PRACTICAL ACTION
Technology challenging poverty

How to build, Use and Maintain

A BETTER BONFIRE KILN

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How to build, Use and Maintain A Better Bonfire Kiln

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Intermediate Technology Kenya 1996

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Cover photo: A member of the Keyo Womens Group at Kisumu adds fuelwood into the firebox.
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Chapter One

INTRODUCTION

Background

There is a story that people first discovered pottery by accident. A basket used for carrying grain, smeared on the inside with mud from a nearby river bank, accidentally rolled into the fire. The basket burned away leaving a brittle shell. The people discovered that this shell did not dissolve in water and in fact could hold water, was heat resistant and so could be used for cooking food.

Figure 1.1 How pottery was discovered

If this story is true, the mud from the nearby river bank must have been clay. Clay is a substance formed by the weathering of rocks such as granite. The tiny particles of rock wear off and are washed down to collect in natural clay deposits.

Firing is the process of baking sun-dried clay which transforms the clay into pottery. During firing, the clay becomes a brittle substance which is no longer soluble in water. Fired clay pots will hold water, are heat resistant and so can be used to cook food. Most earthenware clays change colour during firing.

In Kenya, many traditional potters still fire their pots in an open bonfire, or a bonfire in a traditional pit. This method of firing is advantageous because it is cheap and is fairly simple to operate. The disadvantages are that it does not work well in wet or damp conditions. The bonfire burns and cools very fast. This sometimes causes the pottery to crack. In windy conditions, the firing can be uneven and so some pots do not get fired, thus using a lot of fuelwood and dried grass.

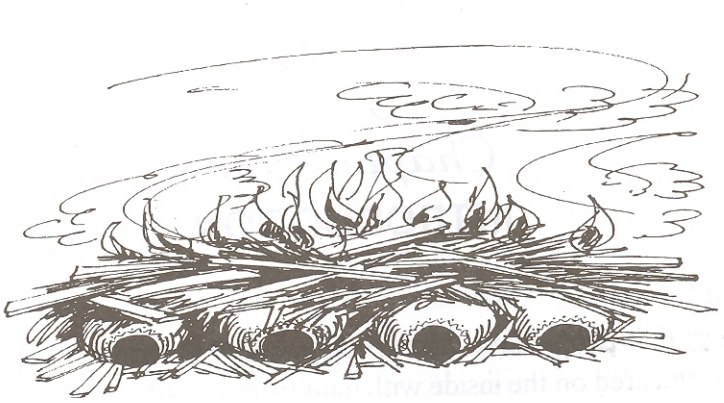


Figure 1.2 A traditional bonfire

A shallow pit or a wall built around the fire can protect the fire from wind and slow down the firing process. This cannot, however, be used in rainy conditions.

Figure 1.3 Pit firing

There are many other designs of kilns, varying from a simple brick or stone surround, to the traditional bonfire to the more sophisticated Bottleneck and Down Draught kilns. The latter can be used to reach higher firing temperatures because they distribute the heat more evenly. Despite being more efficient than the traditional bonfire, such kilns are expensive and complicated to build. They are also difficult to use and maintain.

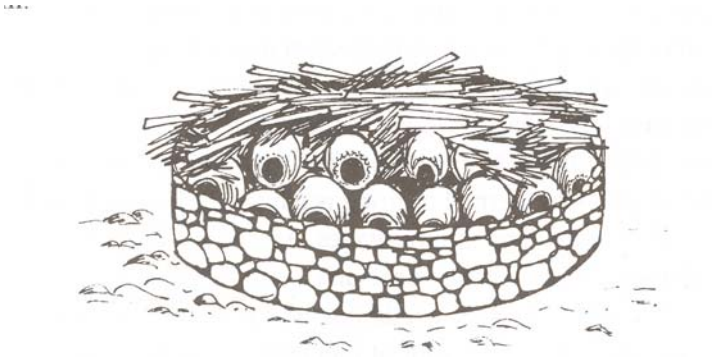


Figure 1.4 A protected bonfire

There are other types of kilns designed to use other fuels such as gas, oil or electricity.
These are, however, too expensive for traditional potters to buy and run.

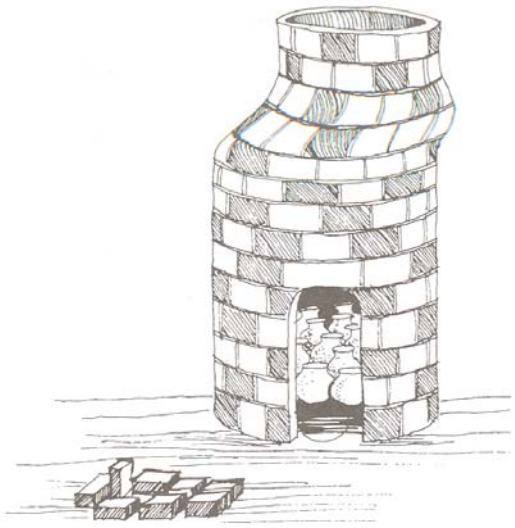


Figure 1.5 A Bottleneck kiln

Figure 1.6 A Down Draught kiln

Why design a new kiln?

