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THE DRYING AND FIRING OF BAKED CLAY PRODUCTS 1/

by

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1/ The views and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO.

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C O N T E N T S

INTRODUCTION

This study deals primarily with operating conditions in tropical and sub-tropical countries, which are significantly different from the corresponding conditions in temperate countries where the ceramics industry has received most of its development and to which most scientific and technical studies consequently refer.

Baked clay products are used primarily in building. These products are usually made from rather impure plastic clay raw materials which must go through four manufacturing stages: preparation of the clay, moulding, drying and firing. The first two stages have been studied in another paper. This paper will therefore be confined to consideration of the drying and firing. As these two stages are greatly influenced by the type of raw material used, however, we consider it necessary to make a quick review of the fundamental factors involved.

I. THEORETICAL DATA ON DRYING AND FIRING

Composition of clays

It should be noted first of all that the definition of clay differs considerably depending on whether clay is considered from the point of view of the study of soils or from the point of view of the ceramics industry. In the first case, clay is considered to be that part of the ground made up of elements less than 10 microns in size, whatever the mineralogical composition may be. For the ceramics expert and the mineralogist, on the other hand, clay is a material made up primarily of a mixture of various argillaceous minerals containing, in addition, impurities such as remnants of the matrix and of the mineralogical constituents of the matrix (quartz, mica, feldspar, olivine, hematite, etc.) as well as altered forms of these rocks and minerals. Argillaceous minerals can be grouped in the following categories:

- kaolinite
- montmorillonite
- illite.

Kaolinite is made up of two molecular lattices: the SiO_4 tetrahedral silicon lattice and the $Al(OH)_6$ octahedral aluminium lattice which may condense in the proportion 1:1 to form a continuous impenetrable lattice with the formula $Al_2(OH)_4Si_2O_5$ or, in the form of oxides, $2SiO_2.Al_2O_3.2H_2O$. It may be found in a hydrated form as halloysite with nH_2O. The molecular ratio $SiO_2:Al_2O_3 = 2$, and the loss on firing is 13.95 per cent for kaolinite and more for halloysite. The crystalline structure is a fairly large, very flat hexagonal prism. This kaolinitic group is found above all in the china clays, the ball clays and the fireclays. It is also sometimes found in the brick clays. It is quite common in temperate areas.

The montmorillonites belong to the group of pyrophyllites of volcanic origin. The SiO_4 lattice encloses an aluminium octahedra lattice, giving a lattice formula of 2:1.

The formula of pyrophyllite is:

$Al_2(OH)_4.2Si_2O_5$ or, expressed as oxides, $Al_2O_3.4SiO_2.H_2O$

The place of the gibbsite $Al(OH)_3$ group may be taken by brucite $Mg(OH)_2$ or ferrous oxide $Fe(OH)_2$, which are of similar structure. If the central lattice is made up entirely of brucite, then this will give talc:

$Mg_3(OH)_3.2Si_2O_5$ or $3MgO.4SiO_2.H_2O$, loss on firing 4.7 per cent.

Pyrophyllite and talc may be considered as making up the group of montmorillonites with the formula $2Al_2O_3.MgO.12SiO_2.3H_2O$, loss on firing 5.3 per cent and molecular ratio $SiO_2/Al_2O_3 = 4$. The lattice of this latter material is not so close as that of kaolinite, and allows liquids, including water, to penetrate it and thus considerably expand its volume. As they have a free charge, these montmorillonites can absorb metallic cations such as CaO, Na_2O, etc., which give various properties to the compounds thus formed, especially a considerable increase in plasticity.

Illites are very similar to the group of micas, where part of the K_2O has been replaced by H_2O. Their loss of firing is about 7 per cent. They are often found in micaceous brick clays and in fireclays.

* * *

In addition to these plastic argillaceous compounds, clays contain other minerals, some of which, such as organic matter, carbonates (calcite in marls), sulphides (pyrites) and sulphates (gypsum), bring about substantial losses on calcination. In hot, humid tropical climates, the clay molecules disintegrate, especially if the clay deposit is under the water table. SiO_2 is gradually eliminated by this laterization, and the residual product will be a laterite, a bauxite, a gibbsite or a geothite. It may be noted that the loss on firing of gibbsite amounts to over 34 per cent. These various non-plastic compounds develop very considerable porosity when fired at 1,000°C and are thus subject to progressive and heavy shrinkage at high temperature. In tropical countries, therefore, this should be borne in mind when selecting suitable dryers and kilns.

Let us take as an example three types of clays, the first a micaceous clay (an altered form of trachyte) from Madagascar and the other two (altered forms of basalt) from Mauritius.

