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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

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Development and Transfer of Technology Series

No. 10

BRICKMAKING PLANT: INDUSTRY PROFILE

UNITED NATIONS

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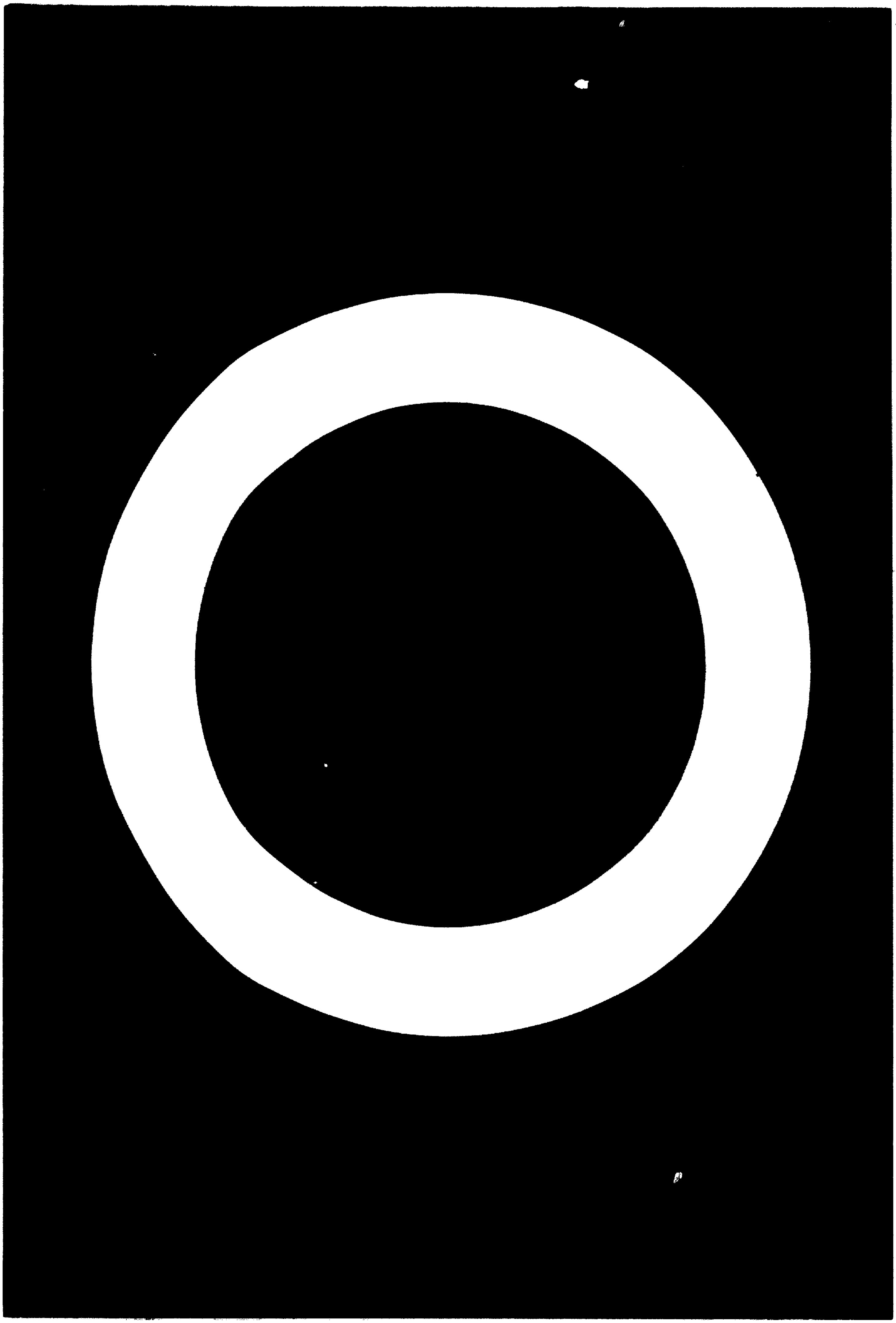

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Preface

In pursuance of its mandate, the United Nations Industrial Development Organization (UNIDO) is promoting the development and transfer of technology through technical assistance, studies, expert group meetings, seminars, training programmes and information services.

One of the main goals of these activities is to strengthen the technological capabilities of developing countries and particularly to assist them to choose the technologies appropriate to their conditions and their priorities and plans. Towards this end, UNIDO is preparing several industry profiles. This study, the first of these profiles, is being published in the *Development and Transfer of Technology Series.*

The intention is to provide the reader—an entrepreneur, national or regional decision maker concerned with planning, perhaps even an investor or an investment institution—with sufficient basic information on all the important parameters involved in setting up and running a mechanized brickmaking plant. The study discusses the available processes; main equipment involved; material used; space, energy and utilities; manpower (number and type) needed for a given capacity; the size of the investment for a specific production; and an idea of product costs.

The present profile deals specifically with mechanized brickmaking technologies; it describes plants with a minimum annual production capacity of about five million standard bricks. It will be followed by another UNIDO profile addressed to the reader more interested in labour-intensive, semi-mechanized or manual brickmaking technologies suitable for rural conditions.

This study has been prepared by Ian Knizek, expert in the manufacture of ceramics, Mexico, D.F., as consultant to UNIDO.

Explanatory notes

References to dollars ($) are to United States dollars, unless otherwise stated.
References to "tons" are to metric tons, unless otherwise specified.

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I. Factors to consider in establishing a brick plant

Brick as the ideal building material

At its price the clay brick is one of the most versatile and useful of building materials. Structures built of brick have "liveable" interiors. This quality of "liveability", very difficult to define, is the result of a combination of characteristics that other building materials do not possess. Brick walls breathe, as is frequently asserted, because the open pores of bricks are large enough to permit the passage of water vapour and air but so small as to impede penetration of rain water.

Sand-cement blocks, which frequently undersell bricks, permit rain to pass through because most of their pore system is composed of open capillaries. This is a serious handicap, especially in tropical countries, where the onset of hot weather after a heavy, slanting rain frequently converts interiors into veritable steam baths.

Bricks possess remarkable heat and sound insulating properties, again the result of their unique system of pores, which only fired earth develops. Either of these insulating properties may be controlled and further improved by providing the bricks with the right number of perforations of the right size and distribution. The mechanical strength of bricks is usually above that required for normal dwellings. In fact, even multistorey buildings may be constructed from bricks set with their extruding direction parallel to their vertical axis. Just about the only disadvantage is their relatively low resistance in tension, a property they share with other ceramic products. But even this drawback has been corrected in the fabrication of prestressed beams combined with reinforcing steel rods and a little cement.

A brick is usually defined as a rectangular shape of fired earth, the width of which can be spanned by one hand. Its length is normally twice the width and the height little over half its width. Accordingly, the approximate dimensions of the early bricks were as follows (mm):

France	220 x 110 x 60
Germany, Federal Republic of	240 x 115 x 71
Italy	250 x 120 x 55
Switzerland	250 x 120 x 60
United Kingdom	277 x 110 x 66 (9 in. x 4 3/8 in. x 2 5/8 in.)
United States	202 x 95 x 57 (8 in. x 3 3/4 in. x 2 1/4 in.)

Although some solid bricks are still being manufactured, most of them are "cored", that is, provided with perforations in varied sizes and shapes. Annex I shows the forms and perforations used in the Federal Republic of Germany. Unperforated bricks have three disadvantages: *(a)* the heat and sound insulating value is low; *(b)* they are not water-resistant; and *(c)* they are expensive to lay. In fact, it was discovered that these standard bricks required four times as many man-hours for laying as the largest concrete block, that is, one measuring 460 mm x 230 mm x 230 mm. Consequently, the large, multiple-hole brick was developed. Annexes II and III show the sizes of bricks now used in the Federal Republic of Germany and France.

Characteristics of brickmaking

Brickmaking is frequently considered one of the simplest industrial activities from both the business and technological standpoints. This erroneous impression is probably based on the fact that practically anybody should be able to produce a few reasonably good bricks in his own backyard with a minimum of tools. When machine-made bricks are involved, however, produced at a rate of some 20,000 per day, the situation is far more complicated, as is demonstrated by the relatively high number of failures of brickmaking ventures even in developed countries. Several reasons may be given to explain these failures. First, the margin of profit in brickmaking is rather slim, so that manufacturing and other expenses have to be watched very carefully and kept low by whatever means. Secondly, comparatively huge amounts of materials have to be processed and moved through the plant to produce a decent return. Nevertheless, judged perhaps by different standards, the brickmaking industry is economically a very satisfying industry on account of its high added value, which is exceeded perhaps only by the firebrick industry.

Clays of suitable quality occur in large quantities in many places, and their cost is what it takes to dig them out and to transport them to the brick plant. In fact, an artificially fixed "value" is sometimes assigned to the clay, since it is considered unorthodox to produce a saleable commodity from "nothing" as happens when extraction and haulage of the clay are considered part of the manufacturing process. Before a decision to embark on mechanized brickmaking is taken, several aspects must be examined. These aspects are discussed below.

The market

Reliable information about the market is essential for the success of any business venture and especially so for mechanized brickmaking. Market research must, therefore, be undertaken. Properly conducted market research will not only enable the prospective brick manufacturer to plan his operation in terms of output, but will also tell him something about market trends and the nature of the competition he is likely to encounter. It will also inform him about the problems a competitor (if any) is encountering in his operation or has had to overcome. The prospective brick manufacturer is therefore able to plan his market strategy.

Unfortunately, comprehensive market research is costly and takes a considerable amount of time. For best results, it must be conducted by professionals thoroughly trained in their field. A recently conducted nation-wide market survey for the brickmaking industry in a developing country cost $40,000.

Few private businessmen in developing countries will be willing to spend so much to secure mere information, however important it may be. Furthermore, professionals with the right kind of background for this kind of work are not always available, so that services of an outside organization must be contracted for, which makes market research still more expensive. Fortunately, a wealth of useful information may be obtained even by untrained personnel if they know where to look for it.

The most important source of information is official statistics on the production or importation of building materials, not necessarily bricks. Much can be extrapolated from the consumption of cement, lime, sand and even steel reinforcing bars. Information about past, present and expected building activities is also useful, if correctly interpreted. Statistics are, however, not always available or they may be outdated or unreliable. Information about government building projects may be obtained from ministries or departments of public works or a housing authority. Information about public programmes must, however, be treated with caution, since implementation of programmes or even projects is chronically dependent on funds that are not always forthcoming.

The next important source of data is the private construction firm. Such firms are normally able to provide information about past activities from which future demand may be extrapolated. Finally, dealers and building materials distributors are usually in a good position to estimate present and future demand for bricks, but information obtained from them is unreliable. The bibliography contains a section of useful literature concerned with market research techniques and evaluation of raw data.

Raw material

Prospecting for clay

Clays suitable for brickmaking are, generally speaking, to be found everywhere. That does not mean that they can be converted into saleable bricks by all of the available manufacturing methods. Although a suitable technological process may now be devised for practically any clay, economic considerations may preclude the use of a particular clay.

In prospecting for brick clays, one usually starts from outcrops exposed by landslides, road cuts or creek and river beds.[1] Samples collected from these outcrops may be tested to provide the first indication of the clay's suitability. Again, considerable caution is recommended in extrapolating from these initial results. Properties of exposed surface clay layers, which have been subject to weathering and leaching after exposure, do not faithfully reflect the characteristics of material from deeper strata.

Apart from certain fundamental properties, the most important characteristics of a clay deposit are its size and uniformity. While experienced workers may be able to judge the thickness of clay strata from the configuration of the surface, there really is no substitute for drilling or for exposing the clay strata by sinking shafts into the ground.

Estimating clay reserves is one of the fundamental tasks of the prospective brick manufacturer. Too many ventures have failed because of an unanticipated shortage of suitable clays. When a clay unexpectedly runs out a substitute is almost always found, but its location may not always be favourable; an increase in costs arising from transportation of the clay from a more distant locality may mean the difference between success and failure.

While a single clay is sometimes used, it is more usual to blend several clays to obtain the optimum properties. Another advantage in blending several clays is that the effects of variation in the physical properties of individual clays are minimized and they frequently cancel themselves out. Clay deposits often contain more than one clay. These may be combined to secure the desired properties. Clays from different pits are often used at the same time.

Testing for suitability

Thorough knowledge of the clay characteristics is essential. Information on these characteristics can be obtained only through a series of tests. The results of testing not only indicate whether the quality of the

[1] The procedure to be followed has been described in ID/WG.81/9, pp. 25-28.

clay or clays is adequate for successful use, but also show the type of products that might be manufactured from them. Furthermore, it is the physical properties that determine the technological process to be used in making these products.

Clay testing, even though appearing simple, is in fact a complex matter if reliable information is to be obtained from it. What is even more difficult, though frequently underestimated, is to apply laboratory testing results to factory conditions.

For dependable results, clay must be tested by experienced persons. Since clay-testing facilities are not always available and few clay technologists are to be found in most developing countries, recourse must be had to one of the institutions that test clays commercially. Annex IV lists a few such institutions.

However, one may wish to determine the approximate suitability of a clay before going to the expense of submitting it for testing. A few simple tests can be run with a minimum of equipment usually to be found in laboratories. Certain properties to be tested are described below.

"Stoniness" of the clay (arbitrarily defined as the proportion of hard, unslakable particles larger than 1 mm)

Special attention must be paid to the nature of "stones" or "pebbles" in the clay. They may be similar to slakable clay, in which case they may be reduced to a manageable size by grinding. If their proportion is excessive, they may be eliminated by use of special equipment, which is costly to purchase and to operate. The stones are frequently composed of calcium carbonate, something that is especially important to detect as soon as possible, since such stones are a potential source of grave trouble. Fortunately, these limestone pebbles or accretions are easily distinguished from other harmful pebbles because of their reaction with a weak acid (even vinegar or lemon juice may be used for this purpose), which is accompanied by violent effervescence. Limestone or calcite particles larger than 1 mm may cause lime blowing, which disfigures the fired brick and may even cause it to crack because the individual calcium carbonate particles are converted in the firing to calcium oxide, or quicklime. Quicklime in turn absorbs atmospheric humidity, and the particles, being thus converted into calcium hydroxide, grow and burst open like popcorn. Calcium carbonate particles in small quantities may be rendered relatively harmless by fine grinding.

Not all clays slake, that is, disintegrate in water, and those that do not are not necessarily unsuitable for brickmaking. Quite to the contrary. Some of the finest face bricks are made in the United States of America from shales, and even slates that unground do not exhibit any plasticity at all. Such materials are widely used there, but they require a different processing.

Drying behaviour of the clay

It is important to know whether the clay will dry quickly and safely without cracking and warping. Warping is usually caused by the presence of the clay mineral montmorillonite, which not only absorbs water greedily but absorbs more of it than any other harmless or even beneficial clay mineral. Therefore, the potential for unfavourable drying behaviour can normally be detected by the water content required to develop a given consistency. This information may be easily obtained by means of the Atterberg method, which incidentally, requires no equipment except a spatula and a dish. Montmorillonite-bearing clays are characterized by very high plastic and liquid limits and as a consequence also high plastic indices. Unfavourable drying behaviour is also indicated by generally high drying shrinkage.