In 1989, IT started to train groups of women potters in West Kenya to produce and market an improved cooking stove. The stove, known as Upesi or Maendeleo, is designed to burn wood and agricultural waste such as maize cobs and stalks. The improved cooking stove uses less fuel than the traditional three-stone fire. It produces less smoke and is safer for both the cooks and their children.

The stove 'liner' is made from fired clay. When the pottery groups first learnt to make the stoves, they fired the liners in Figure 1.7 An Upesi liner their traditional bonfires or pits. The potters were often unable to fire their products during the rainy season. As with their pots, quite a high number of stove liners cracked during firing, sometimes as much as 40 per cent or even higher due to the rapid and uneven heating and cooling processes. The liners have thicker walls than the traditional pots, so they need to be fired for a longer period than pots. Experience of firing Upesi liners in Kenya has shown that if temperatures of 600°C to 700°C are reached and held for two to three hours, the liners will be adequately fired. This is difficult to achieve with a traditional bonfire.

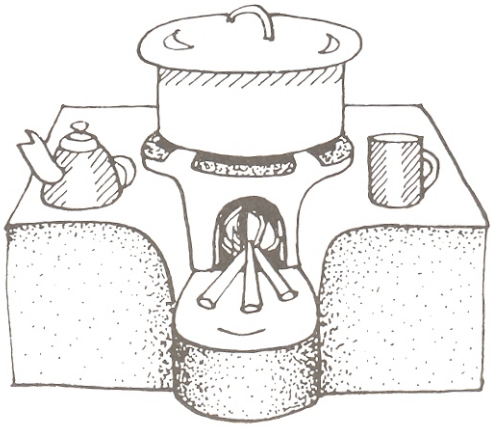


Figure 1.8 An installed Upesi stove

In September 1992, ITDG's Stove and Household Energy Programme in Kenya began a one-year Kiln Project to research on alternative simple and affordable methods of firing pottery products. The idea was to develop an intermediate kiln.

The design criteria were to ensure that the new kiln was:

- made using local materials, in this case local bricks

- affordable
- simple to build, use and maintain
- reduced firing losses to less than 10 per cent
- reduced fuel consumption, especially the use of grass which was becoming increasingly difficult to obtain.

To reduce the firing losses, the new kiln would have to:
- slow the heating stage of the firing
- slow the cooling stage
- make sure that the heat in the fire is distributed evenly.

The idea of the mud dome was borrowed from Asia, where many potters use this simple technique to keep heat in their kilns.

The result of the research was:

THE 'BETTER BONFIRE' KILN

Better because:
- it holds in the heat - so it requires less fuel.
- it heats up and cools down slowly - so less pots and stoves crack (less than 10 per cent)
- it distributes the heat more evenly - so pots and stoves are more evenly fired
- it is made of local bricks using local skills - so it is cheap to build
- it is easy to build, use and maintain.

Purpose of this manual

The manual explains how to build, use and maintain a Better Bonfire kiln. It is intended for potters, women groups engaged in pottery activities, and agencies who work with potters. So, if you:
- get too many cracks
- have problems firing in the wet season
- use too much grass or wood for firing;

a Better Bonfire kiln could be the answer.

There are some points in the use and construction of the kiln that are very important.
These have been marked in the text with the symbol:

Chapter Two

KILN DESCRIPTION

The Better Bonfire kiln is a simple structure built from locally made bricks. The kiln is constructed on a slightly raised foundation to protect it from damp. It is a brick cylinder built over five firebox channels. For each firing, a mud dome is made over the kiln to keep in the heat.

Parts of the Better Bonfire kiln

Foundation	- the solid base of the kiln that raises it slightly above ground level
Firebox	- the channel where the fire burns. There are five fireboxes
Floor	- the area above the fireboxes where the first layer of pots or stoves sit
Wall Mud dome	- the outer wall of the kiln - the dome shaped roof of the kiln made of grass and mud. It reduces heat losses from the top of the kiln
Firing Chamber	- the space inside the kiln above the fireboxes. This is the area where the stove or pots are fired

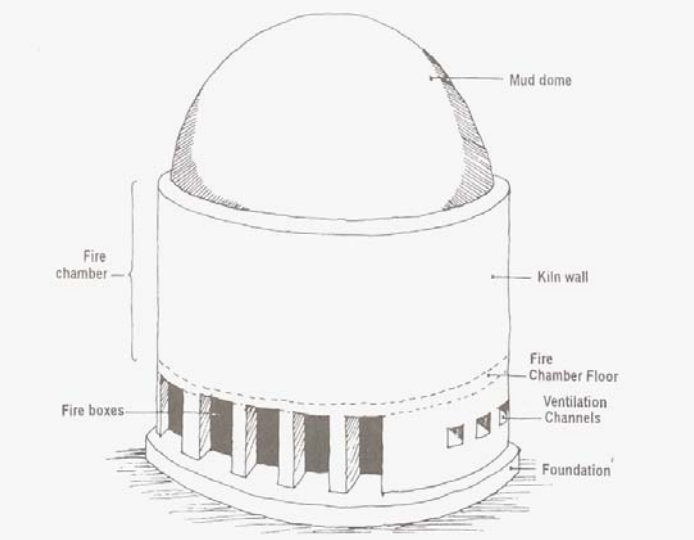


Figure 2.1 Parts of the Better Bonfire kiln `

Chapter Three

KILN CONSTRUCTION

Good quality materials and care in construction will result in a long lasting and effective kiln.

