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LABOUR INTENSIVE AND SMALL SCALE BRICKMAKING *

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PREFACE

In a relatively short document such as this one, it has not been possible to cover every aspect of brickmaking in complete detail. In fact, the document is limited mainly to some labour intensive methods of brickmaking at least some of which can be replicated in almost any country without having to resort to importing equipment or materials. For some people, the document may be over simplistic in dealing with technical explanations, whilst for others it may be too technical in parts. However, it is hoped that sufficient information has been given through the text, photographs and diagrams to indicate the diversity of simple emthods and the results which may be achieved. There is tremendous scope to produce building materials from local resources of raw materials, which can be made in a variety of colours, shapes and textures. The realization of this potential may not be limited so much by raw materials or by manufacturing methods as by lack of imagination and knowledge.

Heavy clay materials can be considered to be part of the group of strategic minerals which, though hardly exotic in nature, are of prime importance in developing local construction industries. Yet, defining the locations, size, and quality of deposits, and solving problems associated with their exploitation, is too often left until after the problems appear instead of being considered as a pre-production requisite.

The manufacture of clay floor and roofing tiles should not be ignored since the methods of production are essentially similar, although better qaulity raw materials are sometimes required. Modern design has developed roof structures which, when used for clay tiles, are often competetive with alternate (often imported) roof covers. There are few roofing covers which have the durability of well fired clay tiles.

It has been the author's[1] experience, after a long association with UNIDO, that they can provide assistance with development of all apsects of the heavy clay industry. The author has expressed his willingness to freely answer any questions on specific problems which are directed to him through UNIDO.

1 The author, Mr. W. Buchanan, is the principal of Building Materials Development (West Australia).

INTRODUCTION

Historical

Even a brief history of bricks and brickmaking could fill several books, and would cover many countries. It would be seen that burnt clay bricks have been made by simple methods for several thousand years, and that such methods are still being used effectively.

Indian architecture is said to have found its earliest expression in brick buildings which were contemporary with buildings of wood. In Pakistan, buildings of burnt clay bricks have been found which are up to about 4,500 years old. Similarly, in the Middle East, burnt bricks were used in the ancient city of Ur about 4,500 years ago. One of the seven wonders of the ancient world, the Great Wall of China, stretches for some 2,400 km (1,500 miles). Both sun-dried and burnt clay bricks were used in its construction, several hundred miles of which is still intact today. The major part of the construction took place some 2,000 years ago, with repairs and considerable extension being completed during the Ming dynasty (1368 - 1644 A.D.)

Shortly after the end of the Ming dynasty in China, the city of London in England was ravaged by a great fire (1666 A.D.). The fire served to show how dangerous timber could be when used as an urban construction material. The Rebuilding Act of 1667 A.D. directed that only stone or bricks might be used for reconstruction, and a new chapter in the history of brickmaking was begun.

No book on bricks would be complete without mentioning tiles as used for paving and roofs. Although bricks were used as early as 250 - 226 B.C. by the Parthians to build the Arch of Khosrow at Ctesiphon (near Baghdad) and which has remained standing until modern times, and although design technology developed to the point where even domes of solid bricks could be constructed, tiles were found to be a much more practical roof cover, and the use of 'box tiles' such as are shown in Figure I. enabled larger roofs of lower weight to be constructed.

The story of brickmaking could be expanded to cover other countries and other times, but the fact would remain that bricks were made by simple methods, and that many of those bricks made in ancient times as well as the methods still exist today.

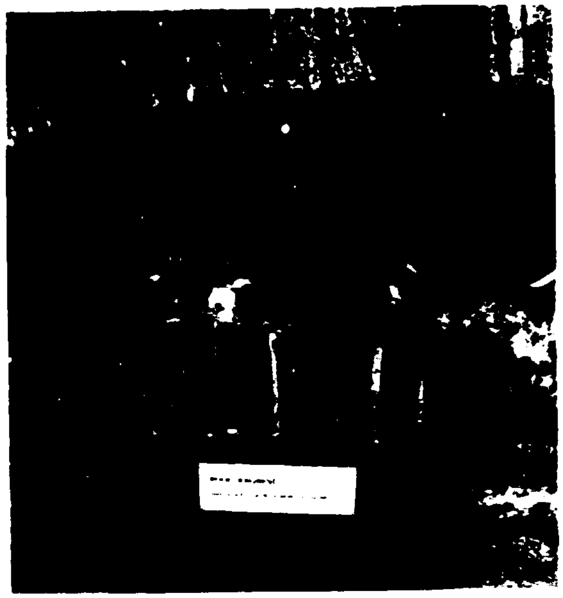

Figure I. Box tiles as made by ancient Romans and used in roof structure. Photograph from Roman baths, city of Bath, England.

Modern Brickmaking

The fact that modern brickmaking is often a mechanized process does not detract from the fact that there are many valid reasons for making bricks by manual methods. It is worthwhile, therefore, to consider some aspects of modern mechanized brickmaking. Mechanized brickmaking developed rapidly with the development of the industrial revolution, to the point where modern factories can produce well in excess of one million brick equivalents per day and much of the administration and process control might be computerized. Obviously, the high degree of automation in such factories demands a high capital investment, as well as suitably skilled personnel to operate and maintain the investment, including suitably skilled personnel to effect the necessary marketing, management, and other functions which contribute to a profitable investment being realized. In this sense, it is relevant to note that the politics of a nation are considered to be irrelevant to the need for investments of people and capital to realize a profit for further investments which will help to develop the nation.

The reasons behind mechanization of brickmaking are varied, and it is important to note that it has not always been necessary to mechanize production to obtain adequate quality bricks for housing. Some of the reasons behind mechanization are as follows:

(a) Increased demand for clay products leading to increased demands for raw materials, some of which could only be processed using mechanization.

(b) Increased demands on the strength and other physical qualities of bricks used in extreme situations where exceptional strength and/or durability were called for. Examples of this are bricks used in bridges, high rise buildings, retaining walls and other exposed situations in severe (e.g. freezing) atmospheric conditions, and in factories or other places where acid, alkali, biological, or other agents may attack the brickwork.

(c) Increased cost of labour per unit of output, or non-availability of labour to meet production requirements with more labour intensive methods.

(d) Development of industrialized building methods which demand that individual building units be manufactured to closer tolerances than can be easily obtained from purely manual methods of production. Similarly, accuracy of size and shape are important where overall standardization of building components has been introduced.

(e) In some developing countries, mechanization has been introduced simply because this appeared to be the modern way of making bricks, when in fact less mechanized methods could have served the purpose just as well with less importation of capital equipment.

It is perhaps ironic, and certainly some sort of judgement on the often monotonous regularity of bricks made by mechanized forming, that a number of the most highly mechanized countries are also making hand made or simulated hand made bricks. It is probably true to say that 90 per cent of the developing countries' needs for bricks could be served by those bricks which could be made by non-capital intensive methods, and that with proper training and management, the cost of such bricks would be less than for those produced by capital intensive mechnanized methods.

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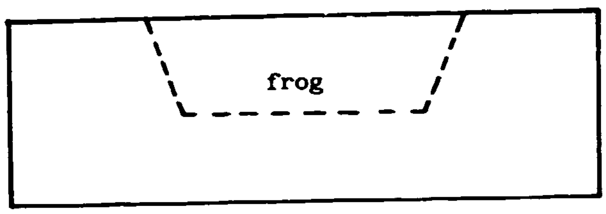
I. MERITS OF BURNT CLAY BRICKS.

Figures II. and III. below, show, respectively, a standard brick (it may be noted that different countries may have different standards or none at all) and various cut or manufactured shapes based on the standard, and, a limited variety of brick shapes which can be made manually. Figures IV. and V. show some bonding patterns for bricks in the wall or when used as paving bricks. From this, and taking into account the wide variety of colours and textures which can be achieved, plus the durability which is characteristic of burnt clay bricks when properly used, it is not difficult to appreciate that the principal merits of burnt clay bricks could be summarized under the three headings of:-
durability; attractive appearance; and, versatility of use.

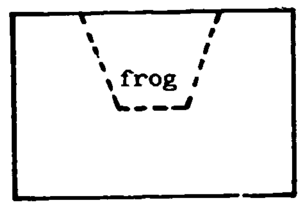
Figures VI. and VII. show some buildings from different parts of the world which serve to show the versatility of use, and in the case of figure VII.b., durability can be assumed since the bricks were made by the ancient Romans. Figure VII.a. shows the use of hand made bricks in urban housing, with attractive yet functional features including arches over the door and windows, and corbelling under the upper windows. Figure VII.c. shows a small scale industrial use of bricks - where they have been used to make a kiln for firing tiles. Also pictured are two of the senior scientists from the Central Building Research Institute in Roorkee, which gives practical assistance to brick and tile makers amongst its many other activities.

It has always been an attractive feature of bricks that they can be made in a wide variety of shapes and sizes. When this is coupled with the variety of colours and textures which can also be achieved, it may be appreciated that, not only is the brick a versatile structural unit, it is also capable of being used artistically to create extremely attractive structures, or simply for decorative purposes. Decorative brickwork was being used as long ago as 600 B.C., and some beautiful examples of work done by the Babylonians and Sumerians can still be seen.

It is sometimes believed that handmade bricks must be of low quality, of poor shape and size, and that only machine made bricks can be of high



a.



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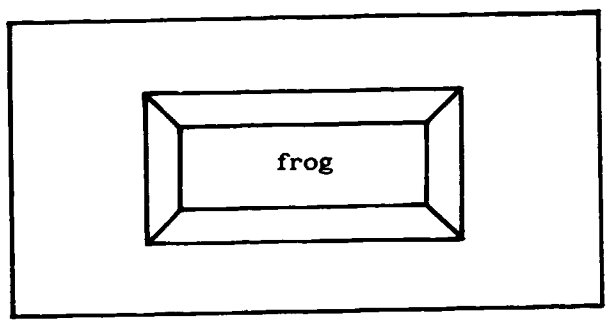


c.

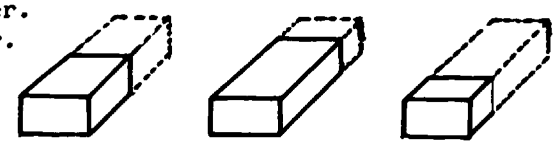
a. = side elevation or stretcher face.

b. = end elevation or header face.

c. = plan view or bed face.

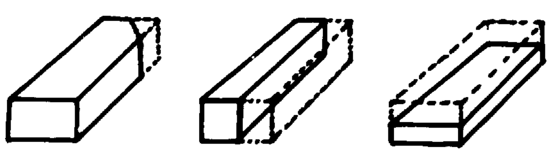
frog = mortar cavity, usually found in pressed or handmade bricks.

d. = half brick, bat, snap header.
e. = three-quarter brick, closer.
f. = quarter brick, closer.



d. e. f.

g. = king closer.
h. = queen closer.
i. = split.



g. h. i.

The special shapes d. tc i., are cut by the bricklayer.

Figure II <u>Brick Nomenclature</u>.

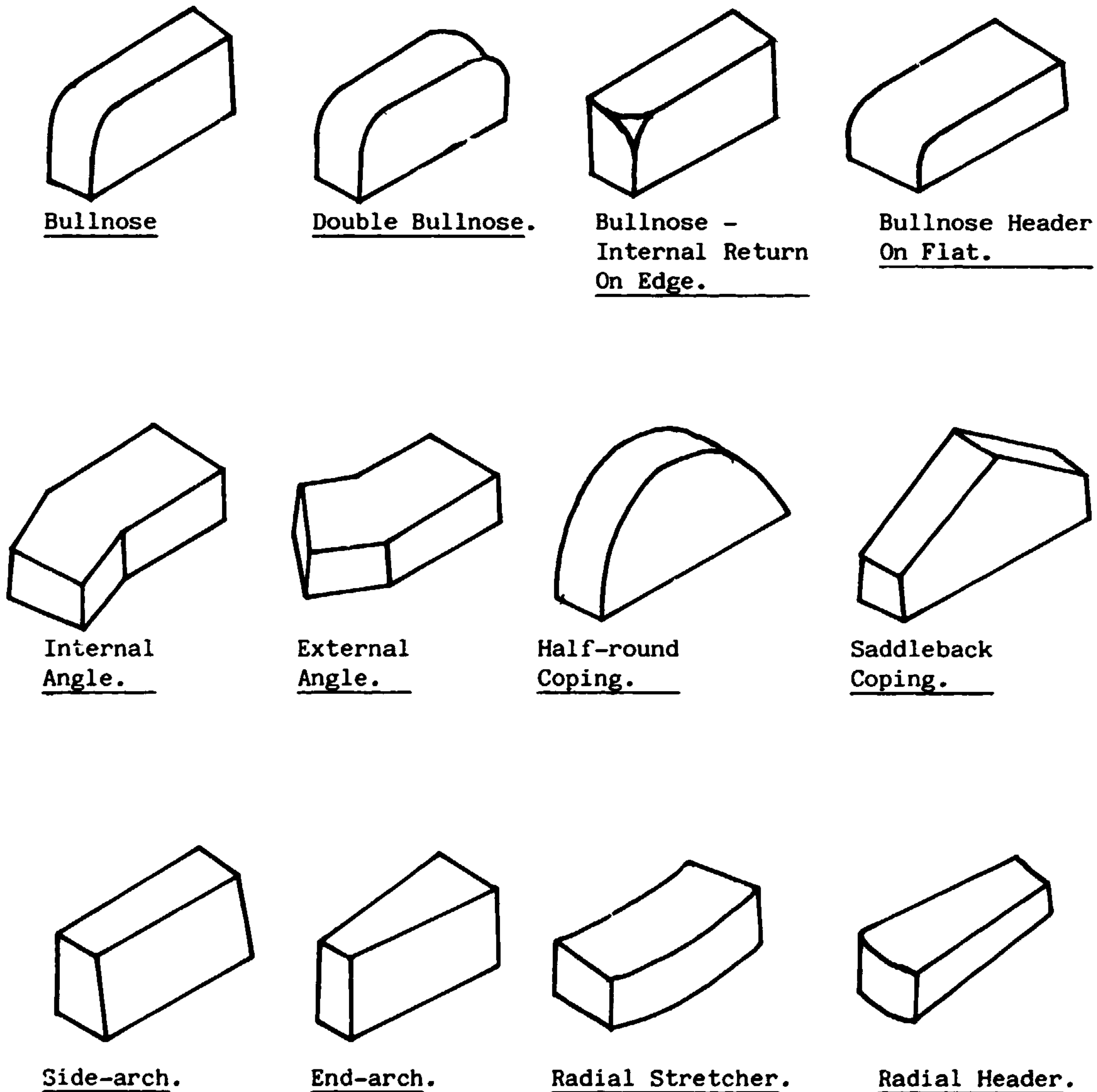
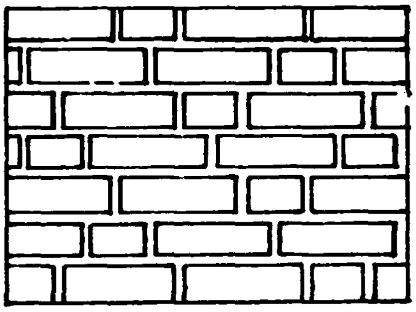
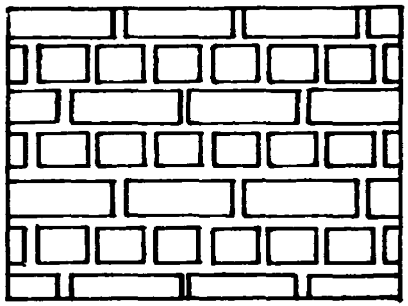


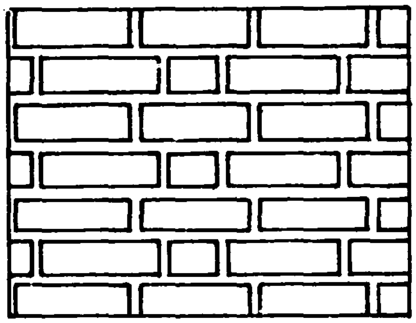
Figure III. Special shapes which can be hand moulded.



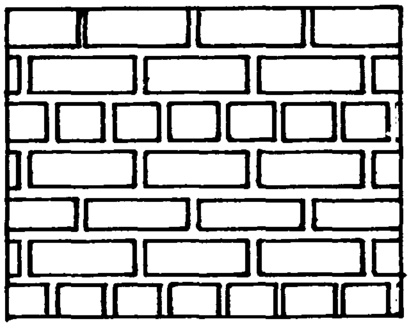
Monk Bond



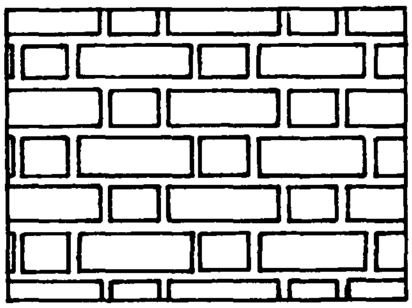
Dutch Bond



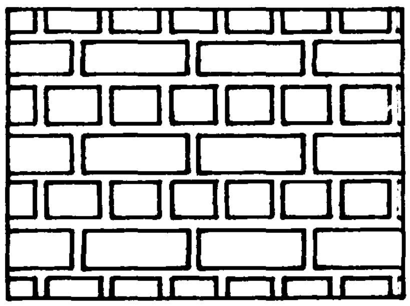
Flemish Garden Wall Bond.



English Garden Wall Bond.



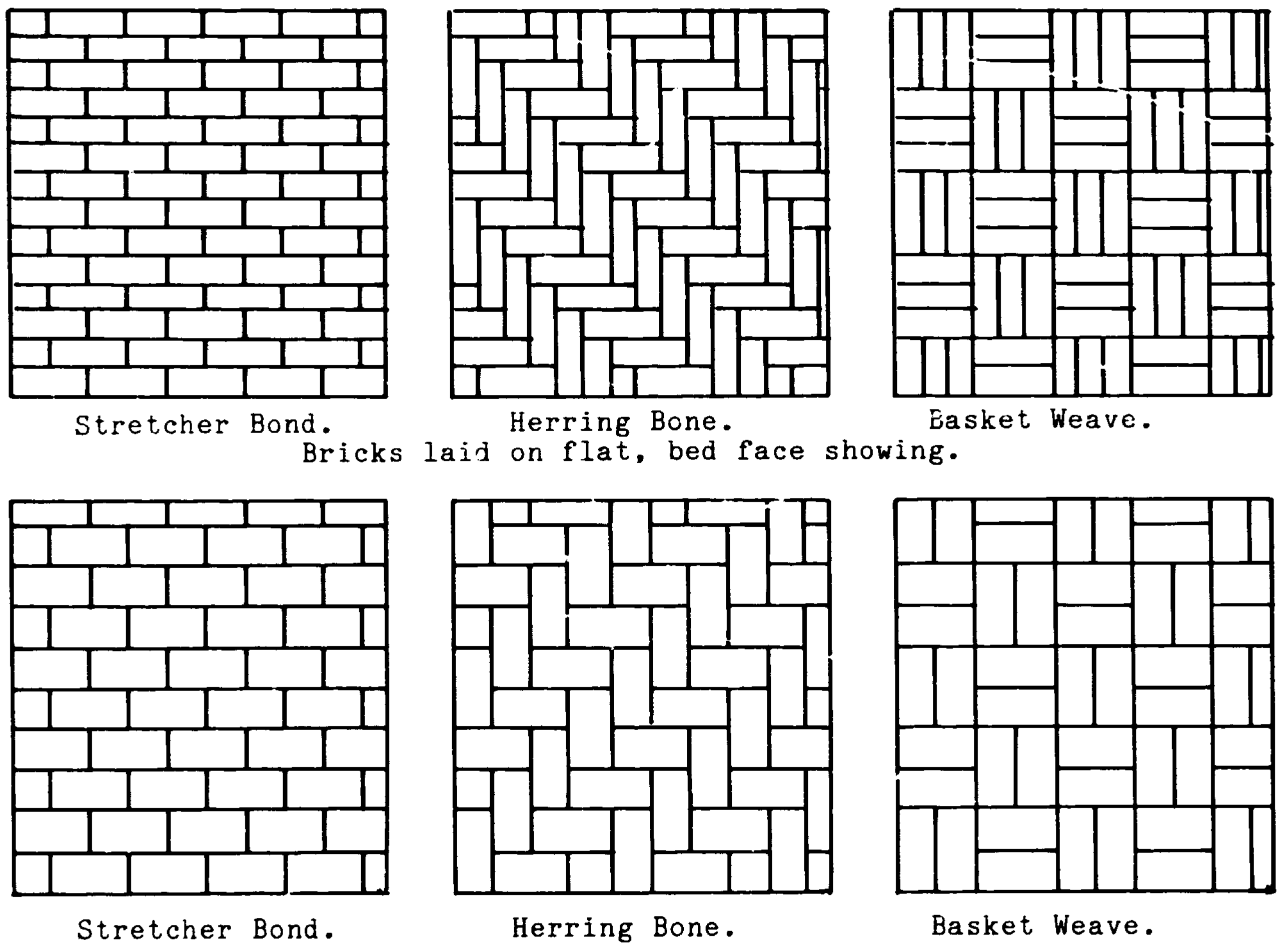
Flemish Bond.



English Bond.

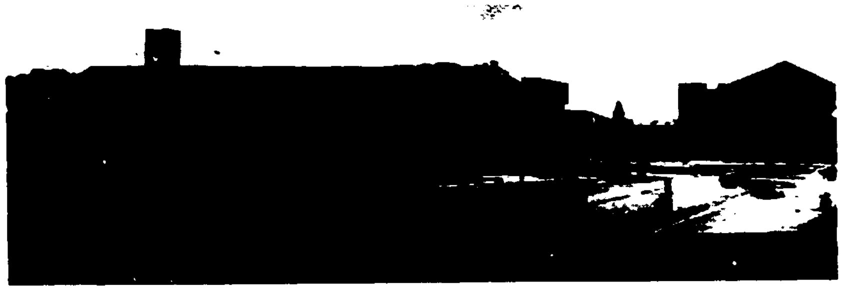
Figure IV. Some bonding patterns.

Bricks laid on edge, stretcher face showing.



The durable and attractive nature of burnt clay paving bricks has been known for centuries. The above Figure shows some patterns which can be laid using 'standard' bricks. Other patterns are also possible, and special shapes can be made for further variations.

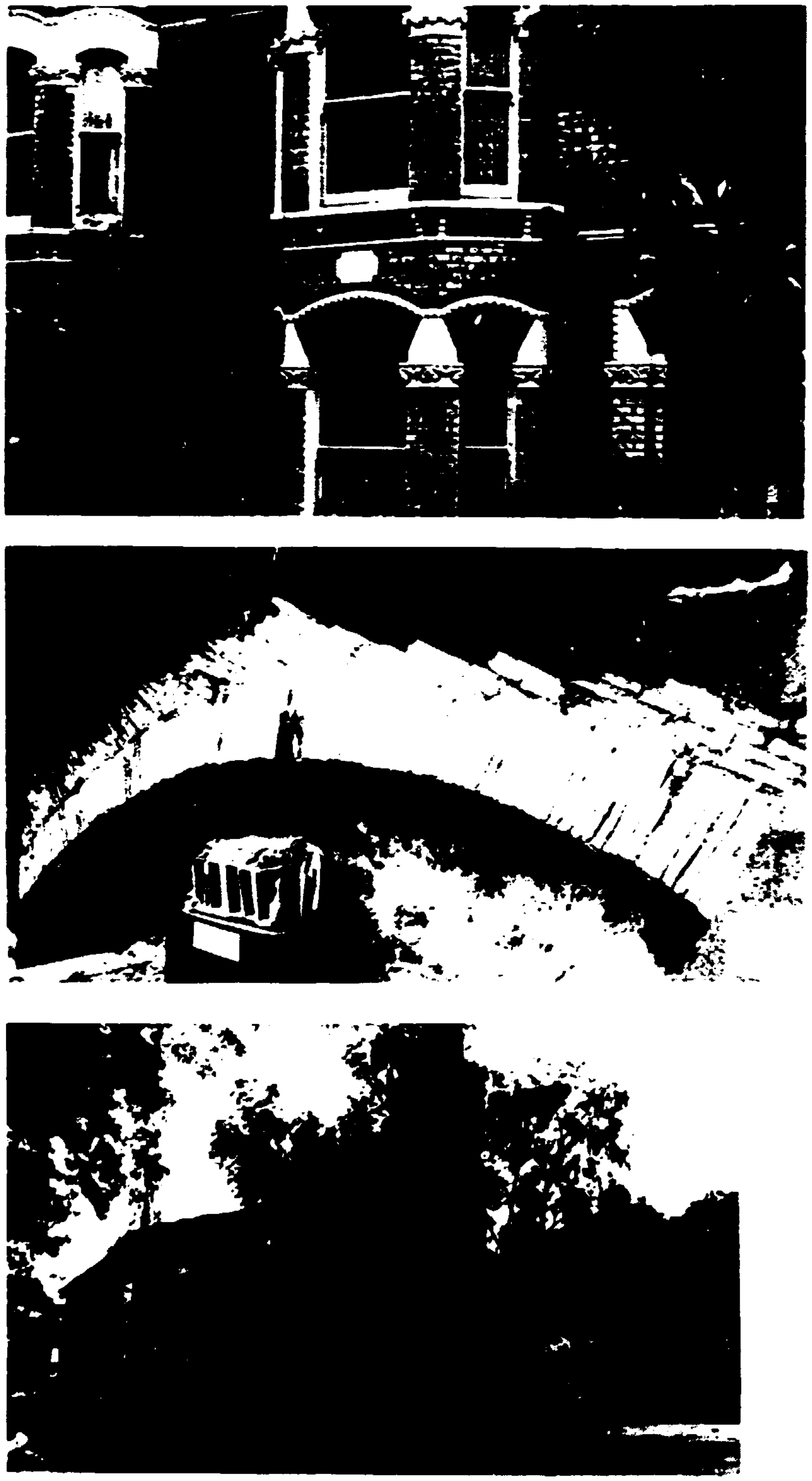
Figure V. <u>Some bonding patterns for laying paving bricks</u>.



Kamuzu Academy, Malawi.
The bricks used as facings were made in a labour intensive, partly mechanized brickworks. The common bricks were mainly slop moulded bricks, handmade.

Low cost housing - Malawi. Handmade brick walls, fibre-cement roof sheets.

Figure VI. Prestige and low cost buildings.



a.

b.

c.

Figure VII. Bricks for functional and decorative use.

quality. That this is a fallacy can be seen not only from the diverse range of buildings that have been constructed throughout the centuries and still exist today, but also from the many handmade and simulated hand made bricks which are produced in several of the developed countries.

With specific reference to bricks made by labour intensive methods, efficient production can give adequate building units at very low cost. Thus, an additional feature of burnt clay bricks can be their low cost. Related to this is the low investment in terms of capital equipment which is required to start production. The actual level of such investment will vary according to individual conditions, but at one end of the scale it is possible to start production with, literally, a shovel and a single brickmould. At low levels of investment, it is possible to vary production according to demand and even to move the production site closer to the customer if the raw materials for production are available. A simple example of the need to vary production level substantially is where bricks are made during the dry season when labour is often plentiful, and no bricks are made during the wet season when it is inappropiate to make bricks and when labour is scarce due to agricultural committments. Obviously, different factors apply in different countries or areas. In some cases, year-round production is essential and this can affect the detailed operation of the brickmaking facility as well as the degree of mechanization which is capable of being profitably used.

The quality of bricks is most often judged by their physical strength, with other considerations being their size, appearance (colour and texture), and shape. For efficient building work, regularity of size and shape, within known tolerances, is extremely important. Similarly with colour, where it may prove a useful guide to quality in some cases, but should at least be regular where the bricks are used as facing bricks and especially for larger and higher cost structures. It is by controlling these variables of colour, texture, shape and size, that the full potential of burnt clay bricks can be realized to satisfy most structural or æsthetic requirements. It is the fact such variables can be controlled, if the materials and the process are understood, that leads to the merits of burnt clay bricks.

From a national point of view, as cpposed to the technicality of making bricks, the use of bricks can have a number of important benefits to the country:

(a) Burnt clay bricks normally use locally available materials in their manufacture, although sometimes fuel is imported. However, even with fuel, it is possible to minimize requirements by careful selection of clays and by maximizing the use of fuels or supplementary fuels which may be available within the country, e.g., wood, sawdust, waste oil, agricultural by-products, etc. The use of locally available materials obviously reduces imports whilst providing further employment locally and expanding the economy from the country's own resources.

(b) Where clay bricks are of the requisite quality and are properly used, they provide the basis for construction of permanent structures which are in themselves a long term investment.

(c) The availability of bricks presupposes the existence of, or at least indicates the need for, designers and artisans. Thus the opportunity exists to develop or expand on a workforce of professional, skilled, and unskilled persons. Even so, with for example, self-help low cost housing, appropiate design which takes into account social needs, envoironmental factors, and the lack of skills readily available, it is possible to construct adequate housing of a permanent nature.

(d) Development of agriculture, industry, education, health facilities, government and institutional facilities, and domestic housing, all require building materials. There are few cases where bricks cannot fulfill the majority of these requirements in, at least, the need for wall materials. Thus locally made bricks not only create industrial development, but support other industries and institutions in their need for building materials.

In the more affluent societies, the provision of permanent structures is seen as an essential part of creating stable investment by making available structures which are permanent in nature whilst being sufficiently durable that their maintenance requirements are minimal. However, it must be stressed that efficiency of production (and of construction) is of paramount importance in minimizing costs and maximizing investment value.

II. WHICH BRICK? WHERE? AND WHY.

With respect to hand-made and simple extruded bricks, we are usually talking about "solid" bricks. In fact these bricks may not be solid, since some classifications accept up to 25% perforations (in extruded bricks) or 25% of the brick may be taken up in the form of the frog(s). This classification is used in this manual, and we can further define the bricks by calling them solid masonary units. A brick is a unit of construction and the types of units can be described according to the function which they fulfill in the structure:

- an ordinary structural unit should have certain properties of strength, durability, size, shape, etc., but need not be of any particular appearance. It may not be seen after being incorporated into the structure, e.g. where it is painted or rendered with mortar. It may or may not be a loadbearing situation, but if it is in a loadbearing situation then it should be classified as loadbearing.
- Facing bricks should have the physical properties relevant to the function which they have to perform as part of a structure, but in addition they should have certain qualities regarding their appearance. These qualities normally apply only to, at least, one stretcher face and one header face, but may in certain cases apply to at least one bed face if the bed face is to be exposed. Bricks of actual size 190 x 190 x 90 mm have four stretcher faces of 190 x 90 mm, and two header faces of 90 x 90 mm. Bricks of actual size 215 x 102.5 x 65 mm have two stretcher faces of 215 x 65 mm, two header faces of 102.5 x 65 mm, and two bed faces of 215 x 102.5 mm.
- Bricks used for special purposes, such as paving bricks or foundation bricks, will have to have certain qualities relating to the type of service which they have to give. Paving bricks should be resistant to impact and abrasion whilst foundation bricks should have a low water absorption.
- Bricks used in exposed situations must be durable under the particular conditions of exposure.

There are number of tests which can be done to give a measure of confidence in the performance of bricks. However, there is no quick test for durability, and it is known that compression strength is not in itself a suitable test. Related to this are the conditions under which a brick is exposed to use. Climatic factors have an obvious bearing on durability, with wet freezing conditions being particularly severe. At the same time, structures can be designed to minimize the effects of climate and other factors. Conversely, insensitive design may be such that the bricks must be of a higher physical standard than would have been necessary with better design. Since higher physical strength usually involves higher manufacturing costs, it pays to consider carefully the specifications for the structure and for the masonary units.

Generally, the more simple and smaller a structure, the lower the physical quality of bricks which can be effectively used, especially where the climate is not severe. If one looks at traditional housing in rural areas, it will be seen that building design has evolved such that the houses fulfill adequate social functions, can be built with reasonable ease, and are resistant to weather insofar as is possible with the building materials available to the people. Where 'wattle and daub' type walls are replaced with more permanent walls of brick, concrete, etc., special attention should be paid to the foundations, since foundation movement can often be accomodated in the relatively flexible wattle and daub type walls (or they can easlily be repaired using some mud), whereas more rigid masonary walls may crack if the foundations are unstable. Even so, given that the foundations are adequate, very low quality burnt bricks can usually be used directly in place of wattle and daub, and because the building design is usually such that the walls are protected anyway, these bricks will be a low cost permanent wall material. With higher cost, prestige, or public buildings, walls tend to be more exposed to the weather, to loadbearing requirements, or they may have to be facing bricks, and the designer should specify the quality required. The actual specifications for particular applications should be made by qualified persons such as the architect or engineer responsible for the design.

It is often the case that a designer is faced with only one type of brick being available, e.g. a simple hand moulded brick fired in a wood fueled clamp. If the quality of such bricks is low, design may evolve such that reinforced concrete is used for the loadbearing framework of structures, and the bricks are used simply as infill panels. In such cases, specialist assistance should be sought to upgrade the quality of the bricks, and to help diversify production to get a range of products. This helps the brickmakers by giving them the opportunity to expand their business, and it helps the designers by giving them a better range of materials to work with. In one country, where there is a great range of colours, sizes, and textures of brick available, it has been said that this variety of bricks is to the architect, what a box of paints is to an artist.