While some extremely fine-grained and therefore highly plastic but otherwise harmless kaolinic or illitic clays may also show high drying shrinkage, their tendency to give trouble in drying may be corrected by additions of coarser or leaner clays or sand. On the other hand, the poor drying behaviour of montmorillonitic clays is seldom corrected by additions of materials that reduce their drying shrinkage, unless an extremely low proportion of the montmorillonitic clays is used. Then they act as a plasticizer, which action may even be required in clay bodies composed of lean clays, such as most shales. However, such clays should never be used as the principal body ingredient unless a suitable technological process has been devised for them, usually the dry- or the semi-dry pressing processes. Extrusion or soft-mud moulding is, however, excluded.

Drying and firing shrinkage

Drying and firing shrinkage may also be determined quite easily without much equipment. A wooden or metallic mould measuring 15 x 5 x 2 cm may be manufactured by any semi-skilled carpenter or blacksmith. The clay is made into a paste from which specimens are moulded. The skill necessary to do this is easily acquired. Drying shrinkage may then be calculated as the ratio (in per cent) of the difference between the length of the fresh (i.e. wet) and dried specimens to the original length. The importance of a low drying shrinkage has been stressed before. Almost equally important is the firing shrinkage, which again is computed from the difference between the dried and fired lengths of the specimen. One of the telling characteristics of most montmorillonitic clays is that while their drying shrinkage is high, their firing shrinkage is low.

Any clay with a combined drying and firing shrinkage greater than 7% when fired to a water absorption of about 15% will need shortening, that is, addition of lean clays or sand. Exceptions to this rule are some of the shale clays used even when their firing shrinkage is as high as 10%. But in such cases the final product is usually a face brick fired to a water absorption of less than 7%.

Good brickmaking clays seldom require firing temperatures above 1,050°C, but there are exceptions, of course. Bricks made from most shales usually require that or even higher firing temperatures, especially if they are fired to low water absorptions. But the average for normal masonry or even low-grade face bricks lies between 900° and 960°C. Such a temperature is easily attainable in any electric laboratory furnace used in analytical work.

Water absorption, which is a good indicator of the clay's fired mechanical strength, is also easily determined by boiling the fired and previously weighed specimen in water for at least two hours. The water absorption is quickly computed from the weight of the absorbed water and is related to the weight of the dry specimen. The fired specimen is judged by its colour. A clean reddish colour is desired if the manufacture of face bricks is contemplated. If only masonry bricks that will be hidden behind stucco coatings are to be made, the fired colour is less important. The same is true for any scumming tendency, which manifests itself through the formation of a white, or sometimes yellowish, "veil" on the brick surface. Again, the presence of such scum renders the bricks unsuitable for facing, though it does not hinder their use as masonry bricks. It should be remembered, however, that a clean red colour is a powerful sales stimulant even when the bricks are to be hidden under stucco or whitewashed. Most forms of drier scumming may be prevented by additions of barium carbonate to the raw brick mix. But such treatment is expensive and adds considerably to the cost.

The few simple tests that have been briefly described above are no substitute for full-scale testing conducted by experts in specialized institutions or laboratories. It is especially the long-range extrapolation from laboratory results to manufacturing behaviour that is of utmost importance. The fact that reasonably good bricks may be hand-moulded from a given clay does not mean that the same clay will work equally well in extrusion. Even if satisfactory results are obtained with a clay in a well-known brick institute or laboratory, it is still necessary to have the supplier of the making machinery verify the results. Only in this way can a guarantee be obtained from him. Most manufacturers of brickmaking equipment run well-equipped laboratories, and the prospective brickmaker should always insist on full-scale tests, that is, a full-sized brick should be made from the available clay before the equipment is ordered.

Selecting the site for the brick plant

Selecting the site for a brick plant is not as easy as it seems. The natural impulse would be, of course, to select a site nearest to the source of the raw material because clays as mined are generally quite humid, carrying variable but still considerable proportions of moisture, but they lose by ignition up to 13% of their weight. In other words, extra freight must be paid for 15-25% of the load transported. While substantially correct, this natural impulse to situate the plant near the clay deposit must sometimes be checked.

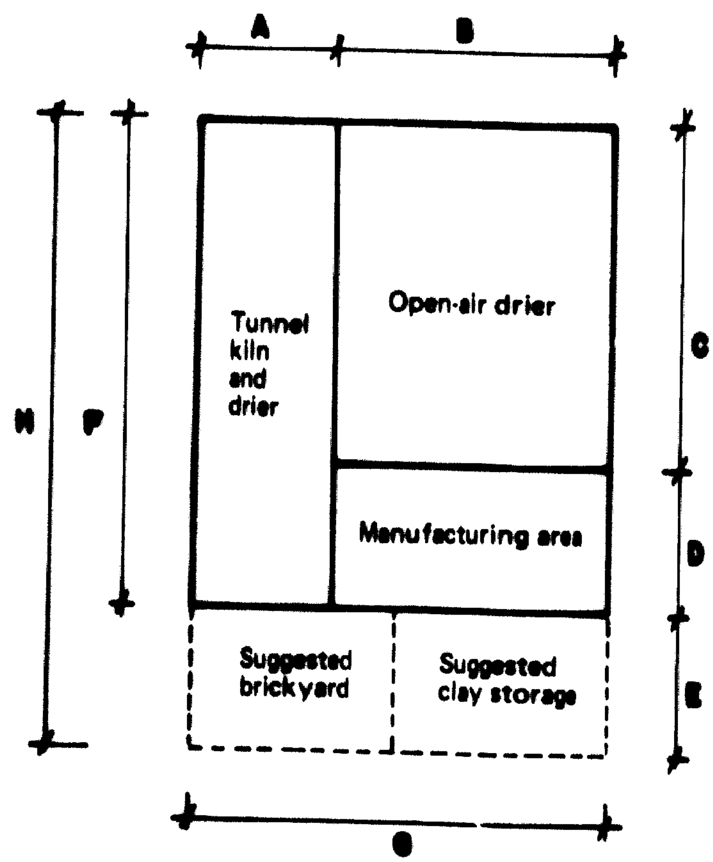
An important factor that may affect the final decision regarding the siting of the brick plant is the condition of the roads between the source of clay and centres of brick consumption. Clay deposits are usually not situated near good, hard-surfaced roads. Transporting the finished product over bumpy, potholed roads causes considerable breakage, especially if rather thin-walled bricks or tiles are being transported. Surface maintenance of earth roads is expensive, since heavy downpours during the rainy season that occur in so many developing countries, combined with the heavy weight of the loads of bricks transported, can destroy an earth road very quickly. Under such conditions siting the works near the consumption centre would be preferable, provided that the cost of land is reasonable.

If a site near a major consumption centre is chosen, careful attention should be paid to the direction in which the city is spreading. Too many brick plants have, within a few years after their construction, been affected by the teeming urban growth that not only drives real estate prices sky high, but also leaves the plant surrounded by urban dwellings, so that it sticks out like a sore thumb.

The argument for siting the plant near a major consumption centre is further strengthened when more than one clay must be used and when they are not all found in the same region. Also, dwellings for workers, supervisors and employees are more likely to be found near large population centres.

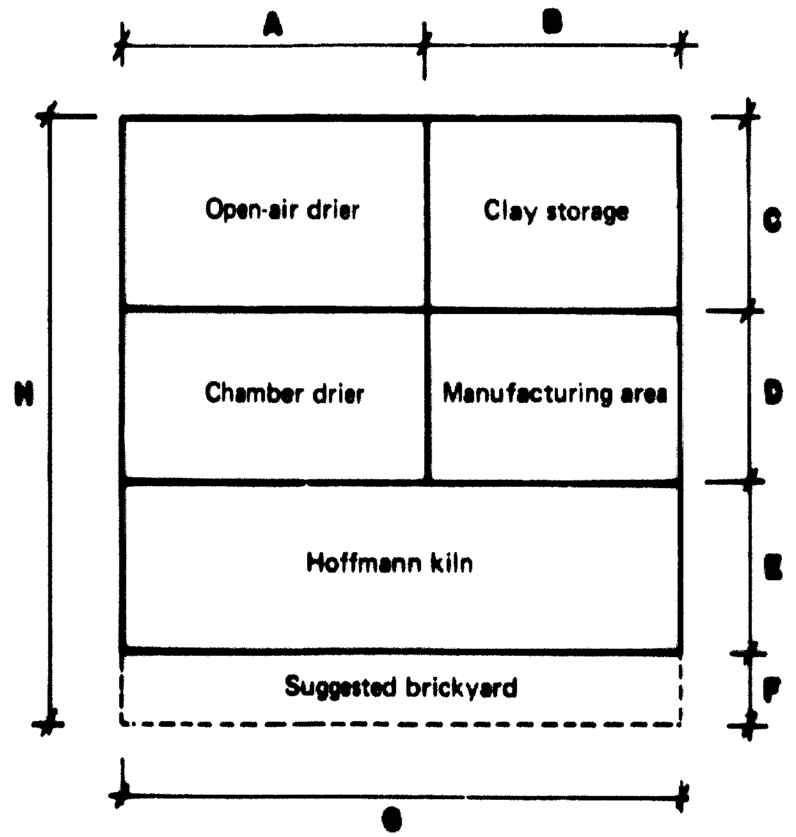
Figures I and II give the approximate space requirements for brick plants equipped with tunnel and Hoffmann kilns of varying capacities.

Figure I. Area requirements of tunnel kiln plants of various capacities



Capacity (tons per day)	*A*	*B*	*C*	*D* (m)	*E*	*F*	*G*	*H*	*Area required (m²)*
40	19.5	28	30.5	20	13	50.5	48.5	63.5	2 880
50	19.5	34	30.5	30.5	12	61	53.5	73	3 905
60	19.5	38	30.5	38	20	68.5	58.5	68.5	5 177
80	30	53	30.5	20	13.5	50.5	83	64	5 312
100	30	63	30.5	30.5	14	61	93	75	6 975

Figure II. Area requirements of Hoffmann kiln plants of various capacities



Capacity (tons per day)	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*Area required (m²)*
				(m)					
40	30	18	28	24	24	7	48	83	3 984
50	37	23	28	24	24	8.5	60	84.5	5 070
60	44	27.5	27.5	24	24	10	71.5	85.5	6 113
80	58.5	36.5	27	24	24	14	95	89	8 455
100	73	46	27	24	24	17.5	119	92.5	11 007

II. Winning and transporting the clay

The clay pit—its opening

Land with clay deposits should never be purchased until the extent, depth and quality of clay deposits have been determined. The information on the thickness and configuration of the clay strata must then be used for planning the pit's operation; at this point any inaccurate information about the clay strata may be corrected. Since for delimitation of a clay pit drilling at intervals of 100-250 m is normally sufficient, one may now wish to re-drill the prospective pit area at 50 or even 20 m intervals.

The need to select clay deposits with little overburden has already been mentioned. However, some overburden will always be found, and it must be eliminated to uncover the strata of good clay. Unless it is rocky, in which case the deposit should not be used at all, the overburden must be removed as cheaply as possible. The best way is, of course, to use a bulldozer, which may be conveniently contracted for rather than purchased, since clearing away overburden is seldom a recurring operation. Some roadbuilding is going on in every country, and any organization having bulldozers and scrapers will be willing to remove the overburden.

The depth of exploitation must be decided next. The decision here depends first of all on the thickness of the clay and on the configuration of the terrain. Frequently there are several strata with different characteristics that may complement each other, or a blend of them may even be necessary. In such a case, several strata are worked together, and this requirement again determines the working depth of the pit. The depth to be worked is also affected by the area of the clay land that is owned. Another factor is the water-table level. Pits that become waterlogged are a source of endless trouble. The general land profile in relation to the clay stratum must also be taken into consideration. It is poor practice to start a clay pit in a depression the higher ground should always be sought, since water should preferably drain off the clay face and not nice versa. The working of the pit should be well organized and always neat; haphazard winning is to be avoided. Pockets of unwanted materials should not be left standing but should be removed promptly.

Clay winning

In most developing countries with abundant and low cost labour, clay winning will be manual, aided in the case of hard clay by blasting. An exhaustive study of shovelling[2] has shown that two men working together during one working day can win and transport by barrow over a distance of 100 yards (91.4 m) sufficient material for 10 tons of fired product. The efficiency of shovelling depends to a great extent on the proper weight and size of the tool; a man equipped with the right kind of shovel will increase his efficiency in spite of himself. Further increase in shovelling efficiency may be gained by instructing workers how to use their tools, something that, surprisingly, few workers know even after having shovelled for years. The most important method of increasing efficiency, however, is to give financial incentives. The bonus system, if carefully supervised by specially trained men, is the preferred system of paying wages. Under this system, a fair wage is guaranteed to the worker for everything he has done up to a certain standard performance. Beyond that, a payment is received for each unit of work done.

In 1967, it was estimated that mechanical clay winning became economic when the output exceeded 20 tons per day of fired product. A great deal has changed since then; because of the increased cost of equipment and fuel, the threshold of profitability may be twice the figure given above, which would mean an output of over 14,000 bricks per day. Nevertheless, a brick manufacturer in a developing country with an output well over that limit will hesitate before acquiring present-day clay-winning equipment at the beginning of his operation. Investment capital has never been abundant in most developing countries and interest rates are high.

The four most frequently used types of clay-winning equipment are the multi-bucket excavator, the shale planner, the face shovel and the dragline.

The first machine has several buckets attached to two endless chains mounted on a jib. The sharp-edged buckets scrape the clay away from the clay face, which may be 45° from the vertical or horizontal. The machine usually moves on rails along the clay face, which for best economy should be as long as possible because the track must be changed after each run of the front. The clay is collected on a belt conveyor and transported wherever convenient.

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[2] G. T. Harley, "A study of shovelling", *Transactions of the British Ceramic Society*, 31, 1-44.

The shale planner, extensively used in the United States of America, works on the same principle but employs knives instead of buckets to cut off the clay, which may be carried away by buckets attached to the same chain or fall down onto a belt conveyor mounted on the same machine. While the multibucket excavator may work either downwards or upwards, the shale planner works from the bottom of the clay face and oscillates through an arch marking a circular cut in the clay face.

Face shovels and draglines move on caterpillar tracks. However, whereas the face shovel has a rigid jib with an arm at about mid-point capable of extending and retracting and carrying a bucket at its end, the jib of the dragline is hinged at the base to permit its angle to be varied, but the bucket is attached by wire ropes controlled by a winch. The face shovel permits pressure to be applied to the bucket in digging and is therefore able to handle even hard shales. This is not the case with the dragline because of its inability to exert pressure. On the other hand, its bucket may be thrown, which greatly increases its range of operations. If the clay face is composed of strata of different materials, the multibucket excavator, the shale planner and face shovels yield a cross-section of all the materials they traverse, thus increasing the uniformity of the clay delivered to the plant. In this respect the dragline appears to be somewhat inferior.

On the whole, therefore, the choice of winning equipment depends on the nature of the deposit. If there are strata of undesirable materials in the deposit, no machine that works over the whole face of the clay bank can be used. Here, picking out the unwanted material by hand digging has to be resorted to or a "skimmer" used. This machine has a fixed horizontal jib on which the bucket runs to make a horizontal cut. Multibucket excavators and shale planners work best on rather soft clays or shales.

