

Simple technologies for charcoal making

THE
SUSTAINABLE
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41



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ENERGY

Simple technologies for charcoal making

Mechanical Wood Products Branch
Forest Industries Division
FAO Forestry Department

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Introduction

This manual on making charcoal using simple technology systems represents another step by FAO to help overcome fuel shortages in the developing world.

Sixty percent of all wood taken from the world's forests is believed to be burnt as fuel - either directly or by first converting it into charcoal. The proportion of fuelwood used to make charcoal can only be estimated. But it is probably around 25 percent or about 400 million cubic metres per year throughout the world.

Charcoal in developing countries is mainly used as domestic fuel for cooking and heating but it is also an important industrial fuel. Large amounts are used in foundries and forges; in the extraction and refining of metals, especially iron, and in numerous other metallurgical and chemical applications. In those developing countries with abundant forest resources the export of charcoal can be a profitable industry.

Making charcoal by using labour-intensive methods is the concern of this manual. Its main purpose is to inform and orient government agencies and industrialists in developing countries concerned with improving production and distribution of charcoal.

This manual cannot reach easily and directly the mass of small Charcoal producers, distributors and users as, in general, they do not acquire knowledge of improved methods from books but from practical experience. This knowledge must be made available to them by government agencies directly or through internationally sponsored development projects.

The manual embodies the collective wisdom of charcoal makers of many countries and is offered in the hope that it will aid both to increase production of charcoal and, at the same time, conserve forest resources by curbing wasteful methods of production.

It is difficult to acknowledge adequately the assistance provided from so many sources. The bibliography gives the more important sources of information drawn on in compiling the manual. The help of the many workers involved is gratefully acknowledged, in particular that of Mr. Harry Booth.

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Chapter 1 - Logistics of charcoal production

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1.1. Developing a fuelwood and charcoal energy policy

The first step a country must take in seeking to guarantee an adequate supply of fuelwood and charcoal for its citizens is the development of a national fuelwood and charcoal energy policy. Such a policy must be national in scope since the allocation of resources needed to satisfy fuelwood requirements calls for action on the national level. (4)

A national fuelwood policy must also be interlocked with a national energy policy covering the whole field of energy use, since fuelwood supply cannot be expanded without corresponding inputs of liquid fuels' electricity etc. Nevertheless it is possible as a first step to begin with fuelwood and charcoal and other fuels used for domestic purposes in significant quantities.

The typical energy budget of a developing country relies heavily on fuelwood and charcoal for domestic cooking and heating.

In drawing up a fuelwood energy policy the three major aspects to be considered are:

- The present size and characteristics of the wood resource and its future development.
- The present consumption pattern of fuelwood and charcoal and probable future development.
- How the present supply is produced and distributed and what the possibilities are for its rationalisation and improvement.

1.2. The energy balance concept

The world consumption of fuelwood per caput, including charcoal, was estimated in 1978 at 0.37 m³. However, in the developed world the per caput usage was only 0.13 m³, compared to 0.46 m³ in the developing world. Developed countries have a high per caput usage of energy as a whole, of which wood is a minor component; developing countries have a low per caput energy input, most of which consists of wood and charcoal.

Table 1 taken from the UN Conference on New and Renewable Sources of Energy (Third Session 1981) shows the relative importance of fuelwood in various regions of the world. (30)

As a starting point it is useful to prepare a series of projections of the present and future consumption pattern which can be derived fairly easily from available population data and typical per caput requirements. From this one can estimate quite quickly the rate at which wood must be being harvested and the area of forest worked over and probably destroyed each year. From a knowledge of the distribution of the forest areas contributing to production

and the main areas of consumption one can fairly easily make a sketch of the main distribution network and probable quantities which must be flowing into the various markets. At this stage various "grey areas" in the image will begin to appear and surveys can be planned to provide the necessary data to clarify the picture.

Table 1. Fuelwood in World Energy Consumption in 1978

	Population	Total fuelwood <u>a/</u>	Consumption per capita	Energy equivalent of fuelwood <u>b/</u>	Commercial energy <u>c/</u>	Fuelwood (percentage of total) <u>d/</u>
	(millions)	(millions of m ³)	(m ³)	(millions of gigajoules)		%
World	4 258	1 566	0.37	14 720	256 594	5.4
Developed world	1 147	145	0.13	1 363	205 115	0.7
- Market economies	775	54	0.07	508	145 148	0.3
- Centrally planned economies	372	91	0.24	855	59 967	1.4
Developing world	3 111	1 421	0.46	13 357	51 479	20.6
- Africa	415	353	0.85	3 318	2 415	57.9
of which least developed countries	138	163	1.18	1 532	255	85.7
- Asia	2 347	796	0.34	7 478	37 558	16.6
of which least developed countries	130	34	0.26	319	180	63.9
Centrally planned economies	1 010	220	0.22	2 068	24 048	7.9
- Latin America	349	272	0.78	2 557	11 306	18.4

a/ Includes wood for charcoal

b/ IM³ = 9.4 gigajoules

c/ IMT coal = 29.3 gigajoules

d/ Not including other sources of non-commercial energy important in some regions

In this preliminary stage of planning it is useful to remember that the per caput fuelwood requirement in the various developing countries is more uniform than one would expect. Most of the developing countries are situated in the tropics and hence are subject to fairly uniform temperature regimes. The exceptions are high mountains and plateaux but, on a country level, these differences are not usually serious and the same figures for the whole population can be used as a first estimate.

The basic per caput consumption can be taken as 1200 kg of 30 percent moisture content fuelwood per annum. This figure applies to traditionally low efficiency stoves and cooking fires. High efficiency stoves can reduce this figure to 450 kg. Charcoal consumption ranges from about 60 kg to about 120 kg per caput per year and for preliminary planning purposes a figure of 100 kg can be used, convertible as follows: the production of 100 kg of charcoal requires about 700 kg dry wood taking into account transport losses. The heat content of charcoal fines of 100 kg of charcoal is equivalent to that of about 300 kg of air dry wood. From these figures it is clear that it pays to encourage the use of high efficiency stoves burning dry wood but that it is better to burn charcoal rather than wood in traditional, low efficiency stoves and open fires. Open fires and poorly designed stoves may have a thermal efficiency as low as three to five percent. A typical charcoal "pot" has a thermal efficiency of 23-28 percent. (See chapter II). There are also savings on transport costs with charcoal.

Whatever strategy is chosen will affect the projected production and consumption plan worked out for the years ahead and exert a major influence on forest management policy.

The following conversion factors will be useful in preparing energy balances:

Table 2

Typical per capita fuelwood consumption range for domestic purposes in developing countries. (Actual figures depend on local climate, supply, traditions, etc.)	0.5 m ³ to 2.0 m ³
Amount of fuelwood used in producing one ton (1 000 kg) of charcoal	7 to 11 m ³ (solid)
Yield of fuelwood obtainable by clearing	
(a) Tropical high forest	80-100 m ³ /ha
(b) Savannah forest	20-45 m ³ /ha
(c) Eucalyptus plantation forest (12-15 years old) of good quality. (Yield of plantations depends entirely on growth rate achieved. Actual inventory is needed to make firm yield predictions)	80-200 m ³ /ha
Annual yield of well-managed eucalyptus plantations on good sites (12-20 year rotation) (Mean Annual Increment: MAI)	14-20 m ³ /ha
1 ton (1 000 kg) of charcoal when burned has an energy output equivalent to:	
(a) Fuel oil	0.55 tons
(b) Electric power, if used to produce heat	7 260 kWh
(c) Bituminous (hard) coal	0.83 tons
(d) Dry wood (15 percent moisture content)	1.65 tons
(e) Green wood (say 60 percent moisture content)	2.5 tons

The next step in developing a fuelwood strategy is to estimate total fuelwood and charcoal consumption for the base year and then construct a tabulation which will show the annual requirement keeping in step with the projected increase in population for a period of about twenty years. This is usually long enough to stabilise the production/consumption situation.

By inserting into the table the harvested yields of fuelwood per hectare typical of the various production zones, the amount of forest to be worked over each year in the future may be quantified.

Various prospects will now begin to emerge. In the case of countries with small population density and large remaining areas of forest, it will usually be found that their prospects appear good. The forest area needed will be adequate and it should even be possible to dedicate forest production zones of sufficient size to yield on a continuing basis the required quantity of charcoal even though these natural forests may have a rather low mean annual increment (MAI) under any feasible management system. However, an implicit assumption must be made that population growth can be stabilised; otherwise no forest resource, however, large, can meet future demand.

In the case of countries with greater population density and less endowed with forests, the available forest area will usually be found to be inadequate to supply future fuelwood and charcoal needs, unless radical steps are taken to bring the situation under control.

Formulating plans to overcome these serious problems requires specialist knowledge and experience. All relevant factors, both technical and social, must be taken into account.

The principal options open to the developing country facing this situation are:

- Better management, or introduction of management where none now exists, of the forested areas may be sufficient to raise yields to a point where natural regrowth will solve the problem.

- High yield forest plantations, frequently of eucalyptus species, may be established permitting sufficient wood to be generated quickly enough to catch up with demand and overcome the problem. However, specialist help and good planning are needed. Plantation sites must be carefully chosen taking into account soil fertility, rainfall, location in relation to consumption centres, and the practicality of permanently dedicating the land for forest purposes.

Usually there is a conflict with the need to use the land to grow food for an expanding population and, under these conditions, the social factors governing the survival and growth of forest plantations in the midst of subsistence agricultural zones become of dominant importance.

High yielding plantations can easily show an MAI per hectare over ten to twelve year rotations of twenty or more cubic metres of wood. This compares with effective MAI's of natural unmanaged forest of around two or three cubic metres. However, it must be stressed that high yields of plantations are not achieved without investment in good land, good management and maybe also fertilizers. (11)

The rate of consumption of wood can also be slowed down by improved methods of charcoal production and distribution and by increasing the efficiency of wood-burning stoves. Sometimes traditional fuel-gathering methods due to inadequate tools result in large quantities of large diameter logs and branchwood being unharvested and left to rot.

1.3. Calculating an energy balance

A hypothetical fuelwood energy balance for a region is calculated below showing the method used and indicating key factors where collection of more accurate data may be necessary to develop a more precise picture.

Fuelwood Energy Balance

Region	'X'
Total area	5 600 km ²
Arable land	620 km ²
Undulating forested land	3 400 km ²
Steep mountain, lakes, rivers and urban areas	$(2 - (3 + 4)) = 1\,580\text{ km}^2$
Population	80 600 of which 9 000 estimated to be urban
Estimated rate of population growth	2.1% per annum
Preliminary estimated annual per caput fuelwood use (taken from table 2)	0.8 m ³ /pc./yr. (solid)
Estimated charcoal sales in townships of zone	110 000 kg
Volume of fuelwood exported from region (estimated)	nil
Weight of charcoal exported from region (calculated from transport tax documents)	35 000 kg
Volume of fuelwood imported into zone	nil
Volume of charcoal imported into zone (calculated from transport tax documents)	7 400 kg

From the above data a preliminary woodfuel energy balance for the region can be drawn up. This is based on production and imports being considered as input, and consumption and exports being considered as output. Thus, the annual fuelwood balance is as follows:

Inputs

1) Wood used to produce charcoal

Total charcoal production	+ 110 000 kg sales
	- 7 400 kg imports
	+ 35 000 kg exports
Net charcoal production	137 000 kg

Assuming that fuelwood to charcoal conversion efficiency is 5 to 1 by weight on an oven dry wood basis.

If density of green fuelwood is 750 kg/m³ (solid) and moisture content is 40%, then each m³ of green wood contains $750 \times 100/140 = 535$ kg of oven dry wood equivalent to $535/5 = 107$ kg charcoal.

To produce 137 000 kg of charcoal needs: 1 286 m³ of fuelwood or 964 485 kg of wet fuelwood. This is equivalent to a conversion ratio on a wet wood basis of about 7 to 1.

2) Amount of wood harvested or used directly as fuel and to make charcoal is:

a) used to make charcoal	1 280 m ³
b) used as fuelwood by rural dwellers	$80\,600 \times 1.2 = 96\,720\text{ m}^3$ assuming per caput fuel wood use of 1.2 m ³ and a rural population of 80 600.
Total:	98 000 m ³ of green wood per year

The estimate of present annual fuelwood usage in the region enables us to estimate the forest areas used each year for fuelwood and predict, in conjunction with estimates of population growth, the amount of forest of various types needed to satisfy a growing population's fuel needs. Using the above calculations the result is not likely to be precise. Where these calculations show that the region could be facing fuelwood deficits, it is then necessary to try to improve the accuracy of the figure to arrive at a more precise estimate of the adequacy or otherwise of the forest resources and take the necessary action to improve the supply situation.

When a figure for annual fuelwood consumption has been estimated, it is possible to calculate the effect of a fuelwood harvest of this dimension on the forest resources of the region. One must also take into account population growth rate. It is also reasonable to base production on a forward period of about twenty years since plantation resources take about this time to reach maximum yield and the effects of some form of management of neglected natural forests may well require ten to twenty years to show results. If the population remained static we could calculate as follows:

Hectares of prime high forest used up for woodfuel at a yield of 80 m³ per ha (98 000/80) = 1 225 ha per year. If the area of prime forest available for fuelwood is known, then the number of years over which supply can be maintained can be calculated. Likewise, if savannah or plantations are to be used, then the area needed each year can be similarly calculated.

As a rule, fuelwood and charcoal are produced from out-over and degraded forests and it is instructive to calculate what area must be put under management to maintain indefinitely such a system. Normally unmanaged but supervised cut-over high forest can maintain a mean annual increment of 2-4 m³ per ha per annum, if the rotation age of the forest is set at forty years, then a yield of 80 m³ of wood for charcoal per hectare can be expected. Population growth means an increase in the area to be harvested each year and the total area to be set aside to obtain a rotation of, say, forty years must take this into account. Using the figures for an initial wood requirement of 1 225 ha/yr, and an assumed population growth rate of 2.1%, then an area of 75 617 hectares of prime forest must be reserved for a forty year rotation. A larger area must be harvested each year to supply the increasing population.

The forest area above was conveniently calculated using the "amortization fund" equation of compound interest. This formula is as follows:

$$FV = PMT \left[\frac{(1+i)^n - 1}{i} \right]$$

where

FV = final value (in area of forest)

PMT = area to be harvested in first year

i = rate of growth of population as %/100

n = number of years considered.

The area needed will, however, continue to rise if population growth continues and problems of forest availability must eventually arise. In cases where large areas of unexploited forest are not available, the problem becomes more complex since out-over forest must be harvested at a lower and varying yield. The level of out should allow regeneration within, say, forty years to a normal forest yielding a out for fuelwood and charcoal of 80 m³ per ha. Setting up such management involves difficult relationship problems of a community to its

forests and galls for specialist help which cannot be covered here. The object of the present study is to point out the implications of maintaining a continuing supply of fuelwood and charcoal and how to go about estimating the magnitude of the forest resource required. Higher forest productivity per area and improved efficiency in fuelwood use and charcoal production slow down the arrival of the resource crisis.

1.4. Unit processes of charcoal production

1.4.1. What is charcoal?

1.4.2. Unit processes of charcoal-making

Charcoal ready for use by the consumer implies a certain sequence of steps in a production chain, all of which are important and all of which must be carried out in the correct order. They have varying incidence on production cost. Noting these differences enables the importance of each step or unit process to be assessed so that attention may be concentrated on the most costly links of the production chain.

1.4.1. What is charcoal?

Charcoal is the solid residue remaining when wood is "carbonised" or "pyrolysed" under controlled conditions in a closed space such as a charcoal kiln. Control is exercised over the entry of air during the pyrolysis or carbonisation process so that the wood does not merely burn away to ashes, as in a conventional fire, but decomposes chemically to form charcoal.

Air is not really required in the pyrolysis process. In fact, advanced technological methods of charcoal production do not allow any air to be admitted, resulting in a higher yield, since no extra wood is burned with the air and control of quality is facilitated.

The pyrolysis process, once started, continues by itself and gives off considerable heat. However, this pyrolysis or thermal decomposition of the cellulose and lignin of which the wood is composed does not start until the wood is raised to a temperature of about 300° Celsius.

In the traditional charcoal kiln or pit some of the wood loaded into the kiln is burned to dry the wood and raise the temperature of the whole of the wood charge, so that pyrolysis starts and continues to completion by itself. The wood burned in this way is lost. By contrast, the success of sophisticated continuous retorts in producing high yields of quality charcoal is due to the ingenious way in which they make use of the heat of pyrolysis, normally wasted, to raise the temperature of the incoming wood so that pyrolysis is accomplished without burning additional wood, although some heat input is needed to make up for heat losses through the walls and other parts of the equipment. The combustible wood gas given off by the carbonising wood can be burned to provide this heat and to dry the wood. All carbonising systems give higher efficiency when fed with dry wood, since removal of water from wood needs large inputs of heat energy.

The pyrolysis process produces charcoal which consists mainly of carbon, together with a small amount of tarry residues, the ash contained in the original wood, combustible gases, tars, a number of chemicals mainly acetic acid and methanol - and a large amount of water which is given off as vapour from the drying and pyrolytic decomposition of the wood.

When pyrolysis is completed the charcoal, having arrived at a temperature of about 500° Celsius, is allowed to cool down without access of air; it is then safe to unload and it is ready for use.

The overwhelming bulk of the world's charcoal is still produced by the simple process briefly described above. It wastefully burns part of the wood charge to produce initial heat and does not recover any of the by-products or the heat given off by the pyrolysis process.

Other woody materials such as nut shells and bark are sometimes used to produce charcoal. Wood is, however, the preferred and most widely available material for charcoal production. Many agricultural residues can also produce charcoal by pyrolysis but such charcoal is produced as a fine powder which usually must be briquetted at extra cost for most charcoal uses. In any case, encouraging the wider use of crop residues for charcoal-making or even as fuel is generally an unwise agricultural practice, although the burning of sugar cane bagasse to provide heat in sugar production and the burning of cornstalks and coarse grasses as domestic fuel in some regions do provide an overall benefit where carried out as part of a rational agricultural policy.

On the grounds of availability, properties of the finished charcoal, and sound ecological principles, wood remains the preferred and most widely used raw material and there appears to be no reason why this should change in the future.

1.4.2. Unit processes of charcoal-making

Charcoal-making can be divided into several stages or unit operation. They are:

Growing the fuelwood

Wood harvesting

Drying and preparation of wood for carbonisation

Carbonising the wood to charcoal

Screening, storage and transport to warehouse or distribution point.

Production costs can also be conveniently analysed by using the following "cost centres" which show more clearly the merits of the various systems:

- The cost of fuelwood placed at the side of the kiln, pit or retort, including financial costs.
- Carbonisation labour costs, including loading and unloading.
- Cost of transport of charcoal to major markets or distribution points.
- Cost of working capital.
- Fixed investment costs of the pits, kilns or retorts.

All costs are expressed on the same unit basis, i.e. per ton of charcoal delivered, so that their relative importance is clear. An extract of studies made by FAO gives the following broad picture. (3)

Where traditional clay brick kilns and a savannah forest yielding about 40 m³ of wood per ha are used, the following unit costs apply (expressed as a percentage of the cost of delivered charcoal):

Cost of wood at kiln	60%
Kiln labour costs	9%
Working capital costs	3.5%
Fixed investment costs	1.5%
Transport costs of charcoal	26%
	100%

The importance of wood harvesting and charcoal transport costs is evident. Together they amount to 86% of costs.

Charcoal-making needs other auxiliary raw materials and inputs which must not be forgotten. Kilns require clay for sealing and making slurry for cooling and bricks which should wherever possible be made near the charcoal-making site. Earth pits and clamps require earth of suitable texture and significant amounts of straw and leaves and branches. Metal kilns require sand and gas welding and cutting supplies and sheet steel for repairs. All charcoal processes need a certain amount of water for cooling fire extinction and making clay slurry. Above all, the whole process requires nowadays a certain input of liquid fuels for wood growing and harvesting, transport of wood and charcoal and miscellaneous transport of personnel and servicing of equipment, etc. All the above are basic to a successful charcoal operation. Further factors which cannot be overlooked are food supplies, housing and other infrastructure for workers and provision of fodder where draught animals are used for transport. If the charcoal is not handled in bulk, then costs of packaging must be added.

The technical aspects of the unit operations of charcoal-making are covered in later chapters. Some information on cost control and economies related to charcoal-making is also included.

Chapter 2 - Growing the wood raw material

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[2.5. Cost of plantation establishment](#)

[2.6. Fundamental factors in fuelwood supply](#)

Charcoal is made from wood and generally about five tons of wood produce one ton of charcoal. Therefore, charcoal-making can only be an on-going industry where the wood raw material resource is managed to provide a continuing supply. For every person in a community who uses charcoal for heating and cooking about 0.5 ha of natural high forest has to be set aside to provide that wood supply in perpetuity. If the wood comes from well managed fuelwood plantations a tenth of the above area would be adequate. However, plantations require a commitment to proper management and the allocation of better quality land which may be needed for food production.

Although wood used for charcoal may sometimes be derived from sawmill waste or land clearing operations, this does not ultimately alter the long term forest land or plantation requirement for fuelwood. The logistics of supplying that fuelwood is the concern of this chapter.

2.1. Forest management and fuelwood supply

The objective of resource management of fuelwood supply for charcoal-making is, simply stated, to reduce the land area committed to produce the necessary fuelwood for the projected charcoal production. The two major ways to achieve this are to make the forest more productive by improving growth and reducing waste in harvesting and to improve the conversion ratio of raw fuelwood to finished charcoal at the user's door.

Decisions in the resource management area to be fully effective have to be made at a national level. At the level of the charcoal burner, the decision is normally made in a simple exploitive way. Managers of large areas of natural forest or plantations can usually make a more far-sighted decision. But whatever decisions are made and acted upon at whatever level, they will ultimately be expressed at the national level in the form of an adequate, or otherwise, charcoal supply situation. The necessity for a national fuelwood policy, as pointed out in chapter 1, is inescapable. In this chapter we are concerned with maximising the long-term growth/yield of the forest resource. Later chapters are concerned with efficient wood harvesting, carbonisation and distribution of the finished product.

2.2. Natural forest for fuelwood

The science of forest management is too complex to be elaborated in this manual. It is sufficient to point out some features of natural forest growth and yield which affect fuelwood supply. A natural forest is a resource which, in the economist's jargon, grew without labour inputs from man. The aim of forest management is to harvest a maximum timber crop from such a forest without destroying its productivity as an on-going ecosystem and, at the same

time, minimise the inputs needed to achieve this. The result of this process is expressed in the mean annual allowable out of the forest, usually measured in cubic metres per hectare. Theoretically, one could remove a volume equal to this each year and the forest would maintain itself. In practice, the intervention of man produces long-term changes in the forest, especially in the tropics, changing the species composition and the diameter classes of the mature, natural forest after harvesting and regeneration. Wherever possible, a forest should be managed to produce the product mix of highest value - sawlogs and veneer logs are first priority. (15). Fuelwood has the lowest value; it is wood which cannot normally be sold for any other purpose. Its price is usually below pulpwood for the paper industry.

The normal method of harvesting a forest is to divide it into compartments or management areas and selectively fell the trees in each compartment in turn, working through the whole forest over a period of 30-50 years, which is called "the rotation". The objective is that the harvested compartments will be ready for harvesting again at the end of the rotation period and, hopefully, will be as well stocked with saleable timber as they were when in their natural state. Rarely is this objective achieved in practice because a rotation (perhaps forty years or more) is a long period in terms of a country's development process. Population grows, national priorities alter, the mix of saleable forest species and products changes and the power of the administration controlling forest operations fluctuates. Although the objective of rational management of natural forests is rarely attained and almost never optimised, it is still possible to estimate in general terms over a whole region or country - providing inventory figures of forest area and type are available - what the total annual harvest of fuelwood could be without harming the forest's ability to recover and produce timber indefinitely. However, even in countries where the annual harvest per hectare over a region appears to be supportable indefinitely - usually due to the uneven intensity of harvesting, mainly due to population density differences the forest ecosystem is in part being destroyed or damaged. The ultimate consequence of this process is not difficult to imagine.

The usual compromise achieved - even in countries where forest management is strong and well-oriented - is that a certain area of forest is allocated for fuelwood supply with the annual allowable offtake, or cut set at a level believed sustainable from the knowledge available at the time. The fuelwood harvesting enterprise then endeavours to stay within the prescribed cut and to maximise the harvest by making effective use of branchwood, dead timber and small diameter wood of poor quality, etc., which is not normally included in the assessed standing volume for yield calculations. To avoid damaging the forest system, however, there needs to be constant monitoring and measurement by the forest management authorities to ensure that target regeneration and growth rates are being achieved and decide if the allowable cut may be increased or must be reduced.

2.3. Forest types for charcoal-making

A study of traditional-charcoal-making practices throughout the developing world indicates clearly that the preferred forest type for charcoal-making is dry, well stocked savannah forest rather than dense humid rain forest. Savannah forests are preferred for a number of reasons. The wood is usually dense, slow-growing and highly lignified, which gives a good charcoal yield when carbonised. The quality of logs available for sawmilling is generally low, due to poor form of the trees and this means that most of the wood is only saleable as fuelwood, which tends to keep wood prices low. The terrain is usually easy, which simplifies harvesting. A short, wet season, and correspondingly long, dry season, means that charcoal operations can continue most of the year and fuelwood dries out quickly with minimum loss through insect attack and fungal decay. The only major limitation in some areas is the low yield of wood per hectare. Typical yields considered good practice are about 35 cubic metre/ha. Marginal commercial operations show wood yields down to 20-25 m³/ha. The classic charcoal production areas of Africa, South America and Asia are nearly all savannah-type

forests. As savannah-type forests have become overcut and uneconomic, the charcoal industry has tended to move into the humid rain forest type. These forests have high available quantities of fuelwood per hectare. It is not unusual for fuelwood yields of 100 m³/ha to be obtained even after saw and veneer logs have been removed. This gives low wood costs at the side of the kiln. In the wet humid climate, however, the fuelwood is mostly of low to medium density, not highly lignified and commonly prone to rapid decay and attack by insects. The rainy season is longer and more severe and, in some areas, there may be two rainy seasons per year, which make it very difficult to dry the fuelwood before carbonisation. Instead, the fuelwood usually rots or is destroyed by insects before it dries sufficiently for optimum carbonisation. Therefore, when making charcoal in humid tropical rain forests it is necessary to carbonise the wood at a higher initial moisture content than is typical in savannah-type forests. This avoids the wood deteriorating, as it is left to dry only a few weeks before carbonising. The yield is lower because more wood must be burned in the kiln to dry out the wood before carbonisation can start. A typical moisture content of wood charged to the kiln under these circumstances can be 50-100 percent, depending on the density of the wood and the weather conditions at the time. Yields fall to one ton of charcoal per six tons of wood or more (on a volume basis about one cubic metre of charcoal to 2.67 to 3 steres of fuelwood). Despite the disadvantages, the increasing unavailability of suitable dry type forest resources are forcing more and more charcoal operations to be shifted to humid rain forest, even though yields and production costs are much higher than the traditional savannah forests.

2.4. Fuelwood plantations

Fortunately, given the problems of fuelwood and charcoal supply in many developing countries where natural forests have been cleared, or otherwise devastated, forest science has developed systems for cultivating man-made plantations of quick growing forest trees. The eucalypts native to Australia have been widely adopted and modified by selection for this purpose throughout the world. FAO's book "Eucalypts for Planting" (11) provides a wealth of information in this field and is essential for anyone seriously interested in this area.

There are many species of eucalypts used in plantations, allowing adaptation to particular local conditions, and, fortunately all make excellent fuelwood and charcoal. Where plantations are established and managed correctly on suitable sites, growth can be rapid. Mean Annual Increments (MAI) of 15-20 m³ per ha over 12-20 year rotations are not uncommon.



Photo. 1. Plantations of eucalyptus saligna for charcoal production. Minas Gerais, Brazil. Photo J. Bim.

Establishment and management of fuelwood plantations is a specialised branch of forestry and should only be attempted when specialist advice has been obtained. To be successful it is necessary that land of suitable fertility be set aside for the plantations, that a suitable tree species be selected and that a proper system of dedicated management be set up. The first crop will not be produced until 12 - 15 years have passed which makes the development of man-made forests a job for government, well organised cooperatives, or a large private corporation.

Producing wood for charcoal from plantations demands that the cost of producing the fuelwood on the stump be carefully calculated to ensure that such a long-term investment is, in fact, worthwhile. On the other hand, the cost or stumpage of wood from natural forests is arbitrary and is set, in effect, by ordinary market forces, somewhere between zero cost where a small-scale charcoal producer gathers wood without payment from vacant forested land, and the cost of producing equivalent fuelwood from plantations. State forest services sometimes attempt to set fuelwood stumpage by calculating the management cost of the natural forest from which the wood is taken. Sometimes private natural forest owners set a stumpage rate as a percentage of the value of the charcoal produced. Around ten percent is a typical charge. Government stumpages are usually less than this when expressed on the same basis.

2.5. Cost of plantation establishment

[2.5.1. Land price](#)

[2.5.2. Reforestation](#)

As an example of the detailed cost items of eucalypt plantation establishment, we have drawn on the valuable experience of the charcoal iron industry of Brazil perhaps world leaders in the production of industrial charcoal derived from plantation-grown fuelwood. Under Brazilian conditions (1977) the costs can be summarised as follows:

2.5.1. Land price

A normal value of US\$ 100/hectare has been used for calculation. At this value land cost has little influence on the final cost of fuelwood.

2.5.2. Reforestation

The costs of afforestation with eucalyptus trees are shown in Table 3. The trees are planted from seedlings and are first out after eight years. Six or seven years later they are re-cut and after a further six or seven years, are re-cut a second time. This gives a total cropping cycle of 20-22 years, after which time the stumps are uprooted and new trees planted.

In a highly mechanized operation the expense per hectare during the first year of a reforestation project represents 50 percent of the total expenses of the complete cycle of 20-22 years, which is US\$ 500 of a total expense of US\$ 1,000. The expenses during the first of the three cycles represent US\$ 700 or 70 percent of the total rotation time of 20-22 years. For manual reforestation the expenses during the first year represent US\$ 800 or 60 percent of the total expenses of US\$ 1 300. Salary for rural workers in 1977 was US\$ 80 per month. The cost of salaries has been included for the first planting and three years maintenance.

The resulting final cost of forestry for the three cycles is US\$ 4.99 per cubic metre of charcoal (equivalent to US\$ 19.96 t), when using maximum mechanization. This corresponds approximately to 30 percent of the 1977 commercial price of charcoal. The tax incentives have not been considered, as they have been decreasing in the course of the last years and may in future become insignificant. However, in 1977 they still represent a saving of 17.5 percent.

It is assumed that, after the third felling, the eucalyptus forest must be replanted. No figures are yet available for Brazilian conditions for sucker growth after the third felling. Coppice regeneration after two rotations may give variable results. For further information on coppice systems see (11).

Table 3. Costs of Forestry Operation in Brazil with Eucalyptus Trees (excluding tax incentives)

With Maximum Mechanisation

Cycle	Total Yield	MIA	Land Cost	Equipmt. Cost	Labour US\$/ha		Fuelwood Cost		Charcoal Cost
	st/ha	st/ha. A	US\$/ha	US\$/ha	a	b	US\$/ha	US\$/st	US\$/m ³
Planting	-	-	100	200	200	-	500	-	-
2-8 yrs. growth	176	22	-	100	-	100	200	-	-
First cut after 8 yrs	176	22	100	300	200	100	700	3.94	8.74
Second cut 13-15 yrs.	152	22.25	-	65	-	85	150	0.98	2.15
Third cut 18-22 yrs	112	16-19	-	65	-	85	150	1.34	2.95
TOTAL 20-22 yrs	440	20-22	100	430	200	270	1,000	2.27	4.99
All Operations Manual									
First cut	176	22	100	100	600	800	4.34	9.99	
Second cut	152	22-25	-	50	200	250	1.64	3.61	
Third cut	112	16-19	-	50	200	250	2.23	4.91	
TOTAL	440	20-22	100	200	1 000	1 300	2.95	6.49	

Notes:

a. Planting

b. Maintenance

c. Costs include land, preparation of soil, roads, tree nurseries, tree planting and maintenance

d. m³ ch. = m³ charcoal produced from 2.2 st. of wood

2.6. Fundamental factors in fuelwood supply

Fuelwood supply is, in the long run, the most fundamental aspect in charcoal-making. With an adequate wood supply charcoal production becomes a problem of social and technical management. Where the wood supply is inadequate, no technical "fix" can provide the charcoal needed of the population. It is surprising how often this fundamental point is ignored or glossed over and too much attention incorrectly focussed on charcoal production details.

A permanent and hopefully expanding supply of fuelwood for charcoal is essentially a long-term problem of land resource allocation and management. Proper management is basic since the crop cycle of trees, whether in plantation or natural forest, is measured in decades. Management must pay close attention to the social interaction between a rural population and forests, if their existence and productivity are to be maintained. The fertility of the forest soils must be maintained, with use of fertilizers if necessary. The long-term effect, for example, of removal of bark from plantation forests on nutrient balance, needs to be studied. The advantages and disadvantages of Coppice rotation on eucalyptus forests as related to

production of higher priced products such as poles, saw and veneer logs, must be carefully evaluated. Finally, the choice of species for charcoal most suited to a particular region is important. What matters in the long run is the yield of charcoal that can be obtained per hectare, expressed in available heat units, delivered at the door of the final user. Choice of species and the way the plantation is managed play an important role, which is only now beginning to be appreciated. Although eucalyptus species are the most widely planted for charcoal and fuelwood, the advantages of other hardwoods and pine species which, in certain cases, may give higher returns by yielding a higher priced wood mix than fuelwood alone, always need to be studied closely when determining a plantation establishment policy.

Chapter 3 - Harvesting and transporting fuelwood

[3.1. Key factors in harvesting and transport](#)

[3.2. Laying out a charcoal production area](#)

[3.3. Equipment for harvesting and transport](#)

Getting the fuelwood from the tree in the forest to the side of the carbonisation kiln or pit is the most costly operation in commercial charcoal production and requires good organization to keep costs under control. The operation is similar to pulpwood harvesting but, typically, is much less capital intensive. A four to sixfold weight reduction occurs when wood is carbonised. Therefore the guiding rule in wood harvesting is to keep the transport distance from stump to carbonisation point as short as possible, allowing the finished charcoal to be transported the greater distance. How short the distance can be depends on the carbonisation technology. There is a trade-off between the fuelwood transport distance and the cost/yield of the carbonisation process. At one end of the scale there are the pit and the portable metal kiln technologies which need a minimum harvest transport distance. At the other end of the scale are the technologically complex, capital intensive, large rinsing gas retorts and the multiple hearth furnace systems which are fixed installations. They imply relatively long transport distances for fuelwood. Brick kilns having a life of several years imply an intermediate distance for fuelwood transport. The fuelwood transport distance associated with brick kilns and high technology retorts and furnaces depends on the fuelwood yield of the forest and the expected life of the equipment for carbonisation. Retorts which may last thirty years or more require a large block of forest so that they can be supplied with wood at the minimum haul distance during their useful life, Brick kilns having a life of about five years, require sufficient forest to maintain fuelwood supply for this period before increased transport costs require the kilns to be moved to a new area.

3.1. Key factors in harvesting and transport

Harvesting and transport can be analysed by breaking the process down into 'unit operations' and treating the 'unit operations' as cost centres to determine their influence on total costs. The 'unit operations' in harvesting are:

- Rooding the forest compartment and defining the coupes or harvesting units of the compartment.
- Felling and bucking to required lengths; splitting may be required.
- Primary transport to secondary collection point.
- Drying of fuelwood in the forest.
- Secondary transport to the carbonisation unit.
- Drying and storage of wood at the charcoal-making centre.

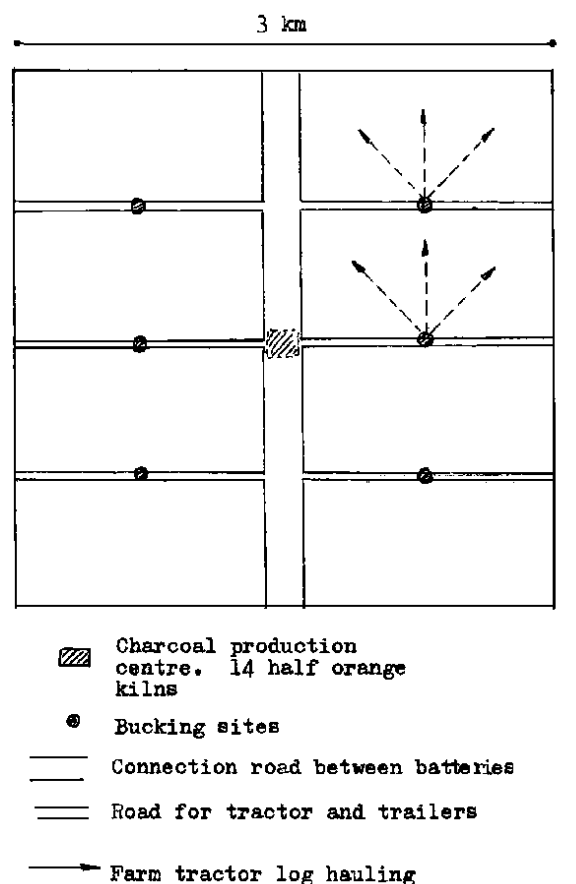
The above processes can be further subdivided or some operations may be combined and others omitted in particular cases.

In the above unit operations the only two which are significantly influenced by the distance between the charcoal production centre and the logging site are the primary and secondary transport of fuelwood. In the case of fully portable systems, i.e. pits, earth mounds and metal kilns, secondary transport is eliminated and primary transport remains more or less constant. For brick kilns it is different. Primary transport can be held constant, if desired, by laying out the forest area with a closely spaced access road network which reduces primary transport to a practical minimum. Flat areas, easy to road, suit this approach. Rough terrain may make it worthwhile to increase the primary transport leg somewhat to reduce roading costs. Experience and accurate costing will indicate the best compromise. Changes in one unit operation usually influence another. In charcoal-making it is not that transport of fuelwood is simply a cost but that some costs are worth incurring in fuelwood transport in order to reap the overall benefits of producing charcoal in organised centres at some distance from the point of wood harvesting.