	Ikopa clay Madagascar	Vacoas clay South Mauritius	Micolière clay North Mauritius
SiO_2	36.7	20.1	18.3
Al_2O_3	38.6	39.6	29.3
Fe_2O_3	2.6	5.2	28.6
TiO_2	0.9	8.5	3.3
CaO	-	(	0.4
MgO	-	(traces	1.1
Alkalis	3.2	(	trace
Loss on firing	18.2	28.3	17.8
Halloysite	48.2	52.7	34.9
Gibbsite	24.9	(	(
Goethite	-	(35.3	(55.4
Other minerals (feldspar and ilmenite)	26.9	12.0	9.7

DRYING

The drying process enables the mixing water of the prepared clay to be removed and provides a firm, more or less dry product ready for firing. Mechanically speaking, it involves evaporation of the non-combined water, together with a reduction of the volume of the product. The removal of the water takes place in two stages: to begin with, it is accompanied by shrinkage proportional to the loss of water, but when the leather-hard state is reached the shrinkage stops while the removal of water continues until dryness. The critical point is given by Bigot's curve. This point is important, as once it has been passed the drying conditions can be radically changed, since there is no longer any fear of the cracking or bursting of the piece as long as the temperature is kept below 100°C.

The water contained inside the blocks of clay rises by capillary action to the surface and brings with it soluble salts which crystallize out at the surface and give rise to efflorescence. The extent to which the temperature can be increased in order to speed up evaporation of the water is limited by the danger of the formation of steam, which would cause the piece to burst, and the practical limit is about 70°C.

The reduction in volume gives rise to internal stresses in the piece, as drying is not equal at every point. These internal stresses manifest themselves in the form of distortion, cracking, and even bursting of the piece if drying is too rapid. Shrinkage varies according to the type of clay concerned, the amount of adjuncts such as sand, and the fineness of grinding. If the shrinkage is too marked, and therefore dangerous for the piece when it is being dried, it can be reduced by adding a leaner clay (which will have a lower degree of shrinkage), sand, or chamotte. Such additions are limited, however, because of the reduction of plasticity which they cause. Normally, the linear shrinkage on drying must not exceed 5-7 per cent. The addition of adjuncts such as sand to make the clay leaner also facilitates the removal of water by giving the clay a less compact structure and thus enabling more rapid drying.

The clay whose structure makes it easiest to dry is kaolinite. It is also the least plastic of clays, this property depending on the size of the argillaceous crystals. Unfortunately, it is quite rare to find substantial deposits of kaolinite in the tropics. It is more usual to find halloysites, which are much more plastic, or montmorillonites contaminated to a greater or lesser degree by iron and aluminium hydroxides. Both these argillaceous minerals are rather tricky to dry, but marls, on the other hand, do not present any difficulties, because the limestone contained in them has the effect of making them leaner.

Knowledge of these facts is very useful when choosing the type of industrial-scale dryer to be used. Ignorance of them explains to some extent the heavy wastage encountered in the manufacture of artisan-produced air-dried bricks.

<u>The amount of heat required for artificial drying</u>

The total number of calories required is consumed not only in evaporating the non-combined mixing water, but also in heating the products, the structures supporting them, the surrounding masonry and the air which is being circulated for the drying process.

Quite a substantial loss is also to be expected through radiation from the masonry. Each of these elements can be calculated theoretically if the weight of the clay material, the weight of the water to be evaporated, the weight of the bearer structures and the surrounding masonry, the surface area of the heated walls, and the amount of circulating air are known. For this purpose, it is also necessary to know the specific heat of each component, as well as the increase in temperature. Except for radiation losses, the following formula is used:

$Q = P \times (T - t) \times$ specific heat.

In addition, it is necessary to add the latent heat of evaporation, which is very important. <u>In practice, for a good artificial dryer, the figure of 1,000-1,200 calories per kg of evaporated water may be taken</u>.

It is always a very good idea to check the temperature and moisture content of the air removed. The heat required for drying varies, as a percentage, as follows:

	Minimum	Maximum
Heat absorbed	16	9
Losses through radiation	10	25
Residual heat in air removed	28	39
Heat of evaporation of water	46	27
	100	100
Calories per kg	1,110	2,140

FIRING

Here, too, the nature of the clay and the type of product to be manufactured are determining factors when deciding on the type of kiln to be used. The temperature required for the firing of baked clay products is between 950 and 1,150°C.

The firing can be divided into four stages:

Water smoking

Pre-heating

Full firing

Cooling.

The water smoking is carried out slowly, up to 150°C, in order to remove the remainder of the mixing water.

The pre-heating extends from 150°C to 850°C. There are various crucial points in it where the temperature must be increased only slowly. At 150°C there is the removal of the mechanical water from montmorillonite; towards 200°C, illite begins to lose its combined water. Between 250° and 300°C, the mechanical water is removed from halloysite, while gibbsite and goethite are dried out towards 300°C. Kaolinite and halloysite are dehydrated between 400° and 600°C, and at 573°C the abrupt passage from alpha quartz to beta quartz, accompanied by marked swelling, takes place. Finally, the carbonic and sulphurous gases are liberated between 650° and 900°C. This temperature of 900°C is the minimum for obtaining a stable product. Below this temperature, the meta-kaolin formed will reabsorb water, thus leading to disintegration of the piece.

The full firing stage causes the aggregation of the particles, together with the beginning of vitrefaction due to elements which give fusible glasses: lime, magnesia, alkalis, ferrous oxide and silicon. Where there is a high proportion of lime, it is dangerous to exceed 1,150°C, as abrupt melting of the silicate of lime takes place. The presence of a high proportion of oxides of iron and alumina calls for firing above 1,000°C, and the fire must be consistently of a highly oxidising nature in order to avoid the melting effect of FeO.