Using bricks which are of inadequate quality may result in structural failure, or rejection by the customer. To use bricks of much higher quality than is necessary can result in unnecessary expense for the customer. Consider two cases which may be found close to each other in a country with a modern urban centre adjacent to a less developed urban or rural area:

(a) A small single storey house is constructed with bricks, under a roof which overhangs the walls on all four sides. The climate is such that there is no frost, and the walls are largely protected from rain.

(b) A multi-storey office block is constructed using a variety of facing bricks which vary both in colour and texture according to designs laid down by the architects. Facing bricks are also used inside the building to achieve attractive effects on feature walls. In front of the building, a paved area has been laid, over which thousand of people will pass each day. It has been planned that, within a few years, a matching complex will be built as part of the development of a new commercial and business centre. The suppliers of the bricks have contracted to supply the bricks for the future buildings and have guaranteed that the bricks will have certain verifiable qualities of strength, dimensions, shape, colour and texture, such that the future buildings and paving will match the existing work.

In the case of the low cost house (a), the bricks cost the equivalent of U.S.$15 per thousand; in the case of the offcie block (b), the bricks cost an average equivalent of U.S.$250 per thousand. In each case the bricks were adequate for their particular purpose. The low cost bricks did not have the strength, dimensional accuracy and regularity, or reproducibility of these qualities which had to be guaranteed for the high cost bricks.

The high cost bricks were more than adequate for the low cost house, but were beyond the means of the house owner to purchase them. In both cases the structures were permanent and suited their intended purpose.

One of the features of well made bricks is that they are attractive without having to be painted or plastered with mortar. Having said that much, it may be apparent that what is attractive to one person is not so attractive to another. The cost of bricks therefore, whilst related to manufacturing costs, might also be influenced by the æsthetic or perceived quality. Such perceived qualities can often be achieved at little cost, e.g., by varying the clay or firing to get a different colour effect, by using different sands on the face of the bricks whilst moulding to get one or more colours and a sand faced effect, by scratching or texturing the surface of the bricks, etc., to get a variety of other effects. Often the cost of achieveing these effects is far below the increase in price which can be applied due to the increased demand for the bricks.

Where Bricks can be used.

If we consider the lowest form of bricks, i.e. broken bricks, they are useful as hardcore or rubble to form the sub-base under buildings and paved areas; to fill in field drains if they are well fired; as a stabilizing material if crushed and added to some clays during brickmaking; and, if underfired, they may form a useful pozzolanic material when pulverized and mixed with lime.

Low fired bricks, commonly called underfired, are useful in non-loadbearing situations where they are not exposed to wet weather or to dampness. They may be used in exposed situations if properly protected by building design or by painting, lime-washing, or plastering with a suitable mortar. They are not usually suitable for use in foundations. One of the benefits of firing to a low temperature is that there are obvious savings in fuel, and in areas where fuel is scarce, this is an important consideration. Bricks fired at low temperatures will be less strong than similar bricks fired at higher temperatures. However, proper selection of clays can result in raw materials which will 'mature' or be well fired at a lower temperature.

The range of bricks which would be called 'well fired' is quite large, and well fired is in itself a relative term since it may be related to the durability of the bricks, which in turn is affected by the conditions under which the bricks are used. What are called well fired bricks may have compression strengths ranging from as low as about 4 MPa (580 lbs/in^2) to as high as about 70 MPa (10,152 lbs/in^2). They may be facing bricks or non-facing, loadbearing or non-loadbearing, and have a wide range of uses as can be seen from the following list which is not claimed to be comprehensive:-

- General building work, foundations and walls, from single storey to in excess of 10 storey height.
- Fireplaces and chimneys, and in other areas where high temperatures are expected. Some bricks are used as low grade refractories[3] whilst others are used away from the hot face behind refractory bricks, e.g. in furnaces, kilns, ovens, etc.
- Paving bricks, used in roads, footpaths, carparks, other paved areas.
- To line drainage ditches alongside roads, in airports, in agricultural areas.
- As loadbearing columns where bricks or other materials may be used as infill panels, and in submerged situations where their durable and inert nature is of benefit.
- To construct water tanks, as retaining walls, garden walls, privacy walls, security walls, etc.
- As a form of insulation against sound and heat.
- For storage of heat, although special high density bricks are usually used for this purpose.
- Glazed bricks are used both for their attractive appearance, and in areas where cleanliness is essential.

It should be noted that the bricks at the extreme upper end of the compression strength range mentioned above require specialized methods of

[3] Refractories are special materials designed to withstand extremely high temperatures at which normal structural bricks would melt.

manufacture, and great must be taken in selecting and processing the raw materials. With respect to hand made bricks, compression strengths of about 20 MPa would be considered good, and suitable for much loadbearing work. A more average figure for hand made bricks fired in wood fired clamps would likely be about 5 MPa to 10 MPa.

Why bricks?

From what has already been said, it may be appreciated that burnt clay bricks are extremely versatile masonary units. They are more resistant to fire than conventional concrete and much more attractive in appearance. It is possible to make a wide range of sizes, shapes, colours and textures to satify the majority of design and sthetic requirements. They are extremely durable, and often increase in attractiveness with time, being resistent to weather and the chemical attack which seems to be a feature of, at least, modern urban and industrial atmospheres.

Clay bricks are usually made from the natural resources already available within the country, thus reducing foreign exchange needs whilst increasing local employment and investment opportunities. At the same time, because of their permanent and relatively maintenance free character, brick structures make durable and attractive investments. The very fact that such a versatile construction material is available locally aids the development of other sectors of the economy and those sectors (government, health, education, industry, etc.) which rely on building materials for their development.

In developing countries in particular, shortage of fuel is a major consideration when considering brickmaking, or expansion of brickmaking. At the same time, the use of agricultural land for clay digging is considered to be a problem. With respect to fuel, proper selection of the brickmaking raw materials and the use of agricultural and other by-products (e.g. waste oil) can greatly reduce the fuel requirements. Certainly, where portland cement is manufactured or imported and concrete blocks or re-inforced concrete is used for construction, the country pays for the fuel used to make the cement in one way or another. Even where wattle and daub is used on any reasonable scale to build houses, the temporary nature of these houses means that the wood used in the construction is consumed as opposed to being invested in the making of bricks which are a more permanent building material.

The siting of clay quarries such that agricultural development is not restricted is a logical possibility given that the location and quality of the clay deposits are known. Investigations into the locations of clay deposits, and determinations to evaluate the quality of the clays is an essential part of the development of this strategic building materials industry. It is, for example, in this way that those clays can be selected which will make the best range of bricks for the lowest cost, and with the greatest measure of operational and financial security to the brickmakers.

III. RAW MATERIALS SELECTION AND TESTING.

The selection of raw materials is one of the most important decisions made by the brickmaker. It may or may not affect his business to the point where it succeeds or fails, but it will certainly affect the economics and future of the process to some extent. The exact details vary according to individual cases and the following factors are some which influence the choice:-

- Physical location of the deposit in relation to the place where the bricks are to be made.
- The amount and type of overburden[4] lying over the clay deposit.
- The depth of the clay deposit, i.e. the thicknes of the clay seam, and the variations in quality which exist in vertical and lateral directions.
- The form of the deposit, i.e. alluvial, soft shale, hard shale, etc, and how easily the deposit may be worked. With respect to harder clays, it is also important to know if or how they will break down into usable material when exposed to the weather, by adding water, or by mechanical means.
- The existence of impurities which have to be removed or neutralized.
- The type of plastic mass which is formed after processing in order to form the bricks, i.e. one which is easily formed or one which has limitations on how it might be prepared.
- The ease with which the plastic (processed) clay dries, the drying shrinkage, and distortion which takes place.
- The ease with which the clay fires, the top firing temperature needed to make a suitable brick, the maturing range of temperature within which a brick can be fired.

Although brick clays come under the general classification of ceramic raw materials, they are probably the most impure and variable of those used in the ceramic industry. It may be appreciated therefore, that 'ideal' clays are seldom encountered, and where investment is involved, testing of the raw materials is of paramount importance. The level of investment in clay testing may be related to the level of investment anticipated in the brickmaking industry, but even with small scale brickmaking, at least some basic testing of raw materials should be done.

[4] Overburden is the name given to the unwanted material which lies on top of the useful clay.

Testing of clays has grown in complexity to take into account improved methods of test, more comprehensive understanding of the nature of clays, and the diverse and increasingly stringent demands made on clay based products. At the same time, it is known that skilled clay workers can often make reasonable evaluations of the character and potential of clays, using their own experience coupled with a limited number of tests. In considering only small scale brickmaking and a relatively simple range of products, it is considered that some of the basic clay tests can be applied and, coupled with the intelligent application of limited experience, a reasonable evaluation can be made as to the suitability of the clays. With time and further experience, the quality of the evaluations will improve.

The test methods which follow are intended to provide the means whereby a reasonable evaluation can be made of clayey raw materials, at least for general purpose bricks, and possibly for other heavy clay products. The subsequent evaluations will be empirical in nature and will rely on a measure of experience and knowledge of clays, or on some professional guidance being available until such experience and knowledge is gained. An evaluation of the clay deposits themselves will depend on reasonably detailed information being available from geologists or others on the location and nature of the deposits, and on the type of products which are to be made.

A list of essential equipment items is attached at Appendix I, and most of these will be common enough in established laboratories. Actual test results may vary substantially between different laboratories, but the essential assessments as to quality of the raw materials should be similar.

Sampling.

Since test results relate directly to the actual sample which has been tested, it follows that if the sample does not in some known way represent the parent body, then the test results are virtually meaningless. Similarly with sub-samples, which must be representative of the paremt sample.

It is usually the case that a single sample from a clay deposit is not, or cannot be, representative of that deposit. However, a study of the available information, including a visual examination of the deposit and/or geologists reports, may give some guide as to the degree to which a particular sample can be taken to represent the deposit.

Pits and trenches probably give the most information on clay deposits, at least within the limits of pitting and trenching. The exposures made can be studied in detail and a regular pattern of pits and/or trenches provides scope for a systematic study of the deposit.

Augering provides a quick method of obtaining laboratory samples, e.g. a 75 mm diameter auger might give about 7 kg to 8 kg of useful sample per one metre of depth, but with dry augering considerable grinding of the sample may take place. With wet augering, considerable mixing can take place. Such mixing can mask the fact that narrow bands of material are being drilled through, and can give the impression that the material is more homogeneous than it really is. In augering, transition from one bed to another can be less clear due to the mixing which takes place in the hole, and false impressions may be gained as to the actual thickness of the material seam. Augers should be cleared frequently and samples taken at one metre intervals, or sooner when a change in the material takes place. During auger programmes, selected pits and/or trenches should be dug to verify the results of the augering.

Core drilling is more suited to harder clays and shales. The water used in core drilling can leach out soluble substances and wash away softer parts of the core. With relatively soft clays, sample retrieval is sometimes less than 10% and test results from such samples must be viewed with caution.

One of the simplest ways of getting a sample is from natural exposures such as river banks or erosion gulleys, or from artificial exposures such as road cuttings. Due care must be taken to get a fresh sub-surface sample, since weathering can alter the chemical, mineralogical, and physical nature of the surface material.

It is worthwhile to note that, even in a fairly small clay deposit, the actual samples sent to the laboratory may only be about 0.000025% of the total deposit. Another way of puting this would be to say that for every 400,000 bricks to be made from the deposit one brick has been tested for raw material quality. It is easy to see why samples should, in some known way, represent the deposit from which they are taken. For those who have no experience in sampling, it would be wise to contact the laboratory which will carry out the testing (if this is reasonably possible) to see if they can give advice on how the samples might be taken, and what information they will require about the samples.

Each sample has its own history, which will include the geographic location from which it has been taken, the method of sampling, e.g. surface exposure, pit, trench, drill hole, etc., the depths underground between which the sample was taken, details of any overburden, and a written description of the sample which will include its colour, physical state, and any other pertinent information available at the time of sampling.

Sample preparation in the laboratory.

When samples are received, all known information about them should be recorded, i.e. information which comes with the sample. A description is then made of the sample as received by the laboratory, and the sample weight is noted. It is also useful to know the purpose for which the raw material is required.

The sample as received by the laboratory should be air dried. This may be accelerated by placing the sample in a warm place, but the temperature should not exceed 50° Celsius. It is permissable to break down any lumps and in fact this may be necessary for future sub-division of the sample. However, this and any other treatment of the sample should be noted on a sample history report. Such reports should always be made out at least in duplicate with one copy remaining with the receiving section and at least one copy following the sample through its various stages of testing.

It must be stressed that since test results relate only to the sample or sub-sample being tested, it is essential that great care is taken when sub-dividing samples. A riffle sample box or other similar sample splitter is recommended, but where such a device is not available the cone and quartering method can be used. It is carried out as follows:-

a) Lightly crush the sample to under 10 mm particle size, place on a clean hard surface and mix thoroughly.
b) heap up into a conical shaped pile, flatten it down, and mix thoroughly again.
c) repeat step b) three more times and flatten into a circular shape.
d) divide the circle into four quadrants, remove two opposite quadrants, mix the remaining two quadrants and repeat steps c) and d) until the remaining two quadrants comprise the desired sample size. In this case, about 1.5 kg.

The laboratory sub-sample, derived as above, is further sub-divided for the various tests as follows:-

a)	Sieve test	200 gm
b)	Test briquettes	1,000 gm
	which is then crushed to pass through a 2.8 mm aperture sieve.	
c)	Loss on ignition	50 gm
	crushed to pass through a 150µ aperture sieve.	
d)	Microscopic examination	50 gm
	further examination can be made as required on the remainder of the primary sample, on the sieve residue, etc.	

The primary sample, after removal of the laboratory sample, should be stored at least until all the test work has been done, the report on testing has been issued, and for a further period of time to permit any questions relating to test results to be answered. A period of one year is usually ample time for this although samples with special interest may be be kept for a longer period. In setting up a testing laboratory it is essential to allow for a sample storage room.

Test Procedures.

1. Sieve Test.

a) The sieve test sample is divided into two approximately equal portions which are tested as follows:

- Weigh the first portion, dry to constant weight at 110° Celsius, cool in a desiccator, reweigh, calculate the moisture content.

NOTE: The moisture content may be expressed as a percentage of the weight loss of the total specimen weight ('wet basis'), or as a percentage based on the weight loss on the dry specimen weight ('dry basis'). Whichever method is used, it should be used consistently in all moisture determinations and recorded as "% wet basis" or as "% dry basis" in the reports.

- The second portion is weighed immediately after the first weighing of the first portion. Place the specimen in an 800 ml 'tallform' beaker, add about 600 ml distilled water and then heat to boiling point, maintain at boiling point for one hour taking care that none of the sample is lost through spurting. Allow to cool,pour onto a 75μ aperture sieve and wash the residue until the wash water passing through the sieve is clear; Any lumps of clay or aggregate bonded by clay may be broken down by gently rubbing them between the fingers, taking care that none of the sample is lost; After washing, place the sieve and residue in an oven and dry at 110° Celsius, then weigh the residue. The residue is then sieved through a nest of sieves comprising sieves of the following aperture sizes: 500μ and 75μ. This will give an arbitrary breakdown for 'rough', 'middles', and 'fines' according to the respective size gradings of +5ooμ; -500μ +75μ; and -75μ which is determined by calculation. If desired, a more complete sieve analysis can be done by using a wider range of sieves such as those with the following aperture sizes:- 2.8 mm; 1.4 mm; 750μ; 500μ; 250μ; 150μ; and 75μ. Although the sieves can be shaken by hand, a vibrator will be found to be most useful and probably more efficient than hand sieving.

Microscopic Examination.

The sample is observed dry through the binocular microscope. Note the presence of any recognizable minerals. In particular, look for siderite, calcite, gypsum, mica, pyrites, and any forms of calcium carbonate. Treat the sample with dilute hydrochloric acid and observe the nature of any reaction to see if the reactant is finely dispersed or in a more particulate form. In the latter case it may be necessary to go back to the primary sample to evaluate particle size and frequency of occurence.

Linear Change.

Linear change is measured between the states of wet and after drying at 110° Celsius, dry to fired at 900° Celsius, dry to fired at 1,000° Celsius, and dry to fired at 1,100°Celsius. Testing at other temperatures may be desirable, whilst testing at 1,100° Celsius may be eliminated or replaced by a lower temperature if it becomes obvious that the sample will melt at 1,100°C. It is advised that the lower temperature tests be carried out first.

The amount of sample needed to make the six briquettes for the linear change test will depend on the actual size of the briquettes. However, extra large briquettes would lead to additional expense by virtue of the larger sized test furnace which may be required. A convenient size is 80 x 40 x 25 mm. The dry sample is placed in a mixing dish and water gradually added, mixing all the time. Thorough mixing is essential with the objective being to achieve a plastic mass which is workable, but not so soft and sticky that it sticks to the hands. It is not possible to say how much water will have to be added to the air-dry sample since different clays will require different amounts. Forming of the sample is made in a steel mould of internal size equal to the desired briquette size.

Lubricate the steel mould by applying a thin, even, coating of petroleum jelly or oil; take a piece of clay, the volume of which is larger than the mould capacity, and fill the mould; level off top and bottom using a spatula or some such instrument. Press the briquette out of the mould using a wooden or steel former. Repeat this procedure until all six briquettes have been made. Weigh the individual briquettes, handling them carefully to avoid distortion. Set the calipers at exactly 70 mm and press them carefully into the briquette to leave indentations which can be remeasured later.

Set the briquettes in a cool, shady place to dry, turning them over every few hours during the daytime to assist with even drying. After the briquettes have become leather hard, complete the drying in an oven at 110° Celsius. Cool in a desiccator, reweigh and calculate the moisture content.

After weighing, measure the dry briquettes and calculate the wet to dry linear change, which in this case will always be a negative figure, i.e. a shrinkage. The linear change wet to dry is related to the moisture content, so that if there is a difference in moisture content between briquettes from any one sample, there will be a difference in linear change. Such differences in moisture content might come about due to the plastic mixture drying out during the course of making the briquettes and hence all six should be made as quickly as possible. Even so, it will be noted that any such difference is such that the higher the moisture content, the higher the drying shrinkage.

The dry to fired linear change is measured on two briquettes for each temperature. It will be found useful to have the briquettes marked with their laboratory reference number as well as their own sequential number such that, if the laboratory number were '451', the six briquettes might be marked '451-1' through to '451-6'. All six briquettes can be weighed and measured for moisture and drying shrinkage, but then numbers 1 and 2 would be used for the 900°C firing, numbers 3 and 4 for the 1,000°C firing, and 5 and 6 for the 1,100°C firing. It is not acceptable to refire briquettes, e.g. if the test has been done at 900°C, it is not acceptable to refire these same specimens for another linear change determination;

A suggested firing schedule for the three temperatures for linear change is as follows:

	° Celsius	° Celsius	° Celsius
raise temperature to	150	150	150
maintain for 1.5 hours at	150	150	150
raise temperature to	375	375	375
maintain for 16 hours at	375	375	375
raise temperature to	600	600	600
maintain for 2 hours at	600	600	600

raise temperature to	900	900	900
maintain for 2 hours at	900	900	900
raise temperature to	xxx	1,000	1,100
maintain for 2 hours at	xxx	1,000	1,100

In each of the three cases, the furnace is switched off after the end of the soaking period at the finishing temperature. The briquettes are allowed to cool in the furnace (usually overnight) until they can be placed in a desiccator. Measure the two briquettes from each firing and calculate the linear change as follows:

$$\%\ \text{linear change} = \frac{\text{dry size} - \text{fired size}}{\text{dry size}} \times 100.$$

NOTES: a) The specimens should be set on end in the furnace. They should not be packed too close together, with at least 15 mm between each specimen, and from the walls of the furnace.

b) If the wet to fired linear shrinkage is required, this should not be calculated by adding the wet to dry and dry to fired linear changes. It should be calculated from the difference in size between the wet briquette and the fired briquette.

Loss on Ignition.

Weigh two clean silica ash crucibles to the nearest 0.0001 gm.; add about 1 gm of the crushed sample, reweigh and then dry to constant weight in an oven at 110° Celsius. Cool in a desiccator and reweigh to get the dry sample weight. Place the crucibles with the dry material in them into the furnace for 16 hours at 375° Celsius, remove from the furnace and cool in a desiccator, then weigh. Replace the crucibles in the furnace and fire for one hour at 1,000° Celsius. Remove from the furnace, cool in the desiccator and then reweigh. The loss on ignition can now be calculated as percentages of the dry weight for the temperatures of 375°C and 1,000°C.

Water Absorption.

Water absorption is determined on the fired specimens from the linear shrinkage tests. If the fired specimens have been stored in ambient conditions, they should be dried in the oven at 110°C and cooled in a desiccator before weighing. Place the weighed specimens in a beaker of clean water, or in some other suitable vessel such as a boiling tank with clean water (it is preferrable that distilled water is used), bring to the boiling point and boil for 5 hours during which time the specimens should be kept totally immersed in water. Allow the specimens to cool still submerged in water, until they have reached room temperature. Working on one specimen at a time, remove from the water, quickly wipe off excess water with a non absorbent cloth, and weigh to the nearest 0.01 gm. If there appears to have been any physical depreciation of any specimen, it should be re-dried at 110°C, cooled in a desiccator, and reweighed to get the correct weight for the water absorption test. At the same time, any such breakdown of a specimen must be recorded on the report together with the weight loss. The water absorption is calculated as follows:

$$\%\ \text{water absorption} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100.$$

IV. EVALUATION OF TEST RESULTS.

General.

It is assumed that the tests and subsequent evaluation will be aimed at defining the quality of clayey raw materials for small scale brickmaking. Such operations would not normally have extensive crushing and grinding equipment. Nor would they have much by way of installed facilities for mixing and blending. Where grinding is necessary, it would likely be done by a rolls grinder, and any mechanized blending might be done in a simple washing mill or by a double shafted mixer. However, the degree to which mechanization has to be employed, will be dictated by the available raw materials and the economics of individual situations. In general, therefore, the clays must be suitable for these relatively simple processes.

It is always important to thoroughly evaluate the results of testing, since such results may be important to national planners as well as to entrepreneurs. It is not unusual that too little emphasis is put on making inventories of raw materials in advance of their being required. All too often the need is seen in retrospect, when for one reason or another, the deposits have been zoned for other uses. Raw materials for the construction industry are of strategic importance. In spite of their low intrinsic value, due priority should be placed on defining their location, quantity and quality. Investment decisions are easier to make and finance easier to obtain when reasonable details are available as to the market, technology and raw material supply.

The clays used in brickmaking vary in themselves, and in the amounts and types of impurities which they contain. Due to this, there is the possibility of an almost infinite variety of clay mixtures available. Although most of the different minerals present may contain some common elements, it is often the mineral which has the predominating effect on the behaviour of the clay, and chemical analysis is not always effective in predicting and analysing the qualities of a brickclay.

The tests which have been suggested here are of a physical nature, and reflect on the mineralogical, chemical and physical states of the raw material. It then becomes necessary to have an intelligent appreciation of the raw materials and of the production methods which might be used in order to make a reasonable evaluation of the potential of these materials. Well established specialist institutions dealing with heavy clays, some of the larger equipment manufacturers and some independant manufacturers have broad expertize in the use of clays and the equipment used to make bricks - although even here it is possible that narrow specializations have developed into, for example, modern brickmaking or brickmaking by a specific method, or using a particular range of equipment. Often this expertize is unavailable to the small scale brickmakers in the developing world. Thus, it is hoped that the tests given here are sufficient to make a basic assessment of the potential of clays for making bricks by relatively simple methods. The test results are related to each other in reflecting the character of the clays, and this also proves to be a useful cross-check on accuracy. It is not possible to set definite upper and lower limits in any numerical sense for the test results. The limits are fairly elastic to reflect the subjective nature of some of the tests, and similar results might be found for some of the tests even when the raw material is of a different nature - but the differences will show up somewhere in the range of tests. For example, a silty clay may have a high percentage of the sample passing through the 75μ sieve and have a high drying and firing shrinkage, suggesting a high clay mineral content. Two characteristics will contradict this: the silty material will have a lower difference in the loss on ignition between 375°C and 1,000°C (but not always) and a poor dry strength relative to its apparently high clay content. This is perhaps an over-simplifictaion, but it serves to illustrate how test results are inter-related and all the results should be considered together in making an evaluation. From the look and feel of a clayey material, it can be deduced which one has a lot of clay and which one has a lot of silt. Similarly, the amount of water needed to make a raw material plastic is an indication of the fineness of the material (finer material has a higher surface area and will usually take more water to develop plasticity).

In evaluating a clay deposit, as opposed to a clay sample, the following general points should be borne in mind:

a) Calculate the potential of the market which might be served from the deposit, and whether the market will be a continually expanding one or whether it might be intermittent as with a limited rural development scheme. From this, total requirements can be assessed in tonnes of raw material, e.g. over a period of 25 years or more.

b) Record any data which will affect the availability of the clay, e.g. overburden, difficult access to the deposit, high water table, etc.

c) Contact planning authorities to determine from them, or through them, what plans there may be for the land which overlies the clay deposit.

d) Assess what effects clay digging will have on the land, what permanent damage might occur, what beneficial effects might be developed, and generally what the ecological implications are. Small scale producers are often ill-equipped to rehabilitate land which they have used for clay digging. On the other hand, there are cases where they only use land which is of little value for agriculture, such as termite mounds. Too little is done in a constructive way to establish how clay digging might be used to advantage in developing land for, say, agriculture and silviculture as it is too often accepted that the results will be harmful.

e) It may seem obvious that the more people in an area, the more emphasis a government might place on evaluating the resourecs of industrial minerals such as clay, sand, gravel, limestone, etc. Therefore, whilst it would be useful always to determine these resources as fully as possible, some consideration must be given to costs and benefits. Small communities need fewer building materials and hence less emphasis may be placed on wide scale, detailed, raw materials location and evaluation. Similarly, the efforts which a geological survey department might put into establishing clay deposits for a single entrepreneur who wants to make only one million bricks per year will be different from what they may consider for a hundred entrepreneurs who want to make fifty million bricks per year. Even so, experience has shown that where government interest and effort are applied to defining raw material sources for brickmaking, entrepreneurs and businessmen come forward to see if and how they can be involved and participate in new developments. In other words, the very act of looking for these industrial minerals stimulates an interest in developing the deposits.

Criteria applying to the clays.

The following criteria should apply to the clays, although it may be noted that they are more easily applied if the details of the production method are known:

a) The raw materials should be suitably plastic when mixed with water, bearing in mind that only limited facilities may be available for processing the clays prior to adding the water.

b) The plastic material should be capable of being moulded into a brick which will retain its shape after moulding, and then during drying without undue shrinkage, distortion, or cracking taking place.

c) The dry bricks should not be friable, and they should be strong enough such that they can withstand reasonable handling during transportation to and setting in the kiln. They must be capable of withstanding the pressure of the bricks which are set on top of them. This setting might be as low as ten courses in some cases, but may be as high as 30 courses in some clamp kilns.

d) On firing, the dry bricks should mature at a reasonable temperature, into an acceptably strong and durable burnt clay brick. What is acceptable in this respect can vary greatly, from bricks fired to about 700°C to bricks fired to about 1,100°C; or from bricks with a compression strength of about

2 MPa (190 lbs/in²) to bricks with a compression strength in excess of 20 MPa (2,900 lbs/in²).

e) The clay should be free from harmful impurities such as disruptive particles of limestone, soluble sulphates, stones, etc. Alternately, it should be possible to purify the clay, e.g. by washing it to get rid of such unwanted impurities.

Where a raw material has some quality which makes it unsuitable for brickmaking, it may be that the addition of another material will compensate for the undesirable qualities. Therefore, all the known raw materials in an area should be considered together to evaluate which ones will be suitable in themselves, and which ones might be mixed together to develop a suitable material. The laboratory can evaluate which mixtures are to be recommended, and can indicate what processing might be required to obtain a suitable mixing of the raw materials.The laboratory can also make rapid assessments of what beneficial effects might be obtained by using various locally available facing sands, or using additives which may have to be imported but which have beneficial effects which make the cost worthwhile. At the end of the day however, the quality of the bricks will depend on the skill of the brickmaker applied to the materials and technology which is available.

Sieve test.

The grading of a material is the arrangement of particle sizes. For our purposes here, the particles are being grouped into ranges called coarse, medium, and fine, these being defined as:-

- coarse — particles which do not pass through a sieve with apertures of 500µ.[5]
- medium — particles which pass through the 500µ sieve, but are retained on a sieve of aperture size 75µ.
- fine — particles which pass through a sieve of aperture size 75µ when estimated by the method previously given.

5 µ = micron, one micron = 1/1,000,000 of a metre.

As indicated in the section dealing with the method of carrying out the sieve test, more sieves can be used to get a more detailed picture of the grading. In addition, the fraction which is washed through the 75μ sieve can be retained and a particle size determination carried out by one of several standard methods. According to Grimshaw (ref 1.) "In a typical clay body for brickmaking a range from 1/4 inch (6000 microns) to less than four hundred thousandths of an inch (1 micron) is normally encountered. No one method of analysis is capable of analysing this range."

The sieve test as used here is a relatively simple check to determine the proportions of coarse, medium and fine material, and to use this information in comparing samples. For example, significant changes in these relative proportions or grading of the material will certainly show up as physical changes during mixing, drying and firing. If the basic sieve test is carried out - and this can be done easily and quickly in the field as well as in the laboratory - it can be predicted from the results plus other observations if the materials being compared are similar or otherwise. The 'other observations' might include visible changes in the mineralogical composition, colour, or 'feel' of the material. In other words, given some historical knowledge of a raw material, the sieve test can be used as a guide to indicate if significant changes in raw material quality have taken place. The sieve test might also be used to indicate the type of texture which could be expected from a fired sample, partial causes of drying and firing shrinkage, and as a check on the quality of mixing of materials of known grading.

Some of the qualities of bricks which are affected by the grading of the material are:-

Permeability: Depends upon the number and diameter of inter-connected pores, i.e. pores which will permit a gas to pass through the fired body. Larger pores allow higher permeabilities than do a greater number of smaller pores with the same total volume.

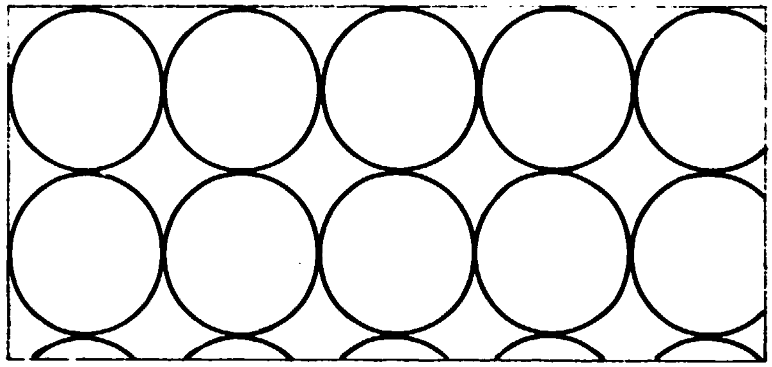
Porosity: The 'true' porosity is the volume of all the pores in the fired body - some of which might be sealed off from the outside. The 'apparent' porosity is the volume of those pores which are open at one or both ends such that their volume can be determined by test. It is the apparent porosity which is determined by the water absorption test, although there are other tests which can measure the apparent porosity more accurately. Porosity is related to the apparent density of a brick, i.e. that density which is calculated simply by weighing and measuring a brick. The higher the porosity, the lower the apparent density, and the more potential for the brick to absorb gas or liquid.

Density. The true density is the density of the solid material which goes to make up the brick, i.e. the apparent volume less the volume of all the pores must be calculated to get the true volume, this being used with the weight to calculate the true density. This is done by grinding a sample very fine and using a standard test to estimate the true volume of a known weight of material. The apparent density (see above) affects such qualities as sound and heat transmission, heat capacity, and compression strength. Higher density, through having a well graded material and hence better packing density, can give better heat transmission in the brick during firing, since the heat passes from particle to particle by conduction. Packing density is influenced by the size and shape of the particles as well as by the proportions of each size/shape present. In Figure VIII, it can be seen that the spheres represented in VIII.(a) are of a single size and spaced such that there is maximum void space or lowest packing density. In VIII.(b) the large spheres are the same diameter as those in VIII.a, but the packing density is higher due to the method of packing, at the same time, smaller spheres have been packed between the large ones to further increase the density. In VIII.(c) angular shaped particles are represented, this being more realistic and closer to what might be found in reality.

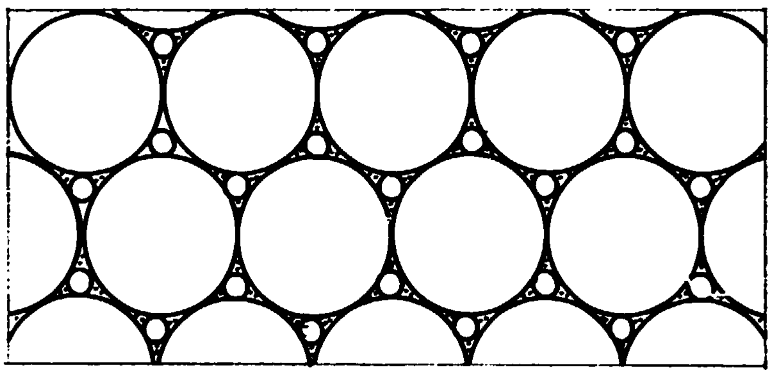
Microscopic examination.