3.2. Laying out a charcoal production area

When fixed brick kilns are used - unlike mobile systems - it is necessary to allocate in advance a certain area of forest to sustain the operation over its economic life. Alternatively, an area of forest may be available and it is necessary to calculate how it can best be turned into charcoal using a fixed kiln system, (3, 32, 33). The calculations indicate the basic parameters. Experience will permit judgement as to how changes can be made to accommodate the local situation and still allow profitable operation. (See Fig. 1).

Fig. 1. Fuelwood Harvesting System Layout (One 900 ha unit)



The following data is needed:

- A map of the forest available.
- Data on the forest types and locations within the area and, for each type, an estimated or measured volume of fuelwood per hectare. The data should be checked from the air and on the ground to show that it is fairly reliable. Often information on fuelwood yields from the forest owner - government or private - is very optimistic and may ignore the slow, imperceptible removal of forest resources by the local people over the years.
- Data on the brick kilns to be used: useful life in years; true capacity in cubic metres of wood; typical charcoal yield per burn; number of days for a complete kiln cycle from loading to unloading.
- Number of kilns which can be operated by a team (usually two or three men).
- Number of weeks per year during which charcoal can be produced, allowing for holidays, rainy season, harvest time, and so on. The number of kilns at a production centre should always be the optimum number to efficiently occupy the operating crew, or a whole number multiple of the optimum number, i.e. 10, 20, 30, and so on.

Assume the following data as an example of calculation

Kiln module = 10 kilns	2 man crew
Kiln cycle = 9 days	6 day working week except for kiln supervision on seventh day
Kiln capacity = 16 m ³ producing 4 tons of charcoal per burn	
Kiln life = 5 years	
Working year = 40 weeks	
Forest area available = Total area 580 ha (type 1 - 310 ha; type 2 - 270 ha)	
Fuelwood yield per ha = Type 1 - 40 m ³ /ha (type 2 - 31 m ³ /ha)	

Calculation:

Number of working days/yr. = $40 \times 6 = 240$ days

kiln cycle effectively is 10 days, including rest day

Production from 10 kiln: 24 cycles from first kiln, plus 23 cycles from other nine, since they are not reloaded at the end of the year.

Total production = $4 \times 24 + 4 \times 23 \times 9 = 924$ tons of charcoal per year

Fuelwood needed = $16 \times 24 + 16 \times 23 \times 9 = 3\,696$ m³ per year

For 5 year kiln life needs 18 480 m³

Forest area available is

310 ha of type 1 at 40 m³/ha and
270 ha of type 2 at 31 m³/ha

Type 1 forest can produce $310 \times 40 = 12\,400$ m³

Therefore, type 2 must produce: $18\,400 - 12\,400 = 6\,000$ m³

But type 2 can produce 8 370 m³, giving an excess of 2 290 m³ which is sufficient for 27 weeks extra operation in the sixth year.

Therefore one module or battery of kilns with some repairs will convert this block of forest to charcoal in five years and 27 weeks of operation.

The siting of the battery must now be decided and an estimate made of the average haulage distance.

The site for a kiln battery may often be determined by local site factors, such as drainage, water supply, location of access roads, settlements, etc. If these factors permit, the battery should be placed in the "centre of mass" of the forest area. Theoretically, this can be calculated from inventory data but, in practice, because the data on wood distribution by forest type is of low accuracy, refined calculations are hardly worthwhile. The best that can be done is to consider possible sites for the battery on the basis of their practical acceptability and then choose the one which is closest to the apparent "centre of mass" of the timber of the area. This location is always towards or within the most densely forested area.

When the location for the battery has been decided the average secondary transport distance can be estimated using the existing road system or after a roading system has been determined. This minimizes the ton/kilometre figure for secondary transport. The road system to link up with primary fuelwood transport usually consists of simple parallel tracks separated by a distance chosen to obtain the optimum balance between roading cost and cost of primary transport from the stump to the logging track. A separation of 500 metres to give an average primary transport distance of 100 to 150 metres is normal practice.



Photo. 2. Mule cart or "zorra" to transport wood billets from stumps to round side and sometimes to kiln where distances are short. Salte, Argentine. Photo J. Bim.

A diagram of the road layout usually favoured on flat or undulating terrain is shown in figure 1.

In the example the forest area was 580 ha and was adequately stocked. Providing it is reasonably square the average haulage distance will be roughly 1.8 to 2 km for the whole of the operating period. This is well within normal practice with brick kilns.

If the estimated average haulage distance because of the shape of the block, e.g. long and narrow, is excessive, then it may be necessary to consider moving the kiln battery after a few years to a new site to reduce haulage distance. In this case haulage cost savings are traded off against the cost of dismantling and rebuilding the kilns. There are many options. Profitable operations require close attention to all costs and close study of the experience of successful operators.

3.3. Equipment for harvesting and transport

[3.3.1. Felling and block preparation](#)

[3.3.2. Drying of fuelwood](#)

[3.3.3. The role of Government in maintaining forest productivity.](#)

[3.3.4. Description of a fuelwood harvesting operation.](#)

Harvesting and transport of fuelwood is usually labour-intensive since low cost labour is available in most charcoal making operations. Animal power has yielded to mechanical in long distance secondary transport but otherwise it still plays an important role.



Photo. 3. Technical loading of eucalyptus wood from plantations. Note length of billets designed to stack vertically in kiln. Minas Gerais, Brazil.

3.3.1. Felling and block preparation

Axes and handsaws are still used to some extent but chainsaws have almost replaced them. Productivity is so much higher and yet their capital cost is tolerable in commercial operations. Axes are still useful where pits or brick kilns are used, as longer length fuelwood can be used. However, with steel kilns which require short blocks for easy loading, use of chainsaws nowadays is almost essential. Short wood dries out quicker and in humid rain forests this is a great advantage. Chain-saws make this possible. With chainsaws, the operator needs to be involved, at least to a certain extent, in the ownership of the saw, otherwise maintenance costs can become prohibitive.



Photo. 4. Transporting billets of mixed tropical hardwood using steel rings, Minas Gerais, Brazil. Photo J. Bim.

Splitting of large diameter blocks where needed for steel kilns is best done with wedges and hammers assisted with large diameter blocks by chainsawing along the grain to provide an opening for the wedge. Hydraulic splitting machines have been used to reduce large diameter blocks so that they can be carbonised, in metal kilns. Results have been good but capital and maintenance costs in commercial operations have not yet been proven to be acceptable. Chainsaws compared to axes usually give a marked increase in the yield of wood per ha, because a chainsaw cut wastes less wood in useless chips than an axe and large diameter deformed logs, etc., are easily reduced to blocks with a power chainsaw. Axemen tend to bypass these difficult logs. This results in a lower yield. In some situations it is possible to combine axes and chainsaws quite successfully on the same area.



Photo. 5. Transporting billets to roadside using mule fitted with special pack saddle, Minas Gerais, Brazil. Photo J. Bim

Blocks are either cut at the stump or from the log at the side of the road. The best method depends on the type of forest and terrain. Flat savannah type forests with large heavily branched irregular growth trees are best cut into blocks at the stump. Plantation eucalyptus stems or long straight trees growing in dense undergrowth favour cutting into blocks at the roadside. It is not common to transport whole logs to the charcoal production centre since this needs heavy equipment to load and transport and there are no advantages over block cutting in the forest, except where automated block cutting and splitting from large trees may be used, e.g. where rinsing gas retorts are installed. Drying out of blocks and measurement of volume may be simplified at roadside. Air circulation and hence drying rates are usually better at the roadside than in the forest itself. Carts drawn by mules, donkeys or oxen may be used to bring blocks or short-length wood to the roadside. Farm tractors are suitable for snagging logs to roadside. Wheel tractors with trailers can be used to collect blockwood at the stump where the terrain is suitable. Whatever system is used, the objective remains the same - delivery of dry blocks ready for carbonising at the side of the kiln at minimum cost. Only careful studies can determine the best method in each instance.

Measurement of the wood is done at stump or at roadside. The usual system is to pile the wood in a frame which contains one stere (a stacked cubic metre). After measuring, stacks of wood are usually paint marked and transported to the charcoal centre. Allowance must be made for loss of volume when wood blocks dry.

3.3.2. Drying of fuelwood

Drying fuelwood has a big influence on charcoal yield. The drier the wood the less fuel is used up inside the carbonising equipment, be it pit, kiln or whatever, in evaporating moisture. The free water in the wood is lost to the air fairly rapidly once the wood is cut into short blocks. Moisture content at felling may be say, 60%. After stacking three months moisture content may be reduced to 30-35%. Further drying is slow. Large diameter blocks of dense hardwood may take more than a year to reach 20%.

During drying there is a loss of weight which makes transport easier and cheaper. One ton of wood at 60% moisture content after drying to 30% moisture content will weigh only 812 kg, a loss of about 2 %. Also, while drying, some species may shed their bark. This is an advantage as bark makes only fragile, high ash charcoal of little commercial value. During drying, wood can rot and be attacked by insects; this is rapid in the humid tropical forest. Therefore, the drying time must be controlled to ensure the maximum drying out occurs quickly before deterioration of the wood.

Good practice in tropical wet forests is to cut the blocks short, pile them carefully and, if possible, off the ground, on scrap wood and in a place which gets plenty of sun and wind. About one or two months is often the maximum drying time allowable in humid tropical forest before severe deterioration occurs. This depends on local conditions species, and season of the year. A certain stock of dry wood is always needed to balance kiln and forest operations. This wood stock, usually about two months' supply, should be built up to a maximum in the dry period at clearings in the forest and at the kilns, and allowed to run down during the wet season. Species which show little degradation should be favoured if possible and stock should be held at those locations having a proven record of fast drying conditions.

In dry type forests, safe drying times of up to one year are not unknown with durable species but one must balance the drying benefit against the capital tied up in the drying stock. Sound dry dead trees should also be harvested for charcoal wherever possible. They give a good yield of charcoal and cost less to transport per unit of charcoal production. The gain in transporting and carbonising air dry wood over green wood is striking. There is a twofold gain. First, one avoids transport of useless water, second, the yield of charcoal from dry wood is high since less of the wood has to be burned up inside the kiln to dry out the remainder so that it will carbonise. For example, 1 000 kg of green wood, after a few weeks drying, may have a moisture content of 50%. It can be expected to yield about 180 kg of charcoal of 80% fixed carbon content. On the other hand, using dry wood of 15% moisture content only, 520 kg must be transported to yield the same amount of charcoal (180 kg). There is a saving of wood substance as well as a saving in useless transport. Green wood dries slowly, especially when it is merely cross-cut into blocks and not split as well. Wood moisture content is one of the most serious limiting factors in the economics of charcoal-making.

An experiment on drying cross-cut blocks of old growth Australian eucalyptus wood for charcoal gave the following results:

Length of blocks: 25 cms.

Drying time in stack	1 week	6 months	12 months	18 months
Moisture content %	54.4%	31.6%	21.6%	15.9%

These results indicate the value of some months of drying. While drying in a humid environment, however, the wood also deteriorates due to fungus and insect attack. The problem of drying fuelwood economically in the humid tropical forests which are today being called upon more and more to provide charcoal remains largely unsolved. It represents a serious waste of wood resource and a significant cost in fuelwood supply.

Problems of drying also affect fuelwood produced in plantations. Fortunately most eucalyptus plantation areas are not as humid as the tropical high forest.

3.3.3. The role of Government in maintaining forest productivity.

The foundation of the charcoal industry is the fuelwood production from a nation's forests. Most forests are nominally under some kind of government control in practically all countries nowadays. Governments can play a critical part in ensuring the present and future productivity of their forests by the management policies they apply to them. They should actively concern themselves with the fuelwood logging process to see that regeneration of the forest takes place properly. They should safeguard the forests against fires and illegal wood cutting. They should assist the development of plantations for fuelwood and should provide credits for extraction machinery and for road building to ensure that the maximum permissible yield of fuelwood is obtained from the forest without damaging its powers to regenerate. Fuelwood gathering for charcoal is not usually regarded as a high prestige occupation. But nowadays it is one of the most significant activities carried on in the forests of the developing world and no government can afford, in the long run, to ignore it or treat it with contempt.

3.3.4. Description of a fuelwood harvesting operation.

To aid understanding of the practical details of a fuelwood harvesting system a brief description is given of a system to harvest sufficient wood to produce 10,000 tons/year of charcoal from humid tropical forest. (32).

Basic Data

Wood requirement	40 000 tons per year over 5 years
Nominal labour cost for calculations	US\$ 10.00 per man/day.
Area available:	3 600 ha divided into four 900 ha blocks each containing a charcoal centre or battern of 14 half orange kilns.
Terrain:	flat to undulating; uniform stacking of mixed species fuelwood. Average diameter of free: 45 cm at butt. Allowable cut: 60 m/ha.
Roading:	Logging track only without consolidation; 3 m wide cleared by hand with axe and cutlass. 18 000 m road per 900 ha block, giving a total of 72 000.
Roading rate:	30 m of road per man/day at US\$ 10.00 per day = \$24 000. Wood recovered from road is used for charcoal. Roads are extended to keep pace with harvesting over the years.

Operations for 4 charcoal batteries

- a) Felling with chainsaws: trees are felled; no bucking is done at stump.

Chainsaws needed: 4

Labour needed: 8

- b) Hauling logs with farm tractor to roadsides

Average distance of haul: - 375 m

Average yield per tractors - 2.5 t/trip or 60 t/day

Tractors needed: 2

Labour needed: 4

- c) Bucking with chainsaw at roadside:

No. of chainsaws needed: 8

Labour needed: 12

- d) Transport of firewood from c) to battery, with farm tractor and trailers:

Average transport distance: 1,500 m

Equipment: 1 tractor and 2 trailers of 10 ton capacity each.

Production per day per unit: 40-50 tons/day depending on haul distance

For 40,000 ton/year firewood following are needed: 3 tractors and 6 trailers (3 units)

Labour: 3 drivers and 9 loaders = 12

Costing for 40 000 tons of wood per year:

Labour rate including overheads: US\$ 10.00 per man/day.

Operation	No. of Men	Annual Cost Labour	Machines	Total
a	8	24 000	4 000	28 000
b	4	12 000	30 000	42 000
c	12	36 000	7 000	43 000
d	<u>12</u>	<u>36 000</u>	<u>46 000</u>	<u>82 000</u>
Total:	<u>36</u>	<u>108 000</u>	<u>87 000</u>	<u>195 000</u>
Roading cost = \$24 000 for 5 years = \$4 800 per year...				<u>4 800</u>
				199 800

Basic cost per ton of wood delivered to side of kiln = \$4.99

Supervision and management costs have not been calculated but could be allowed at 10% of wood cost per ton = \$0.49

Total cost per ton of wood at kiln = \$5.50

No allowance has been made for any infrastructural costs or stumpage.

The above costing should be regarded as indicative of the relative cost and labour productivity of the various operations in harvesting.

Chapter 4 - Carbonisation processes

[4.1. How wood is transformed into charcoal](#)

[4.2. Industrial safety in carbonization](#)

[4.3. Incentives and labour management](#)

4.1. How wood is transformed into charcoal

The carbonization stage may be decisive in charcoal production even though it is not the most expensive one. Unless it is carried out as efficiently as possible, it puts the whole operation of charcoal production at risk since low yields in carbonisation reflect back through the whole chain of production as increased costs and waste of resources.

Wood consists of three main components: cellulose, lignin and water. The cellulose and lignin and some other materials are tightly bound together and make up the material we call wood. The water is adsorbed or held as molecules of water on the cellulose/lignin structure. Air dry or "seasoned" wood still contains 12-18% of adsorbed water. Growing, freshly cut or "unseasoned" wood contains, in addition, liquid water to give a total water content of about 40 to 100% expressed as a percentage of the oven dry weight of the wood.

The water in the wood has all to be driven off as vapour before carbonization can take place. To evaporate water requires a lot of energy so that using the sun to pre-dry the wood as much as possible before carbonization greatly improves efficiency. The water remaining in the wood to be carbonised, must be evaporated in the kiln or pit and this energy must be provided by burning some of the wood itself which otherwise would be converted into useful charcoal.

The first step in carbonization in the kiln is drying out of the wood at 100°C or below to zero moisture content. The temperature of the oven dry wood is then raised to about 280°C. The energy for these steps comes from partial combustion of some of the wood charged to the kiln or pit and it is an energy absorbing or endothermic reaction.

When the wood is dry and heated to around 280°C, it begins to spontaneously break down to produce charcoal plus water vapour, methanol, acetic acid and more complex chemicals, chiefly in the form of tars and non-condensable gas consisting mainly of hydrogen, carbon monoxide and carbon dioxide. Air is admitted to the carbonising kiln or pit to allow some wood to be burned and the nitrogen from this air will also be present in the gas. The oxygen of the air is used up in burning part of the wood charged.

The spontaneous breakdown or carbonization of the wood above a temperature of 280°C liberates energy and hence this reaction is said to be exothermic. This process of spontaneous breakdown or carbonization continues until only the carbonised residue called charcoal remains. Unless further external heat is provided, the process stops and the temperature reaches a maximum of about 400°C. This charcoal, however, will still contain appreciable amounts of tarry residue, together with the ash of the original wood. The ash content of the charcoal is about 3-5%; the tarry residue may amount to about 30% by weight and the balance is fixed carbon about 65-70%. Further heating increases the fixed carbon content by driving off and decomposing more of the tars. A temperature of 500°C gives a typical fixed carbon content of about 85% and a volatile content of about 10%. The yield of charcoal at this temperature is about 33% of the weight of the oven dry wood carbonised - not counting the wood which was burned to carbonise the remainder. Thus the theoretical

yield of charcoal varies with temperature of carbonization due to the change in its content of volatile tarry material. (24, 26, 31). Table 4 shows the effect of final carbonisation temperature on the yield and composition of the charcoal.

Table 4. Effect of carbonisation temperature on yield and composition of charcoal

Carbonisation Temperature °C	Chemical analysis of charcoal		Charcoal yield based on oven dry wood
	% of fixed charcoal	% volatile material	(0% moisture)
300	68	31	42
500	86	13	33
700	92	7	30

Low carbonization temperatures give a higher yield of charcoal but this charcoal is low grade, is corrosive due to its content of acidic tars, and does not burn with a clean smoke-free flame. Good commercial charcoal should have a fixed carbon content of about 75% and this calls for a final carbonising temperature of around 500°C.

The yield of charcoal also shows some variation with the kind of wood. There is evidence that the lignin content of the wood has a positive effect on charcoal yield. A high lignin content gives a high yield of charcoal. Therefore, mature wood in sound condition is preferred for charcoal production. Dense wood also tends to give a dense, strong charcoal, which is also desirable. However, very dense woods sometimes produce a friable charcoal because the wood tends to shatter during carbonization. The friability of charcoal increases as carbonization temperature increases and the fixed carbon content increases as the volatile matter content falls. A temperature of 450 to 500°C gives an optimum balance between friability and the desire for a high fixed carbon content.

The many variables possible in carbonization make it difficult to specify an optimum procedure - generally the best results will be obtained by using sound hardwood of medium to high density. The wood should be as dry as possible and usually be split to eliminate pieces more than 20 cm thick. Firewood which will be burned up inside the kiln or pit to dry out and start carbonization of the remainder can be of inferior quality and smaller in cross section. Its sole function is to produce heat to dry out and heat up the remainder to carbonising temperature. One should try and reach a final temperature of around 500°C through the whole of the charge. With pits this is difficult since the air circulation and cooling effects are irregular and cold spots occur. These produce "brands" of uncarbonised wood. Trying to reach a final overall temperature of 500°C with a pit or kiln having poor and irregular air circulation usually results in burning part of the charcoal to ashes, while leaving other parts of the charge only partly carbonised. Hence the importance of using well designed kilns properly operated for an efficient charcoal operation. More information on the technical aspects of carbonization can be found in references 6, and 7.

4.2. Industrial safety in carbonization

Carbonisation produces substances which can prove harmful and simple precautions should be taken to reduce risks.

The gas produced by carbonization has a high content of carbon monoxide which is poisonous when breathed. Therefore, when working around the kiln or pit during operation and when the kiln is opened for unloading, care must be taken that proper ventilation is

provided to allow the carbon monoxide, which is also produced during unloading through spontaneous ignition of the hot charcoal, to be dispersed.

The tars and smoke produced from carbonization, although not directly poisonous, may have long-term damaging effects on the respiratory system. Housing areas should, where possible, be located so that prevailing winds carry smoke from charcoal operations away from them and batteries of kilns should not be located in close proximity to housing areas.

Wood tars and pyroligneous acid can be irritant to skin and care should be taken to avoid prolonged skin contact by providing protective clothing and adopting working procedures which minimize exposure.

The tars and pyroligneous liquors can also seriously contaminate streams and affect drinking water supplies for humans and animals. Fish may also be adversely affected. Liquid effluents and waste water from medium and large scale charcoal operations should be trapped in large settling ponds and allowed to evaporate so that this water does not pass into the local drainage system and contaminate streams.

Fortunately kilns and pits, as distinct from retorts and other sophisticated systems, do not normally produce liquid effluent - the by-products are mostly dispersed into the air as vapours. Precautions against airborne contamination of the environment are of greater importance in this case.

4.3. Incentives and labour management

Burning of charcoal is a responsible operation which requires skill, patience, experience and readiness to observe correct working methods at all times and in all weathers. The yield achieved in the burning stage affects the economics of the whole operation. Therefore, it is worthwhile to pay the charcoal burning crew an incentive over their normal salary based on the quality and quantity of charcoal they produce. Such a scheme requires proper measurement of the wood entering and the charcoal leaving the system. Measurement can be by volume or by weight but, in any case, must be carried out seriously if it is to function properly and satisfy all parties.

Charcoal production is often a seasonal activity. The rainy season may close down operations or the labour force may traditionally be employed at certain times in harvesting or planting operations in agriculture. This makes it difficult to attract and hold a labour force who are well trained and motivated. But good results depend on a stable and contented work force. Therefore, it is important to endeavour to develop a stable labour regime in charcoal production. This feature will be noted as a characteristic of all successful large scale charcoal operations.

Chapter 5 - Earth pits for charcoal making

[5.1. The pit method](#)

[5.2. Technical and cost data for pit charcoal production](#)

Using earth as a shield against oxygen and to insulate the carbonising wood against excessive loss of heat is the oldest system of carbonization and surely goes back to the dawn of history. Even today it is perhaps used to make more charcoal than any other method. It is, therefore, worthy of careful study to find out its advantages and disadvantages. Obviously it keeps its place because of its low cost. Wherever trees grow, earth must be available and it is natural that mankind turned to this cheap available non-combustible material, as a sealing material for enclosing the carbonising wood.

There are two distinct ways to use an earth barrier in charcoal making: one is to excavate a pit, put in the charge of wood and cover the pit with excavated earth to seal up the chamber. The other is to cover a mound or pile of wood on the ground with earth (5, 12, 16, 19, 20, 21, 28). The earth forms the necessary gas-tight insulating barrier behind which carbonization can take place without leakage of air, which would allow the charcoal to burn away to ashes. Both methods, if skilfully carried out, can produce good charcoal within their technological limitations.

5.1. The pit method

[5.1.1. Making charcoal in miniature pits](#)

[5.1.2. Making charcoal in large pits](#)

A stratum of deep soil is needed for this method. Suitable deposits of soft soil will usually be found along the banks of a creek. Pits can be made very large and a cycle may take up to three months to complete (13, 31, 32). Capital investment is minimal; nothing more than a shovel, an axe and a box of matches is required. But the method is wasteful in resource. It is very difficult to control the circulation of the gases in the pit. Much of the wood is burned to ashes because it gets too much air. Another portion remains only partly carbonised, because it was never properly heated and dried out during the burn. Apart from the gross variations in quality, there is variation in volatile matter, i.e. degree of carbonization within the acceptable charcoal. This is because in the pit carbonization is started at one end and progresses towards the other. Hence, the charcoal at the start of the burn, being heated longer, is much lower in volatiles than the charcoal at the end. For domestic purposes, this is not a serious problem, though it does reduce the overall yield, since the "hard" or overburned charcoal at the firing end with its low volatiles, high final carbon content, implies a low yield (theoretically about 30%30%). Overburning at one end is unavoidable in order to burn the charge as a whole.

A further problem with pits is reabsorption of pyroligneous acid through rain falling on the pit. The pyroligneous acids tend to condense in the foliage and earth used to cover the pit. When heavy rain falls they are washed back down and are absorbed by the charcoal. They cause

jute bags to rot and, on burning, the charcoal produces unpleasant smoke. Nevertheless, skilled operators using pits which are not too big can make excellent quality charcoal. (31). The low capital cost of the system commends its use where wood is abundant and labour costs are low.



Photo 6. Earth pit kiln during loading phase. Note large diameter round timber which can be used. Ghana. Photo Lejeune.

5.1.1. Making charcoal in miniature pits

Small pits or holes up to a cubic metre or so are useful for producing small amounts of charcoal from small, fairly dry wood. The method is employed at the village level, but is usually too low in productivity to supply large amounts commercially. To burn charcoal this way a fire is first started in the pit and dry small fuel is added to make a strong fire. More wood is added to fill the pit, the fire continuing to burn steadily. A layer of leaves about 20 cm thick is placed over the wood fuel and then earth about 20 cm thick shovelled on. The pit is left to complete carbonization and can be opened in two days or less. Water may be needed to prevent ignition when the pit is unloaded. Charcoal is not uniform in quality and, if small wood and bark is used, the proportion of fines is excessive. Sometimes pits are covered by a sheet of old roof iron covered with earth, allowing a few small openings for escape of smoke and entry of air.

5.1.2. Making charcoal in large pits

Typical pits for charcoal are large and burning takes place progressively from one end to the other. The larger pits producing 6 tons or more charcoal per burn are difficult to control, but

are more efficient in use of labour. Somewhat smaller ones have better air flow and produce more uniform charcoal, but the output is lower and use of labour less efficient.

Figure 2 shows a large pit of about 30 m³ gross volume. It will hold a charge of about 26 m³. A sandy loam is preferred with adequate depth. About three man days are needed to dig the pit and a day to add the channels for lighting and for smoke exist.

Fig. 2. 30 m³ Charcoal Pit - Longitudinal section

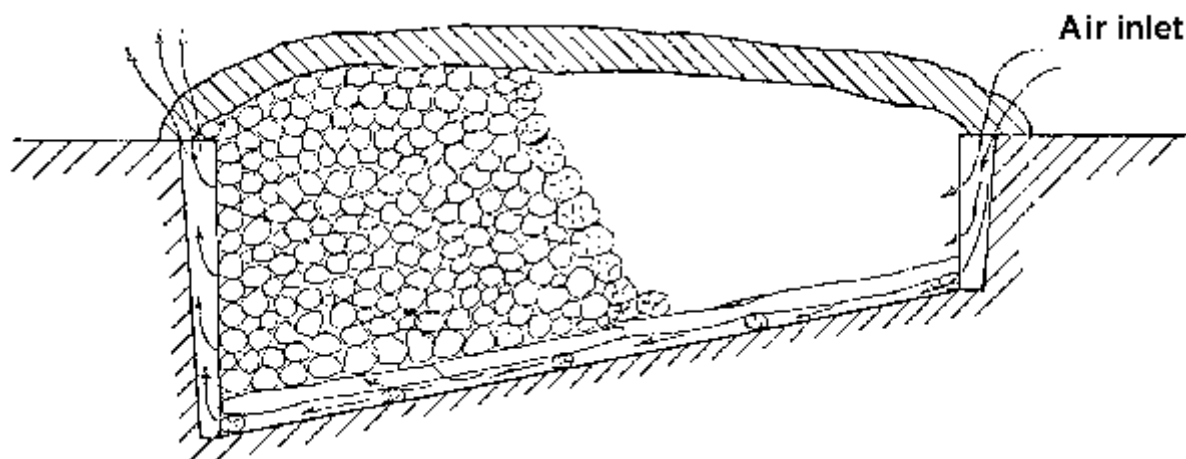
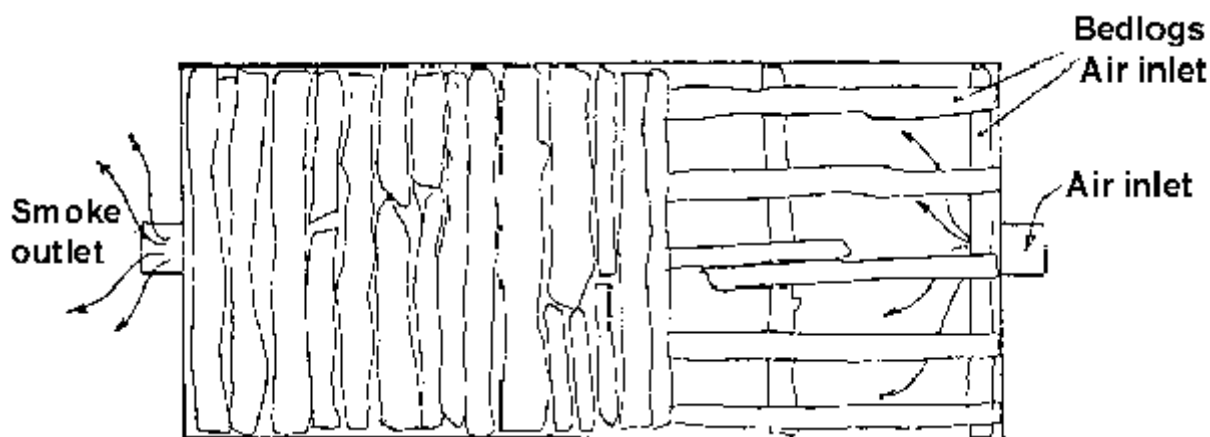


Fig. 2. 30 m³ Charcoal Pit - Plan view - without earth cover



The pit is loaded with logs measuring 2.4 m or less, which will fit easily across the pit. Care must be taken, during loading, to fill as many gaps between logs as possible with branches and small wood to improve volumetric efficiency. The long length of the wood which can be loaded into pits means that crosscutting with axes is still a practical method for the small operator without capital. Nevertheless, chain saws are widely used. To ensure that the wood is properly heated for carbonization, the hot gas is allowed to pass along the floor of the pit by placing the charge on a crib of logs.



Photo. 7. Earth pit during burning. Note steel chimneys and cover used made of steel sheets sprung between stakes. Joints between sheets sealed with earth. Ghana. Photo. Lejeune.

First, about five logs, cut to the width of the pit, are laid evenly spaced along the length; then four logs each equal to the length of the pit are evenly spaced on top of the first layer. This crib structure supports the charge and yet allows hot gases once the pit is lit at one end, to pass beneath the charge, heating it as they travel to the flue at the opposite end. These hot gases produced by partial burning of the wood charged slowly dry out the earth and heat up the rest of the wood to the carbonization point, about 280°C. Spontaneous decomposition of the wood, with evolution of heat, then occurs to form charcoal. Copious volumes of water vapour, acetic and other acids, methanol and tars, are produced at the same time. These also transfer their heat to the drying wood charge on their way to the outlet. Finally, the last of the wood is dried out, heated to carbonization point, and transforms itself into charcoal. The carbonization stage may take 20 to 30 days to complete and it is accompanied by a marked volume reduction of the wood charge to 50-70% of its initial volume. The earth covering the pit slowly sinks during the carbonization and any cracks or holes which form must be closed to prevent air leakage. There is danger of fatal burning to any person or animal falling or walking on the pit and care must be taken to avoid this.



Photo 8. Vents for pit kilns can be timbered where soil is loose avoiding the need for steel. Ghana. Photo Lejeune.

When the covering of the pit has sunk from one end to the other, the burn is considered complete and openings are sealed and the pit allowed to cool, which can take 40 days approximately, depending on the weather. After cooling, the pit is opened and the charcoal unloaded, taking care to separate it from earth and sand and partially carbonised wood. Forks and rakes are useful for this.

The nature of carbonization in a pit makes it difficult to achieve a uniformly carbonised charge. The charcoal at the firing end is normally low in volatiles and the last formed charcoal near the smoke flue is high in volatiles, since it was subjected to carbonising temperatures for only a short time. Further, because air flow may not be uniform, there can be a considerable volume of brands in a charge. Although brands can be recovered and recycled, they represent an inefficiency in operations.

Smaller pits than the one shown in Fig. 2 are used. A typical small pit may measure 3 m long by 1.2 m wide and 1.2 m deep. The length of wood charged measures about one metre and, as in the large kiln, the spaces between large logs must be blocked carefully with small pieces of wood to increase charge efficiency and prevent uneven channelling of the gas from one end to the other, leading to production of "brands".



Photo. 9. Composite steel and earth pit kiln. Note smoke chimneys are buried in ground and kind of fuelwood used. Ghana. Photo. Lejeune.

5.2. Technical and cost data for pit charcoal production

The following technical and cost data is given for the production of charcoal by the large pit system in Guyana where the process has been operated on a commercial level for many years. Annual production has varied widely. Peak output was around 6,000 tons per year in the 1950's.

From data collected in the field and from discussions with people who have been working with this method for many years, the following evaluation for one man or a crew of five men working with one pit are given. The values are in days/per man/per pit.

Size of the pit:

Length 6 m x 2.70 width x lighting point depth 1.20 m x opposite extreme depth 2.40 m:

Nominal volume = 29 m³

Real utilized volume = 26 m³

Time employed:	
- to dig it in soft sand	3.0 man days
- to prepare the inlet and outlet air circulation channels	1.0 man days
- felling-bucking with axe, transporting firewood and packing (length of firewood 2.40 m (8'))	14.0 man days
- to cut bush and cover firewood (thickness of bush 3 cm)	2.0 man days
- to cover with sand 30 cm	1.0 man days
- to prepare sand and stakes around pit	0.5 man days
- to discharge charcoal	1.0 man days
	<u>22.5</u> man days
Process time	
- carbonisation	20.0 man days
- cooling (depends on weather, 30 days when rainy, 50 days when dry) average	<u>40.0</u> man days
	<u>60.0</u> man days

In practice, this pit is prepared by a crew of five men. This crew can produce 1.5 pits per week (7 days), working with axe and shovel, which is equal to 23 days per man per pit. To this value must be added another 8 man days. This is for taking care of the carbonization process during the 60 days it takes. Thus, the total man/days/pit is about 31. The average production of the pit is 6.0t. The nominal volume of the kiln is 29 m³. The useful capacity 90%, so the real volume utilized is 26 m³. By charging the pit with heavy woods 1,000-1,100 kg/m³ the total possible charge will be 27-28t. With a ratio of fuelwood: charcoal of 4.5 to 1, it is possible to obtain 6t per burn with an 82 day cycle. Three burns per year are possible, giving an annual production of 18 tons. This production requires 31 man days per pit x 3 = 93 man days per year.

If, say, 10,000 tons of charcoal are to be produced per year then $10,000/6 = 1\ 666$ pits must be burned per year. Each pit burned requires 31 man days, making the total man days $1\ 666 \times 31 = 51\ 646$.

Cost of producing 10,000 tons per year

The exact cost depends on the way labour can be organised around the cycle time of a pit which is 82 days. If 5 men work steadily digging, filling, lighting and unloading, then the number of pits which can be made and unloaded in a year will be as follows:

Number of days per year available = $365 - 82 = 283$, say 280 days since pits started after day 280 approximately will not be unloaded in that year and their production will not count. Therefore, a 280 working day year is assumed, with labour employed the whole year. No pits are started after day 280.

5 men can produce at 1.5 pits each 7 days in 280 days $280/7 \times 1.5 = 60$ pits each pit produces 6 tons charcoal: yearly production per team = 360 tons

Burners labour is 8 man days per pit. 60 pits need $60 \times 8 = 480$ man/days, i.e. approximately 2 men working through the year.

A nominal net wage without overheads of US\$ 10.00 per day is assumed.

Pit builders 5 men x 360 days x \$10 =	\$18,000
Burners 2 men x 360 x \$10 =	<u>7,200</u>
	\$25,200
Cost per ton = 25,200/360 =	<u>US\$70,00</u>

To produce approximately 10 000 tons per year will need 28 teams each of 5 builders and 2 burners.

Total = 196 men and 1,680 pits must be made and burned each year.

These calculations assume perfect organisation and do not allow for labour overheads or profit. The indicated cost is for charcoal piled for transport at the side of the kiln.

Chapter 6 - Making charcoal in earth mounds

[6.1. Types of mound](#)

[6.2. Making a typical mound or earth kiln](#)

[6.3. Casamance kiln](#)

[6.4. Collecting tar from the Casamance kiln](#)

[6.5. Cost of charcoal produced by the Casamance earth mound \(from experience in Senegal\)](#)

[6.6. The Swedish earth kiln with chimney](#)

The alternative to digging a pit is to stack the wood above the ground and cover the stack with earth. This method is also very old and is widely used in many countries. One finds many variations of the basic method. Studies have been made in some countries to optimise the design. The Swedish work in this area some years ago is notable. Essentially the process is the same as the pit - the wood to be carbonized is enclosed behind an air-tight well made from earth, a universally available material wherever wood is grown. The earth mound is preferred over the pit where the soil is rocky, hard or shallow, or the water table is close to the surface. By contrast the pit is ideal where the soil is well drained, deep and loamy. The mound is also more practical in agricultural zones where fuelwood sources may be scattered and it is desirable to make the charcoal near a village or other permanent site. A mound site can be used over and over again, whereas pits tend to be used a few times and then new ones dug to follow the timber resource. Also where the water table is close to the surface or drainage is poor, pits are not practical. The repeated digging of pits also disrupts cultivation for crops or pasture. The fuelwood to be carbonised, in a mound can also be gathered slowly over a period of months, stacked in position and allowed to dry out well before covering and burning. This fits in well with the life style of a small farmer who may gather scrap wood, branches and logs and stack them carefully to form the mound. After some months, depending on the season, charcoal prices and so on, he covers the mound with earth and burns the charcoal. A small cash income is produced this way which requires no initial cash outlay.

