

PRACTICAL TIPS FOR POTTERS MAKING IMPROVED COOKING STOVES



A MANUAL FOR POTTERS AND STOVE PROMOTORS

prepared
by

Tim Jones



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FOREWORD

Improved cooking stoves designed to make food preparation more fuel efficient are now available in many shops and markets around the world. Their popularity has increased as more households realize for themselves the many benefits associated with the use of these stoves. The most commonly used material for the construction of all or part of stoves is fired clay, also called pottery or ceramics. This is because it is a low cost, easily moulded material that is available in most parts of the world.

The use of common clays in the production of cooking stoves has not been without its problems. These problems occur in two main areas:- (1) production and (2) end-use durability, with the first area being partly responsible for the second part. Improved cooking stoves are not produced in highly sophisticated pottery factories, but in small workshops. The materials are normally not carefully selected and refined but comprise of what is available locally. The production equipment is not expensive machinery, but skilled labour, involving techniques that have been passed down for generations. It has been found that the existing clay mixtures and production processes are not always the most suitable for making cooking stoves. However, with some modifications both can be adapted to produce good quality, long lasting cooking stoves. These modifications are not complicated or expensive, but they do involve more care being taken in the selection and processing of the materials and minor changes being made to the existing production techniques.

This booklet provides information on clay selection, production methods, handy tips, etc. concerning the production of fired clay cooking stoves. These tips have been tried and tested in many countries and have helped considerably to solve the problems experienced in fired clay cooking stove production. They are based on many years of work and problem solving in countries where fired clay cooking stoves have been introduced.

By incorporating these ideas into the existing production processes, losses may be reduced and product durability increased. It has been found that because of the considerable variations in the minerals that make up local clays, there is no clay mixture recipe or production method that guarantees crack free cooking stoves. A considerable amount of trial and error is and will remain involved before the best possible clay mixtures and production processes are determined. What is successful in one country will not necessarily work in another. However, a great deal has been learned about how the chances of success can be enhanced.

The aim of this booklet is not to enable someone without any practical experience with pottery or ceramics to start making ceramic stoves but rather to assist potters and other "stove practitioners", already involved with ceramic stoves, to cope better with the problems which may be encountered. The text has been kept as non-technical and straight forward as possible so that it can be easily understood. There are no restriction as to the use of the book as long as the text and illustrations are not reproduced in any form for profitable gain.

We wish to express our sincere thanks to the author, Mr. Tim Jones, the illustrator Mrs. Debbie Riviere as well as all others who contributed directly or indirectly for their cooperation in writing and preparing this booklet. Thanks also to all those who were involved in the "Clays for Stoves" seminars held in Sheffield U.K. and Yogyakarta Indonesia who encouraged the production of this booklet. Financial support from the Directorate General for International Cooperation of the government of the Netherlands is also gratefully acknowledged. We would welcome your comments on the presentation and contents of the booklet.

Auke Koopmans
HSE b.v.

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INTRODUCTION

Much work has been carried out to develop tests that inform potters if their clays and mixtures are the best for making pottery cooking stoves. It has been found that even using the most analytical equipment to study clay mixtures (and their performance when used to make cooking stoves), that there is no single recipe that works without fail everywhere. Clays vary too much from place to place for any mixing ratio or production method to guarantee success. What has been found is that if certain steps are taken to select, mix and test the available clays and to combine this with the most suitable method of stove production, then cracking during production and subsequent use can be reduced.

There are some clays that are totally unsuitable for stove production and these can be identified and avoided (see Clay Testing).

Often clay mixtures that are used to make other household items need little or no changing to produce cooking stoves.

The tests and production methods included in this booklet have been chosen for their practicality. They do not need expensive equipment or a detailed knowledge of ceramics. They will provide a guide towards achieving the best results from whatever is available. They can not be used on their own but will, combined with an already existing knowledge of pottery, help avoid the most common problems associated with improved cooking stove production.



FINDING AND SELECTING THE CLAY

It is good to be able to have more than one type of clay available as it greatly increases the chances of being able to get the best and most suitable mixture. A combination of a smooth sticky clay with another one containing more sand and coarse particles is often ideal, once the best mixture of the two is worked out. A supply of sand for adding to the various clays also needs to be found.

The first step is to ask people in the area if they know of any places where clay is available. Older people are the most useful as they are most likely to remember where clay was dug in the past. Before transport was available, communities had to produce their own bricks, cooking- and water pots. There were places around the village where the clay was dug for these specific items. Finding and reopening these clay sites can save a lot of time.

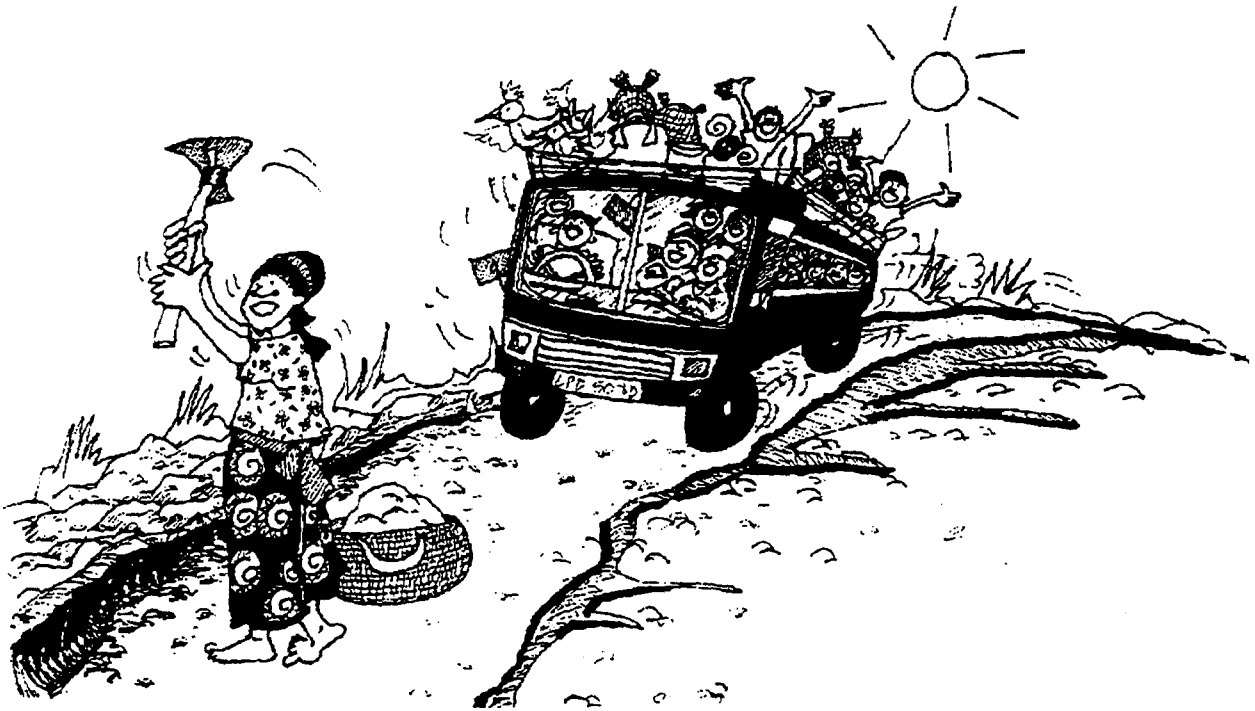
River banks often provide a variety of clays layered on top of each other. If there is a layer that is mainly sand with only a little clay then this will mix very well with a layer which contains a lot of pure clay.



Asking where there is good clay



Diaaina clay from the river bank



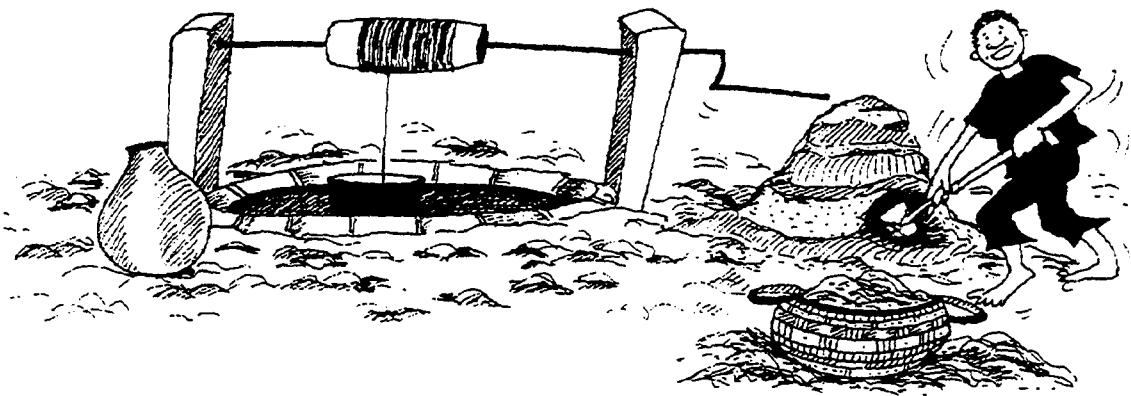
Digging clay by the roadside

Check the river to see if there is a source of fine sand as well that could be collected. Different parts of one sand bank will provide a good variety of sand grains, the river having done the sieving.

Wherever there has been any digging for building a house, road construction or an irrigation channel, the clays can be seen and sampled.

If a good clay is found, then it can be followed by the digging of small test holes in the ground in a place where it can be dug and collected more easily.

The construction of a new well provides an opportunity to find good clays that lie deeper below the surface. These could still be within digging range once the top layers have been removed. There may be larger deposits of good clay that have not been found because of their depth, these are available once located in this way.



Finding clays which are located deeper

TESTING THE CLAY FOR COOKING STOVES

Pure clays with no sand or coarse particles are not suitable for the production of cooking stoves. Experience and research has shown that the mixture for the best stoves must be made up of 50% or less of pure clay. More than 50% pure clay and the number of stoves that crack during production or early in use is too high. There is a method of finding out how much pure clay there is in a sample but it involves the use of a deflocculant (a chemical which allows the clay particles to disperse and settle by itself, small crucibles, accurate weighing scales and an electric test kiln which may not always be available.

A simple and very practical method, which does not involve any testing is to make sure that a clay mixture has more than 50% of non clay material, is to make a mixture of clay to which is added as much sand, grog, sawdust, rice husk, ground up fired clay or charcoal dust as possible but still allows the mixture to be worked. However, this "method" does not guarantee that the most appropriate mixture will become available for cooking stove making.