The following is the list of materials that we used in Kenya. These materials were readily available, but if they are not readily available in your area, you should improvise. For example, if the standard fired clay bricks available are of a different size, you will need to adjust the numbers required.

The materials required for the big and small kilns and their quantities have been given in the tables below. The big kiln can accommodate up to 120 stoves. You can load up to 30 Upesi stoves in the small kiln.

Table 3.1 An example of materials required for construction of the big kiln

Material	Quantity	Specification
Fired clay building bricks	400 100	Large $9_{1/2}$" x 5" x $4_{1/2}$ Small $8_{1/2}$ x 4 x $3_{1/2}$
Polythene sheet	7 metres	Heavy duty 2m width
Stones	10 wheelbarrows	Hard stones that do not absorb water
Murram (clay gravel/laterite mix)	20 wheelbarrows	Medium coarse
Sand	10 wheelbarrows	Building sand if possible
Anthill soil (or building earth)	10 wheelbarrows	
Water	500 litres	This is equal to 4 drums of water
** Reinforced rod	12 metres	$_{1/2}$" diameter twisted bar
** Tire wire	2 kg	$_{1/8}$" diameter
**/* Binding wire	2kg	
* Chicken wire	8 metres	$_{1/2}$" mesh

Table 3.2 Materials requiredfor construction of the small kiln

Material	Quantity	Specification
Fired clay building bricks	100 100	Large $9_{1/2}$" x 5" x $4_{1/2}$ Small $8_{1/2}$ x 4 x $3_{1/2}$
Polythene sheet	2 metres	Heavy duty 2m width
Stones	6 wheelbarrows	Hard stones that do not absorb water
Murram (clay gravel/laterite mix)	10 wheelbarrows	Medium coarse
Sand	6 wheelbarrows	Building sand if possible
Anthill soil (or building earth)	6 wheelbarrows	
Water	300 litres	
Ceramic plates	6	25 x 20 x $2cm^3$

.:. Materials marked ** are for a metal support frame over the firebox doors. This can be replaced by fired clay bars to support the brickwork over the doors.

.:. Materials marked * are for a wire mesh skin to strengthen the wall of the kiln. These are optional.

- The thickness of the kiln wall must be maintained. It will be equal to the length of the bricks. For efficiency and durability, the minimum thickness of the wall should be 10 inches.
- If you are using smaller or bigger bricks, you will need to either increase or decrease the number of courses required to attain the recommended kiln height, which is 75 cm. The recommended height of the firebox channels is 30 cm.

Tools and equipment used for construction

.:. rammer
.:. pick
.:. tape measure
.:. builder's line
.:. mason's hammer
.:. spade or hoe
.:. wheelbarrow
.:. plumb line
.:. spirit level
.:. mason's trowel

Figure 3.1 The tools required

Choosing a suitable site: what to look for

Figure 3.2 A suitable site

Good drainage
The site needs to be well drained and if possible above the surrounding ground. This will ensure that the kiln and its foundations are not under water during the rainy season.

Storage space
You should have enough space around the kiln for stacking stoves and for storing fuelwood.

Safety
The site needs to be a safe distance from houses, structures with grass thatched roofs and stored fuelwood. When firing, smoke and sparks may come from the sealing (roof) and fireboxes.

Chapter Four
BUILDING THE KILN

The foundation

1. Level the ground where you plan to build the kiln.

2. Stand a straight stick upright in the centre of the foundation with a piece of string measuring at least 120 cm long.

3. Tie a short sharpened stick to the other end of the string, about 110 cm from the centre pole. Use the stick to mark a circle of 220 cm diameter. This is the outer diameter of the kiln.

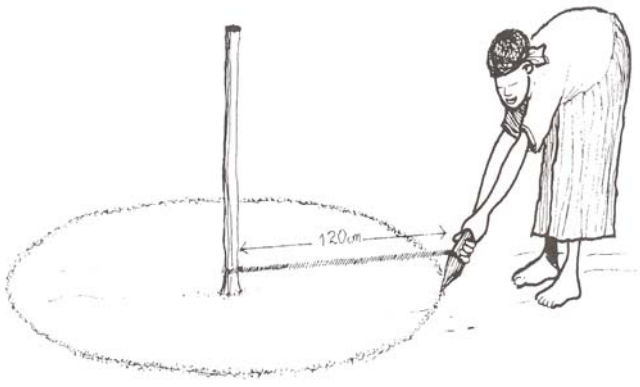


Figure 4.1 Marking the diameter of the circle

4. Dig a circular pit; 220 cm diameter and at least 50 cm deep.

Figure 4.2 Digging the foundation

5. Cover the bottom of the pit with a layer of sand. This layer should be at least 5 cm thick. Lay the polythene sheet over the sand in the bottom of the pit covering the base and the sides of the pit, and overlap at the top by at least 10 cm. This is the damp-proofing. Put another thick layer of sand in the bottom of the pit over the polythene sheet to protect it from sharp stones.