6.1. Types of mound

The mound or earth kiln system is versatile. It is suitable for sporadic small scale charcoal production and yet is also adaptable for large scale production. The now defunct charcoal iron industry of Sweden in 1940 produced more than 80% of its charcoal this way. The mound system was improved in Sweden through research, the main improvements being the optimization of the flue system and use of an external chimney to improve gas circulation. (2).

A hybrid system containing elements of the earth mound and the pit is used in some parts of Africa. A rectangular pile of evenly cross cut logs is stacked on a grid of crossed logs, to allow gas circulation. The volume of the pile is usually about 5-8 cubic metres. The completed pile is then sealed behind earth walls made by ramming earth between the piled wood covered with leaves and a supporting wall of saplings or boards held by stakes. The top of the pile is covered with leaves and earth as in pit burning systems. An opening in the side wall is left for starting the burn and, when this fire is well established, the wall is closed with earth and boards in the same way. Inlets for air are opened at the base of the pile and are used to control the rate of burning.

Attempts have been made to operate a modified form of this system on a larger scale using earth moving equipment. Large logs are rolled into a shallow excavation and further logs rolled and piled on top, using a bulldozer. Foliage is spread over the pile and earth is bulldozed over the heap to cover the fuelwood. A fire is lit at one or more points and, when burning well, the fire points are scaled with earth. The system is successful where no air leaks occur in the cover. In practice, poor yields of charcoal are common because it is difficult with large logs rolled into place to get a well packed stack, gas circulation is erratic and large amounts of uncarbonised wood result. Sealing of the piles is difficult and, at times, dangerous for the operator to repair. The result is that air leaks are not controlled and the charcoal is reduced to ashes in some parts of the pile before the remainder has been carbonised properly. A further problem is that unless the operations of the heavy earth-moving equipment are well managed with adequate maintenance and spare parts, the operating costs tend to get out of hand and the whole operation becomes unprofitable. As a rule, it is difficult to combine high capital cost equipment with a technologically primitive charcoal burning system and expect the operation to be profitable overall unless the quality of management is first class.

The problem of obtaining and maintaining over the whole period of the burn effective sealing against air, and good circulation, are the main factors limiting the size of pit and mound burning systems. It is difficult to detect leaks in the covering and in very large pits and mounds difficult to repair them.



Photo. 10. Earth mound kiln under construction showing firing point. Ghana. Photo Lejeune.

6.2. Making a typical mound or earth kiln

The typical village type charcoal burning mound is about four metres in diameter at the base and about 1 to 1.5 m high, approximately a flattened hemisphere. About six to ten air inlets are made at the base and an opening at the top about 20 cm in diameter allows exit of

smoke during burning. All openings must be sealed with earth when burning is complete and the mound is allowed to cool.

A space about 6 metres in diameter is cleared, levelled and compacted. It should be well drained. A post about 2 metres tall is sometimes erected at the proposed centre of the pile of fuelwood to assist in stacking the wood, to give stability to the pile and to provide a support for the operator when the pile is being covered with earth and the top smoke hole made, and later when the pile is lit. The pole is usually removed before lighting to provide a central opening through the pile.

A grid of crossed small logs about 10 cm diameter is first laid on the ground radially to form a circle about 4 metres in diameter. The wood to be carbonised, is then packed densely on this platform whose purpose is to allow the fire and hot gas to circulate properly. The longer pieces of fuelwood (up to 2 metres long) are stacked vertically leaning against the centre pole. The shorter logs are placed vertically towards the periphery so as to develop a more or less regular profile. Gaps between logs are packed with small wood to make the pile as dense as possible. The surface of the pile is packed out with small fuelwood as necessary, to give as even a profile as possible, and provide good support to the earth covering. It is good practice to allow the piled wood to dry out for as long as possible and to cover the pile during dry weather. To seal the pile, first straw, leaves, coarse grass, etc., are spread over the pile and then earth or sand spread over this layer. A sandy soil or loam which has low shrinkage on drying is preferable. Very plastic clays with a marked tendency to crack and shrink on drying and heating should be avoided. Charcoal fines can be mixed with the earth. The thickness of the covering will vary depending on the smoothness of the wood pile, but around 10-20 cm is typical. The coating should be checked to seal all cracks and to check that the air holes at the base of the mound remain open.



Photo. 11. Earth mound kiln during construction. Note large diameter wood placed at base of pile. Ghana. Photo Lejeune.

If necessary, the earth covering is allowed to dry out about one day and then firing can be started. A shovel of burning wood and charcoal is put in the hole at the top of the pile and

this ignites kindling wood placed on top of the wood pile. Dense white smoke issues from the top indicating that the fire has taken hold. Over a few days the smoke turns bluish and finally becomes practically clear. The time needed to complete a burn depends on the moisture content of the fuelwood and the evenness of the gas circulation inside the pile. The operator must feel for cold or hot spots on the walls and open or close the air vents below them. Red heat must not be visible through them at any stage. If this appears, the vent must be closed. Cracks which may form in the covering must be filled with soft sandy soil. When burning is judged complete, the opening at the top and all the vents at the base must be carefully closed with bricks or stones sealed with clay. The mound will cool in about two or three days, if small.

When the earth kiln is cool it can be opened. About 100 litres of water must be available to extinguish any fires. Since high productivity is not normally associated with earth mounds, they can usually be left long enough to fully cool down before they are opened.

The fully burned lump charcoal is separated from fines and "brands", and placed in bias or baskets for sale. The burned earth from the pile can be set aside and recycled for covering new mounds after it has weathered.

Yields of charcoal vary with skill of burning, dryness of fuelwood and air-tightness of the mound. Yields of 1 ton of charcoal from 4 tons of air dry fuelwood represent good practice. Yields of 1 ton from 6 tons fuelwood are more common.

This type of mound has been modified by inserting a central chimney made of old oil drums welded together. Experiments carried out with this modified system in Senegal have shown good results. The chimney improves gas circulation which reduces the amount of brands and speeds up the carbonization. Less brands means an improved yield of charcoal. This modified earth kiln called a Casamance kiln is shown in fig. 3 and described in the following section.

6.3. Casamance kiln

The base is made up of two layers of small and medium sized wood (16). For the first layer, the wood is evenly laid out radially around the central point of the base and, for the second layer, the wood is tangentially arranged across the first layer. The base plays an important part for it assures air flow in the mound.

The layers composed of large billets (40 cm diameter) are arranged to within 50 cm of the extremity of the base starting from the centre.

The medium sized billets (20-40 cm) surround them and give strength to the mound. They cover almost the entire remainder of the base.

The last ring is composed essentially of short wood (20-40 cm in diameter) arranged on the outer extremity of the base. The diameter of the base varies according to the volume of the mound.

For a mound of 30 m³ a base of at least 3 m radius is needed.

For a mound of 90 m³ a base of at least 4 m radius is needed.

For a mound of 100 m³ a base of at least 5 m radius is needed.

The mound is covered with grass and shrubs and then sand or loam. The chimney is placed at the edge of the pile as in the diagram, with its base opening connected to the base of the pile. The site of the mound should be cleared by rake and roots and stumps pulled out.

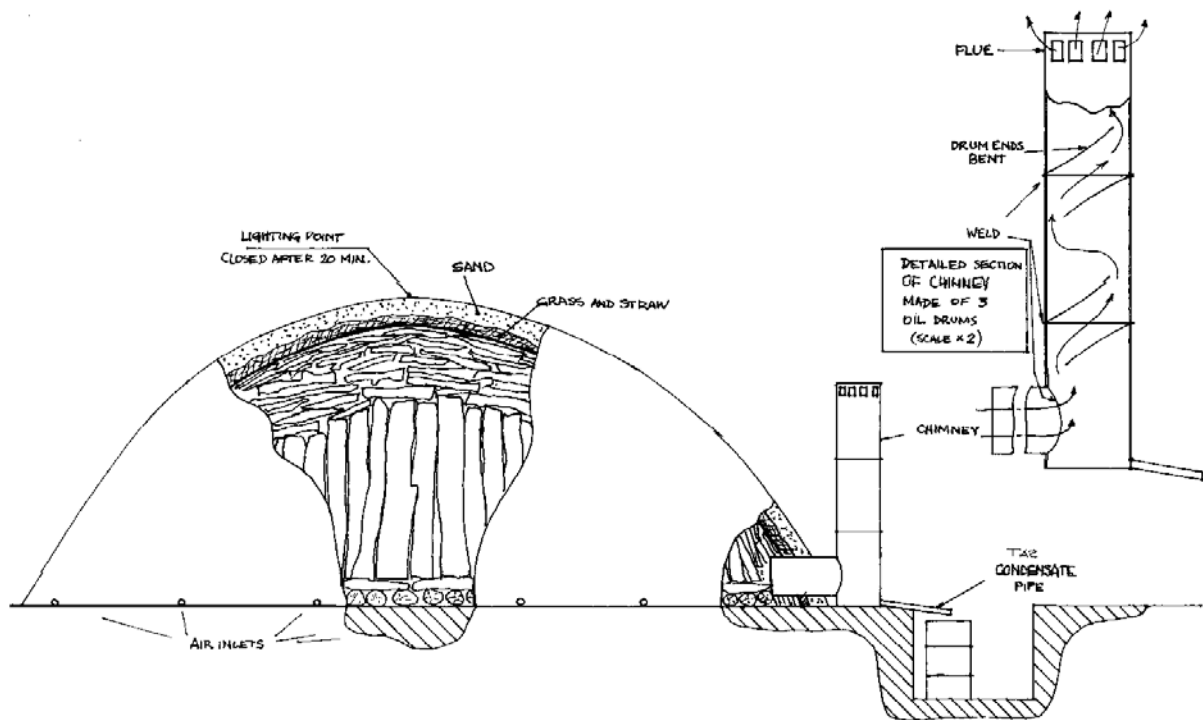


Fig. 3. - Casamance kiln, 100 steres

Rules for carbonization

Once the fire is started constant supervision by the burners (3) is needed until carbonization has finished. The mound is lit in the central hole by throwing in live coals. When the fire has started (15 to 20 minutes) the central hole should be closed. Ventilation holes should be opened every 3 to 4 metres around the base of the mound. A hole should never be made near the chimney as this will only reduce the draught in the rest of the pile. If smoke does not rise out of the chimney, a small fire should be lit in it to make it draw.

As carbonization advances the mound sinks progressively and holes may appear which should be immediately blocked with grass and sand. The chimney should be removed if the side on which it is situated seems to be completely carbonised.

The different stages of carbonization are:

- Heating up: from the ambient temperature to 100°C
- Dehydration: between 100 and 120°C
- Exothermic stage which begins at 270°C, reaching 500 to 700°C when carbonization is complete.
- Cooling during which the chimney is removed and the mound is hermetically sealed.

After cooling the mound is opened with the aid of rakes beginning at the base. The opening should be closed after a part of the charcoal has been removed and this procedure should be continued until the operation is completed.

The fresh charcoal from the mound should be covered with sand to prevent ignition. This avoids loss in quality caused by extinguishing it with water. Only lump charcoal should be put in bags: brands and fines should be discarded. The bags should be closed with twine to which a cardboard label should be attached, for control purposes, indicating the weight and number of the mound.

The brands should be carbonised in the next kiln. Carbonization is at an end when the smoke starts to diminish and turns blue. From this moment it is the charcoal itself which is burning, hence the necessity to withdraw the chimney and close the mound hermetically. During the exothermic decomposition stage by-products are collected as condensate from the base of the chimney. The condensate is a mixture of wood tar and pyroligneous acid. (See section 4). The Casamance mound is based on reversed draught, i.e. air flows in from the bottom of the vent holes and warm gas instead of escaping from the top, flows down and through the chimney which is connected to the base of the mound. During the cooling stage the charcoal burners should begin building the next mound, starting with the construction of the base.

6.4. Collecting tar from the Casamance kiln

Collecting condensate from the base of the Casamance kiln chimney has certain problems which cannot be overlooked. The theoretical volume which can be condensed is considerable and consists mainly of water of no value. From 100 steres of wood (a large Casamance kiln) about 21 metric tons of condensate can be produced. This would require about one hundred oil drums to contain it. The condensate is mostly useless water which is corrosive and contaminates the environment due to its content of acetic and related acids. About two metric tons of tar could be collected, which would fill about 10 drums, assuming none is burned on its way to the chimney. In practice it is essential to allow all the water and acidic substances to pass up the chimney as vapour and escape into the air in the normal manner. Dilution in the atmosphere reduces their contaminating and irritant effects. This is achieved by keeping the chimney hot and avoiding cold winds. Some tar is lost but this is unavoidable with such a simple system; otherwise the collection pit will be flooded by condensate and the area seriously contaminated. Where cold atmospheric operating conditions cause excessive water condensation, the lower section of the chimney must be insulated or a brick chimney built. Keeping the chimney hot, i.e. about 100°C, ensures a steady draught which permits proper circulation of the gases in the kiln with good carbonization. Tar will still be condensed. For more information on collecting and processing condensate from wood carbonization, see chapter 12.



Photo. 12. Unloading charcoal with sacks from earth mound kiln. Note rake used to separate soluble charcoal from earth covering in early stages of unloading. Ghana. Photo Lejeune.

6.5. Cost of charcoal produced by the Casamance earth mound (from experience in Senegal)

Data given is for a mound of 100 m³ size.

Costs and prices in CFA Francs (in 1978 1 US\$ = 310 F.CFA approx.)

1 stere of fuelwood yields 120 kg charcoal.

Manpower: 3 burners per mound.

Production cost for 12 000 kg. of charcoal

		<u>% of total</u>
100 steres fuelwood at 550 F.CFA per stere	55,000	28.0
Labour, including packing	77,040	39.2
Loading trucks at kiln site at 250 F.CFA/ton	3,000	1.5
Transport to main depot	10,449	5.3
Unloading at main depot	2,200	1.1
Bags	15,000	7.6
Tax at 1.5 F.CFA kg.	<u>18,000</u>	<u>9.2</u>
	<u>180,689</u>	<u>91.9</u>
plus contingency costs at 10%, cost w/o tax	16,000	8.1
Cost of charcoal in depot = 16.40 F.CFA/kg.	<u>196,689</u>	<u>100%</u>

Transport to major markets:

a) to Ziguinchor (1.81 F.CFA kg): 18.21 F/kg

b) to Dakar (8.00 F.CFA kg): 24.40 F/kg

Profit and loss on sales in

a) Ziguinchor: market price F.CFA 20/kg

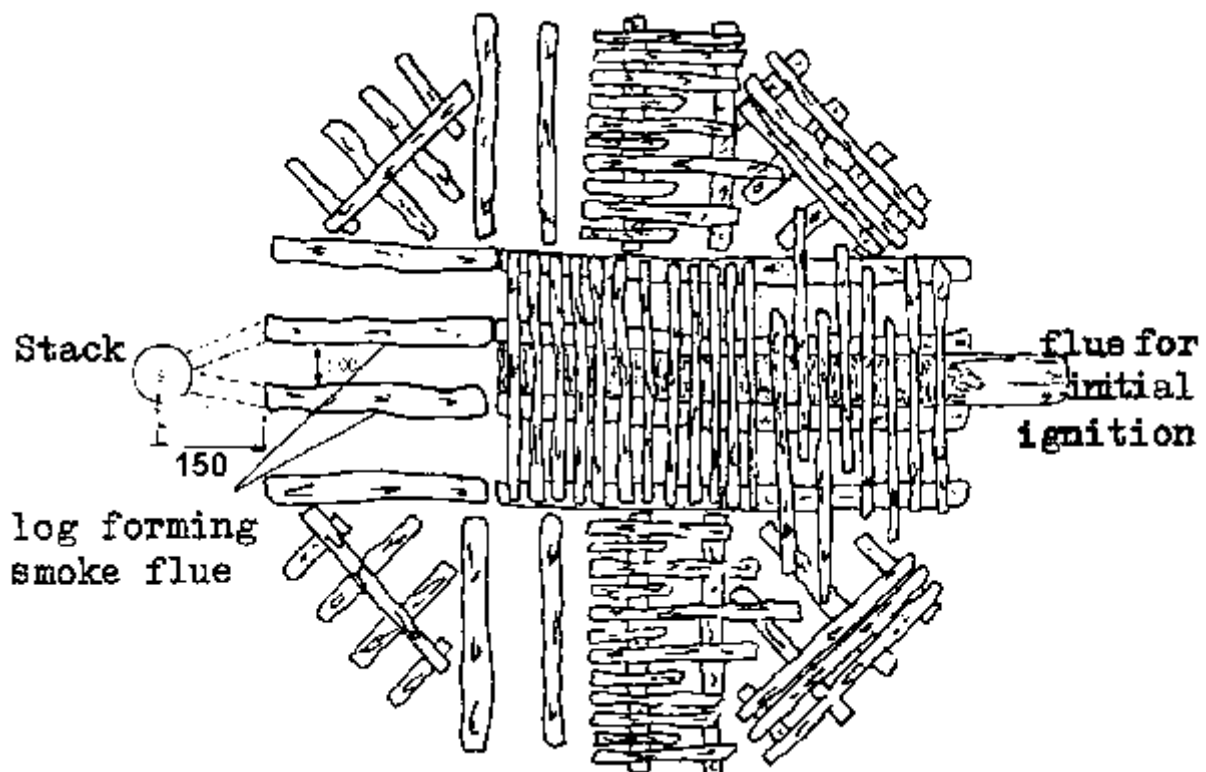
Profit = +1.79 F/kg

b) Dakar: market price F.CFA 22.5/kg

Loss = 1.9 F/kg

6.6. The Swedish earth kiln with chimney

The charcoal iron industry of Sweden (2, 23) brought the design and operation of large mound type furnaces to a high stage of perfection. The main improvements were the use of an external chimney connected to a flue constructed beneath the pile and adoption of a circular ground plan for the pile which reduced heat loss during carbonization and improved gas circulation.



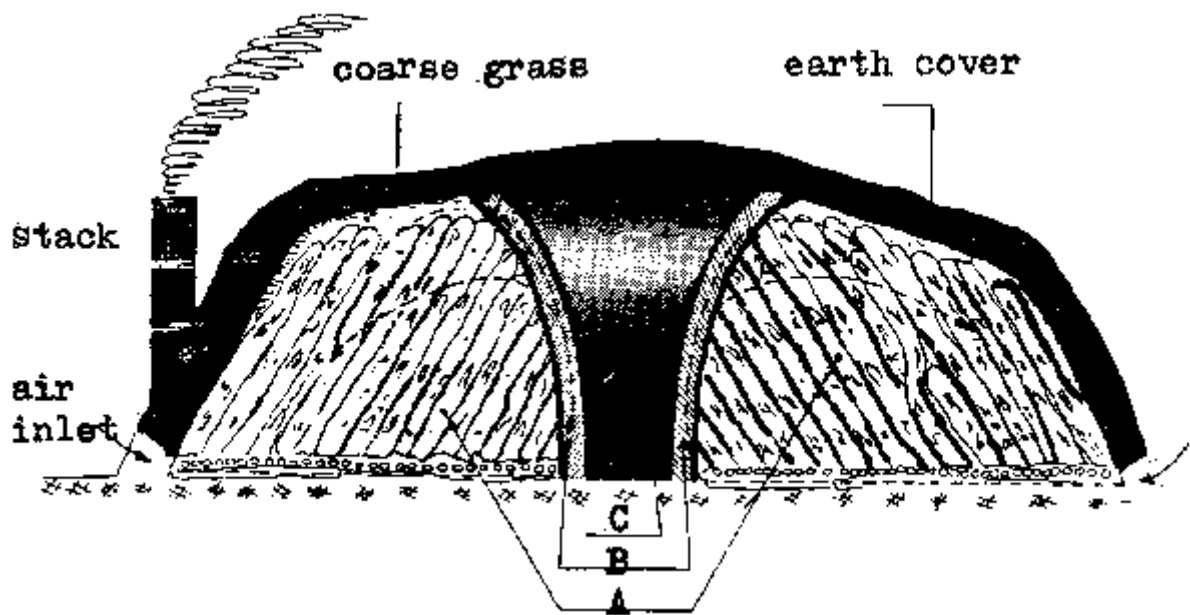


Fig. 4

- A - fuelwood
- B - carbonisation zone
- C - charcoal zone

Although these furnaces formerly produced very large amounts of charcoal for the iron smelting industry they have been superseded in the charcoal iron industry by the brick kiln systems used in Brazil, Argentina and south east Asia.

The kiln is built in the following manner:

The bottom of the base is covered with logs forming a grate or crib on which the wood is piled vertically. The grate forms a free space between the bottom and the wood charge through which the air necessary for the carbonization process passes. The piled wood is covered with leaves and grass and then earth about 20 cm thick.

The pile has an outside stack made of steel drums, which is connected to the pile through a flue cut into the ground, running under the pile and covered with round logs. The pile has a number of air vents located around the circular base.

The carbonization process is started by introducing a torch into the firing flue opposite the stack. This type of pile is reported to be easy to operate to produce good charcoal quality with a yield of 55% charcoal to wood by volume. The pile's volume varies from 100 to 250 m³ of wood. The whole cycle takes 24 days; four days for charging, six days for carbonization, ten days for cooling and four days for discharge. Due to the high carbonisation temperature, approximately 550°C, and the slow process, the charcoal produced in Swedish earth kilns has a high proportion of fixed carbon, low volatile matter and consequently a low bulk density, 130 to 160 kg/m³ for charcoal made from coniferous trees. Due to its low volatile content it has a very low tendency to self ignition. However, the use of earth kilns for large scale commercial operations producing metallurgical charcoal is no longer considered feasible for the following reasons: The kiln must be completely rebuilt after each cycle. The production cycle of 24 days is too long. The kiln operation, although basically simple, requires considerable skill, experience and even a certain degree of artistry. Wherever

simplicity of construction and operation, flexibility and mobility are desired, the simple brick beehive kilns give good yields with operational simplicity and speed of operation.

Chapter 7 - Brick kilns

[7.1. The half-orange Argentine kiln](#)

[7.2. The Brazilian beehive kiln](#)

[7.3. Slope type beehive kiln](#)

[7.4. The Missouri kiln](#)

[7.5. Charcoal production centres](#)

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

7.1.2. Design and construction

7.1.3. Fuelwood

7.1.4. Loading

7.1.5. Operation

7.1.6. Bricks

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 mortar, 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.

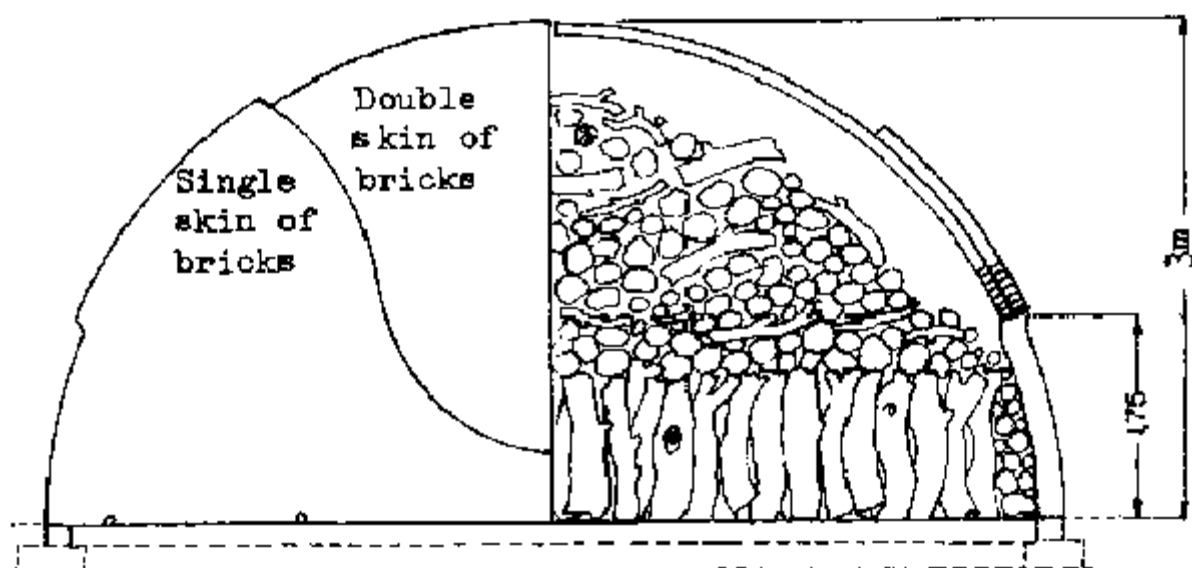
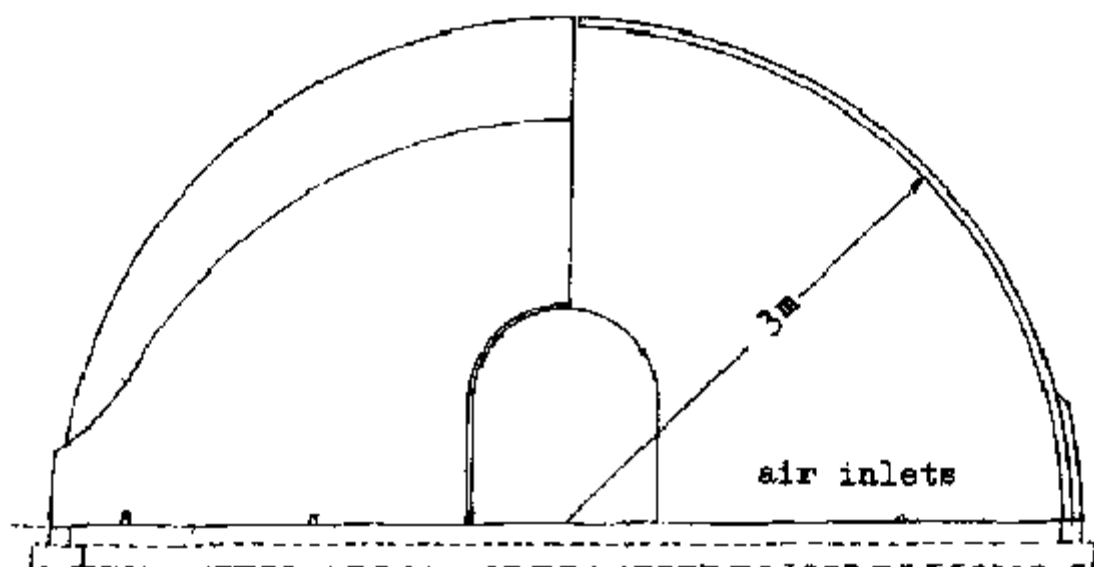




Photo. 16. Closing dome of a half orange kiln under construction. Note radius rod and orientation of bricks in dome. Argentina. Photo. J. Bim.



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.

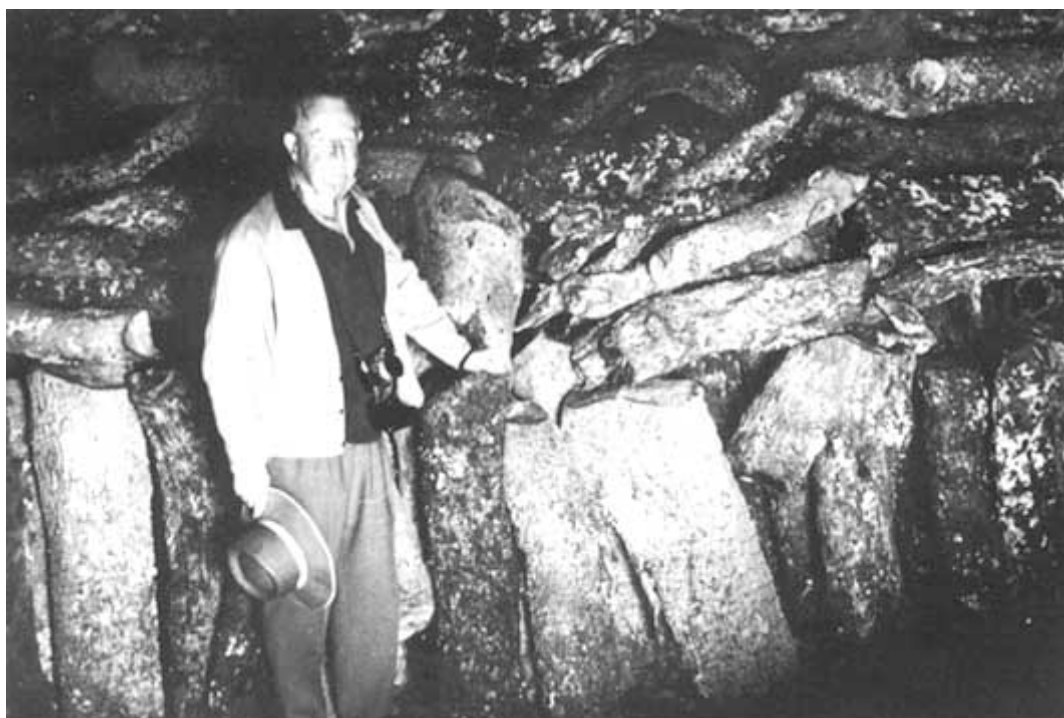


Photo. 18. Typical loading of a half orange kiln, Argentina.

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

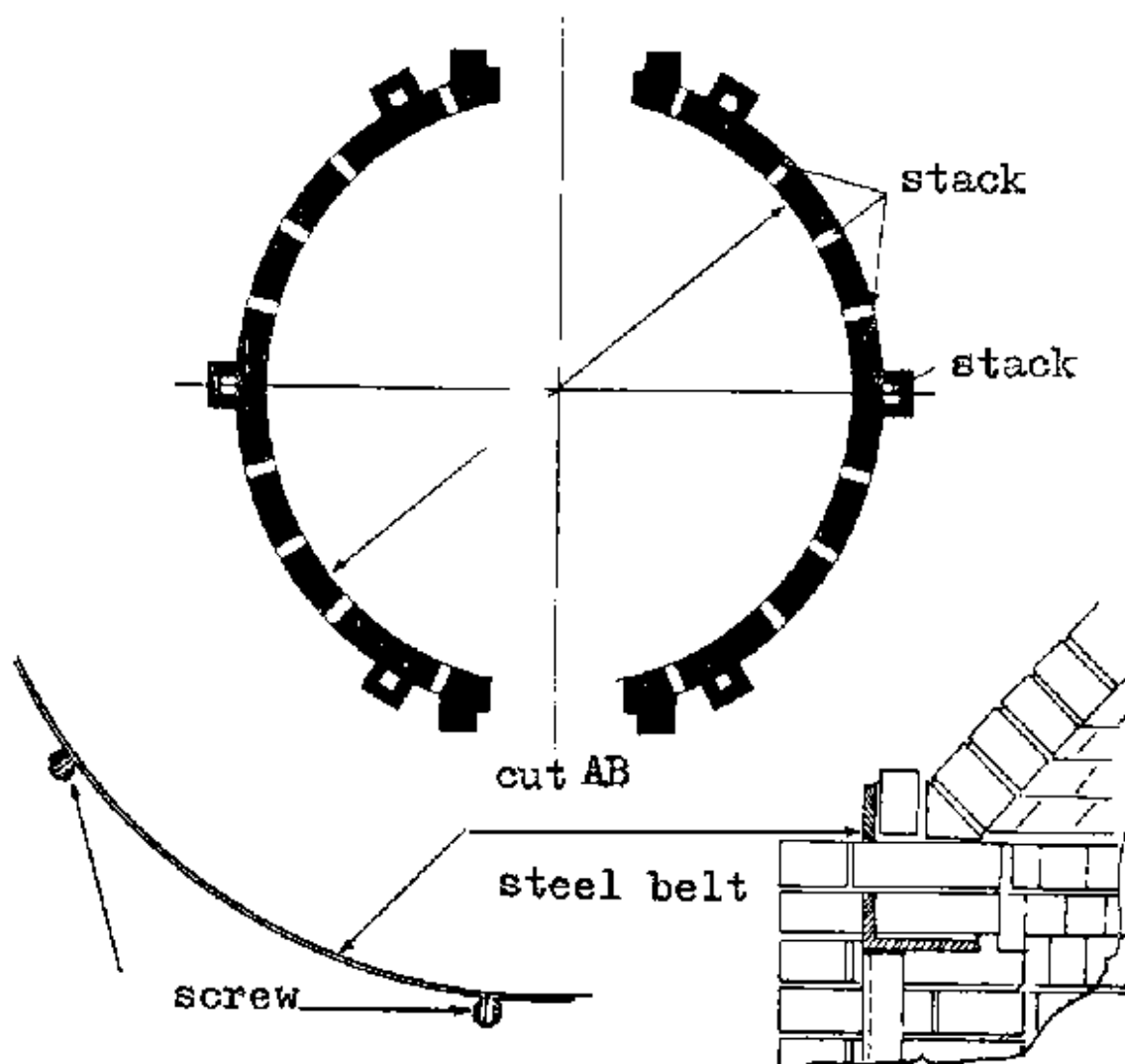
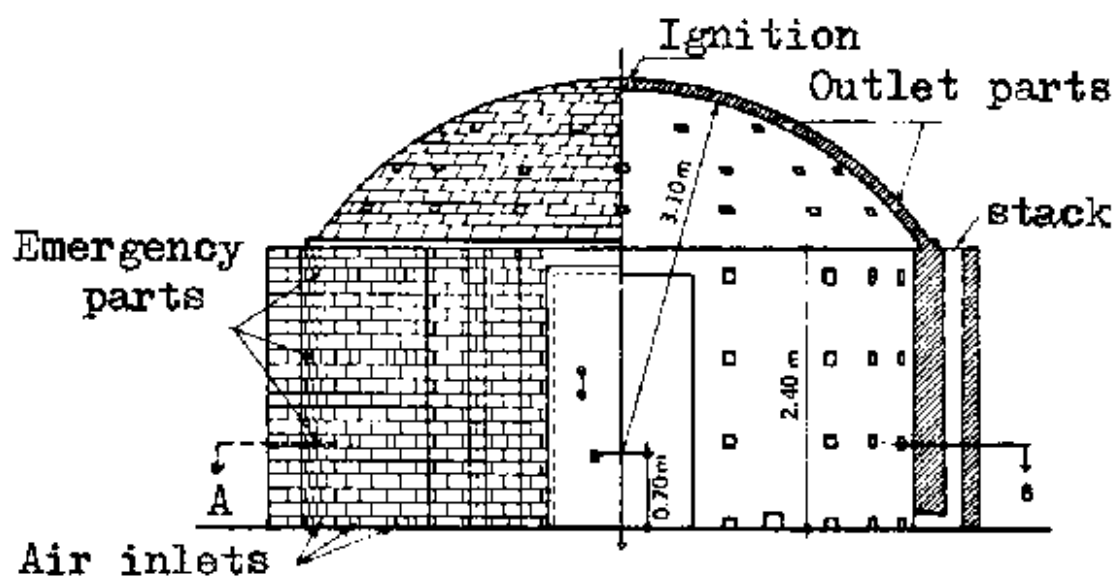
7.2.1. Design

7.2.2. Construction

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 m ³
Effective kiln volume	45.31 m ³
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.

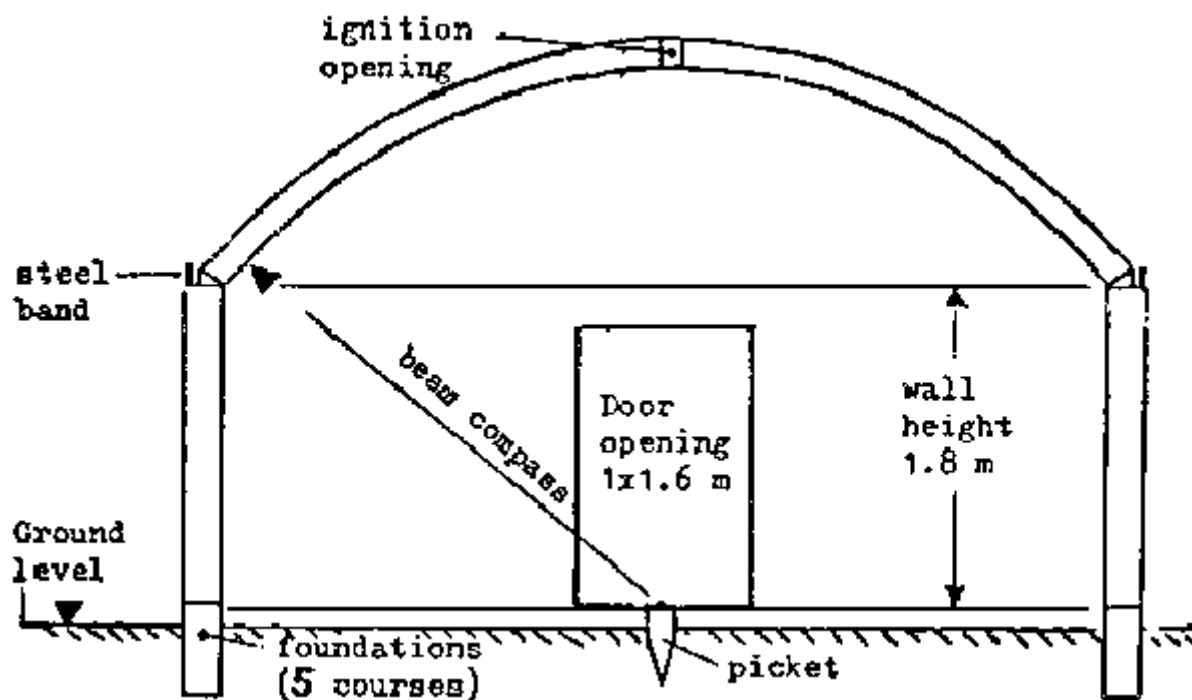
This area is necessary for the seven kilns, storing and curing of charcoal for two days, access roads for the trucks bringing wood, storage space for a certain amount of wood, access roads for trucks removing the charcoal and a truck turn-around area. To prepare the ground for the furnaces and the charcoal 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.