Cooling can be carried out rapidly down to 700°C, but care must be taken at the stage of the transformation of the quartz around 600°C, if any free silicon is present. Below this temperature, the cooling curve will flatten out itself.

It may be noted in passing that firing curves have been greatly modified in the last few years: 50 years ago tiles could not be fired in less than three weeks, whereas nowadays they are fired in three hours.

The firing atmosphere and temperature will have a considerable influence on the quality of the products. Ferruginous earth will give a red-brown brick, a marl will give a yellowish product, while a high content of alumina in a ferruginous clay will lighten the shade to red or fawn.

In a high-output plant, it will be valuable to determine by means of various laboratory tests (differential curves, X-rays, chemical analysis, polarizing microscope examination, levigation, etc.) the various components present in the clay which is to be used. These tests will greatly facilitate the choice of the plant, and firms which specialise in the supply of brickworks plant will willingly carry out such tests.

When selecting the kiln, such considerations as the output required, the quality of the raw materials, the local labour conditions, the fuel and the power sources available and the climatic conditions will greatly influence the decision.

The number of calories needed for firing varies considerably not only from one type of clay to another, but also from one type of kiln to another. For firing to 1,000°C, it will be necessary to assume a consumption of about 1,000 calories per kg fired in a non-continuous kiln, whereas the heat consumption may be less than 400 calories per kg in high-efficiency continuous kilns. Comparable figures cannot be given for temporary kilns, as the temperature achieved rarely exceeds 800°C.

Equipment used

Drying

(a) Natural drying is carried out in the open with successive stacking of the hardened material. The length of the drying process, which may be from three to eight weeks, will vary considerably depending on the temperature, the ventilation, the degree of humidity of the air, and the nature of the clay. The area required for drying is about 2,000 m^2 per 100,000 bricks. The material must be protected from the wind, the sun and the rain by means of movable screens, and drying should be carried out, if possible, in a shed. With a fat clay, wastage may amount to 30 per cent. In a shed, the bricks are either stacked on pallets about 1m x 1.20m in 5 or 6 layers, or else they are arranged on movable shelves. The bricks are transported from the press or to the kiln on wheelbarrows or by means of pallet trucks. A covered area of 1,500 m^2 will accommodate 600 pallets giving a daily output of 20 tonnes. The drying time is much lower for hollow bricks, amounting to only 6 days at Salonika.

(b) Artificial drying: An old system is to lay the bricks on a floor made of concrete or cast iron slabs covering a system of channels through which hot air is circulated. Abour 70 bricks can be laid out on each square metre; the temperature must not exceed 50-60°C. The drying process by such a method lasts a week for solid bricks and 2 days for hollow blocks. In the same category as this process is the method of drying the bricks on top of the kiln, with or without shelves which may be inclined to serve as slides for tiles.

(c) Drying in specially ventilated buildings

I. On fixed installations (drying on shelves)

II. On movable equipment (wagons, conveyor belts, sledges)

I. Fixed-ware dryers

There are two main types of fixed-ware equipment:

(1) The Keller-type corridor dryer consisting of high, narrow, deep parallel chambers provided inside with horizontal supports at regular intervals on which the loaded shelves delivered by a multi-fork transporter truck are placed and removed after drying. The chambers have an average capacity of 10 tonnes and are provided with communicating doors. They can work independently or in groups of 2, 3 or 4 chambers in series, depending on the system of drying selected for the requirements of the material. The principle is to pass hot air saturated with humidity over the green clay product to begin with, and then to reduce the humidity saturation as soon as the crook in the Bigot curve is reached. The final temperature is about 70°C. The drying time varies from 24 to 72 hours, depending on the sensitivity of the product. The air inlets and outlets and the placing of the fans vary according to the design. These dryers are continually checked by means of psychrometers and recording thermometers.

(2) Italian-type chamber dryers: In this type of dryer, the material to be dried is loaded on multi-deck metal shelves which are then placed inside the chambers, where the movement of the air is regulated in accordance with a precise curve. The fans may be fixed to the wall, or they may be mobile and move around between the shelves (Rotomixair). The normal drying time is 24-48 hours, and the same rules regarding the circulation of hot air apply as in the case of the Keller-type dryers. The amount of heat needed is calculated in this case also on the basis of 1,000-1,200 calories per litre of water.

II. Moving-ware dryers

This covers 3 types of dryers:

(1) Tunnel dryers

(2) Conveyor belt dryers

(3) Sledge-type dryers.

In all three cases, the ware passes along a channel in counter current to hot air which enters in the dry state at the exit of the dryer, picks up humidity as it passes over the product, and emerges almost saturated with humidity. Optimum temperatures are about 70°C at the air input and 32°C at the outlet. The distribution of the air is progressive, and is normally along the axis of the dryer sole. Recycling is often carried out by causing saturated air from the outlet to enter the dryer again half-way down its length. Air circulation fans or, better, ventilators which suck in air every five metres from the crown of the dryer and blow it in again at the bottom of the dryer (the sole), regulate the movement of the air. There are multi-line tunnels with reverse cross circulation in accordance with a particular scheme or else with Rotomixair units operating between the lines of shelf trucks loaded with the ware. The operation of the dryer (the input and removal of the wagons) must be very regular, and both the temperature and the moisture content of the air must be constantly checked. A dryer which is operating under proper conditions gives slight condensation of water on the entry door. Under no circumstances should air containing sulphurous gases be used, as these gases seriously attack metal structures and cause efflorescence of the products. Conveyor dryers are usually directly connected with the moulding machines and with the kiln, which is so designed as to have the same extra-low section.

