Chapter 7 - Brick kilns

Properly constructed and operated brick kilns are without doubt one of the most effective methods of charcoal production. They have proved themselves over decades of use to be low in capital cost, moderate in labour requirements and capable of giving surprisingly good yields of quality charcoal suitable for all industrial and domestic uses.

There are many designs of brick kilns in use throughout the world and most are capable of giving good results.

The brick kiln must comply with a number of important requirements to be successful. It must be simple to construct, relatively unaffected by thermal stresses in heating up and cooling and strong enough to withstand the mechanical stresses of loading and unloading. It must be unaffected by rain and weather over six to ten years.

The kiln must allow control of the entry of air at all times and during the cooling phase must be able to be readily sealed hermetically to prevent entry of air. It must be of reasonably light weight construction to allow cooling to take place fairly easily and yet provide good thermal insulation for the wood undergoing carbonization, otherwise production of cold spots due to wind impact on the kiln walls prevent proper burning of the charcoal and can lead to excessive production of partially carbonised wood pieces ("brands") and low yields. The ability of the brick kiln to conserve the heat of carbonisation is an important factor in its high conversion efficiency of wood to charcoal.

Photo. 13. Missouri Kilns made of reinforced concrete. Note steel doors, charcoal stockpile. Missouri, U.S.A. Photo A. Baker

The designs of traditional brick kilns have been refined over many hundreds of years but there are other types of brick kiln in use which have been subject in recent years to systematic experiment to improve them. They are the Brazilian beehive kilns, the Argentine half-orange kiln, the European Schwartz kiln and the Missouri kiln of the U.S.A. The first, second and fourth examples burn part of the charged wood within the kiln to carbonise the remainder. The Schwartz kiln uses the hot flue gases from an external fire grate, passed through the kiln to supply heat for drying and heating the wood to start carbonization. The Schwartz kiln requires considerable amounts of steel for buckstays on the kiln chamber, and steel grates and doors for the furnace. Since its yield (when the firewood is counted) is not in practice superior to the others, it cannot be recommended for wide use in the developing world. The fourth type of kiln well proven in practice is the Missouri kiln developed and still in use in the United States. It is usually made of reinforced concrete or concrete breeze blocks and has steel chimneys and doors. Its yield is similar to the Argentine and Brazilian furnaces. It is fitted with large steel doors which allow mechanical equipment to be used for loading and unloading. It has two disadvantages for developing world use: it requires a lot of steel and cement for its construction, both costly and usually imported items, and it is not as easy to cool as the other furnaces. It is thus more suited for use in temperate cooler climates where the materials and skills for steel and reinforced concrete construction are at hand and low air temperatures permit easy cooling. It is attractive where labour front end loaders etc., are readily available.

The advantages of the Argentine and Brazilian kilns are:

- They can be built in medium and large sizes.

- They are built entirely of soft-burned, locally made clay/sand bricks and mud mortar. They require no steel except a few bars of flat steel over doors and as reinforcement at the base of the dome in the case of the Brazilian furnace.

- They are robust and are not easily damaged. They cannot be easily harmed by overheating; they can stand unprotected in the sun and rain without corrosion or ill effects and have a useful life of from 5 to 8 years.

- The bricks set in mud can be recycled and used again when the kilns are relocated.

- Control of burning is relatively simple especially in the case of the Argentine kiln.

- The kilns are easy to cool using clay slurry and are easily sealed hermetically during cooling. A recent development in fast cooling is US$ of water injection.

- The operating systems for groups (batteries) of kilns have been well researched and standardized so that labour and raw material efficiency is maximised.

- The charcoal produced is suitable for all uses including household, metallurgical, and production of activated carbon.

The major disadvantage of these two kiln types is that they are not adapted for the recovery or recycle burning of and by-product tar or gas. This increases air pollution and slightly lowers the possible thermal efficiency. However, in justice, it must be added that there are no industrially proven brick kilns which are capable of simple recovery of tar without requiring steel components which add greatly to the cost and complexity of the kiln.

Photo. 14. Building a half orange brick kiln. Note the wooden radius rod, the way the bricks are laid and the double layer of bricks over portion of the wall to reinforce the shell of the kiln. Argentina. Photo. J. Bim.

7.1. The half-orange Argentine kiln

7.1.1. Preparation of the site

For a battery of 12-14 kilns, a clear space of 4 000 - 5 000 m² is needed. The wood obtained from this clearing, with the exception of logs that could be used for sawmilling or poles, is utilized as fuelwood. The site on which a kiln is to be built needs to be lightly compacted and then filled to bring it back up to the level of the site as a whole to permit easy drainage of water away from the kiln.

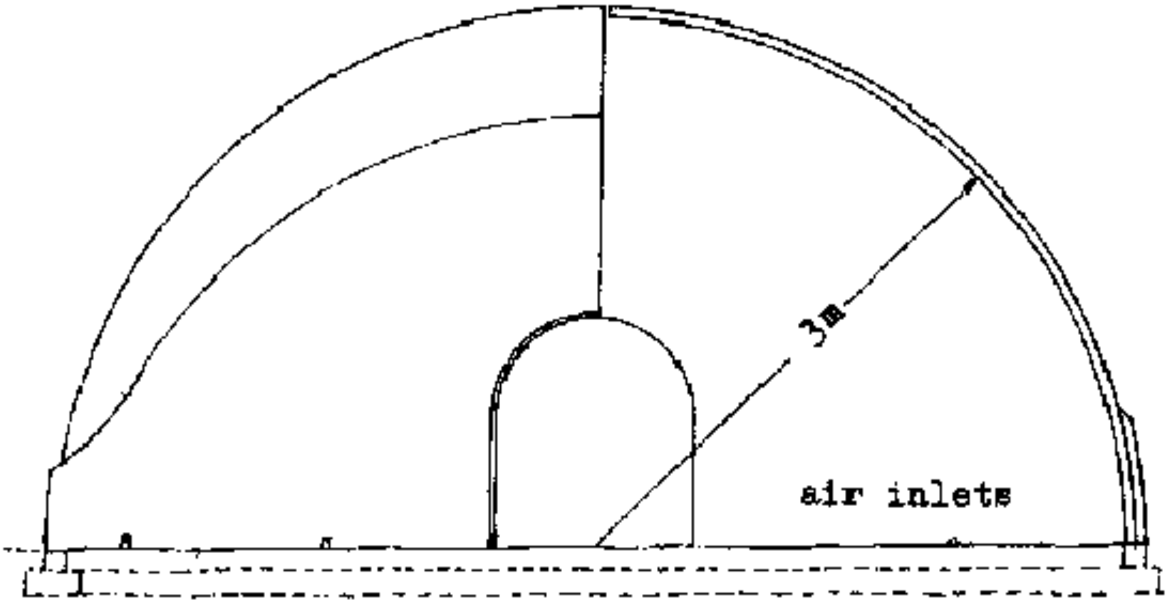
7.1.2. Design and construction

The design of this kiln is shown in figure 5. The kiln is built completely with bricks. Charcoal fines and mud are used as morter, usually with no iron or steel support at any place. The shape is hemispherical, of a diameter of about 6 m (range 5-7 m). The size of the bricks is 0.24 m x 0.12 m x 0.06 m. To construct a kiln, a total number of 5 500-6 000 bricks are required, making allowance for breakage during construction.

The kiln has two doors, diametrically opposite each other. The line of the doors must be perpendicular to the direction of the prevailing winds. The height of each door is 160-170 m, the width at the bottom is 1.10 m and at the top 0,70 m. One door is used for charging the kiln with firewood while the other is used for discharging the charcoal, The kiln doors are closed with bricks built up after the charge is completed and both are opened when the carbonization process is finished. This is a simple operation that is repeated each time the kiln is charged. It only involves placing brick over brick and covering with mud. Approximately 100 bricks per door are needed and they can be used until the bricks start to break from handling, The top of the kiln has a hole (called an "eye") of about 0.22 m-0.25 m diameter. Around the base at the level of the ground are ten holes evenly spaced (0.06 m height x 0.12 section). These holes are air inlets and the eye is the outlet for smoke. The foundation consists of a double row of bricks three courses high set in mud mortar.

Photo 15. A half orange kiln just built. Note reinforced doorway to avoid damage to kiln during loading and unloading. Note way bricks in double skin wall around door are cross bonded compared with single layer wall seen in top right-hand corner. Argentina. Photo. J. Bim.

Fig. 5. Argentine half orange or beehive brick kiln. Kiln is hemispherical with two opposite doors to make loading and unloading easy and provide ventilation. Shell is mostly a single leaf of bricks with a double layer surrounding each door. Extra brick columns at each side of door are common. About 6 000 common hand made bricks are needed, set in mud mortar, mixed with charcoal fines.