The microscopic examination is carried out on the sub-sample as indicated, but may also be carried out on the primary sample. A low powered binocular microscope is used, although other more detailed examinations can be carried out using a variety of more sophisticated microscopes to give additional information on mineral types and particle sizes. Generally, it is the larger or more particulate occurences of minerals which are harmful in the clay material since they may have powerful localized effects on the bricks during and after manufacture. Some of the minerals which should be looked for and their effects on

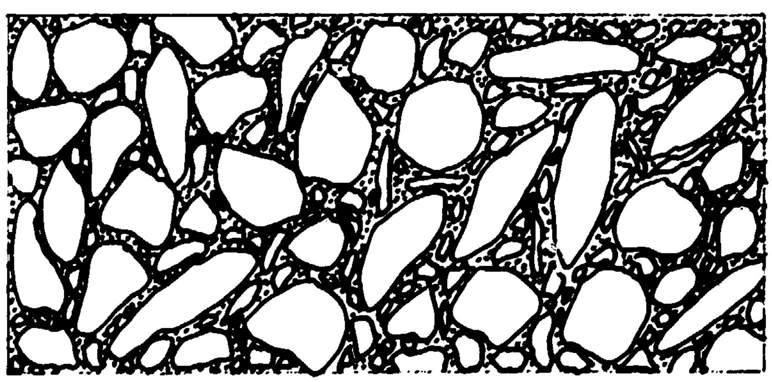
Figure VIII. Packing Density.



(a) Open packed shperes.



(b) Close packed spheres with variety of smaller shperes partly filling the voids.



(c) Angular particles of varying sizes.

the bricks, are given in the following paragraphs.

Siderite, or iron carbonate, may occur as hard particles by itself, or with pyrites, calcite, etc. In a finely disseminated form its main action will likely be as a flux. In more particulate form it may lead to localized cracking of the product, or may cause black spots on the fired brick. What is termed 'blowing' of the bricks may be caused by large particles of siderite.

Gypsum and other forms of calcium sulphate which are soluble in water can give rise to unsightly deposits on the bricks after drying and firing, or to some reaction with the mortar after the bricks have been laid. Barium carbonate is sometimes used to convert the soluble sulphate into the insoluble carbonate, but this solution (to the problem) is seldom available to small scale brickmakers.

Calcite, Dolomite, and various forms of limestone are amongst the best known and most harmful impurities, since the rehydration of the lime formed during firing can cause physical destruction of bricks when they are exposed to the air. However, when present in a finely disseminated form, the main action is as a flux. Finely powdered limestone is added to some brick mixtures to change the colour to a lighter red or yellow.

Mica is probably less harmful to handmade bricks than to machine made bricks where the mica platelets can become orientated together to form planes of weakness in the product. Hydrous micas, or illites, can be particularly bad, since they retain chemical water until quite high temperatures. Under certain conditions, emmission of this water can cause defects in the product. Micas are more likely to be a source of flux material, but the exact effect will vary according to their composition and other factors.

Pyrites may have the same effect as stones and cause localized cracking during drying or firing. They can cause iron spots in the fired product (which may be an attractive feature under controlled conditions) and they are a potential source of sulphate such that soluble salts may be formed. Generally, they are unacceptable.

Sand is found associated with most ceramic clays, but perhaps more so with brick clays. The usual effects of having sand present or of adding sand to a clay, is to reduce the amount of water required for plasticity; reduce the range of water content within which a clay has an acceptable workability; reduce drying shrinkage; and reduce firing shrinkage. However, sand will also reduce dried strength, and if more refractory than the clay material it may reduce fired strength too. Quartz sands may cause an overall expansion of bricks during firing, as opposed to the normal contraction or shrinkage. The physical and chemical nature of the sand, the nature of other materials present, and details of the production process will all contribute to the actual effect which sand has on the bricks during production.

Stones or pebbles are usually harmful to the product in causing localized cracking during drying and firing. In this context, a stone is taken to be larger than 6 mm equivalent diameter, although some authorities may classify a stone as being larger than 20 mm. Depending on the process being used, stones can be removed by washing, by using a special type of roller which squeezes the stones out of the main body of clay material, by other types of 'filtering' machines, and by crushing if they are soft enough.

Linear Change.

The measurement of linear change gives a convenient indication as to the dimensional change which may take place in the brick during firing. It is also a guide to other changes of a physical and chemical nature which have taken place. Due to the nature of clays and influenced by their treatment during production, the changes which take place in the dimensions of length, width, and thickness of a brick will be of different magnitudes.

Linear change from wet to dry gives some indication as to the ease with which bricks will dry. The change is negative, i.e. a shrinkage, and the higher this shrinkage the greater the stresses and strains which might be set up within the bricks. In the test used here, the following class-ifications are applied:

Drying Shrinkage - %	Category
nil - 2.5	very low
+2.5 - 5.0%	low
+5.0 - 7.5	normal
+7.5 - 10.0	high
+10.0	very high

The categories are somewhat arbitrary, being useful mainly to compare one sample against another. However, test results in the lower end, i.e. those which are 'very low' would indicate a material of low plasticity by virtue of a low clay content, and hence a low dry strength. On the other hand, results which are in the 'very high' category might be due to a high proportion of clay, or of some other very fine material such as silt. Thus, the drying shrinkage in itself does not directly reflect the amount or type of clay present even although it will indicate that drying may or may not be problematic.

Linear change on firing is usually a measure of the heat work done on the specimen, influenced by the nature of the reactions which took place. For example, recrystallization of lower density allotropes might lead to an expansion on firing, whereas sintering and glass formation tend to lead to shrinkage. Normally a firing shrinkage is expected from bricks which have been fired up to a temeperature within their maturing range, and a small expansion might be expected from bricks rich in quartz which are fired below or at the lower end of the maturing range. Where raw materials with a known history are being tested, the linear change test is useful to compare results of one batch of material against another.

The linear change test can be used to establish the maturing and vitrification ranges of the material. The term 'mature' as used here is used in a slightly different context from normal ceramic practice. As used here, it is meant to be a temperature at which the product is sufficiently well fired to fulfill its function in use. This may be much lower than is accepted practice in the industrialized world or where extremes of climate demand very well fired bricks, especially in freezing conditions. However, the writer is of the opinion that there are many cases where an unfired brick or one which is fired only to the point of stabilising the material against damp conditions, can filfill useful functions in many parts of some buildings. This reduces the cost of firing and the cost of the bricks, always providing that the bricks are strong enough to be transported without more than normal breakages. With bricks which have to be fired to the upper limit of their maturing temperature, both the actual temperature and the time spent at that temperature are important since it is this 'heat work' (time x temperature) which permits the necessary reactions to take place without over-firing. When the specimens or bricks are becoming over-fired a marked darkening of colour and glassy or vitrified appearance will be observed. Also, with bricks which are over-fired, there is the potential for bloating to take place if the materials are present such that gas forming reactions occur. Firing too quickly, i.e. an over rapid increase in temperature from about 800°C, can cause vitrification of the outside surface and increase the chance of bloating. The colour changes which take place in fired specimens is in itself a useful guide as to the degree of firing. for example, bricks which are orange when fired at 900°C might be red at 1,000°C and brown at 1,100°C. It is also important to be aware that the regular firing conditions and small specimen sizes in the laboratory are not directly applicable to production. Laboratory results can only be taken to be indicative as to what might be expected in production, with experience of individual production methods being necessary to make reasonable assessments. Table 1. gives further information on linear change.

Loss on Ignition.

It is known that different clays have different weight losses between the firing temperatures of 375°C and 1,000°C. This difference, between the loss on ignition at 375°C and that at 1,000°C is used here to confirm that the clay content between similar clays is also similar. It is not used to determine which specific clay types are present. A complicating factor is that there are other reasons which affect the loss on ignition. For example the presence of carbonates in the raw clay will give rise to a weight loss on calcining. Although most of the carbon will be burnt off at 375°C, any which is remaining will result in a weight loss at 1,000°C. Similarly, any oxydation reactions may result in a gain in weight. Similar samples which show significant differences should be examined in more detail to establish the cause.

Table 1. Some factors affecting linear change on drying, and on firing.

Observation	Cause	Remarks
Drying shrinkage	Removal of water leading to particles in the clay moving closer together.	Although this may be an over-simplification, it is one which is generally accepted. Even after the clay body has stopped shrinking, there can still be water left in the pores - an important fact to bear in mind when considering that this water may be driven off as part of the firing process, and can be as much as 5% of the weight of air dried bricks. In a hand made test briquette, shrinkage of more than 10% is very high. The addition of sand, or other granular non-plastic material will reduce drying shrinkage, but will also reduce plasticity and dried strength. Increases or decreases in the specific surface area of the body will increase or decrease, respectively, the ability of the body to absorb water. Since material of small particle size has a proportionately higher surface area per unit weight, changes in this part of the clay body have greater effect.
Firing shrinkage	Liquid formation; Sintering; Higher density crystals formed; Recrystallization of higher density materials.	Liquid forms at high temperatures, filling the pores of the body and causing contraction. The 'starting' temperature and nature of the liquid will depend on the nature and type of fluxes present. The higher the specific surface area of the material, the quicker the reaction rate and the greater is the potential shrinkage. Some other related factors are: a) particle size and shape; b) quantity of fluxes present; c) porosity, which influences heat transfer through the body; d) the amount of 'inert' material present, which tends to reduce shrinkage; e) the amount and form of carbonaceous matter present, e.g. coal and coke dust, or some forms of organic carbon may cause high localized temperatures and increase shrinkage.

continued....

Table 1. (continued)

Observation	Cause	Remarks
Expansion on drying	re-absorption of water.	Measurement of wet to dry linear change will invariably show a contraction or shrinkage. However, an oven dried clay might expand slightly on exposure to an atmosphere from which it can absorb water.
Expansion on firing	re-crystallization of lower density crystals. Bloating.	One of the most common reasons for expansion after firing is the presence of quartz, which goes through an inversion from alpha$\leftrightarrow$beta form with an expansion taking place. This is, in theory, reversible, but in practice may be constrained to leave a lower density body. At high temperature, the quartz to trydimite conversion also causes expansion. Gas forming reactions which take place and cause internal pressure at high temperature when the clay is pyroplastic, can cause bloating or swelling which may vary from slight to very severe. Slight bloating will have little harmful effect, and it has been found that clays which bloated slightly in the laboratory did not, apparently, bloat under production conditions. Severe bloating is often accompanied, in production, by deformation and fusing of the bricks to each other. In laboratory specimens, bloating is easiest seen in the centre of the 'bed' face of the specimen where maximum swelling tends to take place.

Examination of dry and fired briquettes.

The briquettes in the dry and fired states should be carefully examined for any faults which may appear. Such faults in the relatively small briquettes, made under controlled laboratory conditions, could easily be magnified at normal production level. Where there are any doubts about the results, i.e. if it is felt that the test methods have not been properly carried out, the tests must be repeated. This applies even more when the results are apparently good, since it is usually on the basis of good results that investments might be made.

Some of the points to look for in the dry briquettes are:-

- Scum or salt formation, usually more concentrated at the corners and arrises of the briquette;
- distortion, twisting, or bending of the briquette during drying. This is usually associated with fine grained material which has a high proportion of plastic clay, and a high drying shrinkage might also be expected. However, the measurement of drying shrinkage is not necessariliy accurate where the briquettes have become distorted.
- Cracking or crazing, with crazing being a network of fine surface cracks. Cracking may be localized, e.g. where there is a stone present, or it may be more widespread. Drying cracks are usually associated with high drying shrinkage. Some raw materials, sometimes those of volcanic origin, which appear in their natural state to have potential as clays, can have drying shrinkages as high as 15% - 20% and literally fall apart on drying. Where the dry briquette is obviously very badly cracked or friable, there is little point in continuing with firing tests.

In the fired briquettes, some of the points to look for are:-

- Salt formation or scumming on the surface, it is sometimes easier to see on the fired briquette than on the dry one.
- Localized cracking caused by stones, and in particular where the stones are white in colour since this may be lime. It is possible that rehydration of lime will cause cracking or bursting of the briquette after the lime has had time to hydrate, i.e. after a few days or after the water absorption test.

- Distortion through twisting, bending, or swelling. Twisting and bending may be caused by overheating of the specimen, i.e. firing to a temperature at which excessive vitrification takes place. It can also be caused by uneven firing, i.e. where the furnace, or the setting of the briquettes in the furnace, is such that they are unevenly heated on one or more faces. Swelling of the briquettes is usually a sign of over-firing, too rapid firing, in both cases with gas formation inside the specimen, or of excessive gas formation which causes the swelling or bloating even with a 'normal' firing temperature. The bloating is usually seen first at the centres of the plain faces of the specimens. The firing expansion which is sometimes found in materials rich in quartz is of a regular nature (no distortion and swelling of the specimens) and is not considered to be bloating - in any case, it would be of too small a magnitude to be seen visually.
- Fired colour is most important in two areas. Firstly it can reflect changes in raw materials or in firing conditions. For example, more or less, iron compounds in the raw material will give a different fired colour given that processing and (especially) firing conditions have remained the same. Higher firing temperatures tend to make the colour darker and lower temperatures tend to make the colour lighter. With any particular clay it would be unusual for the basic fired colour to actually change, but changes in shades of colour are what is looked for - e.g. if a group of specimens from the same deposit or borehole all fire a particular shade of red at 900°C, but there is one (or more) exception which is a distinctly different shade of red, it may be assumed that the specimens with the different shade are in themselves different in some way and this may be shown up in other tests. Secondly, the fired colour is important in terms of the colour which may be desired in the finished product. If red bricks are required, the fired colour of the test briquettes will be an indication as whether or not such a colour will be attained in production. Some of the factors which affect the fired colour (or shade of colour) are:-

  Particle size and grading; composition of the clay body; firing temperature; and, kiln atmosphere, e.g. oxydising, reducing, neutral.

The colour of the raw material is not always a guide to the colour of the fired material since some white clays fire to a red colour, there are black clays which fire white, but most brick clays fire to a reddish or red colour. The addition of manganese dioxide powder will darken the fired colour, and other materials can be added to get different effects. Additions of such materials are unusual in small scale brickmaking, but there may well be cases where the end result is worth the cost involved. Sand faced bricks often reflect the colour of the sand used and mineral oxides may be mixed with sands to achieve specific effects.

- The porosity of the fired briquettes is a useful indicator as to the effectiveness of the firing. Specimens fired at lower temperatures are more porous, but since different clays may mature at different temperatures porosity cannot be used as a simple comparison of one against another. With fired briquettes, a simple guide as to porosity (in a qualitative sense) is to place the tip of the tongue against the briquette. Considerable suction can be felt with porous specimens whilst, for example, partly vitrified specimens give almost no sensation of porosity and the 'glassy' texture can be easier felt this way than by using ones fingers.
- Two very important features of the fired briquettes are physical strength and friability. A rough guide to physical strength can be obtained by trying to break the briquette in two, using only ones hands; i.e. grip each end of the briquette and try to break it into two pieces. Obviously the ease with which it may break depends on the strength of the person trying to break it. However, given that this is understood, briquettes which can be broken this way can usually be judged to be too weak, hence, for example, a higher firing temperature is required. Of course it is much preferable and more reliable to use a modulus of rupture apparatus if one is available, bearing in mind that with only two fired specimens from each firing schedule, the results may be questionable. Where physical strength is important, it is recommended that at least ten specimens be made and tested for modulus of rupture. However, experience has shown that manual breaking of the specimens is a useful and practical qualitative guide to fired strength. Similarly with friability, where, if the corners and arrises

can be broken with the hands, it is an indication of friability. Both low strength and friability are symptoms of a lack of ceramic bonding between the particles of the fired body. A body which is dense and is made up of angular particles may have a higher compression strength than one which is less dense and/or made up of rounded particles, but the increase in compression strength is not usually in proportion to any increase in modulus of rupture since the fired strength is, perhaps, as much a feature of ceramic bonding as of particle shapes and grading. Even so, bricks which are subjected to higher forming pressures are stronger in terms of compression strength than bricks formed at lower pressures, all other things being equal.

Impurities.

An 'impurity' is somewhat difficult to define insofar as brick clays are concerned since, what is an impurity in one case may be considered a desirable constituent in another case. A number of impurities have been mentioned under the sub-section on 'microscopic examination', yet even here larger particles of limestone (+1 mm) may be considered undesirable whilst lime powder may be added to some clays to get specific effects. The actual amount of clay mineral present in some 'clays' may be less than 15%, and it is obvious that the remaining 85% in such a case cannot be considered to be impurities. In fact, the non-clay minerals are highly desirable and it is the effect which they have on the brickmaking process and the finished bricks which will determine if they are, or are not, impurities.

Some materials such as quartz may be relatively neutral going through the manufacturing and firing process with little change taking place. Others, such as iron bearing minerals, may be highly desirable by imparting a red colour to the fired body. One of the principal iron bearing minerals is limonite, a hydrous iron oxide. Alkalis are useful in that they can be the fluxes necessary to promote liquid formation and related reactions leading to low temperature (+650°C) ceramic bonding. The type and quantity present is most important, as is the effectice particle size, since excessive liquid formation, short vitrification range, or low viscocity liquids, are all undesirable.

As already indicated, harmful impurities include minerals or other materials which may, under different cirmcumstances, be considered as beneficial. Different forms of silica can be harmful if there is too much present, or if the particle size is such that it causes unwanted effects. Such effects vary from reduction of dried strength, reduction of plasticity, to reduction of fired strength. Generally speaking, other unwanted impurities will include those materials which occur irregularly and have the effect of changing the appearance or other qualities of the fired bricks on an irregular basis, or have the effect of changing other aspects of the character of the material or product. Even small scale brickmaking is generally a production process that works more efficiently if the raw material quality only varies within acceptable limits.

One of the features of a good sampling programme coupled with testing and evaluation of all the samples is that even those impurities which are irregular in occurence have an excellent chance of being discovered and evaluated.

V. EXTERNAL TESTING AND RELATED STAFF TRAINING.

No matter how simple some test methods and associated evaluations might be to those people experienced in their use, there can be many initial difficulties for those without experience - even although they may be well qualified in other forms of laboratory work or in other professions. There are several ways in which assistance might be given to institutions who wish to develop a capacity for clay testing and/or for development of related industry. Some of these options are:

a) Direct contact through private consultants who will, for a fee, arrange a programme of testing and training. The cost, venue and other details will vary according to individual cases.

b) Bilateral or international aid sources are usually interested in assisting those countries which intend to develop, improve, or expand the clay building materials industry. With bilateral sources, the aid might be in the form of finance to engage independant consultants, or in the form

Figure IX. Clay survey/exploration team - Lesotho.
UNIDO Project DP/LES/74/023.

Figure X. Field work on a major clay deposit in Lesotho.
UNIDO Project DP/LES/73/023.

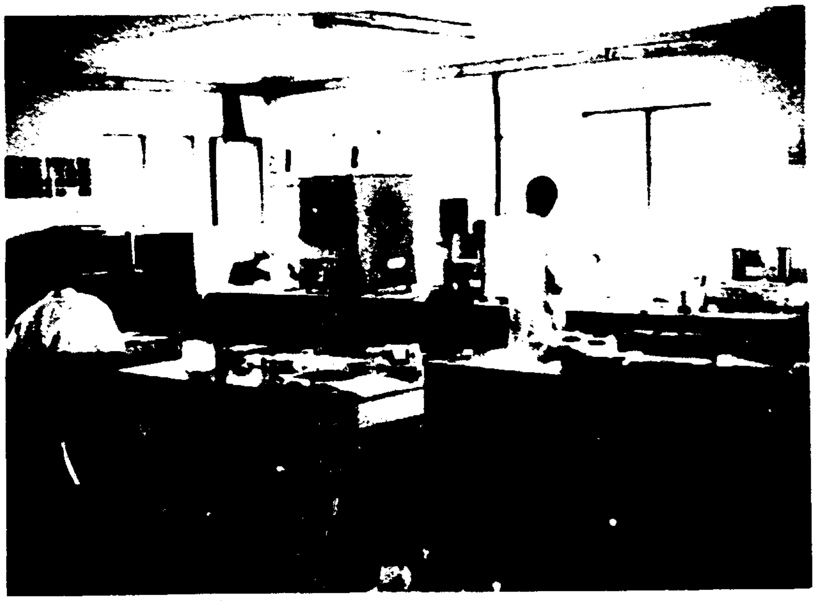


Figure XI. Small clay-test and development laboratory - Lesotho. UNIDO Project DP/LES/74/023.

Figure XII. C.B.R.I. - Roorkee. Simple brickmould with foot operated movable base to eject the brick. This reduces expertize needed for moulding but the method is said to be slower than for normal hand moulding.

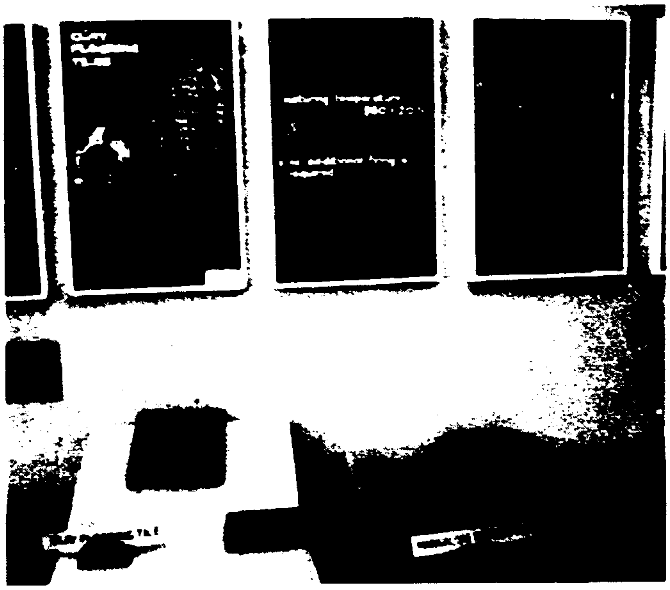
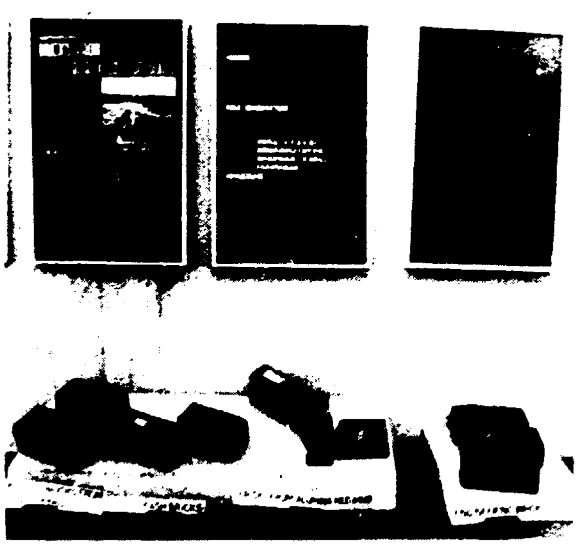


Figure XIII. C.B.R.I. - Roorkee. Development work includes floor and roof tiles of raw and glazed clays. The 'Managalore' pattern tile is an interlocking type giving efficient roof cover.



Considerable development work has been done with a view to using poor quality raw materials to make acceptable bricks, e.g. black cotton soils. Other examples shown here are bricks using clay and fly ash, and using alumina red mud. In the latter case, engineering bricks are made using by-products from aluminium plants. Such bricks have high compression strength and low water absorption.

Figure XIV. C.B.R.I. - Roorkee. Development work on bricks.

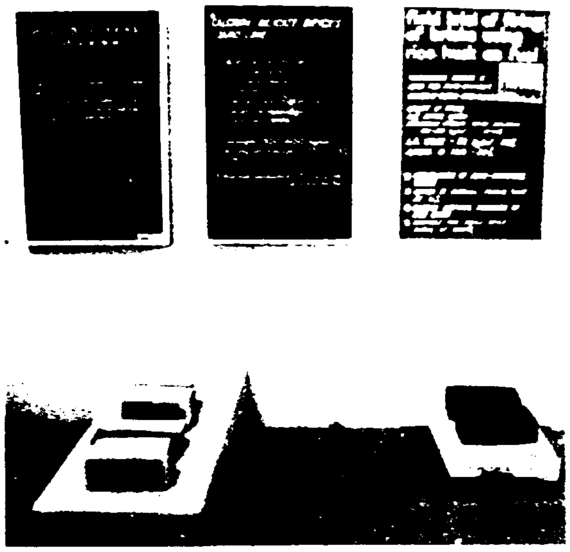
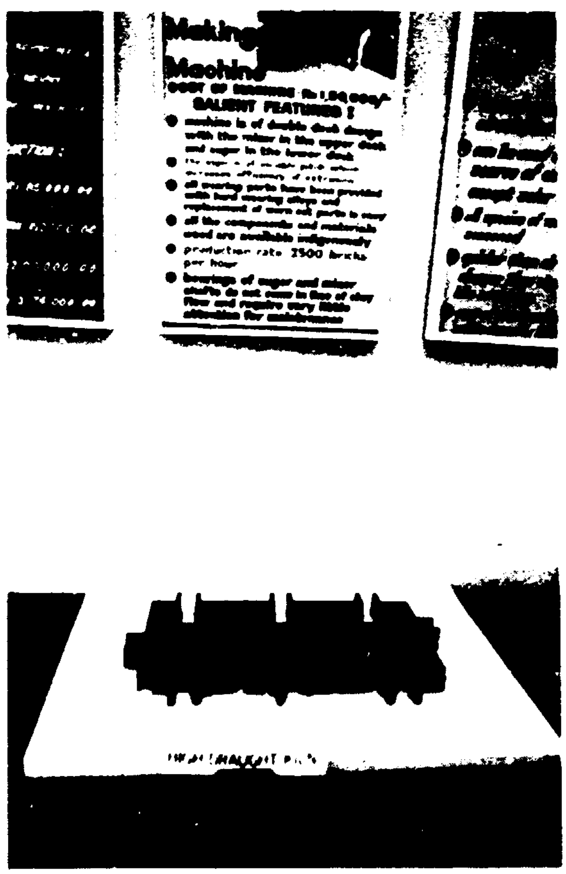


Figure XV. C.B.R.I. - Roorkee. Heavy duty bricks made from alluvial soils, in this case the farming process is mechanized.



Many other developments have been completed, or are in progress. Fig. XVI. shows part of the range which includes a high draught kiln. Other items include a double deck extruder and kiln for seasoning wood.

Figure XVI. C.B.R.I. - Roorkee. High draught kiln.

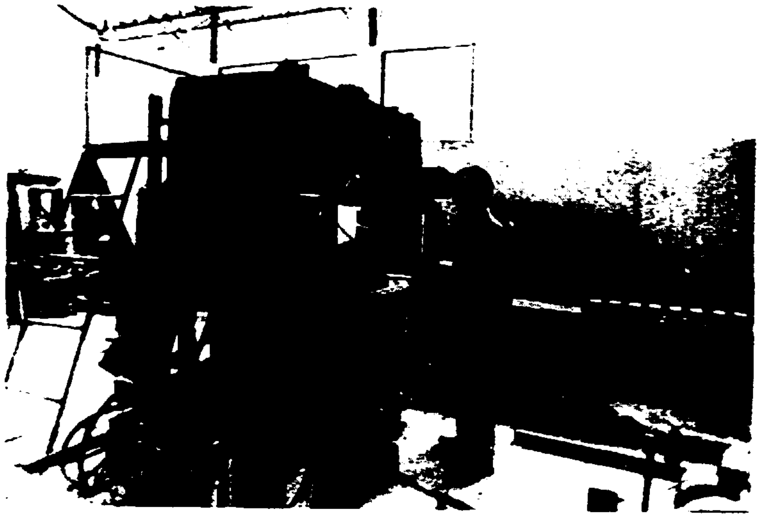
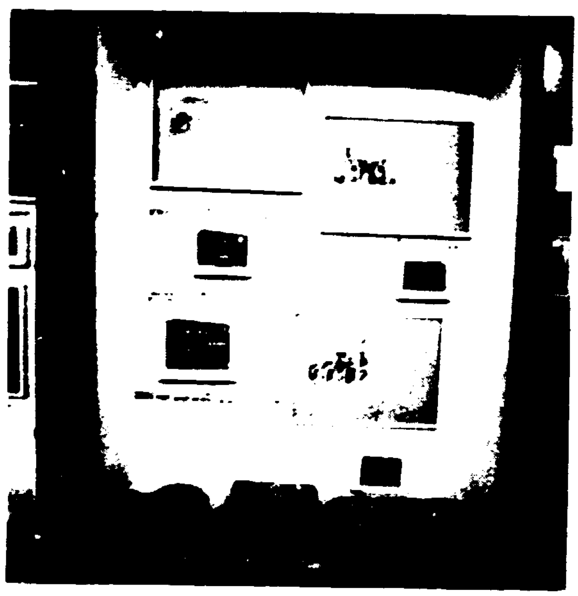


Figure XVII. C.B.R.I. - Roorkee. Hydraulic press for sand-lime bricks.



The history of bricks is not forgotten, with samples from different parts of India, some going back many centuries.

Figure XVIII. C.B.R.I. - Roorkee.

of equipment and/or expertize. With international aid through, for example, the United Nations, the aid may be in the form of specialists in clay building materials coupled with the provision of equipment and training. UNIDO has had particularly wide and successful experience in development of the building materials industry.

Professional advice in defining sources of raw materials is not simply necessary, but often leads to savings in expenditure, in time, and to more efficient investment through the availability of better or more accurate information. The foregoing Figures show a small pick-up truck loaded with all the equipment needed for a programme of clay sampling, together with the camping and other equipment needed for the geologist and two drillers - who can be seen in the cab. The drill is shown set up in the field, and a small but efficient laboratory is also shown. UNIDO supplied the equipment for this particular project. International staff comprised one clay materials/production specialist (UNIDO expert) and one geophysicist/geologist (United Nations Volunteer). National staff comprised a two man drill team and a staff of three in the laboratory. One of the laboratory staff was sent overseas where he succesfully completed a three year course on heavy clays and technical management. The actual amount of staff, equipment, and aid personnel will vary from country to country and according to the particular needs.

Institutions such as the Central Building Research Institute at Roorkee in India have many facilities and a large staff of scientists and technicians working on many aspects of developing building materials. The C.B.R.I. is an Indian Government institution which provides technical services and carries out research and development work aimed at improving the industry on a national basis - no mean task considering the size and population of the country. From the point of view of other countries, taking into account India's willingness to help the developing world, the C.B.R.I. has the capability to provide training and expertize for development of the building materials industry in other countries. Arrangements for such assistance would have to be made on a bilateral basis with the Government of India or, for example, through UNIDO.

The previous figures also give some illustration of part of the activities of the C.B.R.I., with captions providing explanation.

VI. CLAY DIGGING, MIXING, FORMING:

Clay Digging.

Clay digging, or clay winning as it is often called, is relatively simple when applied to small scale operations, and tends to grow in complexity as the size of the operation increases. It is assumed that for the small scale operations being considered here, manual digging, or simple mechanized methods such as ripping and shovelling will be employed.

Since clay digging varies considerably even for small scale operations, from the man who uses termite mounds to the brickworks which might excavate 25,000 tonnes of material in the course of a few months, the larger the operation the more important it becomes to ensure that advance knowledge of the clay deposit is available. This knowledge should include details of the clay as well as of the geology of the area, and should include information on what variations in quality might be expected. Every brickworks which is in continuous operation should, on a planned basis, carry out advance tests at production level to confirm that production will not be disrupted nor brick quality reduced. This should be done well in advance of that area of the deposit being required such that, if there are problems which have not become apparent in laboratory testing, they can be solved without stopping or slowing production.

Hand winning of clay is used where sufficient labour is available at an acceptable cost - with cost being the actual cost of digging each tonne (or other unit measure) of clay rather than the hourly cost of the labour. One of the advantages of hand winning is that small pockets of clay can be won efficiently, whereas such deposits may be unsuitable for mechanized methods which are less selective.

It is often assumed that, because digging with shovels or hoes has been going on for hundreds of years, it must have developed to the point where no increase in efficiency is possible. This is not the case, and there is room for improvement in the use and maintenance of hand tools. The man and his tools form a system which may increase in complexity as more aids to production are added. It is always worthwhile to stand back and examine every operation to see where improvements can be made. In cases where large numbers of people are involved, it may be a government decision to engage a production or industrial engineer to study the methods being used on a national basis and to make recommendations as to how efficiency might be improved. At the same time, social factors have to be taken into account to determine how the recommendations might best be carried out.

For hand winning, a variety of tools might be used according to local conditions or tradition. These vary from picks, shovels, mattocks, to hoes of various sizes. With very plastic clays, a spade is often the best tool to use.