The various types of artificial dryers can only function effectively and economically if there is a regular and quite large output of products which do not greatly vary in volume or weight. The minimum feasible output for such dryers is 20 tonnes per day. In the case of roofing tiles or flooring or walling tiles, drying is a more complicated matter and requires a period of 48 to 72 hours, with even closer supervision throughout the process.

* * *

Firing

As we have already seen, the normal firing temperature is between 950°C and 1,150°C. The optimum temperature depends on the product quality which it is desired to obtain (compressive strength and resistance to weathering and freezing), the raw material used (marls, ferruginous clays, laterites, etc.), the moulding system (the soft mud process, the stiff-plastic process or the semi-dry process, the last two of which call for higher temperatures), and the firing speed as well as the full firing time, rapid full firing also calling for higher temperatures. There are two types of kilns: (a) - non-continuous or intermittent kilns, and (b) - continuous kilns.

(a) Non-continuous kilns

These are of two types: temporary and permanent kilns.

(1) Temporary kilns

Temporary kilns are mainly used by artisans, but they are also still used in Great Britain, the United States, Greece, etc., where they form part of quite a highly developed manufacturing system. For the areas being dealt with by us, however, we shall deal only with the type of kiln typically used by artisans. The size of such kilns depends frequently on the vanity of the artisan, but too large a kiln (more than 50,000 bricks) gives too many under-fired or burnt bricks.

Temporary kilns

These are the classical kilns for starting up the manufacture of bricks. Their capacity can vary widely, ranging from 5,000 to 100,000 pieces or more. These kilns are built each season out of dried bricks in the form of a truncated pyramid with a rectangular base. In the base of the kiln, between the long sides, transverse trenches are dug at a distance of about 1.50m to serve as fire flues. The bricks are stacked in such a way as to leave flues for the draught, and every two or three layers the bricks are spread with a layer of pulverized fuel (lignite, peat, rice husks, etc.). The total height of the kiln is between 2.50 and 3.50m. The top of the kiln is covered with underfired bricks and the outside walls are coated with clay, the whole kiln being covered with a thin layer of earth.

The kiln is lit by first of all lighting faggots in the fire flues, then adding billets of wood or blocks of peat. When the fire has taken a good hold, the flues are blocked up and combustion then spreads through the whole stack.

A firing lasts about 10 days on average. Such kilns give very irregular results, with up to 15 per cent of burnt bricks and sometimes 40 per cent of under-fired or unbaked bricks. The temperature rarely reaches 900°C, and the products are thus of irregular and very inferior quality: at Tananarive, the compressive strength of such bricks is between 5 and 12 kg/cm^2 and they have an apparent density of 1.20 to 1.25. Their water absorption exceeds 50 per cent, and the highly variable dimensions involve heavy consumption of mortar when laying the bricks. Nevertheless, such kilns are indispensable for supplying the bricks needed for the construction of a more highly developed kiln.

(2) <u>Permanent kilns</u>

There are two main groups of permanent kilns:

(a) Non-continuous kilns, and

(b) Continuous kilns which work without interruption.

(a) <u>Non-continuous kilns</u>

The use of these kilns may be envisaged when daily output is not more than 20 tonnes. The cost of these kilns is quite high (250 dollars per tonne of capacity) and their fuel consumption is high, while heat recovery is difficult because of the non-continuous operation. A fuel consumption equivalent to about 1,000 calories per kg of fired product is to be expected.

There are three main types of these kilns:

(1) Direct-flame updraught kilns

These kilns are provided with permanent walls with hearths at the sides. The combustion gases pass through the charge and are removed at the crown. These kilns may be round or rectangular (Suffolk kilns). Their capacity varies from 50 to 150 m^3, i.e. 15,000-50,000 bricks. The investment costs are modest, but the firing is rather irregular, being excessive at the foot of the stacks but insufficient in the middle.

(2) Downdraught kilns

These may be round or rectangular, with the hearth located in the latter type on the long sides. These kilns can reach high temperatures (firing of refractories), and their yeild is better than that of the preceding kilns (800 calories per kg of fired product).

The hot gases rise from the hearths along the walls up to the crown and then plunge down through the mass of bricks and are evacuated through the grille which forms the sole of the kiln to the chimney. The most thoroughly fired products are on top, and thus not subject to crushing. The average capacity of such kilns is from 30,000 to 50,000 bricks, and the firing time is about one week, including charging and discharging. These kilns are advantageous for small mechanized plants because of their flexibility. Rectangular kilns can be connected in series to recover the heat from one kiln to the next, thus making possible progress towards semi-continuous and continuous kilns. In a semi-continuous system, the fuel consumption ranges from 1,000 calories per kg in the first kiln to 600 calories per kg in the fifth kiln.