Slope type beehive brick kiln

Figure Fig. 8.1

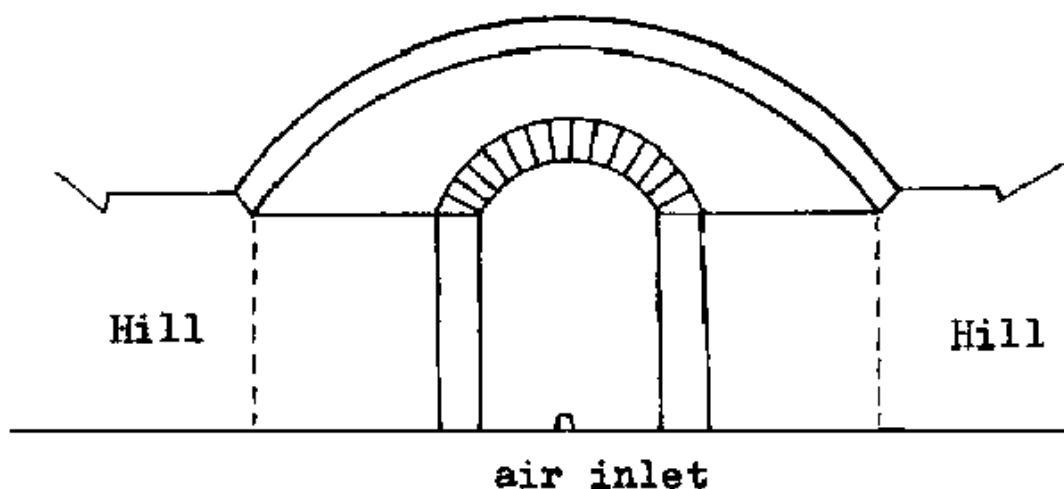
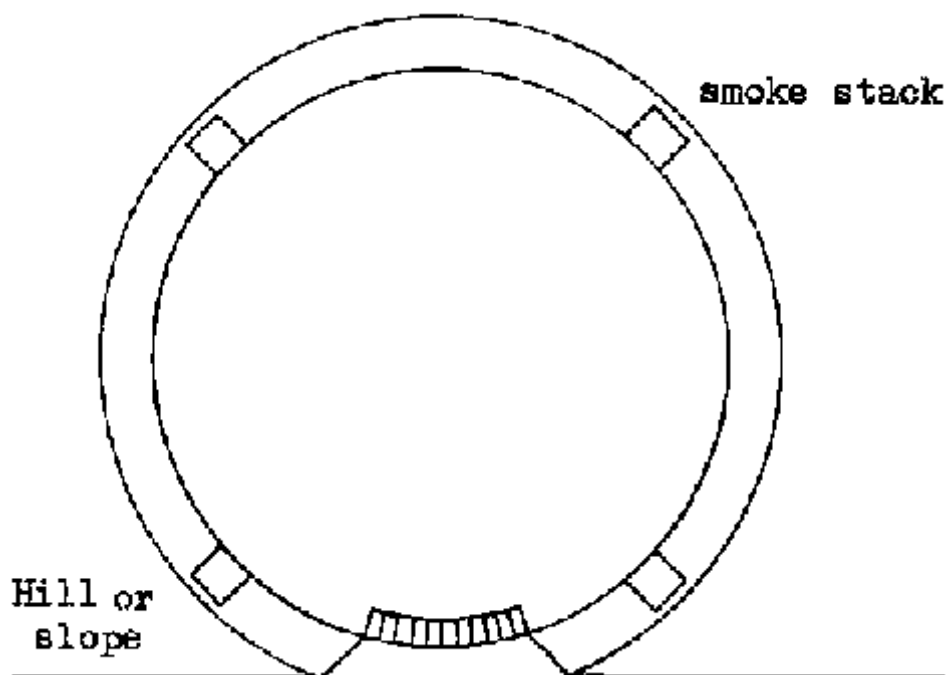


Figure Fig. 8.2



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

[7.3.1. The construction of slope type kiln](#)

[7.3.2. Maintenance of the 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

[7.4.1. Design](#)

[7.4.2. Construction](#)

[7.4.3. Operation](#)

[7.4.4. The Missouri type kiln in the developing world](#)

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 m³ to 350 m³. The optimum median volume seems about 180 m³. This size gives a fairly low cost per m³ 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 m³ capacity (50 cords) composed with four Brazilian type kilns, having a total capacity of about 200 m³. 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

<u>Material</u>	<u>One 180 m³ Missouri kiln</u>	<u>Four beehive kilns total volume 200 m³</u>
Concrete using expanded shale aggregate	46 m ³	nil
Common bricks	nil	34 000
Steel tons total	<u>4.4 m.t.</u>	<u>0.58 m.t.</u>
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:

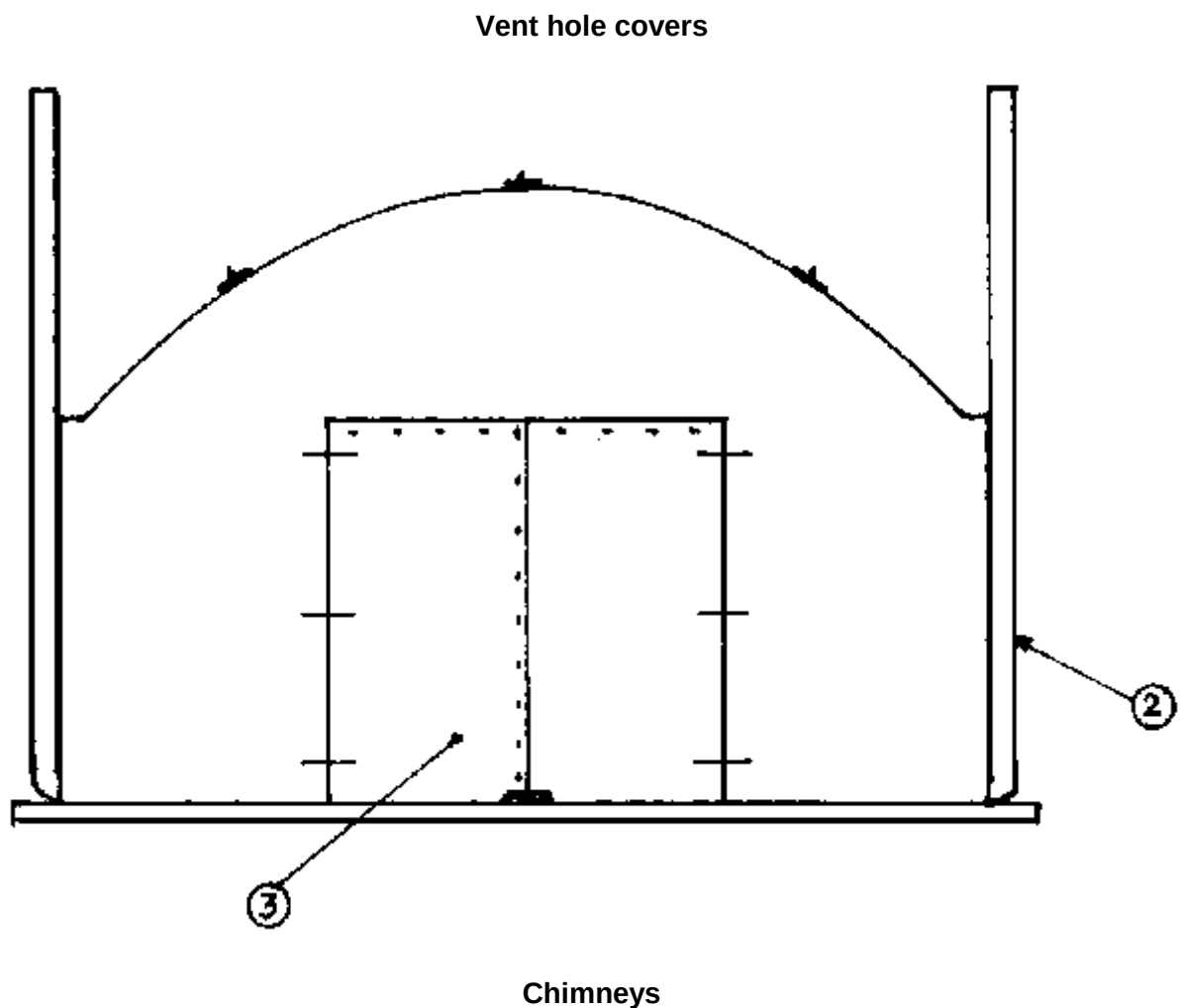
Loading	3 days	2 men plus machines
Burning	7 days	2 men on 12 hour shifts or 3 men on 8 hour shifts
Cooling	21 days (min.)	1 man part-time supervision
Unloading	2 days	2 men plus machines.

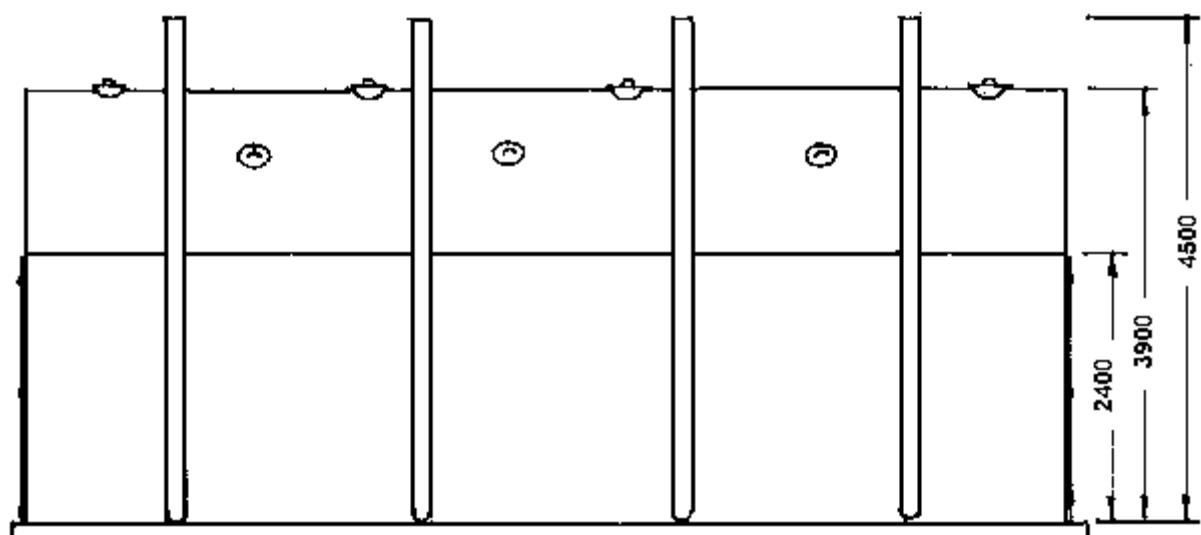
The total time is 33 days. If machines are not available the cycle time can stretch to two months or more.

7.4.4. The Missouri type kiln in the developing world

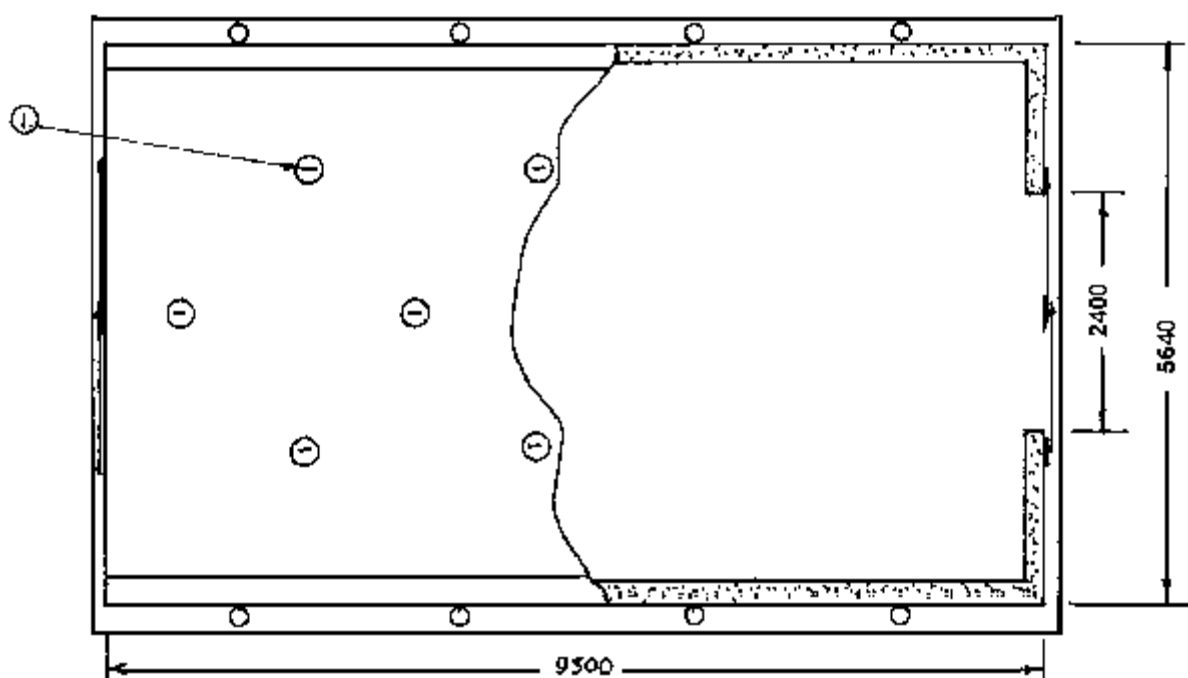
The Missouri type kiln was and still is an important method of charcoal making in the U.S.A. In 1958 when the industry was at its peak about 45 000 tons of charcoal were produced in Missouri by this method. (This production is miniscule compared to production by other methods in the developing world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

Missouri kiln - volume 150 M³





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

[7.5.1. Operational cycle of a seven kiln charcoal battery](#)

[7.5.2. Operating instructions for beehive brick kilns](#)

[7.5.3. Carbonization in slope type kilns](#)

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).

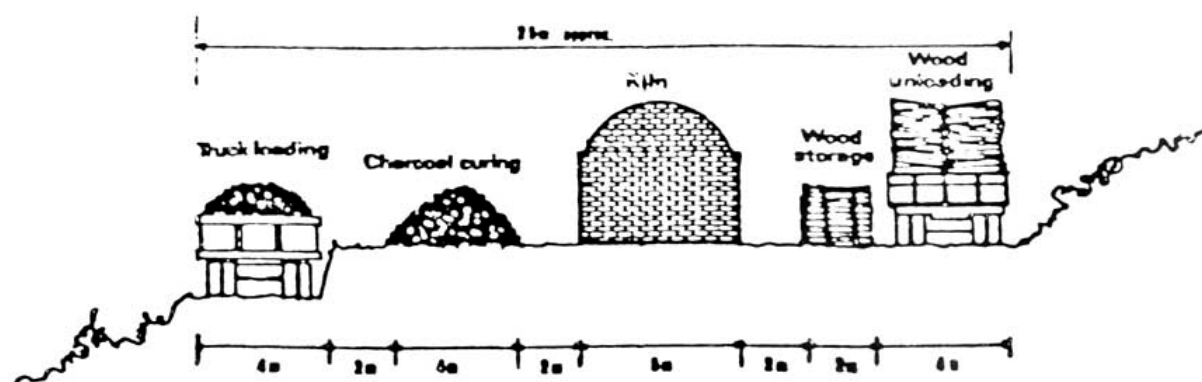


Fig. 10. Operating cycle for beehive brick kilns

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 m ³ 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 $30/8 \times 7 = 26.25$ batches - say 26 batches. Each batch = 17.8 m^3 of charcoal. Monthly production $17.8 \times 26 = 462.8 \text{ m}^3$ charcoal and yearly production $17.8 \times 26 \times 12 = 5\,553.6 \text{ m}^3$ 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 bricks.



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:

<u>Beehive brick kiln</u>	<u>Slope type kiln</u>
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 m ³ of charcoal	Life span: minimum of 350 m ³ 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	Kilns must be built as close as possible to wood supply.

level (See fig. 10).	
Maximum distance from wood supply: 5 km.	Maximum distance from wood supply: a few hundred 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.

Chapter 8 - Metal kilns

- [8.1. Available designs of transportable metal kilns](#)
 - [8.2. Metal charcoal kiln made from oil drums](#)
 - [8.3. Advantages and disadvantages of transportable metal kilns](#)
 - [8.4. Manufacture of the TPI metal kiln](#)
 - [8.5. The transportation and location of kilns](#)
 - [8.6. Selection and preparation of site](#)
 - [8.7. Preparation of the raw material](#)
 - [8.8. Method of operating the TPI kiln](#)
 - [8.9. Alternative method of operation](#)
 - [8.10. Schedule for commercial operation](#)
 - [8.11. The most common operational faults](#)
 - [8.12. Yields of charcoal](#)
 - [8.13. Working life of transportable metal kilns](#)
-

The widespread use of cylindrical transportable metal kilns for charcoal production originated in Europe in the 1930's. During the Second World War the technique was further developed by the United Kingdom (U.K.) Forest Products Research Laboratory. Various versions of the original design have been used throughout the United Kingdom. This technology was transferred to developing countries in the late 1960's, notably by activities in the Uganda Forestry Department. For more information see also refs. 7, 8, 9, 10, 17, 18, 25, 34.

8.1. Available designs of transportable metal kilns

The Tropical Products Institute (TPI), a scientific unit of the Overseas Development Administration, has gained considerable experience in operating transportable metal kilns of various designs both in the U.K. and in many developing countries. The Institute has evolved a kiln design which is considered to be optimal in economy of construction, robustness and durability, ease of operation and maximum efficiency and productivity for developing country situations.

The major features of the TPI designed kiln are:

- 3 mm thick sheet steel is used for the fabrication of the bottom section of the kiln; 2 mm thick sheet steel is used for the top section and cover.
- The two main sections of the kiln are cylindrical.
- 50 mm angle iron shelves are used to support the top section and cover. These are welded to the inside of the uppermost rims of the two main cylindrical sections.
- The eight inlet/outlet channels positioned under the bottom section of the kiln are open based. A collar is provided around the hole in the top face of each channel to support the chimney during the kiln's operation.
- Four equally spaced steam release ports are provided in the cover of the kiln.

Several deviations from the above features are to be found in other versions of transportable metal kilns. Some kiln manufacturers use thinner gauge metal sheets than that recommended in the TPI design. To ensure the maximum working life of a kiln, especially when operated carelessly, the thickness and type of metal used in the kiln's construction is of prime importance. The lower section of the kiln is subjected to the greatest heat stresses and should be fabricated from 3 mm thick sheet steel. For the upper section and cover a thickness of 2 mm will suffice. The use of Corten 'A' steel in the kiln's construction instead of mild steel will further increase its durability. This special alloy has heat and rust resisting properties. Its basic cost is about 10% higher than that of mild steel, but may be greater where special arrangements for obtaining it are necessary.

A kiln widely used in the forests of the U.K. has a tapering upper section so that the diameter of the cover is considerably smaller than that of the lower section. This reduces the weight of the cover, makes the kiln easier to assembly and adds to the overall rigidity of the upper section without affecting the performance of the kiln. It is not used in the TPI design, however, as a tapered section would be more difficult to construct in small engineering workshops found in developing countries and reduces its mobility on the forest floor.

The details of the seals between sections are critical. One design of metal kiln employs channels instead of shelves as the supports for the upper section and the cover. These channels are welded to the inside of the uppermost rim of both the lower and upper sections; they are filled with sand during assembly to form a seal when the upper section and cover are located into them. However, the channels collect the wood tar which condenses on the kiln walls and the high temperatures attained during the latter stages of carbonization bake the wood tar/sand mixture into a hard concrete, requiring many hours of hard effort to clean the channels after each operation. In addition, the sections often fuse together after cooling and the joints are damaged when metal levers are used to prise the sections apart. A further serious design fault is the use of an overshoot cover where a seal is effected by a vertical metal skirt welded to the underside of the cover. Should any leaks at the joint between the cover and the top section be observed after the kiln has been lit, it is extremely difficult to seal these as the overshoot cover prevents the operator from loading extra soil or sand into the joint. These problems do not arise with the TPI design as the angle iron shelves used to support the top section and cover do not trap the tar. Also the location of the cover inside the rim of the upper section permits the operator to add extra sand or soil to the joint for sealing as and when required.

Some metal kilns employ square section pipes as inlet/outlet channels. In practice, it has been found more convenient to use the open based channels of the TPI design. This is because the wood tar which condenses in the chimneys during carbonization flows down into the channels where it is baked to a hard pitch by the heat. Where the channels have an open base, most of the tar is absorbed by the soil and any that remains can be easily removed because of free access to the inner surfaces. Also, after prolonged use, the ends of the inlet/outlet channels inserted into the kiln become distorted with intense localised heat generated in that area by the air meeting the charge. Where a square section tube channel is used, the top and bottom face distort inwardly and this seriously restricts the flow of air and exhaust gases through the channel. To restore the original shape is difficult because the inner surfaces of the tube are inaccessible. On the other hand, the distortion of an open based channel can be easily corrected by inverting it and reshaping it with a hammer.

In some designs the chimneys are inserted into the channel through a hole cut in the top surface. The base of each chimney has a small section cut out to allow the smoke to enter from the channel. This practice may restrict the exit of the gases by accident rotation of the chimney and the channels cannot be cleaned easily during the operation of the kiln.

All transportable metal kilns incorporate some reinforcement to protect the kiln during handling. Excessive reinforcement can, however, create problems as even the most robust kiln can be damaged if unloaded carelessly from a truck. When a highly reinforced kiln is damaged considerable effort is needed to return it to its original shape. This can sometimes be achieved using a lifting jack between two lengths of timber across the diameter of the damaged section. The most important reinforcement recommended for metal kilns is the use of a strip of angle iron continuously welded around the outside of the lower rim of the base section. This will give a double thickness of metal at the lower edge of the kiln where heat stresses are most severe. It also provides a flat surface which distributes the weight of the kiln onto the inlet/outlet channels. The angle iron support shelves welded inside the top rim of the base and top section provide more reinforcement and a flat strip welded around the inside of the lower rim of both the top section and cover provide the rest.

Not all kilns incorporate steam release ports in the cover. After the lighting of the kiln the large quantities of steam released during the initial stage of the process must escape. Without steam release ports the cover must be propped open prior to lighting and dropped into place once the charge is burning fiercely. Alternatively the kiln can be overloaded and the natural sinking of the charge provides a sufficient period of time for the steam to escape before the cover settles into its supporting ledge. The obvious hazards presented by both these practices give rise to some anxiety during initial training programmes to operators of limited experience. Steam release ports have been found more acceptable when introducing metal kilns into new areas in the developing world. Another advantage is in the production of charcoal from small dimension raw materials such as scrub and coconut shells. To maintain sufficient gas flow through the charge during the carbonization of these materials it is recommended that the kiln is lit at the top through the steam release ports of the cover.

Finally, some of the kilns commercially available are equipped with hinged flaps and metal caps on the inlet/outlet channels which are used to cut off the air supply to the kiln on sealing. These extras add to the capital cost of the kiln and are found to be completely unnecessary. The hinged flaps become unusable after only a few days because of rust. Sealing can be achieved more effectively using earth or sand. In some designs handles are provided on the outside of the cylindrical sections of the kiln. Although handles are necessary on the cover of the kiln on the main cylindrical sections, they cause problems when rolling these sections from one site to another. It has been found that the kiln can be easily manipulated without the use of handles on the two cylindrical sections.

8.2. Metal charcoal kiln made from oil drums

Charcoal can be produced in kilns manufactured from standard 45 gallon oil drums. This method has been operated successfully using fast burning raw materials such as coconut palm timber, coconut shells and scrub wood. However, when operated with dense hardwoods, complete carbonization is difficult to achieve and the resulting charcoal is likely to have a high volatile content. Even with low density materials the volatile content of the charcoal produced is somewhat high, although this is not a major disadvantage for a local domestic fuel. If the charcoal is to be produced for export, however, the use of proper metal kilns will enable the high quality demanded by the trade to be achieved.

One man can operate a group of up to 10 oil drum units. The process involves a carbonization period of about two to three hours, followed by a cooling period of about three hours. An experienced operator can cycle ten drums twice each day to produce a total output of up to 30 kg of charcoal from each drum. This means that a one man operation, using 10 kilns, can produce 1½ tons of charcoal per 5-day week, if supplied with adequate prepared wood.

Compared with traditional methods of production the conversion efficiency obtained in oil drum kilns is comparatively high with reported yields of up to 23% (dry basis). (8) The main disadvantage of the method is that the raw material must be less than 30 cm long, with a maximum diameter of 5 cm, to achieve satisfactory results. This means a considerable amount of labour in the preparation of the raw material. Also used oil drums are sometimes difficult and expensive to obtain. The drums tend to burn out rather quickly due to the thin metal used and have to be replaced fairly frequently.



Photo. 25. Retort made from oil drums. Note pipe to collect condensate and fire laid in trench. Ghana. Photo Lejeune.

8.3. Advantages and disadvantages of transportable metal kilns

The main advantages of transportable metal kilns compared with the traditional earth pit or clamp method are:

- Raw material and product are in a sealed container giving maximum control of air supply and gas flows during the carbonization process.
- Unskilled personnel can be trained quickly and easily to operate these units.
- Loss of supervision of the process is required compared to the constant attendance necessary with pits and clamps.

- Mean conversion efficiencies of 24% including fines (dry weight basis) can be consistently achieved. Pits and clamps give erratic, often lower yields.
- All of the charcoal produced in the process can be recovered. With traditional methods (pits and mounds) some of the charcoal produced is lost in the ground and that which is recovered is often contaminated with earth and stones.
- Transportable metal kilns, if designed to shed water from the cover, can be operated in areas of high rainfall, providing the site has adequate drainage. Traditional methods of charcoal production are difficult to operate in wet conditions.
- With maximum control of the process a wider variety of raw materials can be carbonised. These include softwood, scrubwood, coconut palm timber and coconut shells.
- The total production cycle using metal kilns takes two to three days.

The disadvantages of using metal kilns compared with the traditional earth pit or clamp method are:

- Initial capital to cover the cost of the manufacture of the kilns must be obtained. Basic mechanical workshop skills and equipment must be available and the steel used in the kiln construction often has to be imported.
- For ease of packing and maximum efficiency some care is needed in the preparation of the raw material. The wood must be cut and/or split to size and seasoned for a period of at least three weeks.
- Transportable metal kilns may prove difficult to move in very hilly terrain, although more gentle slopes can be easily traversed.
- The life span of metal kilns is only two to three years.

The advantages of using transportable metal kilns compared with fixed installations, including kilns manufactured with bricks are:

- Transportable metal kilns can be easily and frequently dismantled and rolled along the forest floor to follow commercial timber extraction, plantation thinning or land clearance operations. This means that the laborious and expensive transportation of wood to a centralised processing site can be avoided.
- The total production cycle for these units is approximately one week, compared to the two to three days for the metal kilns.

The disadvantages of using metal kilns compared with kilns built from locally made bricks are:

- The cost of manufacturing a transportable metal kiln is usually greater than a brick-built kiln of comparable output. This is mainly because of the cost of raw material. Foreign exchange is needed in cases where the steel has to be imported. Sheet metal working skills and a workshop are needed for manufacture and maintenance.

- Because of the higher thermal insulation of the walls of the brick built kiln, less of the wood charged is burnt during the carbonization process and a slightly higher conversion efficiency is usually achieved than that obtained with transportable metal kilns. Brick kilns can carbonise large diameter wood and less cross cutting splitting is needed.
- The recovery of by-products from transportable metal charcoal kilns is not feasible. Where brick-built kilns are used, there are possibilities that the condensable tars may be recovered.
- Management supervision and logistical support is more readily supplied in a centralised processing situation where batteries of static brick-built kilns are in operation.



Photo. 26. Metallic transport table kiln. Photo. TPI

8.4. Manufacture of the TPI metal kiln

The kiln consists of two interlocking cylindrical sections and a conical cover. The cover is provided with four equally spaced steam release ports which may be closed off with plugs as required. The kiln is supported on eight air inlet/outlet channels, arranged radially around the base. During charring, four smoke stacks are fitted onto alternate air channels.

The kiln can be built locally in a simple sheet metal workshop. If available, Corten 'A' sheet steel 3 mm thick should be used instead of mild steel, as its heat and rust resistant properties will extend the working life of the kiln.

8.5. The transportation and location of kilns

The kilns can be easily using a flat-top truck. To transport the kiln in the back of a pick-up vehicle, the two cylindrical sections can be nested together - by inserting the top section into the lower rim of the base section - and rolled onto the back of the vehicle using a wooden ramp. The conical cover can be positioned inside the cylinders and the load should be firmly wedged and tied to prevent rolling.

Care must be taken when unloading the cylindrical sections from vehicles. If the sections are dropped onto their sides, then distortion is likely and difficulties will be encountered when attempts are made to assemble the sections during use. Slight distortion can be tolerated but severe distortion should be corrected using a car jack and two lengths of timber inserted across the diameter of the damaged section.

For economy of labour it is recommended that two or more kilns be operated as a group within reasonable walking distance of each other. This enables operators to unload and load one unit whilst the other kilns are in the carbonization or cooling stage.

To avoid the unnecessary carrying of wood, the kilns should frequently be rolled to new sites adjacent to the wood supply. The individual sections of the kiln can be rolled by two or three men, usually with two men pushing from behind and one man guiding the section from the front. Wooden levers are recommended for tipping the individual sections onto their sides prior to rolling them to a new position. Rolling the sections is far easier than sliding them horizontally, even where distances of only 1 or 2 metres are concerned. The task of manipulating these kilns on the forest floor becomes considerably easier with experience.

8.6. Selection and preparation of site

A well drained and roughly levelled area, approximately 3 metres in diameter, should be chosen in close proximity to the wood supply. Tree stumps and large root systems should be avoided and excessive undergrowth should be removed from the chosen area and the ground made firm by stamping it down. Loose earth or sand should be available close to the site for sealing off the air supply to the kiln during operation. A sandy or loamy soil is preferred and, if not available, a supply of sand should be obtained from a nearby stream for the initial operations. This material can be re-used and will soon increase in volume as charcoal dust and wood ash, produced during successive operations, are incorporated into it.

8.7. Preparation of the raw material

The wood should be felled, cut up and stacked at least three weeks before kilning, if the maximum yield of charcoal is to be obtained. Dry wood needs less charring time and increases the conversion efficiency of the process. The size of wood most suitable is between 450-600 mm long and up to 200 mm in diameter. Branches up to 900 mm long can be included provided their diameters do not exceed 130 mm and the packing density in the kiln is not markedly reduced. Logs with diameters approaching 300 mm may be used provided they are cut into lengths no greater than 300 mm. Wood with a diameter greater than 300 mm should be split before use.

Branches with a diameter of less than 40 mm should not be mixed in the same charge with timber of maximum diameter. This material should be charged with other small to medium size wood. Approximately 7 stacked cubic metres of wood are required to fill the kiln.



Photo. 27. Wood preparation for charcoal. Note short length of wood. Photo TPI

8.8. Method of operating the TPI kiln

8.8.1. Tools required for a 2-3 man operation:

8.8.2. Assembly and loading the kiln

8.8.3. Lighting the kiln.

8.8.4. Reducing the draught

8.8.5. Control of charring

8.8.6. Unloading the kiln

8.8.7. Bagging of charcoal

8.8.1. Tools required for a 2-3 man operation:

Chainsaw or crosscut saw

Shovels or spades (2)

Cutlass

Axe

Wedges (2)

Sledge hammer

Wooden pole or plank

Sieve chute

Sacks

Needle and string

Heat proof gloves

8.8.2. Assembly and loading the kiln

(a) The bottom section of the kiln is rolled onto the prepared site and lowered into its operating position. Using a wooden pole as a lever the eight air inlet/outlet channels are inserted open side down radially underneath the bottom section at equidistant intervals. Equal spacing will be easily achieved if the first four channels are inserted at 90° intervals and the remaining four inserted between them.



Photo. 28. Assembling of metallic kiln. Photo. TPI

The air channel must protrude a minimum of 250 mm into the kiln to prevent overheating of the kiln wall. The supporting collar on the top of the channel must not lean inwards towards the kiln wall, otherwise it will be difficult to position the chimneys once the kiln has been assembled. When the inlet/outlet channels are in position, it is necessary to check that they are completely clear of any obstruction.

(b) The bottom of the kiln is loaded with wood making sure that the ends of the inlet/outlet channels and the spaces between them are not blocked. To achieve this, the charge is supported on 'stringers' which are medium diameter (150 mm) pieces of cordwood arranged radially like the spokes of a wheel.

(c) At each quadrant of the kiln's base dry kindling wood, together with any inflammable waste (paper, sump oil, etc.) is placed between the stringers from the edge of the bottom of the kiln to the centre to provide four lighting points.



Photo. 30. Inflammable waste is placed between the stringers to provide four lighting points. Photo. TPI

(d) A bridge of small/medium diameter wood and brands (incompletely charred wood from a previous firing) is now placed across the stringers over the kindling in the shape of a cross. The base layer of the kiln is completed by bridging the remaining exposed stringers with small/medium diameter wood.

By supporting the first layer of wood above the ground on stringers, air ducts are formed under the charge which will allow the fire to spread more rapidly into the centre of the kiln.



Photo. 31. Wood charge operation. Photo. TPI

(e) The bottom section of the kiln is loaded with successive layers of wood, filling in as many voids as possible and placing the larger diameter timber towards the centre of the kiln. When the bottom section is full and all the joint surfaces of the kiln are scraped clean, the top cylindrical section is rolled alongside. The top section is then pushed up on to the supporting shelf of the base section.

(f) The loading of wood is continued until the charge forms a conical shape above the rim of the top section but, at the same time, will allow the cover to be located into the rim without hindrance. The cover is then rolled alongside the kiln and pushed up onto its supporting shelf. Two experienced men can load the kiln in about two hours.

8.8.3. Lighting the kiln.

(a) After ensuring that all four steam release ports in the cover are open, a flame is applied to the four lighting points. Where there is a prevailing wind, the area of the kiln on the windward side will burn more quickly. To allow for this, the lighting points facing the wind are not lit until the lee side of the kiln is well alight.



Photo. 32. Lighting points. Photo. TPI

(b) The kiln is allowed to burn freely for about 30 minutes until the bottom section at each lighting point becomes so hot that it is unpleasant to stand close to the kiln*. During this period copious amounts of steam will be released from the four ports in the cover of the kiln. While this is in progress the joints between the main sections of the kiln are filled with sand or soil and the four smoke stacks are placed into position over the supporting collars of each alternate air channel.



Photo. 33. Joints between the main sections of kiln are filled with sand or soil and smoke stack is placed into position. Photo. TPI

8.8.4. Reducing the draught

As each sector of the kiln reaches the required temperature the spaces between the inlet/outlet channels are covered with sand or soil. When all the spaces between the channels have been covered, the ends of the four channels supporting the smoke stacks are sealed. The steam release ports are now closed so that the smoke is drawn out of the base of the kiln by the four chimneys. When the draught has been reduced air enters the kiln only through the inlet channels from where it flows up through the centre of the charge. The combustion gases are drawn down the outer edge of the kiln and are released through the smoke stacks. As the air and exhaust gases flow in opposite directions, this condition is known as the reverse draught.



Photo. 34. Air and exhaust gases flow in the kiln. Photo TPI

8.8.5. Control of charring

(a) Each chimney should emit a column of thick white smoke 15-30 minutes after promoting the reverse draught. Throughout the period of carbonization it is advisable to ensure that even temperatures are maintained around the circumference of the kiln. Control is easier when kilns are operated in sheltered positions. If there is a strong prevailing wind, the temperature profile across the kiln may become unbalanced and it will then be necessary to partially or completely block one or two of the air inlets on the windward side. When operating in wet conditions, or with freshly felled wet wood in windy conditions, more extreme efforts may be necessary to balance the kiln during the initial stages of carbonization. Under these conditions large quantities of water will evaporate from the soil and wood on the hottest side and condense in the cooler regions of the kiln. This water is likely to quench any fires remaining in the lighting points and will further depress the temperature in these areas.

To correct this situation the air inlets on the hot side of the kiln must be temporarily blocked and the spaces between the inlet/outlet channels on the cooler side uncovered to allow more air to enter this region of the kiln. This action will draw the fire over to the cooler side of the kiln and, once the temperature in this area has been sufficiently increased, the spaces between the channels may be resealed. After this, the normal method of controlling the supply of air to the kiln can be followed.

It is important that a burning kiln is never left unattended when the spaces between the inlet/outlet channels are uncovered as serious damage to the kiln could result.

When wet wood is used or when the kiln is operated under wet conditions, the charring period is likely to be extended up to a total of 48 hours. Because of the increased amount of

wood burned internally to drive off the excess moisture, lower yields of charcoal are to be expected.

(b) During charring a certain amount of tar is deposited in the outlet channels and smoke stacks. This tar restricts the exhaust gas flow from the kiln and should be removed when there is a noticeable reduction in the quantity of smoke issuing from any of the stacks. To achieve this the stack is lifted off the supporting collar of the outlet channel using a pair of heat proof gloves or an old sack and any obstruction inside the chimney is removed. At the same time a long stick should be inserted through the channel into the centre of the kiln to ensure that there is no internal restriction.

Some time during the carbonization period (usually 8-10 hours after lighting) the smoke stacks should be moved on to the adjacent air channels to convert air inlets to smoke outlets and vice versa. This creates a more even burn and reduces the formation of ash at the regions where air enters the kiln.

(c) Charring is complete when the colour of the smoke from all chimneys takes on a bluish tinge and becomes almost transparent. This normally occurs about 16 to 24 hours after lighting. At this stage the whole surface of the kiln should be very hot (150-200 C) so that a spot of water applied to the wall of the kiln will evaporate immediately with a spitting noise. When this stage is reached the kiln is completely sealed for cooling.