Where some form of overburden exists (it usually does) it must be removed. It is best to remove enough overburden to permit half a years operation, with the remaineder being removed as a planned 'spare-time' job by any available production workers, but allowing that sufficient clay is always kept clear to let production to go ahead unhindered. With some clays which rely on weathering to make them soft enough to use, it may be necessary to strip off the overburden the year before the clays are to be used.

At this point it is worthwhile to consider conservation, and how topsoil removed as overburden can be replaced. In many places population growth has brought increased pressure to use land for agriculture, and clay deposits may lie below such land. Envoironmental rehabilitation should always be a prime consideration for the brickmaker, since spoiling of arable land will nearly always bring objections, and rightly so. This may result in the refusal to permit clay digging. Where land was not formerly arable, clay digging could have some beneficial effects if it exposed a new soil which had potential for development for agriculture or forestry. The C.B.R.I. in India has examined some ways of utilizing poor soils as brickmaking materials. On a worldwide basis there seems to be much still to be done to examine the ways and means of applying conservation methods in small scale operations, in using raw materials which have little agricultural potential as brickmaking materials, and in developing the full potential of old claypits as land for forestry or for growing food.

Having removed the overburden and, if in any way possible, deposited it on land which is not to be used for clay winning, it is usually necessary to make a working face in the deposit. If the clay seam is thin, i.e. less than 1.5 metres, then that will be the height of the face. Normally with hand winning the face should be at least 1.5 metres, and somewhat more if possible, the diggers maintaining the face as they move forward. The reason for maintaining a good working face is that the clay layers get some mixing as the digging takes place. With mechanized winning the face may be more than two metres high.

The geological history will have already determined what variations there may be in clay quality, and laboratory or other testing may have shown that small variations exist, but significant variations in quality are often visible and can be avoided if they are of irregular occurence. Where there are regular lenses of acceptable 'impurities', extra care should be taken to ensure that good mixing takes place. It is important for all brickmaking, but perhaps more so for mechanized brickmaking, that the clay mixture is of regular quality. Without such regularity, both production levels and quality will fluctuate. Although mixing of clay(s) and water takes place later in the process, the first opportunity for some mixing is at the claypit. The following sketch illustrates how vertical clay winning can assist mixing.

By digging vertically, the two clay seams and the impurities are mixed as part of the digging process. Horizontal or lateral digging would separate the material which has to be mixed.

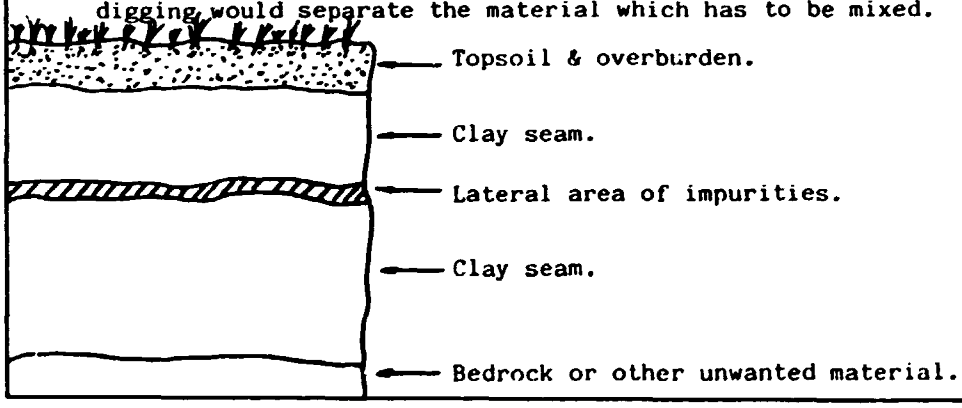


Figure XIX. Vertical clay winning - mixing.

In clay winning we can consider three main operations, these being the actual digging or loosening the clay from the ground, transport of the clay from the people who are digging,and storage in a stockpile whilst waiting for the next stage of the operation. Many small scale brickmakers dig, mix, and mould the clay into bricks almost in the same place. There is very little transport and may be virtualy no storage involved. With other brickmakers, the clay must be transported to a place where mixing with water and moulding take place. With a shovel, a man can throw clay several metres away, with a wheelbarrow it may be economic for him to take the clay up to about 100 metres, for greater distances some sort of wheeled transport of a different nature should be considerd. There are a number of options available, from two or four wheeled carts, manually pushed or pulled, to agricultural tractors with trailers, to small dump trucks and larger trucks. In rural and semi-urban areas, animal drawn carts may have many advantages. Whichever method is to be considered, there are a number factors to be taken into account. Basically, the main considerations are centred on which method is least cost, which is appropiate to the operation in terms of availability and reliability, and what maintenance is available for mechanized transport. Mechanical transport may often be convenient, but it is also expensive in terms of capital costs, if there is not a reliable supply of fuel available it will only be reliable when there is fuel, and similarly with maintenance and spare parts. With animal transport, if brickmaking is during the dry season, it may be difficult to get food for the animal(s), at best it may be expensive.

To get some indication of which transport method is best the following factors might be considered:

a) What are the available options in terms of the methods available.

b) How much clay and overburden has to be moved, and how far, in what period of time? Sometimes production of bricks is a year-round operation but clay can only be won in the dry season, hence the amount to be won and moved is much greater than the daily requirements of the brick moulders or machine.

c) What are the costs (both capital and operating) of the various means of transporting the clay. Experience is a good guide to the costs of manual labour but it may be that an accountant has to be consulted to determine the capital and operating costs of mechanized equipment.

Particularly where capital expense is involved, it may be advisable to compare the experience of others using similar methods. At the same time, it may be worth while considering hiring mechanical equipment instead of buying it. Where a truck is to be purchased, it may not be feasible to consider it only on the basis of the clay digging, but it may be feasible to consider it if other work can be found which will help pay for its purchase and operation - providing such other work can be done without disruption to the clay digging. Since there are many individual variations in circumstances, each case should be worked out on its own merits.

In planning the brickmaking site, it is nearly always better to have the actual brickmaking taking place at a lower level than the clay digging. Of course this is not always possible, but where the land contours permit it, it is easier (and cheaper) to carry the materials downhill, with empty vehicles going back up for fresh loads.

When the clay has been won and transported to the brickmaking area, it may be stored for a very short period of time or for a few weeks, in the form of a stockpile. Throughout the ages, brickmakers have made time work for them. It is only in the past hundred years or so that major items of heavy mechanized equipment have replaced time in treating clays. There is a saying 'time is money' and it simply means that the quicker things are done, the more potential there is to make more money by repeating the process or by starting some other profitable job. This is part of the reasons for using meachanized brickmaking methods. However, there are many cases where mechanization is not less expensive, where people cannot afford to purchase machines, or where the cost of the smallest machine is too high because its designed output is higher than than required by the small scale brickmaker. There are other areas where time can be put to work in the treatment of clay, but having said all this it may clarify matters to say just how time is put to work. Firstly, the weather can cause hard clays to break down into softer material, especially where the weather is cyclic with hot/cold/freezing/wet/dry spells. In this way, the weather helps to process the clay, perhaps whilst it is in the stockpile, and the time involved will depend on the clay and local weather conditions. Most experienced brickmakers know that wetting the clay prior to mixing or pugging it makes the mixing job much easier. Leaving a mixed clay for a week or so sometimes makes a poor clay more workable such that good brick can be made. Most important, if the clay must lie for a period of time before being used, it makes good sense to make use of that time to make the clay into a material that is easier to use or that will make better bricks. Thus, in a stockpile it may be that the weather is sufficient to improve the quality of the clay, or it may be that water has to be added to get some softening before the material passes onto the next stage of the process.

With mechanized clay digging, the same type of exercise should be considered as for transporting the clay from the claypit to the stockpile, e.g.:-

- cost and availability of labour;
- type of mechanized equipment available;
- service and repair facilities available;
- costs of mechanized equipment and spare parts;
- availability of suitable operators for the machines;
- the total amount of work available, e.g. overburden removal, clay-digging, stockpiling, on hire to others if this is definately possible, etc.;
- nature of the raw materials to be won and the type of site on which the machine will have to work.

For many small scale operators, the most convenient type of clay digging equipment is based on an agricultural tractor with ripper tines at the rear to loosen up the clay soil, and with a bucket in front to scoop up the loose material. This indicates that we are not talking about digging very hard clays - which would likley require a much heavier and more expensive machine. One of the principal reasons for favouring the machine based on an agricultural tractor is that there are often other tractors in the area and spare parts and maintenance facilities are better developed.

Mixing.

Mixing of clays in the sense used here, is the mixing together of the different clays used to make the clay body together with fuel and water or any other materials which are required. In some cases it will only be a single clay which is mixed with water.

Making bricks is like forging a chain, with the various links of the chain being comparable to the various stages of brickmaking, i.e. selection of raw materials; digging; mixing; forming; drying; and firing. If any one of the sub-processes is not done properly, then the end result will never be as good as it could have been. Just as with a chain, one weak link can determine the real breaking point no matter how strong the other links may be. With brickmaking, it must be considered that, with each successive part of the process, more time and money is being invested. At the same time, if each part of the process is carried out properly, then each successive part becomes easier to complete.

The first objective of mixing clay(s) and water is to get a homogeneous mass which, because of the properties of the clay, is plastic and can be formed into the desired shape on a repetetive basis. The qualities of this mixture must be such that the finished product will be of regular (good) quality. Some examples of the variety of mixtures which must be blended is as follows:

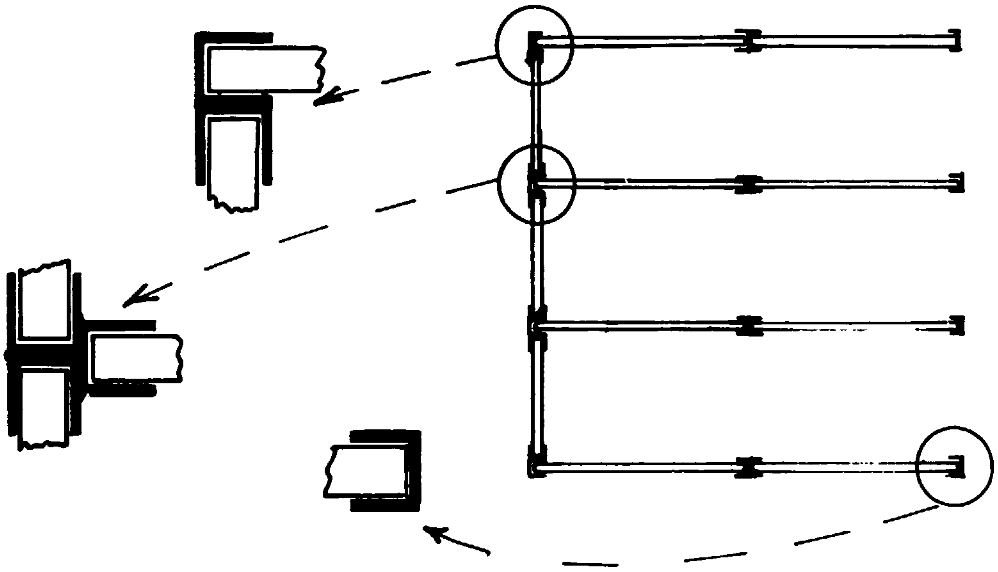
- clay + water,
- different clays + water (e.g. very plastic + less plastic clays),
- very plastic clay + sand + water,
- various clays + other materials + water,
- clay or clays + chemical additive + water,
- clay or clays + fuel + water.

In each case, the clay is mixed with water and sometimes with other clays or other materials to get a clay body which is suitable for making the desired type of brick. Whilst it is convenient and even desirable that only one clay is used, as many as ten different types of materials are mixed by some brickmakers to get the range of products which they want (and which their customers want).

Clay and water are mixed together to make the mass plastic for forming into bricks. As this takes place, the clay mass gains in volume, and when the wet brick dries it shrinks. Now, if the clay and water are not thoroughly mixed, when the brick dries it will do so according to the different amounts of water present in the various parts - i.e. it will shrink by different amounts in different parts according to how much water is in each part. The result is often a cracked brick! Many brickmakers have seen the effect of stones in clay, where the brick cracks around the stone. This is the same principle - the stone does not shrink but the wet brick does and a crack is formed or caused by this different amount of shrinkage between the different parts of the brick.

Before considering some of the different methods of mixing the raw materials, it is worthwhile to summarize the reasons as to why there is a mixture, and why the process of mixing must be efficient:-

- A single clay, with water, will make a single type of brick, i.e. the quality in terms of strength and so on will be the same, assuming that the methods of forming, drying, and firing remain the same. The appearance of the bricks can be altered by using different sands as a coating on the brick face (sand faced bricks), or by cutting the brick face, or by making a rough face on the brick (textured face). Colour changes can be achieved adding small amounts of chemical additives or, if possible, by varying the kiln atmosphere. By changing the firing temperature, it is possible to vary the shades of colour of the fired brick, but such control over firing temperature is seldom easy with small scale brickmaking unless a kiln is available.
- A mixture of various clays is made to get specific results by way of improving the physical quality of the bricks, or to get a range of bricks of different qualities. At the same time, a range of clays might be used to get a range of colours. In addition, the other methods mentioned above (sand faced, cut faced, textured face, etc.) might be used for further variation
- Whether a single clay and water are mixed, or whether a variety of clays and other materials are mixed, it is essential that the mixing of the 'dry' materials and water is efficiently done if the best quality is to be realized and maintained on a regular basis.
- Fuel, in the form of fine coal or coke, or other combustible materials might become a part of the mixture, either to assist the firing or as the sole major source of fuel to complete the firing.
- Bad mixing which results in spoilt bricks is a waste of the money invested to get the process to the stage where the bricks are spoilt.



Clay storage/conditioning bays, depth = 6 metres (20 feet)
width = 2 metres (6½ feet)
height = 1.5 metres (5 feet)

Number of bays shown = 3, but in practice this will depend on nature of the clay and production level.

Volume of each bay as shown is 18 m^3 (24 yds^3), sufficient for approximately 8,000 bricks.

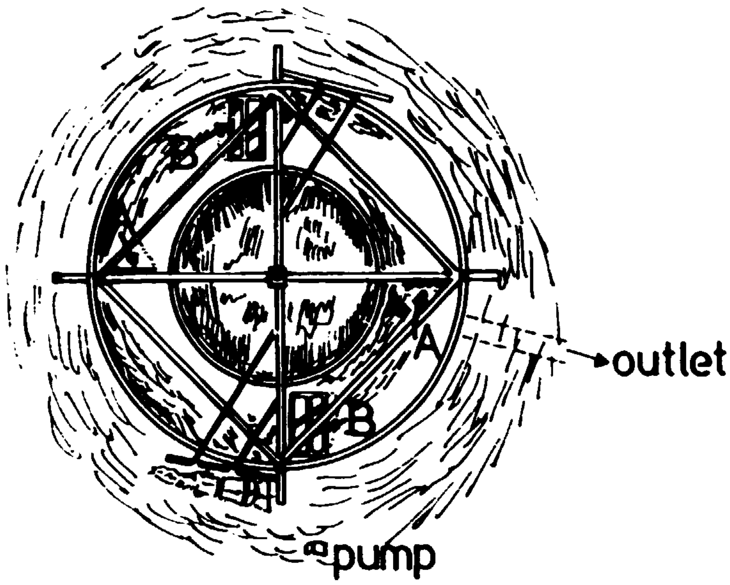
Construction materials in this case comprise channel iron uprights, see details above, with timber (rough boards or poles) walls. The channel irons are welded where necessary and alternate materials can be used instead, e.g. all timber or bricks.

Figure XX. Clay Storage and/or Conditioning Bays.

Mixing of dry materials is relatively simple and involves laying down the dry materials in shallow layers on top of each other, then re-digging them vertically to achieve a mixture as was described in vertical clay winning. With very small scale operations this can be done conveniently on top of the ground, but in larger operations, say +5,000 bricks per day, storage bays are useful. These storage bays can also be used to store wet material which has been mixed with water, or to which some water has been added prior to using a mechanical mixer. An example of such bays is shown in the sketch on the previous page, and it is usually preferable that, with wet material, the bays are covered and that the material is left for at least one week.

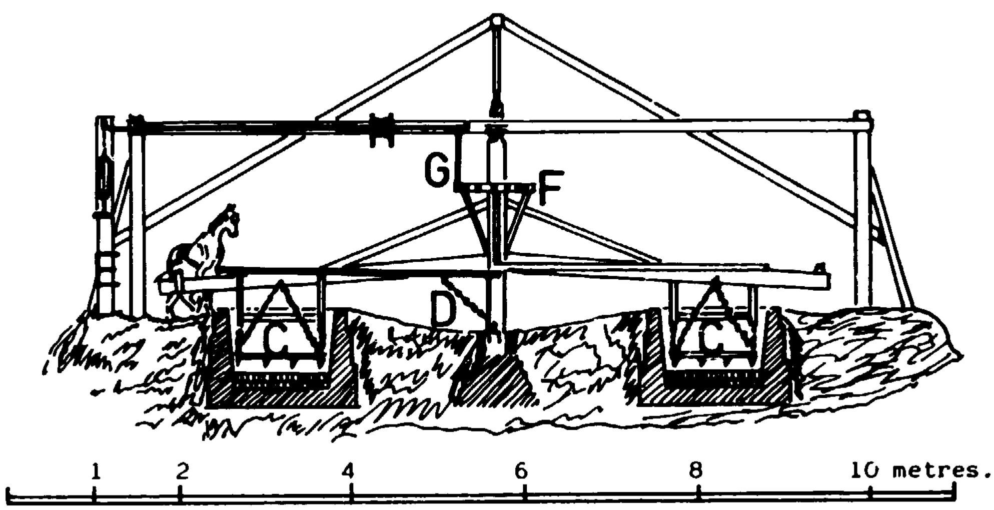
Mixing of water with the clays can be done at the stage of storing/conditioning as mentioned above if a mechanical mixer is to be used, e.g. a double shaft mixer. For manual mixing, the materials are put into a pit, water added and then the whole lot left to permit the water to soak into the clays. In some types of hand making, the pit is shallow, being about 0.5 metre deep and 4 metres diameter, with the actual depth of material being 0.25 metres. After being allowed to soak, the mixture is treaded, using bare feet or animals to get the final mixing of water and clay. In other operations, the pit is deeper and of smaller diameter, say 2 metres deep and 3 metres diameter. In the latter case an excess of water may be added to get a slurry. The slurry is allowed to settle, excess water taken off the top, and the wet mixture either left to dry out until it reaches the right consistency, or it may be taken out of the pit to dry quicker and then re-mixed manually in preparation for moulding.

A useful feature of making a slurry is that any large stones present can sink to the bottom to be removed later. The clay washing mill shown in Figures XXI and XXII., is of simple design and powered by one or two animals (horses or oxen) The output is said to be about one cubic metre per hour, equivalent to about 600 bricks per hour (Ref:6). The sketches shown here are obviously not meant to be working diagrams, nor is it suggested that and identical design is necessary. However, this pricipal of making a slurry which is broken up and stirred by the knives and harrows, can be followed to remove impurities, and/or mix different



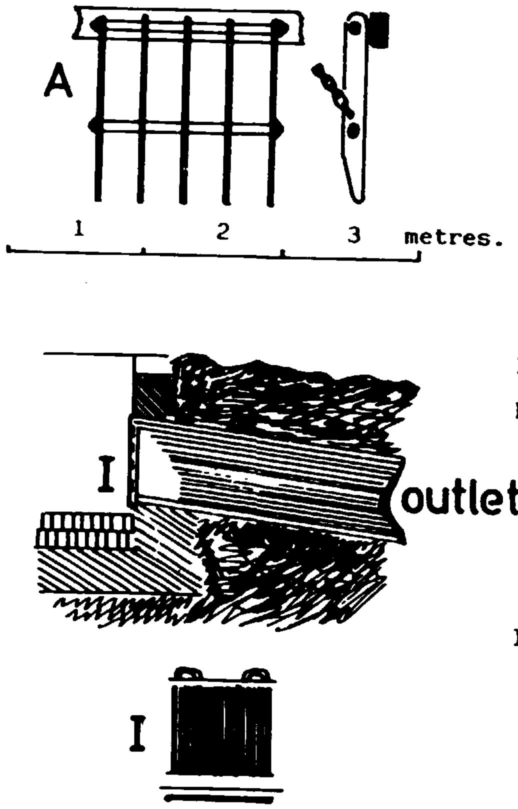
Plan View

Note: see Figure XXII for key.



Sectional Elevation

Figure XXI. Clay washing/mixing mill, Plan and Sectional Elevation.



Key:(to Figures XXI and XXII)

A & C - Knives, or cutters.

B - Harrows, similar to those used in agriculture, suspended on chaines from timber frames.

D - Restraining chain for cutter frame.

E - Pump.

F - Horizontal wheel, provided with friction rollers on its rim to lift 'G', which raises the lever of the pump by means of the spindle 'H'.

I - Grating to filter out stones and impurities.

Figure XXII. Parts of clay washing/mixing mill.

materials together. The process is particularly suited to developing a clay body for high quality bricks and for tiles. The slurry from the mill passes through a grid or screen, down a chute, into shallow beds where it is allowed to settle. The slurry is then allowed to dry to plastic state before being re-mixed and made into bricks. In its original form, the mill was used to mix crushed chalk pulp and clay slurry. The pump was used to raise water into the mill but this assumes that a water supply is available. Later, this type of mill was mechanized by applying the drive through the centre shaft after fitting a large pulley.

Throughout the process of brickmaking, the effects of particle size and grading will be found to be most important. The surface area of the particles in relation to their weight is influenced by the particle size. Simply put, as the size of the particles gets smaller, the surface area increases in relation to a given weight. Related to this is the fact that smaller particles will react quicker, since they have more surface (reactant) area per unit weight. A simple example of this is where fine sugar will dissolve quicker in water than coarse sugar. Smaller particles can adsorb more liquid onto their surface, per unit weight, than can larger particles This can be seen where the finer materials need more water to make them plastic, as opposed to coarser materials which need less water. From the point of view of mixing, it may be appreciated that the very fine grained materials need more work to mix them thoroughly, than do coarser materials. The extra effort is well worth the work, since homogeneous materials are more regular in their behaviour, and a consistently higher quality product will result. Where there is relatively coarse non-plastic material present as a constituent of the clay body (often the case), maximum plasticity will be developed if the non-plastic grains can be evenly coated with clay.

In many cases, a single source of raw material can be effectively used for brickmaking, assuming that intelligent winning and primary mixing is carried out. Even so, there is much to be said for mixing more than one clay or other available materials to get a variety of bricks. Such mixing should be done on a trial basis first to evaluate the quality of the product. Where mechanical equipment is not available to mix the materials, wet mixing should be considered.

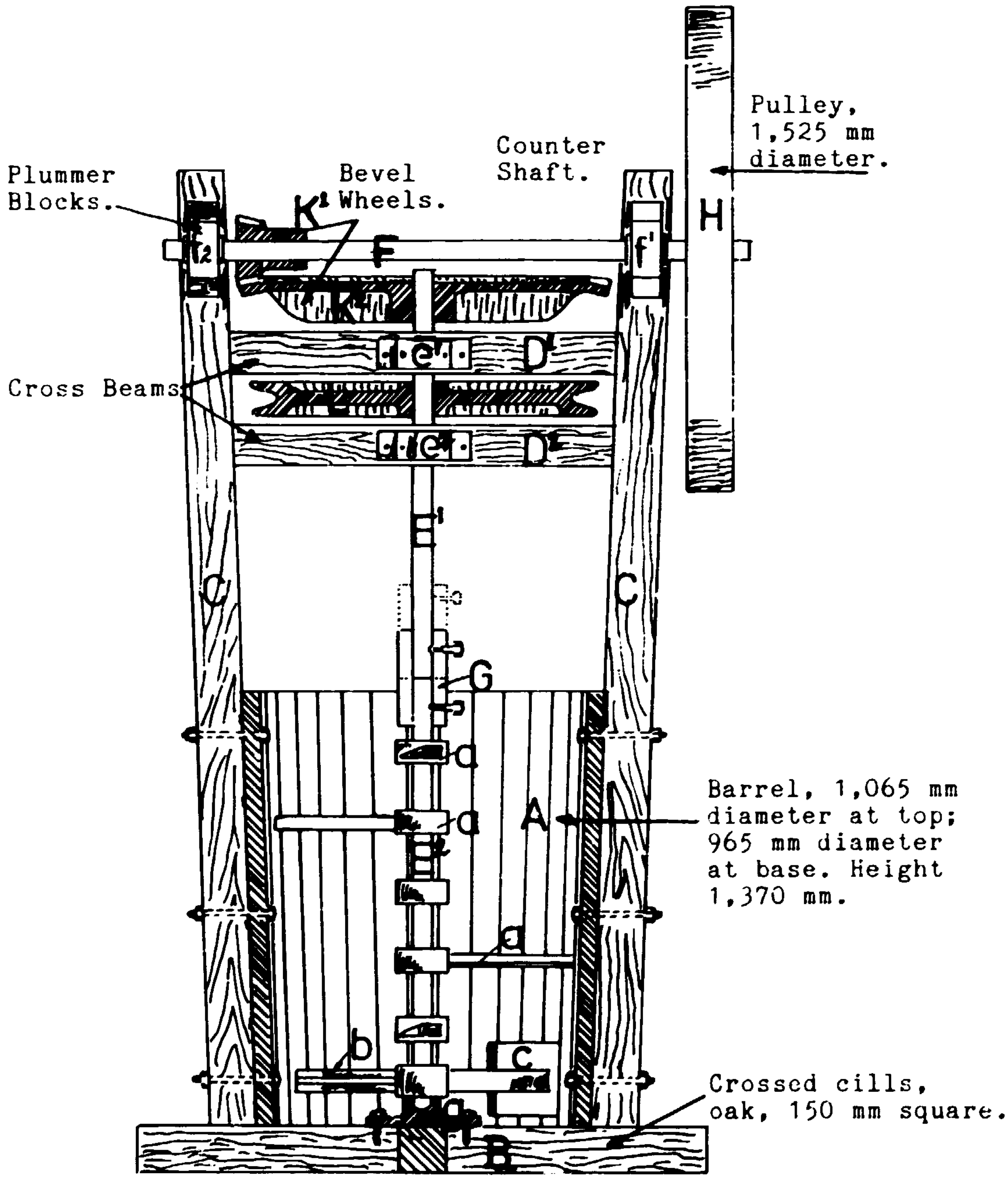
To mix clay and water, the simplest method is to wet the clay, and leave it for one or more days until it is soft. The clay is then fed into a mixer, pug mill, or mixed by treading and left for a further two or three days before being used. When treading is used, the clay in the mixing pit should not be more than 30 cm deep. With very plastic clays, which can be difficult to mix, it sometimes helps to make them into a slurry, then allow them to dry to about the correct consistency before treading the mixture again. However, the exact details depend very much on the nature of the clay and the method of mixing, i.e. manual, animal power, mechanized.

Mixing was one of the easiest parts of the brickmaking process to mechanize. The animal powered mills are in themselves forms of simple mechanization, and they could be directly transformed into steam/diesel/electric powered mills. New machines such as double shafted mixers and blenders were also introduced. The double shafted mixer may be one of the best known mixing or blending machines. It does a reasonably efficient job using low horsepower, provided that the clay is already partly wetted when introduced to the machine. High powered, high output, mixers are also available. With small scale operations, it pays to wet and age the clays before feeding them to the mixer, with final water additions being made in the mixer itself. The mixer will not break down stones or hard lumps of clay.

Vertical pugmills, of the types shown in Figures XXIII. and XXV., give some degree of mixing and, although the output is not high they are simple and inexpensive to make. In the pugmill shown in Figure XXIII., the barrel 'A' is fixed in a frame of oak crossed cills of 150 mm cross-section, the two uprights 'C' and cross beams 'D^1D^2' are of similar cross-section and made of oak or other suitable structural timber. Two plummer blocks, 'f^1 f^2', support the 65 mm diameter countershaft. The vertical shaft 'E^1 E^2', 65 mm square, is turned to receive the two plummer blocks 'e^1 e^2', and at the bottom for the footstep 'g'. The shaft is in two pieces such that by raising the sliding coupling 'G' the drive can be taken off the bottom section. This may be desirable when a separate piece of equipment is to be driven off the chainwheel 'L'. The knives are shown at 'a', the scraper knife at 'b', and the opening in the barrel through which the clay escapes is at 'e'. More details of the knives are shown in Figure XXIV. It would be possible to install a pair of mills opertaing side by side, by extending the countershaft 'F', and using the pulley 'H' common to both.

Figure XXIII. Simple pugmill for clay mixing.

(after Brown, ref: 7)



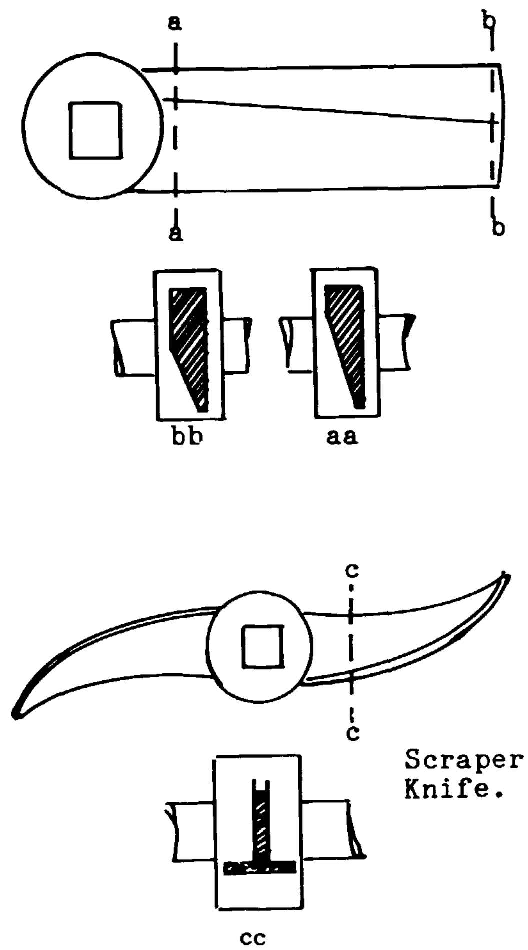


Figure XXIV.

Pugmill knives.

(After Brown, ref: 7)

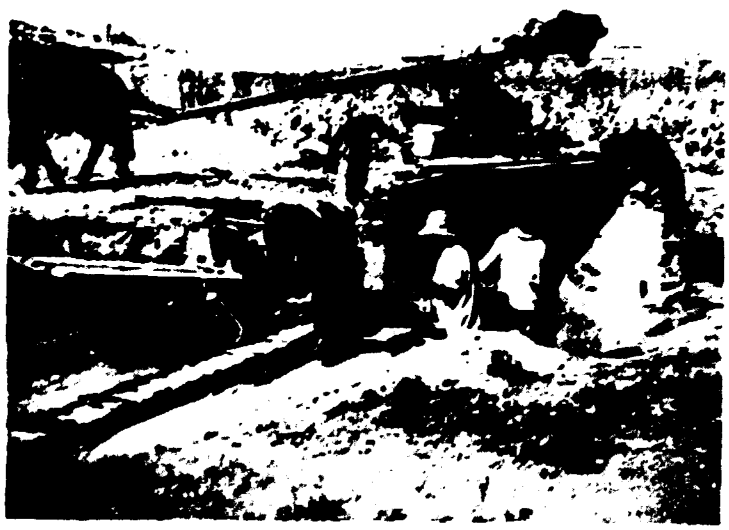


Figure XXV. Horse-drawn pugmill - Lesotho.

Forming.