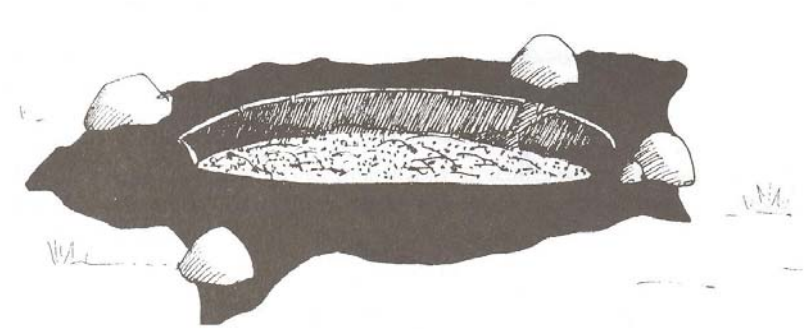


Figure 4.3 Lining the foundation

6. Fill the pit with broken stones. These should be the hard type that do not soak up water. Put a final layer of small stones, chippings or bits of broken pottery and flatten it with a rammer or piece of wood. Spread a thin layer ofmurram over the stones and ram it to form a solid surface. Ensure that the foundation is level using a spirit level if you have one. Where it is not level, use more murram to make it level.

Figure 4.4 Levelling the foundation

The top of the foundation should be just above ground level.

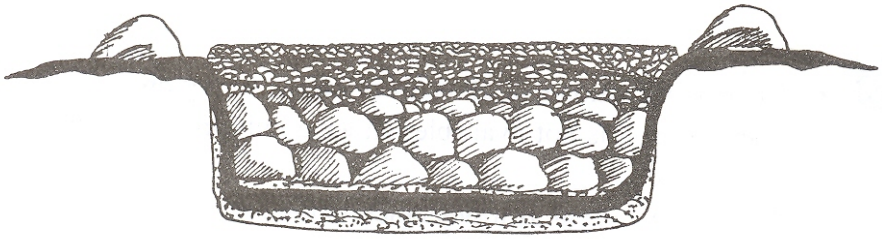


Figure 4.5 A cross section of the foundation

The fireboxes

1. Stand a straight stick upright in the centre of the foundation with a piece of string, (at least 85 cm long) tied to the bottom of the stick. Tie a short, sharpened stick to the other end of the string, 75 cm from the centre pole. Use the stick to mark a circle of 150 cm diameter on the foundation. This is the inner diameter of the kiln.

Figure 4.6 Marking out

2. Mix a good building mortar. In west Kenya, we used the following mixture:
   - one portion of sand
   - two portions of murram
   - one portion of ant hill soil
   - enough water to make it a thick, sticky mixture.

   - Soil making ratios will differ from region to region.
   - If ant hill soil is not available, either good quality building earth or ash can be used.
   - Do not use cement as it will crack in the heat.

3. Spread a thick layer (about 2 cm) of mortar on the foundation outside the 150 diameter circle you have marked. Lay the mortar 5 cm beyond the width of the bricks to be used, laying the bricks as shown in Fig. 4.6, with mortar in each joint between bricks. Level each brick as it is laid until the circle is complete.

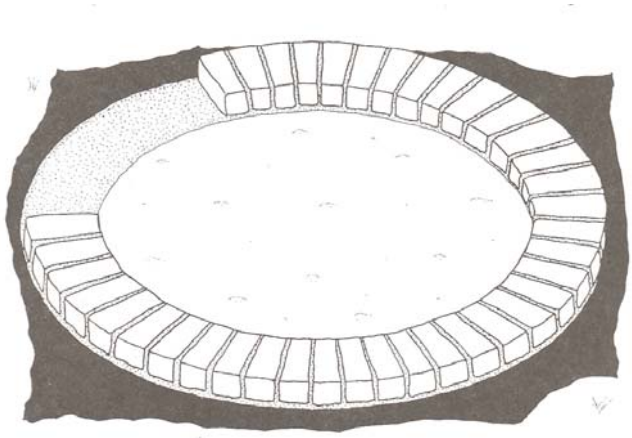


Figure 4.7 Laying the first circle of bricks

4. Trim off the polythene sheet outside the circle of bricks.

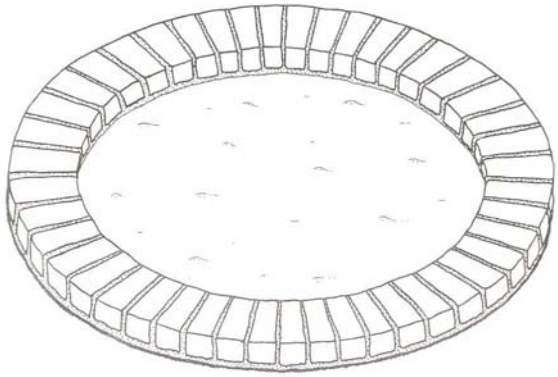


Figure 4.8 The completed circle

5. There are six firebox walls leaving five firebox channels, each 18 cm wide. In Kenya we used the smaller bricks for the firebox walls. Lay and level the bricks in place ensuring that each joint is well filled with mortar. The bricks at the end of each row should be shaped to fit within the outer circle of bricks laid in the previous section.