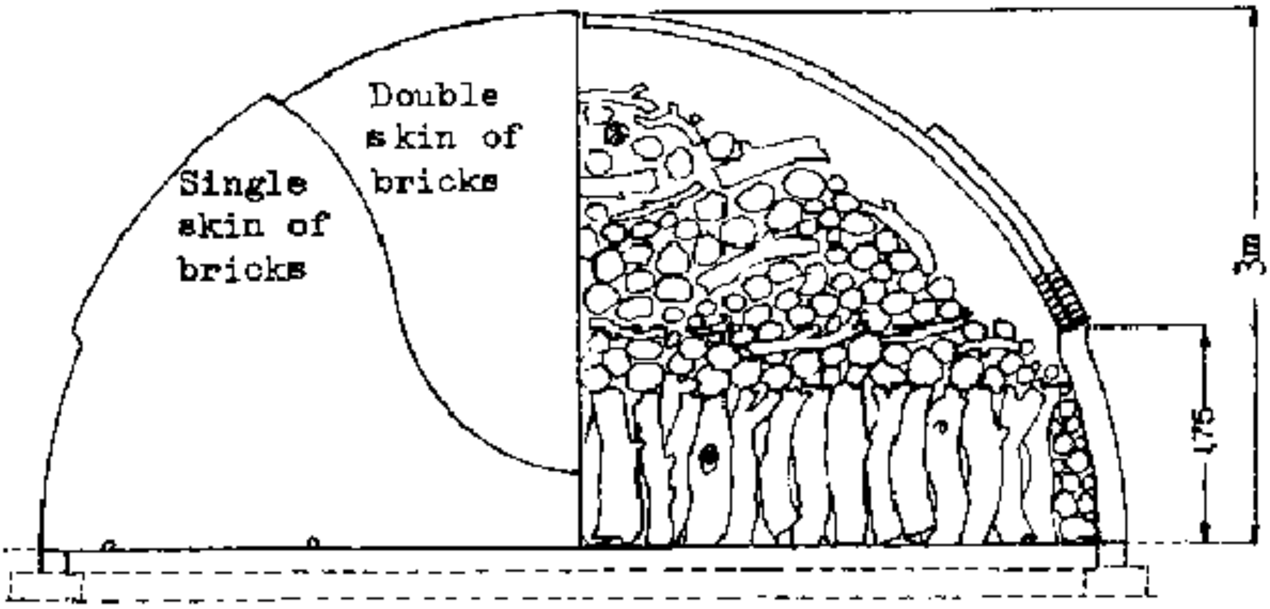


Photo. 16. Closing dome of a half orange kiln under construction. Note radius rod and orientation of bricks in dome. Argentina. Photo. J. Bim.

Photo. 17. Partly completed half orange kiln and completed water storage tank. Note cross bonding of brickwork in the double layer part of wall and way bricks are laid in the single layer section. Argentina. Photo J. Bim.

7.1.3. Fuelwood

Fuelwood to be utilized is cut to about 1.00 m - 1.30 m length with a minimum diameter 0.05 m and a maximum diameter equal to the width of the door. Fuelwood coming from the forest by transport (trailer or animals) must be placed as near as possible to the loading door. Not less than four to five weeks air drying time is recommended. This depends on local weather conditions. Manual or mechanical means may be used for debarking the wood. Many barks simply fall off during the drying period. The kiln can be loaded with roughly 30 t of air dry wood, of moisture content 25%, and average specific gravity of about 850 kg/m³.

7.1.4. Loading

Loading through the door near the firewood pile is most convenient. This operation needs two men and the time taken for completion should not exceed six hours. Stringers over which the fuelwood will be placed must be prepared with small lengths of wood of a diameter of not more than 0.08 to 0.10 m. This is to avoid direct contact of the fuelwood with the ground. The bigger diameter logs must be placed in the centre where prolonged higher temperatures are reached. The fuelwood in the kiln is stacked in a vertical position to a height of 1.20 m (length of wood). Placed over the vertical logs are logs in a horizontal position, bringing the kiln up to complete capacity, as in fig. 5 and photo. 18 of a partly loaded kiln. Special care must be taken that the holes at the base of the kiln (air inlets) are not closed. Some small dry wood is placed on top of the charge under the eye to assist in lighting the kiln. When loading is completed both main doors must be sealed using bricks covered with mud.

Photo. 18. Typical loading of a half orange kiln, Argentina.

7.1.5. Operation

All holes at the base and the eye of the kiln must be open. Some pieces of burning charcoal, dry leaves and small branches are thrown through the eye to ensure that the firewood is well alight. After some minutes a visible dense white stream of smoke starts to come out through the eye. This phase represents first distillation and the wood loses its water content at this stage. The white smoke continues for some days (depending on the water content) and then starts to become blue, showing effective carbonization is in process. This process is controlled by opening and closing the air inlets at the base of the kiln. No flame must appear through the eye. When the carbonization process is completed the smoke becomes almost as transparent as hot air. At this point the holes at the base must be closed with mud or covered with earth and sand. This phase is called "purging". After this phase the top eye hole is closed, starting the cooling phase. The cooling is accelerated by throwing mud (diluted with water) on the kiln. Apart from cooling, this helps to cover any hold or crack in the walls, thereby preventing any entry of air. The slurry of mud and water must be applied about three times per day.

Before discharging the charcoal, when the kiln is sufficiently cool, sufficient water must be available to avoid re-ignition when opening the door of the kiln. One drum of about 200 litres is sufficient for one kiln. The kiln is discharged by two or three men. The charcoal is conveniently removed from the kiln with a special fork known as a stone fork. It has 12-14 teeth and a tooth spacing of 0.02 m. This allows the bulk of the fines (less than 20 mm) to fall through and remain in the kiln. The charcoal is placed on a 1.2 m square piece of canvas and carried by two men out of the kiln.

Typical process schedule is as follows:

Loading	6 hours
Burning	6-7 days
Purging	1-2 days
Cooling	3.4 days
Unloading	3.4 days

A total of 13-14 days should be adequate to complete a cycle to produce 9-10 tons of charcoal with a kiln of 7 m diameter.

Using a kiln of 6 m diameter the approximate yield per burn is 7.5 t or 15t/month. The yearly average obtained by the largest charcoal producer in Argentina, Salta

Forestal S.A., during 1978 was 3.75 tons of fuelwood per ton of charcoal. Both wood and charcoal are always weighed. Lower yields may be obtained when lower density or higher moisture content wood is used.

During the first three to four burns when the bricks and the earth floor are drying out, the kiln is considered "green" or "immature" and the yields are somewhat lower. The useful life is five years at least and no special maintenance is needed. Whenever small cracks appear on the walls, small pieces of brick and mud are used to close them.

The normal number of kilns per battery is 10-14 depending on the type of forest, the area involved and the transport distance. Water supply is also required. A tank of about 3,000 litres capacity can be made with bricks and cement. A battery is operated by 3 men: one burner and two helpers.

7.1.6. Bricks

The type of brick used for kilns is important. An ideal brick is rather porous having good resistance to thermal shock and a good insulator. The kiln walls must insulate the wood which is being carbonised from excessive heat loss, specially that caused by wind and yet during the cooling phase must conduct heat to enable cooling to take place quickly.

For economy bricks should be made and burned near where the kiln batteries will be built. A sandy clay is prepared with a clay content of about 65%. To increase porosity of bricks about 20% of sawdust can be added to the raw clay mix. Dry bricks are self-burned in large piles, using wood fuel.

Dense, machine made, high strength bricks as are used in permanent buildings in cities are not so suitable, being more liable to heat cracking. They also cost much more delivered than bricks made and burned at the site.

Mud (clay) supplies are important. A good type of mud has a fairly high sand and organic matter content and does not shrink and peel when dried. It should also not dry too hard since the clay has to be periodically scraped off the kiln as the thickness builds up after several cooling cycles. This clay can be recycled.

Photo. 19 shows a typical brickmaking site. The bricks are made from sandy clay dug from an alluvial bank of a nearby creek. The compacted damp mixture is cut with a spade to form each brick and placed as shown to dry. The dry bricks are stacked in a large pile of 20,000 to 30,000 bricks. The pile is built with internal flues which open along the top of the pile and start from fire holes built all along the base of the four sides. When the pile is completed fuelwood fires are lit in the fireholes and stoking is continued for 10-12 days or more to raise the temperature of the pile to around 900°C. The pile is then allowed to cool and dismantled. Well burned bricks are sorted from under burned ones forming the outside of the pile. The under burned bricks can be reburned in the next pile or used for low grade constructions.

Typical brickmaking site. Salta, Argentina. Photo. H. Booth.