Forming is the term used to describe the process of shaping the clay mixture into a brick shape. There are a number of methods of doing this, which include the following:-

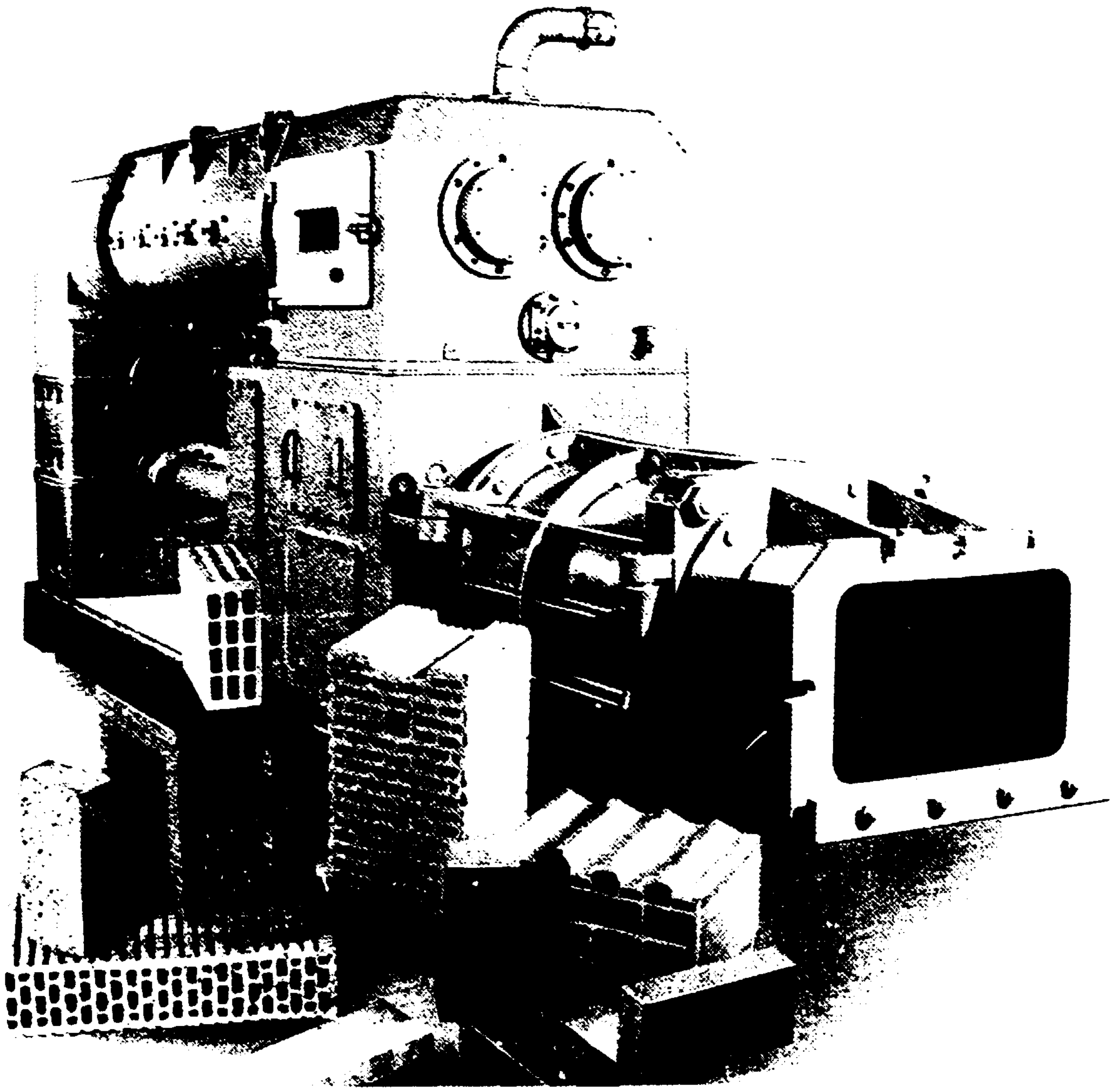
- hand moulding;
- extrusion;
- pressing of a plastic clay body;
- pressing of a semi-dry clay mixture;
- pressing of a virtually dry mixture;
- pressing using tamping and vibratory presses; and,
- casting.

With respect to bricks, any of the above methods could be used, but the most common for small scale brickmaking of the type being considered here are:-

- Hand moulding using wet to almost stiff-plastic clay bodies. The brickmoulds for very wet mixtures need not be exceptionally strongly made, but for the stiffer mixtures, the moulds should preferably by made of steel.
- Extrusion, either de-aired or non de-aired extrusion being suitable according to the capital available and the types of bricks to be made. Extrusion is probably the most common mechanized method used today. The modern extruders used in large brick factories are expensive in terms of capital cost, require reasonable maintenance facilities to keep the extruder and associated equipment running properly, but if there is a market for the product and the materials and expertize is available, they would be one of the most versatile high volume brick-making machines. A modern extruder is shown in Figure XXVI., together with some of the products which can be made.

Hand Moulding.

Hand moulding of bricks is only one part of the wider process of brickmaking. As has already been indicated, each part of the process is important, and with each successive part being completed, the brickmaker has invested more time and money in making bricks. The material therefore grows in value as the process continues. Even after the brick has been



The modern extruder shown above (courtesy of Rieterwerke, Konstanz, West Germany) is in its basic form without ancillary equipment and drives. Such machines from different manufacturers, vary considerably in terms of both price and quality of engineering. Generally one gets what one pays for. It should be noted that this document is not proposing the use of such machines except where a detailed study has shown that they are necessary.

Figure XXVI. Moderm extruder with some products.

moulded, it is a brick in name only until such times as the process has been completed by proper firing. However, the moulding process will determine the shape of the brick, and the characteristics of the clay at this stage will determine other factors. Since it is for the moulding process that the clay has been prepared in a plastic state and the moulding process forms the brick into its final shape, yet leaves it in a condition (wet and plastic) where deformation can still take place, moulding or forming is one of the most important parts of the brickmaking process. As a general rule, the softer the clay mixture, the easier it is to form the brick shape - at least in terms of the power and skill required for hand moulding. At the same time, softer mixing usually make less dense, less strong, bricks. Stiffer mixtures are more difficult to mould, require more skill, but make stronger bricks which can be almost indistinguishable from machine made bricks, and can be load bearing in terms of strength.

The range of bricks which can be made by hand, in terms of shape, size, texture, etc., is seldom realized by many brickmakers who have been making bricks for years.

There are a number of variations on how bricks are moulded, but here we will deal with two basic methods, one of which uses a wet mixture, called a slop brick, and one which uses a stiffer clay mixture, called a sand moulded brick. These terms may have slightly different meaning in different places, but are convenient enough to use in the context of the following details.

Slop moulding uses a soft clay mixture, so soft in some cases that the bricks must be moulded directly on to the ground or a pallet on which they will be dried, since they are too soft to handle. In other cases, the mixture is still very soft, but it is possible to carry them in the brick-mould to the drying area where they are set (carefully!) for drying. The clays used are generally of a sandy nature, and easy to mix into a wet mixture. The mixture is easy to handle, almost so wet that it is 'self-lubricating' in the mould, and the brick slips easily from the mould when it is inverted.

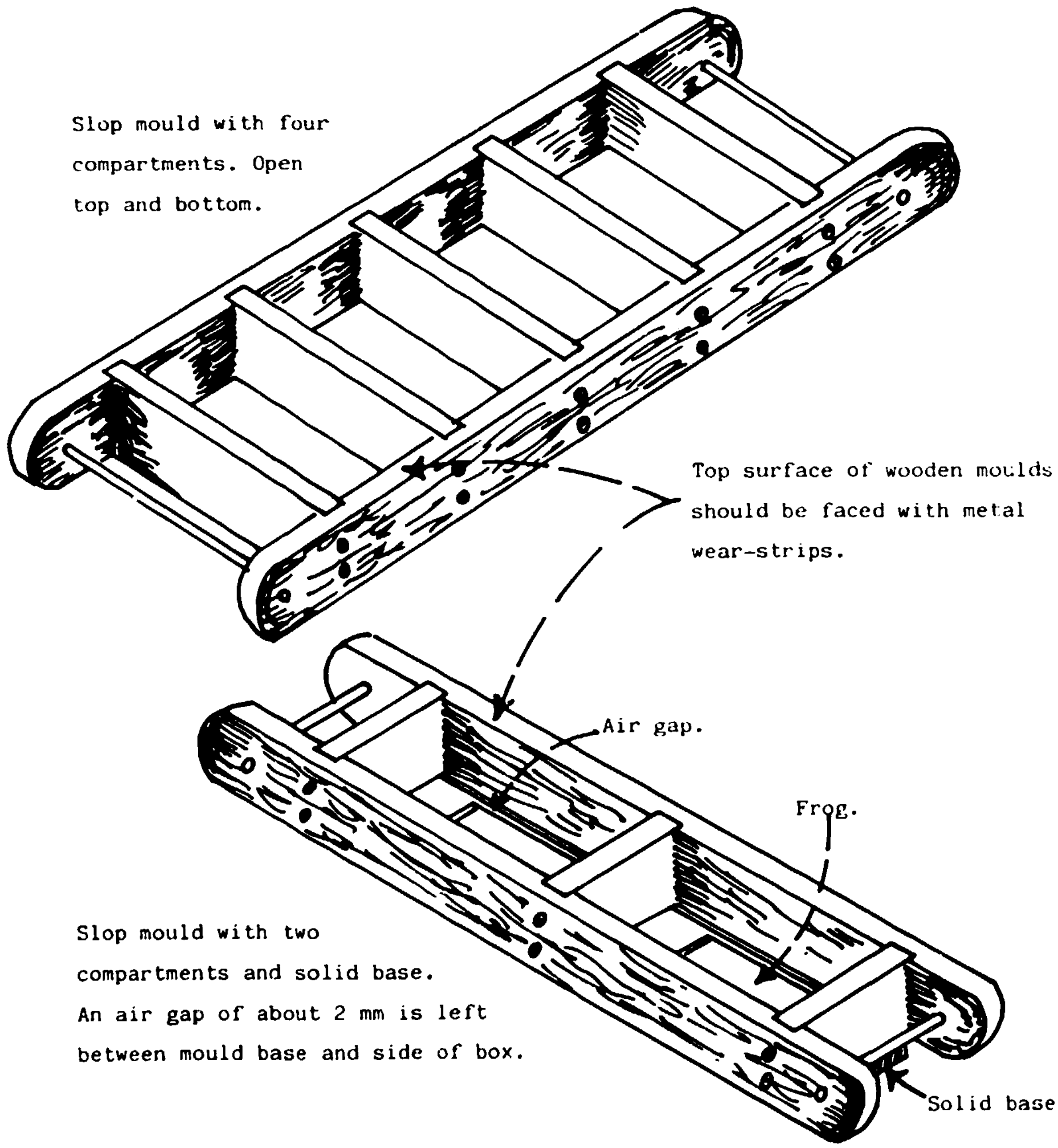


Figure XXVII. Moulds for Slop Moulding.

A typical method used in slop moulding is as follows:

- The wet clay mixture is supplied to the moulder, either at a bench, at a pit in the ground similar to that shown in Figuer XXVIII., or directly to the drying ground. In the latter system, using moulds similar to the 4-compartment mould shown in Figure XXVII., the clay is set on the ground in heaps such that when the moulder has finished one heap he has moved up to the position of the next one.
- The moulder takes a ball of wet clay and dumps it into the pre-cleaned mould, then slaps each end of the excess clay on the box to make sure that the corners are filled.
- Using a short wooden baton, e.g. about 30 mm diameter x 300 mm long, the moulder sweeps off the excess clay from the top of the box, slides the box across to an assistant who takes it to the drying ground, and throws the excess clay back to the clay heap. The process is completed as necessary for multi-compartment boxes before the box is passed on to the assistant.

Moulding pit in the foreground, wooden board for table, and cemented surround. This type used for sand faced bricks, but similar to slop moulding.

Figure XXVIII. Moulding Pit.

It is after leaving the moulder that damage can be done to the brick. Where the brick is carried in the mould to the drying ground, the mould should be held with the top uppermost, similar to when the moulder had it set in front of him. If the box is open top and bottom, a pallet should be placed undereneath to support the brick(s) until it is laid on the drying ground. When the brick is emptied onto the ground, the activity should be done very carefully to make sure that the brick does not fall onto the ground and become mis-shapen. Similarly, when the box has been inverted ready for emptying, and is pushed up to the bricks just laid, care must be taken to see that the freshly laid bricks are not pushed out of shape in trying to lay the bricks closer together. Most important, the ground on which the bricks are to be laid MUST BE SMOOTH. When the bricks have been laid, some form of cover is usually required. This may simply be sand, soil, or ashes, or it may be one of these plus straw, plastic sheet, or woven matting. This prevents the bricks from drying too quickly, and apart from preventing drying cracks, also reduces the tendency for distortion to take place.

The division between slop moulding and sand moulded bricks, in terms of clay stiffness, is difficult to define. Let us say that if the bricks can be emptied from the mould onto a pallet and taken to the drying ground without losing shape, the method could be classed as stiff or sand moulding - according to whether water or sand is used as a release agent in the mould. Anything softer than this would usually be unsuitable for sand moulding and come under the classification of slop moulding. With sand moulded bricks, better preparation of the clay body is required and the stiffer mixture is more difficult to achieve by purely manual methods. However, the results are well worth the effort. The following are some of the differences from slop moulding:

- The mould boxes must be stronger to allow for the force with which the stiffer clay is thrown into them.
- The clay must be of the correct shape to suit the shape of the box, and more skill is need to throw the brick straight into the box.
- The moulding table or workplace should be of a stronger and more stable construction than for slop moulding.
- The process tends to be slower than for slop moulding.
- Single boxmoulds, or mould and stock, are more common than multi-compartment moulds.
- A wide range of surface effects is possible, by varying the moulding sand, or by texturing the surface of the brick after it has been moulded.
- The bricks are usually of better shape and physically stronger than slop moulded bricks.

  Due to the range of finishes which is possible and the higher strength which can be achieved, the bricks are more suitable for use as facing bricks and in some loadbearing situations.

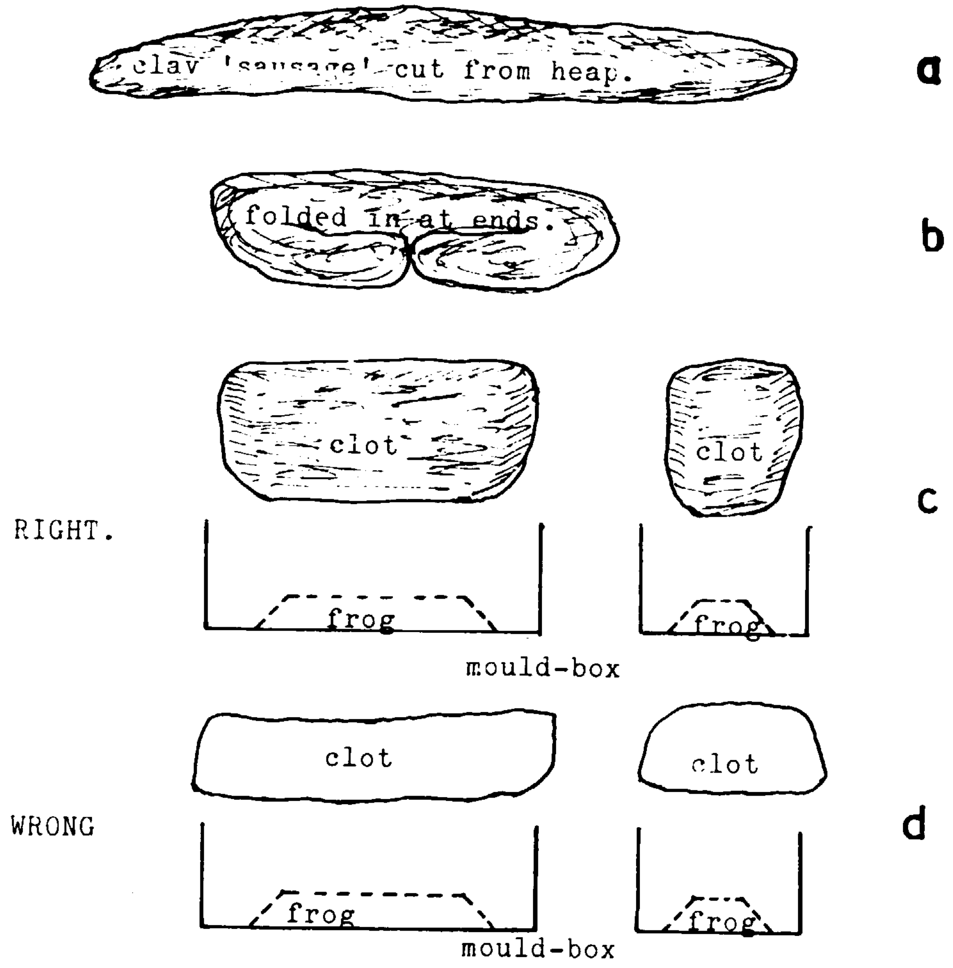
Figures XXIX. to XXXIII. show how the clay is shaped for sand moulding, the priciples of throwing it into the mould, a moulders table set up, and some moulds. The method of making the bricks is as follows:

- The mould is prepared by ensuring that it is perfectly clean inside, wetting the inside by dipping the mould into water - some wooden brickmoulds are left soaking in water overnight. With steel brickmoulds, thin oil might be used instead of water. With a good clay, properly sanded, it is not necessary to clean and lubricate the mould each time, but this becomes a matter of experience.
- The moulder's assistant spreads some sand on the table in front of him. He then cuts a roll of clay from the heap using his hands, folds both ends of it into the middle, and working on the sand bed he forms the piece of clay into a rough brick shape which has a cros section slightly less than that of the mould. The sanded 'clot', as it is called, is passed onto the moulder.
- The moulder has prepared the mould, sprinkles a little sand onto the stock (if a stock and mould are being used), plunges the mould into his sand heap (not always necessary with a good, well sanded clot).
- Taking the clot from the assistant, with it placed between his hands such that it is stetching away from him (if it were a brick he would be looking at a header face), and with his hands held such that the palms are facing each other with the clot held between, and the fingertips upwards, the moulder forcibly 'throws' the clot into themould (see Fig. XXX.).
- It cannot be emphasized too much that the operations just described are the most important ones in forming good quality bricks. Figure XXIX. indicates how the clot should be thrown correctly and why incorect clot size, or poor throwing, influence quality and speed of brick moulding.
- After throwing the brick there is a surplus of clay on top of the mould. The original clot size being equal to 1.25 bricks, there should be the equivalent of 1/4 brick surplus on top of the mould. This is either cut off using a bow (see Fig. XXXIV.), or pushed off with the moulder's thumbs. The bow method is preferred for better bricks. The moulder then takes a piece of wood called a 'strike', and smooths off the top of the brick whilst it is still

Figure XXIX.

MAKING THE CLOT. RIGHT AND WRONG SIZE

RELATIVE TO MOULD-BOX.



a. A piece of clay is cut from the heap, roughly in the shape of a long sausage. It is folded in at each end to make the shape shown at 'b', then quickly worked on the bed of sand tomake the clot shown at 'c'.

The clot shown at 'c', in stretcher and header positions, is smaller in cross section than the box, and if properly thrown, will hit the bottom of the box first, spreading out to fill the mould. At 'd' it can be seen that the clot is too big to go into the box without hitting the sides - it will sweep the sand of the mould, and the cut face of the clot will stick to the mouldbox.

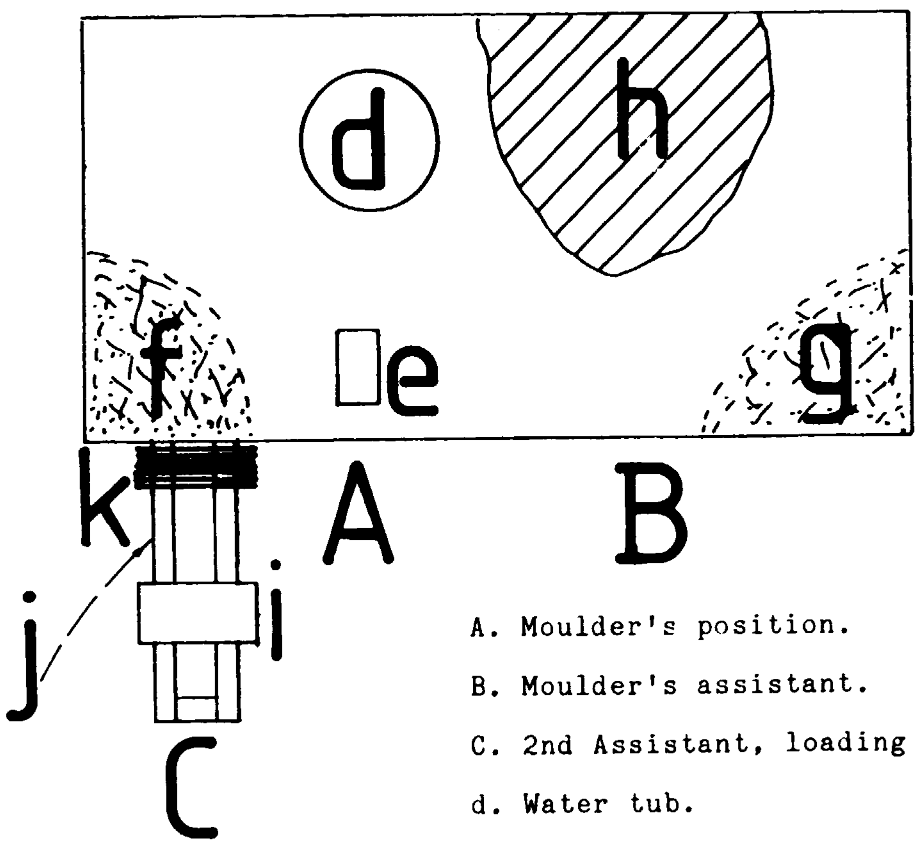
Figure XXX.

WHEN THROWING THE BRICK, THE HANDS ARE HELD IN A 'PRAYING' POSITION.

" - taking the clot from the assistant, with it placed between his hands such that it is stretching away from him (if it were a brick he would be looking at the header face), and with his hands such that the palms are facing each other with the clot held between, and fingertips facing upwards, the moulder forcibly 'throws' the clot into the mould."

Figure XXXI.

MOULDER'S TABLE SET UP FOR SAND FACED BRICK-MOULDING.



A. Moulder's position.

B. Moulder's assistant.

C. 2nd Assistant, loading wheelbarrow

d. Water tub.

e. Mould base, or stock.

f. Moulder's sand heap.

g. Assistant moulder's sand heap.

h. Clay heap.

i. Freshly moulded brick on pallet.

j. 'Page' or frame for pallets.

k. Stack of pallets ready for use.

Note: It is not uncommon to dispense with the moulder's assistant, when the moulder would work alone at the table. However, it is considered to be best to have an assistant who would be a trainee or standby moulder.

Figure XXXII

TYPICAL STEEL MOULD AND STOCK.

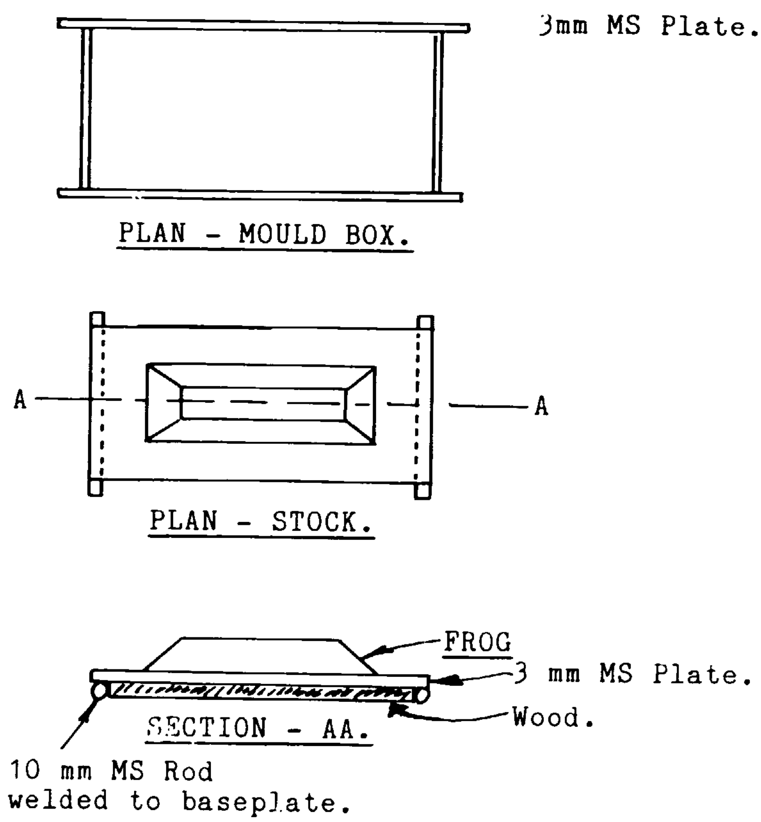
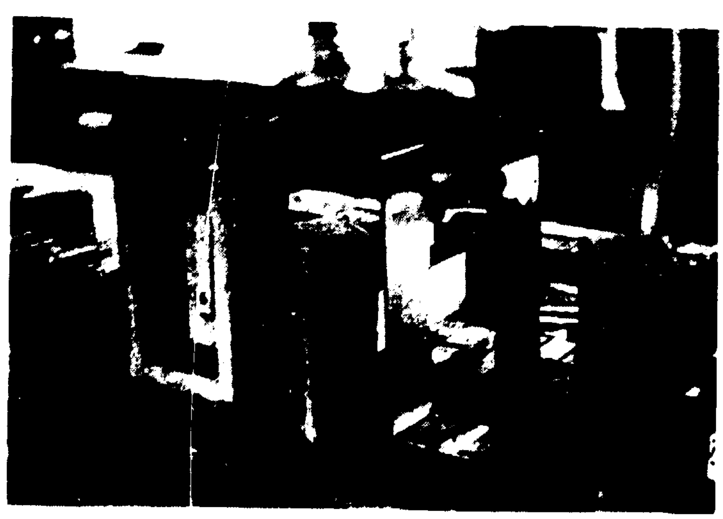


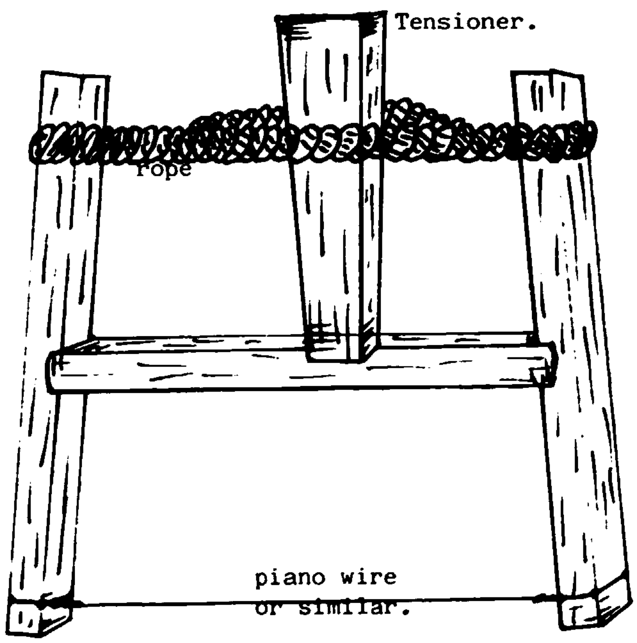
Figure XXXIII

BOX MOULD - SOLID BASE, AND STEEL BOX FOR STOCKMOULD.



in the mould.

- The moulder quickly sprinkles some sand over the smoothed top face of the brick, smartly turns the box on its side and places a pallet over the brick, then turns the box over so that it is now upside down.
- The mould is lifted off the brick - which remains on the pallet, and the brick on the pallet is placed on the page. If the clot has been properly made and the brick properly thrown, the brick will slip out of the box quite easily although sometimes gentle shaking of the mould box is required.
- The mould is checked for cleanliness and prepared to make the next brick.



An alternate method to make a bow is to use a piece of 10 mm diameter steel rod bent into a semi-circle, with a wire tied between the two ends.

Figure XXXIV. Simple wooden bow for cutting clay.

Some of the faults which are found with sand moulding are as follows:

a) Clay which has not been well mixed and aged before coming to the moulder's table.

b) The clot is of the wrong size, i.e. too big in which case the moulder and his assistant get tired by handling too much weight in a day, or of the correct size but of th wrong shape to fit into the box properly.

c) The clot is not properly sanded and may stick to the sides of the box.

d) The mould box is not properly cleaned before each brick is moulded. Although it takes very little effort to clean the box each time, if clay and dirty sand are allowed to accumulate in the mould, it can cause the brick to lose shape or to stick in the box, then time (and production) are lost whilst the moulder stops to clean the box.

e) The clot is not held properly by the moulder and does not throw straight down into the box.

f) The moulder allows his arms and hands to describe an arc when throwing (instead for throwing straight down) and the clot hits the side of the box, resulting in the brick sticking in the box - more lost production whilst the problem is rectified.

g) The clot is too small such that the moulder has to get another piece of clay to fill the box - again, this is lost production time.

Production rate and quality depend very much on the skill of the workers. With slop bricks, production rates of up to 4,000 bricks per day have been seen. With sand moulded bricks, a rate of 1,000 bricks per day (eight hours) is barely reasonable, and up to 2,000 bricks per day has been seen. According to Dobson & Searle (Ref: 2) a skilled moulder with assistant should make 36,000 bricks per week. This was probably based on a 48 hour working week for moulders in England, and would refer to good quality slop bricks.

The following photographs show the various stages of moulding a sand stock brick.

Hand moulding - ʟand stock brick.
i. clot being prepared.
ii. moulder in pit, showing
mould and stock.
Note drying shed in background where bricks are first set one course high, then after a few days they are reset to four or six courses high.

Hand moulding - sand stock brick.

The clean mould is placed over the stock, the clot picked up and thrown forcibly into the mould.

Hand moulding - sand stock brick.

(above) The clot has been thrown into the mould.

(below) The moulder hits each end of the clay in the mould to ensure that the corners of the mould are filled.

Hand moulding - sand stock bricks.


above, left.
The moulder smooths off the top of the brick using a wooden strike.

above, right.
A pallet is placed over the brick face and mould box.

below.
The mould is inverted so that the pallet is on the bottom, and the mould lifted off to leave the brick on the pallet. Brick and pallet are taken to the drying shed.

Extrusion.

The two types of extrusion being considered here are non de-airing extrusion and de-airing extrusion. Both types work on the principle of a helical screw or worm which transports the clay along the extruder barrel, consolidating it and pressurizing it out though a die-mouth which shapes the final cross-section of the brick. The clay extrudes through the die in a continuous column which is then cut into brick sizes on a wire cutting device. De-aired extrusion has an additional stage before the extruder where the clay is first passes through a de-airing or vacuum chamber prior to being fed into the extruder. Both types of machine can handle a remarkably wide range of clay materials, but it is important for any one production line that the feed material is of regular quality.

Non de-airing extruders normally process a wetter mixture than do de-airing extruders. The former type does not easily process very plastic materials or materials of very low plasticity, at least not usually in labour intensive brickworks where optimum mixing of the material is difficult to achieve. Although non de-airing extruders can make bricks with perforations, they are much more limited in this respect than are de-airing machines. Modern de-airing extruders can process material of low water content, in what is termed stiff extrusion, such that bricks can be set on edge to more than 10 bricks high straight from the extruder. Stiff extrusion is a process requiring a high capital investment and has high power consumption.

Some of the criteria to be applied in choosing an extruder are as follows:

- Cost. The extruders used for de-aired extrusion are more expensive, largely due to the additional equipment required.
- Type of Product. The non de-airing extruder is often satisfactory for most types of palin or simple perforated bricks. Surface texturing is possible in many cases. The machines are of relatively simple construction and easier to maintain. On the other hand, de-aired extrusion opens the door to a wider range of perforated bricks and/or to higher strength bricks. Some clays will only extrude satisfactorily with de-airing.

- Both types of extruder are essentially continuous production machines, and with the capital investment involved they are not suited to profitable intermittent production.
- Some non de-airing extruders can be (later) converted to de-airing when market conditions make this possible. This does not apply to all machines and the manufacturer should be consulted in advance.

Whichever method of production is used, it is always better to get independant advice on the market, and on the type of equipment which is required. Manufacturer's representatives, no matter how competent they may be, have a duty to sell their own machine or machines within the product range which they manufacture.

Vertical extruders, of simple design, can be cheaply made. They are in fact pug mills and produce a non-compacted clay column ready for hand moulding. Extruders of this type are shown in Figures XXIII. and XXV. Another type of machine which fits into this broad classification is the soft mud machine, a type of extruder designed to mechanize the job of hand moulding and to produce a simulated hand moulded brick. These machines such as the English 'Berry' machine, are of low output and suited to a small scale factory wishing to make as low as 12,000 bricks per day.

Although modern extruders are powered by electric motors through 'V' belt drives, it is also possible to power a small extruder using an animal (Fig. XV.), or by diesel engine and flat belt drives. UNIDO has helped pioneer the design of a small mobile extrusion plant, meant to supply bricks to rural areas on an intermittent basis. In any case, the power supply should be carefully considered in terms of reliability, cost, and maintenance requirements.

Purchase of an extruder involves a substantial capital outlay, which must be recouped through sales of the product (bricks) at suitable prices. This seems self-evident, but where competition exists from hand made bricks which may sell at lower prices, the extruded product must be of sufficiently high or different standard to sell on a continuing basis at an economic price for the brickmaker. It is essential, therefore, that the market for the product is well understood before going into mechanized production.

With respect to management, as with any business, it is necessary that the management of the operation is efficient in both technical and commercial terms. In developed countries, as many as 50% of small businesses can go into receivership in the first five years of operation. This happens in spite of sophisticated services that are often supplied to the small scale sector. Brickmaking is no different in that there is the possibility of failure as well as the opportunity for success. Therefore, it is of special importance where a brickmaker is starting up for the first time, or expanding, say from hand made production into some degree of mechanization, that he understands the market, marketing, sales, the technicalities of production, as well as efficient operating procedures. This is an area where technical assistance from the international community can be invaluable.