The labour requirements for multibucket excavators are reported to vary from 0.02 to 0.05 man-hours per ton. Other excavators, including face shovels, require from 0.02 to 0.1 man-hours per ton. This is naturally not the most important expense connected with the use of this equipment. Fuel, maintenance and amortization, on the contrary, amount to a great deal of money. Before equipment is acquired, careful calculations must be made to determine the economical feasibility of the investment. It is usually considered that the initial cost of equipment must be paid for by three years' wages of the workers it will displace.

Transporting the clay

The choice of the means of clay transport depends on the distance between the pit and the brick plant. Up to a distance of about 200 m, rope and winch-operated side-tipped tubs are most convenient, and they can be made to discharge into the box feeder. Beyond this distance a diesel locomotive is used. When the distance is over 800 m, a dumper is preferred, but its optimum economic distance is 1,500 m for a dumper with a capacity of 1 m^3. For larger distances tipping trucks are used.

It is customary in most European countries to store a clay supply for even several years and let it "age", or "sour". The clay is stored in concrete-lined pits that are filled from above by an overhead conveyor either equipped with a "tripper" or a "reversing conveyor" for unloading the clay and distributing it along the bin. Frequently the clay is moistened and left aging. To remove it from the pit, a multibucket excavator, travelling along the whole width of the clay pit and discharging the clay on a belt conveyor, is used. The pits are protected from rain and sunshine by a suitable covering so as to control the clay's humidity.

It is still questionable whether these elaborate facilities are worth the improvement in the clay workability they may bring about, and developing countries should avoid setting them up. Nevertheless, keeping on hand a reserve of clay sufficient for the whole rainy season is to be recommended. If such a reserve is accumulated when the clay is very dry, not so much of it has to be stored, since wet clay may be blended with it. Roofed clay deposits are expensive, running at least to $80/$m^2$.

III. Selecting the process

At least two factors are involved in selecting the process: *(a)* the kind of product to be manufactured and *(b)* the physical characteristics of the available raw materials. The first factor is usually determined by the market. If handicraft bricks are produced in the country, the type of product to be manufactured will be similar to the handicrafted brick in size, but harder and lighter, of better colour etc. If there is no tradition of using bricks in the country, the choice of product to be manufactured will be considerably affected by the nature of the competing building material. This material will be, in most cases, a concrete or, more likely, a sand-cement block. In that case the clay product with the best chance of succeeding will be a large brick of a size approximating that of the competing sand-cement block.

That does not mean that other clay products should not be manufactured. It only means that the main product should be similar to the competing product, at least at the beginning. It is bad marketing policy to introduce innovations too soon and try to force them on the buyer. House builders are invariably conservative. However, a range of other products should be introduced as soon as warranted, so that the buyer may be given a choice.

The characteristics of the raw materials available naturally also affect the choice of the products to be manufactured. Not all clays are equally suitable for the manufacture of thin-walled tiles; there is considerably more latitude when simple cored bricks are manufactured.

Technological process versus clay characteristics

If the available clay or clay blend is reasonably workable and has normal drying characteristics, the extrusion or stiff-mud process will probably be the one selected. The extrusion process has many advantages: it can be used equally well for the manufacture of solid or cored bricks and for hollow tiles. Extremely high production can be easily obtained from equipment manufactured in many countries.

Nevertheless, the extrusion process has certain disadvantages. Water must be added to the clay to make it workable, but later it must be eliminated at considerable trouble and expense. The extrusion is effected by a screw that cuts and shapes the clay into two ribbons, which must afterwards be reunited to form a continuous column before the clay emerges from the die to be cut into the finished product. Lamination and cracking may result from this step in the process, as well as from the differential flow taking place when the clay is forced through the die. These defects are seldom visible at the time of extrusion, but manifest themselves only after the product has been dried and fired. During the rainy season, clays sometimes become too water-soaked for efficient extrusion. In spite of these problems, extrusion is still the most widely used brickmaking process.

Next to extrusion, the soft-mud process must be considered. In spite of its being used to produce huge quantities of bricks in the United States and lesser quantities in the Netherlands and in the United Kingdom of Great Britain and Northern Ireland, this process is little known outside these countries. It can be used advantageously for the production of bricks from lean or sandy clays, which do not extrude well. In fact, any clay that can be successfully hand-moulded may be formed by the soft-mud method; the operation of the soft-mud machine imitates the motions of hand moulding. The soft-mud process is particularly suitable for the manufacture of face bricks, particularly sanded ones, sanding of the mould being an essential part of the manufacturing process. Production capacities of the equipment are high, and the process is easily automated. Its two disadvantages are that only solid bricks may be turned out and the water content of the freshly made bricks is higher than that of bricks made by other processes. Thus, drying costs are usually higher.

The semi-dry, or dry pressing process as it is called in the United States, has been little used until recently in the manufacture of common bricks. The greatest advantage of this process is that freshly pressed bricks need no drying if they are to be fired in periodic or moving-fire continuous kilns. The economics of the drying process will be discussed later, but it must be pointed out here that if no waste heat from the kilns is available for drying and heat must be generated especially for this purpose, drying will consume a large amount of energy. One of the disadvantages of the process is the high wear on the mould boxes, which need frequent and costly maintenance. Also, the production capacities of the available pressing equipment are low in comparison with those obtained in extrusion. Semi-dry-pressed clays normally do not attain physical properties, such as porosity and mechanical strength, comparable to those of extruded ones when fired at the same temperature. Consequently, temperatures must be higher and more fuel is used. This drawback, however, can be corrected by using more humid clays.

Most clays are humid, or at least moist, when dug out during most of the year, and in the rainy season they easily become water-soaked. Since for optimum pressing only a definite moisture content can be tolerated, the clay may have to be predried.

In spite of the improvements that have been introduced, the upkeep of the mould boxes is still costly. If the dies are not replaced or resurfaced, excessive featheredging occurs, which detracts much from the appearance of the bricks and reduces their sales appeal. In comparison with extrusion, the output of dry-pressing equipment is still limited. Perhaps the greatest disadvantage of the process is that the size of the product is limited to about 2.5 times that of the standard brick. Also, the possibility of coring is restricted. Just about the only lightened bricks that can be manufactured are either thick-walled hollow bricks with two rectangular cells or large circular cavities.

In spite of the disadvantages, 12 million bricks called "Flettons" are turned out every week by semi-dry pressing in England. However, the clay used for pressing contains 20% water. This may indicate a montmorillonitic character of the clay used, which would make the product, if it were manufactured by extrusion, sensitive to drying. Twenty per cent water is about the moisture content of a clay suitable for soft extrusion. Here, of course the energy-saving argument loses its validity. Thus, the use of the semi-dry pressing process should be limited to clays with poor drying characteristics, provided that they react well to dry pressing and that they are not very abrasive.

The last process to be reviewed here is vibration-compaction. This process has been hitherto used mostly for moulding concrete or sand-cement blocks. It has been little used in connection with clays. It works best with non-plastic materials or with a mixture of granulated non-claylike material with a bond clay. The product as moulded has a low water content, and there are no drying problems. This process is best used for the manufacture of large hollow bricks. Even though the equipment is simple, the development of a suitable clay body needs considerable expertise as the bond clay, of which very little is used, must be carefully compounded or "doctored". Before discussing the three moulding processes, something must be said about methods of preparing the clay for the final shaping of the product, whether by extrusion, semi-dry pressing or soft-mud moulding. Here, too, the nature of the clay has a great deal to do with the selection of the process. Two basically different preparation methods must be distinguished.

The wet preparation process

The wet preparation process is used mostly in continental Europe, much less in the United Kingdom and very infrequently in the United States. This process takes advantage of the fact that most clays as mined are frequently wet or at least humid most of the time. It is suitable for use with rather soft clays that slake in water with relative ease. It should never be used with hard, non-slakable clays, although exceptions are sometimes made to this rule.

At the core of this process are the laminating rolls, i.e. sets of cylinders with progressively narrowing gaps between them. There may be one to four sets of rolls depending on the clay's hardness, proportion of pebbles present etc. These laminating rolls are normally preceded by a feeding box, a large box the bottom of which is formed by a slat conveyor. The length of the box may be divided by movable divisions into compartments. Their heights, or the gaps above the moving slat conveyor, are adjustable. Thus, in this way the various materials used can be proportioned reasonably satisfactorily.

For highest accuracy the size of the lumps loaded into the box feeder should not exceed 5 cm. If the incoming lumps are larger, they must be precrushed. The most frequently used crushers are double rolls, seldom smooth but generally toothed or provided with bar projection. Disintegrators are also used for this purpose. They differ from clay crushers in that they consist of a large smooth roll and a small toothed roll, the latter rotating at a higher speed than the former.

To return to the box feeder, rakers rotating in the direction of the flow of clay are frequently installed above the discharge end of the feeder. They are believed to make the flow of clay uniform. Water also is sometimes added at this point.

The box feeder usually discharges the clay into a wet pan by means of an inclined slat conveyor. Here is where most of the mixing takes place. If more water is required to obtain the correct consistency, it is added here.

The wet pan consists of a pair of heavy mullers rotating on a stationary pan, the bottom of which has slotted perforations. The distances of the mullers from their common shafts do not coincide so that their tracks cover the whole surface of the pan. Strategically placed scrapers direct the clay under the path of the mullers. Considerable mixing takes place here, and the clay is forced through the pan's openings, falling over the entire area of the pan. To collect it at one point for discharge and further transportation, another piece of equipment is needed, the souring mixer, or Mauk mixer. This mixer is also a pan, but its rotation is slower and intermittent. It is equipped with a continually rotating screw or auger, the length of which is less than the radius of the mixer. The clay falling from the overhead wet pan is collected over the whole area of the mixer by the continually rotating screw and is discharged usually at the centre. From the Mauk mixer the clay falls directly into the first set of smooth rolls situated underneath. Sometimes, however, to avoid having to install the wet pan at too high a level, the smooth rolls are installed apart, and the clay from the mixer reaches the pan by means of another slat conveyor. There may be one or more sets of smooth rolls with gradually decreasing gaps between them, the last being not over 0.5 mm. The purpose of the rolls is to reduce the size of the stones or pebbles and to break down dry or hard clay crumbs. If there is more than one set of rolls, the last one runs at differential speed, that is, the revolutions of the two rolls are not equal, so that the clay particles are broken down by a combination of crushing, shearing and rubbing action. The number of rolls is usually determined by the consistency of the clay, amount and size of stones etc. The clay emerges from the last set of rolls as a thin curtain, which easily breaks up and is fed into the making machine. It is sometimes asserted that this practice may increase the tendency of the clay to laminate in the extruder because the thin clay curtains disintegrate after the clay passes through the last set of rolls and may orient themselves with their larger surfaces parallel to the direction of flow. For this reason and to homogenize the clay further, a double-shafted mixer is interposed between the last rolls and the making machine.

This mixer consists of an open trough with two shafts fitted with overlapping knives that rotate in opposite directions. Since the knives are set at an angle the wet clay is forwarded along the whole length of the mixer towards the discharge end. Considerable kneading action occurs through the knives' continuous cutting of the clay as it moves through the mixer, especially when the knives meet at the centre.

Only the simplest type of preparation process has been described here. More sophisticated brick plants in Western Europe may, after the wet pan, use a sieve kneader in which the wet clay is once more squeezed through a perforated bottom by the action of specially contoured paddles. Some modern plants use "clay planners" instead of disintegrators. These consist of a cylindrical container with a rotating bottom provided with adjustable cutting blades that shave the clay away. The clay shavings fall through the container and are collected underneath and transported to the next preparation unit, which is usually the wet pan. The maintenance of the wet pan is very costly, however.

If the clay contains too many stones or if the stones are too large to be handled by the rolls, either a set of helically grooved rolls or clay cleaners may be used. When a stony clay is passed through the helical rolls, the corrugation breaks down the soft clay, but the larger stones move on the top of the helix and are discharged sideways. Helically grooved rolls are said to remove even hard lumps of dry clay. They are more effective with large stones or lumps. In the clay cleaner, the pebbles are screened out of the wet clay by forcing the clay through the perforated walls of a cylinder, closed at one end by the action of an auger rotating within it. Pressure is built up through the rotation of the auger so that the clay is forced to pass through the openings. All stones larger than the openings are scraped off by the action of the knives and transported forward to the closed end of the cylinder. The cylinder is provided with a lever-operated sliding gate through which the accumulated stones are removed from time to time. This equipment is usually installed ahead of the wet pan and the smooth rolls.

One additional piece of equipment that is often installed in brick plants is the souring, or ageing, tower. However, it has never been determined to what extent ageing improves the quality of the finished product or makes its manufacture easier. Nor has it been demonstrated that the benefits, if any, are worth the extra expenses incurred. It is now maintained that the chief benefits of ageing are secured during the first 24 hours. It is for this type of ageing that the *Maukturm*, or souring tower, has been devised. Souring towers of this kind are somewhat conical bodies normally holding 100 tons of prepared clay. They are provided with a rotating base similar to that of the Mauk mixer previously described. The clay is fed in at the top and removed at the bottom by means of a gathering auger or screw. In most modern installations steam is injected into the tower so that the clay is kept at a higher temperature and under pressure above normal. The souring towers are usually installed between the last set of rolls and the extrusion machine or double-shafted mixer.

Whether the installation of a souring tower is warranted must be decided on the basis of intensive and extensive tests. One important fact must be kept in mind. Excellent face bricks are manufactured in the United States from unaged bodies using hard shales of low plasticity. Since, however, most brick plants in the United States use the dry preparation method, they are normally equipped with storage bins for the ground clay. This is necessary for a smooth, uninterrupted operation. Souring towers may be considered the wet preparation process's substitute for the dry-process bins.

In some very sophisticated installations, steam is injected into the clay in a double-shafted mixer situated on the top of the tower. De-aired and steam-heated clay is charged into the souring tower, which is hermetically sealed to prevent loss of steam and heat.

When wet preparation is used in connection with soft-mud manufacture, the process is generally simpler and uses much less equipment. Normally only one or two box feeders, a sieve kneader or a wet pan and a single-shafted or douhle-shafted mixer that feeds the making machine are used.

The equipment normally used in the wet process for preparing clay can now also be used in semi-dry pressing, a recent development. Here the clay passes successively through the clay crusher (if necessary), box feeder and laminating rolls. Only as much water is added as is required for the pressing. If the clay is too wet for successful pressing, part of it is dried through a rotary drier. The scales resulting from this process are fed into the press's mould boxes. When the clay is too dry, the resulting scales are too large for the press to handle. Then a vibrating sieve is interposed between the mixer and the press, and the scales are screened through an 8-10-mm opening sieve. The oversize is returned into a double-shafted or single-shafted mixer where it is further disintegrated.

The dry preparation process

The dry preparation process is widely used in the United States and in the United Kingdom of Great Britain and Northern Ireland.

In this process, if the clay requires preliminary crushing, it is crushed as soon as it arrives at the plant so that a reserve of crushed material is kept on hand at all times. The equipment used for grinding is the dry pan, which consists of a pan attached to a rotating vertical shaft. It may be either of the slotted-bottom or rim-discharge type.

The solid pan is lined with plates that form the running track for two heavy mullers. The mullers' track is surrounded hy a ring built of perforated or slotted plates or grids.