Normally the starting point for a mixture for making fired clay stoves is a sticky/plastic clay. There are some basic and simple tests for finding out how suitable the clay is and what needs to be done to it to improve it:-

Take some clay and dry it as far as possible. Crush it up and place it in any clear glass container 3/4 filled with clean water. Cover the top of the container and shake it until the clay is well mixed with the water. Let it stand undisturbed for a day or two. The coarse particles such as stones and sand in the clay will sink to the bottom first. The soil, also called silt, will be in the middle and the clay layer at the top with any vegetable matter floating on the water.

This test gives a basic idea of what is in the clay sample and provides indications on how it will have to be processed. Check the coarse layer in the bottom of the glass container. Are there many large stones, say over 2 mm. diameter? If there are a lot of stones then it will be better to sieve the clay during the clay preparation process (see Clay Preparation - Mixing) or to abandon the clay. If only a few stones are seen then they can be picked out during mixing and wedging. The amount of sand and its presence in a variety of sizes, is important. A good mixture of different sized sand particles has been shown to be preferable, as long as they are no bigger than 2 mm. The top fine layers in the glass container will be the clay. It should be possible to get an idea of how much clay to other materials there is, just by measuring the height of this fine layer and comparing it to the total height of the sand and stones, silt or soil and the clay layer combined.



Shaking clay sample in a glass jar

Alternatively, the mixture of clay and water can be poured through a sieve, a piece of mosquito netting will do, and the amount of stones and hard particles left on the sieve can be checked.

If there are many stones or many hard particles which can not be easily rubbed fine between the fingers, the clay may have to be abandoned or it will have to be sieved.

If the clay takes several days to settle then it will be a clay with very fine particles. This is not ideal as it will probably shrink a lot and will result in problems with very bad cracking as it dries.

For some clay types this test does not really provide answers as it is sometimes very difficult to establish where the sand or the silt layer stops and where the silt or clay layer starts. In that case other tests will have to be used.

Another simple test is to take a sample from each layer that looks different. Just looking at the clay sample and rubbing it between finger and thumb will give an idea of how much coarse material is in it, how sticky it is and whether there is much vegetable matter such as roots present. Some people take a bit of clay in the mouth and chew it to check whether it contains a lot of hard grains such as sand and small stones.

To give an idea of how well a clay holds together (its plasticity) a handful of clay can be taken from the ground. Add some water, knead the clay until the clay becomes soft enough to leave a clear fingerprint when squeezed but not so soft that it starts sticking to the hands. Roll the clay into a coil with a diameter of about 10 mm. and try and tie it in a simple knot. If the coil of clay does not crack or fall apart then it is good and plastic. If the clay cracks and falls apart then do not discard it as it may be useful for mixing with a more plastic clay.

Having an idea of how much the clay or clay mixture shrinks is very important. The amount by which the clay mixture shrinks should not be more than 10-12%, preferably considerable less, when it is allowed to dry and is fired in the kiln.



Testing clay for plasticity

The more the clay shrinks, the more problems with cracking during drying will be experienced. If the shrinkage is more than 12% and the clay sample shaken up in the glass container took a long time to settle, then it is better to look for another type of clay. The drying, firing and end-use losses will be too high for this mixture to be any good.

When making cooking stoves and liners from clay, it is very important that the right measurements are kept to, or the finished stove will not be as fuel efficient as it could be. It is therefore necessary to know by how much the clay mixture shrinks so that this can be allowed for when the stove is made.

To measure for shrinkage, small bricks 120 mm. by 30 mm. by 20 mm. should be made. These can be made in a simple wooden mould that is lightly dusted with sand as a releasing agent, or a slab of clay 20 mm. thick can be rolled out and the bricks carefully cut from it. Marks are made on several sides of the bricks, exactly 100 mm. apart.



Measuring the shrinkage

The test bricks should then be allowed to dry slowly and evenly, being turned regularly. When completely dry, the length between the marks is measured again and the drying shrinkage is calculated as is shown in the following equation below.

The dry bricks are then fired amongst the other work in the kiln, preferably in various parts of the kiln to see if any noticeable differences occur. The distance between the marks is then measured again and the total shrinkage calculated as shown in the second equation.

$$\frac{\text{Wet length (100 mm.)} - \text{Dry length}}{\text{Dry length}} * 100\% = \text{Drying shrinkage in \%}$$

$$\frac{\text{Wet length (100 mm.)} - \text{Fired length}}{\text{Fired length}} * 100 \% = \text{Total shrinkage in \%}$$

Lime in a clay will cause serious problems causing the fired clay to crack crumble and fall apart because a chemical reaction may take place which results in an expansion of the lime particle. Some steps can be taken to reduce the bad effects of lime in the clay but it is much better if a clay with no traces of lime in it is used. When clay is dug from the ground look for any white or pale gray specks which could indicate the presence of lime. A simple test to show this is to take a lump of the clay straight from the ground and to squeeze lime or lemon juice over it. Look carefully to see if any bubbles appear on the surface of the clay. A few bubbles and it is possible that there may not be a problem, but if the sample fizzes then do not use it at all. If there are no bubbles then the clay is fine. The bad effect of lime in clay mixtures can be minimized only if the particles of lime are very small and well spread within the clay.



Testing for lime with lemon/lime

In case there is no other clay available and clay with lime particles has to be used, the fired stoves should be dunked in water after taken out of the kiln and left there for about an hour. In general this will ensure that the lime, which after firing has become quick lime, is dissolved instead of becoming slaked lime.

The porosity (amount of very small holes in the fired clay) of the pottery or ceramic cooking stoves is important.

This is because the higher the porosity, the better the stove is at withstanding the heat shock conditions it will experience in use. If the porosity is too high, then the stove will not be physically strong enough to withstand everyday use. If the porosity is very low, then the stove will be physically strong but more likely to crack in use. A high amount of porosity is therefore a good thing as long as the stove can still be transported and withstand everyday use.

The same samples used for the clay shrinkage test can also be used for the porosity test. Take the shrinkage test bricks and heat them up on a metal plate over a fire so that any moisture is driven out of them, 10 to 15 minutes will be fine. Weigh them while they are still hot and then drop them into a metal container full of water and boil them for 30 minutes.

Allow the water to cool and remove the bricks. Dry the outside of the bricks with a cloth and weigh them again.

The porosity can then be calculated from the difference between the hot and the wet weight, as shown below.



Testing the porosity

A percentage of between 15% and 22% is acceptable but a range between 17% and 20% would be better.

$$\frac{\text{Hot weight} - \text{Wet weight}}{\text{Hot weight}} * 100\% = \text{Porosity in \%}$$

MATERIALS THAT CAN BE ADDED TO MAKE A BETTER MIXTURE

A very sandy clay found alongside a plastic clay would be ideal but usually sand as a separate ingredient has to be added. The sand should have a good mixture of grain sizes with non bigger than 2 mm. If mosquito netting is used as a sieve it will provide sand of the right size. Sand opens up the clay to allow it to dry more evenly to prevent cracking.



Collecting sand

The only problem with sand is that it consists of silica which goes through a process called the "silica or quartz change". This means that the sand grains expand quite suddenly as they get heated in the kiln, then shrink again at the same temperature as it cools down. If too much sand/silica is in the mixture, cracks can occur during firing. Some sand can be replaced by other materials that will also help the drying process but without the problems caused by the "silica change".

Sieved fine **sawdust**, if added to a clay mixture, will do four things:- It will open up the clay (make more pores) and help with the drying process by allowing the water to leave the drying stoves more easily and evenly. The sawdust burns out during the firing and so increases the porosity of the fired clay which is an advantage, as long as it is not too much and weakens the stove. Stoves need a longer firing time than water- or cooking pots because they are thicker. The sawdust acts as a fuel within the clay mixture, helping to achieve an even firing throughout the thicker stove. It is possible to increase the amount of water in the clay mixture by adding the sawdust wet, or help dry out the clay mixture by adding it dry. This is often useful during clay preparation.



Collecting sawdust



Collecting rice husks

The addition of **rice husk** or rice husk ash has been found to really help with the strength and durability of fired clay stoves. It is often preferable to sawdust if a choice is available. Why this is, is not clear, it may be that it contains very fine particles of silica and adds so to the range of particle sizes within the clay mixture. This in turn is helpful during the clay drying period, when the majority of cracks appear.

Grog is the name for fired clay that is crushed down to a powder and sieved. It helps the stoves to dry more evenly without the problem of the "silica change" that comes with the use of sand.

It is a good use for broken pots and cracked stoves that would otherwise be wasted. Sieved through a mosquito net, it does help get the stoves through the production process and makes them last longer.



Making grog

Other things that have proved to be good when added to the clay mixtures used to make cooking stoves are charcoal dust and any sieved ash from the burning of biomass (plants and trees).

MAKING UP MIXTURES AND TESTING THEM

The First Set of Mixtures

Making up and testing mixtures is a complicated and time consuming business and it is easy to get lost in the process, unless good and accurate records are kept (see the table on the following page) and a methodical approach is taken. With the possibility that there will be two types of clay and two additives e.g. sand and rice husk in the final mixture, there are a lot of different combinations to be tried. If really lucky, and it does happen, one clay will be just the right mixture in itself containing the correct amount of clay and non clay particles to make perfect cooking stoves. Unfortunately this is not very common and the usual mixture is of one or two clays with sand. Even if this mixture works, but there are still more than 10% breakages, it is worth trying other additives in different quantities.

When working on clay plus non clay mixtures it is important to only change one part of the mixture at a time, so that it is possible to know if the change has made it better or worse. Start with the two largest ingredients that will make up the biggest proportion of the mixture.

This will be either two types of clay, one smooth and highly plastic and the other one a coarse clay. Or it may be only one type of clay with the addition of sand. At this point it is better to use crushed and sieved dry ingredients as they are more accurate to measure by volume. It is important that the same container is used to measure all ingredients as otherwise problems may occur. Prepare a sufficient amount of mixture to make a minimum of 5 test pieces or preferably 5 complete stoves out of each batch. The test pieces should be small bowls or cylinders, not flat tiles, as the stresses set up in the round shape of the stove have also to be allowed for.

The test pieces need to be made in the same way as the stoves. This is because different forming methods affect the strength of the finished product.

The results from the first set of mixtures will give an indication of which one is the most promising mixture to continue work on.

The Second Set of Mixtures

Taking the best basic mixture, start adding the next ingredient in small measured quantities (use again the same tool (bucket, etc.) used for measuring the main ingredients) and record the results as numbered samples 1, 2, 3, etc. Increase the amount by the same quantity each time for each new mixture. It is very noticeable when the limits of the mixture have been reached by the marked increase in the number of cracks appearing. Another limiting factor is that the clay mixture will not be able to take any more additives and still remain workable.