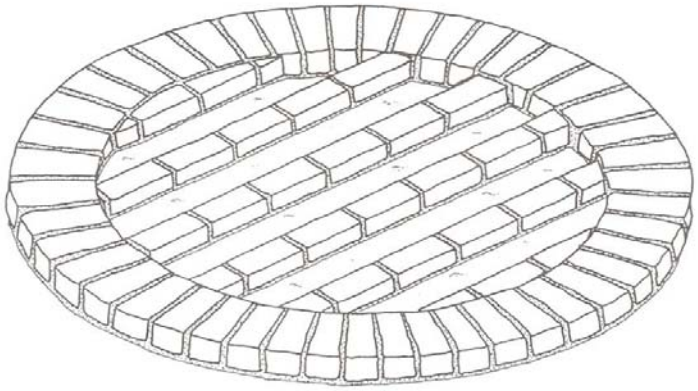


Figure 4.9 The first course of firebox channels

6. Fill the five spaces between the firebox walls with murram to the top of the brick course and use the rammer to level it. If possible, use a spirit level to make sure the area is level.

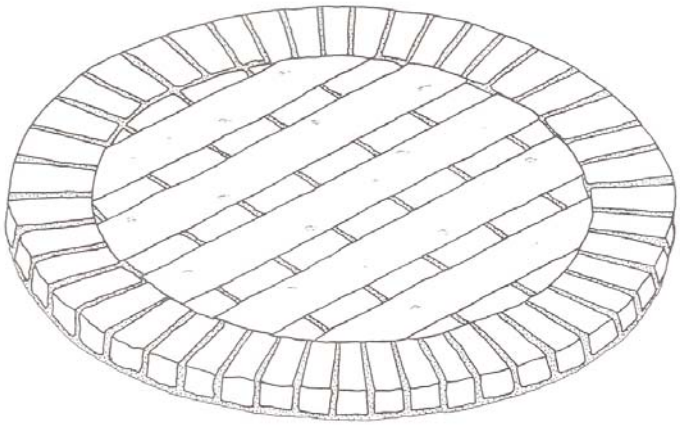


Figure 4.10 The completed firebox floor

7. Lay the second course of firebox wall bricks leaving a 10 cm ventilation gap between each brick. Position the bricks so that the ventilation gaps are not in line with each other. There should be three ventilation gaps in each of the two outer channel walls. This layer of firebox wall bricks will extend out to lie on top of the outer circle of bricks.

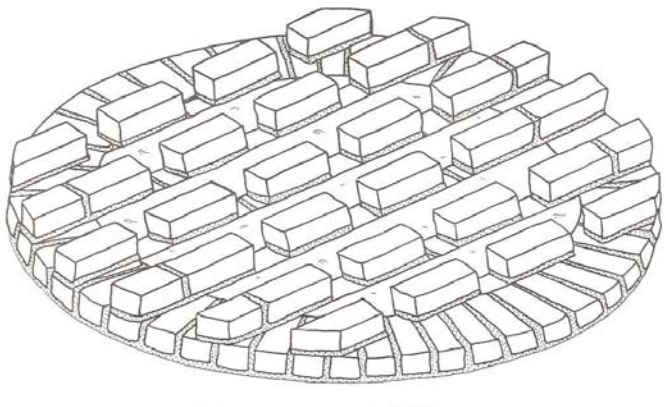


Figure 4.11 The second course offirebox channels with ventilation holes

8. Lay the third layer of bricks on top of the second course, but this time leave no gaps. Ensure that this course is level and that all joints are well filled with mortar.

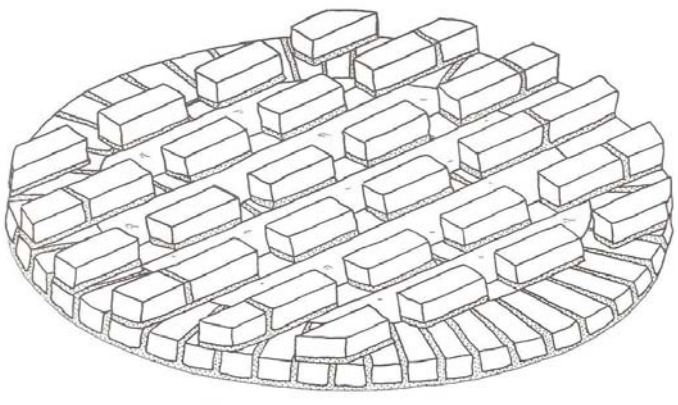


Figure 4.12 The third course offirebox channels with ventilation holes

9. Lay two courses of shaped bricks to complete the outer walls, leaving the three ventilation channels open on each side of the kiln.

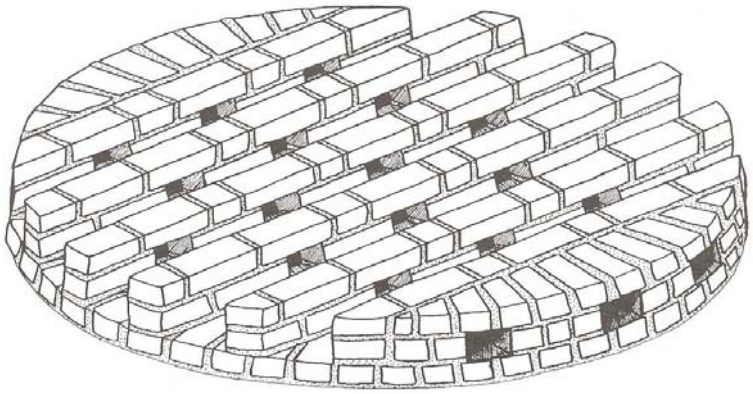


Figure 4.13 The completed fireboxes

The firebox channels are now complete and so is the floor of the firing chamber where the pottery items will sit during firing.

