A view inside the Toft Gate kiln. The rectangular coal feed ports can clearly be seen and the distorted lining shows the impact of high temperatures inside the kiln.
Figure 13 shows the inside of the Toft Gate kiln. Even today the refractory linings of lime kilns require regular replacement.

A very successful advance was made by Hoffmann, who invented an annular kiln. In some places variants of this design are still used today for brick manufacture.

The operation of a Hoffmann kiln is far too complex to describe here. In principle it is a vertical shaft kiln placed on its side, with the three zones of limestone preheating, conversion to quicklime and quicklime cooling located inside an annular tunnel. Although it was efficient, it was very labour intensive because the stone had to be stacked by hand and the quicklime removed in the same way. The active part of the process progressed around the annulus as fresh limestone was added at the front and quicklime withdrawn from the rear. There is a detailed description in David Johnson’s book.

There is a well preserved kiln at Langcliffe near Settle, but it lacks chimney and superstructure. Figure 14 from ‘Limekilns and Lime Burning by Richard Williams, Shire Publications Ltd’ shows how the kiln would have looked when operation.

Fig 14: Now demolished Hoffmann kiln at Buxton, Derbyshire. The walkway gives some idea of scale.
Unless you visit a Hoffmann kiln its size is not easy to comprehend. Figure 15 is a photograph taken in the straight tunnel at one side of the kiln at Langcliffe. A person wearing a blue anorak is standing in the far distance.

![View down the tunnel on one side of the Hoffmann kiln at Langcliffe, near Settle. For scale note the person with a blue anorak standing on the left at the far end of the tunnel. The complete annular tunnel consists of two straight sections, like the one shown, joined by two semi-circular tunnels of the same size at both ends, to close the loop.](image)

Most modern kilns are vertical steel tubes, lined with refractory brick. They are always fitted with induced draught fans to optimise gas flow through the kiln. They operate on a similar principle to that shown in Fig 10.
4 Critical success factors in the manufacture of quicklime.

Much has to be ‘done right’ to make good quality quicklime. Today manufacture is controlled with the aid of a deeper scientific understanding of the process and high quality instrumentation. In earlier times the quality of the quicklime depended on the skill and experience of the ‘lime burner’.

The first important parameter is temperature or, more correctly, the combination of temperature and residence time. Certainly a temperature of between 800 and 900°C is a primary requirement and the residence time must be sufficient for that temperature to be reached in the centre of each piece of limestone feed rock. If the correct time temperature relationship is achieved then the quicklime particle size will be about the same as the limestone feed and the quicklime produced will be highly reactive. In modern production facilities quicklime reactivity is measured by dropping a prescribed weight of quicklime into a standard quantity of water and monitoring the temperature rise. In the old days it would have been sufficient to drop a piece of quicklime into water; the violent reaction would be easy to see, with much fizzing and even local boiling of the water. If limestone is heated to too high a temperature for too long the quicklime particles compact and the resulting denser quicklime is described as ‘dead burnt’. If you drop piece of dead burnt quicklime into water, no sign of a reaction can be seen. For most applications dead burnt quicklime is of little use.

The particle size distribution of the limestone feed is also important. Vertical lime kilns are fed with limestone lumps that typically would be small enough to pass through a sieve with a 60mm square hole and large enough not to pass through a 30mm square hole. The two to one ratio of stone size has historically been a ‘golden rule’ in the industry. Today this ratio has been stretched a bit because of use of induced draft fans with higher ‘suction pressure’. There is a trade-off between electricity consumption and making best use of limestone reserves. In the kiln, the air for combustion and the resulting exhaust gases have to pass between the lumps of limestone and the stone size range must provide sufficient gas permeability. Insufficient gas flow, insufficient heat, insufficient temperature, no quicklime!

A stone that is too large never gets hot enough at the centre to be fully converted into quicklime; a lump of quicklime with a limestone core is known as a bullhead.

For kilns that were loaded with alternate layers of limestone and fuel, the particle size range of the fuel was also important. Physically robust fuels such as coke presented no problems, but fine grained coal, peat and bracken were also used. I can find no reference to the methods employed to use these, more difficult, fuels. Perhaps each layer of fuel, rather than being spread across the whole cross section of the kiln, was placed in a number of discrete heaps. Sufficient permeability would then be maintained through the areas between the heaps. Wood was also used as a fuel. Although up to about 40% moisture content in wood makes it a fuel which does not burn ‘hot’, its moisture would have been reduced in the preheating zone. High ash fuels would be avoided if possible. The ash was likely to fuse and stick the lumps of lime together, causing blockages near the outlet from the kiln. Most lime burners would have had little choice; they would just have had to use what fuel was available and learn to deal with the consequences.

If a limestone quarry is operated solely to produce feedstock for lime kilns then a high proportion of quarried rock will not be in the correct size range. The waste may be as much as 30%, so for economic reasons other uses are normally found for the remainder of the quarried material.
The quality of limestone is a key to the manufacture of quicklime. High purity limestone is preferred. If the limestone is dark coloured because of a high organic carbon content then this may save fuel and therefore be beneficial. However, if the limestone is dark coloured because it contains silica rich impurities of mudstone or shale then problems are likely to arise. The raw material for Roman cement is a mixture of limestone and siliceous mudstone. At a temperature much the same as is necessary for lime burning, the silica and quicklime combine to form anhydrous calcium silicates. Anhydrous calcium silicates are the principal strength forming minerals in cement. They undergo a chemical reaction with water and set hard. Roman cement is not quicklime!

Supply of quicklime to customers involves manufacture and transport. In the seventeenth century, pack horses would have been the principal means of transport. At a trial in 1773 a Clitheroe solicitor, under oath, reported that between 500 and 1000 packhorses per day went through the town en route from the large number of local lime kilns to customers. Quicklime was carried in sacks or boxes slung across the backs of the pack horses. The animals used were small Galloway ponies, known as lime-gals, and donkeys. Quicklime was carried because the addition of water, to convert it to hydrated lime, would have increased the load on the pack horses. However, if water penetrated into the quicklime, the boxes or sacks would set on fire; an unsettling experience for the pack horse!
5 Uses of quicklime

The British Lime Association has a comprehensive list of the uses of quicklime and hydrated lime. Their web address is:

http://www.britishlime.org/

Uses include purification of drinking water, removal of silica from iron ore in blast furnaces, manufacture of aerated concrete blocks, treatment of sewage and mine drainage and flue gas desulfurisation, to name but a few.

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