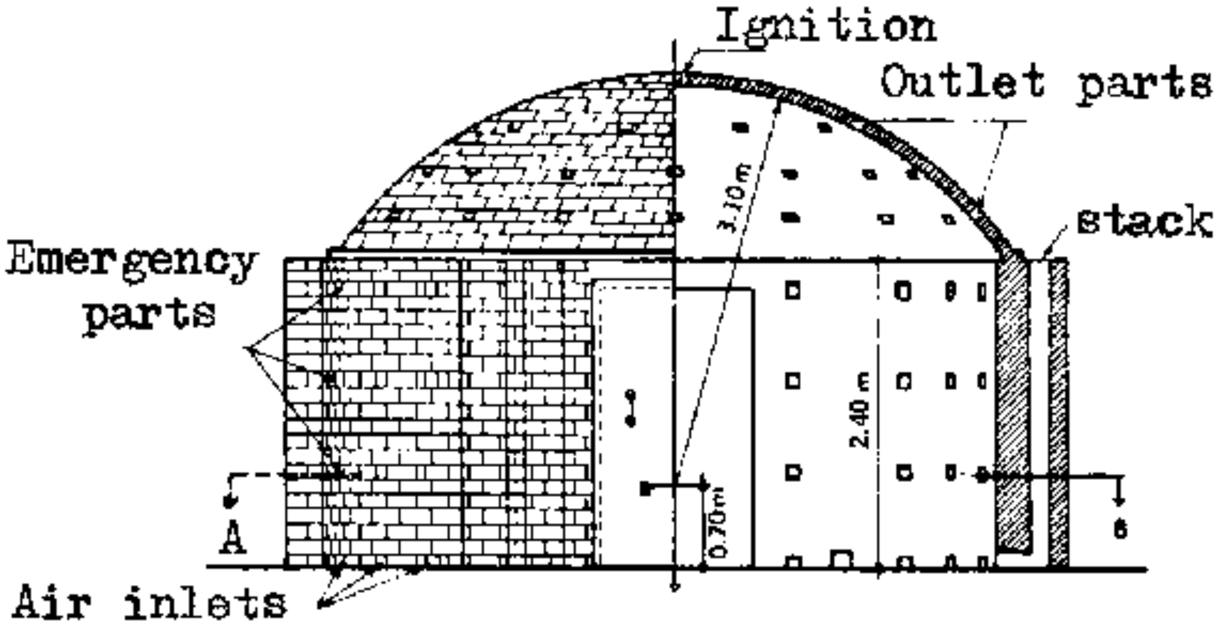
Photo. 20. Brickmaking using hand methods and fired in a pile with flues using wood fuel. Embarcación, Argentina. Photo. H. Booth.

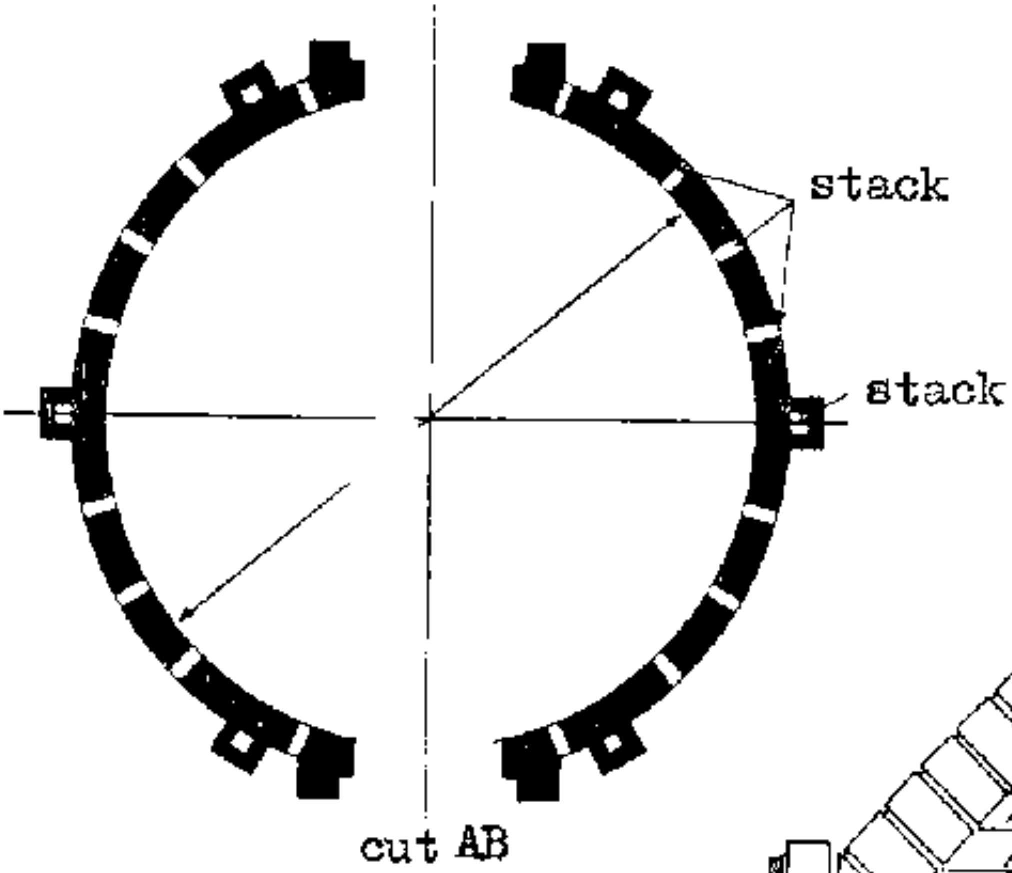
7.2. The Brazilian beehive kiln

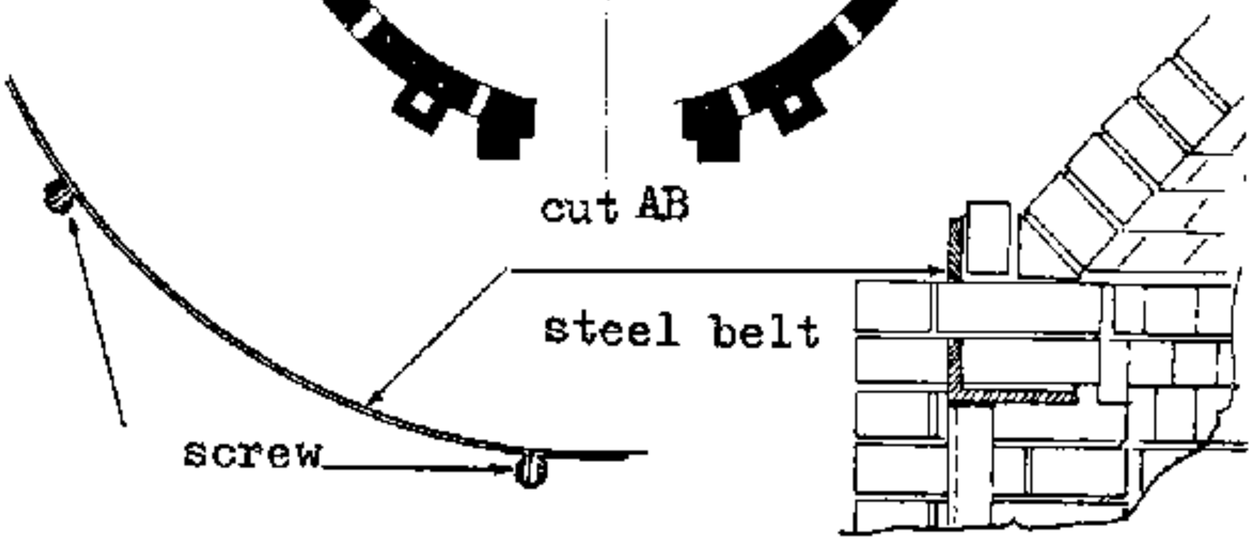
The Brazilian charcoal industry which forms the base of the charcoal iron industry of that country is one of the most successful charcoal industries based on brick kiln technology existing in the world today. There is much to be learned from the Brazilian experience by any country wishing to expand its charcoal production on a sound basis. The description given below follows closely the report by H. Meyers on the Brazilian charcoal iron industry. (23)

The kilns which are operated widely and successfully in Brazil, and especially in the state of Minas Gerais, are internally heated, fixed, batch type. The important iron and steel companies operate several thousand of them. They are circular, with a domed roof and are built of ordinary bricks. The circular wall is totally in contact with the outside air. This type of kiln is referred to as "Beehive Brick Kiln". See figure 6.

Fig. 6. Brazilian beehive kiln







Kiln diameter	5 m
Nominal kiln volume	48.94 m³

Effective kiln volume	45.31 m³
No. of air inlet ports	18
No. of smoke stacks	6
No. of outlet ports	6
No. of emergency outlet ports	50
No. of bricks required	8 500

7.2.1. Design

The Brazilian beehive kiln has the following advantages:

- The gases pass through the wood charge. The heat contained in the gases is partially used in the process of wood drying and carbonization.

- Good yield, up to 62% in volume = 1.6 st. of wood/m³ charcoal when properly operated.

- Low cost, approximately US$ 700 (in 1978) including access roads for trucks.

- Easy construction. Two men can build a kiln in 6 days.

- Simple materials. 8,500 burnt clay bricks with only one steel band for dome. No concrete foundations.