The Third Set of Mixtures

Finally, if other additives are available, start by adding small quantities again and if there is no noticeable improvement try replacing the additive used in mixture two with the third additive. In this case replace the sand with grog or rice husk ash by the same amount. Always keep good clear records of what you are doing and mark the stoves or samples made from each batch very distinctly. By following these three sets of tests it will be possible to find out which is the most suitable mixture that can be produced from what is available. Unless there are very poor clays available in the local area, only the first two tests should be necessary to obtain a good workable mixture.

Table for use in the preparation of the first set of mixtures

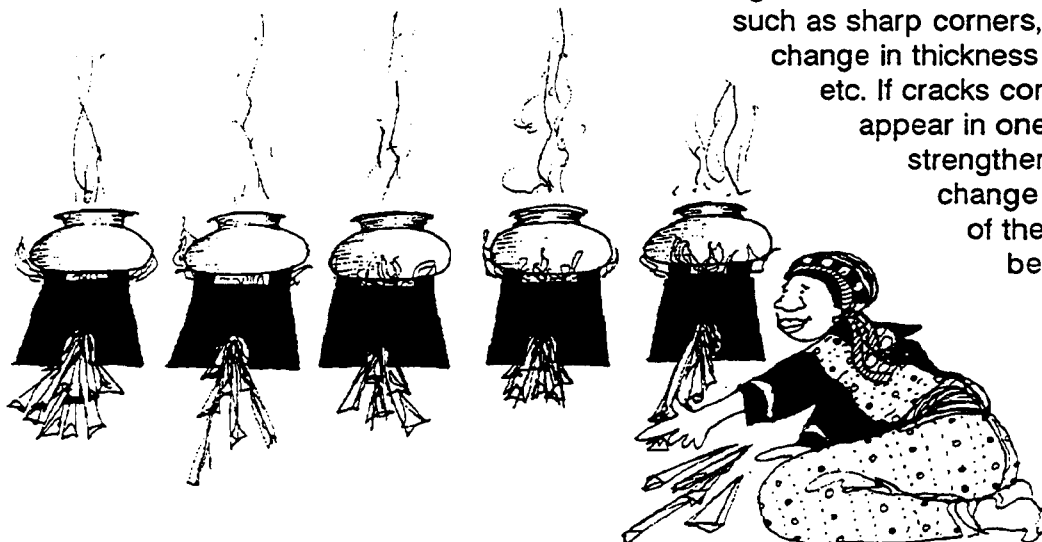
TEST MIXTURE CODE	A	B	C	D	E	F	G
Smooth clay	1	1	1	1	0	2	3
Coarse clay	0	1	2	3	1	1	1
No. of stove/liners made							
No. cracked in drying							
No. cracked in firing							
No. without cracks							

By keeping accurate records of the performance of the stoves produced from each different mixture it will be possible to arrive at the best one and most able to survive the production process.

The samples from the second and third sets of mixtures should be tested for household use. Rather than putting the stoves out in homes it is much easier to test them at the workshop. To do this, the stoves need to have a strong fire lit in them twice a day for at least 4-5 days with the most commonly used cooking pot filled with water on top of the stove.

An example of a record sheet which can be used for this test, which is sometimes also called a "destructive test" is shown on the next page.

If stove liners are being tested they need to be assembled into complete stoves, because support give by the lining will help to prevent and contain small cracks that do not affect the continued use of the stoves. Usually, if the stove is going to crack, it will do so in the first few days so there is no need to keep testing beyond a week. It is important to keep a record of the size of the cracks and where they occur. This is because the clay mixture may not be at fault but the design of the stove has a weak point such as sharp corners, sudden change in thickness of the wall, etc. If cracks continue to appear in one place, the strengthening of or a change in that part of the stove could be the answer.



Testing the stoves for their durability

An example of a record sheet for recording the results of the "destructive test" for cooking stoves

Stove number	Mix number	Day							Comments
		1	2	3	4	5	6	7	
1	1	+/+	+/-	0/	/	/	/	/	Large crack from air hole to top rim
2	1	+/-	0/	/	/	/	/	/	2 cracks down from rim: 20 mm. and 45 mm.
3	1	+/+	-/-	-/0	/	/	/	/	Pot rest fell off, then 60 mm. crack from base
4	1	-/-	-/-	0/	/	/	/	/	Small crack became bigger
5	1	+/+	-/0	/	/	/	/	/	Crack above door arch
6	2	+/+	+/+	+/+	+/+	+/+	+/+	+/+	No cracks
7	2	+/+	+/+	+/+	+/+	+/+	+/+	+/+	No cracks
8	2	-/-	-/-	-/-	-/-	-/-	-/-	-/-	Small crack on stove surface only
9	2	+/+	+/+	+/+	+/+	+/+	+/+	+/+	No cracks
10	2	+/+	+/+	+/+	+/-	0/	/	/	Crack on joint from first pothole to tunnel

Notes: + Stove has no crack

- Stove cracked

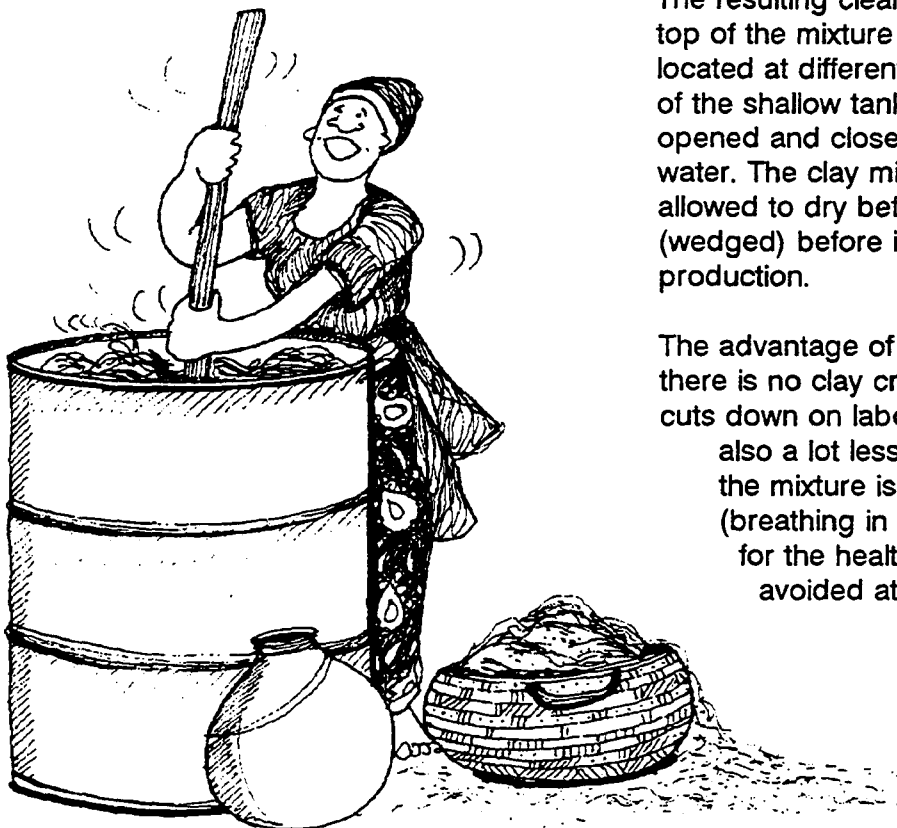
0 Finished testing

CLAY PREPARATION - MIXING

The more care and attention that is given to the preparation of the clay mixture for cooking stoves, the less chances that failure in production and use will occur. There are two different methods of preparing clay, the wet and the dry method. They both have advantages and disadvantages and the choice depends on the climate, the amount of labour available and what the potter is used to.

The Wet Method

The clay from the ground is spread out in lumps to dry and is then soaked in water for several days, being well stirred every day until there are no lumps left. Any other additives such as sand and rice husk are added at this time. The liquid clay mixture (slip) is then poured through a sieve into a shallow tank where it is allowed to settle.



Making clay slip in a drum (wet method)



Sieving the clay

The resulting clear water is taken off the top of the mixture through holes or pipes, located at different heights, in the sidewall of the shallow tank. These holes can be opened and closed when draining the water. The clay mixture left in the tank is allowed to dry before being further mixed (wedged) before it can be used for stove production.

The advantage of this method is that there is no clay crushing needed which cuts down on labour and time. There is also a lot less dust made because the mixture is sieved as a liquid (breathing in clay dust is dangerous for the health and should be avoided at all costs).

The disadvantages are that the larger particles such as sand sink to the bottom while the clay particles stay on top and this requires additional efforts for further mixing. Besides, the mixing and drying of the clay takes many days and because of this several mixing and drying containers are needed to provide a continuous supply of clay. This makes the wet method more expensive to begin with than the dry method.