(b) Continuous kilns

These kilns offer by far the most economical method of firing and also give products of the most consistent quality, but they call for quite high output, exceeding 20 tonnes per day for Hoffmann kilns and 80 tonnes per day for a tunnel kiln. Moreover, their operation is much less flexible than that of non-continuous or semi-continuous kilns, as the production range must be kept within the proportion 1:2, since a reduction of output automatically brings about an increase in the consumption of fuel. Two main types of continuous kilns are available:

(a) Moving-fire, fixed-ware kilns
(b) Fixed-fire, moving-ware kilns

(a) Moving-fire kilns (Hoffmann kilns, zig-zag kilns)

The introduction of this kiln by Hoffmann in the middle of the last century revolutionized the activities of artisan brickmakers by bringing them up to the industrial stage. The two main advantages are the considerable reduction in fuel consumption and the improvement of the average quality of the product. Moreover, this type of kiln enables the hot gases to be recovered for use in the dryers.

The kiln consists of a continuous vaulted gallery made of refractory brickwork in which there are doors at regular intervals to permit the charging and discharging of material. A longitudinal internal channel enables the gases to be removed after they have passed through the raw products and heated them. The fuel is fed in through firing doors placed at regular intervals in the crown, and the combustion air is heated by passing over and cooling the fired product. The fuel can also be introduced through the sole (gas kilns), or partly through the side (Belgian kilns). Heat is recovered by passing air over the fired products. The gallery itself may be circular (as in the older kilns), made up of two parallel galleries joined at the ends (modern type), or else of zig-zag form, this latter more compact form providing facilities for mechanical charging. The gallery of the kiln may have a total length of 70 to 120m, with a width of 2.5-4m and a maximum crown height of 2-3m. The cross-sectional area varies from 5 to 15m^2, giving a capacity of 3.5-10 tonnes of solid bricks per linear metre or 2-6 tonnes of hollow bricks. The firing time is 2½-6 days. Previously, these kilns were charged by hand, but now there is a tendency to remodel them by constructing doors only at the ends of the galleries to permit the transport of materials by means of forklift trucks. The fuel used is very varied: long wooden logs, lignite, coal, heavy fuel oil, natural gas or producer gas. The fuel consumption may be the equivalent of as little as 400 calories per kg for a firing temperature of 1,000°C. Wood, however, has the disadvantage that it is of low calorific value and scarcely permits 900°C to be reached even at very high fuel consumption figures (750 calories/kg).

Fuel was originally fed in by hand through the stoke holes, but solid fuel is now pulverised and pulsed or injected into the kiln by mechanical stokers.

The rate of advance of the fire, which was originally 10-15m per day, is now as much as 50m for certain hollow products (in Italy).

An economical variant of the gallery kiln is Bull's trench kiln, where the top of the crown is at ground level. The side walls of this type of kiln are of permanent construction and it has a gas removal flue communicating with the chimney. When stacking of the ware has been completed, the crown is constructed, leaving stoke holes for hand stoking of fine fuel. This semi-artisan type of kiln is successfully used in Greece for the rapid firing of hollow blocks.

(b) Fixed-fire kilns (tunnel kilns)

There was much hesitation before these kilns were introduced for the firing of bricks and tiles. They are now used in highly mechanized brickworks.

This kiln has a straight gallery with a fixed firing position located a little before the centre of the gallery. The ware is loaded on wagons which have refractory soles and which slide in a bed of sand so as to protect their undercarriages. Charging is generally carried out by loading two batches of bricks on each 2-metre-long car, with a space between them corresponding to the stoke holes. The fuel is introduced through the crown by the same kinds of stokers used in Hoffmann kilns. The cars are pushed into the gallery at regular intervals, and their speed of advance varies from 1.5m to 3m per hour. The firing time is 2-3 days. As in the case of Hoffmann kilns, heat is recovered for the dryers from the cooling area.

The dimensions of the kiln depend on the output required. The length of the kiln may be from 60 to 120m, and its width may be 3-4m. The height of the kiln may vary considerably from 30cm to 3m, depending on the design selected. The fuel consumption is approximately the same as for a Hoffmann kiln, and may even be as little as the equivalent of 300 calories per kg fired.

The main advantage of tunnel kilns is that they provide a top quality product which is of consistent colour and size. The minimum production which is economically interesting is two-thirds of maximum production capacity. Because of their high production, these kilns can only be envisaged in quite highly developed countries where there is a large demand for standardized products.

II. CHOICE OF FUEL

The choice of fuel will obviously depend on the facilities for its supply and, likewise, its cost delivered to the plant and the cost of installing facilities for using it.

In the case of the <u>dryers</u>, the first source of heat is hot air recovered from the kiln. Such hot air forms the major part of the heat required when tunnel kilns are used, and it represents a very considerable part of the required heat when Hoffmann kilns are used. By using such recuperated heat, up to 50 per cent of the calories needed for drying can be saved. In order to provide the remaining calories needed, hot air generators or steam must be used. In view of the relatively low temperatures which need to be achieved, fuels can best be selected from among residual products such as sawdust, bagasse, oil press residues, rice husks, etc., with quite a low calorific value (1,500-3,000 calories). It is also possible to use such fuels as wood (3,000-4,000 calories), peat (1,500 calories), lignite (2,000-3,000 calories) or fuels of higher calorific value such as coal (7,000 calories), heavy fuel oil (10,000 calories) or natural gas (8,000 calories per m^3). It may be noted purely for purposes of comparison that electricity provides 830 calories per kW.