- Long life span. Up to 6 years on the same site. Can be dismantled without substantial loss of bricks and rebuilt at another site.

- Carbonization time of 9 days with a production of 5t/cycle.

- Uniform carbonization.

- Uniform cooling because the walls are completely in contact with outside air.

- Short operating schedule; approximately nine days. This time could be shortened through forced cooling with fine water sprays.

- Uniform control of interior combustion through 18 air inlet portholes for entrance of necessary combustion air.

- Easy and cheap maintenance, little repairs, no wall cracks, no electricity, very little water, approximately 100 litres per kiln and per batch.

Photo. 21. Battery of brick kilns in various stages of burning cycle. Minas Gerais, Brazil. Photo. J. Bim

7.2.2. Construction

One 7-kiln battery requires a site with the following dimensions:

Length ... 70 m
Width ... 25 m.

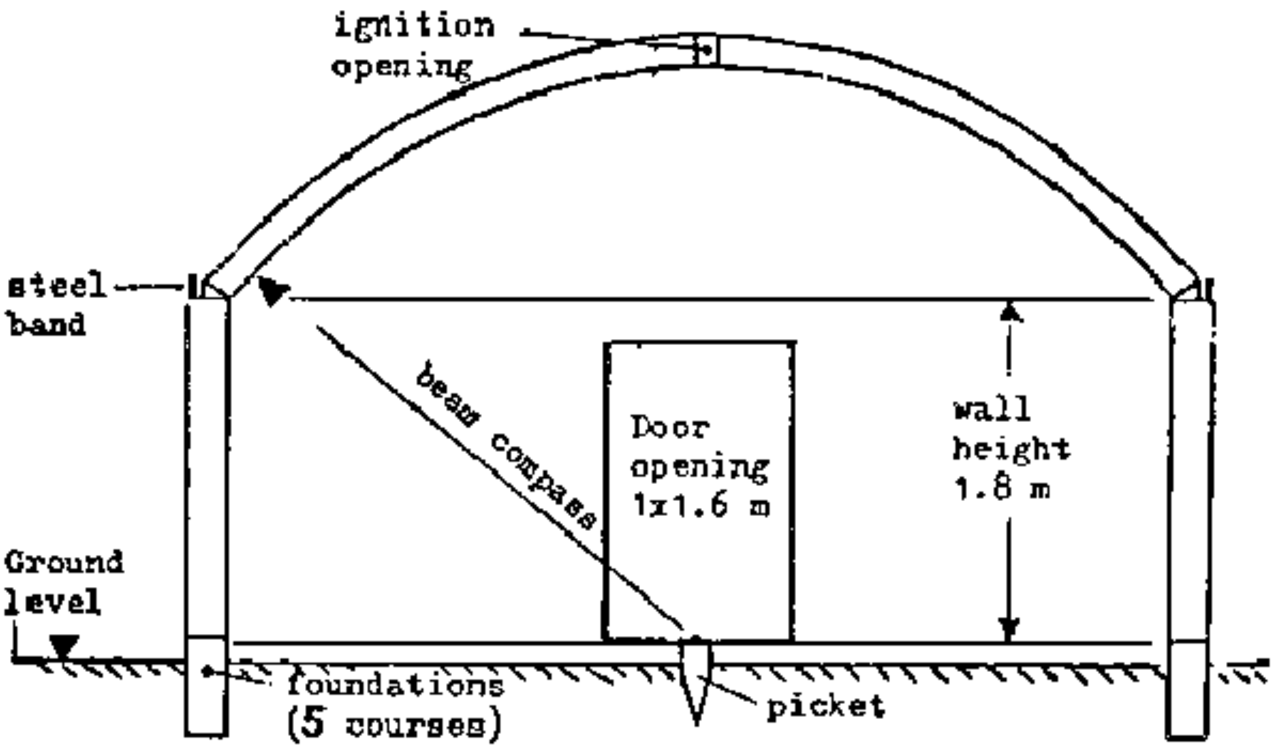
This area is necessary for the seven kilns, storing and curing of charcoal for two days, access roads for the trucks bringing wood, storage space for a certain amount of wood, access roads for trucks removing the charcoal and a truck turn-around area. To prepare the ground for the furnaces and the charcoal loading platform some earth moving by caterpillar tractors will always be required. The terrain must be slightly sloping to allow the drainage of rain water. Two or more kiln batteries will frequently be grouped together in one line. This is the case when the surrounding forests are vast and large amounts of firewood are available at a short distance. All batteries should consist of seven kilns and the total area will be a multiple of the surface given for one battery. The construction of a large number of batteries permits good centralized operations and supervision, resulting in good charcoal quality and yields.

The total number of kilns at one centre must be limited to 35 or 42 due to the fumes from the chimneys as, although not harmful to health, these fumes irritate eyes and lungs. Charcoal manufacturing centres should therefore be located at least two km away from villages. The prevailing wind direction should also be taken into consideration.

When laying out a battery the centre line is first marked on the ground. The kiln centres are eight metres apart. The centre of each kiln is marked with a two metre pipe driven vertically into the ground. The inside circumference of the kiln is traced at a 5.00 m diameter, the outside circumference at a 5.40 m diameter.

The two one metre-wide doors, the foundations for the door pillars, the six chimneys and the kiln foundations are marked and the excavation of the footing trench is made. The kiln foundations must extend four courses of bricks below the surface of the ground and one course of bricks above the ground. All courses must be laid carefully and on the level.

Fig. 7. Section through beehive kiln showing construction techniques.



A 2.50 m wooden pole will be fixed horizontally onto the central pipe to serve as a guide for the building of the walls. When building the walls, openings for the doors should be left but pillars for them built. Mortar is made of ten parts of clay and one part charcoal fines, previously sieved. When laying the first course of bricks, the necessary openings for the air ports should be left, three between each pair of chimneys, a total of 18, symmetrically distributed. Sizes of air ports are: width: 0.10

m; height: 0.08 m. The chimneys are built simultaneously with the wall. The inside dimensions of the flues are: 0.12 m x 0.10 m. When building the kiln wall, care must be taken that the different courses of bricks are level. A wooden guide should be used. After laying five courses of bricks, two emergency openings should be left vertically above the two air inlet ports located next to the stacks. After a second layer of five courses, one central emergency opening should be left. After the next five layers, two emergency openings should be located vertically above the first ones. The emergency openings are 0.07 m x 0.07 m. Each pair of stacks should have five emergency ports. When the wall has reached 1.60 m height the steel angle lintels should be placed on top of the door pillars and building of the surrounding wall should continue. In this way the two door openings, 1,00 m wide and 1.60 m high, will be ready. After loading the kiln with firewood and closing the doors with bricks, the burner should leave one air inlet porthole at the same height as the others in each door wall.

Total height of the vertical wall will be 1.80 m and the last course of bricks must be well levelled. On top of it one more course of bricks should be laid using a mortar and, against this last course, four segments of steel band loosely bolted together should be laid.

The first course of bricks for the dome should be adjusted by cutting to the top course bricks of the wall laid on their edge. The central pipe should be removed and replaced by a picket or short stake driven into the ground flush with the last brick course of the foundation. The beam compass of a guide length of about 3.10 m should be attached to this picket for the building of the dome, built to a thickness of half a brick, using a minimum of mortar. The strength of the dome is ensured through the pressure of the bricks against each other.

Emergency openings 0.07 m x 0.07 should be left at the fifth course of bricks, another ten at the tenth course, and six at the fifteenth. The ignition opening, triangle-shaped and 0.10 m x 0.10 m x 0.10 m should be left at the top of the dome. After the dome is completed the steel band should be tightened, the walls plastered with a fine clay mortar and the dome brushed with a clay slurry to close all cracks and openings.