The kiln is sealed by removing the smoke stacks and completely blocking all air channels with soil or sand. If necessary, additional soil or sand is added to the joints of the main sections of the kiln and the steam release ports to ensure that they are fully sealed and that no air may enter. The kiln is allowed to cool for between 16 and 24 hours before opening and unloading. Cooling will be greatly assisted if rain falls.

8.8.6. Unloading the kiln

(a) The kiln must not be opened until the contents are cold and the outside surface of the kiln is cool to the touch. The action of direct sunlight could obscure this and the temperature of the inside of the kiln can be more easily assessed by feeling the surface of the bottom section in an area shaded from the sun. Following this the temperature of the remaining surface of the lower section should be assessed to ensure that no "hot-spots" exist. If the contents of the kiln are still hot after a cooling period of 24 hours, then complete sealing from the outside air has not been effected and efforts must be made to achieve this. Furthermore, if the kiln is opened and part of the charcoal is seen to be still alight, the kiln must be resealed for a further cooling period.

The charcoal must be removed immediately the seal on the kiln is broken even when the contents appear to be completely cold. Any delay could result in localised fires igniting the charcoal and, in addition to this loss, serious damage to the kiln may occur.

(b) During carbonization the wood will have been reduced to about half its original volume and it will be possible to remove the cover and top section once the kiln has cooled, leaving the charcoal in the lower section. The cover is removed with a minimum effort by lifting one side from its supporting shelf and inserting the end of a long branch or plank into the resulting gap. This piece of wood can then be used as a ramp on which the cover is slid gently to the ground. The same method is used to remove the top section of the kiln.



Photo. 35. During carbonization period wood has been reduced to about half its original volume. Photo. TPI

(c) To remove the bottom section the inlet/outlet channels are first removed from one side of the kiln using a lever. By applying the lever to the opposite side, the bottom section can be tipped onto its side leaving the charcoal free to be loaded into sacks. A bucket of water or a quantity of sand or soil should be on hand while unloading the kiln in order to quench any small fires.

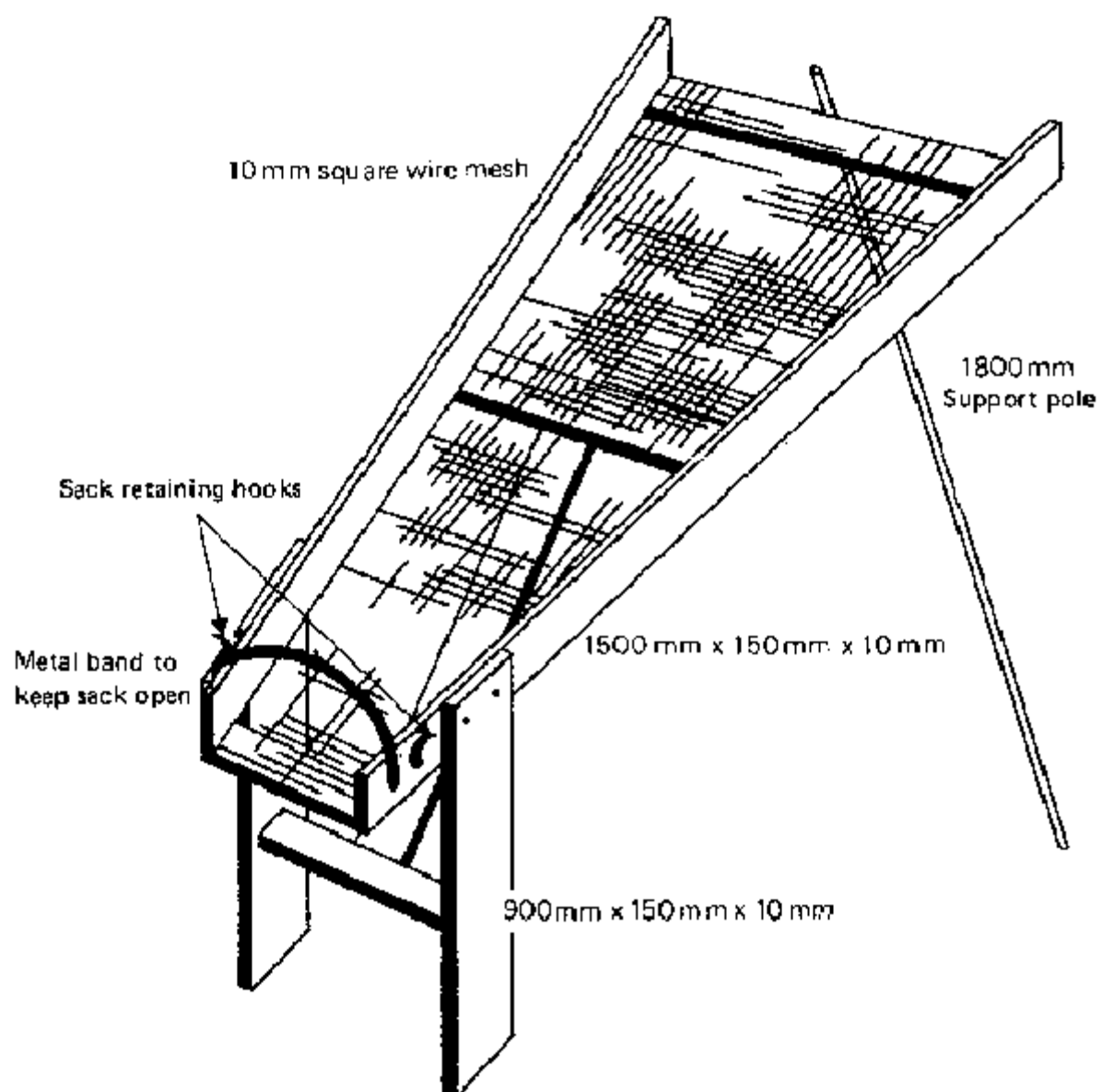
8.8.7. Bagging of charcoal

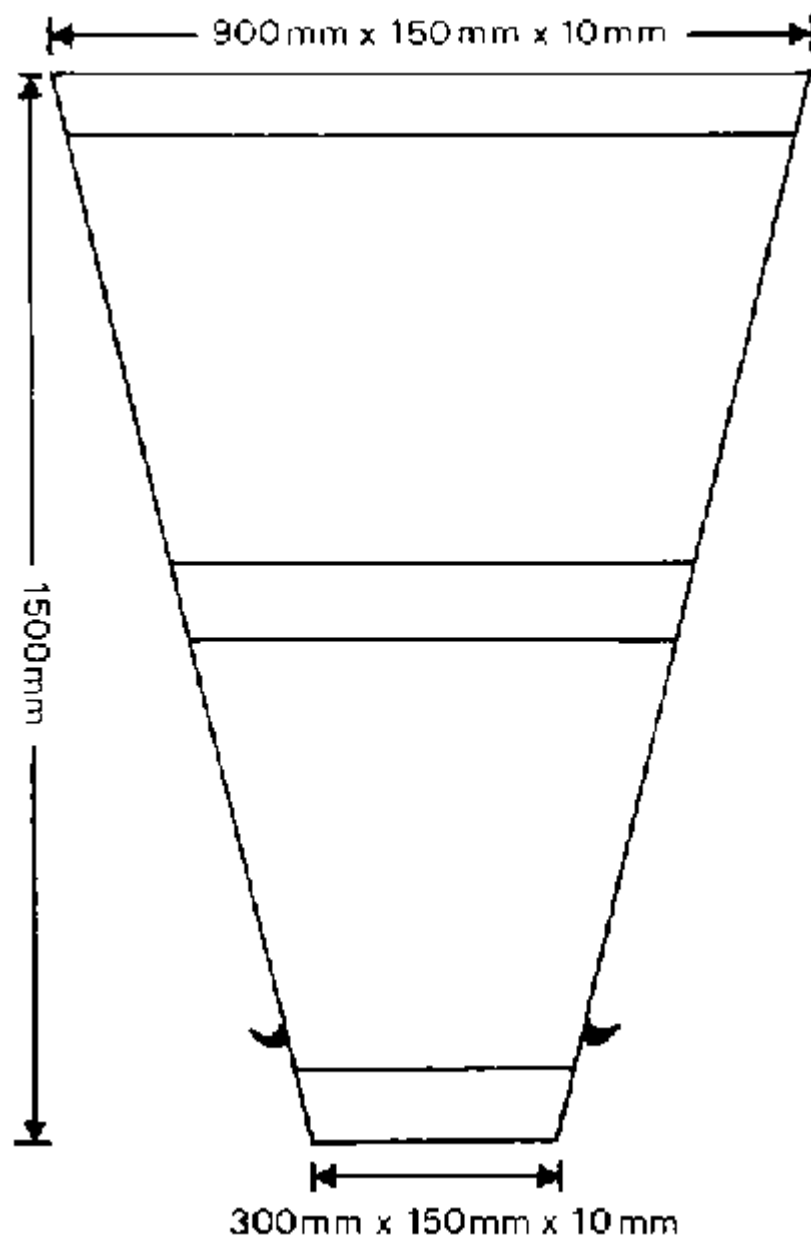
To speed up this operation a sieve chute should be used to separate the large charcoal pieces from the fines and dust. The construction of the sieve chute is shown in figure 11.

It is recommended that the bottom section of the kiln be positioned on the leeward side of the charcoal and used to support the sieve chute. This will not only increase the stability of the sieve but will reduce the amount of dust reaching the operator.

If required a free-standing sieve chute can also be used. Two men can unload it and fill the sacks with charcoal in about an hour.

Fig. 11. Sieve chute for loading charcoal into sacks





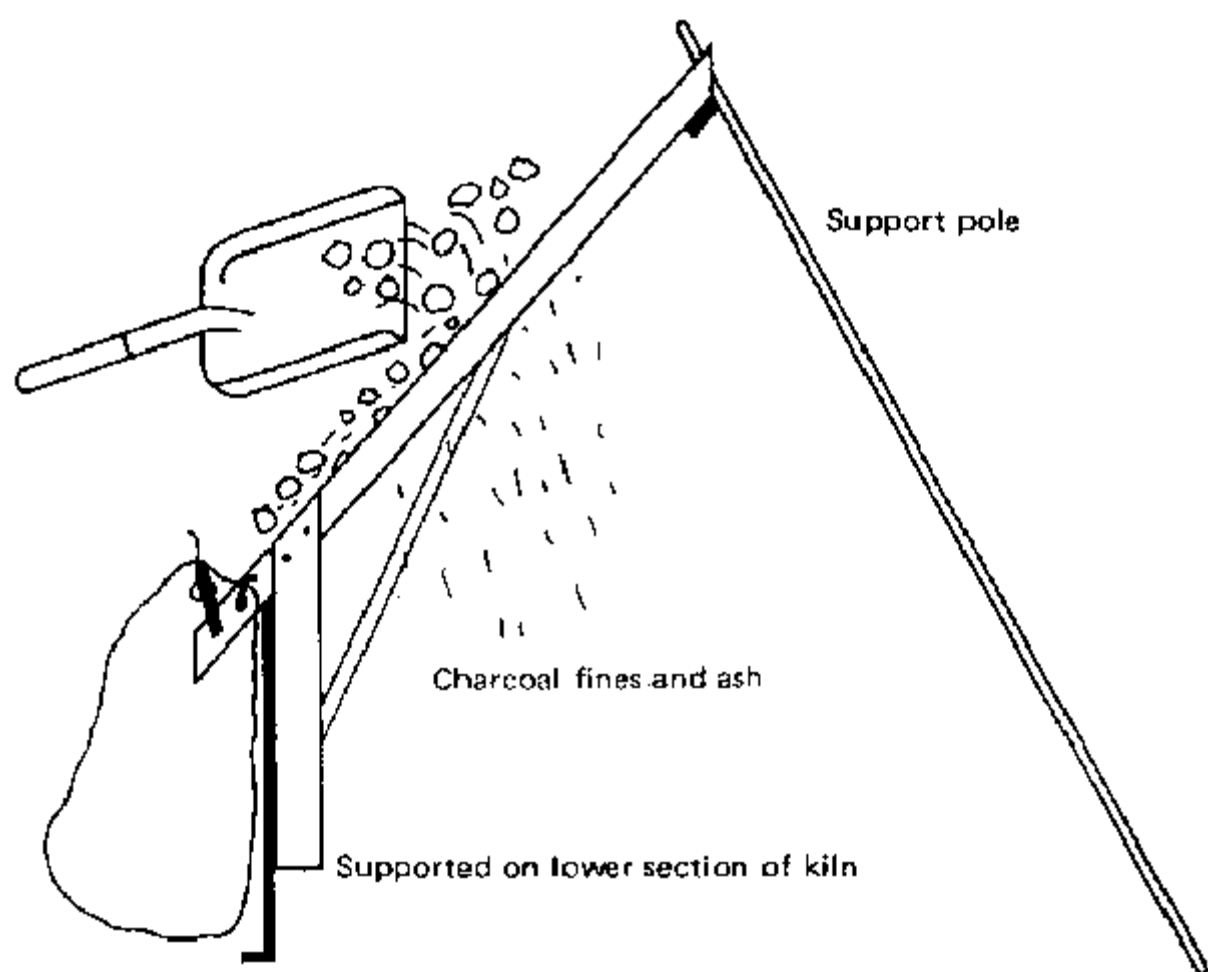




Photo. 36. Sieve chute should be used to separate the large charcoal pieces from fines and dust. Photo. TPI

8.9. Alternative method of operation

8.9.1. Loading

8.9.2. Lighting

8.9.3. Reducing the draught

Lighting the kiln from the top is a method which is particularly suitable for the carbonization of small wood or coconut shells, as it ensures a sufficient gas flow through the charge.

8.9.1. Loading

The kiln is loaded as previously described, without kindling between the stringers at the base. The kindling wood is placed instead in a depression 250 mm deep on top of the charge, which is then covered with a final layer of wood.

When carbonising coconut shells the use of stringers is not required. Care must be taken to ensure that the shell material does not block the ends of the inlet/outlet channels inside the kiln. To achieve this, a flat piece of wood (for example, a piece of rib from a dead palm frond) is placed on top of the end of each channel before covering it with shells.

8.9.2. Lighting

The fire is lit at the top through one of the four steam release ports and the charge is allowed to burn with a completely free access of air into the base of the kiln. The smoke will escape through the four ports in the cover. This stage is allowed to continue for about two hours until the whole of the top section of the kiln is too hot to touch with bare hands.

8.9.3. Reducing the draught

When the top section is sufficiently hot the spaces between the inlet/outlet channels are covered with sand or soil and the chimneys are placed in position. The steam release ports are sealed. The reverse draught and control of the supply of air to the kiln are achieved as in the normal method of operation described above.

8.10. Schedule for commercial operation

Two experienced men can operate two transportable metal kilns producing 23 tons of charcoal per week. Depending on local conditions and facilities, assistance may be required in cutting the wood and moving the kilns and, in some cases, the use of a third man, preferably a chain saw operator, may be necessary.

Experience has shown that the most successful commercial ventures involving the use of transportable metal kilns have been those offering maximum incentives to the operators. An example of this is a cooperative run by kiln owner/operators where the members receive most of the proceeds of the sale of the charcoal.

A suggested 5-day week work plan is outlined below. Modifications can be made to this schedule to allow for variations in daily working hours and a 6-day working week. Moreover, if arrangements can be made for someone living near to the production area to undertake a half hour period of light duty to seal the kiln during the weekend, then extra operations can be achieved.

Monday	08.00-10.00	Kiln 1 and Kiln 2		Unload both kilns.
	10.00-12.00	Kiln 1		Load kiln with wood.
	12.00-13.00	Kiln 1		Light kiln and reduce draught.
	13.00-17.00	Kiln 1		Control charring. Change and clean stacks at 16.30.
			Kiln 2	Load kiln with wood.
Tuesday	08.00-08.30	Kiln 1		Change and clean stacks.
	08.30-11.00			Prepare wood for future operations.
	11.00-12.00		Kiln 2	Light kiln and reduce draught.
	12.00-17.00		Kiln 2	Control charring. Change and clean stacks at 16.30.
		Kiln 1		Shut down kiln when charring is complete. Prepare wood for future operations.
Wednesday	08.00-08.30		Kiln 2	Change and clean stacks.
	08.30-14.00			Prepare wood for future operations.
	14.00-15.00	Kiln 1		Unload charcoal from kiln.
	15.00-17.00	Kiln 1		Start loading kiln with wood.
			Kiln 2	Shut down kiln when charring is complete.
Thursday	08.00-10.00	Kiln 1		Finish loading kiln with wood.
	10.00-11.00	Kiln 1		Light kiln and reduce draught.
	11.00-13.00		Kiln 2	Unload charcoal from kiln.
		Kiln 1		Control charring.
	13.00-15.00		Kiln 2	Load kiln with wood.
		Kiln 1		Control charring.
	15.00-16.00		Kiln 2	Light kiln and reduce draught
	16.00-17.00	Kiln 1		Change and clean stacks
			Kiln 2	Control charring.
Friday	08.00-09.00	Kiln 1 and Kiln 2		Change and clean stacks.
	09.00-13.00	Kiln 1		Shut down kiln when charring is complete. Prepare wood for future operations.
			Kiln 2	Change and clean stacks at 12.30.
	13.00-17.00			Prepare wood for future operations.
			Kiln 2	Close down kiln when charring is complete.

8.11. The most common operational faults

(a) Failure to insert the inlet/outlet channels sufficiently under the lower rim of the bottom section of the kiln during assembly. The high temperature produced at the inner end of the air channel causes serious damage to the kiln wall if the required distance between the hot zone and the kiln wall is not maintained.

(b) Failure to achieve sufficient gas flow through the system by not removing deposits of tar from the outlet channels and chimneys. This results in low kiln temperatures and prolonged charring periods.

(c) Excessive periods allowed for cooling the kiln which reduces the number of operations possible in the working week.

(d) Reluctance to move the kiln closer to the available wood supply, resulting in a waste of time and effort in carrying the wood to the kiln.

(e) Insufficient supply of wood available in the area adjacent to the kiln for loading immediately the previous operation has been completed.

(f) The practice of allowing large fires to develop next to the surface of the wall of the kiln during the lighting stage. This usually restricts the flow of air under the kiln and prevents the fire spreading quickly to the centre of the charge. It can also cause serious damage to the kiln wall. Once the prepared kindling has been ignited inside the kiln, a maximum flow of air is all that is normally required.

(g) The laborious and time-consuming practice of hand picking the charcoal into sacks instead of using shovels and a sieve. Excessive time spent on unloading the kiln causes a delay in loading and lighting the next operation.

8.12. Yields of charcoal

The weight of charcoal produced in each batch operation of a transportable metal kiln is related to several physical factors. The main factors which contribute towards maximum yields are:

- high timber density
- low moisture content of wood
- dry operating conditions and a dry well-drained site for the kiln
- high packing density of charge obtained with regular size and shape of raw material.

In practice, it is seldom found that all of these conditions can be arranged and consequently the yields and conversion efficiencies reported vary to a considerable degree. (7, 10, 18, 31).

Training programmes by TPI in seven countries gave an average charcoal yield including fines, of 26% on a dry basis. The maximum weight of charcoal obtained from a single operation was observed in Guyana where 1 083 kg of charcoal was produced from 3 852 kg (dry weight) of regular sized billets of a high density hardwood. The moisture content of the wood used was approximately 25% (wet basis). This indicates a conversion efficiency (dry weight basis) of 28.12%. Higher conversion efficiencies have been obtained in the arid coastal region of Ecuador where a 31.40% recovery was observed.

Conversely, the lowest weight of charcoal obtained from a single operation was from soft wood slab wood waste in Sudan. 297 kg of charcoal was produced from an estimated 1 568 kg (dry weight) of timber. This indicates a conversion efficiency of 18.94%. The moisture content of the freshly sawn slab wood was approximately 57% (wet basis).

8.13. Working life of transportable metal kilns

The durability of kilns depends to a large extent on the care and expertise shown by the operators. If the kilns are not operated by the owners but by casual labourers, then the incentive to prevent operational damage is reduced. Untrained operators are also likely to reduce the working life of the kiln.

Experience so far has shown that these kilns can be expected to survive continual operation for a period of three years. After this time the bottom cylinder will usually need replacing or

substantial repairs. The top section and cover are not subjected to the same amount of heat stress as the bottom section. Provided care has been taken in transport and assembly a longer period of use should be expected. In West Africa, a TPI designed kiln in continuous operation after a period of two years showed only minor signs of distortion in the lower part of the bottom section. The top section and cover remained in first-class condition.

The components of the kiln which suffer most in use are the 8 inlet/outlet channels. The high temperatures experienced at the inner ends of the channel distort the metal in these localised areas. Channels have to be regularly reshaped and will almost certainly have to be replaced after a period of three years continuous use.

Chapter 9 - Transport, storage and distribution of charcoal

[9.1. Unit operations in transport of charcoal](#)

[9.2. Good practice in charcoal protection and storage](#)

[9.3. Transport of charcoal in the iron and steel industry](#)

[9.4. Distribution of charcoal](#)

The distribution phase, i.e. packaging, loading and transport of the charcoal from the kiln to the point of wholesale distribution or large scale industrial use, can represent up to 25% of the total production cost from the forest to the wholesaler. Where charcoal is produced close to a major market, the cost fraction due to distribution will be much lower. However, there are no longer many localities today where the wood resource is close to the final charcoal user and this step in the production chain is, therefore, significant and becoming more so as forest resources are used up. Moreover, transport requires scarce and costly liquid fuels.

The cost of transporting charcoal in terms of heat energy units is much lower than transporting fuelwood, because the calorific value of the charcoal is about twice that of dry fuelwood. Hence, charcoal can tolerate a relatively high transport cost and implies that charcoal should be produced wherever possible close to the wood supply and then transported to the market. These transport logistics are of primary importance in planning charcoal production systems.

9.1. Unit operations in transport of charcoal

The cost centres or unit operations in charcoal transport are as follows:

- Loading charcoal onto transport vehicle
- Primary transport
- Secondary transport, if used with unloading/loading costs
- Unloading and storage operations at major market point.

Important factors in charcoal transport are:

- Low bulk density requiring high volumes to be transported and handled.
- Fragility leading to production of "fines" at every stage of handling and transport
- Tendency of fresh charcoal to spontaneous heating and ignition through adsorption of oxygen from the air.

Experience shows that transport problems are less when there is only a single loading and unloading stage. This is achieved easily when trucks are used. Costs per ton/km are usually lowest when large unit loads are transported. Twenty ton loads using a truck and trailer both equipped with high sides are practical. In this case the charcoal is handled in bulk. Most fines are produced in loading/unloading operations. To reduce this problem transport of charcoal in a single operation from charcoal kiln to main distribution/storage point is recommended.

Bulk handling and transport is often not regarded by traditional producers as practical, so that bagging of charcoal is necessary. But where large quantities of charcoal are regularly transported between a production centre and the distribution point, bulk transport without bags should be developed in order to keep down packaging, transport and handling costs.

Charcoal easily absorbs water and, therefore, tarpaulins or other covers must be used during transport, to prevent wetting. There is always a risk that charcoal will be wet by rain during the few days it is "curing" at the side of the kiln. Cured charcoal should be transported as soon as practical to reduce this risk. Plastic sheet covers or a galvanized iron open sided storage shed can be used where large amounts must be accumulated prior to transport. Every effort should be made to avoid double handling at the kiln, leading to wasteful production of fines and unnecessary labour costs.

9.2. Good practice in charcoal protection and storage

Intermediate storage is necessary when large amounts of charcoal must await transportation because of irregular availability of transport, such as road or rail trucks or poor road conditions in remote areas. The following requirements should be observed when laying out an intermediate storage station.

It must be sufficiently large to accept the quantity of charcoal to be stored under abnormal conditions, e.g. during a prolonged rainy season, or a period of scarcity of railway transportation. The storage house should be divided into sections, of approximately 2 000 m³ each, separated by walls. It must be covered and must have sufficient facilities for easy and fast handling of the charcoal on its arrival and departure. Unloading into the storing house can be done from the outside through wooden or metallic chutes and loading of railway cars and trucks through manually operated wooden or metallic trapdoors. Trucks should not be allowed inside the storehouse because of fire hazards from internal combustion engines and smoking by truck drivers. Conveyor belts may also be used but mechanization should be minimized because it is expensive. The height of the heaped charcoal should be less than six metres to avoid spontaneous ignition. Incoming charcoal should be dropped as little as possible (two metres maximum) to reduce formation of fines. The charcoal should be unloaded onto a naturally formed slope of charcoal and handling should be reduced to a minimum as each movement produces some fines. The building must be well ventilated and open on all sides to give rapid and easy access in case of fire. It should have no intermediate columns across the roof span.

The building structure may be of brick, concrete or steel. The roof should preferably be galvanized sheet but asbestos may be used. The floor may be brick, stone, concrete or even rammed earth. Water pipes with hose connections should be available at different points but, in case of fire, the best method of saving the charcoal is to push the unburnt charcoal out of the building with tractors equipped with shovel blades.

9.3. Transport of charcoal in the iron and steel industry

[9.3.1. Truck transport](#)

[9.3.2. Transport by rail](#)

[9.3.3. Aerial rope or cableway transport](#)

[9.3.4. Mule packs](#)

[9.3.5. Water](#)

The transport of huge tonnages of charcoal from the points of carbonization to the side of the blast furnace has been highly developed in Brazil. The following description of methods followed may be useful for situations requiring transport of large quantities.

9.3.1. Truck transport

Approximately 70% of all charcoal produced in the State of Minas Gerais, Brazil, is transported by truck. This is a flexible and fast means of transportation, but expensive. Charcoal can be moved from the kilns to the iron and steel plants immediately after curing. With trucks little charcoal fines are produced as the number of handlings are few. Most of the small pig iron producing plants have no railway connection and must rely solely on truck transportation. Trucks are able to reach isolated kilns, located close to poor roads. A typical truck has the following characteristics: diesel engine powered 145 HP two axles for normal road driving and a third one for fast and safe highway driving to comply with State regulations of maximum axle loading. Carrying capacity 48 m³. Some transport companies use 60 m³ trailers but these are not able to operate on poor roads and have a tendency to overturn. Transportation distances vary from a few to 1 000 km.



Photo. 37. High side truck and trailer for charcoal transport. Note position of unloading doors in sides. Salta, Argentina, Photo. J. Bim

Many truckers prefer to carry the charcoal in burlap bags (about 25 kg bag or 11 bags/m³ of charcoal). This practice allows general purpose trucks to be used which, on the return journey, can carry other merchandise. Bagged charcoal is bulkier than loose charcoal which "settles" during transport with a volume loss of 2-5%.

Trucks loaded with burlap bags also have a greater tendency to overturn than when loaded with lump charcoal. The unloading of burlap bags must be done manually which is a disadvantage.



Photo. 38. Basket used to unload charcoal from brick kilns. Note high side charcoal transport truck. Minas Gerais, Brazil. Photo. J. Bim

Trucks carrying lump or loose charcoal must have their side height increased to about four metres with mesh type side sheeting to give a reasonable volume corresponding to the truck's weight capacity.

9.3.2. Transport by rail

All medium and large iron and steel plants in Brazil have rail connections and use rail transport to the maximum because it is much cheaper.

Some large companies transport about 40% of their charcoal by rail. One also uses a cable car system. Most railway cars have a capacity of 54 m³, a few 80 m³ and recently some 100 m³ cars have been ordered.

There are still some older cars in use with 20 to 30 m³ capacity; these have flat bottoms and wide discharging doors but must be unloaded manually. However, they may also be used for other merchandise as return freight. The newer and larger cars have sloped bottoms and self-discharging doors on both sides of the track, which permit a rapid discharge directly into coal bins or into the storage house. The rail cars are sometimes loaded at the railway siding directly from trucks but mostly from a reloading and storage depot, through hand operated gates or by conveyors.

One company has started transporting charcoal by rail over distances of 700 km in big, plastic, bagshaped containers of 3 m³ volume. The savings in transportation costs compared with truck transport are worthwhile.

The plastic containers also protect the charcoal against moisture. They are loaded by a mobile crane. The experiment may be extended to fill the containers at the charcoal kilns thus avoiding handling lump charcoal between the kilns and the railway sidings. Rail freight for charcoal is calculated on the basis of 300 kg/m³ of charcoal. All handling at the loading

and unloading stations is done by the iron and steel companies which also supply all the necessary equipment and bear all expenses. The cars, however, belong to the railway company, which is government owned.

9.3.3. Aerial rope or cableway transport

Since 1957 Belgo-Mineira has used an aerial cableway to move a certain proportion of the charcoal produced in one of the principal charcoal manufacturing centres in the Rio Doce region, which is east of their Monlevade iron and steel plant. The length of the cableway is 50 km; the charcoal at 40 t/hr is carried in steel boxes of 1.4 m³ which are suspended from the ropeway and move at 10 km/hr. Another cableway transports all charcoal from the works central storage place to the blast furnace bins, a distance of 1.2 km at 60 t/hr, in boxes of 1.5 m³, moving at 10 km/hr.

Cableway transport can be economic and efficient but it must be operated at near full capacity, as the investment is high and its operation must be continuous to be economical.

It is therefore necessary that the supply of charcoal at the loading station is continuous and the delivered charcoal volume close to the capacity of the cableway. These conditions are seldom encountered in charcoal manufacturing.

9.3.4. Mule packs

For short distances, up to 20 km, and for small quantities, transportation by mules or horses should not be overlooked. It has been used for many years in the State of Minas Gerais. Each mule carries two baskets of 60 kg each. Transportation speed is six km/hr. Loading and unloading are manual. Mules are now only used for intermediate transport of the charcoal to the trucks, when the kilns are located in remote places with difficult access.

9.3.5. Water

The iron and steel plant at Manaus, Siderama, located on the Amazon river uses barges for all its iron ore and charcoal transportation.

Water transport is very cheap and should be considered when conditions are suitable.

9.4. Distribution of charcoal

[9.4.1. Charcoal properties](#)

[9.4.2. Stockholding](#)

Charcoal usually reaches the ultimate domestic user by a complex route which is not the main concern of this manual. But a few remarks are relevant to distribution problems in general.

9.4.1. Charcoal properties

Charcoal is a product which is difficult to adulterate, does not deteriorate in storage and whose only fault is its friability - the fact that it breaks and powders during handling and transport. There is a variation in its quality due to variation in its fixed carbon content.

A soft burned charcoal has a high volatile matter and a low fixed carbon content, is corrosive to metals, paper and fibre and packaging material (but not bags of film or woven plastic) and it also tends to smoke during burning. It is fairly resistant to shattering and thus transports and handles without producing very many fines. Hard burned charcoal, on the other hand, is high in fixed carbon content, low in volatiles and is much more friable (an exception is charcoal carbonised at very high temperatures around 1000°C, which is almost pure carbon and can be quite strong. This type of charcoal is rarely seen on the market and is not normally produced for commercial purposes). Hard burned charcoal burns cleanly but may be difficult to ignite. The ideal compromise product when dry has a fixed carbon content of about 75%; a volatile content of about 20%; an ash of about 5% and a bulk density of around 250-300 kg/m³. It is moderately friable.

Water is the main adulterant found in charcoal. Good quality charcoal will normally have a moisture content of 5-10%. More than 10% is excessive and indicates rain wetting or adulteration to increase weight.

Purchasing charcoal by volume has much to recommend it. It renders invalid the addition of water and other materials as adulterants and discourages mixing in fines to increase weight or handling the charcoal carelessly, thus producing fines, since this would, at the same time, reduce the bulk volume. Therefore, agreement to buy charcoal on a volume basis is fair to both buyer and seller, providing there is a previously agreed method of measurement.

9.4.2. Stockholding

Charcoal, once it has been cured for two days, can be stored under cover indefinitely. This allows holding stocks to balance seasonal demand. A wholesale distributor's stock of about two months, annual sales held at the point of wholesale distribution would be good practice. Stocks should be built up before the start of the rainy season and allowed to run down towards the end. In this way retail prices can be stabilised providing the stocks are adequate to service most of the retail market system. Sometimes charcoal production workers who are idle during the rainy season can be employed on retail packaging during this period. Type of packaging depends on the type of retail market and the number of links between wholesaler and final user. The fewer the links, the greater the economy of distribution. Today, in most developing countries, demand is usually strong and, hence, the steps in the distribution system can be simplified, though normally at the inconvenience of the final user. However, in those areas where it is desired to increase sales of charcoal, one must remember that the number of retail points of sale are crucial and that a distribution system must be developed which recognises this. The price structure of retail charcoal sales must reflect adequately the cost of gaining the increased distribution of the product. Otherwise no worthwhile result will be achieved.

Chapter 10 - Using charcoal efficiently

[10.1. The quality of charcoal.](#)

[10.2. Burning charcoal efficiently](#)

Charcoal will go further if it is used efficiently and if its quality is optimum for the particular end use. Charcoal quality can be specified and measured in various ways which are usually derived from the various end use requirements. Efficiency in use normally means transferring the maximum amount of the heat content of the charcoal to the object to be heated, be it water for cooking, the air of a room, or the charge in a blast furnace. Efficiency depends on the use of properly designed charcoal burning equipment.

10.1. The quality of charcoal.

[10.1.1. Moisture content](#)

[10.1.2. Volatile matter other than water](#)

[10.1.3. Fixed carbon content](#)

[10.1.4. Ash content](#)

[10.1.5 Typical charcoal analyses](#)

[10.1.6. Physical properties](#)

[10.1.7. Adsorption capacity](#)

The least demanding market for charcoal, quality-wise, is the domestic one. The reasons are that performance cannot be measured easily, the power of consumers as individuals to specify and obtain good quality charcoal is minimal and there is a certain trade-off possible between price and quality which the household consumer uses to obtain satisfactory results. However, this does not mean that quality control is not worthwhile. Provided it does not become unwieldy and bureaucratically counterproductive, a system of quality guidelines for household charcoal is a worthwhile step in ensuring maximum yield from the wood resource, nevertheless giving adequate household performance. On the other hand, large users such as the charcoal iron industry know from their operating experience and research, the properties they seek in charcoal and have the means in the form of concentrated buying power and control over at least a part of their own charcoal production, to ensure that the charcoal they use conforms to their specification and produces pig iron at minimum overall cost.

Most of the specifications used to control charcoal quality have originated in the steel or chemical industry. When charcoal is exported, buyers tend to make use of these industrial quality specifications even though the main outlet of the imported charcoal may well be the domestic cooking or barbecue market. This factor should be borne in mind since industrial and domestic requirements are not always the same and an intelligent appraisal of actual market quality requirements may allow supply of suitable charcoal at a lower price or in greater quantities beneficial to both buyer and seller.

The quality of charcoal is defined by various properties and though all are interrelated to a certain extent, they are measured and appraised separately. These various quality factors are discussed below.

10.1.1. Moisture content

Charcoal fresh from an opened kiln contains very little moisture, usually less than 1%. Absorption of moisture from the humidity of the air itself is rapid and there is, with time, a gain of moisture which even without any rain wetting can bring the moisture content to about 5 to 10%, even in well-burned charcoal. When the charcoal is not properly burned or where pyroligneous acids and soluble tars have been washed back onto the charcoal by rain, as can happen in pit and mound burning, the hygroscopicity of the charcoal is increased and the natural or equilibrium moisture content of the charcoal can rise to 15% or even more.

Moisture is an adulterant which lowers the calorific or heating value of the charcoal. Where charcoal is sold by weight, keeping the moisture content high by wetting with water is often practised by dishonest dealers. The volume and appearance of charcoal is hardly changed by addition of water. For this reason bulk buyers of charcoal prefer to buy either by gross volume, e.g. in cubic metres, or to buy by weight and determine by laboratory test the moisture content and adjust the price to compensate. In small markets sale is often by the piece.

It is virtually impossible to prevent some accidental rain wetting of charcoal during transport to the market but good practice is to store charcoal under cover even if it has been bought on a volume basis, since the water it contains must be evaporated on burning and represents a direct loss of heating power. This occurs because the evaporated water passes off into the flue and is rarely condensed to give up the heat it contains on the object being heated in the stove.

Quality specifications for charcoal usually limit the moisture content to around 5-15% of the gross weight of the charcoal. Moisture content is determined by oven drying a weighed sample of the charcoal. It is expressed as a percentage of the initial wet weight.

There is evidence that charcoal with a high moisture content (10% or more) tends to shatter and produce fines when heated in the blast furnace, making it undesirable in the production of pig iron.

10.1.2. Volatile matter other than water

The volatile matter other than water in charcoal comprises all those liquid and tarry residues not fully driven off in the process of carbonization. If the carbonization is prolonged and at a high temperature, then the content of volatiles is low. When the carbonization temperature is low and time in the kiln is short, then the volatile matter content increases.

These effects are reflected in the yield of charcoal produced from a given weight of wood. At low temperatures (300°C) a charcoal yield of nearly 50% is possible. At carbonization temperatures of 500-600°C volatiles are lower and retort yields of 30% are typical. At very high temperatures (around 1000°C) the volatile content is almost zero and yields fall to near 25%. As stated earlier, charcoal can reabsorb tars and pyroligneous acids from rain wash in pit burning and similar processes. Thus the charcoal might be well burned but have a high volatile matter content due to this factor. This causes an additional variation in pit burned charcoal in wet climates. The resorbed acids make the charcoal corrosive and lead to rotting of jute bags - a problem during transport. Also it does not burn cleanly.

The volatile matter in charcoal can vary from a high of 40% or more down to 5% or less. It is measured by heating away from air, a weighed sample of dry charcoal at 900°C to constant weight. The weight loss is the volatile matter. Volatile matter is usually specified free of the moisture content, i.e. volatile matter - moisture or (V.M. - moisture).

High volatile charcoal is easy to ignite but may burn with a smoke flame. Low volatile charcoal is difficult to light and burns very cleanly. A good commercial charcoal can have a net volatile matter content - (moisture free) of about 30%. High volatile matter charcoal is less friable than ordinary hard burned low volatile charcoal and so produces less fines during transport and handling. It is also more hygroscopic and thus has a higher natural moisture content.