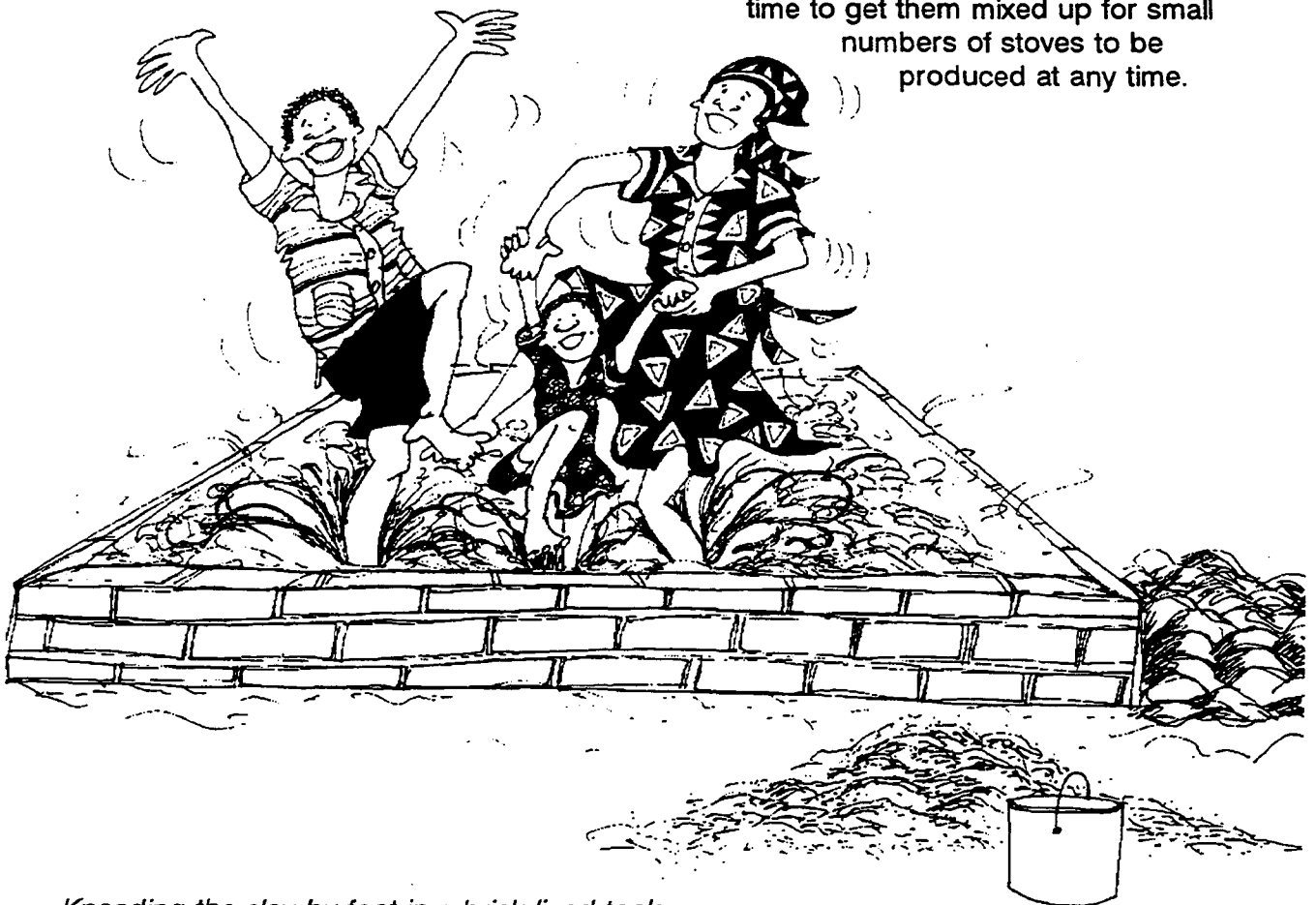
The Dry Method

This method has basically two variants: the semi-dry and the dry method. With the former method the clays and additives are used in the raw state which may be dry or moist. The ingredients are spread out on the floor in horizontal layers in the required mix ratio.

The layers are watered where after more layers of the ingredients are added. The water is left to soak into the clay overnight. The following day the clay is dug vertically and set aside into small heaps which are then kneaded manually (by foot). Finally all heaps are combined into one large heap while kneading it continuously. The advantage of this method over the dry method is that less dust is created but, at the same time it has also disadvantages.

The semi-dry method is very laborious and mixing is not very good.

With the dry method the clay is dried, crushed and sieved before any water is added. It is then mixed until the right consistency is produced. The advantages of this system are that once the dried parts of the mixture are ready they can be stored, it does then not take much time to get them mixed up for small numbers of stoves to be produced at any time.



Kneading the clay by foot in a brick lined tank

The measuring of the correct mixture is easier and more accurate if the ingredients are crushed and sieved before being measured. The disadvantages of this method are the amount of labour involved it takes to crush and sieve the clay as well as to mix the dry ingredients with water. Besides, crushing and sieving the clay is very dusty and this results in an un-healthy situation for the workers.

CLAY PREPARATION - Crushing

Crushing with two stones is still used in many places to prepare the clay for mixing. It is not a very good way to do it and if any other method can be found then it is better. This method is good for producing small quantities of clay, a sieve is not necessarily needed as the small stones can be removed by hand.

However, this method is very slow and laborious and the dust made is very dangerous to the worker. Using a weight to crush the clay on a hard surface is faster and the danger from the dust is reduced.

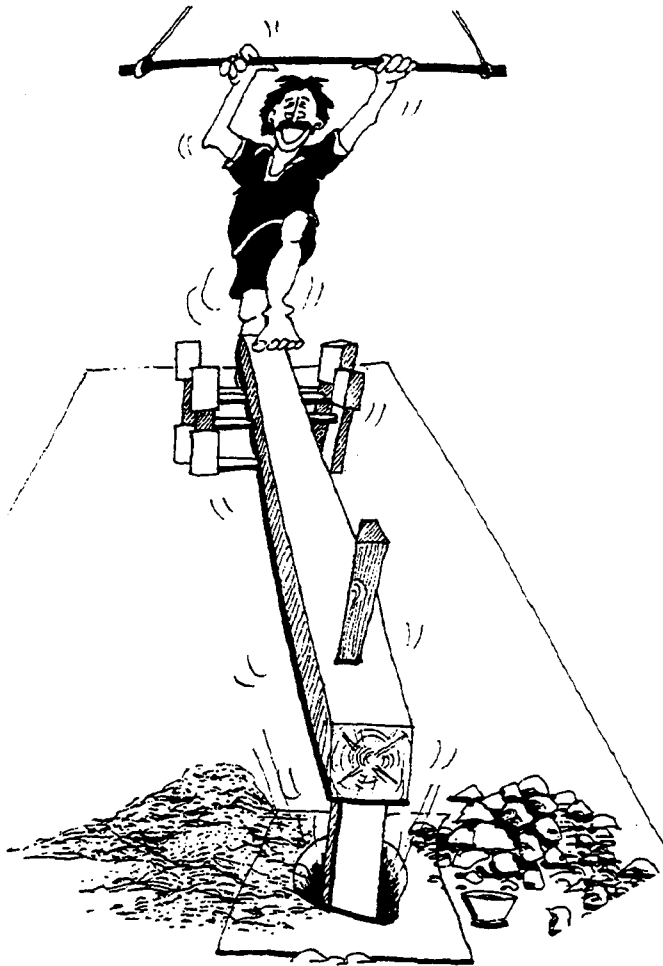


Using stones to crush clay



Crushing clay with a heavy piece of metal attached to a stick

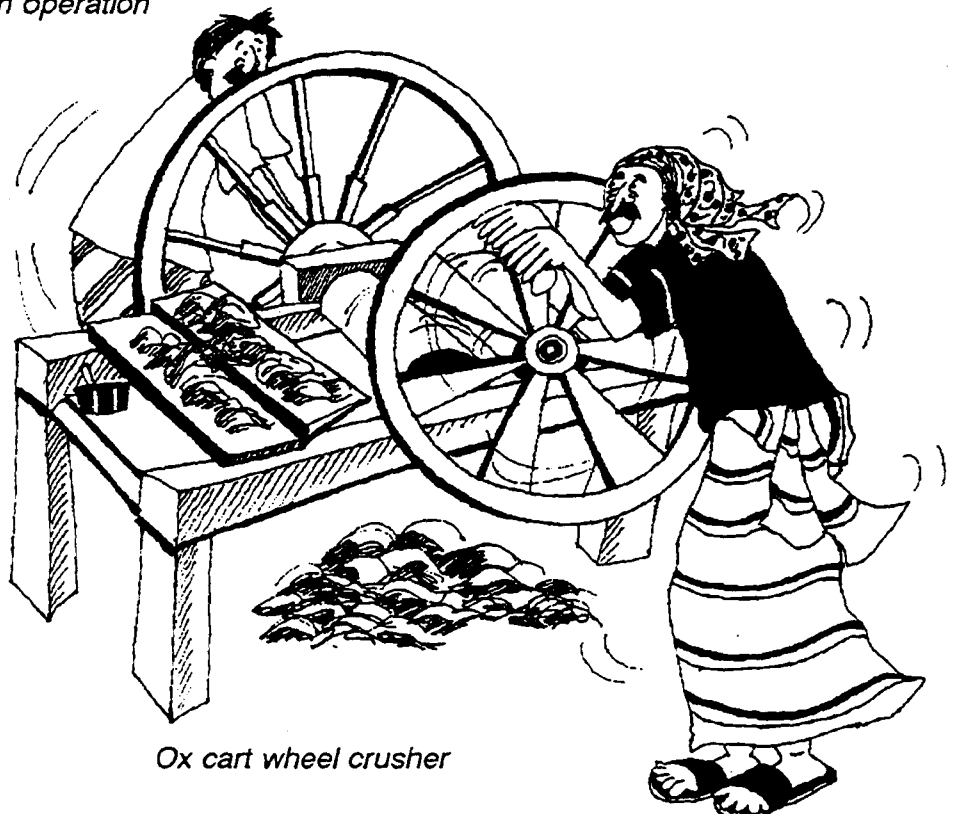
It is not very expensive to find a piece of iron with a flat surface suitable for attaching to a stick. The further the worker is away from the dust the better. The crushed clay has to be sieved and the lumps that do not go through the sieve returned for more crushing.



A lever crusher in operation

A lever crusher works well if the clay is very hard. It produces very fine particles and sieving should not be necessary, if the crusher is operated correctly. It requires two people to operate the crusher in order to make the process faster. This type of rocking crusher is generally quite cheap to construct depending on the material of which the bowl is made. In some cases it is made from a solid piece of rock, in particular when very hard materials are to be crushed.

Ox cart wheel crushers are made from two ox cart wheels which are attached to steel rollers and mounted on a solid wooden table. The rollers are rotated towards each other while damp clay straight from the ground is fed between them. It mixes the clay and crushes any small stones very effectively. No clay drying or sieving is required, the clay is mixed together by the crusher. The main disadvantages are the cost and that it requires three people at a time to operate.