<u>Slope type beehive brick kiln</u>

Figure Fig. 8.1

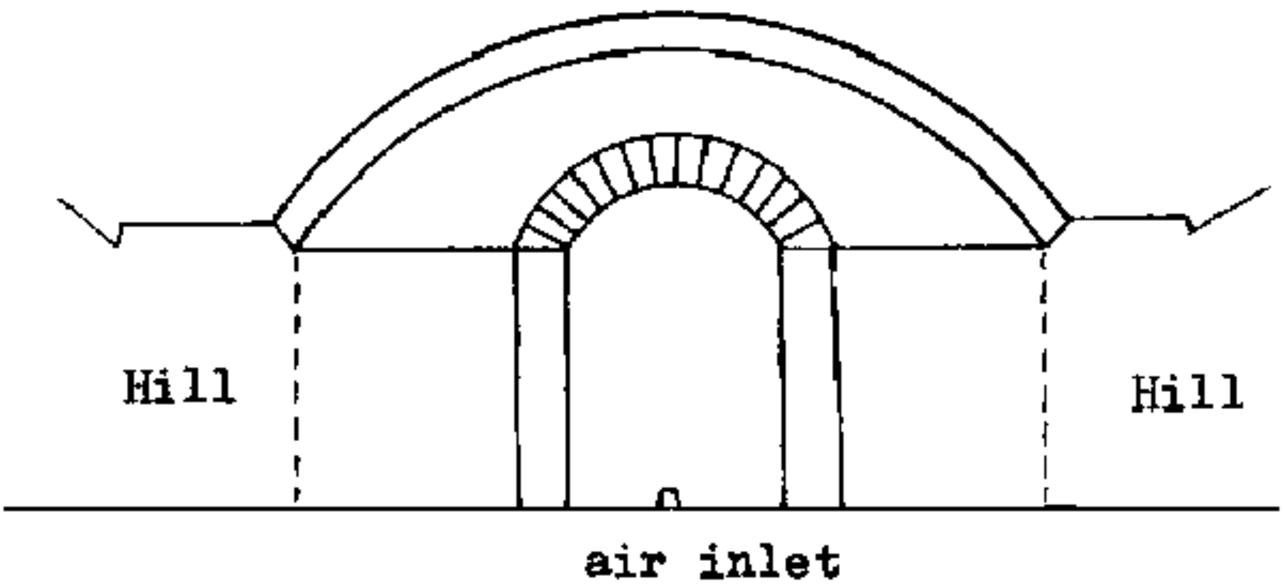
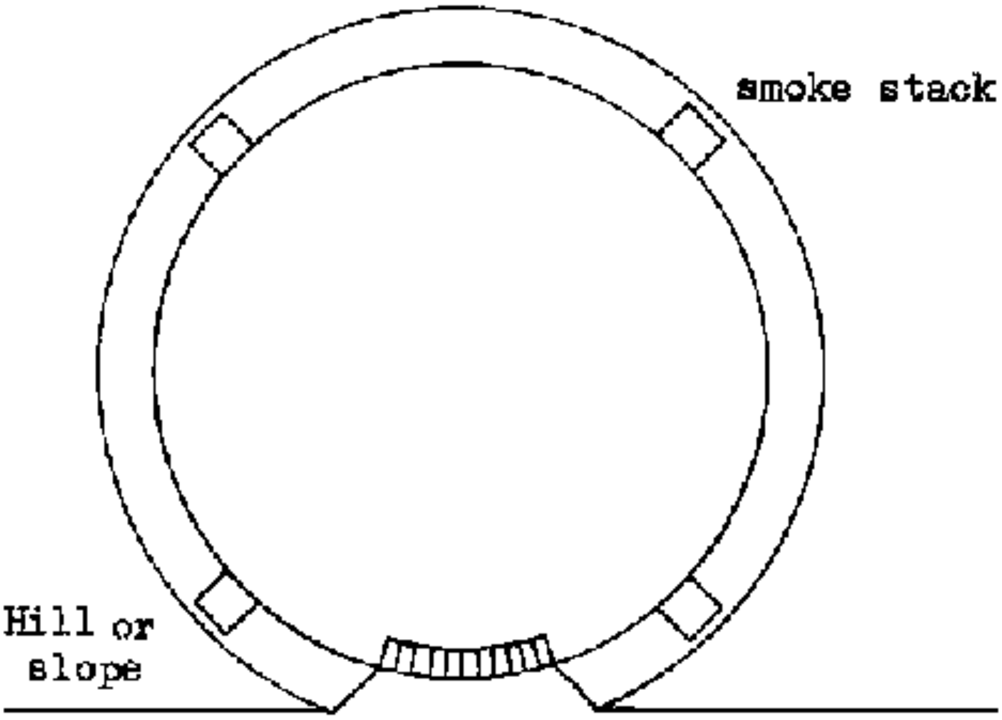


Figure Fig. 8.2



Kiln diameter	4.0 m
Nominal kiln vol.	24.8 m^3
Effective kiln vol.	21.6 m^3
No. of air inlet ports	1
No. of smoke stacks	3
No. of outlet ports	4
No. of emergency outlet ports	4
No. of bricks	2 000

7.3. Slope type beehive kiln

In figure 8 is shown a variation of the beehive brick kiln. It is a circular, 4 metre diameter kiln, built into a slope or hill which forms its side and rear walls. This will be referred to as the Slope type kiln. It uses considerably fewer bricks. Many thousands of these kilns are in operation in Minas Gerais and other states of Brazil. They are very popular among the small independent charcoal producers. Their operation is somewhat easier than that of the beehive brick kiln because they have only one air port to control, as compared to 18 for the beehive kiln. The chemical and physical composition and yields of the charcoal produced in slope type kilns are very close to those of charcoal produced in beehive brick kilns. No significant differences between the qualities of the two charcoal types are reported.

Photo. 22 Brazilian slope kiln built into hillside, sealed ready for lighting. Brazil. Photo. J. Bim.

7.3.1. The construction of slope type kiln

A circular surface six metres in diameter should be cleared at the kiln site and a circle four metres in diameter marked. The kiln chamber 1.40 m high should be excavated and the floor well levelled. The position of the door, 0.60 m wide and three or four smoke stacks (0.35 m x 0.35 m section) at some distance between them should be marked. (Fig. 8).

Openings for the door and the three stacks should be dug into the bank to a height of 1.40 m and the chimney stacks raised to a height of 1.50 m with bricks laid on their edge.

A picket should be driven into the centre of the floor with the beam compass for building the arched dome attached to it. The guide length will be the exact inside height of the dome, i.e. 2.45 m.

If the height of the bank or hill is insufficient it will be necessary to reach the 1.40 m wall height by the addition of some layers of half bricks. The mortar used is the same as for the dome. A brick arch should be constructed over the door opening. The necessary sloped incision for the dome rest should be made around the dome base.

The dome is built in half brick thickness, with little mortar, made of ten parts of clayish soil and one part of sieved charcoal fines. Four symmetrically placed emergency holes, 0.07 m x 0.07 m should be left in the tenth course of bricks and after ten more courses four more holes 0.08 m x 0.08 m should be left. At the top of the dome an ignition opening, 0.10 m x 0.10 m should be left.

The arch over the door opening is built of bricks laid on their sides and bonded to the dome brick structure. Near the kiln door an opening is made into the bank to facilitate the handling of the firewood. After the kiln has been loaded with wood and the door closed a porthole for the air inlet should be left at the level of the ball. Dig necessary water drainage trenches round the kiln.

7.3.2. Maintenance of the kiln

Periodically the excess clay which has been formed by the successive brushes of clay slurry should be rasped. This improves cooling of the charcoal.

The structure of the kiln can be damaged by impact; for instance by trucks, carts, logs, etc., and this should be avoided. The door pillars should be protected by two corner poles. Bricks which have fallen out of the walls or have become loose should be put back in place and rammed tight.

The outlet and emergency portholes must be closed with wedge shaped bricks without mortar and brushed with clay slurry on the outside. The stack flues must be carefully cleaned with a long, flexible wooden rod.

The chimneys must terminate above the steel band of the dome to reduce corrosion by fumes. Corrosion of the band will, in any case, take place after a few years. The steel band of the dome should be tightened regularly and any corroded parts replaced.

The kiln floor should always be kept level. When necessary, some wet clayish soil should be put in and stamped down. If the soil of the kiln platform cracks, it must be closed to avoid damage to the kiln foundations, for instance through water infiltration. The water drainage trenches should be kept unobstructed at all times.

Stray animals should be kept out of the charcoal manufacturing centre by fencing with barbed wire or other material.

7.4. The Missouri kiln

The Missouri kiln was developed over many years in the deciduous hardwood forest zones of the State of Missouri in the U.S.A. The design had become more or less standardised by about 1960 and recommended dimensions and construction details have been published by Pitts Jarvis in the "The Wood Charcoal Industry in the State of Missouri" (English Series Bulletin No. 48, Engineering Experiment Station, Columbia, Missouri). The Missouri kiln is adapted to a severe winter climate, high labour costs, mechanised loading and unloading, and uses construction methods and materials which may be costly and difficult to obtain in the developing world.

The Missouri kiln must stand up to severe freezing winter conditions which can be very destructive to lightly built brick kilns. The frost heaving of foundation soils and the freezing of water in masonry cracks are two of the major hazards. Heavy reinforcement of foundations, walls and roof, and a monolithic reinforced concrete structure are essential to avoid rapid deterioration of the kiln. Low air temperatures also call for a well insulated structure to reduce heat loss and excessive production of unburned brands in the charge.

The Missouri kiln is designed to allow easy entry of mechanical equipment such as small tractors, trucks and front - end loaders to allow the kiln to be loaded and unloaded easily and rapidly. This is one of its most attractive features where labour costs are high.

7.4.1. Design

Typical Missouri kilns range in volume from about 4 m^3 to 350 m^3. The optimum median volume seems about 180 m. This size gives a fairly low cost per m^3 of volume and yet does not make the kiln so large that it is difficult to control. Such a kiln is about three times as large as a half orange or a beehive type kiln. (See 7.1 and 7.2).