10.1.3. Fixed carbon content

The fixed carbon content of charcoal ranges from a low of about 50% to a high or around 95%. Thus charcoal consists mainly of carbon. The carbon content is usually estimated as a "difference"; that is to say, all the other constituents are deducted from 100 as percentages and the remainder is assumed to be the % of "pure" or "fixed" carbon. The fixed carbon content is the most important constituent in metallurgy since it is the fixed carbon which is responsible for reducing the iron oxides of the iron ore to produce metal. But the industrial user must strike a balance between the friable nature of high fixed carbon charcoal and the greater strength of charcoal with a lower fixed carbon and higher volatile matter content to obtain optimum blast furnace operation.

10.1.4. Ash content

Ash is determined by heating a weighed sample to red heat with access of air to burn away all combustible matter. This residue is the ash. It is mineral matter, such as clay, silica and calcium and magnesium oxides, etc., present in the original wood and picked up as contamination from the earth during processing.

The ash content of charcoal varies from about 0.5% to more than 5% depending on the species of wood, the amount of bark included with the wood in the kiln and the amount of earth and sand contamination. Good quality lump charcoal typically has ash content of about 3%. Fine charcoal may have a very high ash content but if material less than 4 mm is screened out the plus 4 mm residue may have an ash content of about 5-10%. Buyers naturally suspect fine charcoal and it is difficult to sell (and use, unfortunately).

10.1.5 Typical charcoal analyses

To illustrate the range of composition found in commercial charcoal Table 7 lists the composition of random samples of charcoal from various kinds of woods and various kinds of carbonization systems. In general, all woods and all systems of carbonization can produce charcoals falling within the commercial limits.

Table 8 records the variations in charcoal composition as found in the blast furnace charge at a large charcoal iron works at Minas Gerais in Brazil. All of this charcoal was made using beehive type brick kilns. The wood used was either mixed species from the natural forests of the region or eucalypt wood from plantations.

Table 7. Some Typical Charcoal Analyses

Wood species Production Method		Moisture content %	Ash %	Volatile matter - m.c./%	Fixed carbon %	Bulk density raw kg/m ³	Bulk density pulverised kg/m ³	Gross calorific value KJ/kg Oven dry basis	Remarks
Dakama	Earth pit	7.5	1.4	16.9	74.2	314	708	32410	Pulverised fuel for rotary kilns <u>1/</u>
Wallaba	Earth pit	6.9	1.3	14.7	77.1	261	563	35580	Pulverised fuel for rotary kilns <u>1/</u>
Kautaballi	Earth pit	6.6	3.0	24.8	65.6	290	596	29990	Pulverised fuel for rotary kilns <u>1/</u>
Mixed Tropical Hardwood	Earth pit	5.4	8.9	17.1	68.6				Low grade charcoal fines <u>1/</u>
Mixed Tropical Hardwood	Earth pit	5.4	1.2	23.6	69.8				Domestic charcoal <u>1/</u>
Wallaba	Earth mound	5.9	1.3	8.5	84.2				Well burned sample <u>1/</u>
Wallaba	Earth mound	5.8	0.7	46.0	47.6				Soft burned sample
Oak	Portable steel kiln	3.5	2.1	13.3	81.1			32500	<u>2/</u>
Coconut shells	Portable steel kiln	4.0	1.5	13.5	83.0			30140	<u>4/</u>
Eucalyptus Saligna	Retort	5.1	2.6	25.8	66.8				<u>3/</u>

1/= Guyana.

2/= U.K.

3/= Brazil.

4/= Fiji.

Table 8. Characteristics of Charcoal for Blast Furnaces in Brazil

Chemical and Physical Composition of Charcoal Dry Bass - by weight	Range		Yearly Average	Charcoal considered good to excellent
	Max.	Min.		
Carbon	80%	60%	70%	75-80%
Ash	10%	3%	5%	3-4%
Volatile matter	26%	15%	25%	20-25%
Bulk density - as received (kgs/m ³)	330	200	260	250-300
Bulk density - dry	270	180	235	230-270
Average Size (mm) - as received	60	10	35	20-50
Pines content - as received (-6.35 mm)	22%	10%	15%	10% max.
Moisture content - as received	25%	5%	10%	10% max.

The ranges and yearly averages refer to charcoal used by Belgo Mineira. This is a mixture of 40% eucalyptus charcoal produced in company operated kilns and 60% heterogenous natural wood charcoal manufactured by privately operated kilns. "Good to excellent" charcoal refers to that produced from eucalyptus wood in company kilns.

10.1.6. Physical properties

The properties described so far are referred to as chemical properties but physical properties, especially for industrial charcoal, are no less important. It is in the charcoal iron industry that physical properties have great importance. The charcoal is the most expensive raw material in the blast furnace charge. Charcoal's physical properties influence the output of the blast furnace whereas chemical properties are more related to the amount of charcoal needed per ton of iron and the composition of the finished iron or steel. (1).

Blast furnace charcoal must be strong in compression to withstand the crushing load of the blast furnace charge or "burden". This compression strength, always less than charcoal's rival, metallurgical coke made from coal, determines the practical height and hence efficiency and output of the blast furnace. The ability to resist fracturing when handled is important to maintain constant permeability of the furnace charge to the air blast which is vital in maintaining furnace productivity and uniformity of operations.

Various tests have been developed to measure fracture resistance; a rather difficult property to define in objective terms. These tests rely on measuring the resistance of the charcoal to shattering or breakdown by allowing a sample to fall from a height onto a solid steel floor or by rumbling a sample in a drum to determine size breakdown after a specified time. The result is expressed as the percentage passing and retained on various sized screens. Charcoal with poor shatter resistance will produce a larger percentage of fines when a sample is tested. Fine charcoal is undesirable in the blast furnace since it blocks the flow of air blast up the furnace. Fragile charcoal may also be crushed by the weight of the charge and cause blockages.

10.1.7. Adsorption capacity

Wood charcoal is an important raw material for activated charcoal. This product is beyond the scope of this manual but some data could be useful where charcoal producers are selling charcoal to be turned into activated charcoal by specialist factories.

As produced, normal wood charcoal is not a very active adsorption material for either liquids or vapours because its fine structure is blocked by tarry residues. To convert the charcoal to "activated" this structure must be opened up by removing the tarry residues. The most widely used method today consists in heating the pulverised raw charcoal in a furnace to low red heat in an atmosphere of superheated steam. The steam prevents the charcoal from burning away by excluding oxygen. Meanwhile the volatile tars can be distilled away and are carried off with the steam, leaving the pore structure open. The treated charcoal is run off into closed containers and allowed to cool. Activation furnaces are usually continuous, i.e. the powdered charcoal passes continuously cascade fashion through the hot furnace in the steam atmosphere.

After activation the charcoal is tested to quality specifications to determine its power to decolorise, by adsorption, watery solutions such as raw sugar juice, rum wine, and so on; oils such as vegetable oil and to adsorb solvents such as ethyl acetate in air. Adsorptive power tends to be specific. Grades are made for aqueous solutions, others for oils and others for vapours. The tests measure the adsorptive power. There are small differences in the finished product made from raw charcoals of different origin but generally all are useable if properly burned. A good basic charcoal for making activated charcoal can be made from the wood of Eucalyptus grandis in brick type kilns.

Charcoal for adsorption of gases and vapours is usually made from coconut shell charcoal. This charcoal has high adsorptive power and resists powdering in the adsorption equipment - a very important factor.

10.2. Burning charcoal efficiently

10.2.1. How charcoal burns

Given good quality charcoal it must still be burned efficiently to produce the best results. This is specially true in domestic use where most charcoal is burned. Industrial furnaces for burning charcoal such as blast furnaces, cupolas, sintering furnaces and so on, are usually efficiently designed and operated. They will not be discussed here. The main use of charcoal in the households of the developing world is to heat water either to cook food or provide hot water for washing, etc. Some food is cooked by direct heating without immersion in water, such as when corn or meat is roasted. A cooking system would be 100% efficient if all the heat released by burning the fuel were taken up by food being cooked. In practice, this is far from the case, A typical result for well designed and operated equipment is an efficiency of around 30%, that is 70% of the heat escapes uselessly. In a cold climate, some of this waste heat may be captured and used to heat up the air of the room, thereby performing a useful function which raises overall efficiency.

In theory, it is possible to increase the efficiency of transfer of heat from the burning charcoal to the food being cooked by increasing the cost and complication of the stove. This is rarely practical. Those who could afford such complication would usually not be found burning charcoal but some other fuel of higher social prestige or convenience. A compromise is necessary to achieve the best possible efficiency, consistent with reasonably simple, low cost stove equipment which can be used by the bulk of charcoal users. Charcoal, unlike fuelwood, transfers a good deal of its heat to the cooking vessel by radiation from the glowing fuel bed. Burning fuelwood, where the hot gases are produced by long lazy flames, must transfer a good deal of the heat to cooking vessels by convection. For heat transfer by

convection, the hot gas must actually contact the pot but radiant heat is transferred by infrared radiation emitted directly from the fuel bed and absorbed by the surface of the pot or other object. Thus the pot must be able to "see" the fuel bed to be able to collect and absorb the radiant heat energy. The surface of the pot plays an important part. It must be preferably dull black. The pot itself should be a good conductor of heat as well. Thin fire blackened aluminium is probably ideal. Thick low density earthenware is probably the worst. Fire blackened pots should not be polished outside, but surface layers of loose soot and soft tar should be removed.

10.2.1. How charcoal burns

Charcoal reacts with oxygen of the air at a glowing red heat to form colourless carbon monoxide gas, which then burns with a blue flame with more oxygen from the air to produce carbon dioxide gas. Due to the heat liberated by both of these reactions, the charcoal reaches a glowing red and radiates heat energy and the hot carbon dioxide gas leaves the combustion zone, hopefully giving up by convection most of its heat by direct physical contact with the cooking pot. The gas temperature falls as it transfers heat and it passes off into the room. Flues are not usually used with charcoal, since its combustion is relatively odourless and smoke-free compared to wood or coal. Unburned carbon monoxide gas can be given off by burning charcoal. It is very poisonous and ventilation of rooms where charcoal is burning is essential.

The fact that charcoal can be burned in a compact portable stove not requiring a flue, is one of its most important attributes and explains its widespread popularity, especially in cities and built up areas. Even though it is more efficient in overall energy terms for a country to endeavour to use actual wood burned efficiently for cooking rather than convert it first to charcoal, such a policy is difficult to implement. For most people at present who burn charcoal, changing to wood is difficult. A wood burning stove with a flue is costly. The stove itself may be of rammed earth and may cost nothing, but a metal flue may cost \$10 or more. For those living in cramped city housing, installing flues may be impossible and the pollution free features of charcoal fuel are compelling in these cases.

The important factors noted in efficient well designed, domestic, charcoal-burning units can be summarised as follows:

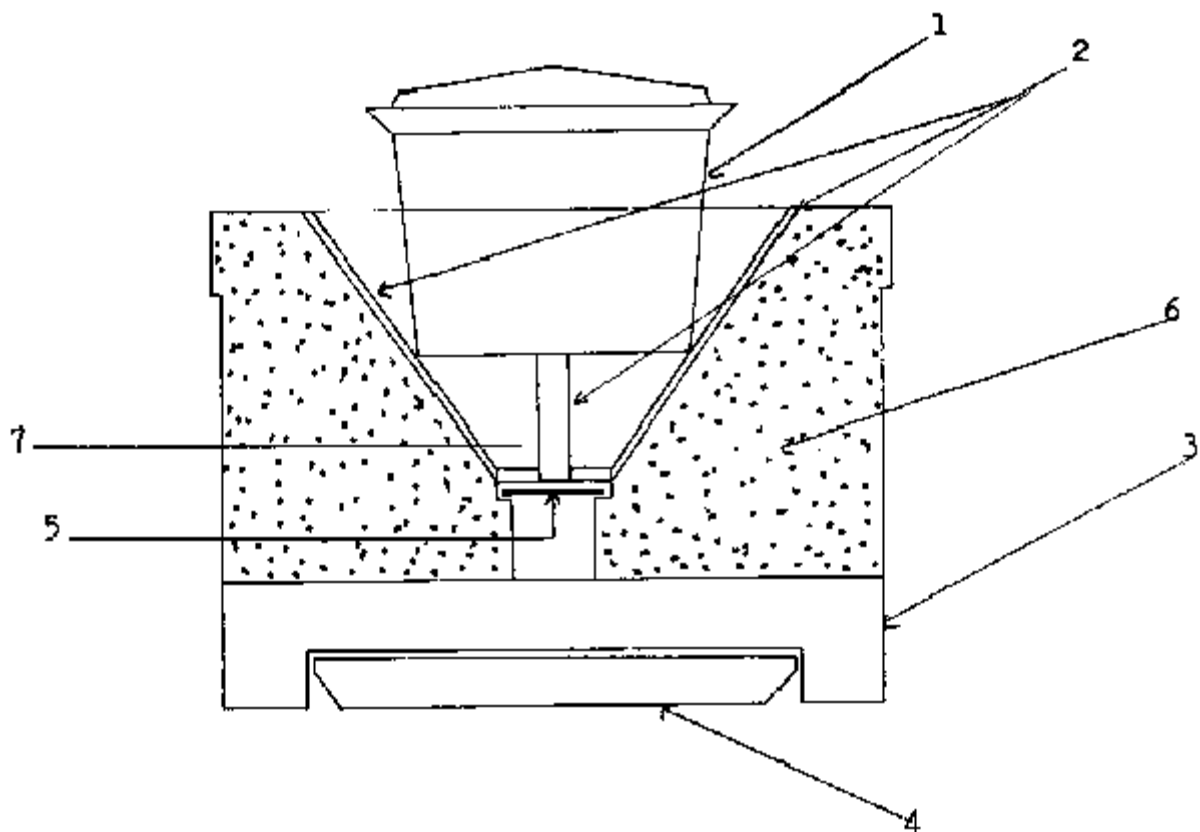
- (i) The charcoal fuel bed must "see" the pot it is heating and should be as close to it as possible. The walls of the fuel bed chamber should not "look" directly at the fuel bed. This implies a combustion space shaped somewhat like an inverted cone of 80-90° included angle with the fuel bed located at its vertex.
- (ii) The stove body should be made of refractory material, not metal, unaffected by temperatures around 1 000°C and should be a good thermal insulator, in order not to conduct heat away from the fuel bed. A good material is porous earthenware made from a white burning clay to reflect heat better onto the pot. The stove body should be replaceable in the support frame of the stove to reduce maintenance costs. A cheaper and more or less satisfactory stove body can be made by ramming a damp plastic mixture consisting of 60% clay, 20% sand and 20% charcoal fines approximately, into a wooden mould and allowing it to dry. Though not as permanent as burned earthenware, it is cheap.
- (iii) The conical fire hole of the stove should have about four flue gas channels in its surface, about 30 mm wide and 4 mm deep to permit the hot gas to pass out, even though the cooking pot may be a close fit in the cone.

(iv) The grate should be of steel sheet with 3 mm nail holes spaced approximately 1 per cm².

(v) The frame of the stove which can be made of recycled steel sheet should have legs giving a clearance of 4-5 cm between the bottom of the clay stove block and the floor. A recycled steel sheet tray is placed under to collect hot ash, so that the stove may be placed on any surface without creating a fire hazard.

The design shown in fig. 12 is only one of many. But all good designs adhere to the principles enumerated in this section. It is worth emphasizing that the objective is maximum efficiency at minimum cost, otherwise the equipment will not be used.

Fig. 12. Charcoal Cook Stove of Good Design



1. Round cookpot
2. Channels for flue gas in stove body
3. Recycled steel shell
4. Recycled steel ash tray
5. Recycled steel perforated grate
6. White-burning earthenware stove body or clay-sand-charcoal fines mixture
7. Burning charcoal

Chapter 11 - Briquetting of charcoal

- [11.1. Properties of charcoal fines](#)
 - [11.2. The techniques of briquetting](#)
 - [11.3. Economics of briquetting](#)
 - [11.4. Briquetting as a cottage industry](#)
 - [11.5. Using fine charcoal without briquetting](#)
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Transport and handling charcoal to point of use produces fines which may amount to about 10% by weight in the most favourable cases and 20% or more in the worst ones. The more the charcoal is handled and the more transport stages, the more fines are produced.

11.1. Properties of charcoal fines

Charcoal fines have a much lower purity than lump charcoal. The fines contain, in addition to charcoal, fragments, mineral sand and clay picked up from the earth and the surface of the fuelwood and its bark. The fine powdered charcoal produced from bark, twigs and leaves has a higher ash content than normal wood charcoal. Most of this undesired high ash material can be separated by screening the fines and rejecting undersize material passing, say, a 2 to 4 mm screen. This fine material may still contain more than 50% charcoal depending on the level of contamination but, nevertheless, it is difficult to find uses for it. Material retained on the screen will be mostly fragments of good charcoal and, after hammer-milling is suitable for briquetting. Fines cannot be burned by the usual simple charcoal burning methods and hence are more or less unsaleable. But if fines could be fully used, overall charcoal production would rise by 10 to 20%. Briquetting - turning fines into lumps of charcoal - seems an obvious answer. Unfortunately, experience has shown up to now that, though it is technically possible to briquette charcoal fines, the economics are not usually favourable, except where the price of lump charcoal is very high and the fines are available at a very low or zero cost.

11.2. The techniques of briquetting

Briquetting requires a binder to be mixed with the charcoal fines, a press to form the mixture into a cake or briquette which is then passed through a drying oven to cure or set it by drying out the water so that the briquette is strong enough to be used in the same burning apparatus as normal lump charcoal.

Charcoal is a material totally lacking plasticity and hence needs addition of a sticking or agglomerating material to enable a briquette to be formed. The binder should preferably be combustible, though a non-combustible binder effective at low concentrations can be suitable. Starch is preferred as a binder though it is usually expensive. Highly plastic clays are suitable providing not more than about 15% is used. Tar and pitch from coal distillation or from charcoal retorts have been used for special purpose briquettes but they must be carbonised again before use to form a properly bonded briquette. They are of good quality but costly to produce.

The press for briquetting must be well designed, strongly built and capable of agglomerating the mixture of charcoal and binder sufficiently for it to be handled through the curing or drying

process. The output of briquettes must justify the capital and running costs of the machine. Briquetting machines for charcoal are usually costly precision machines capable of a high output. Brick making presses have been used but there do not appear to be any commercially effective, really low cost machines for this purpose. Charcoal is quite abrasive so that equipment for screening fines, grinding, mixing them with binder, Briquetting and so on must be abrasive-resistant and well designed.

The binders which have been tried are many but, as stated, the most common effective binder is starch. About 4-8% of starch made into paste with hot water is adequate. First, the fines are dried and screened. Undersized fines are rejected and oversized hammermilled. This powder is blended with the starch paste and fed to the briquetting press. The briquettes are dried in a continuous oven at about 80°C. The starch sets through loss of water, binding the charcoal into a briquette which can be handled and burned like ordinary lump charcoal in domestic stoves and grates. Generally briquettes are not suitable for use as industrial charcoal in blast furnaces and foundry cupolas, since the bond disintegrates on slight heating. For this briquettes bonded with tar or pitch and subsequently carbonised in charcoal furnaces to produce a metallurgical charcoal briquette of adequate crushing strength are needed. The cost is too high for the process to find industrial application in most countries.

It is possible to add material to aid combustion of briquettes such as waxes, sodium nitrate, and so on, during manufacture to give a more acceptable product. Also clay as a binder, silica, and so on, can be mixed with the fines to reduce the cost of the briquette. This, of course, lowers the calorific value and is merely a form of adulteration for which the user pays, though claims may be made that burning is improved. But well made briquettes are an acceptable, convenient product. The virtual absence of fines and dust and their uniformity are attractive for barbecue purposes. Generally they sell at around the same cost per kg as lump charcoal in high price markets and have more or less the same calorific value as commercial charcoal of 10-15% moisture content.

Successful briquette operations are found mostly in developed countries. An example is the industry based on carbonization of sawdust and bark in the southern U.S.A. using rotary multiple hearth furnaces which produce perhaps 25 to 50 tons of fine charcoal per day. When briquetted, this charcoal, intended for barbecues, can be sold in retail outlets. The furnace gases are burned to produce steam or electric power, thus transforming the waste sawdust and bark into two useful products, electric power and charcoal briquettes. Air pollution and waste disposal problems are minimised at the same time.

11.3. Economics of briquetting

The cost of briquetting mainly depends on three factors. The cost of the fine charcoal delivered at the plant ready for processing, the cost of the binder and the incidence of capital costs. Fines which normally have little value, are usually reckoned to have zero cost to justify the briquette plant investment. However, this is not true because to supply the fines to the plant from sources, even close by, costs money. If the fines are not all derived from captive operations of the briquetting organization, it will be found that the price of purchased fines moves steadily upward as soon as the briquettes appear on the market. The binder of preference is starch which is a food material and costs about ten or more times the cost of raw lump charcoal at the side of the kiln. Hence, as a 4-8% addition to charcoal fines is needed to make the briquettes, it is a very significant cost item. Successful briquetting operations such as those operating in the U.S.A. and other developed countries depend on a favourable conjunction of factors which are usually absent in developing countries. They are:

- An established high priced household market for barbecue fuel.
- Ability to produce fine charcoal for briquettes at very low cost, close to major markets, and in steady volume through the year.
- A high volume of sales adequate to absorb the potential production of the plant.
- Adequate capital for good equipment and skilled labour for operations and maintenance.
- A proper marketing, packaging and distribution system to enable the product to achieve adequate market penetration at a rewarding price.

Generally speaking, and this is supported by the lack of successful briquetting operations in the developing world, it is better to concentrate attention on producing charcoal efficiently from fuelwood, striving for maximum conversion yield and minimum production of fines by careful handling of the product. Furthermore, such production using simple brick kilns requires a low level of imported components, whereas briquetting machinery is normally a costly imported item. Unless a briquette plant can be kept operating over the year at near full production, the capital charges become a drain on profitability.

11.4. Briquetting as a cottage industry

There is no doubt that unused charcoal fines are a waste of resources and alert management will always be seeking an economic outlet for them. Unfortunately, there is no simple, really satisfactory means of briquetting them on a small scale industry level. It is possible by primitive means to press charcoal fines mixed with starch paste or clay in a mould and dry them, each cakes of charcoal are made in a number of countries but success depends on providing charcoal fines at a very low price to households. Normally this is not possible since fine charcoal in quantities is mainly to be found near the production centres and not in the cities where unpaid household labour is available to produce the product. But despite the difficulty, opportunities of this type should be closely studied in the interests of overall national fuel economy.

11.5. Using fine charcoal without briquetting

Charcoal fines when available in large quantities do have industrial uses. Unfortunately, the customary lack of a developed industrial infrastructure where charcoal is usually made in the developing world precludes using charcoal fines this way. The main industrial uses of fine charcoal are as fuel in metallurgical and calcining operations. For example, in charcoal iron making fine charcoal can be injected at the base of the blast furnace with the air blast. About 5% of the total charcoal can be injected this way. The charcoal iron works in Wundowie, Australia, was able to use up all its fine charcoal this way. Fine charcoal is excellent for producing sinter, partially reduced iron ore, to provide a high grade feed to the blast furnace. This is one of the best ways to use charcoal fines as the amount which can be used is not limited to a percentage of the total as is the case of injection into the base of the blast furnace. (1, 22). Sintering with fine charcoal is used in Argentina and Brazil. Pulverised fine and lump charcoal can be burned in rotary furnaces producing cement clinker and calcium bauxite. Such cement plants operating in Kenya and Guyana are experimenting with pulverised charcoal for bauxite calcination.

Despite these possibilities, the fact remains that, for the typical charcoal producer, it is better to reduce fines production to the minimum by good charcoal making techniques, rather than

invest money in a marginally economic production of wood from plantations or natural forests and to use this wood to expand profitable production of charcoal.

Chapter 12 - Recovery of by-products from hardwood carbonization

[12.1. Proligneous acid](#)

[12.2. Small scale recovery of tars](#)

Recovery of chemicals from the vapours given off when hardwood is converted to charcoal was once a flourishing industry. However, as soon as petrochemicals appeared on the scene, wood as a source of methanol, acetic acid, speciality tars and preservatives became uneconomic. Wherever charcoal is made the possibility of recovering by-products is discussed. Present high costs of petroleum are advanced as an argument. Unfortunately the price of wood rises correspondingly removing most of the price advantage. Although the outlook for recovery of by-product chemicals from wood distillation does not appear promising, there are possibilities of recovering tars and using the wood gas as fuel to assist in making the carbonization process more efficient. The economics, however, appear to be rather marginal but, since recovery of by-products does reduce atmospheric pollution from wood carbonization, the combined benefit makes it worthwhile having a close look at the possibilities in this direction.

When wood is heated above 270° C it begins a process of decomposition called carbonization. If air is absent the final product, since there is no oxygen present to react with the wood, is charcoal. If air, which contains oxygen, is present, the wood will catch fire and burn when it reaches a temperature of about 400-500°C and the fuel product is wood ash.

If wood is heated away from air, first the moisture is driven off and until this is complete, the wood temperature remains at about 100-110°C. When the wood is dry its temperature rises and at about 270°C it begins to spontaneously decompose and, at the same time, heat is evolved. This is the well known endothermic reaction which takes place in charcoal burning. At this stage evolution of the by-products of wood carbonization starts. These substances are given off gradually as the temperature rises and at about 450°C the evolution is complete. The solid residue, charcoal, is mainly carbon (about 70%) and small amounts of tarry substances which can be driven off or decomposed completely only by raising the temperature to above about 600°C.

In the common practice of charcoal burning using internal heating of the charged wood by burning a part of it, all the by-product vapours and gas escapes into the atmosphere as smoke. The by-products can be recovered by passing the off-gases through a series of water to yield so-called pyroligneous acid and the non-condensable wood gas passes on through the condenser and may be burned to provide heat. The wood gas is only useable as fuel and consists typically of 17% methane; 2% hydrogen; 23% carbon monoxide; 38% carbon dioxide; 2% oxygen and 18% nitrogen. It has a gas calorific value of about 10.8 MJoules per m³ (290 BTU/cu.ft.) i.e. about one third the value of natural gas.

12.1. Proligneous acid

[12.1.1. The yield of pyroligneous acid](#)

[12.1.2. Refining pyroligneous acid](#)

Proligneous acid is the name of the crude condensate and consists mainly of water. It is a highly polluting noxious corrosive liquid which must be either worked up properly to produce by-products for sale, or burned with the help of other fuel such as wood or wood gas to dispose of it.

The non-water component consists of wood tars, both water soluble and insoluble, acetic acid, methanol, acetone and other complex chemicals in small amounts. If left to stand, the proligneous acid separates into two layers comprising the water insoluble tar and a watery layer containing the remaining chemicals. Recovery of the water insoluble tar, often called wood or Stockholm tar, is simple - it is merely decanted from the water phase. This wood tar has uses as a veterinary antiseptic, a preservative for wood, a caulking agent, and as a substitute for road tar. Generally the quantity available and its price and physical properties make it a poor substitute for tar derived from the oil and coal industry for use in road-making. It does, however, have limited markets as a speciality industrial chemical. If it cannot be sold it can be burned as liquid fuel. One ton of dry wood, however, only produces about 40 kg of tar, i.e. about a 4% yield.

The water layer contains water soluble tars which are complex tarry chemicals, acetic acid, methanol, acetone and methyl acetone and small amounts of more complex acids and other substances.

12.1.1. The yield of pyroligneous acid

The economics of by-product recovery depend on the yield of the more valuable components, especially the acetic acid, but also the mixture of methanol and acetone. Yield varies greatly with the kind of wood distilled. Wood with a high pentosan content such as European beech (*Fagus* spp.) gives a high yield of acid, eucalyptus wood gives low to intermediate yields. The yields from wood distillation quoted by various authors vary widely. Not only the kind of wood but the type of plant, its condensing efficiency, efficiency of the by-product refinery and so on all effect yields. Therefore it is of the utmost importance before investing in by-product recovery to be quite sure what sort of yields can be expected. For example, a plant in Europe working with beech and close to good markets for pure acetic acid may be economic. But a plant working with eucalyptus or mixed tropical hardwood far from markets for its products and obtaining only about half the yield of acid may be quite uneconomic. Therefore, proper full scale tests are necessary to find out what the yields are likely to be from the actual wood which will be carbonised. Careful market and plant design studies are essential. For guidance, the following yields can be taken as typical of northern hemisphere deciduous hardwoods:

Yield per ton (1 000 kg) of air dry wood

Acetic acid	50 kg
Methanol	16 kg
Acetone and methyl acetone	8 kg
Soluble tars	190 kg
Insoluble tars	50 kg

12.1.2. Refining pyroligneous acid

To recover saleable by-products from the pyroligneous acid a refinery somewhat similar to a small oil refinery but built of stainless steel or copper is required. The cost would nowadays be of the order of U.S.\$ 5-10 million but it is rather difficult to give a precise figure since such a refinery must be specially designed and built. They are not available as a stock item.

The whole process resembles quite closely in plant and technology to an oil refinery but on a very small scale. Unlike oil refining, however, which uses a feedstock which is theoretically 100% saleable, the refining of pyroligneous acid involves throwing away about 90-95% of the feedstock as contaminated, unsaleable water. The whole of the pyroligneous acid, less the insoluble tar, must be evaporated to separate the methanol and acetic acid from the soluble tars. Evaporation of water is costly as it requires a large fuel input. Furthermore, the acid products are very corrosive and the plant must be built from copper or preferably stainless steel, adding greatly to its cost. The products are sold in competition with products of the huge petrochemical industry and competition is therefore difficult. On the credit side, the quality of the acetic acid is high and it usually can be sold easily. But the distance from major markets reduces profitability. Although the continued operation of these existing wood distillation by-products recovery plants may be marginally profitably, the construction of new by-product recovery plants seems unlikely. The future will probably see some increased recovery of tar for sale and the use of the off gases and vapours from carbonization plants for heating of retorts and boilers. How to do this effectively without investment in costly plant, however, still remains largely an unsolved problem.

The crude condensed liquid is decanted to separate insoluble tar which is sold usually without further processing. The watery phase must now be processed to recover three saleable products: methanol acetone, acetic acid and soluble tar. The acetic acid is the most valuable. The liquor is distilled in a primary steam heated still to separate the methanol acetone and acetic acid from the soluble tars. The soluble tars remain in the bottom of the still and the vapours consisting mainly of methanol acetone, acetic acid and waste pass to a distillation column which separates crude 85% methanol containing acetone from the mixture of acetic acid and water. The crude methanol can be sold as a solvent.

The acetic acid is nowadays solvent extracted from the liquid phase using a solvent, usually ethyl acetate or ether. These solvents do not mix with water and dissolve or strip the acetic acid from the water phase, leaving only a trace of acetic acid in the water phase. After the recovery of any ethyl acetate or ether dissolved in the water phase, it is run to waste. It may still contain about 0.1% acetic acid. The ethyl acetate or ether solution of acetic acid (about 3%) must now be processed to recover the solvent for recycling and the acetic acid for sale. The solvent is distilled out in a fractionating column, the crude acetic acid (70%), freed of its solvent, is run from the base of the column and is purified by fractional distillation to 90% or more concentration, depending on market requirements. The solvent is recycled to extract more acetic acid from fresh feedstock. There is a small loss of solvent, which is topped up as needed.

12.2. Small scale recovery of tars

12.2.1. Collecting the tar

The recovery for sale of some of the tars produced in carbonization is possible on a small scale and is now being carried out by some producers of charcoal.

The insoluble tars are so called because they separate as a distinct black tarry phase when the vapours evolved from the retort or kiln are condensed. The other phase in the condensate is mainly waste containing acetic acid, methanol, acetone and the so-called soluble tars which are complex tar-like compounds, which will mix with water and do not separate as a distinct phase. The insoluble tar is the product known commercially as Stockholm or wood tar. These tars are chemically complex but do contain definite phenolic compounds, particularly guaiacol, which are useful antiseptics and preserving agents. Stockholm tar has uses in veterinary medicine, as a caulking agent in boat-building and as a wood preserving paint or mastic. Today in the developed world a variety of other substances are substituted for Stockholm tar. Nevertheless, in the developing world there can be markets for wood tar as a wood preserving paint and caulking compound. Some use as an antiseptic is also possible. Though this tar can be used as a road binder the small and sporadic amounts available and the low price and huge quantities of road tar produced by the pit industry make this outlet unattractive. The price of wood tar at the point of charcoal production should be somewhat higher than road tar. Tar can be burned as a fuel but it is generally more reasonable to use wood wherever possible and collecting tar merely to burn it is hardly worth the effort required. Wood tar is more valuable for other uses.

12.2.1. Collecting the tar

Tar can be condensed usually wherever the vapours from the kiln pass through a metal flue. The heat is lost to the air through the metal wall of the flue and tar condenses on the inside surface. The flue must be inclined or preferably vertical to allow the tar to drain into a receiver, otherwise the build up of tar on the walls of the flue acts as an insulator and condensation practically ceases. A little acid water may condense at the same time but this is easily separated from the collected tar.

It is not feasible to condense tar from brick flues since their conductivity is too low to permit the tar to condense in any significant amount.

Metal (steel) flues are required and this calls for metal working skills and availability of suitable steel. The two types of kiln most suited for tar collection are the portable metal type and the Casamance kiln, or any other type fitted with a steel chimney. In all cases the chimneys have to be modified to allow condensed tar to drain into a receiver of some kind. Other types of carboniser are not generally modified to collect tar, either because the smoke does not exit through a flue, e.g. the pit system, or because the cost and trouble of modification is too great to make recovery of tar worthwhile.

The amount of tar which can be collected in practice is not large. In practice about 25-35 kg of tar can be collected from each ton of air dry wood. It is difficult to set a value but about US\$ 0.50 per kg is a reasonable assumption.

Chapter 13 - Comparative performance of carbonization systems

[13.1. Performance indices of carbonising equipment](#)

[13.2. Influence of wood characteristics on carbonization methods](#)

Throughout the world wood is turned into charcoal by a surprising variety of systems. Choosing the optimum carbonization method is of interest to every potential charcoal producer. A close look reveals the reasons why so many ways of carbonising wood can coexist, different in detail, by relying on the same fundamental principle.

Most charcoal is made by small scale peasant type producers, either for their own local needs or for a restricted market. There is relatively little international trade in charcoal and hardly any competition between producers in one region with those in another. This fact tends to isolate charcoal producers in various countries and allows marked regional differences to continue.

The reason for carbonising the wood is a further factor. On the one hand, those who make charcoal for industry are interested in striving for maximum productivity and efficiency. At the other end of the scale are those who carbonise wood simply because they cannot subdivide the wood fuel in log form for use in domestic cooking by any other method. They have a totally different set of guidelines. The first group has access to capital and technology, the latter may not even possess an efficient axe or saw and must choose a method which requires the absolute minimum of capital investment. If this implies wasteful use of resources or human labour power, there seems no other alternative to them.

Tradition, the embodied wisdom of rural societies, plays an important part. To use the established method which is known to work successfully in a locality is the logical option for those who cannot afford to take risks because of their precarious economic situation. Where social factors are dominant, it is usually very difficult to introduce a new technology of charcoal-making unless the social factors are changed. Frequently one sees attempts to modify the technology of charcoal-making by providing aid: inputs such as chain saws, new kilns and so on. When these inputs are no longer available, economic necessity forces the producers to revert to the traditional, successful method with all its obvious technical faults. Therefore carbonising methods cannot be evaluated just on the basis of technical factors; social factors are of equal importance.

But good technology is important in the long run in improving social conditions. Therefore, if social factors permit, methods which give higher yields of better quality charcoal at lower cost should be used. These technical considerations are the concern of this chapter in comparing the different methods of converting wood to charcoal.

13.1. Performance indices of carbonising equipment

The various carbonising methods are classified (13). The method followed is based on reference 29 which gives a useful overall view of the range of methods available.

The first major difference is between systems which heat the wood by external means, using wood, oil, gas, etc., and systems which allow combustion on a limited scale to occur inside the carboniser by burning part of the wood charge and using this heat to dry and carbonise the remainder.