In the rim-discharge pan there are no screen plates. The clay fed into the pan is crushed and ground hy the action of the mullers and is then thrown hy centrifugal force across the screen plates. The material small enough to pass through the grid's openings falls through and is collected underneath. The rest is directed again under the path of the mullers hy stratcgically placed scrapers. The ground material is thrown by centrifugal force against the outside rim of the pan and passes through the peripheral openings into a circular collecting channel below. By means of scrapers attached to the underside of the pan, the material is continuously swept and falls through an opening in it below, where it is collected for transport.

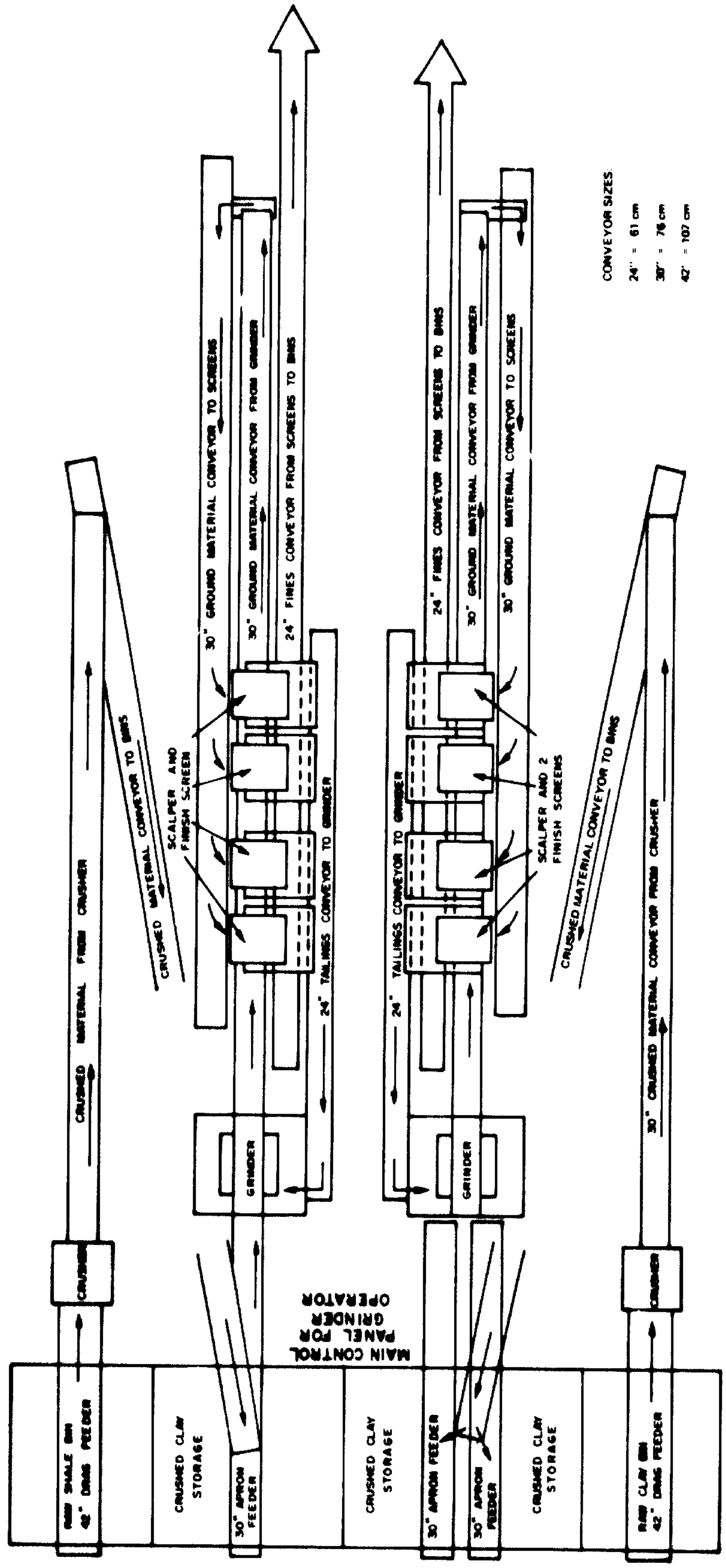
The oversize material, which is normally returned to the pan after having been rejected by the screens, represents a serious problem, since its change of being further reduced by the action of the mullers is slim. It sounds logical, therefore, to have the oversize from screens hypass the pan and go instead into a separate pulverizer or hammermill, where they are further reduced in size, before they are passed once more over the screens. The circulating load is thus reduced to a considerable extent. Incidentally, for the same size the rim-discharge pan has a larger grinding capacity, but the circulating load is much higher. The ground product collected underneath the pan (and there are at least two ways of collecting it) must be transported to the screens to be sized.

In older plants the ground product was transported to the screens usually by bucket elevators. This method is no longer considered economic. Bucket elevators waste energy and are difficult to service. Instead, inclined ruhber conveyor belts are increasingly being used. Because of the necessity of maintaining a suitably low angle to prevent backsliding, conveyors have to span longer distances. To save space, the clay may be conveyed back and forth by several shorter conveyors. Figure III shows this type of installation.

The screens that are such an important part of the dry-grinding process used to be located high above the ground floor, now considered an unsatisfactory arrangement, since equipment situated 20 m above the general plant level will be neglected. Today the screens are located on the ground floor, where they may be kept under close observation, which their operation requires. The still frequent use of old-fashioned screens with their high-angle inclination complicates matters. Fortunately, the development of low-angle, high-volume, low-velocity heated vibrating screens has made it easier to locate the screens on the ground floor. The availability of screens that operate in the horizontal position has further simplified the problems connected with the positioning of screens on the ground floor. Here the screen moves simultaneously upwards and forwards, so that the material travels over the whole screen surface towards the discharge end. Figure IV shows this type of installation.

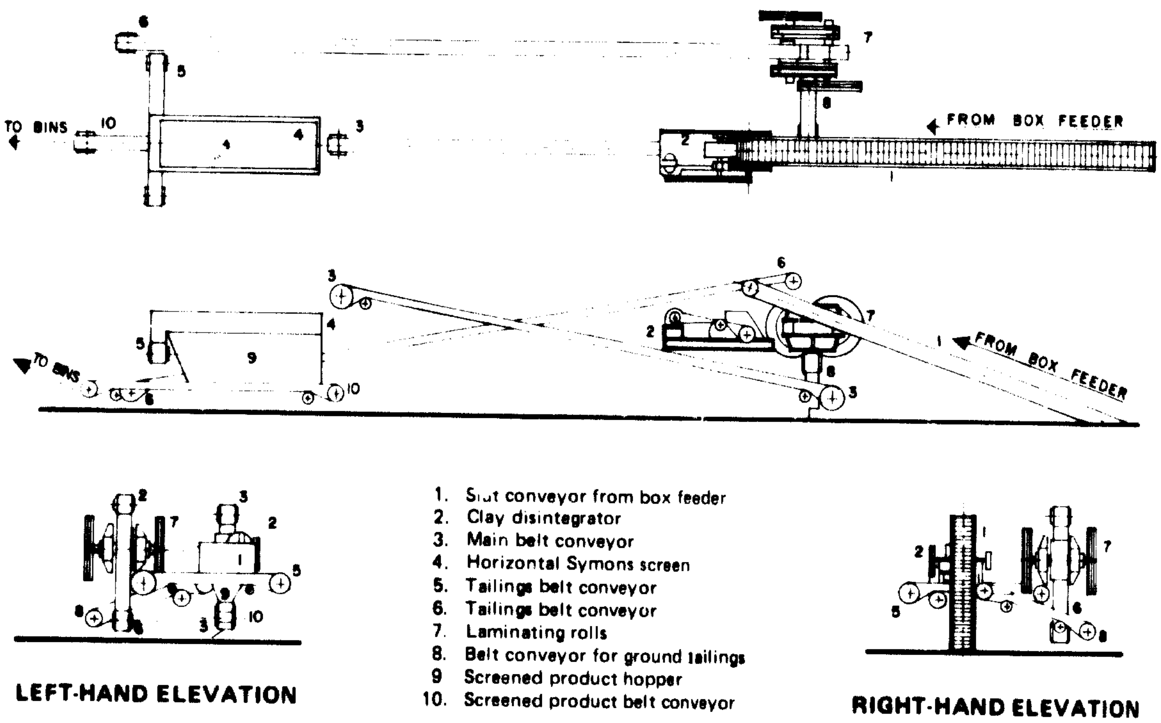
The screened product must be deposited in bins, one or more according to the number of clays. The transport from screens to bins is again better accomplished by inclined belt conveyors than by elevators. For distributing the individual clays to their respective bins, there are at least three possibilities. If the number of clays is limited and bins are in a quatrefoil position, distribution by chutes is quite satisfactory. With more than four materials (which is seldom the case) and bins arranged in one or two rows, distribution by a "shuttle belt" or a "tripper" is more appropriate. The tripper is used only when the number of ingredients is exceptionally large. The size of the bins should be large enough to hold a supply for at least two days. Bins consisting of an upper cuboid part and a lower wedge-shaped one have the best shape. Bins with vertical walls are sometimes advocated. Such bins are not completely self-emptying and thus require additional labour to shovel the clay into the discharge opening when they are to be completely emptied. It is believed, however, that they reduce bridging.

Figure III. Grinding department layout



Source: Brick and Clay Record, October 1956.

Figure IV. Disintegrator grinding plant with horizontal screen



To get the materials out of the bins and into the making machine, some kind of feeding, transporting and mixing equipment must be provided. If there are several m[illegible]rials, each contained in a separate bin, each n[illegible] rovided with a feeder. Several feeders may then discharge on a single belt conveyor, which takes the material to the mixer, which in turn feeds the making machine. The most common but not very accurate feeder is the so-called rotary disc feeder. It consists of a rotating disc attached to the bottom of the bin. The material falls through the bin's opening and forms a cone on the disc, and a stationary but adjustable plough scrapes off the required amount of material. This arrangement is quite satisfactory in most cases. Rotary-vane feeders are also popular, but their upkeep is costly because of the abrasive action of the clay. Apron conveyors are also frequently used when the amounts to be fed are large. They operate on the same principle as the box feeders but are smaller.

The materials fed can be more precisely controlled through the use of vibrating feeders. In their simplest form they consist of a trough to which a controllable electric vibrator is attached. The rate of flow may be easily controlled by changing the amplitude of the vibration by means of a rheostat. Vibrating feeders are capable of feeding from a few grams to several tons per minute.

The so-called poidometers are much simpler and less expensive constant weight feeders. Although efficient, they are now seldom used. They consist of a hopper attached to the lower part of the bin and provided on one side with a rectangular opening, the height of which can be adjusted by a sliding gate. A short length of canvas belt, supported on rollers, is suspended from the hopper. Two or three of the rollers are suspended from one arm of a lever, the movement of which is transmitted to the sliding gate. These are the "measuring rolls". The amount of material to be fed is controlled by weights placed on the counterlever. If the height of the sliding gate above the belt is adjusted to give a certain rate of flow but the amount of material passing through it increases for whatever reason, the measuring rollers become depressed; and this movement, transmitted to the sliding gate's mechanism, causes the gate to slide downwards by the amount necessary to decrease the flow. Thus constant weight feeding is maintained.

Assuming that the less mechanical equipment there is in a brick plant the better, because of decreased maintenance cost, proportioning the material in the grinding pan may be the most satisfactory procedure. It may be effected either by using wheelbarrows alternately loaded with one or the other material. Another and even better method is to count the shovelful of each material thrown into the wheelbarrow. The proportioning thus achieved can be surprisingly accurate. Some brick plants use side-tipping tubs that are divided into compartments by adjustable baffles. The compartments, the size of which is determined by the amount of each clay needed, are filled with the clay and the entire contents dumped into the pan.

A dry pan is a durable piece of equipment. Although working best with precrushed materials, it can grind even surprisingly large lumps without damage but at the cost of increased power consumption and maintenance and decreased output. All wearing parts of a normal dry pan can easily be replaced. Spare parts are of simple design and may usually be cast in any large foundry. Unfortunately, the dry pan's efficiency decreases with the moisture content of the clay, the upper limit being taken as 12%. There are, however, no fast rules as regards the allowable moisture content. A hard shale of low plasticity will probably tolerate more moisture than a relatively soft surface clay, which under certain circumstances may even form a relatively hard cake on the mullers' track. Since most clays get wet at some time during the year, caking may become a problem. The best solution is to accumulate a large enough reserve of dry clay to last for the duration of the rainy season. This solution requires heavy capital investment. The inability of dry pans to handle moist clay is one of the limiting factors of the dry preparation process, which otherwise has much to commend it, especially because it consumes less power per ton of product than other processes.

Several grinders have recently been devised that are capable of grinding clays with up to 30% humidity. The power consumption, however, increases steeply as does the wear on the equipment.

Special attention must be given to grinding and preparing clay for dry or semi-dry pressing. A normal dry pressing operation tolerates only so much moisture. If the clay is wetter, it must be dried. Under such circumstances most of the advantages accruing from not having to dry the pressed product before firing are lost, as suitable clay driers are expensive but less so than brick driers. And, as has been pointed out earlier, drying is expensive. It is frequently possible to dry the clay while it is being ground by using surge heat generated for that purpose. The Raymond and Novorotor mills are of this kind. Both are, unfortunately, expensive and require high maintenance and are therefore not suitable for grinding common clays.

In preparing clay to be used for semi-dry pressing in the rotary Spengler press, the traditional approach is to use dry ground clay, the preparation of which has already been discussed. Such clay or clays are taken out of the bins in which they are stored and proportioned, usually by volume, since weighing would be complicated and expensive and is unnecessary. The clay is moistened in a muller mixer of the Eirich, Lancaster or Clearfield type. Here the clay is pelletized, and upon discharging from the mixer it is fed into the press. The Spengler machine comes equipped with its own cylindrical feeder. Since all the above-mentioned muller mixers are essentially batch mixers, that is, intermittently working equipment, an intermittent means of filling the feeder must be used. The best equipment for this purpose is the bucket elevator, which should be so installed as to make it receive its charge of pelletized clay direct from the mixer. This procedure, though recommended by the Spengler Company, is too complicated for use with common bricks.

Equally satisfactory is the procedure whereby the clay is ground and humidified simultaneously in the dry pan. This procedure must be followed when the required pressing humidity is low, i.e. under 10%. If the clays require higher pressing humidities, the same equipment is used as in the wet preparation process. Since in the United States dry grinding is used in connection with the soft-mud process, the arrangement used at a plant at Sugarcreek, Ohio, United States, should be mentioned. Here the clays are dry ground in a pan, screened and double-pugged in two separate pugs, tempered to about 20% moisture and forced through a perforated plate provided with 25-mm holes. The pugged material is cut off and the slugs transported and dumped into a vertical tub above the making machine.

Extrusion pressing

In the extrusion process the clay, which has been humidified and kneaded in the pug mill or double-shafted mixer, is fed into the extrusion machine, which consists of a helix rotating within a cylindrical barrel. This helix, more generally called an auger, forwards the clay and compresses it by forcing it through a die from which it finally emerges as a continuous column.