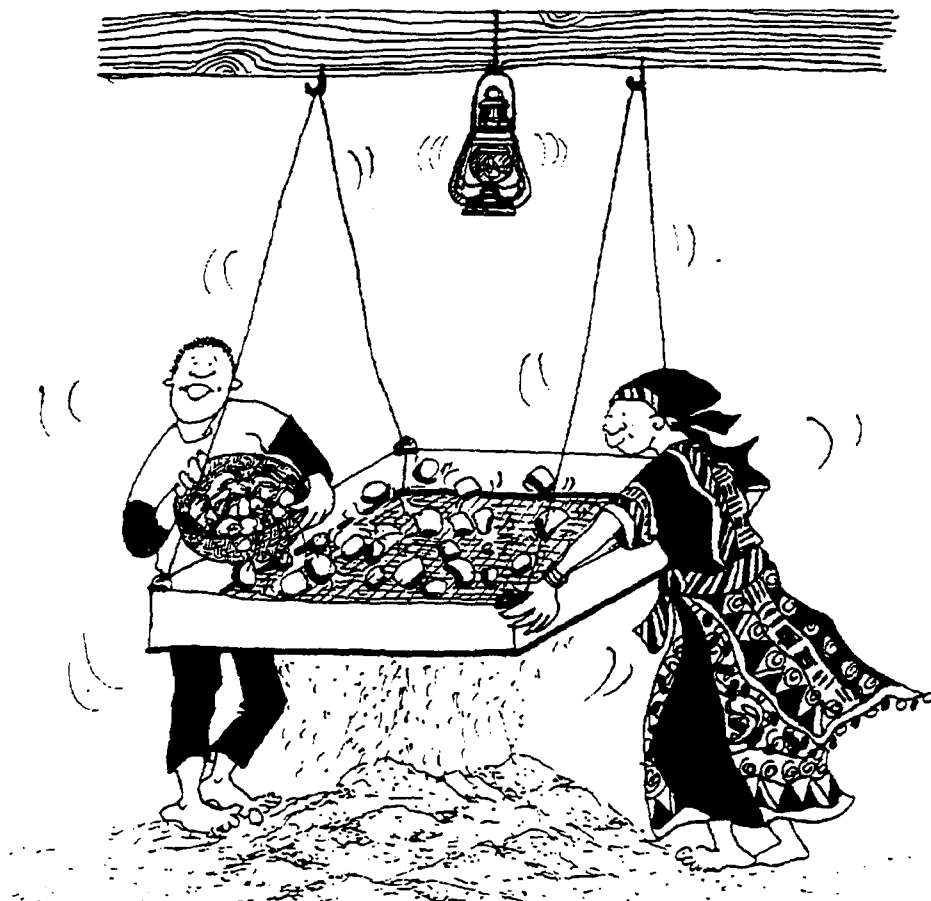
Ox cart wheel crusher

CLAY PREPARATION - Sieving

Sieving is a fast and efficient way of removing stones, roots, etc. They are cheap and easy to build but are not widely used. Instead the stones are usually picked out by hand during mixing and wedging. Whether they are not used because of the extra expense or that sieves get lost or damaged easily is not clear. A well maintained sieve speeds up clay mixture production a lot. A good variety of wire mesh is normally available in many countries though it is usually not sold for use in sieves but for keeping out mosquitos, flies, crop drying, etc. A simple square or rectangular wooden frame is easy to make. If a sieve with a fine mesh is required then the mesh needs to be supported with another coarse mesh underneath.

Sieves need to be looked after well as only a small hole will allow a lot of stones through into the clay mixture. The sieve needs to be examined regularly and repaired immediately. It often takes only one stone in a fired clay stove into making it crack and it then can only be used as grog.

The larger the sieve, the faster it is to operate. Having the sieve supported in some way while it is shaken means that the worker does not have to keep bending down to pick up the sieve every time it is loaded.



Suspended sieve



A supported sieve

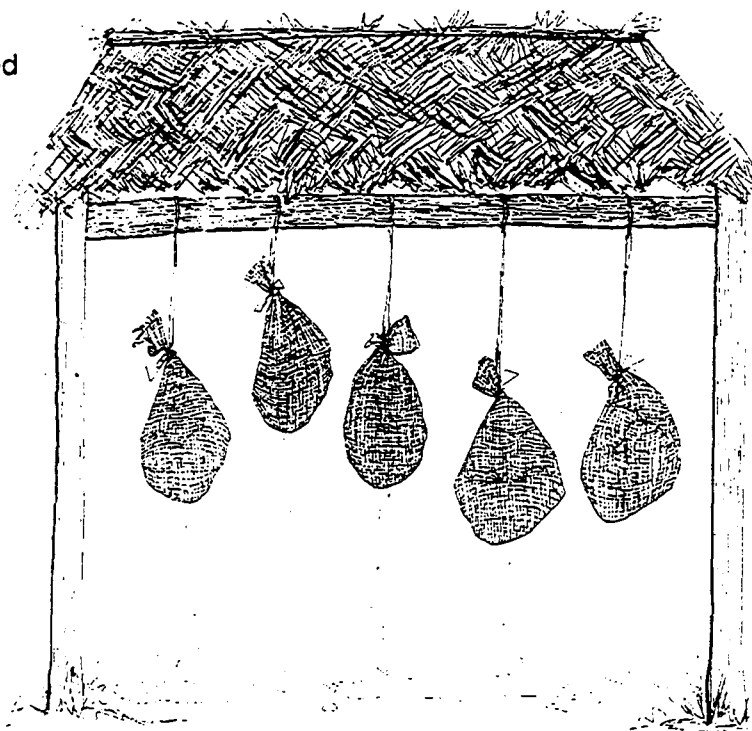
A free standing sieve, that can be moved to the different materials to be put through, is useful. One or two people can shovel material through the sieve very quickly. The sieve does not clog up as long as the material going through is dry. The lumps are left in front of the sieve to be crushed again or thrown away. Sieves and dry materials make dust, so always position the sieve down wind from the workers. If the wind changes, move the sieve round to help minimize the breathing in of the dust.

The breathing in of dust into the lungs can cause "silicosis", often a fatal sickness, and should therefore be avoided at all cost.

DRYING THE CLAY

There is a cheap and efficient method of drying small quantities of clay that have been processed by the wet method. This method does not need the clay to be crushed and is much better for the pottery workers' health. After the clay has been poured through a sieve to remove all stones and debris it is returned to the mixing drum. The clay settles and as much surface water as possible is carefully removed. The remaining clay sludge is then placed in cotton sacks that are hung up to dry.

The remaining water is squeezed out by the weight of the clay in the sack. The air passing around the sacks evaporates also part of the water. The condition of the clay in the sacks can be checked by squeezing it and the clay can be removed at just the right consistency.



Drying clay in bags

STORING THE CLAY

Once the clay mixture is prepared it needs to be stored for as long as possible. This is often overlooked and results in that the clay not being as good as it should be. Keeping the clay wet and sealed up allows the water to spread evenly throughout the mixture. Bacteria should be given time to grow in the clay. This separates the clay particles and allows the water to penetrate fully. If the clay mixture develops a strong earthy smell then it means that the bacteria are at work. Even if the clay is left for only one month, an improvement in its workability will be noticed. This will provide a stronger mixture more able to withstand being made into stoves that will last longer.

To encourage the growth of bacteria in the clay, the mixture can be stored in a pit in the ground lined with plastic sheets. Each layer placed in the pit is sprinkled with water as they are built up to the top, which is formed into a dome.

Finally a large sheet of plastic is placed over the top to cover it over. The pit needs to be sealed carefully so that the water can not escape and covered with grass and leaves to keep the temperature inside constant. The action of the bacteria can be encouraged and speeded up by mixing in some clay mixture that has already been stored in this way with the new batch. Keeping the prepared clay in a cool, damp corner of the workshop covered in wet sacks or plastic sheets will also work, as long as it is not allowed to dry out.

The advantages of preparing clay well in advance and giving it time to stand can not be over emphasized. Clay that is not fully mixed and is not allowed to stand is more likely to fail during production.



Storing the clay in a pit and covered with plastic sheets

FORMING THE STOVES

Hand building

Stoves are made by starting with a lump of clay and pulling it up from the centre to form the basic hollow shape. Once the walls are the right thickness, coils of clay are added to the top to build it up to the correct size. This is the traditional way of making pots in Africa and it can be adapted to make cooking stoves.



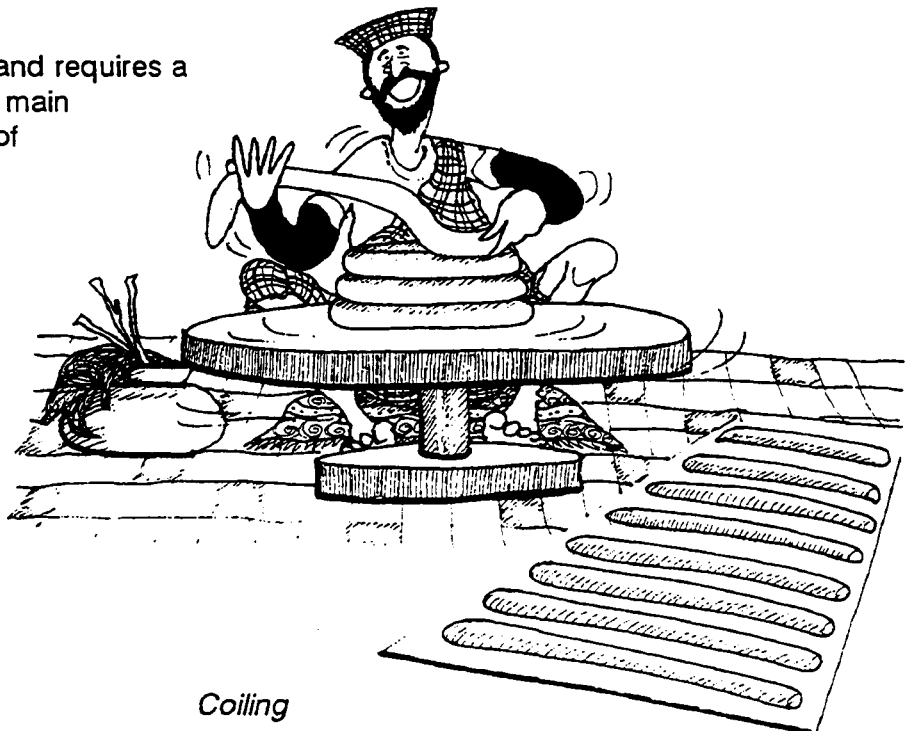
Handbuilding

It is not as easy as it looks and requires a lot of skill and practice. The main problem is getting the size of the cooking stove right every time. This method, however skillfully used, produces different sized stoves which may affect the efficiency of the stove. This method is also very slow with only a few stoves being made a day.

The stoves made in this way will be strong as long as the clay mixture is good and they are fired fully. The reason for this is that the clay particles do not lie in any one direction but are all randomly mixed up. This means that the clay shrinkage is not greater in any one direction within the clay, so there is a reduced chance of drying stresses being set up, and less chance of cracking. For individuals making a small number of stoves it is a practical method of production. Very little equipment is needed and it can be done at home.

Coiling

Coiling is where the stove is built up from coils of clay laid on top of each other, then smoothed together to build a circular wall. It's a little faster than hand building and can be more accurate, especially if templates are used for the stove dimensions.



Coiling

It requires less skill than hand building, some form of turntable and wooden boards make it easier and quicker. Care should be taken to join the coils securely and evenly as otherwise there is an increased chance of cracks occurring between the coils. Using this method ensures that the direction of the particles are random and this is known to help reduce cracking. The coiling method is slow but will produce good stoves if expertly applied.