The most usual fuel for <u>temporary kilns</u> is wood (eucalyptus), peat, lignite or rice husks, while lignite, coal or, more rarely, wood, fuel oil or natural gas are used for <u>non-continuous kilns</u>. The hearths must naturally be adapted to the type of fuel selected.

For <u>Hoffmann</u> and <u>zig-zag</u> kilns, wood should if possible be avoided and lignite, coal, heavy fuel oil, or possibly gas should be used. <u>Tunnel kilns</u> use the same fuels and, in a few cases, electricity.

<u>The determining factors in the selection of the fuel are:</u>

(a) Local possibilities for supply and transport of the fuel
(b) The cost of the fuel delivered to the plant
(c) The calorific value of the fuel
(d) Local reserves (bearing in mind the danger of deforestation)
(e) Installation and storage costs.

III. LABOUR

This question is of paramount importance in the developing countries. The need to provide work for the population of the country often very considerably influences the choice of the installation to be made. Often, however, this labour force is unstable, subject to religious taboos, and frequently inadequate from the point of view of physical capabilities. Another difficulty is that of the training of skilled workers. Every brickworks needs supervisory staff and skilled workers with experience of their trade. At present it is fairly easy to find capable mechanics, electricians or carpenters, but they may be attracted away later by higher wages offered by richer industries.

This question of technical knowledge is of vital importance in connexion with the ceramics industry. Sending selected personnel to Europe for technical training more often than not leads to great disappointments, as these employees come back with remarkable pretensions regarding their knowledge of their subject, but no-one in these countries has any doubts about the long practical experience needed to give a ceramics specialist a full knowledge of his subject.

Finally, the legal provisions regarding wages, female labour, trade unions, unemployment, social welfare costs, etc., must be borne in mind. If such legal provisions have not yet been formulated, then it must be expected, fortunately, that they soon will be introduced in the country.

A technician responsible for establishing a ceramics factory will often come across prejudices, habits and preconceived ideas regarding the value of the products to be manufactured, if these products are as yet unknown in the country. I am thinking here of resistance in Madagascar to hollow clay products, to the failure to appreciate the qualities of baked clay products in Mauritius, and to ancestral building habits in Iran or even in Southern Italy.

It is high time for consideration to be given to the establishment in Africa of an international institute of ceramics technology for the training of skilled workers, masons and supervisory staff for the ceramics industry.

IV. DETERMINING CRITERIA FOR THE ESTABLISHMENT OF A BRICKWORKS

1. Existence of an adequate market

The market will be determined by the amount of construction which goes on in the area. Roughly speaking, it has been established that the potential market for bricks represents about 5 per cent of the total expenditure forecast for building. This coefficient may, however, be doubled in the case of the construction of small economic units, as in Mauritius or Madagascar. In addition, the consumption of bricks depends on per capita income and it increases in proportion to this income and the financial possibilities of the country. Brick consumption will amount to about 2 bricks per head if income is less than $80, 5 bricks if income is around $130, and 8 bricks if income is $200. We have here two distinct cases:

(a) Where artisan-made bricks are already in use in the area

In this case, builders will be used to solid bricks derived from blocks of laterite or unbaked bricks, and it will require a great deal of conversion work to induce builders to accept hollow products (bricks and hollow blocks). Although industrially-produced bricks cost more, the fact that they involve a lower consumption of mortar and roughcast and enable walls to be built more quickly, to say nothing of the improvement in technical quality, heat and sound insulation, etc., which they permit, allows them to compete with artisan-produced bricks.

(b) Where baked clay is not yet in use in the area

In this case, natural stone or concrete blocks will be used for permanent constructions in the area. An economic study should be carried out when the necessary argillaceous raw materials have been detected in sufficient quantities and sufficiently close to the centre of consumption.

In both cases, the establishment of an industrial-scale brickworks in a develop-ing country will only be justified, if the works is to be viable, when there is a potential market of at least 40 tonnes per day. A smaller market will more often than not lead to the bankruptcy of the factory (there have been several cases of this in Madagascar). This lower limit will, of course, vary depending on the state of development of the country, and it will increase to about 100 tonnes per day in developed countries. Furthermore, transport costs, which normally limit the radius of operations of a factory to less than 100km, must be borne in mind.

The most important competing product is parpaing (concrete blocks), which are easy to make on the spot with a vibrator. The possibilities of these blocks should be studied in the light of their production costs (crushing of materials, price of cement, etc.), bearing in mind that these blocks are considerably heavier and of a much less pleasing appearance than bricks, while baked clay products also have advantages from the point of view of sound and heat insulation.

2. Where there are suitable deposits of clay for brick making (and also, possibly, deposits of clay improvement agents (sand)).

The deposits should be such that they will provide resources for at least 20 years. They should be checked from the point of view of consistency of composition, ease of open-cast exploitation, and production cost of materials delivered to the factory.