Production efficiency could simply be described as production of as much as possible at the lowest cost. The implementation of production efficiency is a never ending process of examination, self critisism, and constant striving to change for the better. It involves human relations as well as technical understanding of the process and process equipment. Poor efficiency can be built into a brickworks and for this reason, initial design is important. Simple examples are:-

- The moulding tables used by hand moulders should be at a level to suit each moulder. Alternately, the table should be high enough to suit the tallest moulder and a solid platform supplied for others who are not so tall. This reduces fatigue as well as helping to keep up a good production level.
- Where the clay column from an extruder is cut manually before going into the wire cutter, care should be taken to ensure that a minimum amount of clay is wasted. In one case a piece of scrap steel was used to cut the clay column, the waste amounted to nearly 20% of production. A special tool was made at very low cost which made it easier to cut the column straight and waste was reduced. At the same time, the man cutting the column found that the new tool was much easier to use.
- In another case, wheelbarrows were used to take the wet bricks to the drying area. Each man had his own wheelbarrow. However, when one man stopped for a few minutes, the extruder had to stop until the

next man came along. Provision of an extra wheelbarrow meant that there was always one wheelbarrow waiting at the extruder to be filled up, and this acted as a sort of temporary store which permitted short delays from the people wheeling the bricks.

- An extruder is usually fixed inside a building or at least under some sort of cover. Similarly with other heavy equipment associated with brickmaking. There are cases, where to save costs, the building is too small, the walls too close to heavy machinery or the roof too low. When the time comes to do major maintenance it is often necessary to get lifting gear or a crane. This presupposes that there is space to get this eqipment into position so that it can be used. There have been a number of cases in the past where whole walls or roofs have had to be removed so that the lifting gear could get into position to lift the brickmaking machinery for maintenance. This causes a loss in production, more than should have been necessary, as well as the extra cost of making alterations to the building.

That the raw material should be of adequate quality and properly mixed has already been mentioned. With mechanized forming, this is even more necessary than for hand-moulding where each moulder or his assistant can immediately complain about poor quality material. The extruder has fairly fixed limits within which it can work efficiently, and outside of these limits output, quality, or both, will rapidly deteriorate. This deterioration is reflected in deterioration of profits! A clay mixture which is too stiff can cause the extruder to seize up, and a prolonged stoppage of production takes place whilst the stiff clay is cleaned out. Soft material, whilst it will often extrude, may be so bad that the bricks cannot be handled or processed through the cutter. In many cases, extra soft material going into the extruder will not extrude at all, since the stiffer material in front of it creates too much back pressure and the extruder worm simply turns inside the soft material which tries to flow back along the barrel. Control of the water content is therefore most important, even although it may be difficult where a double shafted mixer or pugmill is not available.

The next factor regarding raw material is that the supply from the claypit must be regular in quantity and of consistently good quality. If any deficiency here is not noticed until the problem shows up at the extruder, the delays in rectifying the problem can sometimes run into several days. Therefore, the manager must always be aware in advance of what is happening at the clay pit. Finally, a common fault with many brickmakers is that the rate of feed to the extruder is not uniform. Extruders work at maximum efficiency when they are supplied with the correct or optimum quality material at a rate which suits the particular extruder. Fluctuations in feed will cause fluctuations in output and often cause varying quality of output. Overfeeding of the extruder can cause blockages which take time to clear with the usual loss of production and profit.

As with any mechanical device, maintenance is of paramount importance. Maintenance can be broken down into planned maintenance and emergency maintenance. Planned maintenance includes preventative maintenance which is designed to keep the equipment in good working order and reduce downtime. Planned maintenance also includes scheduled stoppages such that repairs can be carried out. For example , if the oil filter is changed in a car at, say, 8,000 km intervals because the manufacturer says that it should be, it is possible to plan that the car is serviced and make other arrangements whilst it is not available. With brickmaking equipment, it is best to carry out such servicing work outside of normal production hours so that production is not lost. However, the important point is that, as with a car, there are certain items of brickmaking equipment where replacement of parts takes place even before they fail in service. Equipment suppliers should give a detailed maintenance programme with all equipment which they supply. The suppliers should also give a list of recommended spare parts to be kept in stock by the brickmaker - this is of particular importance where the spare parts come from another country and, as is often the case, it takes time to get foreign exchange to purchase spare parts. Money spent on maintenance is usually well spent, since it helps to guarantee continued production, without which there are no profits to keep the business going and expanding.

VII. DRYING.

The drying of bricks is another important part of the process of brickmaking, and can generally be divided into atmospheric drying and 'artificial' drying where heat is generated by combustion of some material to dry the bricks. With atmospheric drying, natural ambient conditions are utilized to dry the bricks, i.e. wind and sun. During atmospheric drying, the bricks may be handled more than with artificial drying, and the time taken may vary from as little as two days to as much as five weeks, according to the type of material being dried and the ambient conditions.

Hand made bricks contain from 20% to 30% of water, and even extruded bricks may contain well in excess of 20% of water. With solid hand made bricks weighing from 3.5 to 4.5 tonnes per thousand, it is obvious that to remove from 1.05 to 1.35 tonnes of water per thousand bricks requires a very substantial amount of energy. According to Knizec (Ref: 3.) "In terms of energy consumption drying is actually the most expensive part of the process.".

The choice of drying, or drying method, will depend on the usual factors of capital cost, availability of labour, cost of labour, cost of fuel, and type of bricks being dried - including the raw material characteristics. The forming process also has a decisive effect on the choice of dryer, since the denser product often produced by the de-airing process can be difficult to dry under atmospheric conditions, according to the nature of the raw material. The main point, is that the drying method should be suited to the drying characteristics of the bricks. In this section we shall consider briefly what happens when a brick dries, fully exposed atmospheric drying, covered atmospheric drying, and hot floor drying. Other types of dryers not covered in any great detail here include chamber dryers and tunnel dryers. Most reputable equipment suppliers will also supply suitable designs for dryers if this is required.

Bricks dry by a process of evaporation of water from the exposed surfaces of the brick. This evaporation takes place in several stages:-

a) Free evaporation from the surface, with water from inside the brick moving to the surface to continually replace that which is being evaporated.
b) Particles in the clay body (brick) moving closer together, until they touch each other, as the water which separated them transfers to the surface. This shrinkage stops when the particles are touching.
c) Breakdown of the continuous water film on the surface, but with evaporation still taking place from the ends of pores which are still connected to a water supply within the brick.
d) Final drying, usually taking place as part of the firing process, where the remaining interstitial water is removed.

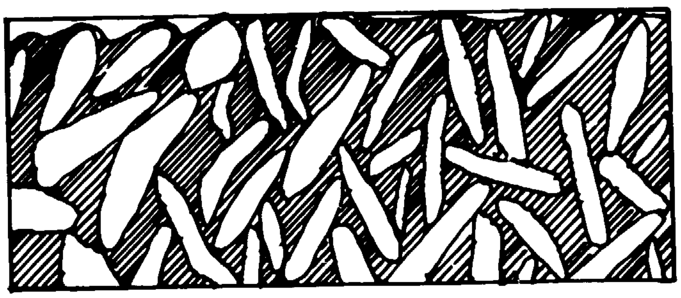
A critical stage in drying is where the particles start to touch each other. At this point shrinkage virtually stops, but there is still a considerable amount of water left in the brick. In fact, the various stages a) to d) above, do not take place in such a well ordered way throughout the body of a brick or throughout a mass of bricks set to dry. In production, bricks are set together, or individually in the drying place such that at least one face is covered, e.g. when single bricks are set on the ground the face which is lying on the ground is covered and evaporation cannot take place from that face at the same rate as from the exposed faces. In bricks which are set in a stack, different parts of various faces might be effectively covered by being in contact with other bricks. It this which causes unequal drying rates from different faces, as well as the effects caused by the direct actions of the media (sun, wind, hot air) which cause the water to be removed from the bricks. The fact that water is removed from the surface, in itself means that a stage is reached when the surface is dryer than the inside of the brick. All this causes stresses and strains to be set up within the brick and over-rapid drying, or excessively uneven drying, or an inadequate clay body, may result in cracks being formed. Hence the need to make certain that mixing and ageing are carried out efficiently to maximize the inherent strength of the material.

Figure XXXV. on the following page depicts the changes which take place in a clay body as it dries.

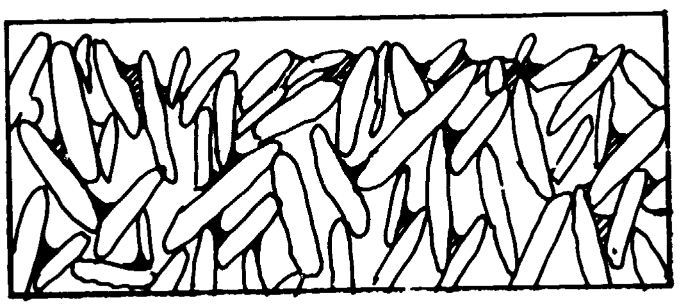
Figure XXXV.

Stages in the drying of clay.

1. The clay particles are separated by water. The continuous film of water on the surface permits free evaporation to take place with water inside acting as a reservoir.



2. As water is used up from inside, the particles of clay move closer together, the body shrinks. When the particles are touching, shrinkage effectively stops. Drying continues through the pores.



3. When water film on surface broken, colour change took place. Only some interstitial water left. This will likely be driven off at start of firing process.

From the above, it may be appreciated that open textured clay bodies will dry easier than close textured bodies, especially after stage 1. has passed and drying is influenced by how easily water can pass through the pores.

One of the simplest illustrations of the shrinkage of clay is to look at a water hole in the process of its drying. Where there is clay, cracks will form, usually leaving large 'plates' which curl up round the edges to give a saucer effect. What has happened is that the surface of the clay has dried rapidly (sun and wind) whilst the material underneath is still wet. In drying, the surface material shrinks, but the (wet) underlying material does not shrink to the same extent. The surface material becomes too small to cover the original area and cracks form. A similar effect is trying to take place when bricks dry, the outer surface dries first and the point is reached when the outer surface will be drying and shrinking quicker than the inner section. If drying of the outer section is too rapid, if the inherent strength of the clay body is not high enough, or if drying throughout the brick becomes uneven for other reasons, the brick may crack. The most rapid drying rates in bricks take place from exposed surfaces, with the corners and edges (arrises) having greater rates of evaporation due to the fact that the ratio of surface area to volume is higher there.

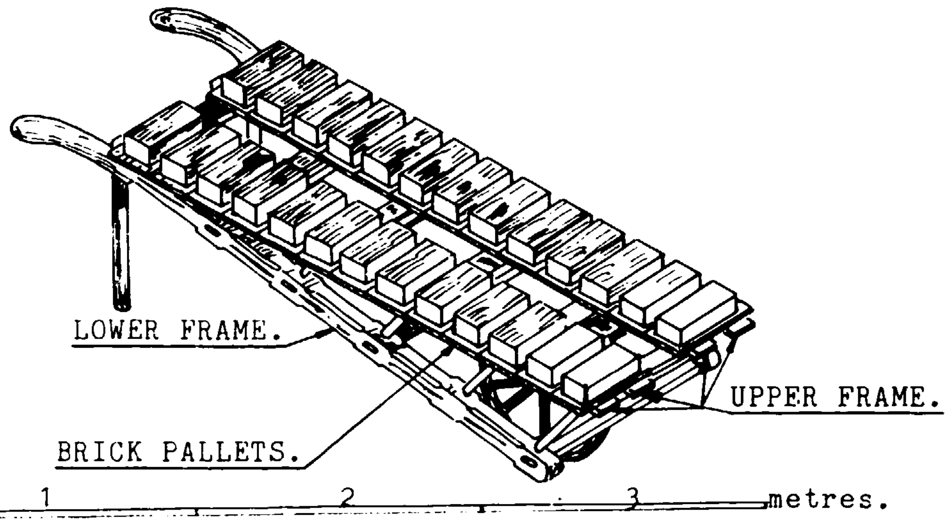
Atmospheric Drying.

Atmospheric drying, as the name suggests, is drying using only the effects of the atmosphere, i.e. sun, wind, and prevailing temperature. Even in cold climates, atmospheric drying can be effective since it is largely the effects of wind which accounts for much of the drying. However, wet bricks must be protected from freezing conditions.

The first stage in getting bricks dry is to transport them from the forming process to the drying area, the exception being those bricks which are moulded directly on to the ground. The most common way to do this for hand made bricks is for the the bricks to be carried in the mould, the bricks to carried on pallets, or to be carried on a wheelbarrow in which case they may be in the mould or on pallets. Figures XXXVI. and XXXVII. show two similar wheelbarrows, the former where the bricks are carried on individual pallets, and the latter where larger pallets are used with a number of bricks on each pallet. It should be noted that the wheelbarrow shown in Figure XXXVII. was photographed during the demonstration

Figure XXXVI.

WHEELBARROW USED TO CARRY WET HANDMADE BRICKS.

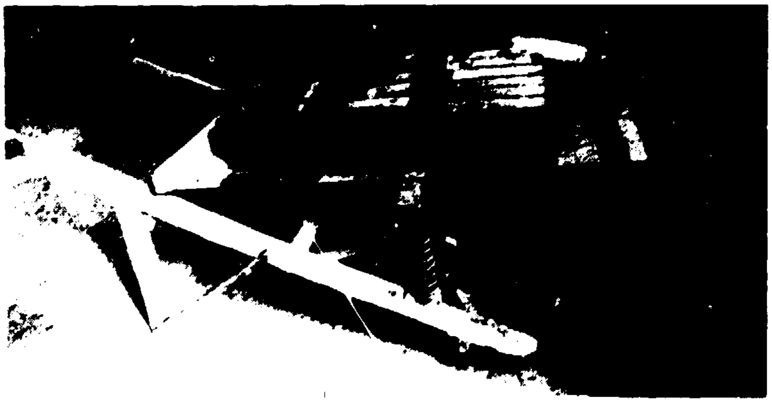


The wheelbarrow is relatively level when being wheeled such that the bricks do not slide into each other. It is of simple construction and could have a wooden, cast iron, steel or rubber tyred wheel. The legs would have to be braced to the lower frame.

Figure XXXVII.

WHEELBARROW MADE AT THE C.B.R.I., ROORKEE, INDIA.

Note the sprung frame to make allowance for rough ground.



of an extruder and the wheelbarrow is not fully loaded.

Where the bricks are set outside to dry, the surface on which they are laid to dry will be determined to some extent by the nature of the brickmaking operation. For example, where brickmakers move from place to place, the surface will likely be earth, smoothed out to some extent. Where the brickmaker is producing in one place, the surface may vary from earth to bricks, tiles, or mortar. Whichever type of surface is used, it should be smooth and free from stones, holes, or sharp projections such as roots. It is during the setting of wet bricks, and on the surface that they are set, that many bricks are spoiled. Training and good supervision is essential to get good setting practice. The person setting must be shown what to do and supervised to see that it is done correctly on an ongoing basis. The ground must be properly smoothed - not always an easy job - and if possible, sand, fine gravel, or the dust from fired bricks used to level off the surface. As already mentioned, each successive stage in the brickmaking process represents an increased investment, and increasing care should be taken to make sure that the bricks are kept up to a high quality standard.

From the time the bricks leave the forming process until drying is nearly complete, they are in a plastic state such that they are easily deformed, e.g. by being laid on rough ground or by bad handling. Many brickmakers do not see the need to make better bricks, since what they make sells anyway. This is a very shortsighted view. Better bricks should be easier to sell, often fetch a higher price, they look better, and are easier and quicker to lay. Although hand made bricks may not always be as regular of shape as machine made bricks, they can be of good shape (see Figure XXXIX.). All this leads to better acceptance of bricks as a building material, which in turn helps to increase the market for selling and the opportunities for the brickmakers.

Slop bricks are usually laid on flat to dry. This takes up more space in the drying area. as indicated by Figure XXXVIII. Because such bricks are very soft when they come from the moulder they can only be laid one course high until such times as they have dried enough and developed sufficient strength to be set higher. Figures XXXIX. to XXXXI.

show bricks set on edge to several courses high. In Figure XXXXI. the bricks were set four courses high initially, then reset to six courses high. During the resetting, the bricks were turned to expose fresh faces for drying and this helped to get more even drying of the bricks. Where the bricks can be set several courses high, on edge, the reduction in drying ground area means that the cost of providing weather proof cover is reduced. Figure XXXXIII. shows bricks which were damaged by rain.

The decision as to what type of drying cover to provide depends on the following factors:

a) The need to provide cover, e.g. the type of bricks and the nature of the raw materials, the space available for drying and the production level, and the climate.

b) The cost and availability of suitable cover. This may vary from sand or ashes, straw, woven grass mats, plastic or canvas sheets, corrugated iron or similar materials, to specially constructed drying sheds.

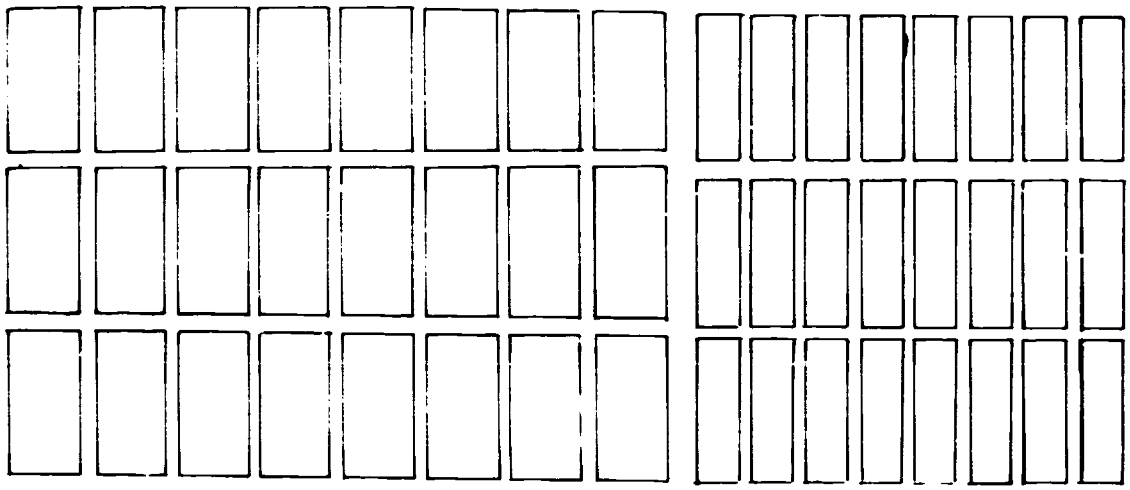
c) The nature of the brickmaking operation, which might be located in one place, change location according to the needs for bricks, or may be a seasonal operation. Seasonal operations are often such that bricks are only made during the dry season, or during the 'off-peak' agricultural season when labour is available.

The cheapest form of drying cover is often long grass or rushes, dried to straw, and laid on top of the wet bricks as the bricks are set. No supporting framework is necessary and this provides an effective cover against the sun, to some extent against the wind, and even against light rain showers. Next to this comes a variety of (probably) local materials such as woven matting and timber boards. Finally, a variety of manufactured materials may be considered, such as corrugated iron, canvas, and plastic sheets. The best type of material to choose will rest with the brickmakers who have to decide on what degree of cover is needed according to local conditions of weather, how easily their bricks dry, and what is available.

Where a brickmaker intends to stay in one location, and especially where brickmaking is a year-round operation, irrespective of weather, permanent drying sheds are worthwhile considering. This may simply take the form of a roof cover where bricks are dried on the floor, or it may

Figure XXXVIII.

SETTING AREA FOR BRICKS ON FLAT VERSUS BRICKS ON EDGE.



Plan View representing 24 bricks on flat and 24 bricks on edge.

Figure XXXIX

END VIEW OF BRICKS SET ON EDGE FOR DRYING.

(NOTE STRAW IN BACKGROUND, USED TO COVER BRICKS)

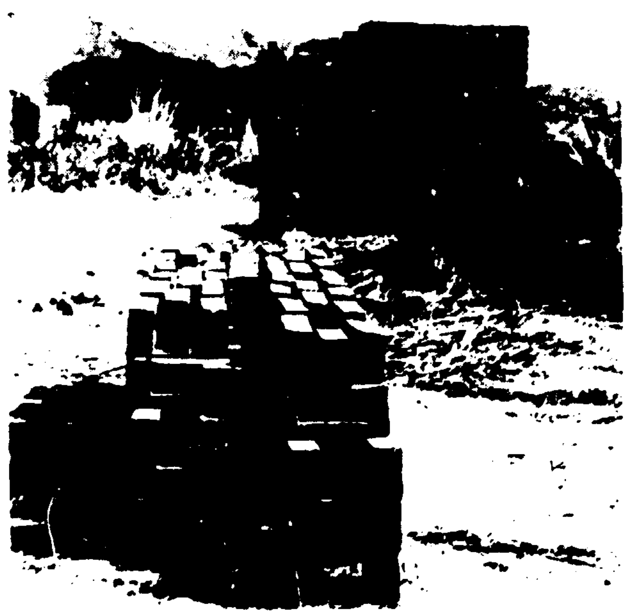


Figure XXXX.

FRONTAL VIEW OF BRICKS SET ON EDGE FOR DRYING.

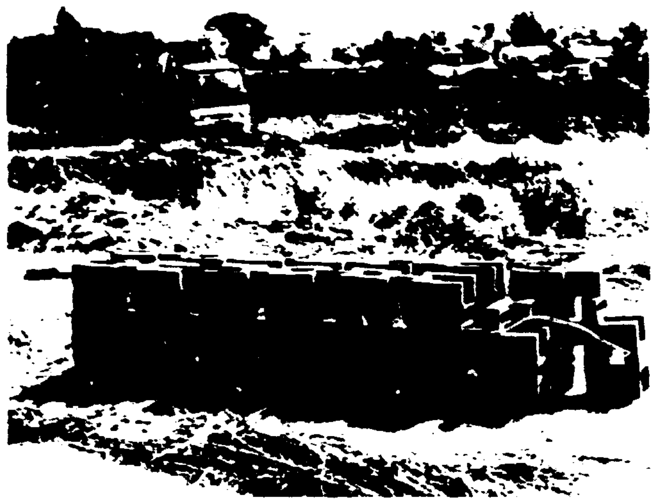


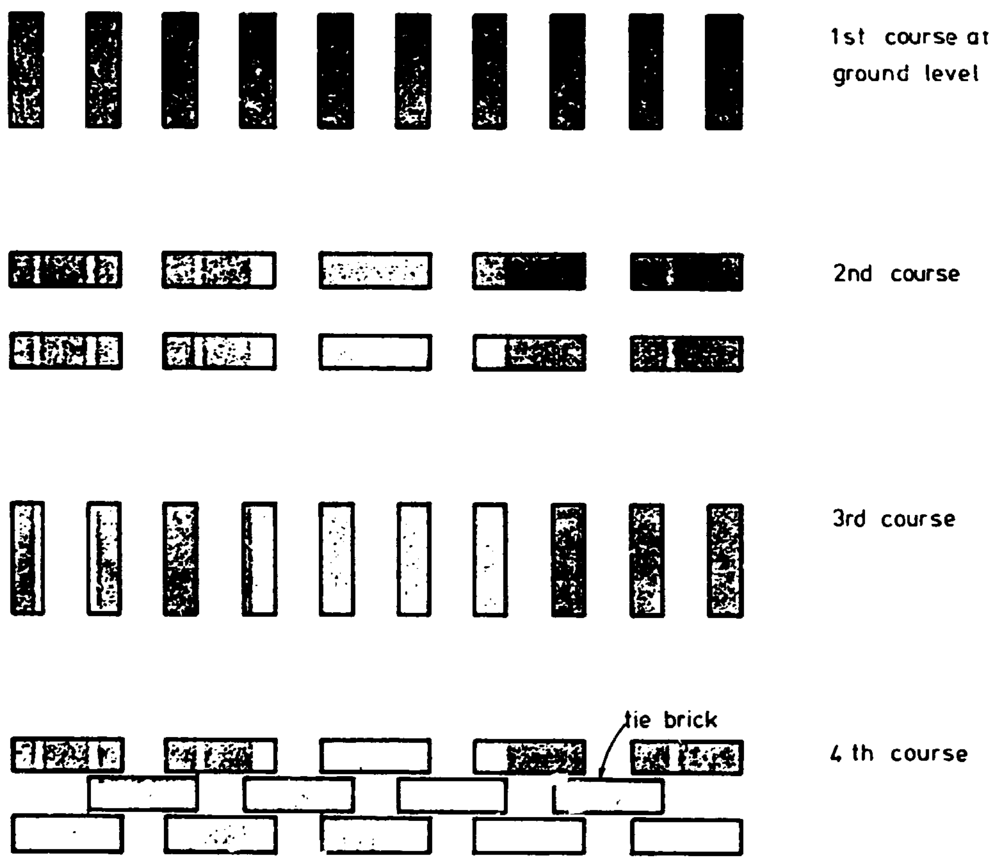
Figure XXXXI.

DRYING LINES OF SMALL BRICKWORK IN LESOTHO.

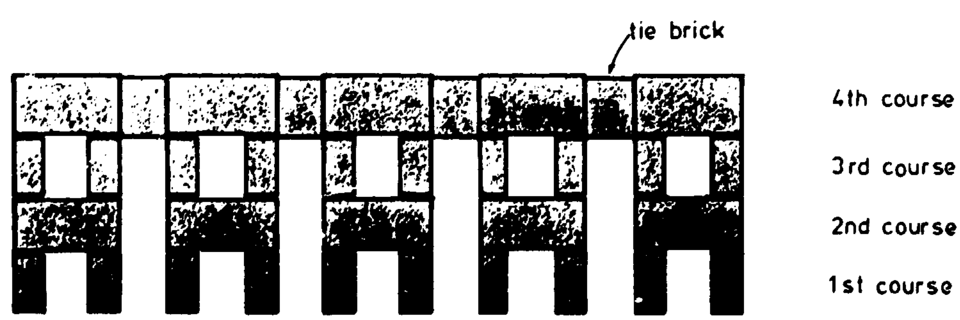
The foundations are made of rows of broken bricks raised above ground level and levelled off with sand.

Figure XXXXII.

SETTING PATTERN FOR DRYING BRICKS.



Plan view of individual courses



Front elevation - brick setting

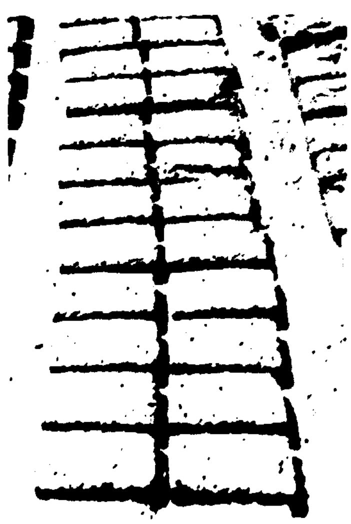
Figure XXXXIII.

BRICKS BEING DRIED IN LIMITED AREA.

Small drying ground can be seen to left of picture. When bricks are dry enough, they are piled up as shown and covered in straw. Note broken bricks left on drying ground.

Figure XXXXIV

RAIN DAMAGED BRICKS.



These bricks were set to dry and subsequently damaged by rain. Climatic considerations are most important in deciding whether or not to have more permanent drying cover.

be a specially constructed shed with provision for drying the bricks on racks or shelves. The main considerations are that the covered area should be large enough to suit the production level, it should protect the bricks from sun, wind, and rain, yet permit sufficient wind through such that drying takes place. With some bricks, the air flow must be retarded during the initial drying stage, and this can be done by having some form of louvred openings in the walls, or by hanging mats, old sacks, etc. down the side of the drying shed, or otherwise covering up the spaces through which air enters. The following diagram depicts the end view of one bay of drying racks, showing how pallets of bricks are loaded. The outer wall of such a drying shed might be built of checkered brickwork, or simply left open and temporary covers used as a windbreak.

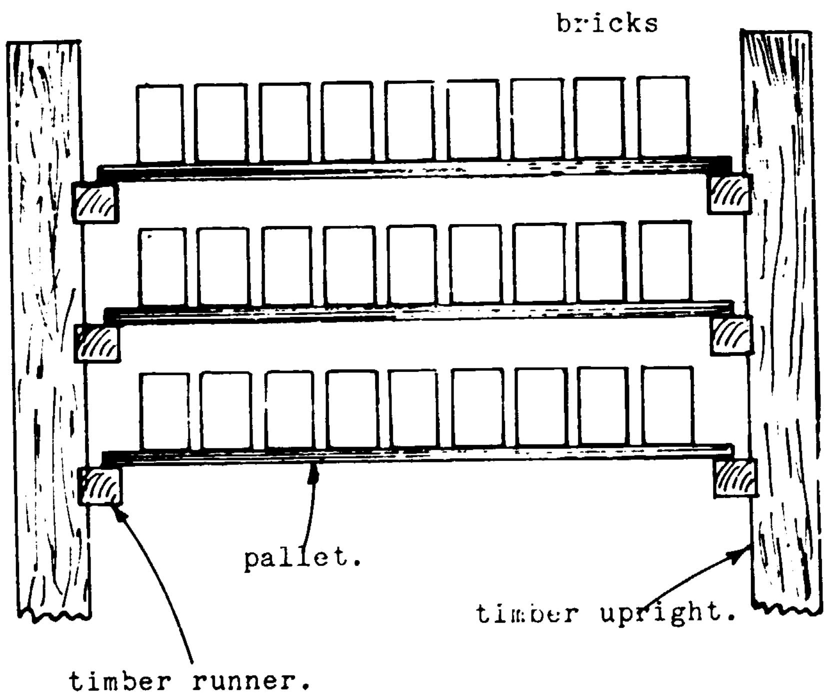


Figure XXXXV. End view of drying rack.

Hot Floor Drying.

Hot floor drying is only useful nowadays where there is source of cheap fuel or waste heat. The dryer is relatively simple to build, and consists of a series of flues running below the dryer floor. At one end of the flue system is a fire or fires, and at the other end a chimney to induce some draft. Hot combustion products passing through the flue system heat up the floor on which the bricks are set and also raises the temerature of the drying room such that drying can be relatively independant of external weather conditions. The hot floor dryer is better suited to climates which are cold, and is less necessary in hot climates where the sun and wind are cheap drying agents.

Since the actual temperature in a hot floor dryer does not have to be high as compared with firing bricks, it is possible that the fires could be kept going using a variety of by products such as coffee and rice hulls, waste oil, bagasse, sawdust, etc. Where the cost of fuel is high, it is difficult to justify a hot floor dryer since it has a very low efficiency in terms of useful work done per tonne of fuel consumed.

Other Dryers.

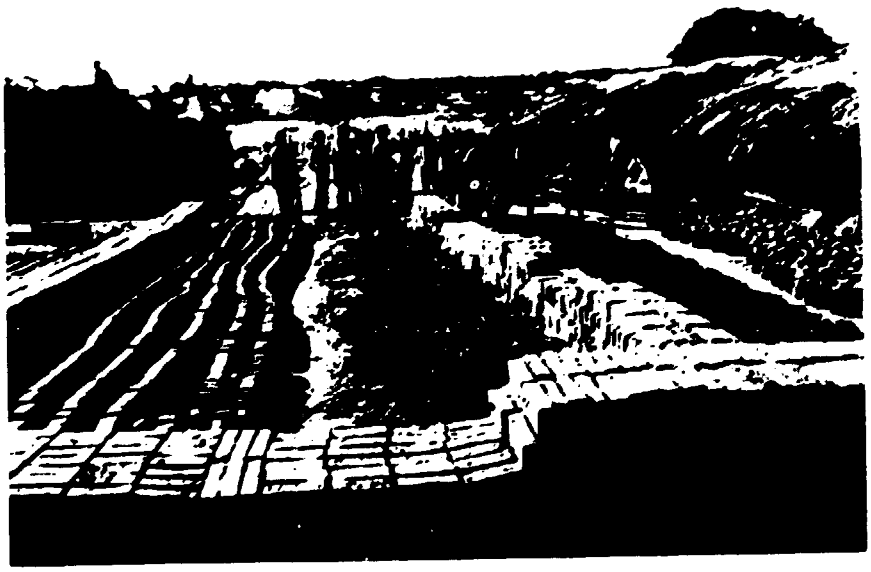
A variety of modern dryers are available for construction, using various fuels to raise the temperature and chimney or fan induced draft to get the air flow through the dryer to remove the wet air. Intermittent or chamber dryers can be quite sophisticated with controlled humidity and temperature making it possible to dry difficult clays. Tunnel dryers have the bricks set on cars which are moved through the dryer on a continuous basis if part of a tunnel kiln arrangement. Even with slop bricks and soft mud bricks, it is possible to set the bricks on pallets and then on dryer cars to be moved into the dryer and out again when dry, on an intermittent or continuous basis. Such dryers usually represent a high capital and operating cost and the economics of the drying system should be carefully calculated before deciding which type of dryer to use.

Humidity control in atmospheric dryers.

The drying of bricks relies upon an air stream to take away the humid or moist air developed through the process of drying. Both temperature and relative humidity affect drying rates. This knowledge can be used even with simple dryers to help control drying rates such that even bricks with a tenedency to crack might be dried safely. With bricks being dried outside, complete cover by an impervious material such as plastc sheeting permits the humidy to rise under the sheet. As the bricks dry in the heat of the day, the relative humidity rises under the cover, until at 100% relative humidity, drying has effectively stopped. When the plastic sheet is lifted, the moist air dissipates, the relative humidity drops, and drying can start again. Bricks made of weak, e.g. silty, clays can be safely dried using this method. Usually the bricks are covered as soon as they are set in the drying lines and the plastic sheets are lifted each evening then replaced each morning. After a day or two it is often possible to remove the sheets and let the bricks dry at a natural rate, but the exact conditions will depend upon the bricks.