The kiln is rectangular in plan (Fig. 9), about 7 m wide and 11 m long. The walls are about 2.5 m high to allow mechanical equipment to enter. The maximum height of the vaulted roof is about 4 m above the floor. The walls are about 250 mm thick. Photo 13 shows a typical group of Missouri kilns.

The quantities of materials needed to build a Missouri kiln are impressive and must be carefully costed by potential builders. Table 5 compares the material needed for one Missouri kiln of 180 m^3 capacity (50 cords) composed with four Brazilian type kilns, having a total capacity of about 200 m^3. The greatest disadvantage of the Missouri kiln in developing countries is its high content of cement and steel, both usually imported and often costly and difficult to obtain. Skill to work with them in a typical charcoal making area may be limited. The advantage - that the kiln is easily loaded and unloaded mechanically - must be carefully judged on a case by case basis.

The cost of steel can be critical in developing countries so it is important to compare the relative efficiency with which it is utilized by different types of kiln.

A useful index is to calculate the production of charcoal per kg. of steel used in construction for various types. Obviously earth mounds and pits are best since they use no steel at all and the index is infinite. We can usefully compare the Missouri, the Brazilian, beehive and the steel portable kiln. Using values for charcoal produced over the lifetime of the kiln, when used efficiently, taken from this manual, the indices are as follows: Brazilian beehive: 8,200 kg of charcoal per kg of construction steel; Missouri kilns 550 kg of charcoal per kg of construction steel and the portable steel kiln: 330 kg of charcoal per kg of construction steel. The beehive kiln thus uses steel 15 times more efficiently than the Missouri. The Missouri uses steel about 1.5 times as effectively as the all steel portable kiln.

The Missouri kiln is an engineered structure which must be constructed carefully to design specifications. Collapse of the structure will occur if inadequate reinforcement steel is used or it is not correctly located. If expanded shale aggregate is not used and/or the kiln becomes overheated, the vaulted roof will collapse due to yielding of the reinforcement steel in the roof and walls. Collapse of such a costly kiln would be an economic disaster for most producers and, if skilled construction labour and the specified materials are not available, construction should not be undertaken.

Table 5 - Use of materials for Missouri kiln and four equivalent beehive kilns

Material	One 180 m³ Missouri kiln	Four beehive kilns total volume 200 m³
Concrete using expanded shale aggregate	46 m³	nil
Common bricks	nil	34 000
Steel tons total	4.4 m.t.	0.58 m.t.
Reinforcement	1.56 m.t.	0.58
Door frames	0.74 m.t.	
Air ducts	0.34 m.t.	
Doors	1.11 m.t.	
Miscellaneous	0.20 m.t.	
Stoneware flue pipes	37 m of 150 mm diameter	nil

7.4.2. Construction

The walls, floor and roof of the kiln are of poured reinforced concrete construction with doorway frames of steel cast in place. The recommended aggregate is lightweight expanded shale to improve thermal insulation and resistance to heat spelling. Expanded shale aggregate is usually not available in most charcoal making areas of the developing world. The double doors of the kiln are a critical and costly component. They must be easy to open, yet capable of being sealed tight to prevent air leaks during cooking. Rolled steel plate 10 cm thick is recommended to reduce warping which prevents proper sealing. The seal is made by bolting the doors to the steel door frame embedded in the walls and to each other where they meet. 18 mm (¾ inch) bolts are recommended. Each door leaf weighs more than a quarter of a ton so they must be well hung on heavy duty hinges to stand repeated opening and closing.

The kiln is fitted with eight chimneys made from 15 cm (6 inch) stoneware drainage pipes. Steel or cast iron pipe can also be used. Each chimney is about 4.5 m high and is supported by brackets off the walls of the kiln.

Kilns are usually grouped in batteries of three to six or more. This makes for economical use of equipment and labour. To reduce pollution sometimes in the U.S.A. batteries of kilns are connected to a central flue and after-burner system feeding to a common chimney stack. The normal flues are dismantled and the smoke outlets are connected by horizontal steel flues to the after burner. The after burner, which is fuelled by oil, is needed to heat the incoming flue gases and ensure that they are totally reduced to carbon dioxide and water by mixing with the oil burner flame before being discharged via a fan into the atmosphere. Obviously, such a system can only be economic where the price of charcoal is high, making it economic to burn some fuel oil in order to produce charcoal.

7.4.3. Operation

The conversion yield of Missouri type kilns is similar to brick kilns of the Brazilian or Argentine type when all types are operated under optimum conditions. The high construction cost of the Missouri kiln is traded off against the labour savings brought about by using mechanical loading and unloading equipment. Theoretically, since a large Missouri kiln has the volume of about 4 Brazilian type kilns, there should be additional savings in burning labour costs. In practice, the Missouri kiln does not achieve its full potential, especially in warm climates, because of its slow cooling. There is a close relation between kiln surface area, volume, ambient temperature and cooling rate. Very large kilns and pounds are slow to cool and, if construction cost is high, they represent an inefficient use of capital because of the reduction in output which slow cooling implies.

The burning of the kiln is controlled in a similar way to the portable metal kiln. The gas circulation system is rather similar. Yields are usually better because the better thermal insulation and greater ratio of volume to surface area means that the endothermal heat of carbonization is better utilised and the kiln is not so subject to the cooling effects of winds and rain as the uninsulated metal kiln.

Missouri kilns are usually equipped with thermocouples to read the temperature at several points within the kiln. This is important with such large kilns as it enables cold and hot spots to be readily detected and corrective action taken by the operator by closing or opening air vents along the base of the kiln. The cooling process can also be checked and the kiln opened only when the temperature of the charcoal is low enough. This avoids fires which, in such large kilns, are not easy to control even with mechanical handling.

A crew of two men are needed for loading and unloading, equipped with a front-end loader and truck. One operator per shift is sufficient to control the burning and, providing thermocouples are used, one man per shift can supervise a number of kilns.

The kiln cycle is usually about 25 to 30 days depending on cooling rates. The capacity of two 180 m kilns is about equal in wood consumption to a standard battery of seven Brazilian kilns. But because the cycle time is different, the utilization of labour is not as efficient as it could be unless there were more kilns to a battery. Utilisation of mechanical equipment is not optimised unless the number of kilns is sufficient to keep it working more or less continuously.

The cycle time of a Missouri kiln in a warm climate is at least one month, made up as follows:

Loading	3 days	2 men plus machines
Burning	7 days	2 men on 12 hour shifts or 3 men on 8 hour shifts
Cooling	21 days (min.)	1 man part-time supervision
Unloading	2 days	2 men plus machines.

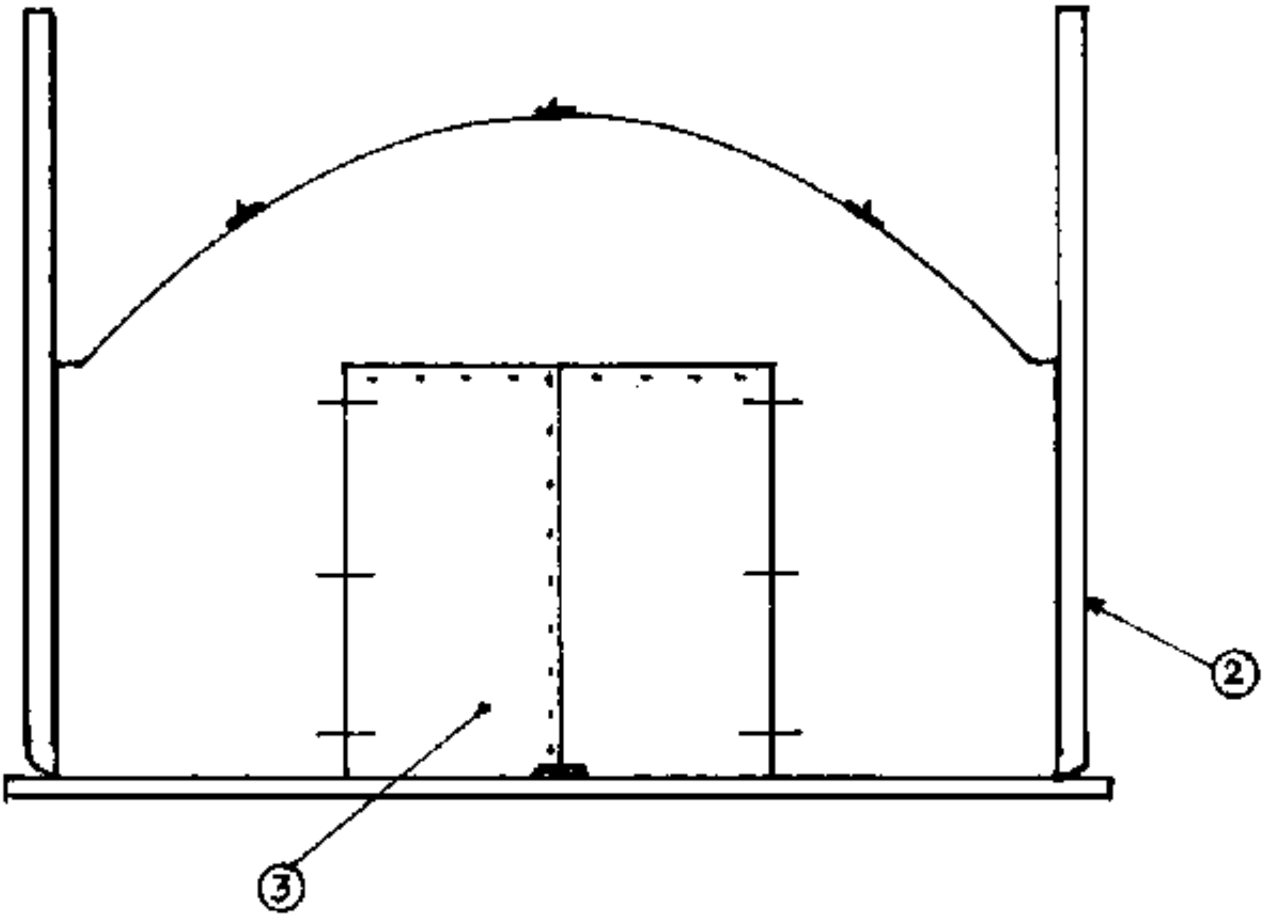
The total time is 33 days. If machines are not available the cycle time can stretch to two months or more.