Slabbing

Clay can be rolled out in sheets of even thickness and then cut to shape.

It is then wrapped around a simple former (a former is something to wrap the clay around to give it shape such as for instance a round piece of wood, etc.). If the roller, with which the clay is rolled out, rests on two wooden rails of equal thickness laid either side of the clay, very even slabs of clay will be obtained. A simple template, laid on the slab of clay and cut around to provide the basic clay shapes, is useful. Clay slabs can be built into all shapes and sizes. If the process is to be made faster and more accurate, simple moulds can be introduced. A shallow wood or steel mould lined with plastic sheet can be used to give the right slab thickness and size every time.



Rolling slabs in a mould

The clay is rolled into the mould and then peeled out ready to be wrapped around the stove former. The former has to be able to slip out easily from the clay wrapped around it (see moulding).

Slabbing is a quick and quite accurate clay building method, producing thin and even walled stoves. Care has to be taken with this method as quite a lot of stress will be set up in the clay. This is because the clay particles get lined up as the slabs are rolled out. These stresses will result in stoves that can crack and distort unless the drying is done carefully. Special care has to be taken where the slabs are joined together around the former as this can be the weakest point in the wall of the stove. More equipment is needed for this method in the form of a roller, former, table, perhaps a flat mould and plastic sheets. These tools will increase the expense but also help increase the accuracy and reduce the skill levels required.

Moulding

Improved stoves have to be made to the right size every time for them to be as efficient as possible. Making them by hand, however skilled the potter, will still result in a number of stoves that are slightly different. Where unskilled workers are used to make stoves, they need help in keeping the size and thickness of the stoves right. Therefore to reduce the number of stoves that are made incorrectly, moulds can be used for all or part of the production process. Moulds have to be strong and well made so that they last a long time and do not change shape. They need to be as cheap as possible and straight forward in design so that they can be easily cleaned, repaired or replaced as necessary. They will require a releasing agent (a material which prevents that the clay sticks to the mould) so that the moulded part comes out easily with a good smooth finish.

The cheapest, most freely available releasing agent is sieved dry ash. The mould is cleaned of old clay, sprinkled with ash while still wet, and the clay is placed carefully inside so that it does not disturb the ash layer. Sand and waste engine oil, a mixture of kerosene and coconut oil, etc. can also be used as a releasing agent but they are in general not as good as ash. In particular where oil is used as a releasing agent, any clay that has come into contact with it has to be thrown away as the oil may cause problems in case the clay is used again for stove making. Plastic sheets are also good for slabs but they leave marks on the clay that have to be smoothed over.

Press Mould

Press moulds are the simplest form and are used to make sure that the outside dimensions of the stove are correct. The inside dimensions and an even wall thickness depends on the skill of the mould operator. The moulds can be made of wood or steel sheet but do need skill and machinery to be made properly. Press moulds made from a block of material like fired clay, plaster or cement are very useful for moulding pot rests, etc. These types of moulds can be easily cast over a well made and finished clay original. Of these, cement has proved to be the cheapest, most hard wearing and freely available material, but it still needs the use of a releasing agent.

Paddle Mould

A paddle mould is the next step after press moulding. It is a bowl shaped press mould that slots onto a base plate that is fixed to a table. The base plate has a hole into which fits a rotating paddle, when the paddle is turned it accurately forms the inside dimensions of the stove. The wall thickness is kept even and the clay is compressed up the sides of the mould, helping to strengthen it.



Stove moulding with a paddle mould

The paddle is removed, the bowl comes off the base plate and the stove can be tipped out to dry.

Throwing on the Wheel

Forming stoves on a potters wheel requires a lot of skill. Where these skills are available, this method produces beautiful round stoves of even thickness quickly. Getting the dimensions right still requires measuring sticks and templates, at least to begin with. There are some disadvantages though: Clay particles do get lined up along the surface of the stove when made by this

method. This does increase the possibility of stresses being set up within the clay and cracks may be formed as a result. Besides, a very plastic clay that requires a lot of grog, sand, rice husks, etc. in the mixture can become too coarse for the potter to work on the wheel.



Hand throwing stoves on a potters wheel

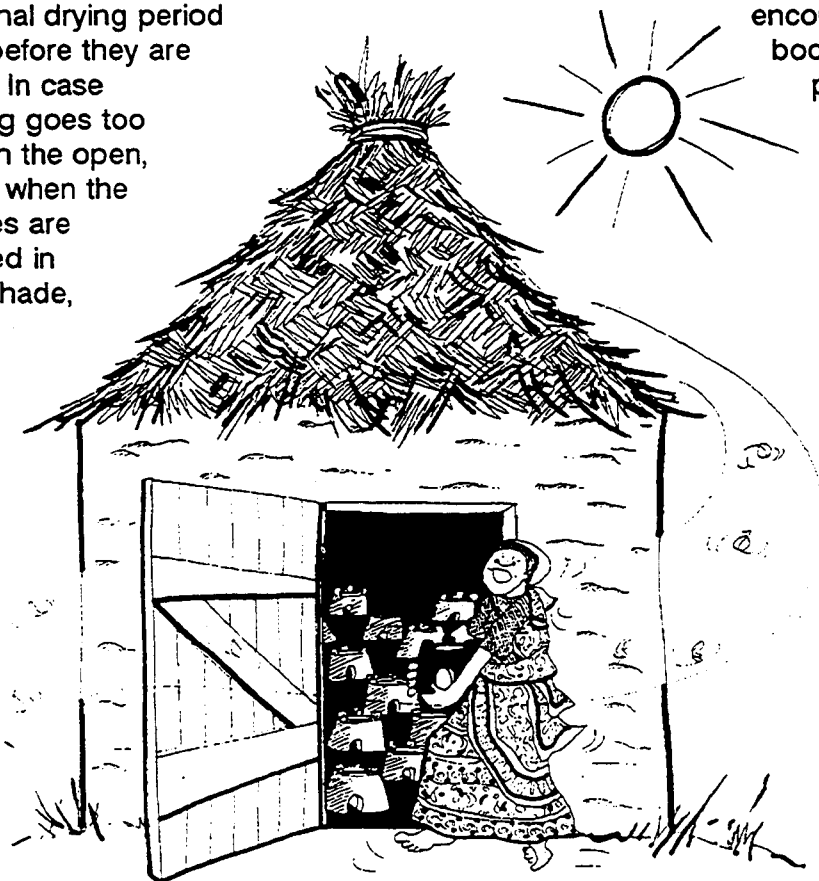
DRYING THE STOVES

Improved cooking stoves and liners are much thicker than the water- and cooking pots that rural potters usually make. They take a lot more time to dry and because of this they dry unevenly. Most of the shrinkage takes place during drying and not later when it is fired. As clay dries it will shrink a lot (up to 10% or more). If the stoves are allowed to dry unevenly stresses are set up within the stove because of the uneven shrinkage that results. If the stress becomes too great, cracks form that can be seen immediately or can be seen later after firing. It is therefore important to dry clay stoves as slowly and evenly as possible.

Stoves need to be kept out of any wind or direct sunlight until the final drying period just before they are fired. In case drying goes too fast in the open, even when the stoves are placed in the shade,

the stoves should be placed in a draft free and damp atmosphere for the first few days. If they can be covered by plastic sheets it would be good, or they can be placed in a closed area where wet sacks are hung up to provide a moist atmosphere. The stoves need to be turned at regular intervals throughout the drying period, which could last several days, depending on the weather. A test to see if there are any drying cracks in the stoves once they are dry, is to paint them with kerosene. The kerosene quickly evaporates from the surface of the stoves, but takes longer from any cracks, so that they can be easily seen.

Cracks can be repaired by several methods but, as this often leaves a weak spot, should not be encouraged. Anyway, this booklet is aimed at preventing cracks in the first place, so it is not covered here.



Drying stoves in the shade is sometimes necessary to prevent cracking

FIRING THE STOVES

The firing of stoves and stove liners needs to be done in the same way as the drying, slowly and for a longer time than for thinner pottery items. Stoves have thicker walls than cooking- and water pots and during the first part of the firing (water smoking), the water has to be allowed to slowly leave the centre of the clay. If this stage goes too fast, the water becomes steam within the clay, and may build up enough pressure to crack the sides of the stove. Up to 120 degrees Celsius (°C) a very small fire should be maintained over a long enough period of time. Burning waste biomass such as sawdust, rice husks, coffee husks, etc., which can be left to smolder, is ideal for this period.

One of the benefits of improved cooking stoves is that they save fuel by being more efficient. If they consume a lot of wood fuel when they are being fired, they then have to save the fuel that made them, before having an impact on the overall wood fuel situation. Therefore the more available waste fuels and the less wood the kilns consume, the better. Using a variety of fuels for each firing can reduce the amount of wood used and also make the process less expensive for the potter. Starting the kiln firing with a slow burning waste material like sawdust is ideal, then, as the temperature rises, a faster burning fuel like coconut husk, maize cobs or straw can be used. Wood need then only be used to obtain and hold the top temperature, which is not very high by pottery standards. Most clay stoves are fired to between 750°C and 850°C though the maximum temperature depends on the type of clay and mixture used. A balance has to be found where the stove is fired at the lowest temperature possible but still leaves it strong enough to withstand transportation and daily use.

The lower the temperature means less vitrification (melting and glass forming) which results in a softer and more porous stove. This in its turn is better at withstanding the heat shock conditions of the fire place.

Once 120°C is passed and the kiln has stopped steaming, the firing can move much faster up to the top temperature. The first visible indication that the temperature is around 500°C is when the stoves begin to glow a dull red. It is from this temperature that the ceramic changes begin in the clay as the water in the clay crystal structure is removed. This goes on until between 600 and 700°C as the colour in the kiln changes from a dull red to strong red. Once this crystal water is driven off it can not be replaced anymore and the clay has changed to pottery. Next the carbon in the organic matter (small parts of roots, etc.) and sulphur begin to burn out slowly and this will continue to 900°C and beyond.

At 800°C vitrification begins, though with clays containing a lot of iron and in a reducing atmosphere (shortage of oxygen) it can start earlier. Vitrification is where the silica first melts followed later by the clay particles themselves. In melting they stick together to form a strong brittle material. This is a gradual process that starts with the silica in the mixture melting to form glass that fills up the gaps between the particles sticking them together like a glue. The temperature at which this starts and the speed at which it occurs depends on the amount and type of fluxes in the mixture. Fluxes are mineral oxides that react with the silica getting it to melt and turn into glass.