Combination of different drying methods.

Different methods of drying can be combined for convenience. Where it is too expensive to build a shed to cover all production, it may be sufficient to build a smaller shed, and when the bricks have partly dried, reset them outside for final drying. The following photograph shows a low cost shed (to right of photo.) used for initial drying and bricks stacked outside to complete the drying process.



VIII. FIRING.

General.

The firing process, including emptying of kilns and sorting/stacking the burnt bricks, is the end of the production process. During firing, changes will take place in the bricks which make them into strong and durable building units. According to the materials which comprise the bricks and the firing process, the particles of the brick will fuse and sinter together. The clay is effectively converted into other materials, no longer plastic and no longer classified as being clay. Good bricks are born of and matured by heat, but never destroyed by it.

In a short document such as this one, covering many aspects of brickmaking, it is not possible to cover the details of firing to suit every individual case. As with other aspects of brickmaking, each case should be considered on its own merits. With respect to firing, some of the factors which should be considered are as follows:

a) The type of bricks to be made, e.g. low temperature or heat stabliized bricks, general purpose bricks, load bearing, engineering, paving, etc.

b) The nature of the raw materials, especially the maturing range or top temperature range within which the bricks can be safely burnt, and the temperature at which the bricks will vitrify or become over burnt.

c) The production level, determined by the market for the bricks, and taking into account estimates of future expansion.

d) The cost and availability of fuel, which fuels are available on a regular basis, taking into account future requirements.

e) The frequency of production, e.g. continuous or seasonal.

f) The availability of capital to construct a kiln.

g) Climatic conditions, and nature of the ground on which a kiln may have to be constructed.

h) Special considerations such as the need for imported materials for some kilns, e.g. refractory bricks, burners, electric motors, skilled personnel, etc.

The choice of firing method, or kiln type, may be a simple one based on tradition and production of a single brick type which is already well accepted. Where a market exists for more than one type of brick, more than one firing method may have to be considered. For example, if most of the bricks produced were of the general purpose type and fired in a Bull's Trench or clamp kiln, but a market existed for better quality facing bricks, then a small downdraft kiln might also be considered to produce the appropiate range of bricks. Similarly, a small kiln might be considered for production of tiles and other special products.

Two of the main factors to be considered in the firing process are temperature and time. Within certain temperature ranges fairly well known recations take place when bricks are fired, but the time spent at these temperatures must be long enough for the reactions to take place. At the end of the firing process, the time spent at the top temperature should not be so long as to let the reactions go too far. There are periods where the temperature rise might be deliberately slowed or stopped to let some reactions take place slowly. A simple example is at the start of firing, where the temperature rise is restrained until the bricks are completely dry. With clamp firing and with some materials which are high in carbonaceous matter, it may be difficult to control the firing process. the reactions which take place in clays during firing are summarized below:-

Approximate Temp. Range.	Reactions.
Up to 150°C	Completion of drying. Up to 10% water may be left in the bricks, according to making and drying method. Slow drying is required during this period, hence temperature in a kiln would be held to 150°C until drying is complete.
up to 300°C	Start of decomposition, some oxydation and burning out of carbonaceous matter.
up to 800°C	Most of the carbonaceous matter burnt out but dpends on availability of oxygen. Decomposition of clays continues. Decomposition of other materials including some carbonates and sulphides. Firing can be speeded up in this range, but depends very much on the nature of the clays. With fine

grained carbonaceous material, slow firing may be advisable to avoid bloating. Bloating is not usually so much of a problem in clamp kilns when fuel is mixed with the clay mixture.

+800°C

The full fire period when maximum heat input is required to raise the temperature up to that required for finishing the firing. With low fired bricks and many wood fired clamp kilns, this temperature is not reached and firing stops at a lower temperature. Annular kilns with a dead grate seldom go above 950°C and clamps with coal or coke mixed in the clay might reach from 900°C to 1,100°C. Kilns with live grates can reach +1,100°C, but for most structural bricks a maturing temperature of less than 1,000°C is preferred.
Vitrification may well have started below 800°C, but generally has not developed to any great extent at this temperature. Most brick clays will mature at some temperature above 800°C and it is normal to hold the kiln temperature within the maturing range for a few hours to develop a good ceramic bond without overfiring the bricks.

Kilns.

The kilns used for firing bricks can be grouped under the two main classifications of intermittent kilns and continuous kilns. Intermittent kilns are loaded with bricks, fired, and unloaded after being allowed to cool. Continuous kilns can be sub-divided into annular kilns, where the fires are moving around the kilns, or moving ware types where the bricks move through fixed firing zones such as in tunnel kilns. In both cases, with continuous kilns, loading, firing, unloading are going on virtually all the time. Some examples of kilns are detailed below.

The clamp, scove, or field kiln is an intermittent kiln which is usually completely constructed and dismantled with each firing. The capacity can vary from as low as 5,000 bricks, to as much as 1.5 million bricks. Firing times can vary from three days to five or six weeks. The bricks must be at least air dry when set. Fuel for firing may be supplied externally via firing channels running across the kiln with, sometimes, additional fuel being incorporated in the setting. Alternately, the bulk of the fuel may be mixed in with the clay in the form of coal or coke, and again some additional fuel may be incorporated in the setting. Where the bricks have fuel mixed into the clay body, the base of the clamp is set on a bed of fuel to start the firing process. Small clamps are not economic in fuel consumption, but the larger clamps can compete favourably with many continuous kilns. The bricks produced vary somewhat according to the raw materials and the fuels used. The main benefits of this type of kiln are that the size can easily be varied according to production needs, it is relatively easy to set, and with (at least) coal and coke firings an attractive multi coloured range of bricks can be obtained.

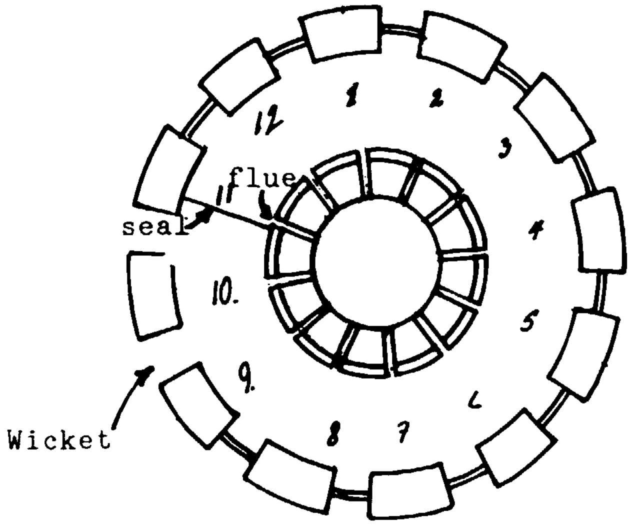
Updraft kilns are intermittent types of simple construction, with permanent walls. They may be set with bricks which are in a stiff plastic condition but it is preferable that the bricks are at least air dry. Firing times vary from about three days to about two weeks. The term 'updraft' is used because the combustion products from the fires rise up from floor level and exit through the top of the setting. Fuels may vary from wood and coal to oil and gas, whilst it is possible that a variety of agricultural by-products could also be used. The kilns are usually of a single chamber type with a capacity of 10,000 to 30,000 bricks, although the climbing kilns of Korea, China, and Japan could be considered multi-chamber types. This type of kiln is useful for small scale producers, can be more fuel efficient than a clamp of comparable size, but overall would be considered wasteful of fuel when compared with continuous kilns. Depending upon kiln design and the fuels available, the kiln can reach temperatures in excess of 1,000°C, but are more suited to firing below this temperature.

Downdraft kilns are also intermittent in operation. The combustion products rise from the fire up to the roof or crown of the kiln, then are forced downwards to exit from or below floor level via flues and a chimney. The firing tends to be more efficient than for updraft kilns and higher temperatures can be reached. The capacity and firing times tends to be similar to updraft kilns. Kilns such as the Cassel and

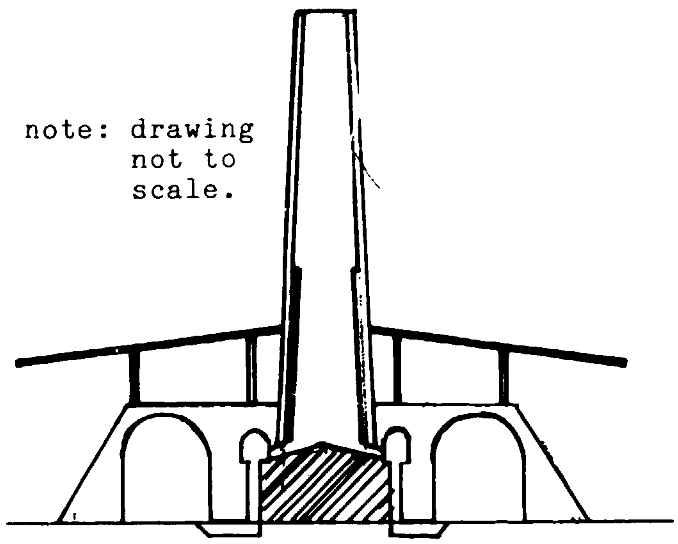
Newcastle types are termed horizontal draft kilns, but are included with updraft kilns here. As with updraft kilns, the bricks nearest the fires tend to be overburnt and those farthest away from the fires less well burnt. With such kilns, a clay with a long maturing temperature range is preferred such that over and under firing are minimized. In order that the downdraft effect can be achieved, it is necessary that these kilns have a roof and that the walls are designed to take the weight of the roof under the various firing conditions. However, a downdraft kiln using a temporary roof has been constructed and worked well using wood as fuel. Such 'roofless' kilns are much less expensive to build but require extra labour in operation.

Continuous kilns range from some big scove kilns which are operated on a continuous basis to Hoffman and Bull's Trench kilns. Modern continuous kilns, apart from the modern Hoffman types, include tunnel kilns where the bricks are set on kiln cars and move through the drying, preheating, firing, and cooling zones of the kiln. Tunnel kilns are major capital investments, not simply for the basic kiln, but for the ancillary equipment of firing systems, kiln cars, railway lines, etc.

The Hoffman kiln is probably the best known continuous kiln. It was invented by Friedrich Hoffman in 1856, and patented in 1858. The original design consisted of a circular chamber enclosed in a massive outer wall through which twelve wickets (entrances or doorways), equally spaced around the wall, gave access to the chamber. Twelve underground flues connected from the inside of the chamber wall to a central structure which fed into a single chimney and effectively permitted the single chamber to be divided into twelve operating compartments or chambers. Each of these chambers was served by its own wicket and exhaust flue. Fuel is fed through the kiln roof and burns amongst the setting. Figure IVL. on the next page, shows the general outline of the early Hoffman kiln. The kiln has since been developed that there are sixteen or more chambers, the flue system can provide for taking off clean hot air for drying, and the plan of the kiln is more rectangualr rather than circular. Hoffman kilns have been built using temporary roofs, i.e. two or three courses of close packed bricks on top of the setting covered with ashes, sand, soil, or



PLAN.



ELEVATION.

The circular chamber was divided into twelve by chamber dampers which could be raised or lowered. Later kilns used paper seals instead of these dampers, utilizing suction to keep the seal in place. In the example shown above, chamber 10 is being filled, 9 is empty or being emptied, 5,6,7, and 8 are cooling with air coming in through 9 and 10. The air gets heated up in the process, passing on through 4, where firing is almost complete, to 2 and 3 which are under full fire - fuel being fed through fireholes in the roof. Hot combustion gasses then pass on to chambers 1, 12, and 11, bringing them up to red heat. The flue gasses being vented through chamber 11 as indicated by the arrow. The setting, firing, and emptying process moves round the kiln making the operation a continuous one.

Figure IVL. Early Hoffman kiln.

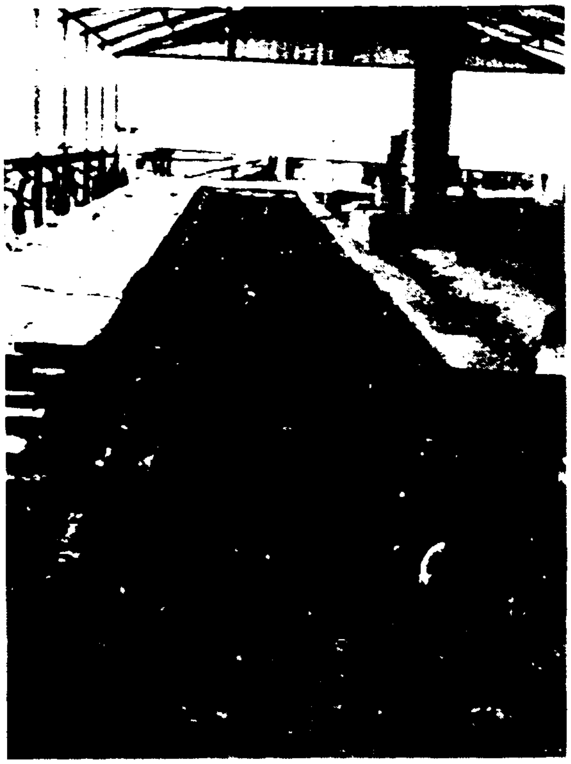
clay. Such roofless kilns are much cheaper to build, more labour intensive in operation but may have higher operating costs than a kiln with a proper roof. However, where capital costs are a deciding factor, the roofless kiln can be a viable alternative.

A simple form of the roofless Hoffman kiln, is the Bull's Trench kiln, used in Egypt, Pakistan, and India. The principle is the same as for the Hoffman, but about one metre in depth of the kiln is below ground level. The walls, extending above ground level, are banked with soil on the outside, and the flues may be in the outer walls venting to a single or double chimney which is transported around the kiln in front of the fires. On the following pages there are a number of Figures showing details of the Bull's Trench kiln.

As with the Hoffman kiln, the size of the Bull's Trench kiln can vary considerably according to the output of the brickworks. Because of the capital investment involved and the need to maintain maximum production, the size of the kiln should be carefully chosen. A large kiln of 30 chambers each of about 4.6 metres in length and 8.6 metres wide would have a capacity of about 28,000 bricks per chamber. A smaller kiln of 30 chambers has chamber lengths of 4.6 metres and width of 4.3 metres, with the chamber capacity being about 14,000 bricks. In both cases the height of the trench is 2.1 to 3.0 metres. An Egyptian kiln, virtually identical to the Bull's Trench type was said to have an output of 15,000 bricks per 24 hours, firing on a rice husk/fuel oil mixture. The kiln had only ten chambers whilst another kiln of 14 chambers (also in Egypt) had 14 chambers, fired with fuel oil, and an output of 23,000 bricks per 24 hours.

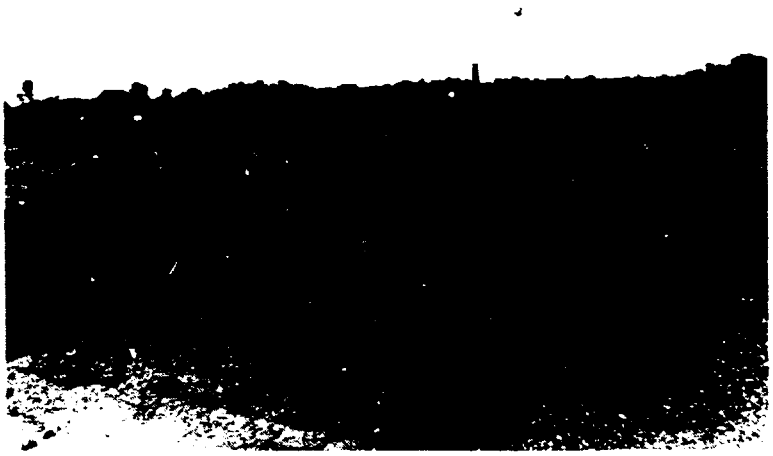
As already mentioned, the Bull'S Trench and Hoffman kilns are top fired. Large kilns may have as many as 10 feedholes in each row, spaced across the top of the kiln. Smaller kilns may only have 4 feedholes per row. As the bricks in front of the zone being fired reach a suitably high temperature, i.e. hot enough to ignite and burn the fuel which is being dropped in, a new row of feedholes may be taken on. By this time, the feedholes at the back of the firing section (where the bricks have been adequately burnt) can be closed off, and the fires move forward. In practice, the holes in the centre of the row are often ready to be taken

Figure IIIL. 'Roofless' Hoffman kiln - Botswana.



The kiln has a fixed metal stack (chimney) with fan induced draft. The outer walls are brick skins with earth infill. Note the subsidence on top of the setting which was originally level with the top of the walls. Measuring the amount of subsidence of the setting is a method sometimes used to judge the effectiveness of the firing. The feedholes can be seen in the foreground.

Figure IIL. Bull's Trench kiln near Roorkee, India.



A.

B.

A. shows one side of the kiln and two of the flue entries can clearly be seen in the centre section.

B. shows the twin chimneys with the men to left and right giving some idea as to scale.

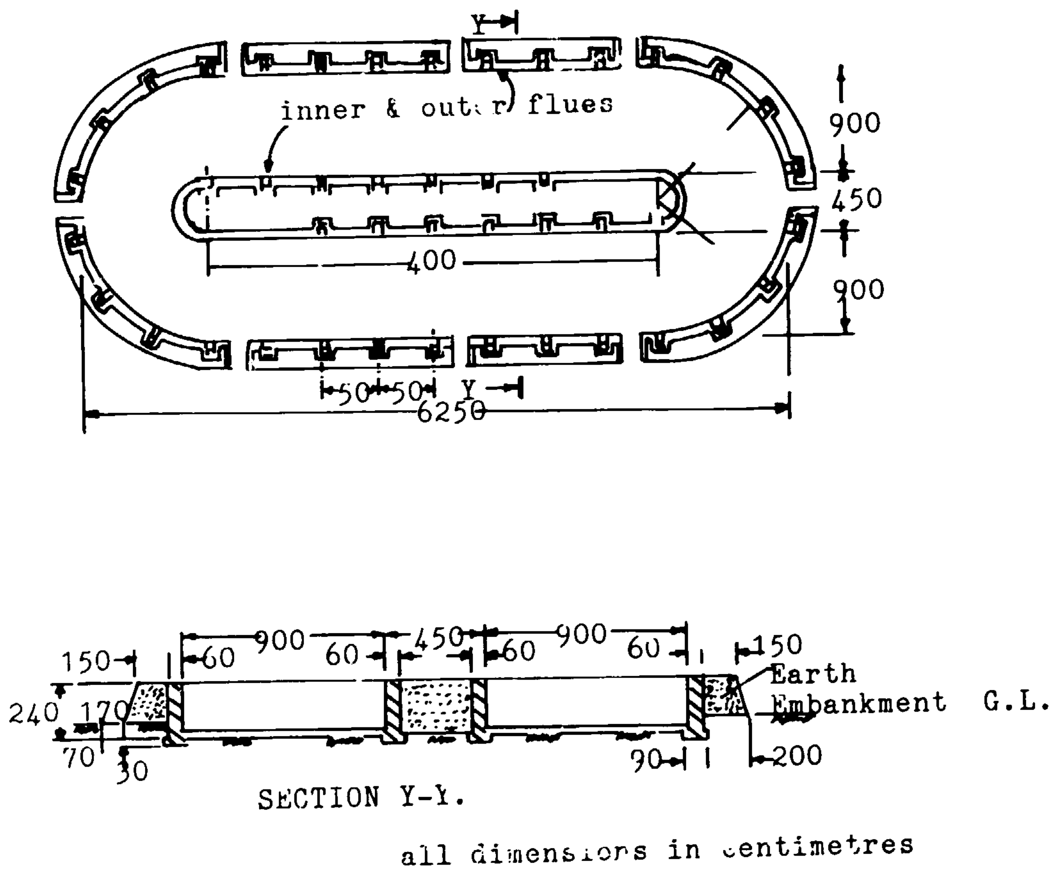
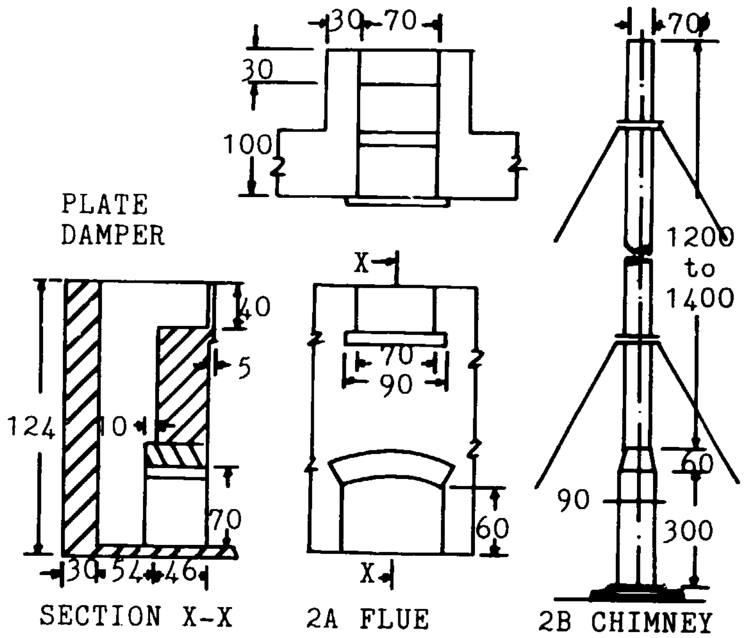


Figure IL. Details of Bull's Trench kiln. (after Sedalia).



all dimensions in centimetres

FLUE AND CHIMNEY.

Figure L. DETAILS OF FLUE AND CHIMNEY FOR BULL'S TRENCH KILN. (after Sedalia.)

on before those at the sides, and the fires may move forward in a 'V' formation. The rate of fire travel is dictated by the fuel and how well it burns, the kiln loading, and the nature of the clay from which the bricks are made. When new feedholes are opened up, the rate of feeding is kept low - otherwise the fuel does not get a chance to burn properly in these lower temperature areas. As the temperature rises, the rate of fuel consumption increases and heavier, more frequent firing is possible. Where solid fuel such as coal is being burnt, larger pieces of coal will fall to the bottom of the kiln to complete the burning there, whilst fine particles will burn near the top of the kiln. This gives rise to the possibility of different temperatures between the top and bottom. By choosing well graded fuel, some measure of control is possible such that more even temperatures can be maintained from top to bottom of the kiln.

Most kilns have individual characteristics due to variations in their individual construction, the nature of the raw materials being fired in them, and their physical location, e.g. altitude. This affects the details of the firing from a kiln which may be located at sea level in a humid coastal situation, and a similar kiln which is located at a higher altitude. The nature of the bricks also affects kiln operation and regularity of firing. A kiln should have a charge (bricks) set in a regular pattern each time it is fired. The actual pattern may vary for different types of bricks or tiles, or for different raw materials, but it should otherwise be regular. The spaces between the bricks are an important part of the 'internal flue' system of the kiln, since these spaces permit or obstruct the passage of the combustion gasses. Crudely shaped bricks are almost impossible to set in a regular pattern, and very difficult to set such they are stable. If the spaces between the bricks are irregular, it may be expected that the quality of firing will also be irregular.

The clamp or field kiln is probably the easiest to set up and fire. It is also more susceptible to variations in firing due to weather such that fired bricks can vary considerably from overfired to practically unfired. Since the economics of a kiln is related to the efficiency of firing, including the percentage of good quality bricks obtained from the firing, it is important to take some simple precautions when making a clamp. The setting of big clamps, e.g. one million bricks or more, is a skilled job which has developed to the point where such big clamps, using coke as fuel, are as economical as many continuous kilns. Saleable product from these clamps is often in excess of 95% of the bricks set for firing.

Setting small clamps is relatively easy, but some simple precautions should be taken which will be worthwhile in terms of fuel savings and fired brick quality. Most of the following points apply to all clamps:

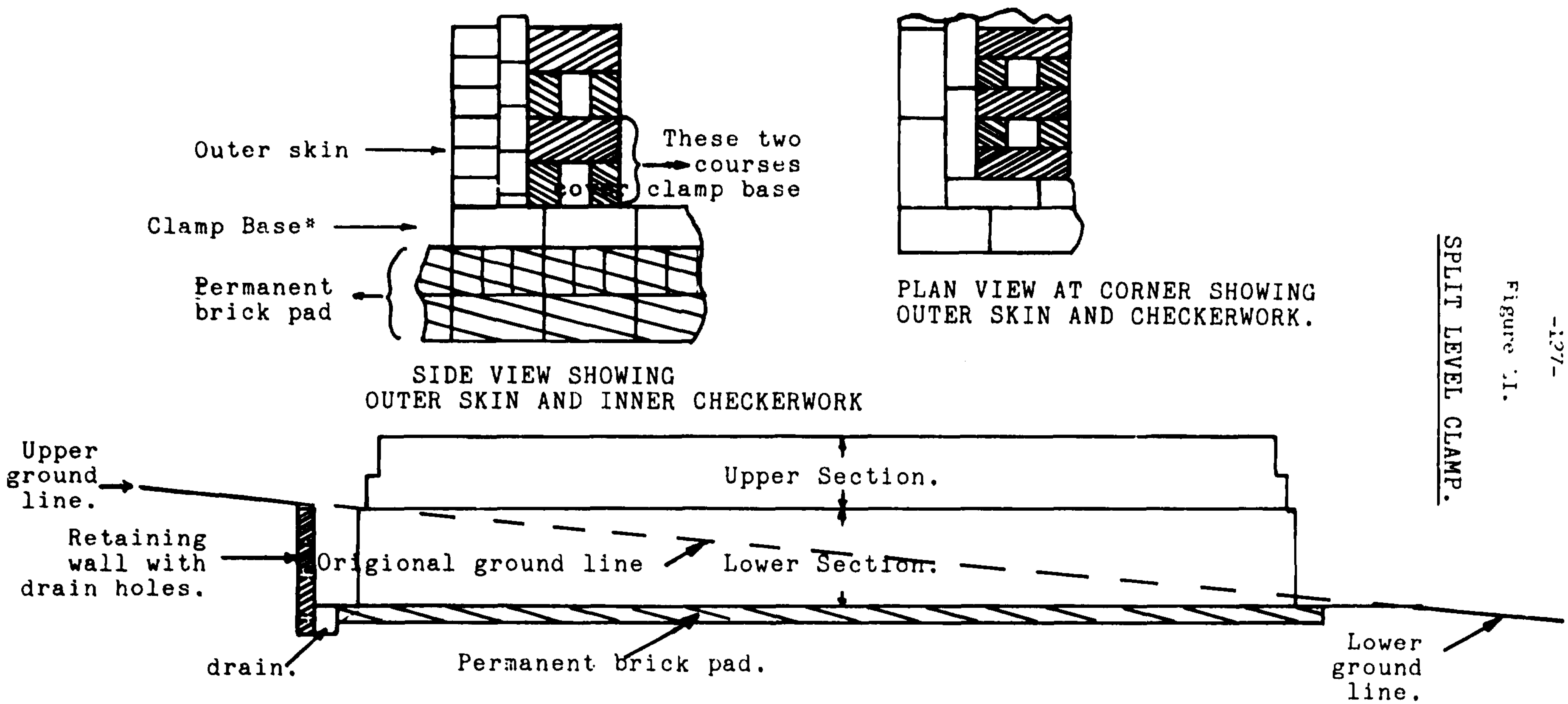
- The site of the clamp must be dry, a slightly elevated site being preferred to one in a hollow or depression.
- If possible, the clamp should be sited downhill from the drying ground such that the transport of bricks to the clamp is made easier.
- A 'split level' site saves manpower and makes loading and unloading easier. However, not all locations are suited to this system.
- Where possible, a foundation of burnt bricks should be laid on which the clamps will be constructed.
- Clamps which have firing channels running through them, e.g. wood fired clamps, should have a baffle wall built in the centre of the firing channels. This will prevent the wind blowing the fire through the firing channel. A windbreak of straw or matting, built around the clamp, will also help to reduce the effects of wind.
- Low quality burnt bricks and/or broken bricks can be kept to build the outer casing of the clamp. This leaves the actual clamp setting for bricks which will be saleable after firing. It is a waste of time and money to set broken and low quality bricks inside the clamp if they are such that they will not be saleable even if they do get well burnt.
- The wood used for wood fired clamps may be green wood for the first 24 hours of firing. This slows down the temeprature rise and permits the bricks to dry slower, i.e. final drying and such that steam damage is minimized. After this initial stage, only dry wood should be used since this has more available heat than green or wet wood.
- Larger clamps are more efficient in terms of fuel consumption and good bricks produced than are smaller clamps.

Figure LI. shows how an existing slope has been utilized to construct a split level site where the clamp is built in two stages. The lower section is built first, planks are laid across the gap between the retaining wall and the top of the lower section such that the bricks can be carried, e.g. on wheelbarrows, across the lower section to the far end and the upper section is then constructed, working backwards towards the upper ground level. This saves the extra time and labour need to throw bricks up to the upper level, reduces the handling of the bricks, and the loading method can be reversed for unloading. Also shown are some details of the outer wall. The outer skin comprises a layer of bricks set on edge, and on the outside of that is another layer set on flat. Immediately inside this outer skin is a checkerwork of bricks which acts as an insulating barrier between the hotter inside of the clamp and the cooler skin. The checkerwork can also be filled with fuel to increase the heat on the outer sections of the main setting.

Figure LII. shows the plan of the ground course of a wood fired clamp. The width is limited to 6 metres such that the logs of wood can more easily be pushed into the fireholes. In the middle of the fireholes are baffle walls which help prevent the wind blowing the fires through. The length of the clamp is only limited by the number of bricks available to be set. With smaller clamps, the width might be less than 6 metres. In Fig. LIIB. an actual clamp under construction can be seen. It may be noted that the layout is slightly different from the diagram above, and in practice, different brickmakers build their clamps according to traditional methods. With bricks of poor shape, as is often the case unfortunately, the bricks must be set close together to get a stable setting. In any case, the poor shape of the bricks effectively leaves spaces between them such that the combustion products can pass up through. With bricks of good shape, it helps to set the bricks above the fire channels in an open setting with spaces of not more than 10 mm between the stretcher faces. The top three courses are set in a close packed setting. The outer casing of these clamps is usually covered with mud which acts as a seal. Figures LIII. and LIV. show sections of a wood fired clamp, and of one which has the fuel mixed in the clay body.

Figure 11.

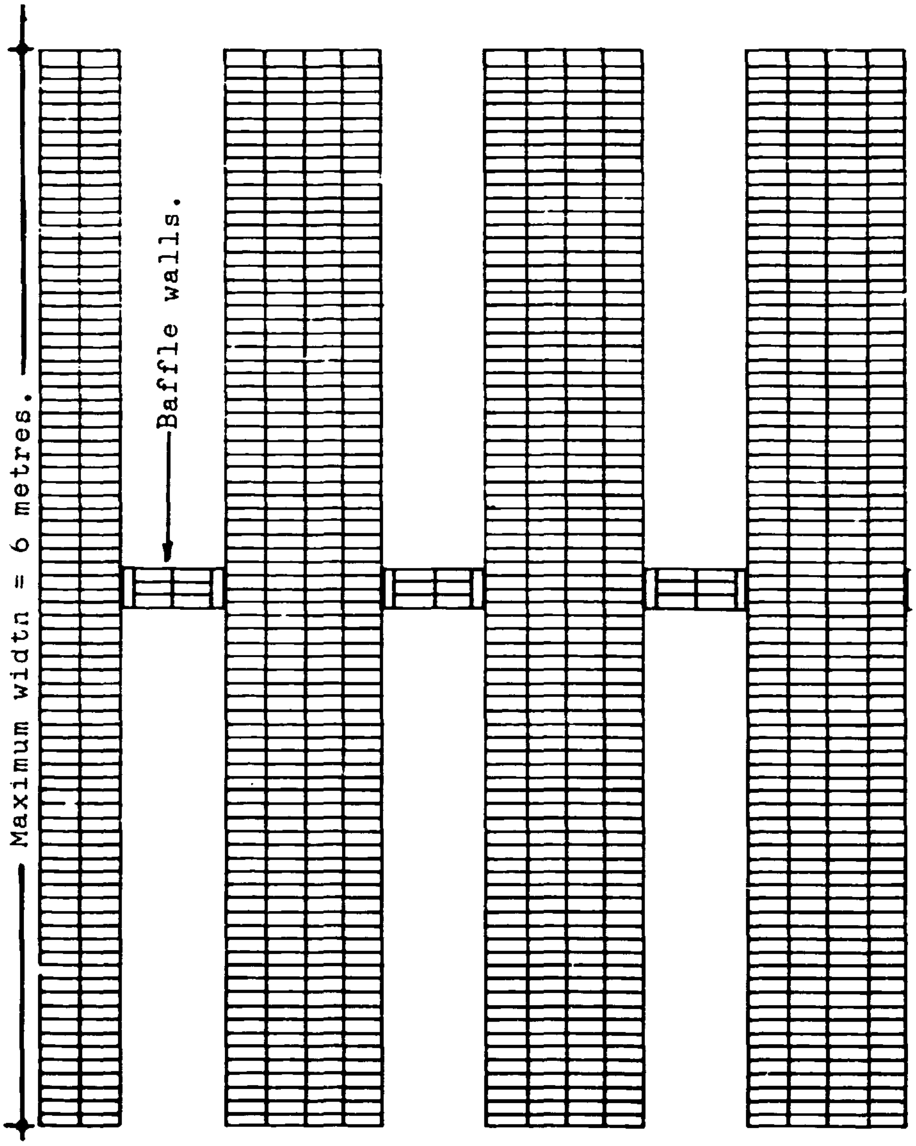
SPLIT LEVEL CLAMP.