The kiln wall

1. The kiln wall **must be supported above the firebox doors**. This can either be done using a metal frame, fired clay bars, or specially made large bricks. To make the metal frame, cut four pieces of reinforcing rod each 3 m long. Bend two of them to a radius of 80 cm and the other two to a radius of 90 cm.

   Take one rod with the larger diameter and one with the smaller diameter and using tie wire and binding wire, construct a frame as shown in Figure 4.14.

   Repeat this with the other two lengths of rod.

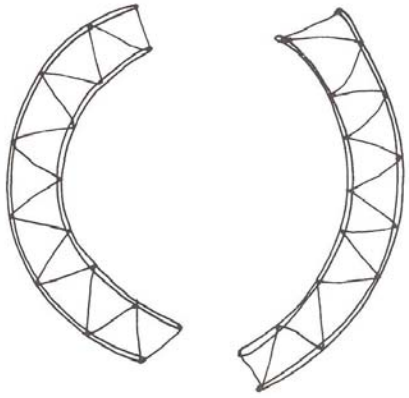


Figure 4.14 The complete metal frame

   Alternatively potters can make ten fired ceramic plates measuring 25x15x2 cm3, to bridge the firebox doors. Usually, only six plates are required, but to be on the safe side, you should make about four extra in case of any breakages, since ceramic products are very fragile.

2. Lay the metal frames or pottery bars across the top of the firebox doors as shown in Figure 4.15.

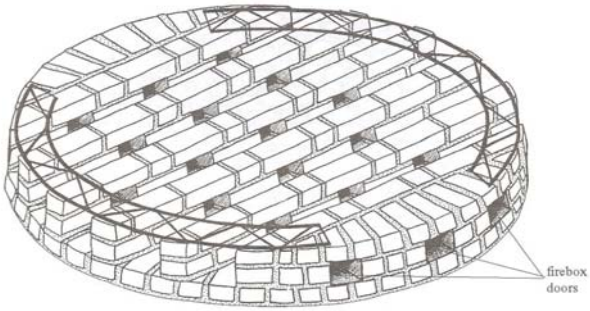


Figure 4.15 Metal supports over the firebox doors

3. Lay and level a full circle of bricks as shown in Figure 4.16.

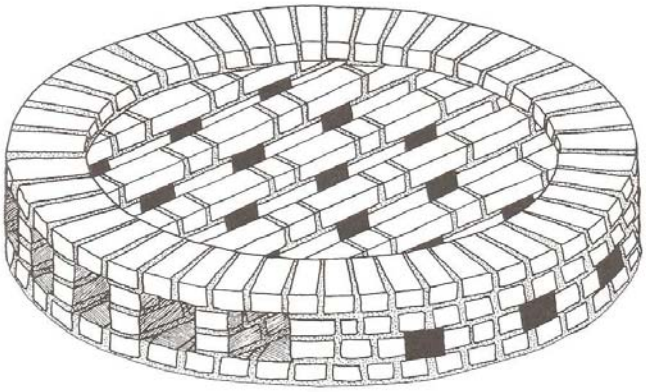
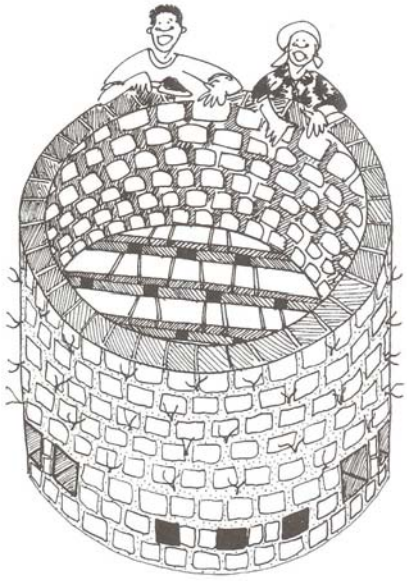


Figure 4.16 Starting the kiln wall

4. Continue laying and levelling the bricks to form the kiln wall up to the recommended height of 75 cm.



If you have chosen to reinforce the kiln wall with wire mesh, mortar in lengths of binding wire between the bricks at random over the complete diameter and overall height. Allow about 15-20 cm of wire to protrude outside the wall. These will be used to secure the wire mesh to the outside of the kiln wall.

Figure 4.17 The kiln wall with wire ties

Reinforcing the kiln wall

1. Wrap the chicken wire around the outside of the kiln wall and ensure that it is securely tied with the lengths of binding wire protruding from the brickwork.