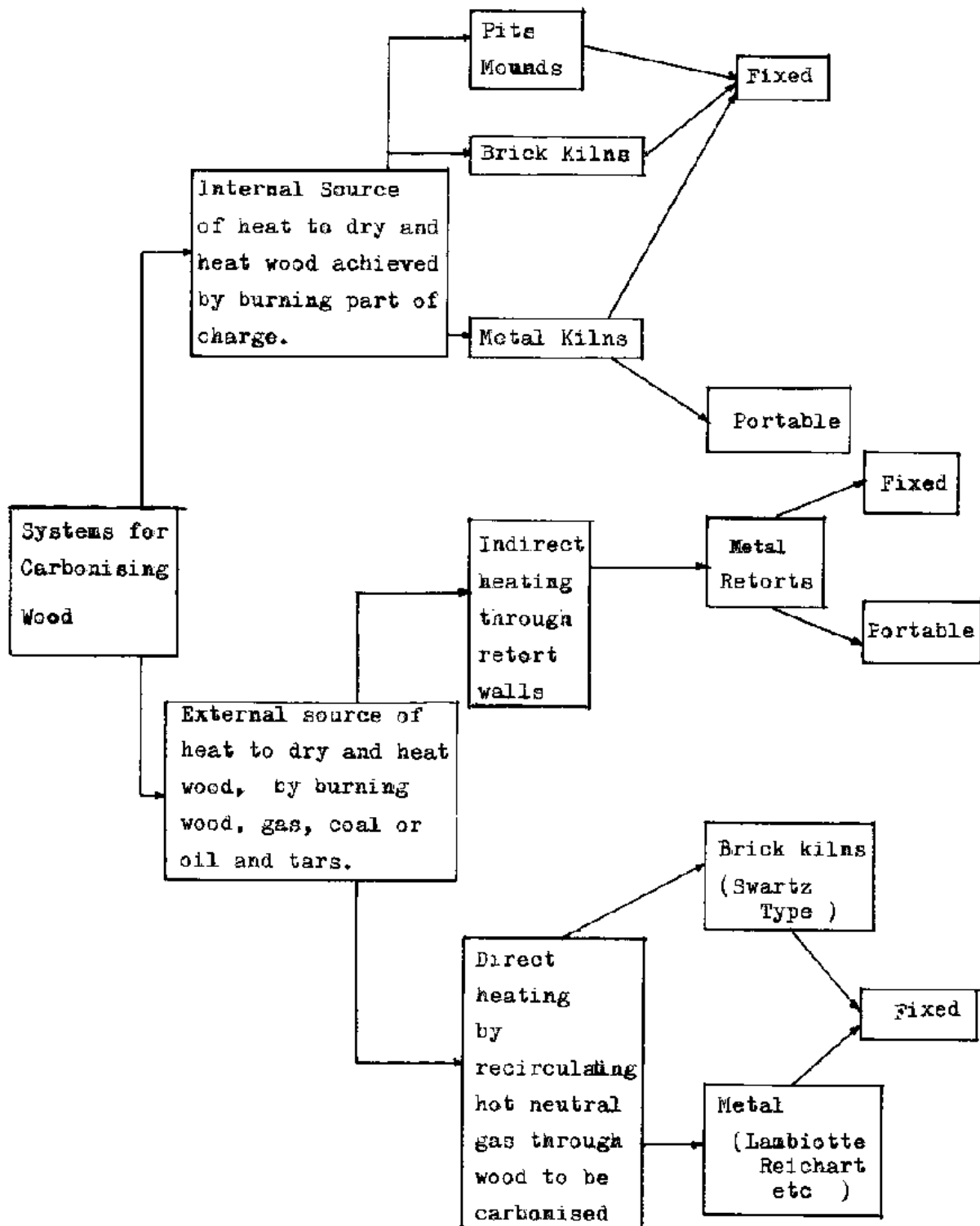


Fig. 13. Classification of carbonization systems

This method should be the most efficient since the heat is generated where it is needed, using low cost wood fuel. In practice, it is difficult to control the combustion and some extra wood is burned which lowers the yield.

Indirect (external) heating allows more precise control but to transmit the heat to the charge is difficult and inefficient and metal retorts are almost essential. By-products can be recovered free of contamination from the products of combustion. A hybrid method heats the charge of wood by passing hot gas through it. The hot gas is obtained by burning a fuel which can be wood, oil or gas. Precise control is needed to ensure that the hot gas is free of oxygen, otherwise some of the wood will be burned instead of being merely carbonised. Heat transfer from the hot gas to the wood is quite efficient and where the gases are recirculated under proper control, it is feasible to condense and collect by-products and the combustible wood gas.

Systems using internal generation of heat can be further divided by their method of construction. The three possibilities found are earth, which is lowest in cost, bricks or masonry of intermediate cost, and steel which is the most expensive. Steel kilns are further subdivided into portable and fixed types.

Steel kilns have two advantages: they can be moved easily, which may be very useful, and they cool quickly, allowing a shorter cycle time. However, portability is not always an efficient idea, since it makes it difficult to organise and supervise production efficiently and fixed brick kilns can be cooled quite rapidly using a slurry of clay and water (with care,) by injecting water spray into the kiln. Although cycle times are still around six to eight days, compared to two for steel kilns, the greater volume and much lower cost of brick kilns make them preferable except where portability is essential.

Earth kilns and pits even when operated efficiently, are slow burning and slow cooling and contaminate the charcoal with earth. However, where capital is limited or non-existent, they have real advantages.

Kilns heated by an external source of heat are subdivided into those heated by passing hot gases through the charge and those where heat is transferred through the walls of the retort. Most carbonisers in this subdivision are of metal but there is one exception, the Schwartz kiln, still commercially used, which is of brick and heats the charge by pressing hot flue gas from a bonfire burning wood built at the side of the kiln. Theoretically excellent since low quality wood and bark can be burned, in practice the kiln suffers in comparison to internally fired brick kilns by its high construction cost requiring steel and cast iron components, difficulty of precisely controlling the fire, and sealing the kiln for cooling, leading to air leaks and loss of charcoal.

Steel retorts heated through the walls are not used much today because of high cost and intrinsic low efficiency but some portable and semi-portable experimental retorts have appeared recently (14), e.g. the Constantine retort and the Jamaican oil drum retort. The steel retorts heated by circulating gases are efficient, produce charcoal of excellent quality and allow by-products to be recovered. However, their high capital cost makes them unattractive, except where the labour costs of traditional systems outweigh the high capital cost. These retorts are mainly applied today for making high grade charcoal for metallurgical and chemical use. Their use in the charcoal industry once seemed attractive but recent developments in making high purity iron without charcoal and changes in the world steel industry based on coal, make their use problematic until a lower capital cost version is developed. It seems unlikely that they can make any major contribution to the production of charcoal for domestic use in developing countries.

Having classified the various types of carboniser, they can then be compared, using various calculated indexes (29) such as production per unit of internal volume, unit area of space occupied, unit of capital invested, etc. These calculations are best carried out to compare types within a subdivision when the basic type of carboniser needed has been chosen on broad social and technological grounds. In practice, as far as the developing world is concerned, the choices are limited to deciding between pits, earth kilns, brick kilns and steel kilns, all internally heated. Where capital is the limiting resource, and wood is available, earth kilns are preferable. Where some capital is available and a serious effort is to be made to produce quality charcoal efficiently, brick kilns will probably be preferred. Steel kilns may find use where mobility is of such overriding importance that it overcomes high capital and repair costs.

13.2. Influence of wood characteristics on carbonization methods

[13.2.1. Species](#)

[13.2.2. Moisture content](#)

[13.2.3. Wood size](#)

The characteristics of the wood raw material have a significant effect on the choice and performance of carbonization equipment. The three important-factors are species, moisture content, and dimensions of the wood itself.

13.2.1. Species

Generally all species of wood can be carbonised to produce useable charcoal. There is a variation in the ash content of different woods but this is generally not significant. Bark, however, has an unacceptably high ash content and the structure of bark charcoal is too friable to be useful for most purposes. Therefore, where possible, bark should not be used or the amount of bark charged with the wood should be minimised.

Softwoods generally produce a softer, more friable charcoal than hardwoods but where available in quantity at a suitable price, they are a good raw material and can produce all types of charcoal.

Where a choice of wood supply is possible, such as where plantations are being established to provide wood, it is worthwhile to choose the species and manage its growth rate to optimise charcoal properties. Eucalypt species produce good dense charcoal and are the favoured plantation species for the purpose. Careful tests should be made before unproven, little known species are planted.

What counts in the long run is the mass of saleable charcoal produced per unit mass of wood substance. The volume of wood grown per hectare is only a rough indicator of the mass of wood substance produced. A high volume increment may correspond to low density and hence low yield of charcoal per unit volume of wood. Also denser wood usually produces a denser, less friable charcoal. Therefore research to determine what species and what management regime produces the maximum yield of wood substance by weight from plantations is worthwhile. This is an area of active research and definite answers are not yet available. But eucalypts are still the favoured genus.

13.2.2. Moisture content

Moisture in wood charged to the kiln has to be evaporated by burning extra wood and this lowers overall yield. Also the time to complete a carbonization cycle is extended, thus increasing costs. The volume of unseasoned wood is also higher than dry wood and the packing fraction of the kiln is thus marginally reduced when green wood is used. Wood will dry in the air without any heating cost. Air drying costs are mainly financial plus the wood loss due to fungal decay and insect attack. It is necessary to strike the optimum time balance in drying so that the maximum amount of moisture is lost in the early period when water loss is rapid. Financial costs are less and wood loss due to insect and fungi is still low. About three months of drying is roughly optimum but this varies with climate and kind of wood. Effective drying is difficult in the humid tropics.

13.2.3. Wood size

Carbonization rate is closely related to wood size. Large wood pieces carbonise slowly since the transfer of heat into the interior of the wood is a relatively slow process. Sawdust, for example, can be flash carbonised very rapidly but the powdered charcoal produced is of low market value. On the other hand, large diameter trunks of dense species may shatter when carbonised making the charcoal more friable than otherwise. Studies have shown that charcoal with optimum properties for the iron industry is produced with wood pieces measuring about 25-80 mm across the grain. Length along the grain has little influence. (26).

With plantation grown wood uniformity in wood size is possible but natural forests yield a wide range of sizes. Cutting and splitting of wood is costly in labour, fuel and capital and should be avoided wherever possible. For carbonising large diameter trunks and mixed size charges of wood the slow cycles are best. The pit system is optimum. Of the masonry kilns the slower cycle, larger kilns are best. They are a well proven method for carbonising large diameter (around 0.5 m) dense wood from natural forests. Trouble in carbonising can be reduced by placing the large diameter blocks in the centre of the charge. Metal kilns which lose much heat through the walls and cool quickly are ineffective in carbonising large section wood.

The cost of cutting up wood is a serious and growing one as fuel, labour and capital costs increase and this favours the use of earth pits, mounds and brick kilns. It is also usually easier and faster to charge kilns with large size wood, especially if its length conforms with the size of the kiln, pit or mound. It is worthwhile carefully studying the relation between growing, harvesting, drying and kiln charging to decide the optimum dimensions of the wood both in length and diameter, so that overall handling and carbonising costs are minimised and charcoal of optimum properties for the final end use is obtained.

Poor rural dwellers who cannot afford saws and axes often convert large diameter wood to charcoal so that it can be broken up for use in cooking fires. When the relative efficiency of wood to charcoal conversion and burning efficiency of wood and charcoal cooking fires are compared, the practice has much to commend it. Further charcoal is dry and can be stored indefinitely without deterioration. Calculation shows that carbonising large diameter wood and burning the charcoal is about twice as efficient thermally as burning the wood direct in an open cooking fire. Furthermore, without axes, saws and wedges, large diameter wood is unused and may rot before it can be burned.

Chapter 14 - Problems of economics and cost control in charcoal production

[14.1. Economic analysis and cost control](#)

[14.2. The methods of economic project analysis](#)

[14.3. Cost control in established enterprises](#)

Charcoal producers fall into two groups. The first are subsistence producers who only market charcoal to acquire cash needed to buy goods or pay taxes, etc. Economics and cost control are of little interest to this producer. He needs the cash and selling some of his charcoal is a way to acquire it.

The second group produce and sell charcoal as a business in which the circulation and growth of the capital they have invested in the business is their main concern. Economics and cost control are important for them.

Although the first group is personally not much concerned with economics, government authorities concerned with improving the charcoal industry must study the economics of subsistence charcoal production. An economic analysis must be the basis of any assistance programme to enable these producers to make more and better charcoal. In many countries subsistence produced charcoal is a major part of total charcoal production. Economic analysis is important to define the future of this sector of the industry, reveal its positive and negative features, and its long term viability.

14.1. Economic analysis and cost control

It is difficult to draw a sharp line to divide these two activities. Generally, economic analysis is of direct use in the planning phase of the development of the enterprise to project the cost of constructing and getting it into production. The objective is to demonstrate the economic feasibility of the proposal, then mobilise the investment funds required and lay down how they will be managed and repaid. Cost control, on the other hand, is concerned more with an enterprise which is up and running. It is the management tool which enables the enterprise to remain economically viable.

Production cost control is built around and forms part of the operations of a producing enterprise. It can be carried out with a background knowledge of accountancy or even just bookkeeping. The main requirement is to always use production data and statistics which are measured in the plant itself. On the other hand, economic analysis of projects requires a deeper knowledge of economics and a technical knowledge of the processes which will be used. A large project calls for a team of technicians, some more qualified in economics, others in technology and engineering.

14.2. The methods of economic project analysis

The process of economic analysis of projects is often called a feasibility study but, strictly speaking, this is only one step along the road to setting up a complete project. For large and medium size charcoal projects (3, 22) a team of professionals is required who must cover the fields of economics, forestry, building and civil engineering, technology of the process of

production, finance and marketing. The complete study for the charcoal industry has the following aims:

1. To provide that a market or end use of adequate size exists for the charcoal and any by-products and to quantify it in detail.
2. To prove that suitable and adequate wood raw material exists and can be harvested economically for the expected life of the plant or to prove that a suitable raw material resource can be economically generated by forest plantations.
3. To choose the production technology to be used and to design the entire production system from wood harvesting through to packaging and marketing of the finished charcoal.
4. To prepare complete financial projections showing the method of financing, detailed expenditure budgets for land plant, site preparation, infrastructure, construction, start-up and training costs. The financial projections must be carried forward approximately twenty years to a point where debts incurred in construction of the plant have been liquidated and the enterprise is functioning as an established business. For the manufacturing enterprise about twelve to fifteen years projection may be sufficient but, if the enterprise is to establish plantations for wood supply, then it is necessary to extend the financial projection till the plantation has gone through a complete rotation, involving replanting which could be twenty years or more. The financial projections will be in the form of a financial model showing profit and loss, sources and expenditure of funds, taxation and cash flow.
5. To prepare documentation for negotiations with government agencies on questions of forest resources, plant site, power and water supplies and other tax concessions, infrastructural needs, control of pollution, etc.
6. Prepare documentation and negotiate with financing agencies, both national and international, to secure financing for the project.

The list of requirements is formidable and costly and time-consuming to accomplish. Fortunately, more or less routine procedural sequences for accomplishing this work have been worked out by international finance authorities and the process is divided into a number of steps which are designed to test the feasibility of the project before committing funds for a complete technical and financial study. Normally the complete project study is preceded by, at least two steps, called a pre-feasibility and a feasibility study. If the results of these studies are positive, then it is worth committing funds for a full project planning exercise leading to the financing and construction of the enterprise.

The value of the complete study depends, in the long run, on the quality of the basic data on which the study rests. A study based on false premises is useless. Only experience in the field can indicate whether the data base is reasonable or not. As a guide to the effect of errors in basic assumptions, it is usual to test the complete financial model of the project, using varying values of key assumptions such as selling price of charcoal, percentage of fines, charcoal yield during carbonization, cost of wood delivered, growing and harvesting costs, growth rates of plantations, and so on. The degree of risk entailed by variations in principal cost factors then becomes clearer and enables key factors to be more closely scrutinised. Once the financial model has been prepared and programmed on a computer, such studies are relatively simple to carry out. Planning is relatively simple: the difficult task, especially nowadays with high interest costs, is to construct the plant and get it operating profitably within the available financial resources. If there are serious cost overruns or construction delays, a situation can easily arise where the project cannot be completed or

can never operate profitably. Hence the need to seek solutions in charcoal making which require minimum capital investment.

14.3. Cost control in established enterprises

[14.3.1. The unit operations](#)

[14.3.2. Unit costs and budgeting](#)

[14.3.3. Supervision and management overheads](#)

Procuring finance for and constructing a large new enterprise for making charcoal nowadays is a difficult and costly proposition. As stated earlier, capital and interest costs are so high that a few construction delays can transform a profitable project into a permanent loss maker. Therefore, more attention needs to be given to improving and developing established charcoal making operations by building on the intrinsic expertise and resources they possess, eliminating or reducing constraints which prevent them from functioning at maximum efficiency. It is usually easier and often more successful financially to expand an existing enterprise than to construct a completely new, large scale one and expect it to operate profitably without difficulties.

Established enterprises and traditional production systems are not all successful or soundly based. Nevertheless there always exists a structure of skill and experience within the system which can often be mobilised to work more effectively by proper cost control.

14.3.1. The unit operations

The first step in cost control is to set down the unit operations of charcoal making and decide on a system of cost centres, usually the same ones as the unit production operations. The following example is taken from operations in the Chaco forests of South America (3) where charcoal is made on a large scale by traditional but well organised methods. The unit operations are shown in figure 14. These unit operations can be used as cost centres and unit costs calculated for each one. As total production cost is the sum of each unit cost, providing they are expressed in a common unit of measurement, e.g. per ton of charcoal at the side of the kiln, the relative importance of each unit operation becomes clear. For example, the unit cost of harvesting wood and delivering it to roadside may be calculated as \$5 per stere. This cost must be expressed in dollars per ton of charcoal at side of kiln before its contribution to overall costs can be clearly seen. This cost depends on the yield of subsequent unit process steps. In general, the only significant one is the loss during carbonization. The cost of \$5 per stere must be multiplied by the number of steres needed to produce one ton of charcoal free of fines. A typical figure could be 7.3 steres of wood produce one ton of charcoal free of fines. The cost of the wood at side of the road per ton of charcoal is then $\$5 \times 7.3 = \36.50 per ton of finished saleable charcoal at side of kiln. This process must be applied to all unit costs to determine their overall effect on product cost. Technical knowledge of the process as well as cost accounting skill is needed for this and to decide whether efforts to reduce the effect of a particular unit operation on costs could be worthwhile; e.g. yield of wood per hectare could be raised, by gathering more small diameter branchwood. But if this wood mainly produces only fine charcoal in the kiln, the effort could be counterproductive. Tests would be necessary to clear this point. Hence the need to combine the efforts of the technician and the cost accountant to control costs.

14.3.2. Unit costs and budgeting

Cost targets have to be set up in the budget for cost control. It is easier for each sector if its budgeted costs are set in the unit of measure it uses at that point, e.g. stere of fuelwood, ton of charcoal, ton/kilometre of charcoal, and so on. These figures are combined by management using appropriate conversion indices to check on overall performance in terms of the budget for the whole enterprise. To measure performance for the whole enterprise it is necessary to carry out process inventories on a regular basis, about every one to three months. The physical stock of raw material, semi-finished and finished charcoal, when combined with the input of wood and shipments of charcoal over the inventory period, enable the overall results to be calculated. In addition, records must be kept in each department of the material used, output achieved, number of kiln cycles. Unusual events such as floods, prolonged rainy periods, very dry conditions, labour shortage, equipment breakdowns, and transport delays also need to be noted in the production records of each department. Means to weigh and measure are essential.

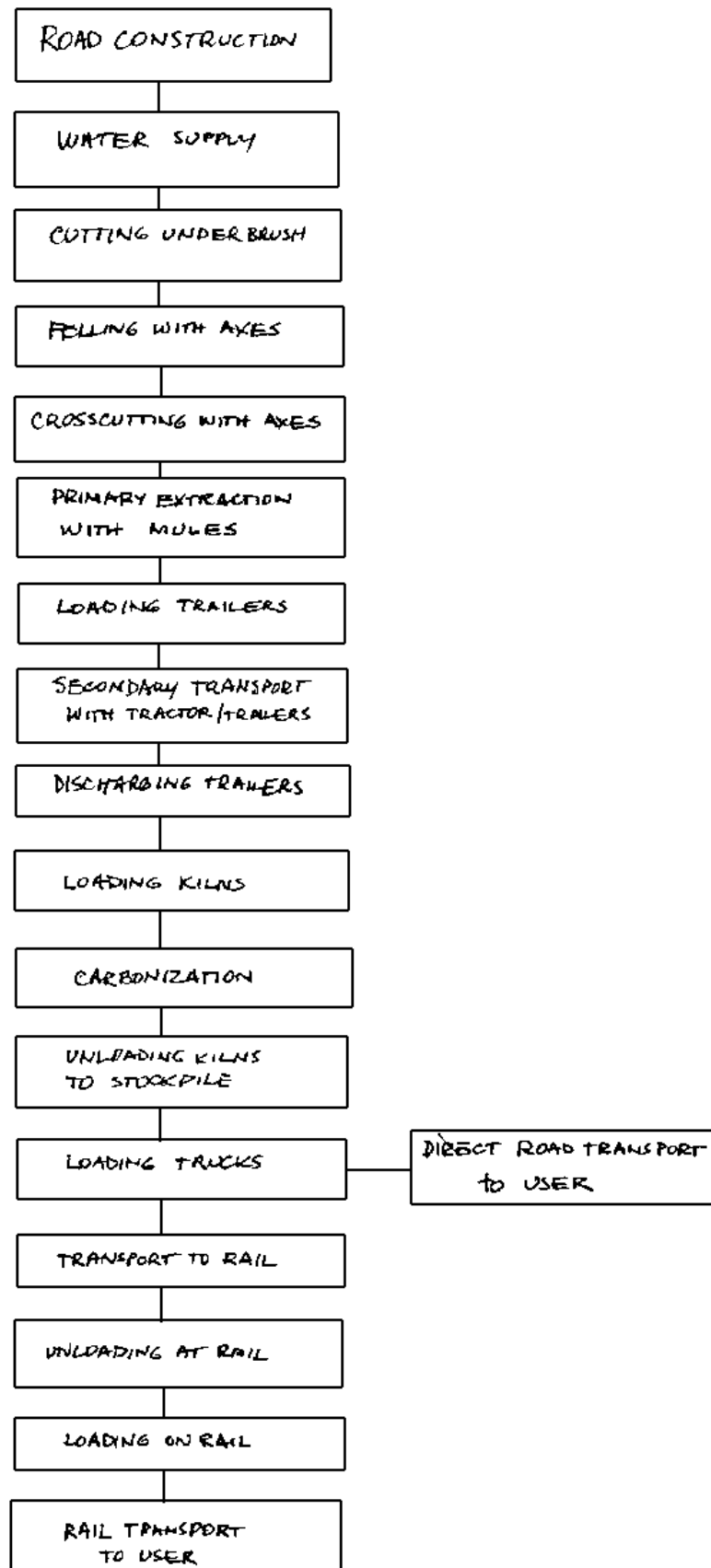
14.3.3. Supervision and management overheads

Every system of management control and cost budgeting requires staff and costs money. The effort achieved has to be worthwhile. Therefore the costs of management, again divided into sectors, must be calculated and the cost apportioned to the various sectors. Cost analysis for each unit operation may reveal whether some operations could be better carried out by subcontract. This normally requires less supervision and overhead costs. Transport is a particular case where contractors may well be cheaper than an internally organised system.

Collection and assessment of cost control data normally requires an extra technician who may also be responsible for quality control, etc. The processing of the raw data for management use is then usually carried out by the clerical staff of the office.

Calculated costs of actual unit operations are then compared by management with the budgeted costs set up at the start of the financial year. Action can be taken to reduce cost overruns where they occur and, at the same time, the financial situation of the enterprise is revealed on at least a month by month basis. The actual profit and loss result of the enterprise is not known down to the last cent by this process. The exact financial results come from the normal financial accounts which are kept parallel with the cost accounts. The financial accounts, however, give only a historical picture of results, which may be too late to enable corrective action to be taken.

Fig. 14. Unit operations in charcoal production



Appendix 1 - Building and Operating the Brazilian Beehive Kiln*

* Extract from FO DAP/ARC/70/536, Documento de Trabajo No. 15, "Leña, Carbón y Carbonización" por Laércio Osse, Salta, Argentina, 1974.

[1. Building](#)

[2. Operation](#)

[Discharging of the kiln must start only when it is sufficiently cool.](#)

1. Building

Surface furnaces (kilns) are rarely constructed single. They are most commonly constructed in groups or batteries including various units.

The site of construction is chosen after careful study covering many aspects, principally the availability of wood fuel at a convenient distance; access, with particular account being taken of entry of fuelwood and exists for the charcoal; water supply for the furnaces and the personnel; the vicinity of villages or houses or the possibility of constructing them; the nature of the terrain (preferably flat) and the quality of the earth (preferably impermeable and firm).

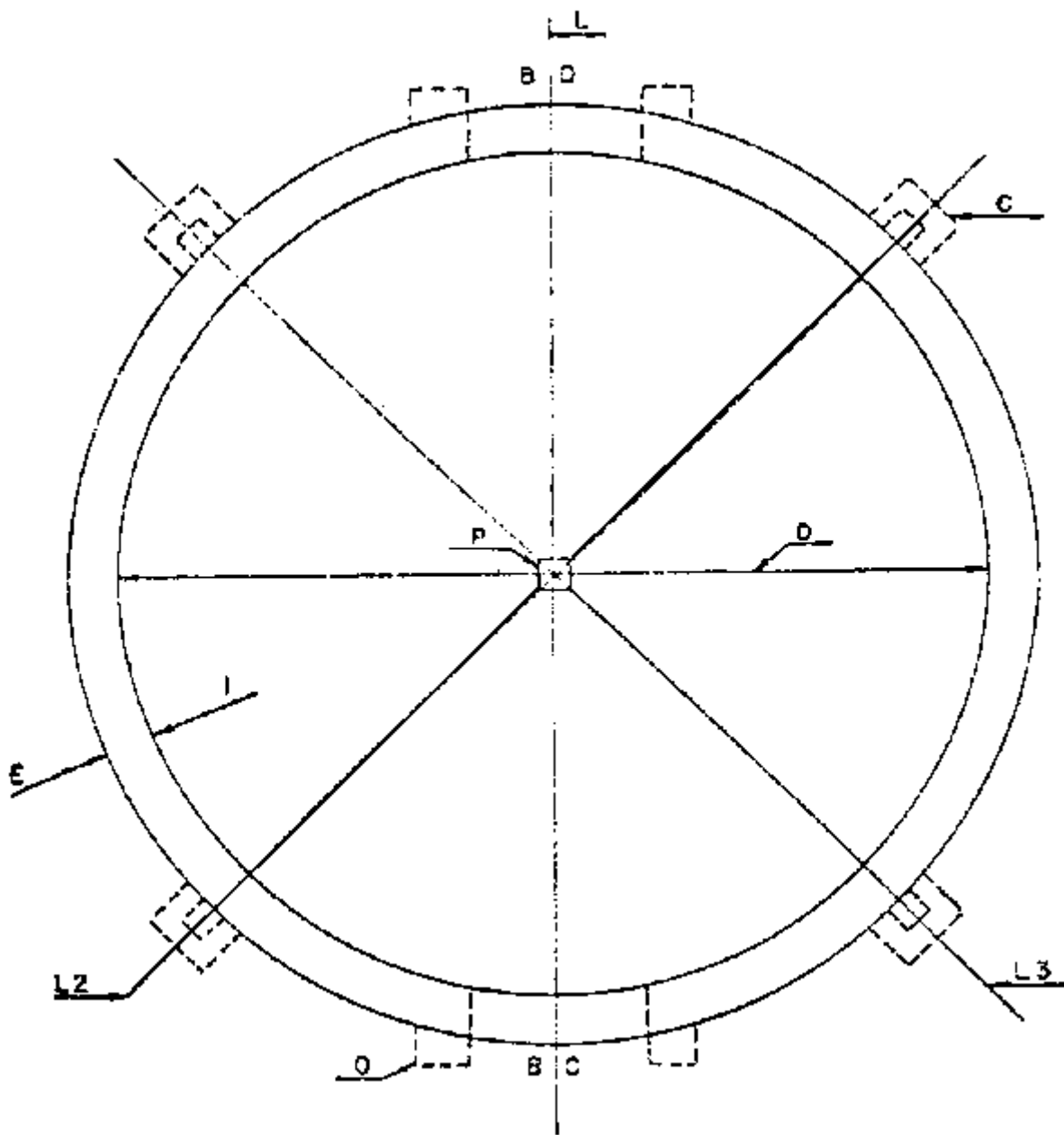
When the site has been chosen construction follows the routine: (see Figs. 15, 16).

- 1) Clean and carefully level the spot where each kiln will be constructed.
- 2) Mark the centre of the kiln and, at this point, drive in a round stake P.
- 3) Mark the line L bearing in mind loading and unloading doors of the kiln will be marked above it. For this reason line L must be oriented with that of the loading and unloading entrances (BC and BD).
- 4) Mark line D perpendicularly (at a right angle) to line L.
- 5) Having as centre the stake P, draw circles I and E; the length of the line D will be equal to the diameter of the kilns; the internal circle I will be drawn exactly at this diameter; the external circle E will be traced with this diameter, plus 40 cm.
- 6) Taking half the distance between lines L and D in the four marked quadrants, trace lines L2 and L3.
- 7) Where line L cuts the circles mark the openings for charging BC and discharging BD, each with a width of 1 m, and, at the same time, mark the shoulders of each. Where lines L2 and L3 cut the circles, mark the chimneys C.
- 8) Thickness of the wall: 1 brick. Door columns reinforced with one additional brick. Walls of the chimney: half a brick. Cross section of the chimneys: space equivalent to half a brick.
- 9) The plan of the kiln is now visible on the surface of the ground.

- 10) Dig out the foundation trenches in accordance with the plan. Normally a depth of 20-30 cm is sufficient.
- 11) Make the footings, not forgetting the door openings (BC and BD). The footings should be one brick wider than the body of the kiln. The surface of the footings must be perfectly level.
- 12) Attach a wooden pole to the centre post P by nailing a loop at a convenient height. (The nail will prevent the loop from falling). This pole will serve as a guide for building the kiln wall. The cord can be moved around the centre post P like a large compass.
- 13) Start building the wall leaving openings for doorways and making the door columns and chimneys; more than one cord can be used so that two or more brick layers can work at the same time; use mortar made from one part of soft clay (sandy soil is not suitable) and one part of pulverised charcoal, plus sufficient water to give the correct consistency; test the wall frequently with a plumbline and level.
- 14) When ground level is reached, leave three equally spaced openings between each pair of chimneys T. These openings are called "tatus" and have a cross section equal to that of one brick.
- 15) When the wall is at a quarter of its height (approximately 45 cm above the footing) leave two openings between each pair of chimneys in line with the two outer "tatus" S, and when the wall reaches three-quarters of its total height (around 1.35 m above the base) leave another two openings between each pair of chimneys in vertical alignment with the outer tatus; these openings are the safety openings and have a cross section of 7 x 7 cm.
- 16) When the wall reaches 1.6 to 1.7 m height, place across the door columns, in line with the walls, a steel plate or pieces of bamboo and continue the laying of the bricks of the walls over these. The openings for the doorways 1 m wide and 1.6 to 1.7 m high are now completed.
- 17) When the wall reaches a height of 1.80 m it is complete and must be perfectly plumb and its top surface perfectly levelled.
- 18) On top of the wall lay a row of bricks on their edge (E Fig. 16); use very little mortar between these bricks; around the outside of this ring of bricks place a steel ring or several rounds of fencing wire with or without barbs and adjust it without tightening too much. (Final adjustment is made after the dome is complete CI)
- 19) Cut bricks to form the base of the dome and set them inside the ring of bricks facing each other.
- 20) Remove the guide post used for the construction of the wall and substitute it by a small peg, to the top of which is attached a cord which is used to guide the construction of the dome of the kiln.
- 21) The dome is constructed with the thickness of half a brick and it is extremely important that a minimum of mortar is placed between the bricks. The bricks are laid and kept in position more by lateral pressure than by mortar.
- 22) At a quarter of the distance from the base of the dome to the top leave 10 small equidistant openings (B Fig. 15); half way up the dome leave another 10 openings and three-quarters of the distance from the base leave six more openings also equidistant. These

apertures are called "bainas" and they have a cross section of 7 x 7 cm. At the top of the dome leave an opening 20 x 20 cm for the lighting hole (A Fig. 15).

23) The flue of the chimneys must start from the inside of the kiln at an angle of 45° and then ascend vertically (Fig. 16). A chimney starting from the inside of the kiln at a right angle with the vertical portion does not function well and is more difficult to clean.



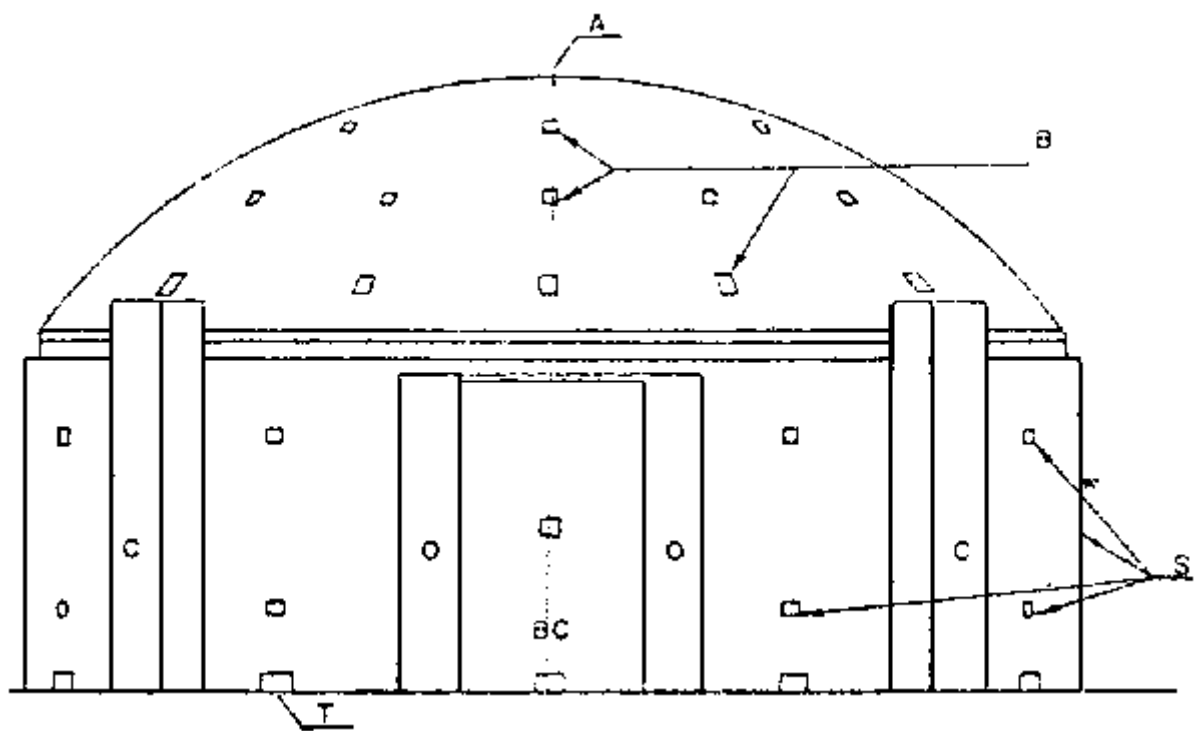


Fig. 15

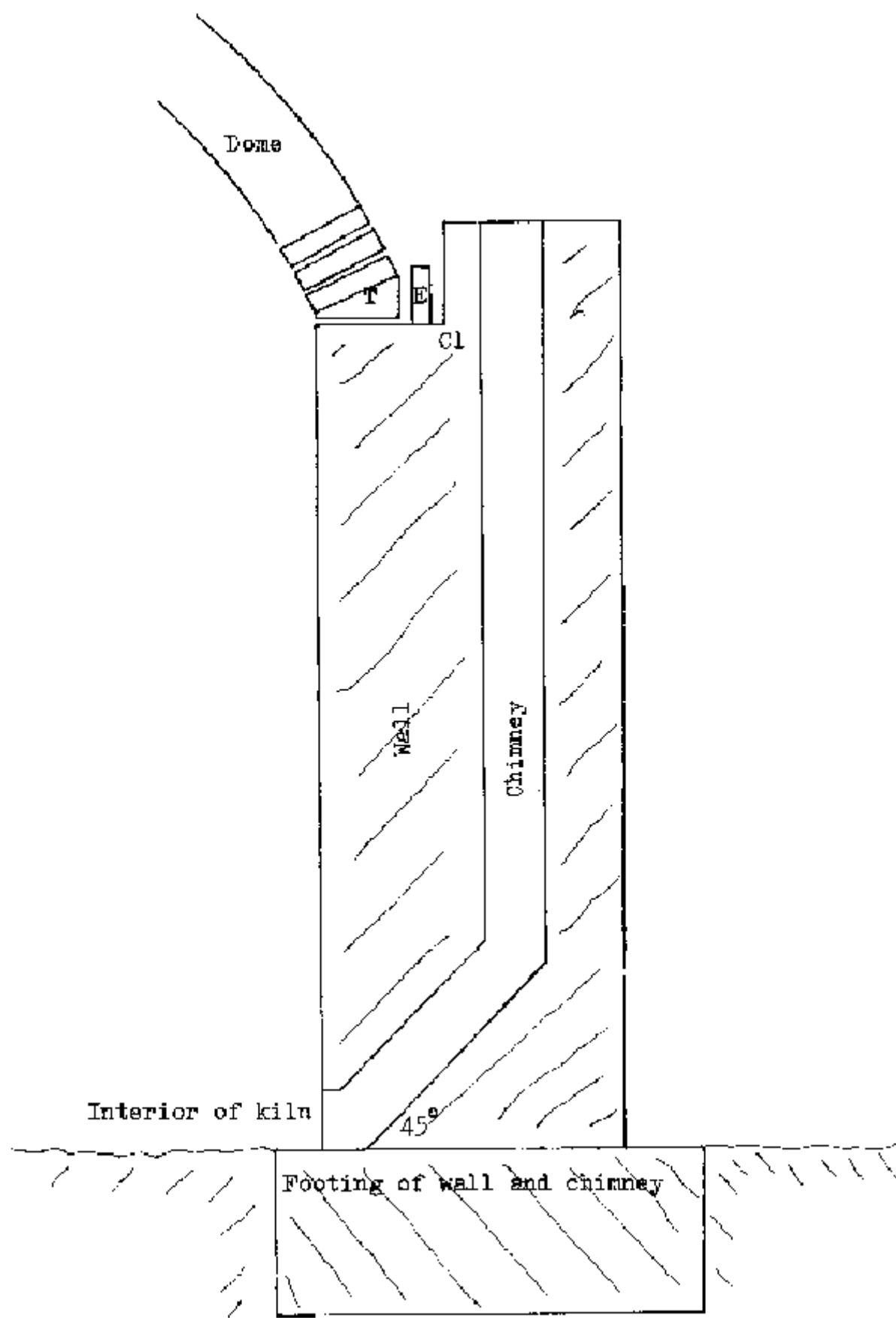


Fig. 16

When the brick work of the kiln is finished, the walls can be rendered and the dome covered with mud, or as is more usual, both the walls and the dome are plastered with mud.

The plaster is a fluid mud prepared as follows: clay soil is mixed in plenty of water to the consistency of thick soup which is left until the sandy portions of the earth sink to the bottom of the mixing vessel. The mud free of sand is poured over the surface of the kiln and closes perfectly all cracks left during construction, especially in the dome where the quantity of mortar used is minimum.