The auger is composed of two parts. The first is the forwarding part, where, aside from some consolidation of the granular material that is fed into its path, little compression takes place. Here the auger's pitch remains constant. The second part of the extrusion unit is the auger tip, which forces the clay into the die. The auger tip may have several forms depending on the size of the die opening. Tapering or almost straight auger tips may be used.

To improve the clay's characteristics, modern clay extruders use de-airing, whereby the clay passes through a de-airing chamber before being extruded. Here the clay is exposed to a high vacuum. This raises the problem of providing an efficient seal to maintain the vacuum while permitting the clay to enter and to be extruded. There are several ways of sealing, but generally two augers are superposed. The upper one, also called the sealing auger, not only seals, but also forces the clay through a perforated shredding die. The finger-thick slugs fall through the de-airing chamber and directly into the extrusion auger below. To assist de-airing, the slugs are sometimes cut by a rotating knife fitted to the sealing auger's shaft.

Still another design uses a sealing auger in combination with a square open die through which the clay is forced into the de-airing chamber. A second, vertical auger rotating in the cylindrical vacuum chamber precisely in front of the sealing die shaves off very small slugs, which again fall into the wings of the extrusion auger rotating below.

Most extrusion machines are equipped with their own pug mills where the tempering and kneading takes place. Double-shafted pug mills are used in connection with European-made machines, but they are seldom found in the United States, where single-shafted pugs are generally used.

There are two variants of the extrusion process. The first, which should be called "stiff-mud" extrusion, was developed in the United States, where extrusion humidities down to 10% may be used. Stiff-mud extrusion naturally requires more sturdily built extruders and extruding power skyrockets. This is one of the reasons why extruders built in the United States that take 800 hp are no longer exceptional.

Stiff extrusion as practised in most United States brick plants puts a heavy demand on the bridges supporting the cores, which may be one of the reasons why most United States bricks have fewer cores than European ones. Furthermore, the production of hollow tiles, which require especially bulky cores, is practically non-existent in the United States, where most of the products manufactured are face bricks.

In spite of the much increased power consumption, much is to be gained through stiff extrusion. One advantage is the low humidity content of the extruded brick. A 5-7% difference in the moisture content means a great deal in terms of fuel economy. Furthermore, freshly extruded bricks may be stacked up several courses high in bungs or packs that may be picked up by fork-lift trucks. On the other hand, most European-made bricks must be individually set on laths and not stacked.

The extruded column must be cut to produce bricks or tiles. Many cutters are available. For bricks, a multiple-wire cutter is to be preferred, and rotary cutters are superior to the reciprocating ones. The wires of the rotary cutter enter and leave the brick column on the diagonally opposite edges, whereas in the reciprocating type of cutter the slicing takes place parallel to the smaller side of the column, the wires leaving it at the opposite side. Since the wires usually become plucked through the resistance of the clay column, they swing back when near to the surface of the column, tearing away pieces of clay and causing unsightly edges. The least that can happen is that feather-edges form along the cut edge. In a more recent design this drawback has been partially corrected by making the angle of the wires to the horizontal less than 90°. The wires no longer enter the column parallel to its smaller side but through the edge, even though side-way slicing still takes place.

Wire consumption is also lower with the rotary type of cutter. What is still more important is that wires do not break so often. When they do, however, they can be replaced more easily in the rotary reel cutter than in the reciprocating side cutter because the rotary cutter has four sets of wires, of which only one is used at a time, whereas the reciprocating cutter has only one set.

The slicing operation is mechanically synchronized with the motion of the measuring belt or rolls, which are dragged along by the column as it is extruded. Sometimes, however, the column is not heavy enough to drag the measuring belt with it. This situation occurs occasionally when hollow tiles are extruded. A smooth iron pulley, usually carried on arms pivoted about a fulcrum attached to the conveyor's frame and resting on the column, increases its friction against the measuring belt. For this reason rotary hand cutters are still frequently used for slicing columns for hollow tiles.

A cutter much used in Europe is the hacking cutter, a fine precision piece of equipment operating with a single wire. However, difficulties in adjusting and servicing it have frequently been encountered in developing countries. This cutter works best with hollow tile or heavily cored soft-extruded columns of the continental type. Another of its weaknesses is that it operates with a single wire. When breakage occurs production stops until the wire is replaced.

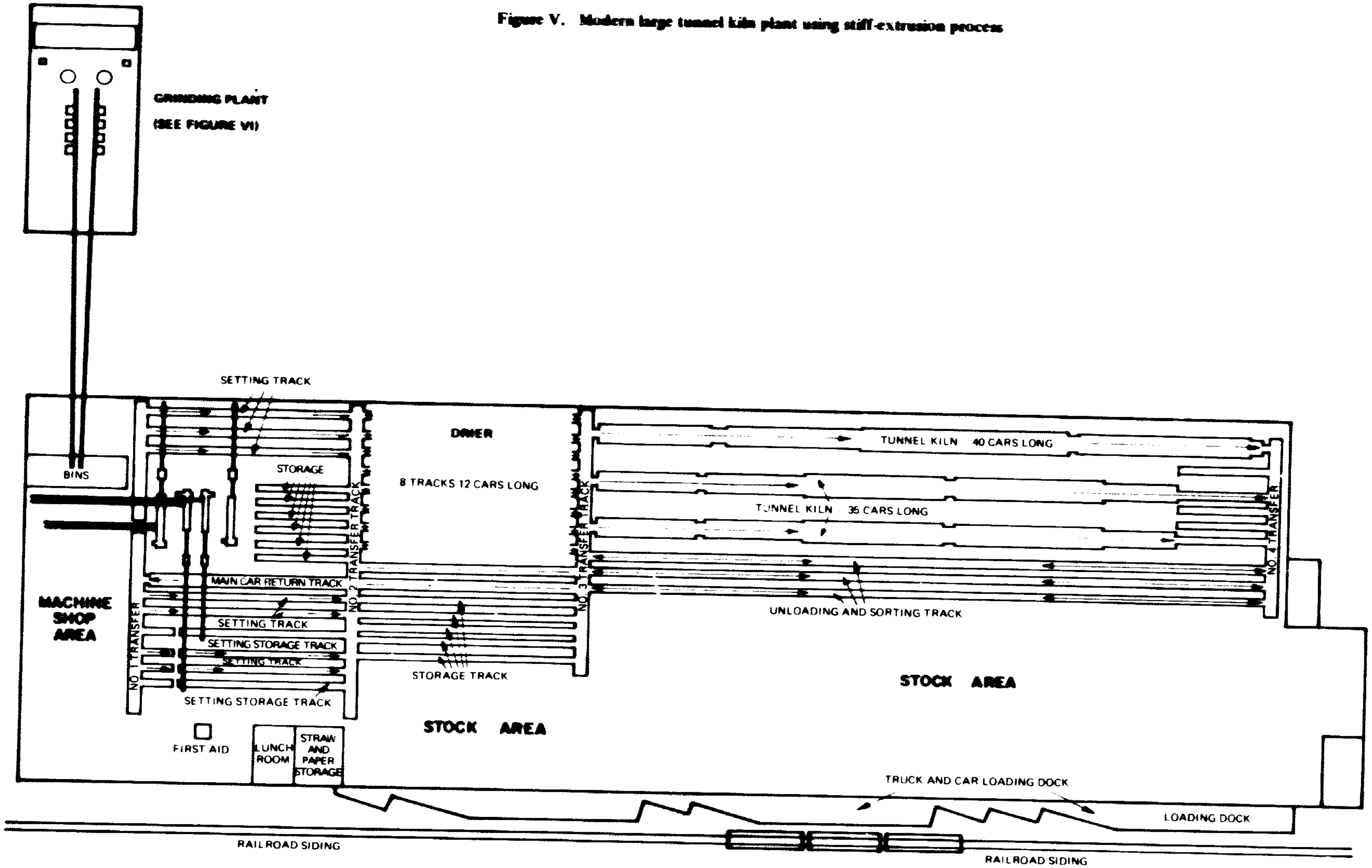
Most European brick plants use some automatic system to load the freshly cut bricks on pallets or, more frequently, on laths. It normally consists of a lath-loading system, an elevator to receive the laths and a finger car to take them off the elevator and transport them to the drier or drying sheds. The finger car usually moves on tracks and may be hand-propelled or hauled by an electric tram or diesel engine.

Such automatic loading equipment costs approximately $125,000 (as of end of 1975) and does the work of three persons. If its cost is to be paid by three years' wages of the persons it displaces, which is the rule of thumb for calculating profitability of equipment, such equipment becomes profitable only when the wages of each of the workers involved are at least $38.05 per day. Such wages, however, are scarcely to be expected in most developing countries.

With stiff-extruded bricks, one-course setting of bricks is no longer necessary, since the bricks can be stacked on pallets to a height determined experimentally but seldom over 10 courses high. These pallets are then transported either manually or mechanically by fork-lift trucks. If they are transported manually, special tilting trucks may be used.

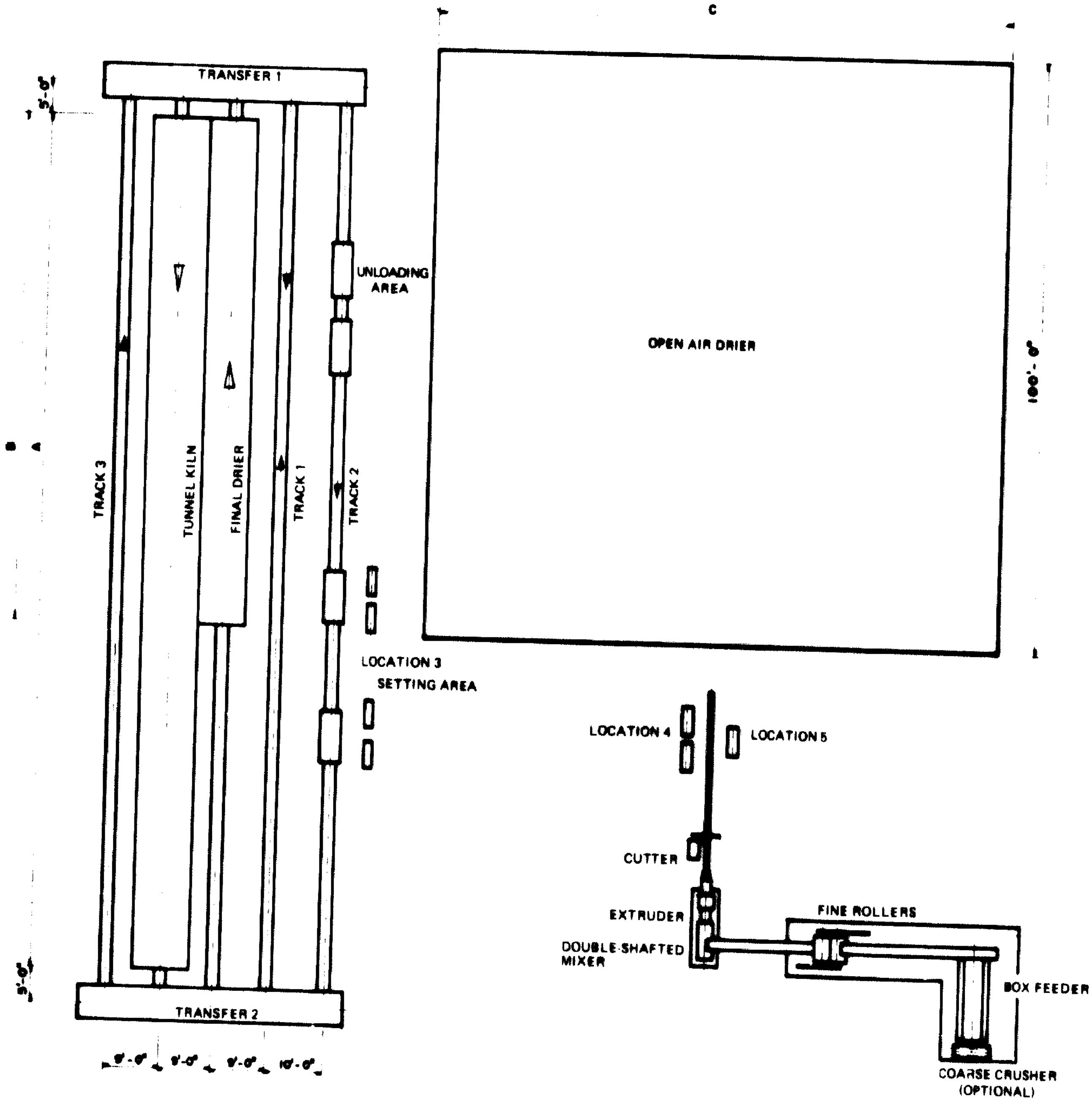
Figure V shows the layout of a large stiff-extrusion plant equipped with tunnel kilns. It produces about 44 million bricks per year. Figure VI shows the layout of a 60 t/d brick plant using the soft-extrusion process. It is also a tunnel kiln plant but of much

Figure V. Modern large tunnel kiln plant using stiff-extrusion process



Source: Brick and Clay Record, October 1956.

Figure VI. Tunnel kiln plant using soft-extrusion process



simpler design. A layout of a brick plant also with a capacity of 60 t/d but using a wood-firing Hoffmann kiln with its heads cut off is given in figures VII a and VII b.

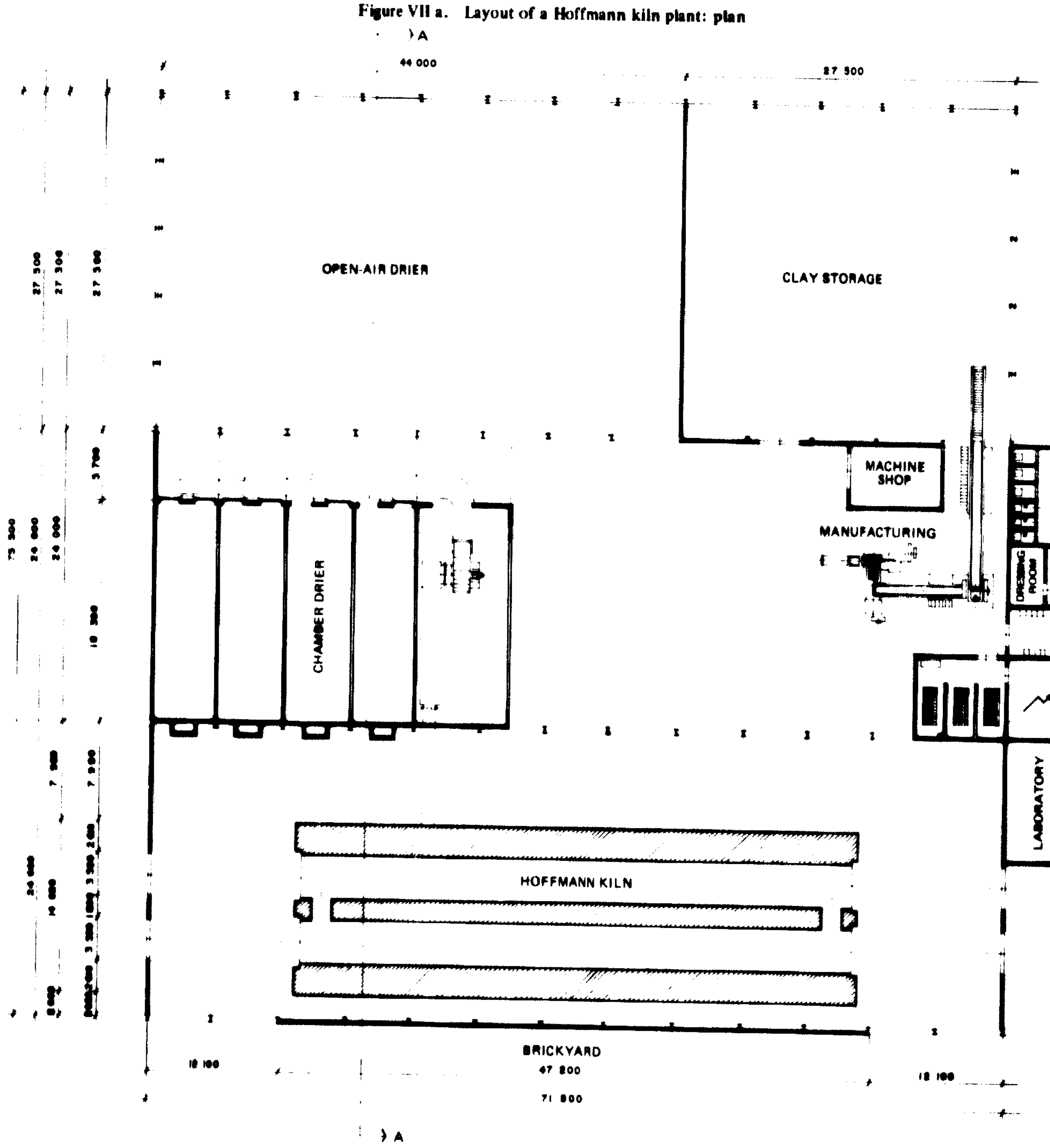
Semi-dry pressing

The semi-dry pressing process is sometimes referred to as dry-pressing process, a misnomer, as the material to be pressed is never dry; it contains at least 5 % moisture. Semi-dry pressing is a much apter term.