If the atmosphere in a kiln during firing does not have much oxygen in it because it is all used up by the burning fuel it is said to be reduced. If the fuel is not using all the oxygen being drawn through the kiln then the atmosphere is said to be oxidized.

The amount of oxygen in the kiln is important because it affects the fluxes in the kiln which in turn affects when vitrification starts, and how fast it takes place. Kilns burning biomass fuels tend to have a reduced atmosphere which gets the fluxes started at a lower temperatures. This means that the fired clay is stronger at a lower temperature.

THE FIRING CYCLE

Temperature in °C and colour inside the kiln		
1000	Yellow	VITRIFICATION Soda and potash flux the free silica to fuse the clay particles together
900	Orange	
800	Bright cherry red	BURNING OUT
750	Cherry red	Carbon and sulphur are burnt out. Porosity starts to reduce
700		
650	Dark red	CERAMIC CHANGE The water that is part of the clay's crystal structure is driven off at this stage. This results in the change from clay to pottery
480	Lowest visible red	
350		
120		DECOMPOSITION Any organic matter is burnt off at this stage. (Firing can proceed quite quickly)
20		WATER SMOKING The remainder of the water is finally driven out of the clay. (Firing should proceed very slowly)

KILNS

Stoves, due to their thickness, require a firing that is slow and steady to start with and then increases quickly to the top temperature. The top temperature then has to be held for at least an hour, while the heat penetrates the clay. To be able to control the heating up and to slow the cooling down, some type of kiln is required. Kilns have fireboxes, stoke holes or air holes that allow control of the fire. They improve the efficiency of fuel combustion by creating a controlled draft through the fire. They allow for the efficient burning of different fuels. They contain the heat produced so that as much as possible is concentrated on the stoves being fired in the kiln.

Fired clay stoves and stove liners made from the majority of locally available clays do not need a very high firing temperature, so complicated and expensive kilns are not necessary. The efficiency of the kiln is also important. It needs to get as much of the available heat as possible into the stoves to be fired and not let it escape up the chimney or into the open.

Kilns exist in all shapes and sizes and before one is built, the potter needs to think carefully about the needs and balance this against the available resources. There are a few questions to be asked:-

1. What is the capacity of the workshop and how often does the potter want to fire the kiln to maintain the cashflow? This will influence the size of the kiln.
2. How much does the potter want to spend, both in time and money? This will influence the sophistication of the kiln as well as the choice of building materials to be used for the kiln. Can the potter make his own bricks and parts of the kiln or does this have to be bought along with the necessary masonry skills?
3. What is the level of expertise and assistance available? This will influence the type and complexity of the kiln chosen. Will the potter build a design that is only for his needs, or copy and adapt the type of kiln already used locally.
4. What fuel types are available and at what cost? Fuel for the kiln is usually the biggest continuous cost involved during production. Kilns are designed to burn certain fuels more efficiently than others.

Answering these questions will limit the choice of kiln considerably, but still allow room for new ideas and modifications. For small workshops the kiln is always better built small, which makes its operation more flexible. Also it should be straight forward to build and operate, as its reliable and continuous use is vital for the livelihood of the potter.

The Round Enclosed Fire Kiln

This kiln has many advantages over more sophisticated types of kilns:-

- It is cheap and easy to build and does not require too much skill to operate.
- It is adaptable in that it can be built to any size and will burn all types of fuel.

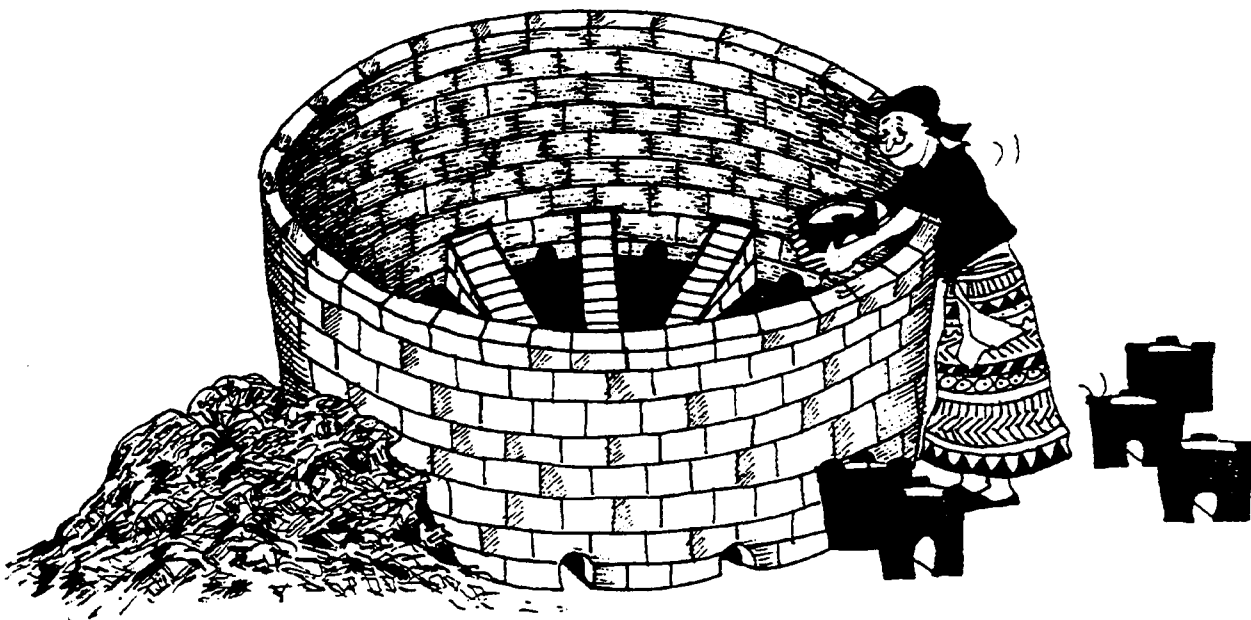
The disadvantages are:-

- It is not easy to control as once the fire is started no more fuel can be added.
- Controlling the combustion is difficult and it does not burn the fuel very efficiently.
- The firing can go too fast for cook stoves and be uneven across the kiln.

The kiln consists of a circular wall enclosing a raised floor which is arranged like the spokes of a wheel. There are small air holes arranged around the bottom of the wall that are positioned between the brick spokes of the floor. The kiln is loaded with wood at the bottom between the spokes. The stoves are then placed on top so that they rest on the spokes. The kiln is filled with sawdust, rice husk, charcoal dust, etc. and covered with a thick layer of grass or straw. The top can be covered over with a layer of mud or iron sheets.

A layer of mud is better at holding the heat and controlling the fire, as holes can be made in it during the firing, to help spread the heat throughout the kiln load. The air holes around the sides of the kiln can be opened and closed during the firing to control the heat within the kiln. The direction and strength of the wind, which may affect the speed and evenness of the firing, has to be taken into account when using this type of kiln by opening or closing the air holes.

The basic design of the kiln can be improved by building a circular double wall instead of a single wall. This increases the strength and working life of the kiln structure. It also provides better insulation to increase the available heat in the kiln and to slow down the cooling of the firing in particular when the small cavity, left between the inner and the outer wall, is filled with an insulating material such as clay mixed with rice husks, sawdust, etc. It is better not to fill this cavity with loose material such as ash, as the ash will also flow into cracks in the kiln wall and this may destroy the kiln as it no longer can contract freely during cooling.



The round enclosed fire kiln

Square Traditional Kiln

This is a square or rectangular kiln, single or double walled, that has three or four stoking holes running through the middle. It is easy and straight forward to build because of its square shape. The floor consists of short brick pillars that the stoves have to be carefully placed on, so that they bridge the spaces between the pillars. The heat flows between the pillars under and up through the stoves. Special long bricks are made to bridge over the stoke holes at regular intervals. The advantages are:-

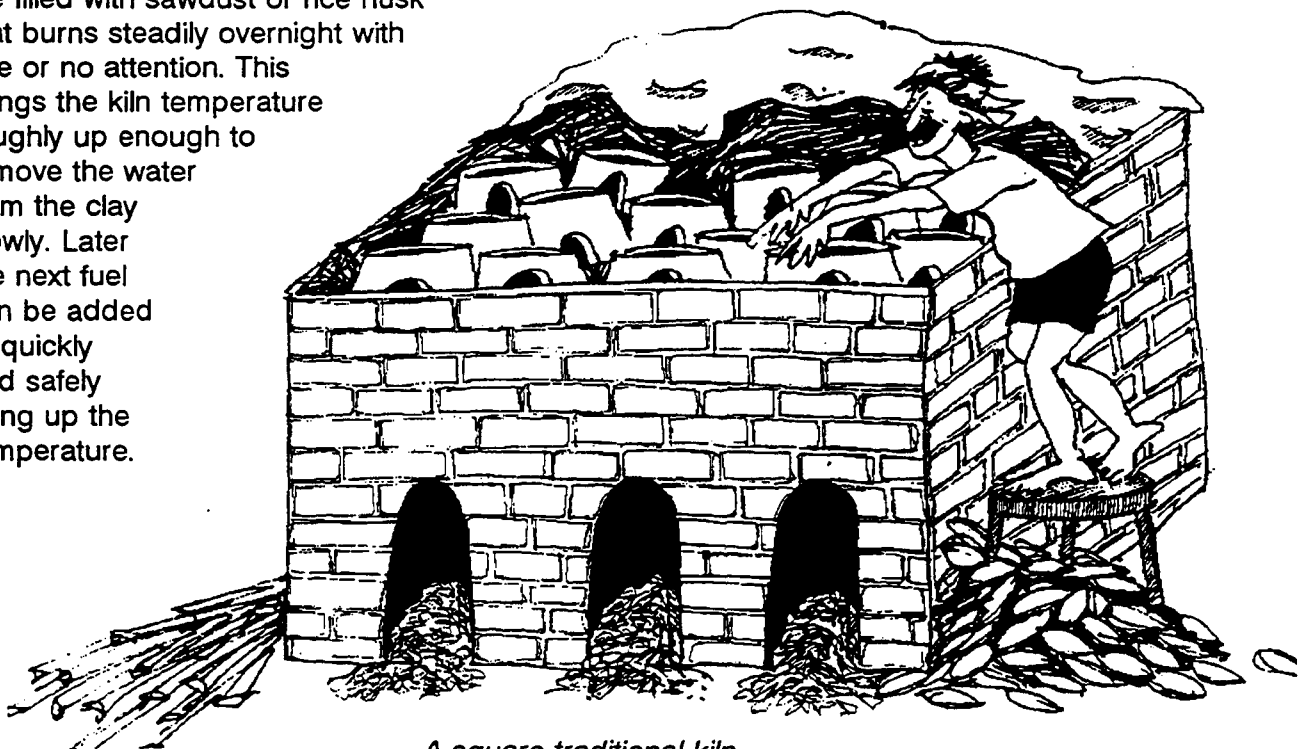
- Cheap and easy to build though care does have to be taken with the building of the floor of the kiln.
- It is not too difficult to operate and can be controlled by increasing and decreasing the fuel in the stoke holes.