3. Availability of local facilities for major repairs

This point is very important for the proper maintenance of the plant, although a considerable proportion of the repairs will in any case have to be entrusted to an attached workshop.

4. Local resources of skilled labour

We will not return to this point, which has already been dealt with above.

5. Financial possibilities of the country

These possibilities, together with the local interest rates, are also of paramount importance. It will often be necessary to resort to external financial assistance provided by banks, institutions set up for this purpose by the United Nations or the government concerned, or, to some extent, foreign suppliers.

If the conditions summarized above are not fulfilled, then there will be no alternative but to restrict operations to artisan-type brickworks or to study the possibility of using mobile brickworks, which will be dealt with later.

V. COMPARISON OF PRODUCTION COSTS

We will limit outselves here to five examples: three examples taken from our recent studies in Madagascar and Mauritius, and two examples taken for purposes of comparison from Switzerland.

Prices are considerably influenced by the following items:

- Wages
- Cost of fuel
- Cost of electric power
- Interest rates.

While the item of wages (6 francs per hour for a labourer in Switzerland as against 4 francs per day in Madagascar) plays a paramount role in highly-industrialised countries and forces them to adopt a degree of mechanisation bordering on automation, it is much less important in developing countries. Nevertheless, it must be expected that wages will play an increasingly important role as the country progresses, and advantage should be taken of the present state of affairs in order to train supervisory staff and skilled workers, who will be increasingly sought after as mechanisation develops.

1. Artisan-made bricks

In Madagascar, it takes one moulder one working day to mould 400 bricks (an output of about one tonne per day). The associated work (preparation of the clay, drying, and construction of the kiln) take up an equal amount of time, so that the output per worker comes to 0.5 tonnes per day. No account has been taken here of the help provided by the artisan's family in the construction of the kiln. The cost of the raw material has been calculated, after consultation with artisan brick maker, at one-fifth of the cost of the product, and the consumption of fuel (wood, peat dug on the spot) has been assumed to amount to 15 per cent of the tonnage produced. This therefore gives the following figures per tonne:

Labour:	400 Malagasy francs
Fuel:	250 Malagasy francs
Raw materials:	200 Malagasy francs
	850 Malagasy francs

2. Industrial-scale wood-fired brickworks

This works was built 15 years ago to give an output of 20 tonnes per day. The bricks are prepared mechanically, dried in a tunnel dryer and fired in a Hoffmann kiln using eucalyptus wood fuel.

3. Modern brickworks with a Hoffmann kiln fired with heavy fuel oil

This planned works will produce 60 tonnes of baked clay products of standardised type per day. There is provision for mechanical preparation after weathering, automatic loading into the Kell[illegible] corridor dryer, and charging by forklift truck of the Hoffmann heavy-oil-fired kiln.

Details of the following two brickworks are given for purposes of comparison:

4. Swiss brickworks

Output 145 tonnes per day, mechanised preparation, Keller dryers, oil-fired tunnel kiln.

5. Automated European brickworks

Output 120 tonnes per day, mechanised and synchronised moulding, conveyor belt drying, extra-low tunnel kiln.

The annexed table gives a comparison of these five types of plants.

This table speaks for itself: it shows the extensive mechanisation carried out in countries where wages are high, and the need to modernise old mechanical brickworks without, however, going too far with mechanisation and losing sight of the need to provide employment. Finally, it shows the improvement in quality which can be obtained by taking care over the preparation and firing.

The proportion of wastage is as follows (wastage due to burnt and under-fired bricks is shown separately from wastage occuring in the drying process):

	Plant type 1	Plant type 2	Plant type 3	Plant type 4	Plant type 5
Percentage wastage in firing	40	10	2	1	1
Percentage wastage in drying	20	20	3	1	0
Total wastage for whole plant	60	30	5	2	1

COMPARATIVE TABLE OF PRODUCTION COSTS

	Artisan-made bricks (x)	Hoffmann kiln. Wood fired. Madagascar	Hoffmann kiln. Fuel oil fired. Madagascar	Tunnel kiln. Fuel oil fired Europe (o)	Tunnel kiln. Fuel oil fired. Automated plant
Annual output (tonnes)	200	5,000	22,000	50,000	44,000
Number of workers	2	70	27	34	15
Installation cost (Swiss francs)	10,000	300,000	3,000,000	7,000,000	15,000,000
Wages	47%	50%	21%	25%	26%
Raw materials	24%	11%	13%	13%	16%
Fuel	29%	17%	37%	13%	19%
Power	-	14%	16%	4%	6%
Maintenance	-	8%	5%	17%	24%
Not identified	-	-	-	11%	-
Miscellaneous	-	-	8%	17%	9%
Manufacturing costs per tonne (Swiss francs)	20	55	40	45	26
Depreciation costs per tonne, calculated over ten years (Swiss francs)	5	16	13.5	12	34
Price per tonne (Swiss francs)	25	71	53.5	57	60
Output per worker per day (tonnes)	0.25	0.21	2.20	4.25	8
Compressive strength, kg/cm^2	<10	80-100	150	500	300

(x) Inferior quality

(o) High-strength, top-quality products

VI. MOBILE BRICKWORKS

The term "mobile brickworks" means a brick-manufacturing installation which combines a mobile unit with several fixed installations comprising the dryers and kilns. In practice, the mobile unit consists of a truck on which a grinder and extruder, as well as the necessary driving motor set, are mounted. This unit travels from one dryer kiln installation to another as needed, thus enabling the cost of the moulding plant to be spread over several brickworks.