There are many semi-dry presses on the market. They may be either crank-, cam- or toggle-operated. They are used for specialized purposes like pressing fire-bricks but seldom for common or face bricks because of their low production capacities. However, a cam-operated single-cavity press with a capacity of 1,200 bricks per hour is used a great deal in the United Kingdom.

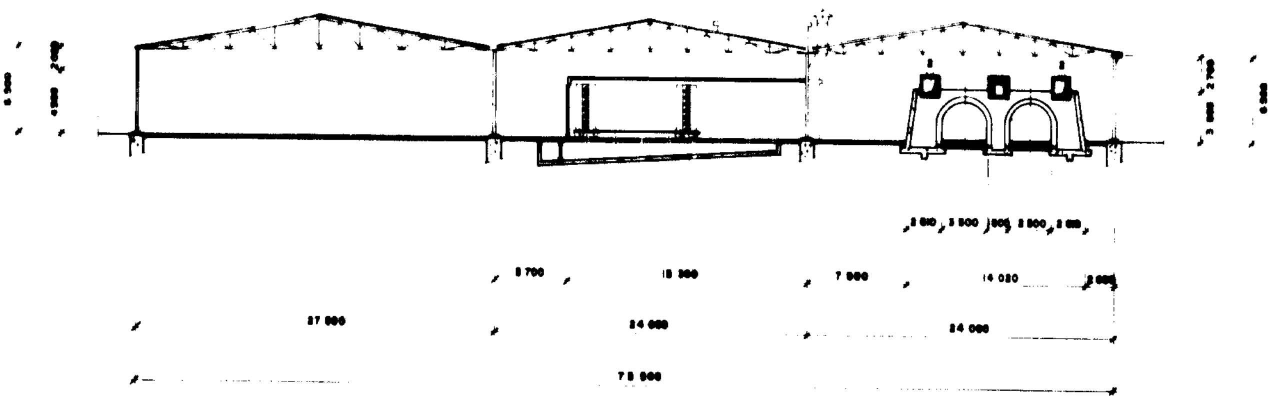
Only rotary table presses will be considered here. The British-made Hercules and Emperor presses are

Figure VII a. Layout of a Hoffmann kiln plant: plan



reported to produce up to 1,800 bricks per hour. The Spengler press has been improved recently and seems to be the semi-dry rotary press with the highest output now on the market. The continuously rotating table of the Spengler press differentiates it from other similarly named presses whose turntables move discontinuously. The press accommodates 6-8 moulds or dies for shapes up to twice that of the standard size, and the making pressure is applied to both sides. The combination of generation of purely mechanical pressure and hydraulic pressure control enables 6-8 working strokes to produce, in steps, a compact product. A rotary feeder is used to fill the die boxes direct from the side hopper. The boxes are then struck or scraped off by the filling box itself. A preliminary pressing and first de-airing is effected by a light stroke of the top die. The next stage is when preliminary making pressure is applied together with the second de-airing, before the third and final stroke in which the bottom die assists in giving the pressed

Figure VII b. Layout of a Hoffmann kiln plant: section A-A
(Dimensions in millimetres)



brick its final shape. The brick is then pressed out of the die box by the bottom die and automatically fed to a belt conveyor. After that the die box is cleaned and prepared before a new pressing cycle can begin. The application of electrical heating to the top and bottom dies can facilitate release of the moulds.

The greatest output of such a press is 2,500 pieces per hour, which is low in comparison with the output of modern extrusion equipment. The dimensions of the largest brick that the press can make are about 240 mm x 171 mm. The maximum filling height is 240 mm, which when fully compressed would give a final product about 150 mm thick.

Apart from the possibility of eliminating drying (only in the case of bricks fired in a continuous moving-fire kiln) the dry-pressing process requires somewhat less power about 20% less than that required for an equivalent extrusion process. The equipment cost is much higher; the press costs over $180,000.

The advantageousness of the process cannot be denied. Since it apparently permits the use of clay containing up to 20% humidity, which is more than the amount of water used in stiff extrusion, many of the disadvantages of dry pressing have been eliminated. About the same porosity and mechanical strength are obtained with it as in extrusion without recourse to higher firing temperatures. Lower strength and higher porosity have always been the characteristics associated with dry-pressed bricks (6-8% moisture).

Even if the bricks with 20% humidity have to be dried, the drying process involved is always simple because no stresses have been incorporated in the bricks as happens in the extrusion process. One manufacturer is able to set semi-dry pressed bricks containing 20 % water directly into the Hoffman kiln and water-smoke them there with the heat from the cooling chambers. Apart from the questionable merit of converting a kiln into a drier, it is certainly a remarkable achievement.

Semi-dry pressed bricks are usually much better looking than extruded ones and are more suitable for facing.

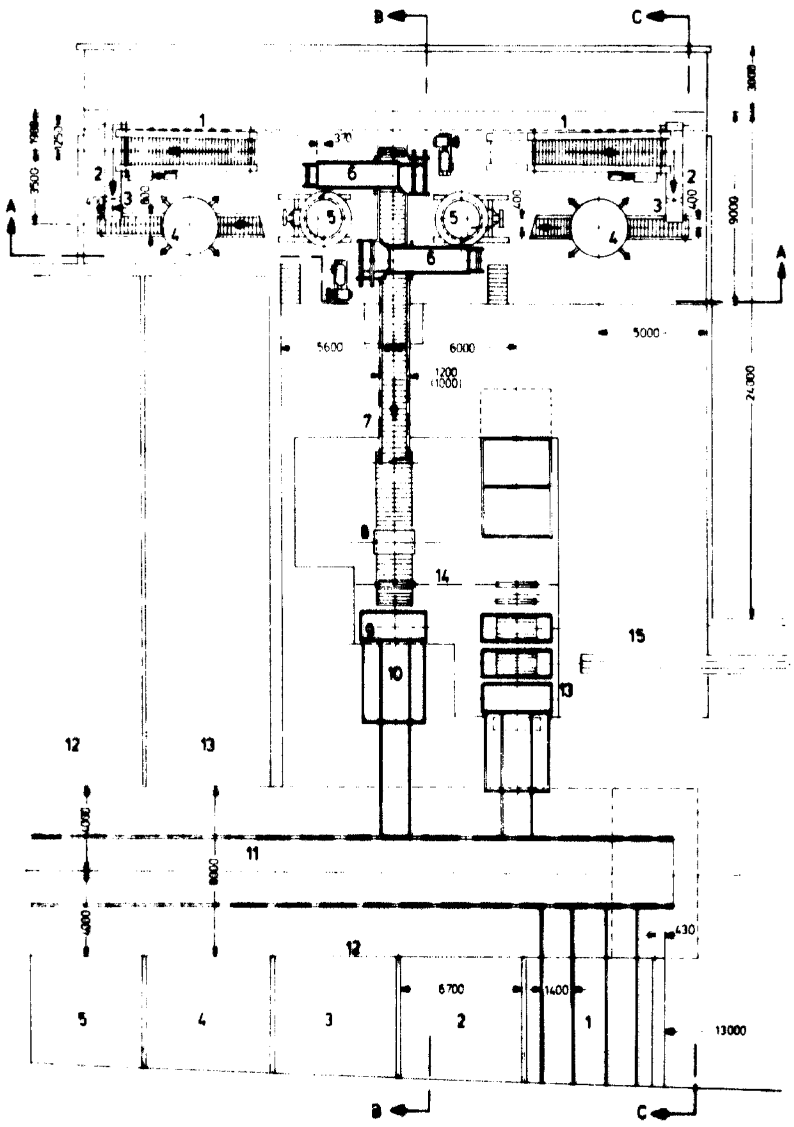
The soft-mud making process

In most soft-mud making machines the moulding action imitates the traditional filling of moulds by hand. Therefore, any clay that can be successfully hand-moulded should be suitable for this process.

The process is used most extensively in the United States and in the Netherlands, less so in the United Kingdom, where it seems to be confined to the stock brick industry. In the Netherlands and in the United Kingdom the use of the soft-mud process is dictated by the nature of the available raw materials. In the United States, on the other hand, the process is used because it imparts a particular character to the bricks that is highly desired in those to be used for facing.

Probably the simplest machine available is the Berry soft-mud brick machine, used almost exclusively in the United Kingdom. Here the clay, which is normally much softer than the clay used in extrusion, is forwarded in a cylindrical barrel through the action of pug-mill knives mounted on a central shaft. The barrel is closed at one end but is provided with discharge openings at the bottom. Blades or spatulas mounted on the same shaft over the discharge openings force the clay through them and into the moulds situated underneath. As with all soft-mud machines, the moulds must be sanded, which may be done either manually or mechanically. The moulds made of wood are automatically pushed under the discharge openings and out again on the other side of the machine. After having been filled, they are knocked against a stop on the table, inverted so that the bricks are discharged on a table where they are placed between thin wooden boards and set on pallets. A four-mould Berry machine makes about 1,400 bricks per hour. The Netherlands and United

Figure VIII. Layout of a brick plant using soft-mud process
(Dimensions in millimetres)



1. Box feeder
2. Rubber-belt conveyor
3. Tramp iron magnetic collector
4. Feeder for additives
5. Sieve kneader
6. Single-shafted mixer
7. Slat conveyor
8. Soft-mud making machine
9. Mould recovery
10. Gathering equipment
11. Transfer track
12. Chamber drier
13. Storage rack for bricks
14. Return of pallets

Source: Ziegelindustrie, No. 5 (1975), p. 201.

States machines are much more sophisticated. Though they operate on the same general principle, there are subtle differences between them.

The United States machine has a single-shafted mixer that delivers the clay to a vertical (but sometimes horizontal) pug mill. The moulds, attached to a continuous belt, are moved under the discharge opening, where they receive their load of clay and the excess is automatically scraped away. Automatic bumpers loosen the moulded bricks, and automatic dumpers deposit the bricks on plywood pallets. The empty mould returns to the machine for resanding and further use.

In the largest Netherlands-built machine, which may be fully automated, 10 bricks can be formed at a time at a rate of 28 moulds per minute. The moulds then travel in a closed circuit loop holding 64 wooden-frame brick moulds. After the moulds have been filled, they move towards the unloader and are struck by a rubber belt. The trimmed-off scrap is returned to the press. A plywood pallet is placed on top of the filled moulds, and the pallet and the moulds are turned over so that the bricks rest on the pallets. As the pallets move forward they are vibrated, which ensures not only that they will be released easily from the sanded mould but also that they will be full. Then the wooden moulds are stripped from the pallets by a mechanical unit that lifts the end of the mould and places it in a clampling shelf, which supports it until it is pushed off. The full pallet continues on the rack elevator and is placed in the gathering frame. The finger car transfer picks up a load 6 deep by 16 high and transfers the moulds to the chamber drier. The empty moulds that are shunted aside are fed through an automatic high-pressure washing cycle followed by a high flow of air, which removes excess moisture. Then the moulds, still with the cavity facing down, come up behind the press and are sanded from below by a sand thrower. They are then turned up into the "cavity up" position and fed into the press. Figure VIII gives the layout of a modern soft-mud brick plant.

IV. Drying

The products manufactured by the extrusion and soft-mud processes must be dried before they are permitted to enter the kiln. In terms of energy consumption, drying is actually the most expensive part of the process. Evaporating the water contained in freshly pressed bricks alone takes approximately 2,440 kJ/kg of water. To that must be added the heat required to raise the temperature of the clay body, which comes to about 230 kJ/kg of clay. Furthermore, the air that effects the drying must also be heated, and the corresponding amount of heat varies according to the type and efficiency of the drier between 1,700 and 4,200 kJ/kg of water evaporated. Furthermore, heat losses account for about 400-7,000 kg of water eliminated.

The amount of heat required to evaporate 1 kg of water contained in the green brick will, according to Macey[3] vary from 4,200 to 12,000 kJ. What the brickmaker needs to know, however, is what it will cost to dry 1,000 bricks 240 x 115 x 71 mm cored so as to give a bulk density of 1.8 kg/l. Such a brick when freshly extruded will contain about 700 g of water. To dry 1,000 such bricks requires 2,900-8,200 MJ obtained by burning 70-196 litres of No. 5 heavy oil costing \$3.50-\$9.80.

Unless waste heat from the kiln is available, to generate heat for drying is not to be recommended. Although attempts have been made to extract heat from the cooling scove and other updraft kilns, the procedure is awkward, since a movable sheet-iron hood has to be placed over the top of the cooling kiln. Usually the sides of the hood are equipped with wheels that move on tracks placed on either side of the kiln. These tracks are fixed to concrete or iron beams supported on columns. In the case of moving-fire continuous kilns, the maximum of about 250 kJ/kg of bricks may be recovered, enough to dry only approximately 30% of the bricks to be fired. This heat should be drawn exclusively from the cooling chambers of the kiln. Some brick plants use the fumes drawn directly from the kiln for drying. This should be done only when non-sulphurous fuels are used. Most heavy residual oils and almost all coals contain much sulphur, which on burning oxidizes to form sulphurous and sulphuric oxides. Since combustion fumes also contain much water, sulphuric acid is produced and deposited when the dew-point temperature is reached. Because of the presence of sulphuric acid, the actual dew point may be as high as 180°C. The deposited acid water not only may cause unsightly scum on the surface of the bricks, but it also corrodes all metallic parts of the drier with which it comes into contact.