The kiln will burn all types of biomass fuels. The first stage of the firing, where the stoves need to warm up slowly can be achieved with ease. The stoke holes are filled with sawdust or rice husk that burns steadily overnight with little or no attention. This brings the kiln temperature roughly up enough to remove the water from the clay slowly. Later the next fuel can be added to quickly and safely bring up the temperature.

Disadvantages are:-

- The floor is delicate and the kiln has to be loaded very carefully and skillfully because of this. The bridging bricks over the stoke holes have to be frequently replaced as they take a lot of heat and crack.
- The fuel does not burn as efficient as it could. This is good for starting but not so good later on in the firing.
- Due to its square shape the heat distribution of this kiln is not very good and the corners fire at a lower temperature than the rest of the kiln.

Modifications were tried with the stoke holes going from corner to corner. This solved the heat distribution problem, but was not accepted by the potters who kept with the side to side model. The corner to corner stoke holes were too long and, because they crossed in the middle, they could not be stoked straight through. It also made the construction of the kiln more complicated.



A square traditional kiln

Bottle Shaped Kiln

This basic shape is good at concentrating the heat in the kiln and provides a good draft to help the fuel burn more efficiently. In its most basic form it is loaded with fuel and stoves, the doorway is closed up to leave a small spyhole at eye level and an air inlet at ground level, the kiln is lit and just allowed to go. The air inlet can be opened and closed to allow for some firing control, but this is minimal.

A raised floor can be built in to allow the heat from one or several fireboxes, built around the outside of the kiln, to flow in and up through the stoves stacked inside. Fireboxes allow for much more efficient burning of the fuel and, fitted with firebars (grate) and air control, a lot more heat can be obtained.

This shape of kiln can be built with a firebox running under the floor through the middle of the kiln. The advantage of this is that all the heat goes up into the kiln instead of being partly lost through the walls of the outside fireboxes. Fireboxes are designed to be highly efficient for one main fuel, they do not work so well with multiple fuels. Unless specially designed, they tend to block up in case fuels such as sawdust or rice husk are used.

Kilns with fireboxes are not really necessary for the firing of cooking stoves as the temperatures required are not very high. Fireboxes are expensive to build and complicated to operate and will provide temperatures of 1,000°C and above, which is generally not needed for stove firing.



A bottle shaped kiln

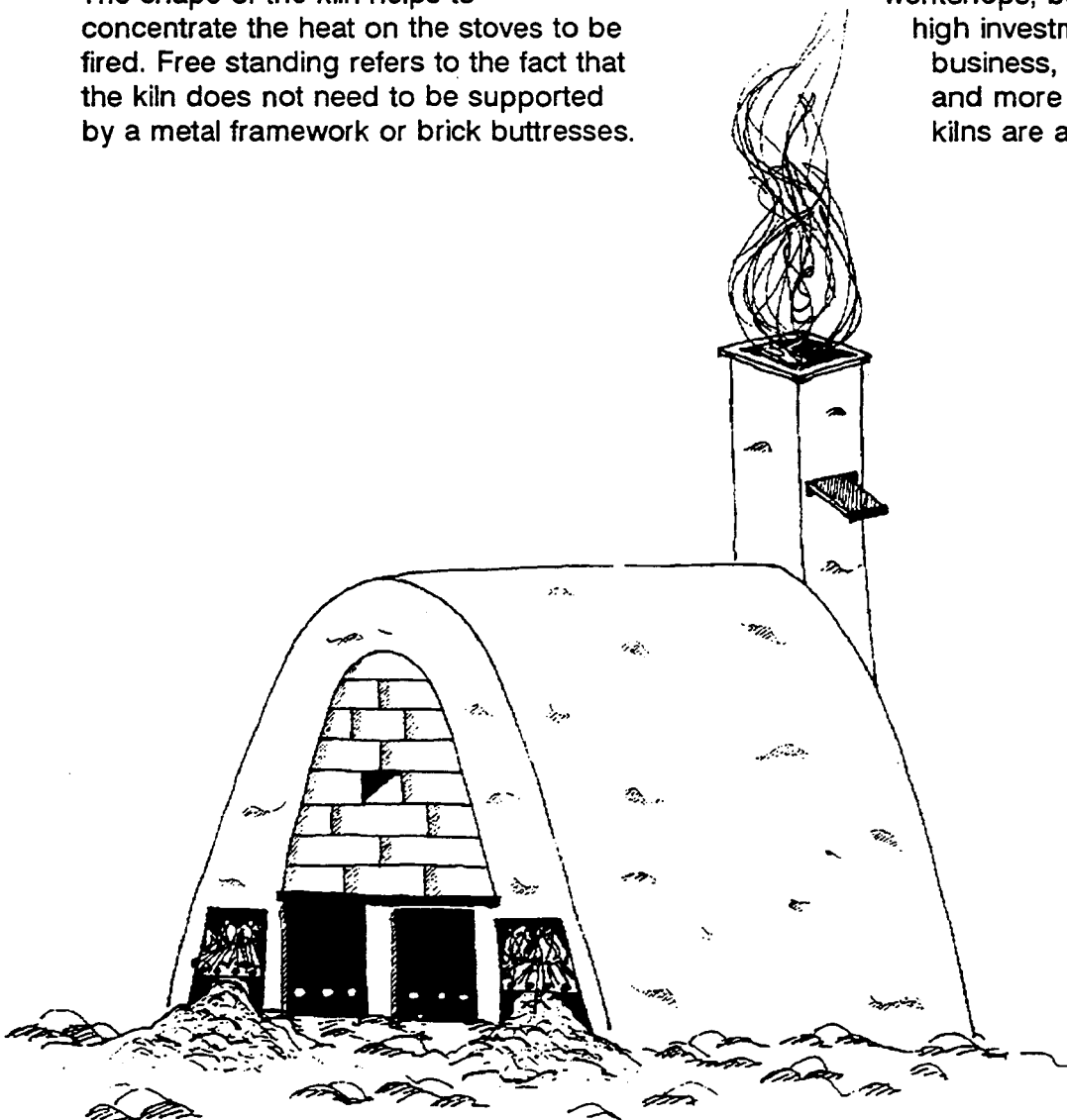
Catenary Arch Kiln

This is a highly efficient free standing down draft kiln. Fuel efficient because the fireboxes run down either side inside the kiln, so all available heat is inside the kiln. It is also efficient because it is a down draft. This means that the heat from the side fireboxes first goes up and then is drawn down through the floor of the kiln and out of the chimney. This means that the heat travels further and spends more time in the kiln, so is more able to be transferred to the stoves inside the kiln.

The shape of the kiln helps to concentrate the heat on the stoves to be fired. Free standing refers to the fact that the kiln does not need to be supported by a metal framework or brick buttresses.

This type of kiln is complicated and expensive to build and to operate. There are steel plates or doors that fit over the fireboxes. These are fitted with two sliding doors to allow the adjustment of both primary and secondary air. A sliding metal damper is fitted into the chimney to control the hot gasses leaving the kiln. This kiln uses wood as fuel unless specially and expensively fitted to use sawdust and other biomass fuels. The kiln can reach high temperatures, if built

the right sizes for small workshops, but represents a high investment for a small business, when cheaper and more appropriate kilns are available.



A catenary arch kiln

SUGGESTED FURTHER READING

"Testing Clays for Ceramic Cooking Stoves: A manual on the clay/non clay ratio measurement technique" This manual is referred to on page 4 of this booklet and describes the so-called "Clay to Non-Clay Ratio" in detail. Written by Dr. Anura Gaspe, Dr. Peter Messer and Pete Young. The publication is available from ITDG, Myson House, Railway Terrace, Rugby CV21 3HT, U.K.

Three books written by Henrik Norsker, and all available through GATE-GTZ in Germany, P.O. Box 5180, D-6236, Eschborn are also good general reference works for potters. The titles are: "Clay Materials for the Self-reliant Potter", "Forming Techniques for the Self-reliant Potter" and "Glazes for the Self-reliant Potter". The latter book deals with glazes and is of little interest to potters who only make stoves.

"Testing of Pottery Clays" Final report of a project dealing with research on clay types used for the manufacturing of ceramic stoves. Report available through HSE, P.O. Box 167, Chiangmai 50000, Thailand.

"Improved Wood Waste and Charcoal Burning Stoves; A practitioners manual". Available through ITDG or from IT Publications, 103-105 Southampton Row, London WC1B 4HH, U.K.

"The Kenyan Ceramic Jiko: A manual for stove makers". This manual describes in detail the manufacturing techniques used to make the Jiko stove. The book includes detailed construction drawings of production equipment and a bottle kiln.

THE AUTHOR



Mr Tim Jones was born in 1949 in Bromley, South London. He taught Ceramics at Charles Darwin School Biggin Hill for six years before moving to Kenya to work for three and a half years as the Ceramics Specialist and Production Manager for the Women and Energy Improved Cooking Stove Project. In Kenya he was responsible for the R & D of the Ceramic Parts of the Meandeleo cooking stove, establishing 5 stove production centres across the country.

He returned to England in 1987 to work as a Project Manager for I.T.D.G., the Intermediate Technology Development Group until 1991 when he left to become an Independent Consultant specialising in Rural Energy and Ceramics in Developing Countries. It was during his time in Kenya and at I.T.D.G. that he was involved in working on clay mixtures and production methods suitable for the manufacture of ceramics components for use in a wide variety of improved cooking stoves worldwide.

This booklet is based on his experience gained while working with potters in 13 countries over 12 years of full time involvement in the area of rural energy and ceramics. The finding and processing of clays and the production of many different ceramic products by small scale producers around the world has been and still is his speciality. He is currently working the design and promotion of efficient low cost kilns, furnaces, ovens and dryers for use by small scale entrepreneurs in developing countries. This work is of growing importance in many areas because of dwindling woodfuel supplies and the growing awareness of the detrimental effects of air pollution.

If there are any questions relating to this booklet or requests for further information Mr Jones will be pleased assist and can be contacted in the U.K. on Tel/Fax +44 (0)5394 46811. Just leave a message or fax if he is abroad for a while.

Cumbria U.K. 14th June 1994