This idea of mobile brickworks originated in Africa and has been under study since 1965 in Ghana and Chad. A Hungarian unit is said to have been supplied to Ghana in 1966, while at the same time a French company was studying the establishment of such a unit in Chad.

As it was my responsibility, during my tour of duty as an expert in 1968/1969, to study the possibilities of producing bricks in Madagascar, I considered it useful to go more deeply into the question of mobile brickworks on the island, as it is particularly rich in clay deposits and the centres of population, except in the case of Tananarive, cannot absorb the output of a fixed brickworks, several ill-fated attempts already having been made. I was also lucky enough to meet there the technician who has studied the problem in Chad and who allowed me to consult his documentation on the subject.

Economic and technical considerations

"A mobile brickworks" can be envisaged for use in an area where the centres of population are too small and scattered to provide a suitable market for industrial-scale brickworks but which can nevertheless consume an output of bricks which it would be difficult for artisan brickmakers to provide in the required amounts and qualities.

The first condition which must be fulfilled is the presence in the immediate vicinity of the population centres of sufficiently large clay deposits.

A second condition is that several centres which are a certain distance from each other and have the required other qualities must be connected by a road or sea transport route which permits the transport of the heavy machinery unit.

Plant required

(1) A mobile motorized unit which can transport from one place to another, in accordance with local needs, a set of plant for the preparation and moulding of stiff plastic pieces. This set of plant will consist of the following items:

- One electric generating set of about 100 horsepower
- One grinding unit, possibly with stone removal equipment
- One mixing and extrusion unit.

The necessary feed conveyors will form a single unit mounted on a tractor truck which will also serve to transport the necessary machinery and skilled workers and can also be used for the transport of fuel, clay and fired products. The manufacturing (preparation and moulding) unit is mounted on a trailer.

The moulding unit should be supplemented with a wire brick cutter, a water pump unit, hand trucks and extrusion dies.

(2) A series of fixed drying and firing installations located at the places where the bricks will be consumed

Drying would be carried out in the open air on pallets or shelves placed under a shed.

Firing would be carried out in kilns of simple construction which could be modified to suit the magnitude of the output, such as the Scotch type without a fixed crown, the Bull type (a Hoffmann kiln in a trench, without a fixed crown), or a direct horizontal draught kiln (Newcastle or Kassel kiln) with a fixed crown.

The brick needed for the construction of the kilns would be provided by a temporary kiln.

In developing countries, an average consumption of 5-10 bricks per person per year can be expected. This consumption might temporarily be subject to great increases, however, in the event of rapid development of an area (industrialisation centre, agricultural centres, etc.). For an installation to be profitable it is necessary to be able to rely on a consumption of at least 200,000 units per centre per year.

As the mobile unit can produce 10-20 tonnes per working day, a stay of at least six weeks would be needed for the moulding. Scotch or Newcastle kilns could produce about 30 tonnes per week, while a Bull kiln could produce up to 100 tonnes.

The moulded products would be stacked up for storage in sheds after sufficient drying, so that firing could extend over several months if necessary. It would therefore be necessary to have an entrepreneur on the spot to supervise the drying, firing and storage of the finished product.

Cost of the installation

(1) The cost of the mobile unit would be as follows:

- Currently available preparation and moulding machines:	$50,000
- Berliet GLR 160 trailer truck:	$20,000
- Miscellaneous:	$ 5,000
Total:	$75,000

(2) The cost of the fixed installations at each site would be:

- Shed 750 m^2:	$10,000
- Kiln, 50 m^3:	$10,000
- Miscellaneous:	$ 5,000
Total:	$25,000

If we assume that there will be 6 working sites, the total cost will be:

- Mobile unit:	$ 75,000
- 6 fixed installations:	$150,000
Total:	$225,000

Operating costs

The costs given below have been worked out on the basis of Madagascan conditions, in thousands of Malagasy francs per year:

- Mobile unit staff (4 skilled workers and foreman)	480
- Local personnel working for three months (27 workers x 6 groups)	2,400
- Fuel 400kg of wood per tonne fired, output 3,000 tonnes	2,000
- Fuel for truck and driving motors	4,000
- Machinery maintenance, 5%	1,000
- Kiln and dryer maintenance, 2%	300

- Administrative and management staff		1,800
- Depreciation of truck over 5 years		1,000
- Depreciation of machinery over 10 years		1,400
- Depreciation of masonry over 20 years		340
	Total	14,720
Miscellaneous costs		1,280
		16,000

This represents a price of 5,300 CFA francs (US$20) per tonne.

This price is equivalent to about $2.50 per m^2 of building, whereas parpaing (concrete blocks) would cost $4 per m^2 and would also involve considerable costs on the import of cement.

These figures are, of course, only given for guidance. Nevertheless, they show the importance of this matter for the economy of developing countries which have the right resources for this type of manufacture.

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