7.4.4. The Missouri type kiln in the developing world

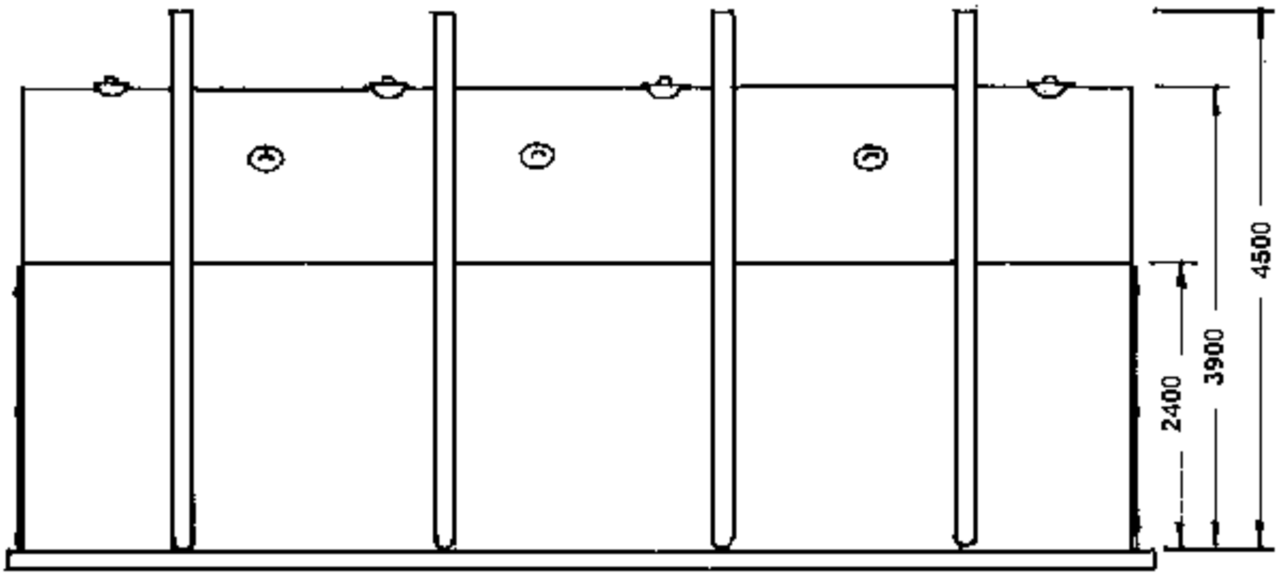
The Missouri type kiln was and still is an important method of charcoal making in the U.S.A. In 1958 when the industry was at its peak about 45 000 tons of charcoal were produced in Missouri by this method. (This production is miniscule compared to production by other methods in the developing world but is enough to attract interest in the method.)

Missouri kiln - volume 150 M³

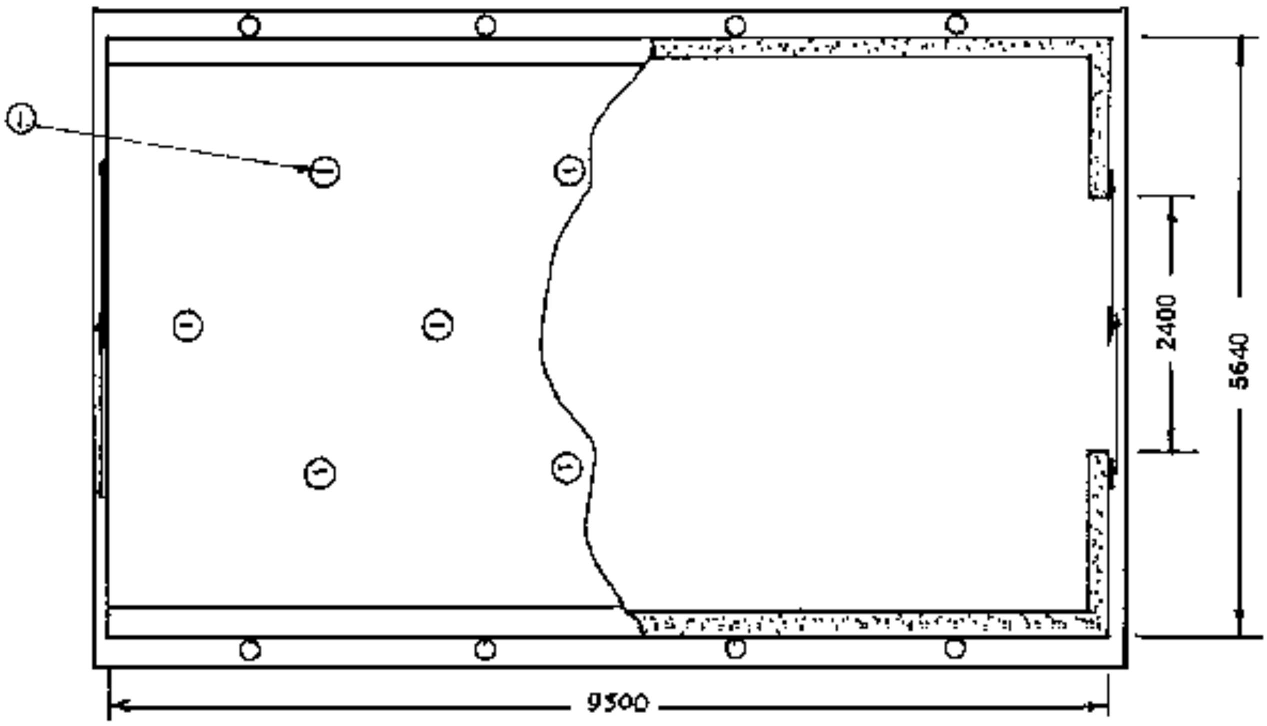
Vent hole covers



Chimneys



Steel plate doors



The Missouri kiln's greatest advantage compared with brick kilns is the possibility, in fact the necessity, of mechanical loading and unloading.

Its disadvantages are its high cost due to high use of steel and concrete and its immobility. Unlike brick kilns it cannot be demolished and rebuilt. Hence a ten-year wood supply must be available within economic haul distance of any group of kilns. The amount of wood for a group of some 180 m³ kilns would be 120 000 m³ approximately. About 4 000 ha of forest capable of yielding 30 m³ per hectare would have to be set aside for ten years to supply this amount of wood. Such an area would give a mean haulage distance of about 2.5 km, which is reasonable.

Missouri type kilns or their equivalent would be more acceptable if construction were lighter and hence cheaper and if they could be cooled more rapidly, perhaps using water injection. The Brazilian industry is experimenting in this direction. Faster cooling and simpler construction has been achieved in the U.S.A. by building the kilns from insulated steel sheathed panels. Unfortunately, construction cost steel remains high - a barrier in the developing world where such products must be imported.

As far as transferring the technology is concerned, the experience of the FAO/UNDP project in Ghana is useful. A Missouri kiln was built and, technically, operation of this kiln is a success. The problems are the high cost of construction and the mechanical loading/unloading equipment.

Battery of half orange kilns more than 8 years old and still in use. Los Tigres, Argentina. Photo H. Booth.

7.5. Charcoal production centres

The beehive brick kilns are grouped in batteries of 7, 14, etc., (always a multiple of 7). The slope type kilns are grouped in batteries of 14, 28, etc., (always a multiple of 14).

Fig. 10. Operating cycle for beehive brick kilns

Charcoal discharging and firewood charging	8 hours
Carbonization	96 hours
Cooling	88 hours
Total cycle:	192 hours or 8 days

Each battery is attended by only two men, one charcoal operator or burner and one helper.