The rendering or mud treatment carried out after the kiln is finished and before the first burning is invariably repeated during each cooling cycle. It prevents entry of air and fires. It also helps considerably in cooling the kiln.

2. Operation

The charging of the kiln must follow a routine which is, in general, as follows:

- 1) Close the discharge doorway using only mud to join the bricks together; do not use mortar which makes opening up difficult and results in almost total loss of the bricks.
- 2) Stack the long fuelwood on its end carefully distributing first smaller fuelwood around the walls of the kiln and then towards the centre fuelwood or increasing thickness. The wood should preferably have its ends cut at an angle to facilitate circulation of the gases. It is particularly important that the tops of the thicker wood are cut at an angle.
- 3) Carefully fill all the spaces between the lengths to eliminate open spaces, holes and any fault in the way the wood is piled. This operation is called refilling or smoothing. The piling of the fuelwood and its filling is called stacking.
- 4) Do not mix fine fuelwood with thick fuelwood. Carefully follow the recommendations of point 2: fine wood around the outside near the walls and, progressively thicker wood towards the centre, the thickest trunks occupying the centre or core of the pile.
- 5) On top of fuelwood stacked on its end, fuelwood should be stacked on its side in a horizontal position under the dome of the kiln, again starting with fine wood near the walls and thick wood towards the centre. Fill up all open spaces carefully.
- 6) Near the lighting hole at the top of the dome stack wood which is easy to ignite to facilitate the start of carbonization.
- 7) Close the charging doorway of the kiln using only ordinary mud to set the bricks, as was done for the discharge door. When the kiln is charged, that is to say full of wood with all the apertures open ("bainas"), safety openings, "tatus" and lighting holes carbonization is started. This operation is called cooking the wood fuel and its phases are briefly as follows:
 - i) Light the kiln by adding a good shovel full of burning coal through the lighting hole to ignite the fuelwood, which should take fire immediately. Burning coals may be substituted by gasoline, kerosene, diesel, oil, etc.
 - ii) Do not use any other opening to light the kiln, except the lighting hole at the top.

- iii) When combustion is started, smoke comes out through the lighting hole; first white in colour and getting darker a few minutes later. Then, when the smoke has taken on a dark colour - a signal that the fire has "taken" close the lighting hole with brick and mud.
- iv) When the lighting hole is closed, the smoke will start to come out from the "bainas" (openings in the dome) initially white, then turning blue after some time. When blue smoke comes out, it is a sign that the carbonization zone is expanding and one must start to close "bainas".
- v) When the "bainas" are closed, the chimney starts to function (which also can happen before all the "bainas" are closed) and when the four chimneys are functioning normally, close all the safety openings; leave open only the "tatus".
- vi) The kiln will continue to operate in this manner until the end of the process.
- vii) The charcoal burner takes note of the colour of the smoke; when the smoke is white, grey-white, or somewhat dirty, it signifies that the process is developing; when the smoke from the chimney commences to turn blue or blueish, one must close the "tatus" on each side of the chimneys.
- viii) The smoke does not turn blueish in all the chimneys simultaneously. Thus it is necessary to close the "tatus" in turn as the smoke takes on a blueish colour.
- ix) The chimneys may continue giving off smoke for many hours after the closing of the "tatus". In this case closing the chimneys must not be allowed as it would result in the production of great quantities of brands (semi-carbonised material) near the chimneys.
- x) The chimneys must be closed only when they stop giving off smoke.
- xi) When all the openings and the chimneys are closed and emission of smoke has completely stopped, carbonization is finished; the kiln may be covered with mud slurry and allowed to cool. Any parts of the mud coating which fall off must be immediately and carefully re-applied as any entry of air will provoke fire in the charcoal.
- xii) The cooling of the kiln may be accelerated by means of a water spray across the lighting hole.
- xiii) Wind may interfere with the functioning of the kilns. To protect against wind, openings oriented in the direction of the wind should be partially or, in some cases, totally closed. The chimneys also need protection to deflect the wind away from their tops as it interferes with the discharge of smoke and consequently carbonization.

Discharging of the kiln must start only when it is sufficiently cool.

Theoretically, the ideal temperature at which to open the kiln and start discharging is 60°C (140°F); in practice, the charcoal burner estimates the temperature, feeling the bricks blocking the loading and unloading openings.

A kiln which is not sufficiently cool must never be opened: if this rule is not followed, a fire in the charcoal will certainly start up. If put out immediately with water the result is powdered charcoal - waste.

Before opening the kiln an indispensable element of precaution is to have plenty of water near the discharging door for use in case of emergency, for example, a hose connected to a water pipe, a drum of water, etc.

The spot where the charcoal is going to be stored must be cleaned immediately.

The discharge doorway should be opened quickly. The charcoal burner checks by the smell of the gases given off if there is a fire in the charcoal and, if there is he quickly opens the door so that the fire can be extinguished with water.

Once the discharge door is completely opened and the bricks are carefully stacked to one side the charcoal is taken out of the kiln and stacked. During discharge good charcoal should be separated from all impurities such as stone, bricks utilized as wedges during loading, brands, ashes, etc. The remaining charcoal is marketable. Charcoal unloaded from the kiln absorbs air and, as a result, heats up which may provoke spontaneous combustion. It is, therefore, necessary to leave the charcoal in the open air for at least 24 hours so that it absorbs all the air it can before transfer to silos and stores.

The surface furnace (kiln), as any other installation or plant, needs maintenance to ensure its efficiency.

1. When the coating of mud becomes thick due to many applications, the kiln must be cleaned off and given a fresh coat of mud. A mud coating which is thick increases the cooling time and reduces productivity of the kiln.

2, Although fairly solid and stable the kiln can be damaged on impact and it must therefore be protected.

3. Bricks frequently become loose and must be replaced immediately.

4. The safety openings and the "bainas" should be closed with bricks cut in the form of wedges and sealed with mud; mortar or thick clay should never be used for this purpose as the plugs must blow out easily when the kiln "puffs". The kiln could explode or collapse if it cannot puff freely.

5. When the kiln is charged with small size and very dry wood and the chimneys start to operate, an increase in pressure of the gases in the kiln is common. Their escape channels are the safety openings which are progressively closed as carbonization proceeds. When expulsion of gases occurs the kiln puffs or breathes and, if no way free for exit of gas is allowed, it can provoke an explosion and destroy the kiln.

Appendix 2 - Building a T.P.I. Steel Kiln*

* A detailed description of the kiln's construction is given in Rural Technology Guide No. 13 available from the Tropical Products Institute. (34)

[1. Description](#)

[2. Manufacture](#)

1. Description

The kiln consists of two interlocking cylindrical sections (1, 2) and a conical cover (3). The cover has four equally spaced steam release ports (4) which may be closed off with plugs (5) as required. The kiln is supported on eight air inlet/outlet channels (6) arranged radially round the base. During charring, four smoke stacks (7) are fitted on to alternate air channels.



[Fig. 17. The T.P.I. Steel Kiln](#)

2. Manufacture

You will need the following tools and equipment.

- 1) Sheet metal bending rolls able to take sheet at least 900 mm wide and 3 mm thick.
- 2) Angle bending rolls for bending the reinforcing angles (a skilled blacksmith should be able to make these if rolls are not available).

- 3) Oxy-acetylene welding/cutting equipment.
- 4) Engineer's large vice.
- 5) Hand tools, e.g. hacksaw, files, hand drill and bits.
- 6) Clamps for holding pieces during welding.

Also desirable but not essential:

- 7) Guillotine or bench shear.
- 8) Folding machine for sheet metal up to 3 mm thick.
- 9) Electric arc welding equipment. (This would speed up construction).

The materials required (with their metric measurements) are listed below. Good results may not be obtained if changes are made in dimensions or proportions of the kiln. If you wish to make major modifications to the design please approach TPI before starting work.

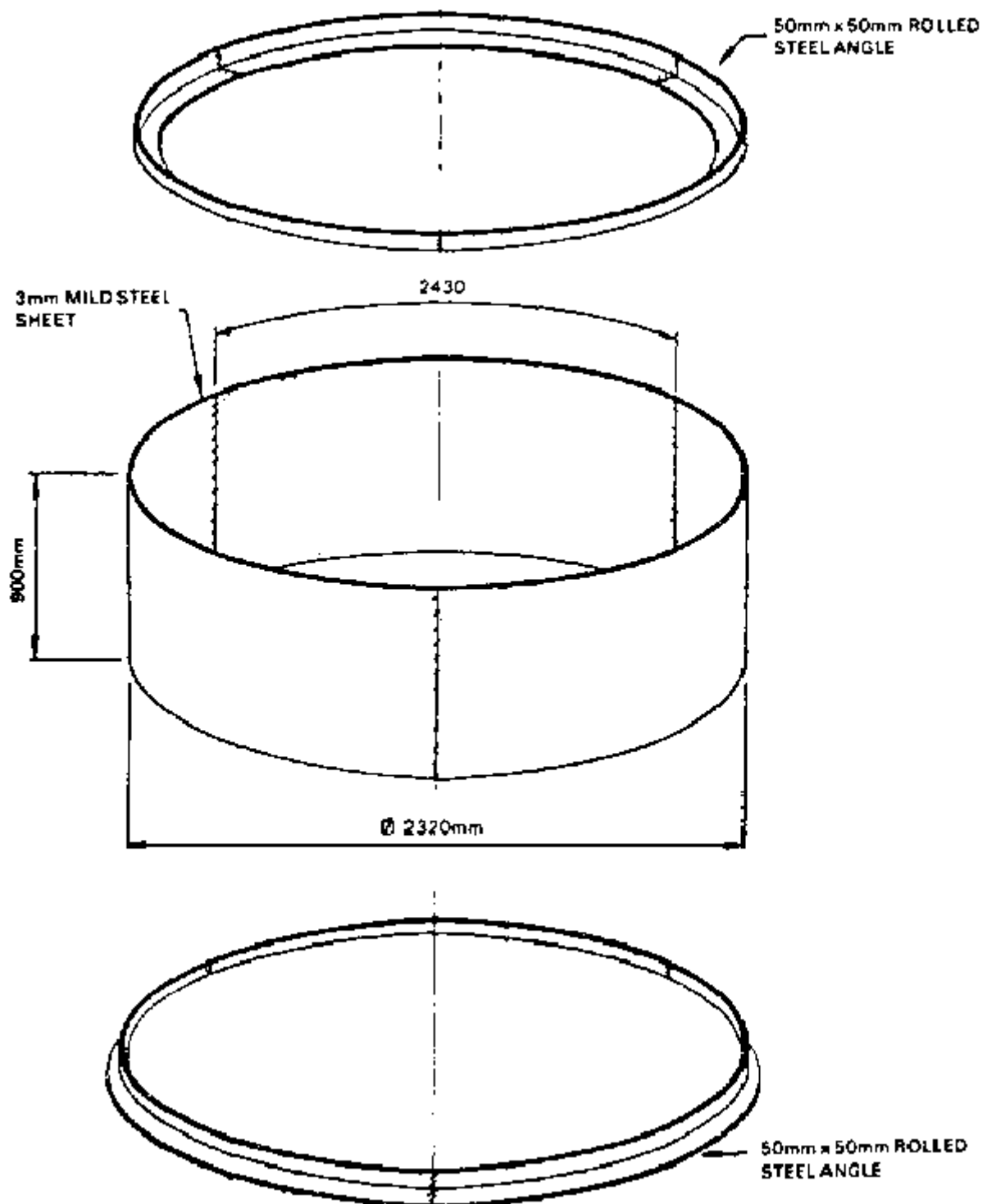
Construction and assembly instructions follow. Fig. 18 is a dimensional constructional drawing. Read instructions carefully before starting to construct kiln.

2.1. List of Materials

	<u>Part</u>	<u>Material</u>	<u>Quantity sufficient to cut:</u>
Base section	Top and bottom rings	50 mm x 50 mm x 3 mm mild steel m.s. angle	6 pieces, each 2 430 mm long
	Body (Construction Method 1)	3 mm m.s. sheet (Note 1)	3 pieces, each 2 430 mm x 900 mm
	Body (Construction Method 2)	3 mm m.s. sheet	3 pieces each 2 480 mm x 900 mm n
Upper section	Top ring	50 mm x 50 mm x 3 mm m.s. angle	3 pieces, each 2 398 mm long
	Bottom ring	50 mm x 50 mm x 3 mm m.s. strip	3 pieces, each 2 398 mm long
	Body	2 mm m.s. sheet	3 pieces, each 2 448 mm x 900 mm
Top cover	Cover sectors	2 mm m.s. sheet	2 pieces, cut to dimensions shown in Fig. 22
	Steam ports	50 mm x 3 mm m.s. strip	4 pieces, each 630 mm long
	Lifting handles	10 mm diameter m.s. rod (concrete reinforcing tar)	4 pieces, each 500 mm long
Steam port covers (4 per kiln)	Bodies	Either 50 mm x 3 mm m.s. strip OR 140 mm diameter steel pipe. (Use pipe if available)	4 pieces, each 440 mm long OR 4 rings, each 50 mm wide
	Top discs	3 mm m.s. sheet	4 discs, each 190 mm diameter
	Handles	5 mm diameter steel rod (concrete reinforcing bar)	4 pieces, each 180 mm long
Base channels	Channel sections	3 mm m.s. sheet	8 pieces, each 500 mm x 500 mm

2.2. How to make the base section

Fig. 19. Kiln base section



Top and bottom rings:

1. Cut six 2 430 mm lengths of 50 mm x 50 mm x 3 mm m.s angle.

2. Take three of these lengths to make the bottom ring. Bend each length, using the bending rolls or by blacksmithing, to a radius of 1 160 mm. The vertical flange must be on the INSIDE.
3. Check that the ends fit together well - if not, trim the ends with a hacksaw.
4. Tack weld into a ring.
5. Check that the ring rests flat on the ground - if not, break and re-weld or twist until it is satisfactory.
6. Complete the welds.
7. Take the remaining three lengths to make the top ring. Form them into a ring with the vertical flange on the OUTSIDE.
8. Make the top ring in the same way as the bottom ring.

2.2.1. Body (Method 1)

1. Cut three pieces of 3 mm thick m.s. sheet each 2 430 mm x 900 mm.
2. Remove any sharp edges.
3. Bend the pieces to a radius of 1 160 mm, using the bending rolls.
4. Tack weld the edges of the pieces together to make a cylinder.
5. Check that the rings fit well on the cylinder and tack weld them in place at three points round the cylinder. Note that the bottom ring fits OUTSIDE the cylinder and the top ring fits INSIDE the cylinder.
6. Check that the cylinder stands upright on the ground.
7. When satisfactory, weld the seams. The side seams should be continuous welds. Any gaps will allow air to get into the kiln.
8. Weld the rings. In this case, several welds spaced round the cylinder will be adequate, as any gaps will be sealed with earth or sand when the kiln is in use.

2.2.2. Body (Method 2)

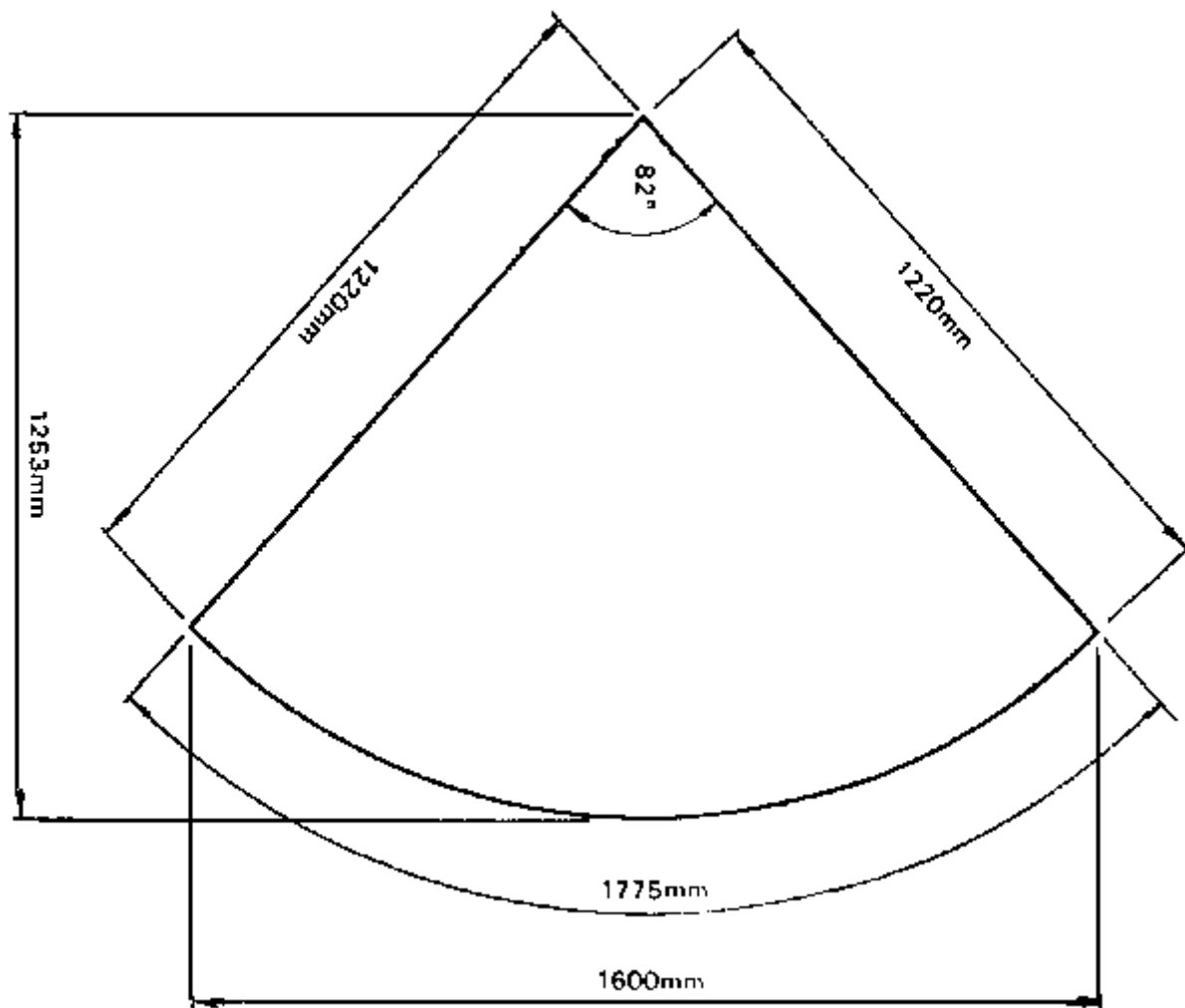
For ease of welding this alternative method can be used.

1. Cut three pieces of 3 mm thick m.s. sheet each 2 480 x 900 mm.
2. Remove any sharp edges.
3. Bend the pieces to a radius of 1 160 mm, using the bending rolls.
4. Tack weld the edges of the pieces together to make a cylinder. The extra length of each piece gives an overlap of 50 mm at each joint.

5. Fit the bottom ring OUTSIDE the cylinder; the top ring INSIDE.
6. Check that cylinder stands upright on the ground.
7. Weld the side joints, inside and out. The outside welds should be continuous to prevent air getting into the kiln. The inside weld may be intermittent. It is easier to weld an overlap than to weld two plates which butt together and this method also gives an allowance for errors.
8. Weld the rings finally into position as before.

2.3. How to make the upper section

Fig. 20. Kiln upper section



Top and bottom rings:

1. Cut six 2 398 mm lengths of 50 mm x 3 mm m.s. strip.
2. Take three of these lengths to make the bottom ring. Bend each length to a radius of 1 145 mm.
3. Tack weld the lengths together to form a ring.

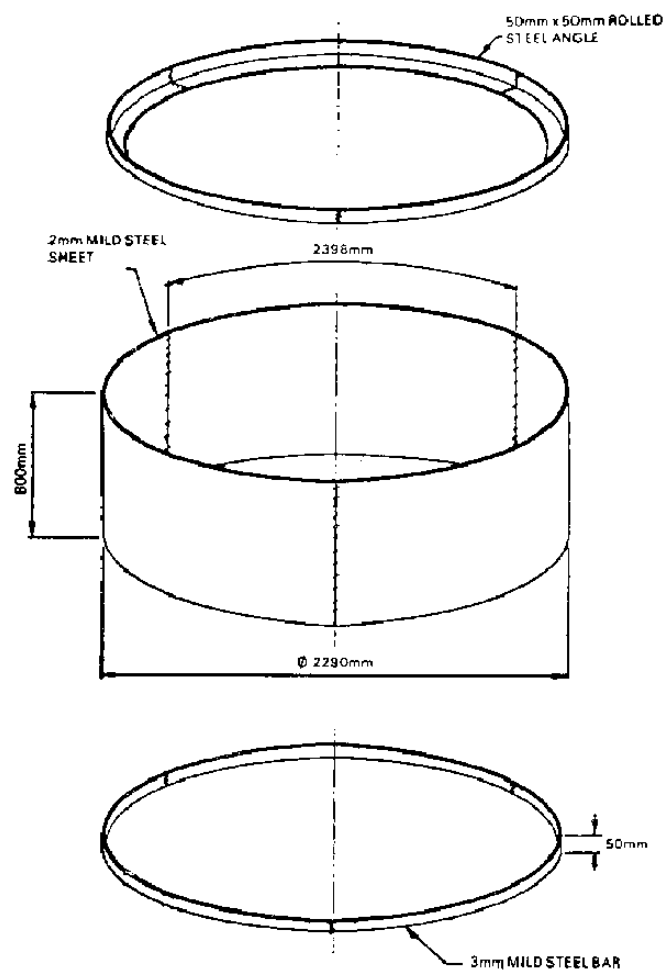
4. Lay the ring flat on the ground to check that it is true.
5. Complete the welds.
6. Take the remaining three lengths to make the top ring.
7. Bend to a radius of 1 145 mm with the vertical flange OUTSIDE.
8. Weld into a ring as described above.

2.3.1. Body

1. Cut three pieces of 2 mm m.s. sheet, each 2 448 mm long x 800 mm wide.
2. Bend to a radius of 1 145 mm.
3. Make up into a cylinder as described for the base section (Body: Method 2). Note that the flat ring is welded INSIDE at BOTTOM: the angled ring is welded INSIDE at TOP.
4. Make sure at the tack welding stage that the cylinder fits on to the base section correctly.

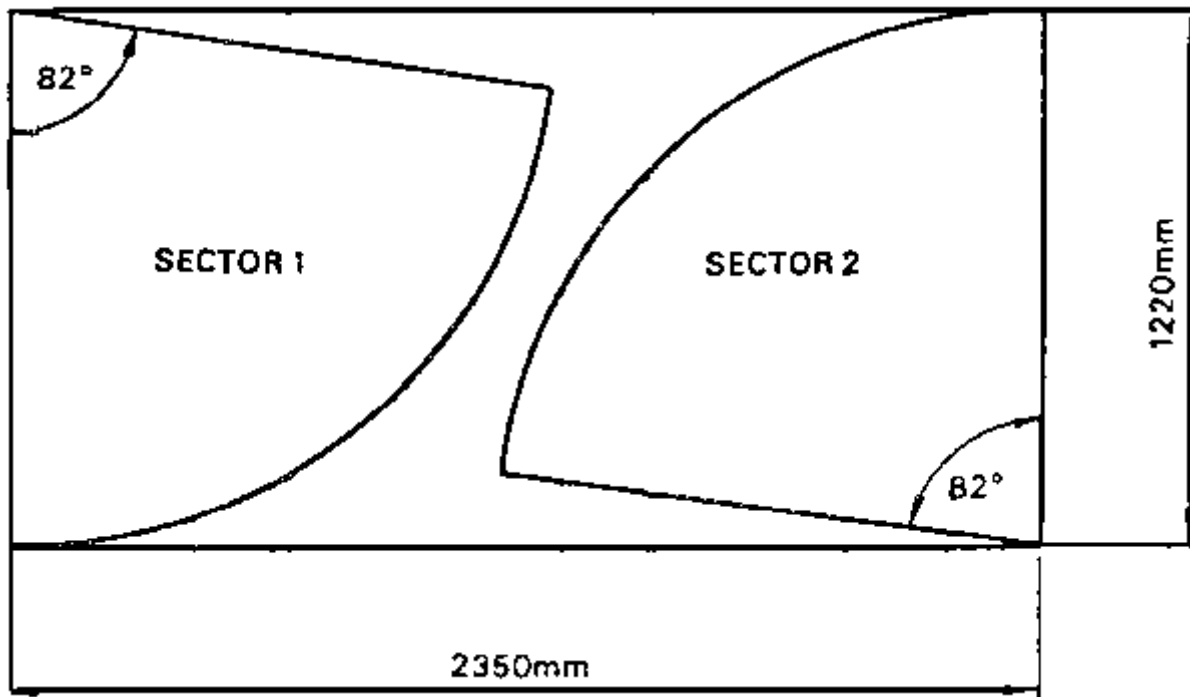
2.4. How to make the top cover

Fig. 21. Dimensions of top cover sector (4 required to make cover)



1. Mark out 4 sector shaped pieces of 2 mm m.s. sheet to the dimensions shown in Fig. 21. Two pieces can be cut from one sheet as shown in Fig. 22.
2. Cut out sectors, remove any sharp edges.
3. Mark out and cut out a 150 mm diameter hole in each sector for the steam release port.

Fig. 22. Cutting two sectors from standard sized sheet metal



2.5. How to make the smoke stacks

Base channels (8 required)

1. Cut eight pieces of 3 mm m.s. sheet, each measuring 500 mm x 500 mm.
2. Bend and fold up as in the drawing (Fig. 18) into channels. If no folding machine is available the bending can be done in a bench vice. Mark the bend lines on the metal and make each bend in several stages. Do not try to form each bend to 90 in one attempt.
3. To make the spigots cut eight 150 mm lengths of 120 mm diameter steel pipe OR cut eight pieces of 3 mm mild steel, each measuring 375 mm x 150 mm and roll up into tubes of about 120 mm diameter. Make sure they are all as nearly as possible of the same diameter.
4. On each channel mark the centre of a hole 100 mm from one end.
5. Carefully cut out the holes until they are the same size as the inside diameter of the spigots.
6. Weld the spigots into position over the holes. Make sure they are upright.

Smoke stacks (4 required)

These stacks must fit over the spigots in the base channels. They must not be a tight fit. Otherwise, when the kiln is in use and hot, they may be impossible to remove. However, they should not be too loose either.

1. Simply cut four 2 300 mm lengths, if suitably sized steel pipe is available.
2. If no pipe is available, make the stacks from sheet metal. They can be made in one piece if a large set of bending rolls (2 300 mm wide) is available. Otherwise, make the stacks in several sections and join together.
3. Divide the length of the stack (approximately 2 300 mm) into the smallest number of equal lengths which can be formed to the bending rolls available. Add about 50 mm to each length to give some overlap for assembling the stack sections.

Check that this dimension will still fit between the rolls, i.e. for 900 mm wide rolls, three lengths of 770 mm will give a stack height of 2 310 mm. Adding on assembly allowance of 50 mm gives: $770 + 50 = 820$ mm section length.

4. Cut the required number of pieces from 2 mm m.s. sheet.
5. Form into tubes. These tubes should be of slightly different diameters so that the top section is smallest and fits tightly into the section below, which, in turn, will fit tightly into the next section down, and so on. The bottom section should fit well, but not tightly, on to the spigots in the base channels. Make sure that all the stacks will fit all the channels so that the stacks can be easily changed round when the kiln is in use.
6. Assemble the tube sections, pushing each section about 50 mm into the section below.

Make sure that the assembled stack is reasonably straight and will stand upright on the channel sections.

7. Weld the stacks together but do NOT weld the stacks onto the channels.

Appendix 3 - Building and operating the Argentine Half Orange Kiln

This kiln is a hemisphere and the diameter ranges from 5 to 7.5 m. Capacity and cycle time vary with diameter as follows;

Diameter (m)	Gross Volume (m³)	Cycle time (day)
5.0	32	7.8
6.0	56	8.10
7.0	90	15-17
7.5	110	17

A 6 m diameter kiln requires about 6 000 bricks of 0.24 x 0.12 x 0.06 m.

Actual charge capacity is less than gross volume due to the spherical form. A 7 m kiln has a practical charge capacity of about 60 steres of wood, or two-thirds of gross volume. The ratio is somewhat less for smaller kilns.

The commonest diameter formed is about 7 m. The yield percentage varies but typical yields are from 4.5 to 6 tons of fuelwood yielding one ton of charcoal.

1. Site selection and preparation

See paragraph 7.2.2 in main text of manual.

2. Brickwork

Drive in a stake in centre of kiln to be built and leave it projecting about 30 cm. To the top of stake attach by means of a leather strap a light wooden radius rod of equal length to dimension required for the diameter. In the end of the rod drive a stout nail to act as a precise measuring point to which each brick is laid (Fig. 23 photo 14).

The footing of the kiln is laid in a circular trench marked out to correspond with the radius rod. The trench is 0.3 m deep and wide enough to allow a footing the length of a brick wide and three courses thick to be laid. Make the footing 0.45 m wide beneath the two doors to provide a firm foundation.

Bricks are laid in mud mortar consisting of clay, sand and charcoal fines. The mortar must be firm and strong when dry, without peeling and shrinkage cracks. Keep the joints thin otherwise the kiln will not be strong and durable.

At ground level lay the first course of bricks around the kiln using the radius rod to maintain the correct internal diameter. The lower three courses above the footing are double thickness all around the wall.

Leave 12 air inlets at ground level evenly spaced, each hole being about 0.07 m square.

Then begin to leave out bricks in the outer ring from this point beginning at each end of a diameter at right angles to the axis of the doors. In this way a double thickness wall is built up to reinforce the kiln around each door (see fig. 23 photos. 15, 16, 17). The main kiln wall is single thickness.

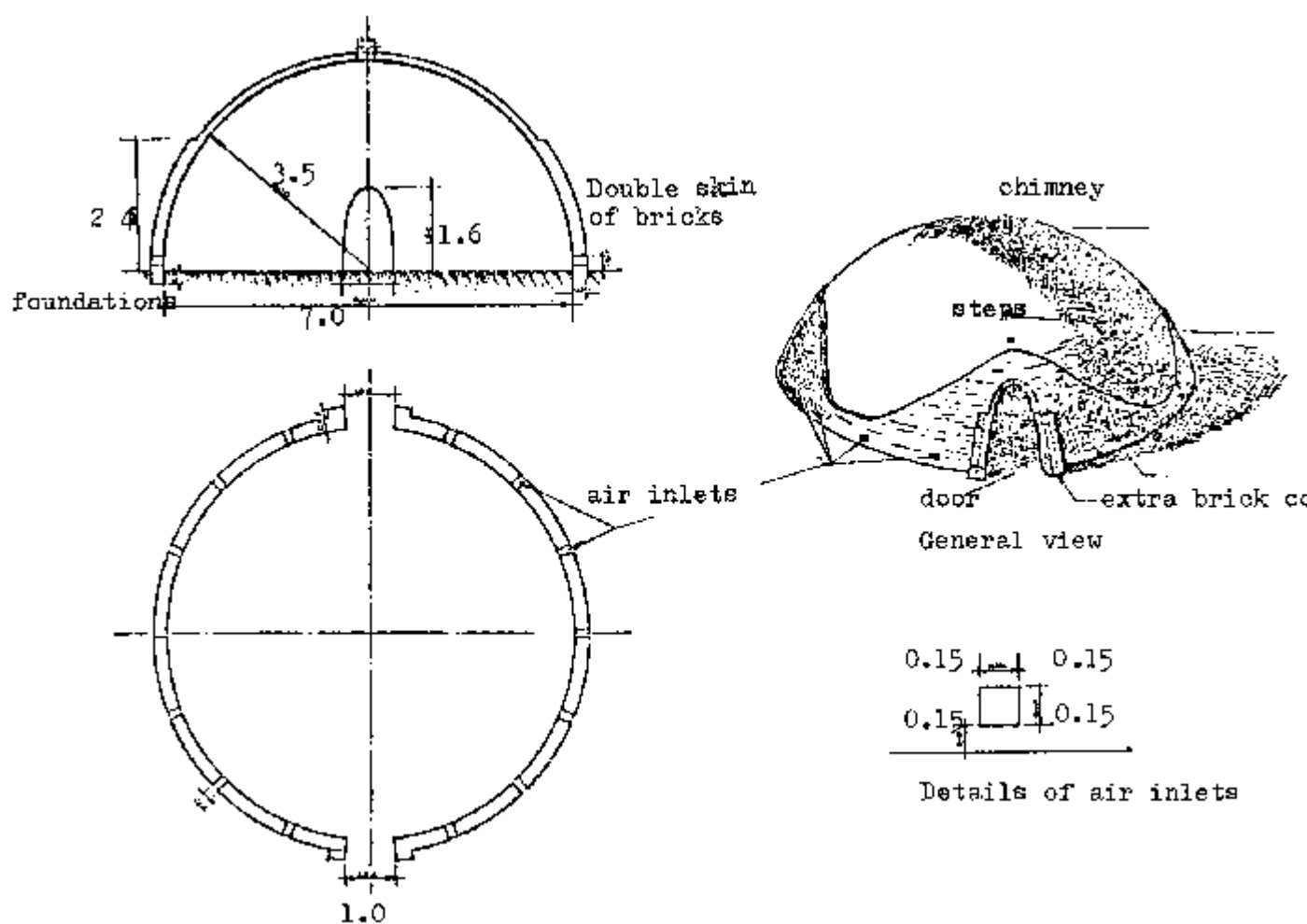
Take care as the kiln wall nears the top to put each brick hard up to its neighbour, keeping joints as thin as possible so that each run of brickwork is tight and bricks cannot fall out through loss of mortar when the kiln is in use.

At the top of the kiln leave a circular hole or "eye" about 0.2 m diameter. This hole is for lighting and to allow emission of smoke and fumes during carbonization.

Before use the kiln must be allowed to dry out for about two to three weeks. The curing and drying out of the kiln walls and the earth floor is completed over the first three or four burns. The cracks and pores in the bricks become filled with tar and at the same time a lower yield of charcoal is obtained due to air leakage and the extra heat necessary to dry out each floor and the brick walls.

Any cracks which appear in the kiln walls must be immediately filled with clay slurry and any loose or faulty bricks replaced. This is important during the early life of the kiln but inspection and repair is also necessary after each burn to ensure long life for the kiln.

Reinforce the doorways of the kiln adequately as they are subject to shock loads when the kiln is being charged with wood. A steel or wooden post can be set each side of the door, clear of the kiln wall, to absorb accidental blows during loading operations.



Appendix 4 - Useful conversion factors

Length:

1 centimetre = 0.3937 inches
1 inch = 2.54 centimetres
1 metre = 1.0936 yards = 3.2808 feet = 39.370 inches
1 kilometre = 0.6214 miles
1 mile = 1.6093 kilometres

Area:

1 hectare = 10 000 square metres = 0.1 square kilometres = 2.471 acres = 11 960 square yards
1 acre = 0.4047 hectares = 4 047 square metres = 4 840 square yards = 43 450 square feet
1 square kilometre = 0.3861 square miles = 100 hectares = 247.1 acres
1 square mile = 2.5898 square kilometres = 254.98 hectares = 640 acres

Volume:

1 litre = 1 000 millilitres = 61.026 cubic inches = 0.21998 Imperial gallons = 0.26418 U.S. gallons
1 Imperial gallon = 4.5460 litres = 1.20096 U.S. gallons
1 U.S. gallon = 0.83267 Imperial gallons = 3.78528 litres
1 U.S. barrel = 42 U.S. gallons = 34.972 Imperial gallons = 0.15899 cubic metres
1 cubic metre = 1 000 litres = 35.3148 cubic feet = 1.30795 cubic yards = 219.97 Imperial gallons = 264.18 U.S. gallons = 6.290 U.S. barrels
1 m³ solid = 750 kg. fuelwood with 40% moisture

Mass:

1 kilogram = 2.2046 pounds = 1 000 grams
1 pound = 453.592 grams = 0.4536 kilograms
1 ton, English = 2 240 pounds = 1 016.05 kilograms = 1.01605 tonnes (metric tons) = 1.12 U.S. tons = 20 hundred weight (cwt)
1 tonne = 1 000 kilograms = 0.98421 tons (English) = 1.10231 U.S. tons = 2 204.62 pounds
1 U.S. ton = 2 000 pounds = 17.8572 hundred weight (cwt) = 907.184 kilograms = 0.907184 tonnes = 0.89286 tons (English)

Density:

Bulk density of commercial charcoal = 250 to 300 kilograms per cubic metre

Approx. weight of a stacked metre (stere) of:

- Plantation grown radiate pine (partly seasoned) = 550 to 650 kilograms
- Plantation grown Eucalypt wood (partly seasoned) = 600 to 700 kilograms
- Medium density tropical hardwood (partly seasoned) = 700 to 800 kilograms
- Dense tropical hardwood = 900 kilograms

Energy:

1 kilowatt = 1.3405 horsepower

1 horsepower = 0.746 kilowatts

1 kilojoule = 0.2389 kilogram calories = 0.948 British thermal units (BTU) = 0.001 megajoules = 0.00027778 kilowatt hours

1 kilowatt hour = 3 412 British thermal units = 1.34 horsepower hours = 3 600 kilojoules = 3.6 megajoules

Prefix table:

10 ¹²	tera	T
10 ⁹	giga	G
10 ⁶	mega	M
10 ³	kilo	k
10 ²	hecto	h
10	deca	da

Heating Value: (See conversion factors to calculate values in other units)

Fuel	High Heating
Green wood*	15 000
Dry wood*	19 000
Charcoal	31 000
Coke	30 000
Bituminous coal	27 000
Fuel oil	44 000
Kerosene	46 000
Wood tar	20 000
Natural gas	45 000
Producer gas	5 000
Wood retort gas	6 000

* Influence of moisture on heating value of wood:

Net heating value (MJ/kg) = 19 000 - 220.

where is moisture content in percentage of total weight.

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