Only modern tunnel kilns with their superior fuel efficiency permit all the bricks to be fired to be dried by the recovered waste heat alone, and then only under certain conditions. Such kilns are found in few developing countries.

Open-air drying

In open-air drying solar energy should be used efficiently. Bricks set on pallets may be dried in the sun, but must be protected by suitable covering such as palm leaves or corrugated sheet iron during the early stages of drying. Open-air drying is somewhat more complicated during the rainy season, when the bricks must be sheltered. Not only the tops of the bungs, but also their sides must be protected from rain. Permanent shelters, which need not be expensive, should be erected. Simple wooden structures covered by palm leaves are satisfactory, at least at the beginning. They should be high enough to enable a worker to walk into them upright. If a fork-lift truck is to be used, the shelters must be designed to permit unhindered passage and operation of this equipment.

Bricks and tiles that are automatically placed on laths or pallets only one course high may also be dried under open-air sheds. Light-weight lateral structures with ledges must be provided, however, to receive the brick-loaded laths from the finger car.

Small brick plants that cannot afford laths or pallet-loading equipment frequently use metallic racks in which the bricks are set only one course high. Depending on their size, the loaded racks may then be transported either by hand-operated lift trucks or by motorized fork-lift trucks either to the open air or chamber driers. A typical rack for transport by hand-operated lift trucks measures 150 x 50 cm and is about 60 cm high, accommodating roughly 200 bricks measuring 20 x 10 x 6.5 cm.

Artificial driers

Whenever a continuous kiln is available, about 30% of the kiln consumption is dried in some kind of artificial drier, in most cases a chamber drier. A

[3] H. H. Macey, *Drying in the Heavy Clay Industries*, National Brick Advisory Council Paper No. 3 (London, HM Stationery Office).

chamber drier normally takes the form of a fairly long tunnel with ledges on both sides for supporting the brick-loaded pallets or laths. These pallets are usually introduced into the chamber by a finger car, which moves on tracks. After the bricks have been dried, the pallets are withdrawn in the same manner. In some older brick plants the finger car with its load of dry bricks is pushed to the kiln, unloaded at the corresponding door and then conveyed into the chamber to be set. Either belt conveyors are used or the bricks are unloaded on hand-pushed trucks, which are then wheeled into the kiln. It is here that more manpower is wasted than in any other of the many brickmaking operations. At the same time the bricks are generally mishandled and damaged considerably. In more modern brick plants the dry bricks are unloaded from the finger car and immediately set into packs to be transported and deposited in the kiln. The correct setting pattern to obtain the optimum circulation of the hot gases in the kiln must be strictly maintained.

Very stiff-extruded bricks may be set into such packs right at the making machine's conveyor belt. The first course of the pack that is compressed by the lift truck's fork is sometimes set with fired bricks. Since for firing the setting of packs must be permeable to permit the gases to circulate, the same "permeability" permits the packs to be dried.

The driers must permit the movement of hot air through the packs. If the packs are set in a tunnel-like chamber, hot air may be blown into the packs *(a)* from both sides at the same time and drawn off at the top; *(b)* from one side and drawn off at the opposite side; *(c)* from the bottom and drawn off at the top. The packs are introduced into the chambers and removed from them by a lift truck. Normally no humidity control should be used. The apparatus required for it is expensive and hard to service. Thus clays sensitive to drying should not be used. Since, however, fans are required to blow in the hot air, a rudimentary way of controlling the humidity of the air during the early stages of drying is to recirculate part of the spent and humid air drawn off from the drier. The fans should take the drying air partly from the cooling area of the kiln and partly from the drying chambers by means of damper-controlled flues. A brick manufacturer would be ill-advised to design and construct his own driers, something that requires a great deal of knowledge and experience. A suitable design and specifications for a drier should be obtained from a specialist in drying techniques and the drier built by a responsible engineer.

In tunnel kiln plants in which solid or cored bricks are manufactured, the bricks should be extruded as stiff as possible and set directly on the kiln car tops. They are then dried in tunnel kiln driers heated by waste heat recovered from the kiln. The design of the tunnel-kiln driers is similar to that of the driers used for drying packs handled by fork-lift trucks. Sometimes, however, for increased efficiency the three ways of air circulation described above are applied successively in the same drier.

Soft-mud bricks, which are normally discharged on plywood pallets, are usually carried off by finger cars and dried in the same way as bricks or tiles manufactured by soft extrusion. Semi-dry pressed bricks fired in continuous moving-fire or periodic kilns do not require any drying and may be set directly in the kiln from the press. For firing in tunnel kilns, however, they must be predried by passing through a tunnel kiln drier.

Recently brick drying has been revolutionized. It was realized that drying bricks in bulk was not efficient. Most bricks can be fired much faster without damage by exposing them to the drying air from all sides. This principle is being applied in new driers in which bricks are dried in a matter of hours. Since, however, much development work is still needed, brickmakers in developing countries should for the time being stick to the old-fashioned chamber drier and make as efficient use as possible of solar energy.

V. Types of kiln

Facilities for firing bricks range from something that is not even a kiln to sophisticated installations costing hundreds of thousands of dollars. At one end of the scale is the "clamp", in which the charge to be burned is also the kiln. At the other extreme is the modern tunnel kiln. For developing countries, the degree of sophistication of the chosen installation will depend on local conditions, above all the stage of development, the type and the size of the available market and the available capital.

Periodic kilns, either rectangular or round (also called beehive kilns) will not be considered here, since their use is only justified for firing high-quality face bricks to give special effects. They consume sometimes five to seven times as much fuel as a continuous kiln. Furthermore, even these kilns for specialized uses are being replaced by modern, large shuttle kilns holding up to 60,000 bricks and capable of firing them in 48 hours cold to cold.

The most convenient type of kiln is the moving-fire continuous kiln originally associated with the name of Hoffmann but of which there are now many designs. The old type of Hoffmann kiln, the so-called zig-zag kiln, characterized by its ungenerously dimensioned doors through which the bricks were introduced loaded on pushcarts to be hacked, or set by hand, have been gradually superseded by the modified Hoffmann, with its heads cut off to permit access of fork-lift trucks. In these kilns the whole cross-section of the tunnel is the charging door. The so-called bull's ring kiln, which is to the Hoffmann what a scove kiln is to a periodic kiln, derserves special mention.

Tunnel kilns were used first in the United States, where practically all bricks are face bricks. After the Second World War their use spread to Europe. Continuous kilns of the moving-fire type are hardly ever used now in France and the Federal Republic of Germany. Some of them are still in use in Italy, but no new ones are being built.

Fuels

Until a few years ago it might have seemed wise for a developing country having no fossil fuels of its own and using, for instance, coconut husks for fuel to extract oil from this crop of agricultural waste, use the fibre for textile purposes and import the cheapest grade of fuel oil. This policy should no longer be followed. With the advent of the energy crisis, the use of oil for heating is out of the question in many developing countries.

In the third world the amount of energy obtained daily from wood and dung fuel is approximately equivalent to the amount contained in the total flow of crude oil to the world's commercial markets, that is, around 30 million barrels a day. What characterizes poverty is not so much the low *per capita* consumption of energy but the relatively small amount of useful work that is obtained from that energy. The problem is to increase the efficiency with which these available and largely renewable resources are used.

While undoubtedly few persons would seriously consider using dung as fuel in firing bricks (even though it is still used in many countries to fire pottery) certain agricultural wastes like coconut, rice and groundnut husks, chaff and straw can almost always be found, which when properly used make very satisfactory fuel for brick kilns. Coconut husks, for instance, have the surprisingly high calorific value of 14,700 kJ/kg. Although dependable statistics are lacking, it has been estimated that even a small country like Togo produces close to 12,000 tons of husks per year capable of generating 176,000 million kJ. Agricultural wastes are, therefore, potentially the best fuel for brick plants, and they should be used extensively. Unfortunately, such wastes are seldom available where they are needed, and their bulkiness increases the cost of transport.

Next in importance is wood. Conservationists used to object because of wide ranging deforestation that resulted from the uncontrolled and indiscriminative use of wood for fuel. Deforestation can be avoided if a reasonable conservation policy is devised and strictly enforced.

Completely dry wood yields between 17,000 and 21,000 kJ/kg. In African forests, for example, clear felling of all standing timber may yield up to 60 tons of timber per hectare, though it would be unwise to obtain such a yield. On the other hand, coppicing provides some 125 tons of wood per square kilometre per annum, a considerable amount.

However, the use of wood and agricultural wastes limits the choice of kiln. All these fuels may be used in moving-fire continuous kilns, but their use in modern tunnel kilns is questionable. Some tunnel kiln advocates suggest incorporating chaffs or rice husks within the clay body and the product in an oil-fired tunnel kiln, but only a small amount of these wastes can be used in the clay body without impairing its mechanical properties. They should not form more than 5 % of the clay body.

The use of tunnel kilns should possibly be limited to countries having sufficient reserves of fossil fuels.

Updraft kilns

The "scove" kiln seems to be a development of the clamp, which has already been mentioned. Here the bricks are set in an open pattern up to 40 courses high forming a steep truncated pyramid. The width depends on the fuel being burned, being around 60 stretchers for oil-fired kilns and about 40 for wood-fired ones. Fireboxes are left in the lower part of the structure, generally 3 stretchers wide and up to 13 courses high. Their centres are about 5-6 stretchers apart. Hot gases generated in the fire-boxes rise through the setting to the top, where they escape into the open through strategically placed flues. Originally the outside of the brick setting was smeared, or "scoved", by mud to avoid heat losses. Large kilns are now provided with an outside skin of fired bricks, which are then used repeatedly, a considerable improvement over the original scove kiln. The proportion of underfired bricks is much lower than it was with the earlier scove kilns, in which as much as 20 % of the output had to be rejected or refired.

Until recently such kilns were used extensively in the United States. Extremely large kilns, sometimes holding over a million bricks, were built and fired at one time. They were usually fired with heavy fuel oil, but almost any type of fuel can be used. The fuel economy is fairly good. With heavy fuel oil, consumption varies according to the type of clay and the hardness desired. The lowest consumption reported is 1,400 kJ/kg of bricks and the highest 3,600 kJ. Heat consumption of 2,100 kJ/kg of bricks is reported from an African country where coconut husks were used as fuel.

Updraft kilns of this type are convenient tools for a new brick plant because heavy capital does not have to be diverted immediately to the construction of a permanent kiln, which even in its most simple form is expensive. Instead, a permanent kiln may be built later from profits accumulated during the initial operations based on updraft kiln firing. In fact, even if the construction of a permanent kiln is planned from the very beginning, it will be almost inconceivable not to start with an updraft kiln to fire the bricks needed for the erection of the permanent kiln.

Updraft kilns lend themselves very well to mechanized setting and unloading. Analyses of expenditures for labour in a brick plant frequently show that hauling, setting and drawing take up as much as 40 % of the total manpower involved. Having no permanent walls nor doors, large updraft kilns may be easily set by means of fork-lift trucks. Even moving gantries equipped with cranes have been used for this purpose.

Sometimes permanent updraft kilns are built to save the labour required to build the outside shell every time a new setting is erected and removed again after the end of the burn. Some fuel saving is also obtained in such permanent updraft kilns, but it is insignificant, being limited to the prevention or diminution of radiation losses. At the same time, more heat is lost owing to storage in the thicker walls. The economic success of updraft kilns depends on their ability to be fired rapidly.

Continuous kilns

The fuel economy of most periodic kilns is poor; in fact, most of the heat input is lost in *(a)* flue gases, which in this type of kiln leave the kiln at the temperature at which goods are fired; *(b)* sensible heat stored in the kiln walls; and *(c)* heat content of the bricks. In updraft kilns the fumes leave the kiln at a much lower temperature, which means that less heat is lost. This economy is, however, achieved at the cost of underfired bricks on the top of the setting.

In continuous kilns fuel economy is achieved through reducing the three types of heat losses referred to above. Losses due to *(a)* are greatly reduced by using the hot gases of combustion to preheat bricks still to be fired, whereas heat normally lost due to *(c)* is used for drying. Heat losses due to *(b)* are dealt with below.

There are two basically different approaches to the problem of heat saving. What both of them have in common is that the firing is never interrupted. But whereas in one type of continuous kiln the brick charge remains stationary while the fire moves, in the second type the fire remains stationary and the brick charge moves. This difference between the two types of continuous kilns determines how the heat losses due to *(b)* can be reduced. In the moving-fire continuous kilns the heat stored in the kiln's masonry, together with that given off from the cooling ware, is used in drying. In the tunnel kiln this heat remains stored in the kiln walls and crown and is lost only when the kilns must be shut down, which happens infrequently, generally not oftener than once a year. However, heat losses from conduction through the kiln walls and its subsequent radiation may be pronounced. This problem can easily be dealt with either by insulating the walls efficiently or by using the conduction heat for drying. This type of heat loss can be dealt with solely through the design.

Moving-fire continuous kilns

Although the Bull's ring kiln is of much later origin than the Hoffmann kiln on which it is based, it will be mentioned first, since it is the more primitive of the two. The Bull's ring kiln consists of a circular or oval trench dug out of the ground. Though dimensions vary widely, the commonest type may have a diameter of 30-50 m. The trench itself is roughly 6 m wide and some 2.5 deep. Another also widely used design consists of two parallel trenches connected at either end. The brick setting is normally made up of free standing bungs one stretcher square with 7-8 cm space all around them for fire travel. In the last three courses the bricks are laid close together, thus bridging the free spaces underneath. Feeding holes are left in this brick covering and also one or two radial slits, one for each of the sections or chambers into which the setting is divided. The sections are separated from each other by large metallic dampers reaching from top to bottom that seal off the entire width of the trench. The above-mentioned brick layers are then covered with 10-15 cm of coal ash.

The most distinguishing feature of this kiln is the movable stack. Made of sheet iron and up to 15 m high, it has a lower collecting chamber, or plenum, which is placed over the slits in the kiln covering referred to above. It provides the draft required for the operation of the kiln. The kiln may even have two of these stacks. They are moved over to the next section's slits as the fire advances. Afterwards the dampers are removed and new fireholes put into operation.

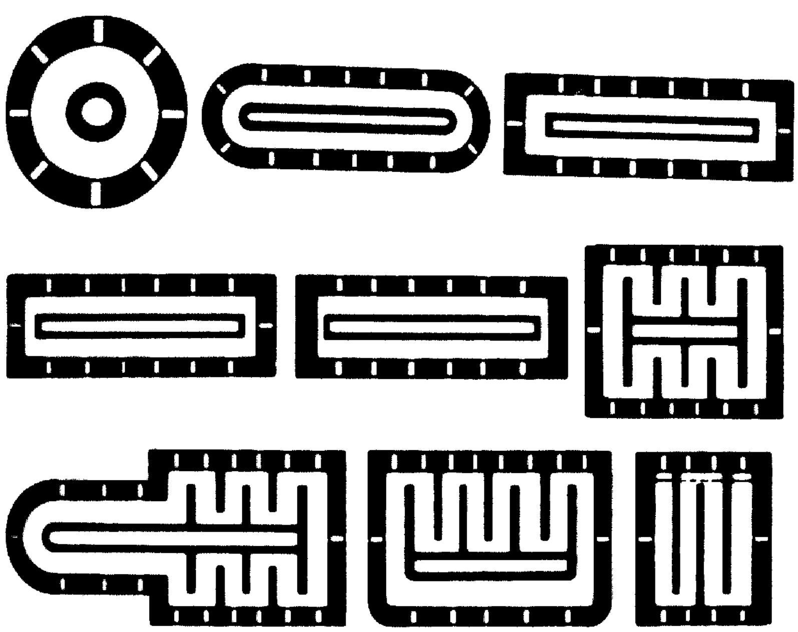
In more advanced kiln designs the side walls may be built of bricks or partially built of bricks and partially dug out. Sometimes the exhaust flues are built into the walls. The outside wall usually carries the flues, but sometimes the inside one does. The flue openings are connected with horizontal shafts over which the travelling chimney is placed.