* the clamp base bricks are spaced not more than 10mm apart to allow air into the clamp. This applies to clamps set with bricks which have fuel mixed with the clay body, not to 'externally' fired clamps.

Figure LII.

WOOD FIRED CLAMPS.



A.

Plan view showing Layout of bricks for first course of setting.

The side view of fireholes can be clearly seen in the photograph below. A checker-work base would not be used in this case, but the checkerwork could be included in the side walls as shown in Fig. 55.

B

Partly completed clamp. The alternate header and stretcher courses can be seen in the main setting, which also tapers in as it rises to maintain stability.

Figure LIII.

PART OF WOOD-FUELD CLAMP SHOWING FIREHOLES.

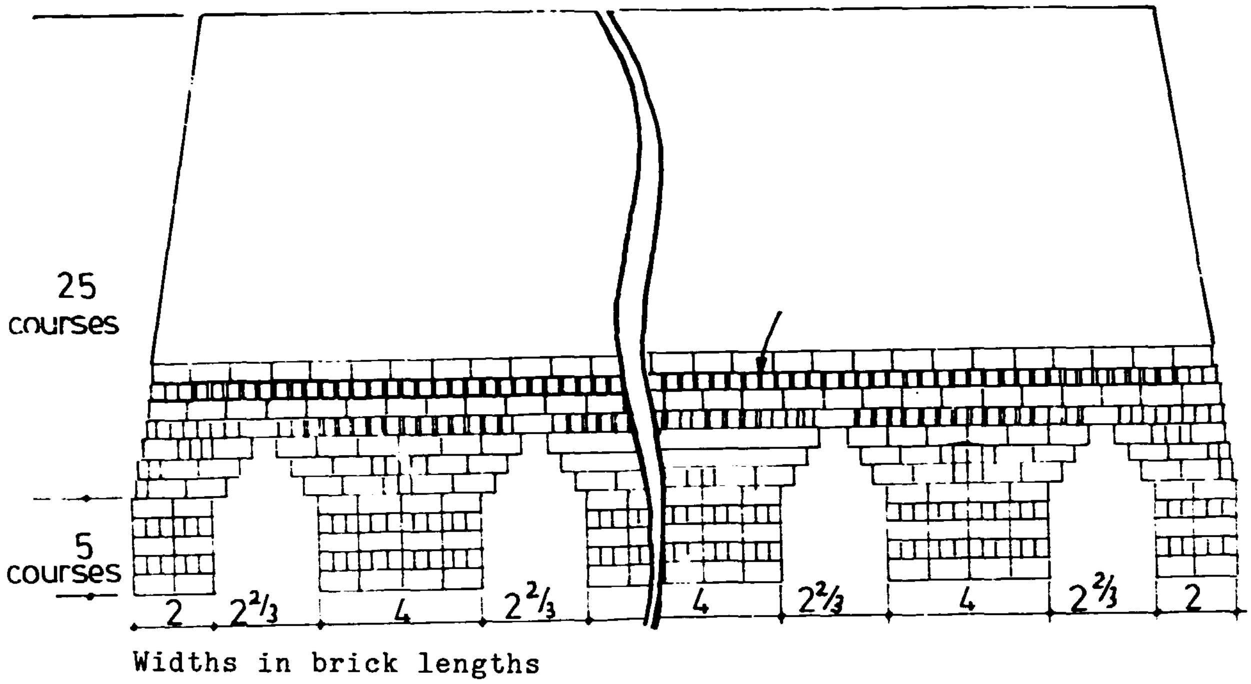
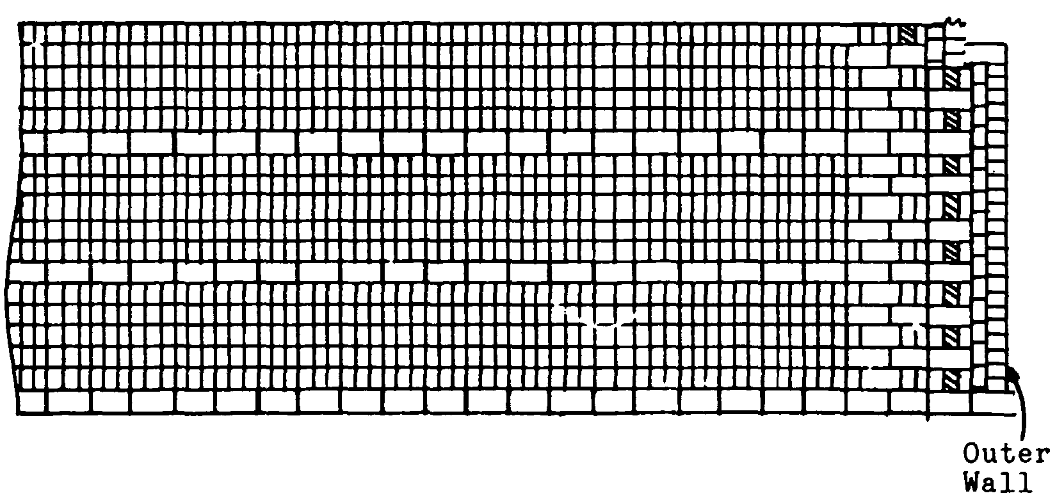


Figure LIV.

SECTION OF SETTING OF CLAMP
HAVING BRICKS WITH FUEL IN MIXTURE.



The Zig-Zag kiln was developed to use a smaller kiln on the same pricipal as a Hoffman, such that more efficient continuous firing could be achieved using a high rate of fire travel in a zig-zag path through the chambers. The C.B.R.I. in India has proposed a zig-zag type as being more efficient than the Bull's Trench kiln, and much cheaper to construct than a conventional Hoffman kiln. Their "Project Proposal No. 19" has this to say about the kiln:

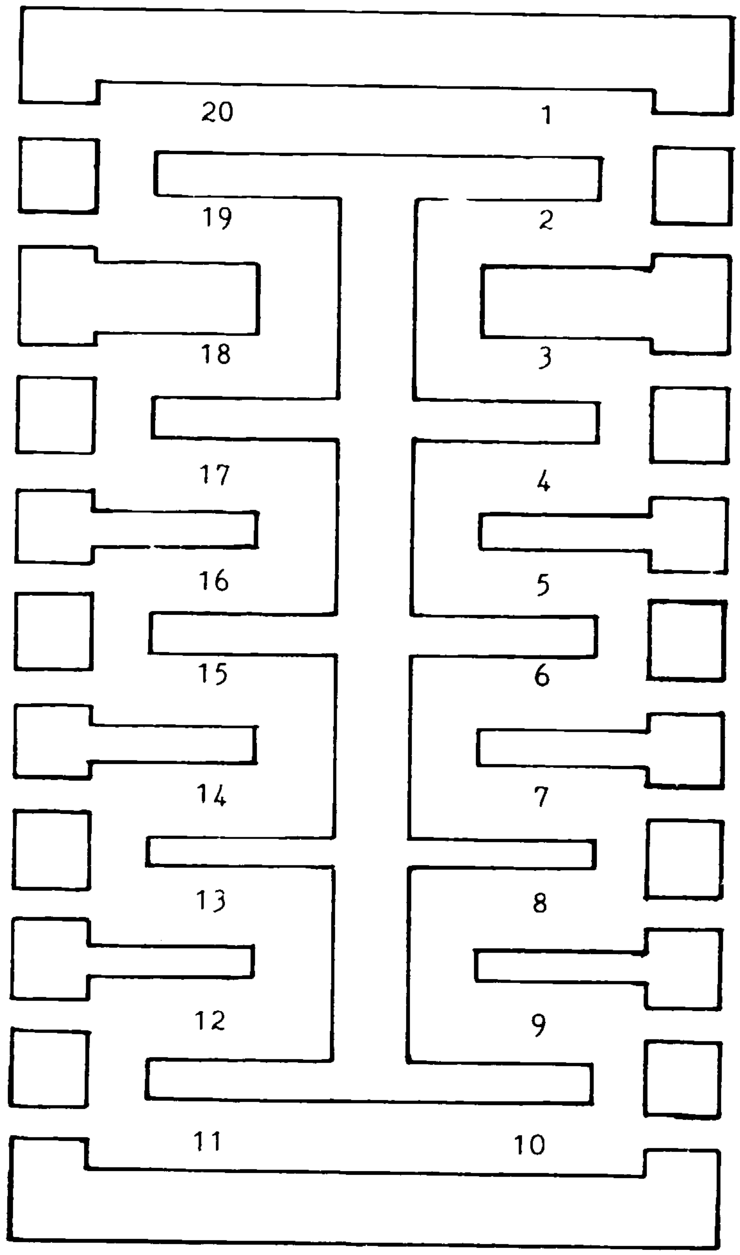
> "Basically, the kiln (Fig.3) is an archless, top fed, coal fired continuous kiln in which the fire follows a zig-zag path. The setting area is divided into a number of chambers by partition walls. The partition walls are built with unfired bricks and are dismantled at the time of unloading the bricks from a chamber. About 7,500 bricks can be loaded in each chamber and a daily output of 15,000 bricks can be secured. Similar kilns of enlarged dimensions can be designed for burning up to 30,000 bricks per day."

The Project proposal also considers that a kiln with a daily output of 20,000 bricks per day would be the smallest economic unit. A model of the kiln is shown in the photograph in Figure XVI.

If the Bull's Trench kiln can be considered to be a low cost example of the Hoffman kiln, the zig-zag kiln referred to above could be considered a low cost example of the original zig-zag kiln and similar to the Habla kiln which also used unfired bricks to make the inter-chamber walls and had a temporary roof of two or three courses of bricks laid on flat over the main setting. Zig-zag kilns may have as few as twelve chambers, but could also have as many as 28 chambers with an output of 250,000 bricks per week, which might be commons, facings, or engineering bricks (Ref: 3.). The basic plan view of a 20 chamber kiln is shown in Figure LV.

Figure LV.

ZIG-ZAG, OR BUHRER, KILN SHOWING CHAMBER LAYOUT.



In this type of kiln the high rate of fire travel usually necessitates a fan to produce high draft. This makes it necessary that the bricks should be dry before setting.

IX. FUELS.

Most fuels are substances which, when raised to combustion temperature in the presence of air, will combine with the oxygen of the air with the evolution of heat. Some clays contain organic or carbonaceous matter which can substantially reduce the amount of fuel used in firing. Common fuels used in brickmaking are wood, charcoal, coal, coke, oil, gas, and various agricultural by-products. Where gas is used, it is normally natural gas, but there are some instances where liquid petroleum gas might be used. The main determining factors are suitability of the fuel to raise the temperature high enough, cost of fuel per tonne of burnt bricks, and availability. Agricultural by-products could perhaps be used more widely if suitable feeding methods were better developed to get sufficient material into the fires. The low bulk density of materials such as coffee hulls makes it difficult to feed them by hand.

The easiest fuels to use are probably coal, coke, oil, and gas. They are concentrated sources of heat and their application in firing is relatively simple and controllable. Next to these would be wood, which has a lower heat content, but also has the greatest potential to be replaced. According to one report (Ref: 4.) eightysix per cent of all the wood consumed annually in the developing countries is used for fuel, and half of this is used for cooking. However, critical shortages are being experienced and even from the author's own observations, the situation could be considered extremely serious. Whilst governments in many countries are actively engaged in promoting tree planting, much more could be done if funds were available and concentrated on the most efficient ways of developing firewood crops. The report referred to above proposes the development of selected trees and shrubs, but notes that because they are aggressive and of quick growing nature, they should be introduced with great care.

Coal may be used to feed the fires manually, or it may be fed through automatic stokers which can be set to various feed rates according to the needs of the kiln at any particular time. These stokers can be of a type that feeds under the fire, over the fire, or from the top of the kiln such as in the Hoffman kiln. They are usually more economical in fuel consumption than manual feeding, but the capital costs of installing an automatic feeding system should be ...fully considered. The benefits of automaic feeding may include better quality bricks being produced due to better control of the firing process, but in other cases this may not be of major importance.

Different types of kilns and feeding methods will require different types and sizes of coal. For example, hand feeding might use coal up to about 100 mm size, with smaller coal of about 20 - 50 mm size being used when reaching top temperature. Top fired kilns would use smaller coal than for hand feeding, 5 mm to 25 mm size, but it should be graded such that much of it burns as it drops through the kiln. High volatile coals are preferred in top fired kilns. The temperature at which the ash forms clinker is important since the clinker may stick to the bricks in top fired kilns, or block the grates in grate fired kilns. The cost of coal landed at the brickworks is an important factor. This cost should be judged on the heat capacity or calorific value of the coal, since some high grade coals which are more expensive in terms of (say) dollars per tonne can be the least expensive when the cost at the brickworks is compared on the basis of heat content.

Both coal and coke can be used to mix with the clay body, especially for clamp firing, but to a lesser degree in some other firings in kilns. The coal or coke should have a particle size below 5 mm, but very fine dust is often not suitable. Coal ash, e.g. from power stations is sometimes a useful fuel although it has a low heat content. Charcoal is also a possible fuel, but the price is generally too high for it to be economically used.

Wood is a fuel which is much misused! Many brickmakers use green or wet wood simply because it is more easily available that way. It is also preferred at the beginning of a clamp firing because the rise in temperature is retarded and this is necessary in the initial firing stages. However, the same logic will show that when higher temperatures are being aimed for, the green wood will still retard the rise in temperature. After the initial drying period, usually about 24 hours in wood fired clamps, only dry wood should be used for the firing. This not simply reduces the amount of wood required, but by doing so acts as a conservation measure.

The following table may be of some use in comparing the heating values of some woods with coal. It will be seen from the table that there is a substantial difference in heat content between green wood and air dried wood, in this case the average difference being about 9.5%, and this would be greater if the comparison were made between green wood and dry wood, since air dry wood still contains an appreciable amount of water. It can also be seen from the Table that the woods with the highest densities have the highest heat contents, and this can be used as a guide when choosing wood fuels. It is better to buy wood by weight rather than by volume, if this is possible.

Table 2. Heat content of some wood fuels compared with coal. (Ref: 5.)

Variety of wood	Weight per cord, lb.		Available heat units per cord, millions B.t.u.*		Equivalent in heat value to tons of coal**	
	Green	Air Dry	Green	Air Dry	Green	Air Dry
Ash, white	4,300	3,800	19.9	20.5	0.77	0.79
Beech	5,000	3,900	19.7	20.9	0.76	0.79
Birch, Yel.	5,100	4,000	19.4	20.9	0.75	0.80
Chestnut	4,900	2,700	12.9	15.6	0.50	0.60
Cottonwood	4,200	2,500	12.7	15.0	0.49	0.58
Elm, white	4,400	3,100	15.8	17.7	0.61	0.68
Hickory	5.700	4,600	23.1	24.9	0.89	0.95
Maple, sugar	5,000	3,900	20.4	21.8	0.78	0.84
Maple, red	4,700	3,200	17.6	19.1	0.68	0.73
Oak, red	5,800	3,900	19.6	21.7	0.75	0.83
Oak, white	5,600	4,300	22.4	23.9	0.86	0.92
Pine, yellow	....	....	21.1	22.0	0.81	0.85
Pine, white	....	....	12.9	14.2	0.50	0.55
Walnut, black	....	....	18.6	20.8	0.72	0.80
Willow	4,600	2.300	10.9	13.5	0.42	0.52

* B.t.u. per pound = 2.326 kJ/kg.

** Short ton (2,000 lbs) having a heating value of 13,000 B.t.u./lb.

Agricultural by-products have uses as compost and as sources of fuel in processing plants associated with their production. For example, bagasse is used by sugar processing plants. Even so, there is often a surplus which may be available to brickmakers. Where the material has a low bulk density, it may not be economic to transport it any great distance, unless some way of compressing it can be utilized. Where the material is in a finely divided form, such as rice and coffee hulls, only limited amounts can be added to a brick mixture. Fine material could be fed into kiln fireholes but it would be better if it could be made into pellets or briquettes first, or fed through a suitable stoker. sawdust can be mixed with clay, probably not more than 10% by volume being acceptable, or it can (if dry) be fed into kiln fireholes. However, sawdust burns slower than coal and may not be suitable for live grates. There would seem to be a good case for using more of these products during the early stages of firing when the rate of fuel consumption and temperature rise is slower. Experience with using sawdust between the setting of bricks in clamp has not always been satisfactory since, in some cases, it did not burn and blocked the passage of other combsution products from passing through the ware. Even dried grass and rushes can be used as fuel, being tied into bundles and fed into the fires.

X. MARKET DEVELOPMENT.

The term 'market' as used here, refers to all those people to whom the bricks are sold plus all the people to whom bricks could be sold. In the latter case, the people might not know that they want bricks, or there may not be bricks available of a type and quality which they want. It is up to the brickmaker to keep his present customers supplied and satisfied, and to educate the other section of the market (those who do not yet know that they want bricks) such that they too will buy bricks. We shall differentiate between the two sections of the market by calling one the existing market, and the other the potential market.

Marketing is the activity which brings the brickmaker and his customers together. It involves getting the potential market to buy his bricks as opposed to buying alternate building materials, and this means that the brickmaker must make what the customers want. It is by developing the market, by intelligent marketing, that the brickmaking business develops and expands.

The existing market, and perhaps the potential market, is what the brickmaking facility has been designed to serve. It is the estimated market size that limits the size of brickmaking facilities - but it is also, sometimes, the imagination and knowledge of the brickmakers which limit the real size of the total market. The limitations of product type and quality, locations of producers versus users, and designers who are prepared to specify burnt bricks, are all important factors in determining the actual, if not the potential, size of the market. The potential market will grow as population grows, and as development and investment increase. It is important therefore to continually bear in mind the following points:

- Many people are not aware of, or have mistaken impressions of, the benefits of burnt clay bricks. They should be made aware of this at every opportunity.
- Quality should not simply be maintained, but should be improved upon continually.
- production costs and production efficiency should be examined regularly with a view to reducing costs and improving efficiency. In this way, stable

prices and reasonable profit margins can be maintained. Competitiveness against other products can also be maintained or improved upon.

- Wherever possible, government or local authorities should be encouraged to sponsor courses for designers and artisans. The quality of design and efficiency of construction are as important in developing a brickmaking industry, as is the actual process of brickmaking.
- Brickmakers should, wherever possible, form associations to stimulate co-operation amongst themselves. This does not prevent competition, but by improving themselves as an industry, they help to develop better market opportunities.
- Continual contacts should be maintained with the people who use the bricks, such as builders; with the people who specify their use such as architects; and with other concerned people in government and the various private sectors. This even includes the people who live and work in building made of brick, to [illegible] what satisfaction or disatisfaction they might have with the bricks.
- Complaints should always be investigated to see how future complaints can be avoided. Not all complaints are reasonable, and not all reasonable complaints can be satisfied, but every effort should be made to satisy the customer. Every satisfied customer should be looked upon as being several customers - the one whom you have satisfied plus those he recommends because he is happy with your product.
- The source of raw materials should be checked in advance to make certain that there is enough for continued production. Where the raw material source is limited, new sources should be found and proven with respect to quality before the old source is finished.
- Where there are national standards for bricks, the brickmakers should make themselves familiar with these standards. They should also liaise with the national standards institution to ensure that the standards are reasonable, and to seek assistance in meeting specifications.

Marketing, it has been said, is not directly involved with actual production. It is a broad enough subject to deserve recognition as a field of operations in its own right. This is true, but most brickmakers in developing countries have to be a mixture of production manager, technical manager, sales manager, and marketing manager. They may have to supply their own finance without recourse to banks or other lending institutions. As individuals they have limited access to technical assistance, and few of them can afford advertizing campaigns. Thus, it is in developing the potential market that most brickmakers have problems. Sometimes this may be in understanding the concept of marketing, more often they simply do not have the knowledge and access to the right people to develop this sector of the market. In most developing countries the potential market is much larger than the existing market, therefore it is of paramount importance that efforts be made to develop this sector. Where the brickmakers are having problems in this area it may be that they can get assistance through their local or national government. Where a national government does not have suitably qualified staff of their own, they can usually get assistance from international sources or through the private sector.

In considering marketing, it is essential to have at least one product, but preferable several, to sell. It has already been pointed out in Section IV. 'Mixing, Forming, Drying' that a variety of surface effects can be achieved fairly simply, e.g. by using different sands when using the sand moulding process, or by using mixtures of different clays to get different coloured bricks. These methods are the first to be considered since they can be implemented without any great capital or operating cost being involved.The following list gives some of the relatively simple methods which can be used to increase the range of products:

- Use of different clays, which fire to different colours or which makes it possible to produce bricks of different quality.
- Use of different facing sands to give different colour effects on the face of the bricks.
- Addition of mineral based powders to the clay mixture such that a different coloured brick is made. For example, managanese dioxide powder will change the colour to a brown or black, according to how much is added. Other powders are added to the facing sand to get similar types of effect.
- Sand faced bricks are a useful alternative to slop moulded bricks, and by simply making both types the customers have a choice of product.

- By scratching the surface of the bricks, using a form of metal or wooden comb, a textured effect can be achieved. This may have to be done when the bricks have dried somewhat such that they can be handled, and care should be taken not to deform the bricks in the process. With extruded bricks, a similar effect can be achieved by scratching the face and ends of the bricks as they come out of the extruder die.
- The use of different coloured mortars gives different effects to the apparent colour of the bricks in a building. This may be a job for the builder rather than the brickmaker, but it is worthwhile remembering.

The main point is that, by simple methods, it is possible to get a range of products which will appeal to different sectors of the market.

A practical example of product diversification, developed to satisfy the widest possible market, is the state of Western Australia which is possibly the biggest per capita manufacturer and consumer of burnt bricks in the world. The brickmakers there sponsor training not only to artisans but also to the general public who buy bricks for 'self help' home construction and improvement, inlcuding paved driveways and courtyards. One company had the following range of bricks available, although it should be noted that the names for each product line are devloped by themselves:-

Utility bricks	Commons seconds (when available)
Mexican (wire cut face)	Cream, Hawaiian, Napoli, Dallas, Venetian Bronze, Antique Silver, Bahama Beach, Pompeii.
Barkface	Red, Cream, Coral, Moroccan Leather, Chestnut, Chocolate.
Smooth Face Bricks	Red, Hawaiian, Cream, Colombia, Venetian Bronze, Antique Silver.
Texture Face	Heritage.

Ranch Style (rumbled)	Antique Silver (smooth), Antique Silver Mexi Cut, Bahama Beach Mexi Cut, Cream Mexi Cut, Napoli Mexi Cut, Dallas Mexi Cut, Venetian Bronze Mexi Cut, Pompeii Mexi Cut.
Clinker Bricks	Red, Brown.

In addition to the above, the company* produces paving bricks and tiles, modular sized bricks, air-vent bricks, and a range of simulated handmade bricks. Although their process is now modernized, they started off with relatively simple equipment and firing in simple updraft kilns. The success of this company has been an inspiration to many brickmakers, and they provide a singular example of market development and education. It may go without saying that a great deal of hard work, and faith in what they were doing, also played a great part in their success.

*Midland Brickworks, Middle Swan, Western Australia

Appendix I.

Equipment List.

The list of equipment is simply given as individual items which would be useful or necessary to test clays by the methods given in this document. It has been assumed that laboratory facilities already exist. Where such facilities do not exist, professional advice might be sought on the setting up and equipping of a clay testing laboratory. It is likely that UNIDO could assist in this respect.

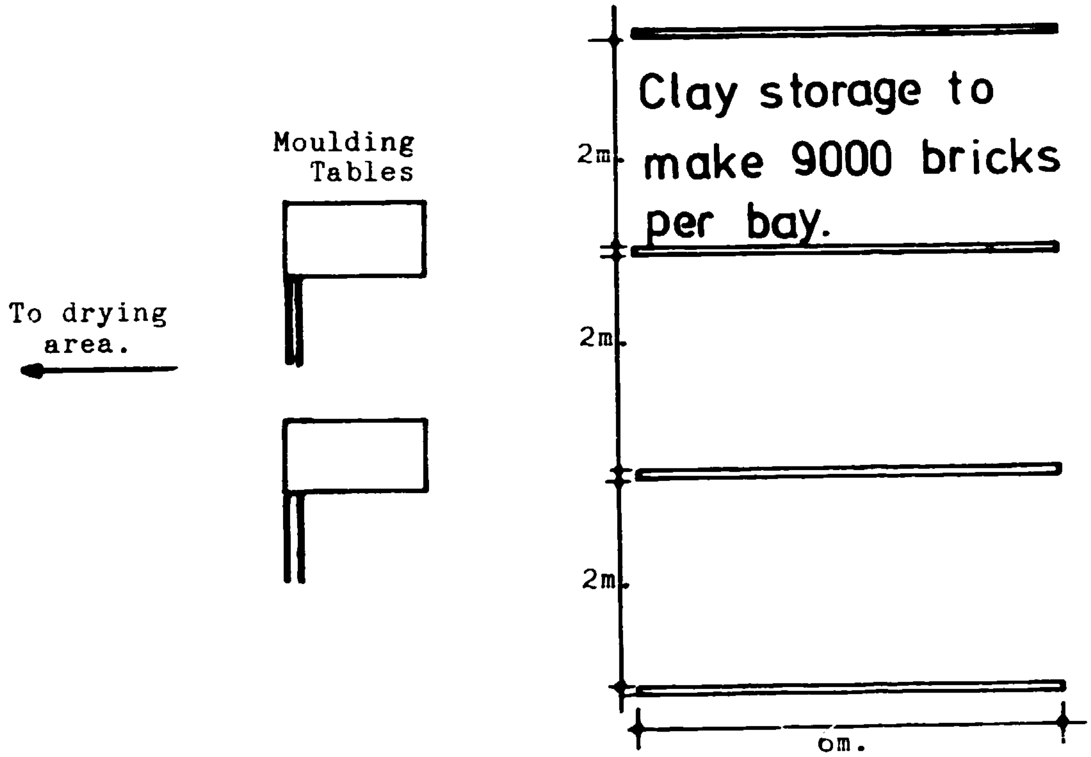
1. Riffle sample splitter.
2. Steel mould, open top and bottom, internal size might be 80 x 40 x 25 mm deep. The mould could be made from 5 mm steel plate, but the inner faces should be ground or filed smooth. There is some merit in having the internal mould size in proportion to the size of the full sized bricks which will be made or which is the national standard.
3. Drying oven, ventilated, internal fan circulation, thermostatic control with an operating range between ambient and 120° Celsius.
4. Vernier caliper gauge large enough to measure test briquettes, reading to nearest 0.02 mm.
5. Desiccator, with suitable desiccant.
6. Balance, analytical, weighing to 100 grams, by 0.0001 gram.
7. Balance, weighing to 150 grams, by 0.01 gram.
8. Beaker, tallform, 800 ml, stainless steel.
9. Standard sieves (e.g. to British Standard 410), nesting, with cover and receiver set. Aperture sizes 2.8 mm., 500μ, and two at 75μ for basic sieve testing. Where more comprehensive sieve tests are required the appropiate sieves will also have to be ordered, with all sieves of aperture size less than 500μ being in stainless steel.
10. Sieve vibrator.
11. Low powered binocular microscope.
12. Mixing bowl or dish, about four litre capacity.
13. Muffle furnace, with temperature controller, capable of operating at 1,200°C. If electric, it is preferrable that the elements are wound round the muffle to give heating from all four sides.

Appendix II.

Brickworks Layout.

The design of a brickworks takes into account the many factors of raw materials, type and production level for the various bricks to be made, availability of capital and operating costs, technical and managerial skills, etc. The simplest case may be one person who does all the operations and produces a few thousand bricks each month with the help of his family or friends. At the other end of the scale there are the two alternatives, of a labour intensive brickworks making 40,000 bricks per day or more, and a small scale mechanized brickworks making upwards of 8,000 bricks per day.

The following two Figures give layouts for small operations, one of which uses a double shafted mixer for mixing the clays. In both cases the bricks are made by hand. In Figure LVII. it can be seen that there is provision for further mechanization, which might take the form of an extruder and cutting table. Most equipment suppliers will give some guidance on the layout of particular brickworks, although it should be borne in mind that their prime objective is to sell their own equipment. Professional advice should be sought for any larger brickmaking facility, such that an objective opinion can be obtained regarding both design and equipment.



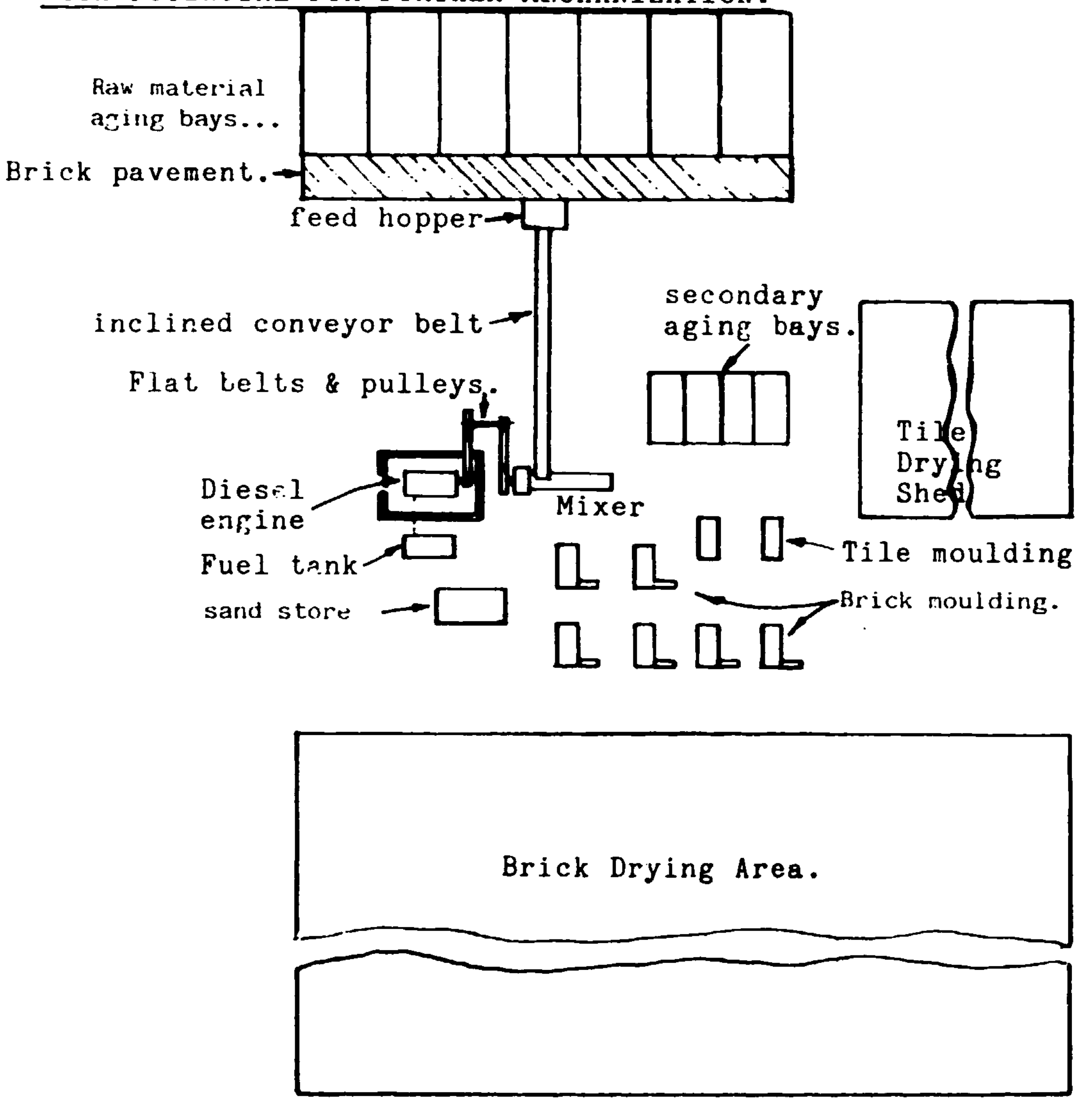
Using tables, as opposed to pits, means that the job of moulding is cleaner and dryer for the moulder. This applies particularly to slop moulding.

The use of aging bays has several advantages. In addition to providing better quality material, the bays act as surge hoppers or storage bays such that delays in clay digging need not stop production. If a cover is provided over the bays, production can still go ahead in wet weather.

Figure LVI. Hand moulded bricks, two moulder's tables using clay from aging bays.

Figure LVII.

PARTLY MECHANIZED SET-UP FOR PRODUCTION OF HAND MOULDED BRICKS AND TILES WITH POTENTIAL FOR FURTHER MECHANIZATION.



The brick drying area might be open, with drying lines, the exact size of which will depend on actual output, climate, etc. Alternately, a drying shed could be used.

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