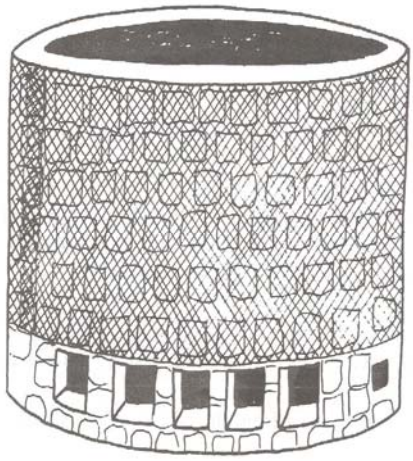


Figure 4.18 Chicken wire reinforcement

2. Allow the kiln to dry for at least three days before plastering the outside.

Figure 4.19 Plastering the kiln wall

3. To make a good plaster, either mix equal quantities of sand and good quality clay, or use the best local mixture for plastering houses. Apply a thin layer of the mixture (less than 1 cm thick) by hand to the outside of the kiln wall. Finally, plaster the top of the last layer of wall bricks.

4. If the bricks that you have used to build the kiln are of poor quality, you should plaster the inside of the kiln to protect it from the fire. Plaster used on the inside must be heat resistant. A good mixture is equal quantities of grog (a powder of ground fired pottery), ash and good quality clay.

5. The construction of the kiln is now complete. Allow it to dry for at least 28 days. Complete the drying process by lighting small fires in the kiln.

6. The kiln can be protected from the effects of the weather by a simple shelter.

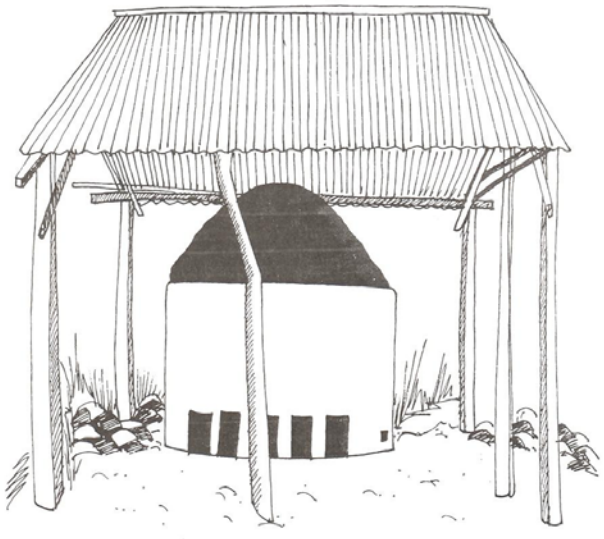


Figure 4.20 A kiln shelter

Chapter Five
USING THE KILN

Loading the kiln

The kiln holds between 60 and 120 Upesi stoves. If you overload the kiln some stoves will be under-fired.

Check each stove or pot before loading it into the kiln. If there are small " cracks or if it is badly made, do not fire it. Instead, break up the pot or stove and soak the clay so that it can be re-used. Poor quality products often crack during firing which is a waste of time, effort, clay and fuel.

1. When the stoves or pots are ready for firing, put them in the sun for at least one day to make sure that they are completely dry.

2. Put the first layer of stoves or pots into the chamber with the bottom of the stoves resting on the firebox bricks.

Figure 5.1 Loading the kiln

3. The rest of the stoves or pots should be packed to reduce the amount of "free" space in the kiln. Do not pack them in neat stacks. Pack each stove or pot so that it cannot move easily. Continue loading the kiln above the level of the kiln wall to form a dome shape.

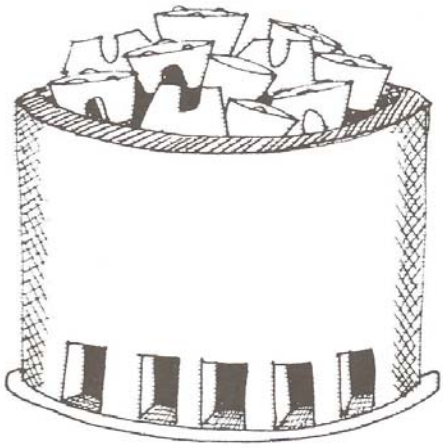


Figure 5.2 The loaded kiln

Making the mud dome

1. Fill spaces between the stoves in the top layer with pieces of broken pottery. Spread a layer of dried grass or straw about 2-5 cm thick evenly over the top of the dome.

5.3 Making the dome

2. Mix equal quantities of earth, cow dung and sieved ash (two buckets of each) and add just enough water so that the mixture can be spread, but does not drip. Spread a thin, even layer of this mixture over the grass to form a sealed mud dome.

Figure 5.4 Mudding the dome

Firing

During firing, the temperature should ideally rise slowly for two to three hours and then be maintained at a steady level for a further six hours. The following instructions should help you to achieve this:

1. If it is windy, light the fire in the fireboxes from the same side as that from which the wind is coming. Light the fire in three (the two at the ends and the centre one) fireboxes, leaving the others unlit. These act as 'chimneys" for the other fireboxes.
   Use small pieces of fuelwood to light the fires.

2. Once the three fireboxes are lit, feel the outside of the mud dome to find the cool areas. To draw heat towards these areas, make small holes in the mud dome with your finger or a stick. You can fill these holes later with more mixture if they draw too much heat.

3. Feed fuelwood into the three fireboxes at a steady rate to maintain the temperature of the fire. After about two hours, light the other fireboxes.

4. Repair any cracks that appear in the mud dome with a thin layer of the mud mixture.

Figure 5.5 Feeding fuelwood into the fireboxes

5. Ensure that the fires are evenly distributed along the length of the fireboxes. If the wind is strong close the firebox doors in that direction using bricks. When it is necessary for the fireboxes to be loaded with fuelwood, these bricks can be removed and then replaced.