A charcoal production centre comprises one or more batteries of kilns each complete with the infrastructure necessary for continuous operation. For example, stockyard for firewood, for charcoal storage, for charcoal loading facilities, access roads, water supply, etc.

7.5.1. Operational cycle of a seven kiln charcoal battery

The operational cycle of each of the seven kilns starts on successive days. If kiln No. 1 is discharged and recharged (eight hours) on a Monday, then kiln No. 2 is discharged and recharged on a Tuesday, etc. Kiln No. 1 will then be ready for discharging and recharging on the following Tuesday and kiln No. 2 on the following Wednesday, etc.

Sunday is a rest day on which no kiln discharging or charging is done. Kilns due to be discharged on Sunday are dealt with the following Monday. Thus the cycle recommences on a Monday for each kiln in turn after six weeks.

Table 6: Characteristics of beehive and slope type kilns

Type of kiln	Volume of Firewood in steres		Ratio Real/Nominal	Charcoal volume in m³ per batch	Average yield Firewood/Charcoal
	Real	Nominal			
Beehive brick kiln 5 m diam.	48	37.34	70%	17.8	2.1 : 1 (vol.)

Slope type kiln 4 m diam.	24.8	17.40	60%	8.9	2.2 : 1 (vol.)

The above average yields are those obtained until about 1975. Since 1976, through continuous research and experiment, the improvement of operational conditions, the training of charcoal burners and better supervision, the yields of company operated kilns have continuously improved to: 1.9 : 1 (53%); 1.8 : 1 (55%) and 1.7 : 1 (59%). Yields of 1.6 : 1 (60%) are being obtained recently in routine operation (1977).

Production of a 7 beehive kiln battery in 30 days 30/8 x 7 = 26.25 batches - say 26 batches. Each batch = 17.8 m^3 of charcoal. Monthly production 17.8 x 26 = 462.8 m^3 charcoal and yearly production 17.8 x 26 x 12 = 5 553.6 m^3 charcoal.

7.5.2. Operating instructions for beehive brick kilns

(i) Charging

First fit two logs crosswise on the inside of the discharging door. Then block up the discharging door with bricks laid without mortar. The outside of the door should be brushed with a clay slurry but only after charging has been completed.

Charging can now commence. The logs are placed vertically, the thinner pieces against the wall, the thicker ones towards the centre of the kiln where the temperature will be higher. Put the chisel-shaped bases of the logs on the kiln floor to make circulation of the gases easier. The wood piled under the dome ceiling must be placed horizontally on top of the vertically piled floor wood. Fill up well into the dome. The wood must be piled as close together as possible to obtain a maximum amount of material inside the kiln. Use a loose structure and some kindling close to the ignition opening to make ignition easier. If there is some deteriorated wood, this must be placed near the discharge opening as the charcoal produced from it will have a tendency to ignite easily and, if that happens, it can be rapidly removed when discharging the kiln. Close the charging door in the same manner as was done for the discharge door.

When the kiln is ready for ignition, all portholes and openings must be kept open.

(ii) Ignition of kiln

Introduce through the central opening in the dome a shovelful of glowing (incandescent) charcoal. In the rainy season it may be necessary to help with some kerosene or used lubrication oil. Use the central opening only for ignition, as the carbonization process must proceed from top to bottom. At the start of the ignition period smoke will issue from the ignition opening first white and minutes later dark coloured. This is a signal that the fire has caught. The opening must then be plugged with a brick brushed with clay slurry.

(iii) Carbonization

Immediately after ignition, smoke issues from the outlet portholes, initially white coloured, which means that the carbonization area is increasing. The emergency outlet portholes and the ports located in the dome are now plugged.

The stacks (chimneys) start smoking. The kiln operates from now on exclusively with the controlled air supplied through the air inlet portholes and on the draft of the stacks expelling the carbonization gases.

The carbonization process proceeds from top to bottom and also horizontally. The chimneys must be watched to ensure they work uniformly. This is achieved by controlling the draught of air entering the air inlet portholes by varying the position of a brick loosely inclined against the porthole entry.

The charcoal burner controls the carbonization by observation of the colour of the smoke issuing from the stacks. Carbonization proceeds as long as the colour is white. Later it turns bluish white and then transparent blue. When this colour becomes steady, the air inlet portholes must be closed.

At the end of the carbonization the smoke becomes colourless and transparent. When a zone of approximately 20 cm height of colourless smoke appears on top of the stacks, the chimneys are closed.

The stacks do not present simultaneously the same smoke colour even after every precaution has been taken. It is therefore necessary to regulate, one after the other, the air inlet portholes and to close the corresponding stacks. These will continue to issue smoke some time after the air portholes have been plugged. The stacks should not be closed too soon to avoid the presence of uncarbonised pieces of firewood.

Once the stacks have been closed, the carbonization process is terminated. After closing all openings, they must be carefully brushed with clay slurry to prevent any air entering.

(iv) Cooling the kiln

The kiln is brushed all over with several layers of clay slurry to close all openings, leaks and cracks. The number of brushings varies between three and six. The better this operation is done, the faster will be the cooling of the kiln. When leaks are not fully closed, air will continue to penetrate into the kiln, preventing the extinction of the fire, causing loss of charcoal through its combustion and an increased ash content.

(v) Unloading the kiln and curing the charcoal

The kiln is opened and the charcoal is discharged when the kiln is sufficiently cool. The burner knows the correct temperature - 60 - 70°C, by feeling the door wall with the back of his hand.

A kiln must never be opened until it is sufficiently cool to avoid spontaneous fire. Such a fire may be extinguished with water but, in most cases, it will be necessary to close immediately the kiln. The result is always a loss of charcoal. Sufficient water, at least one barrel - 200 litres - must be readily available before the kiln is opened. The space in front of the kiln where the charcoal will be stored, must be clean. Fresh charcoal must never be placed on top of older charcoal. The kiln is opened rapidly. The burner will observe by the smell of the issuing gases, whether there is fire in any place and, in that case, will extinguish it with water spray.

The bricks from the door opening are put on one side not to impede the discharge operations, which are done manually with a special large fork and a basket. It is good practice to separate all uncharted pieces of wood bricks, ashes, charcoal fines and clay remnants. Incompletely carbonised pieces of wood are separated and reloaded with the next batch. The discharged charcoal is heaped and stored in a way to allow thorough aeration. This is also called curing. Fresh charcoal absorbs oxygen. This chemical reaction is accompanied by a rise in temperature which can cause spontaneous ignition. Therefore, fresh charcoal is required to "cure" in the open air for two days before being transported to the intermediate storing houses or to the iron and steel plants. It is, of course, difficult to control whether this operation is always done with the necessary care. Principally at the end of the month, when charcoal operators are anxious to complete their monthly quotas of charcoal production, it frequently happens that the charcoal is insufficiently cured, causing fire hazards.

During curing, the charcoal heaps should not exceed 1.50 m height or depth, to permit a thorough contact between the charcoal and the outside air.

After unloading, the bottom of the kiln is cleaned. All air ports and stacks are opened and cleared from carbonization residues. The entire inside of the kiln becomes heavily coated with hard tar or pitch which condenses and builds up during successive charges and protects the tricks.

Photo. 24. Unloading charcoal from a brick kiln in Salta, Argentina. Fork is used to allow fires to be separated. Photo M. Trossero

7.5.3. Carbonization in slope type kilns

This is the same as in beehive brick kilns. The operation is simpler because there is only one air inlet porthole to watch and regulate. These kilns are frequently located at places of difficult access without roads. The unloaded charcoal must be transported to the nearest road or to a reloading place by mules. The following points of comparison may be considered in making the correct choice between the two types of kilns:

Beehive brick kiln	**Slope type kiln**
No special topography required	Necessary to have a natural slope or to prepare an artificial one.
It will be frequently necessary to do some important earth moving to prepare a good-sized flat area.	Very little earth movement required
No special requirements as to the texture or composition of the soil. In case of sandy soil, floor must be made of clay brought from another place.	The texture and composition of the soil are important. When very clayey it will crack through the effect of carbonizing heat and false air will enter. When sandy, the wall will collapse easily and retain too much heat to permit fast cooling.
Life span: minimum of 1 200 m³ of charcoal	Life span: minimum of 350 m³ of charcoal
Kiln platforms must be laid out to permit handling of charcoal directly into trucks after curing. The trucks should arrive at a, lower level (See fig. 10).	Kilns must be built as close as possible to wood supply.
Maximum distance from wood supply:	Maximum distance from wood supply: a few hundred

5 km.	metres.
Labour: 2 men for each battery of 7 kilns	Labour: 2 men for each battery of 14 kilns
Charcoal burners must have developed considerable skill in order to observe correctly and regulate the 18 air inlet portholes. Training of labour is recommended.	Easy operation. Only one air inlet port hole. No special training required.