6. Continue to check that the heat is evenly distributed, either by feeling the outside of the dome or by checking that the cracks in the mud dome are evenly distributed. If you find 'cool' areas pierce the dome to draw the heat towards that area.

7. After eight hours, check the bottom layer of stoves by looking through the firebox doors. If the stoves are' glowing', the firing process is nearly complete.

8. Distribute the unburnt embers evenly through the length of each firebox and close all the firebox doors using bricks and mud. Leave the kiln to cool for 20-24 hours. Continue to repair any cracks in the dome during the cooling process.

Figure 5.6 Waiting for the firing process to end

- For a Better Bonfire, a nine-hour firing duration is recommended. This slow firing process helps to prevent cracking in the two critical temperature ranges.

- All unfired pottery contains some residual water which will vaporize at 100°c. If this happens too fast the pottery will crack.

- At 580°C the quartz in the clay and expands. If this happens too fast the pottery will crack.

Unloading the kiln

After 20-24 hours the stoves should be cool enough to handle. Remove the mud dome and the supporting pottery pieces, and carefully unload the stoves or pots.

Figure 5.7 Unloading the kiln

If you open the kiln too early it will cool too fast. This may cause breakages.

Repairs and maintenance

1. After each firing inspect the kiln for:
   - Bricks that are beginning to sink.
   - Joints which have become loose or fallen out.
   - Cracks.

2. Repair any of these defects immediately.

3. Replaster the kiln regularly.

Chapter Six
TROUBLESHOOTING

Experienced potters should be familiar with what causes cracks and how to prevent them. Trial and error will help you to understand the causes of cracking and how to remedy the situation. Remember, every clay is different, and weather conditions vary. Only through experience will you be able to achieve maximum efficiency from the kiln.

Below are some of the most common problems and possible solutions.

PROBLEM	POSSIBLE CAUSES	POSSIBLE SOLUTION
The kiln is difficult to light	Wind in opposite direction of the flames	Light the fire from the direction of the wind
	Wood is not dry enough	Use dry wood
	All fireboxes were lit at the same time	Light the two fireboxes later
	Too little ventilation	Make more holes in the dome
Flames come out of the firebox door	Wind in opposite direction of the flame	Light the fire in the direction of the wind
Too much smoke in the fireboxes	Wet wood	Use dry wood
	Too little ventilation	Make more holes in the dome to draw out the smoke
Underfiring	Too little fuelwood	Use more fuelwood
	Too little draught especially to the dome top and at the wall or dome joints	Make more holes in the dome
	Wet wood	Use dry wood
Stoves overfired	Firing at too high temperature	Reduce amount of fuel used
Stoves crack During firing	Damp liners	Dry liners before firing
	Damp kiln	Ensure that the kiln floor is above ground level and is provided with a damp-proof layer
		Shelter the kiln
	Clay is not properly Prepared	Allow clay to mature for several weeks before use
	Clay is too pure	Add sand to the clay

PROBLEM	POSSIBLE CAUSES	POSSIBLE SOLUTION
	Clay is too dense	Add fine sawdust or fine chopped grass
	Firing process is to fast	Reduce stoking rate fast
Stoves crack during	Cold draughts	Close firebox doors during firing
	Stoves damaged due to mishandling of wet liners	Use boards to carry liners. This must be done with care
	Air holes in liners	Wedge clay to remove air bubbles before moulding
	Fast cooling rate	Seal the cracks and firebox doors

One of the most common reasons for stoves cracking is poor quality control during the production

Dome collapsing or cracking	Unstable dome	Make the dome higher
Wall cracking	Thermal expansion in the joints and bricks	Repair the cracks
	Joints in line	Rearrange the joints
	Using the kiln before it is dry	After construction, allow the kiln to dry for at least 28 days
Explosions	Damp liners	Dry liners in the sun before firing
High fuel consumption	Wet fuelwood	Use dry wod
	Waste as flames flow out of the kiln chamber	Close the fireboxes after each stoking
Firebox mortar falling off	Weak joint	Replace and repair the joints
Stoves on the kiln floor are cracking	Overfiring	Reduce fuelwood consumption rate
	Firing process too fast	Reduce stoking rate
	Cold draughts	Close firebox doors during firing

GLOSSARY

Brittle	easily broken
Clay	a substance of very fine flat particles which can slide across each other, making a pliable material that can be shaped into pots or stoves
Diameter	a straight line passing from side to side through the centre of a circle
Firebox	the channel where the fire burns
Firing	the process of baking clay pots or stoves
Firing chamber	the space inside the kiln above the fireboxes where stoves or pots are fired
Grog	this is made by grinding broken pottery into a fine powder. It can also be made by grinding dry clay and then firing the powder
Kiln	an oven or furnace in which dried clay products are fired
Pottery	fired clay products
Soluble	that which can dissolve in water

Further Reading

Moses Agumba and Pete Young 1994: A Better Bonfire Kiln: A simple Kiln to Fire Upesi Liners, ITDG Rugby, UK.

IT Kenya has published a series of booklets based on their experiences on household energy in East Africa.

How to Make an Upesi Stove
How to Market Stoves
Technical Notes on Stoves
Mudstove Manual
Biogas Review