A kiln of the dimensions given above may contain up to 600,000 bricks, and the output will be about 30,000-35,000 each 24 hours. The average consumption of fuel varies from 1,150-1,900 kJ/kg coal. In view of this good fuel economy, the Bull's ring kiln deserves to be more widely known and used. At present it is used mainly in India and Pakistan. Its operation is labour intensive; firing itself requires six men.

Two general types of kiln must be distinguished according to their construction. The first type is built with a continuous longitudinal or barrel arch; the second is divided into several transverse chambers each with its own barrel arch. Kilns of the first type are known as Hoffmann kilns even though the original design has often been changed significantly. Figure IX shows some of the developments of the originally round Hoffmann kiln and examples of the zig-zag kiln, which is one of the multiple-chamber transverse arch type of kilns.

The modern Hoffmann kiln consists of two long barrel-vaulted chambers connected at each end by a flue. The small side doors (or wickets), so typical of the early Hoffmann kilns, have disappeared. Now the whole cross-section of the chamber is a door for setting and drawing purposes. Some must be closed

Figure IX. Historical development of the Hoffmann kiln design



Source: W. Avenhaus, *Rechnungsgrundlagen für den Entwurf und den Betrieb keramischer Brennöfen* (Hatte, Knapp).

for firing and demolished when necessary. The inside of the kiln thus is accessible to the fork-lift truck. Not only is the hacking and unloading the most labour-intensive operation, but it is also that operation in which the most bricks are lost because of the carelessness involved in multiple handling. All brick plants in developing countries should introduce the use of fork-lift trucks into their brickmaking. That is one phase of mechanization no brick plant in a developing country should be without.

A well-run Hoffmann kiln uses a minimum of 1,340 kJ/kg of bricks at a firing temperature of about 1,000°C. Using 2,500-3,400 kJ is more common. Approximately 250 kJ/kg of bricks can be withdrawn from the cooling chambers to be used in drying, which means that only about 30 % of the kiln's load can be dried by the recovered waste heat.

Any type of fuel may be used to fire the Hoffmann kiln. Coal was and still is the most widely used fuel, followed by oil whenever it is available. Countries lacking fossil fuels should concentrate on using wood and or agricultural wastes.

A Hoffmann kiln can be built more cheaply than any other type of continuous kiln. For equal capacity it costs about 30% less than a tunnel kiln. It is normally built of the same type of bricks that will later be fired in it. No fire-bricks need to be used, since each part of the kiln becomes successively accessible for inspection and eventual repair. However, to minimize maintenance cost, the flue openings connecting the kiln space with the main exhaust flue and sometimes even the main flue itself should be lined with good-quality fire-bricks. In old Hoffmann kilns the draft necessary for the operation of the kiln was provided by a stack. Today better results are obtained by means of exhaust fans.

The tunnel kiln

The tunnel kiln is certainly the most efficient tool for firing bricks. If correctly designed, it has a remarkable thermal efficiency, and waste heat recovered from it is under certain conditions sufficient to dry its entire load, that is, if the firing temperatures are at least 1,000°C.

The operation and the setting and unloading can be easily mechanized. Many automatic and semi-automatic setting machines are being marketed. Setting machines are complex and expensive, and developing countries will probably have to do without them for some time. However, a modern tunnel kiln may easily be set and unloaded by fork-lift truck, especially the modern, wide and low kilns in which the setting on the car is divided transversally and laterally into bungs or packs. Modern tunnel kilns are becoming wider and lower. A width of over 6 m is common; the optimum would be about 30 stretchers across and up to 10 courses high.

The ultimate development is the "one-high" kiln, in which the setting is just what the name implies, that is, one course. Such a kiln can be fired at very high speeds and may be set automatically by the simplest type of setting machine. The number of rejects is reduced to a minimum. However, the definite merit of such kilns has not yet been proved. These kilns are of interest only marginally because the bricks required by most developing countries will probably be a combination of masonry and face brick, that is, bricks that can be used for either purpose.

A tunnel kiln may be described as a long tunnel internally lined with fire-brick. It is normally divided into a preheating section; a firing, or high-temperature, section; and a cooling section through which the bricks, set on refractory-lined platforms, successively pass in the process of firing. The three main sections are further subdivided. One may distinguish a separate zone of flues, or exhaust zone, where the fumes drawn from the firing section pass through the setting of incoming bricks that are giving up their heat content and are exhausted through several lateral openings by a fan. The next zone is sometimes referred to as "water-smoking" zone, even though in a properly designed and operated tunnel kiln, no "water smoking" should take place. Then comes the preheating section followed by the high temperature, or firing zone, where the bricks are actually fired.

The cooling section comes, of course, last. Its first subdivision may be a fast cooling zone in which, by forced recirculated air, the bricks are rapidly cooled from the temperature at which they were fired to the one somewhat above that at which they may suffer from thermal shock, which is about 800°C. After that temperature has been reached, subsequent cooling is much slower. Depending on the kiln design (affected by the quartz content in the fired brick or its porosity) there may be a zone where indirect cooling may take place through a series of thin refractory or sheet-iron baffles, followed again by direct cooling by air that is blown in.

The hot air from cooling bricks is utilized in at least two ways. Part of it is drawn into the firing zone, where it may serve as source of secondary air for combustion purposes. Another part is exhausted and used to dry bricks.

The cooling bricks are, however, not the only source of waste heat. An additional and by no means inconsiderable amount of heat is available above the kiln vault. The presence of this hot air is due to conduction through the refractory vault. While the passage of heat through the kiln's vault may be theoretically prevented entirely through proper insulation, it is not usually advisable, since the mean temperature to which the vault is exposed increases considerably. A compromise is usually reached in the sense that just enough insulation is applied to the extrados of the vault to obtain sufficiently hot air for drying. For obvious reasons the cooling section's crown is left uninsulated, and a reasonable amount of heat is collected from the space above it.

The heat input takes place in the firing section. The tunnel kiln is ideally suited for burning gaseous or liquid fuels. The traditional way of firing the tunnel kiln is from both sides by means of suitable burners using low-pressure or high-pressure air for atomization and as primary combustion air. The secondary air was in the past partly induced by the action of the burners and partly drawn in from the cooling section. The tendency now is to use sealed-in burners. Some kilns even utilize preheated air that may be brought in from the cooling end and blown into the kiln space in front of the burners.

Particular problems are presented to countries without liquid fuels of their own and unwilling or unable to import them. In countries having coal, producer gas used to be manufactured from it. But producer gas is a fuel of low calorific value and not much favoured as fuel for tunnel kilns because of the high volume of combustion gases resulting from its use, which in turn cause considerable losses in the heat going through the chimney. In a few countries pulverized coal is fed from the top directly into the spaces provided in the setting, thus in a way imitating the operation of a Hoffmann kiln. This practice leads to uncleanliness in the plant and to frequent brick discoloration in places where the coal is in contact with the ware. Modern tunnel kilns are now seldom directly coal-fired.

Even with liquid fuels top firing is frequently used. Today, opinions regarding the convenience of top and side firing are about equally divided. The case for top-firmed tunnel kilns was probably enhanced by the already mentioned fact that brick tunnel kilns were growing ever wider, which meant that if side firing was used the sides of the setting were either overfired or an underfired core was left in its centre. This obstacle, however, has been overcome either through the use of special burners in which the complete combustion actually takes place in the burner or through undercar firing, that is, firing under the brick setting.

The car tops above the metal chassis are normally built of refractory material, which may be fire-bricks, special large, hollow tiles or refractory concrete, the first-mentioned material being the least satisfactory. In countries where refractories are not manufactured or are too expensive, car tops may be built from the same kind of bricks as those being fired. This possibility is determined by the bricks' firing temperature; the practice is seldom recommended for firing temperatures over 1,000°C. With platforms made from common brick, maintenance is more frequent. A better but still expensive possibility is to grind and screen discarded fire-brick bats to about an 8-mm size and prepare from the ground material a refractory concrete (or castable as this material is called in the United States) mixing it with about 20% of a high alumina cement (lafarge cement) and 5% of clay. The car tops may then be cast from such a mix.

For best results tunnel kilns must be heavily instrumented; full automatic firing control is indispensable. This requirement again poses a further problem for some developing countries, since tunnel kiln instruments must be carefully maintained and serviced; but the kind of service they require is not readily available. A second choice in such a case is to train an engineer to service a pyrometer or pyrometric equipment. Facilities for the training, however, must be sought outside.

Modern tunnel kilns use 1,450-2,300 kJ/kg of clay. Generally speaking, the longer the kiln, the better should be the fuel economy. Much depends on the kiln's insulation, the weight of the cars etc. Whether the waste heat recovered from the kiln will dry all the bricks it will fire depends on many factors, not the least important being the kiln's design. Of cardinal importance are the volume and temperature of the exhaust fumes.

The volume of exhaust fumes depends on the excess of air with which the kiln operates and on the degree of infiltration of "false air". The volume may be expressed as a ratio of the volume of fumes to the volume of bricks. Most tunnel kilns operate with a ratio of 5.5, and the temperature of the exhaust fumes is 150°C. The loss of heat in exhaust fumes is about 3,000 MJ/h, or 41.5% of the total heat input. By reducing the temperature of exhaust gases to 100°C and maintaining a volume of fumes/volume of bricks ratio of 2.5, about 37,000 litres of heavy oil may be saved each month.

Whether this saving can be achieved depends a great deal on the amount of excess combustion air used in the operation, which again is a function of the carbon content of the clay. Also a high volume of exhaust fumes aids in preheating, which permits higher firing speeds. There is, therefore, a limit to which the volume of exhaust fumes can be reduced. The amount of false air is determined by the kiln design.

The temperature of the exhaust fumes depends chiefly on the sulphur content of the fuel. With very high-sulphur fuels, the temperature of the exhaust fumes must sometimes be as high as 180°C because of the danger that the sulphuric or sulphurous acid-laden fumes, which have a high dew point, may condense on the incoming bricks and cause scumming.

Whether the waste heat recovered from the kiln will dry all the bricks to be fed into it depends on many factors, not the least important of which is the kiln design. To provide enough hot air for drying, fuel efficiency is sometimes sacrificed. Other factors, which affect the number of bricks the recovered waste heat will dry, depend on the firing temperature and the moisture content of the fresh bricks. According to a survey of 14 brick firing kilns in the Federal Republic of Germany with an average energy consumption of 1,737 kJ/kg of bricks produced, the amount of heat recovered in hot air for drying was

322 kJ/kg (which corresponds to 18.5% of the total heat input and 46 % of the heat actually used in firing, excluding kiln losses).

Tunnel kilns designed in the United States are expected to dry all bricks to be fired in them, the bricks being stiff-extruded and in extreme cases containing as little as 10% moisture. The above-quoted figures would indicate, however, that most tunnel kilns do not provide enough waste heat to dry soft-extruded bricks containing 20% or more humidity, especially if the firing temperature is less than 1,000°C.

The tunnel kiln has certain advantages as against the moving-fire continuous kiln, although a well-designed and properly run kiln of the latter type consumes about as much heat per kg of bricks as a tunnel kiln of comparable capacity and the cost of labour in setting and unloading is about the same if fork-lift trucks are used. However, an automated tunnel kiln requires much less supervision than a moving-fire kiln, and its firing uniformity is far better. To obtain uniform production from a moving-fire kiln, considerable skill both in setting and firing it is required. Unquestionably the tunnel kiln produces a superior product, and the proportion of rejects is much lower. Furthermore, moving-fire continuous kilns can seldom be used for firing at temperatures over 1,000°C, whereas in tunnel kilns there is no limit as far as the firing temperature is concerned.

One disadvantage of the tunnel kiln is its inability to burn other than liquid and gaseous fuels. The second disadvantage is its high initial cost, which inflates considerably the investment cost of a brick plant and increases the product's amortization charges. The figure quoted for a 60-ton-per-day tunnel kiln may compare with the approximate cost of a Hoffmann kiln of the same capacity given in annexes VIII and IX. It may be seen that the cost of the latter represents only 54% of the former.

VI. Detailed comparison of tunnel kiln plant and Hoffmann kiln plant of same capacity

The cost of manufacturing, drying and firing equipment for an annual production of 1 million bricks decreases very slowly with increasing total capacity, as annexes V and VI show. The rate of decrease will be slower for the Hoffmann kiln plant than for the tunnel kiln plant because of the lower ratio

$$\frac{\text{Cost of drying and firing equipment}}{\text{Cost of manufacturing equipment}}.$$

The convenience of projecting for a higher production capacity than that required is immediately obvious. The higher production capacity is not needed at the moment but is installed because of the favourable investment: the production-to-capacity ratio will depend on the results of the market research carried out especially as regards potential for growth. Subject to this reservation, two specific projects for brick plants will be described.

Both plants operate under identical conditions, differing only in the manner in which the extruded bricks are handled for drying and firing. Each plant has a daily output of 60 fired tons of perforated bricks, each of which is 240 x 115 x 75 mm in size and weighs 2.5 kg. The clays are won by hand digging and shovelling in a pit with an average of 1 m overburden approximately 5 km from the brick plant. The clay is transported to the plant by a tilting truck holding 10 tons of material.

The soft-extrusion process is used and the clays available permit the use of simple equipment. The clays are crushed in a preliminary crusher and then fed into a box feeder. The box feeder in turn feeds one set of fine laminating rolls that prepare the material for the double-shafted mixer, where a homogeneous body with the proper water content is prepared, to be extruded through a de-airing pug and cut by a single-wire automatic cutter. Up to this point the two plants are identical.

In the tunnel kiln plant the cut bricks are set manually on racks at locations 4 and 5 (shown in figure VI) so that several workers can unload and load simultaneously. The loaded drier racks are transferred to the open-air drier by manual lift trucks. The usable area of this drier is roughly 1,200 m^2; its purpose is to eliminate enough water to make the bricks sufficiently stiff to set on tunnel kiln cars. The racks are brought to area 3 for setting the bricks on tunnel kiln cars. The empty racks are transported back to location 4 or 5 for reloading. The set tunnel kiln cars are transferred by means of transfer track 2 into the tunnel drier or, to accumulate a reserve of loaded cars for the remaining shifts of the day or for weekends, to track 1. After passing through the final drier, the cars, by now dry, enter the tunnel kiln via transfer 1. The final drier uses exclusively waste heat recovered from the tunnel kiln. The fired ware is transferred to track 3 for unloading, sometimes directly on the waiting trucks for delivery to the customers; or the bricks may be stacked in the uncovered yard alongside transfer track 1.

The tunnel kiln itself is a top-fired one, 65 m long, burning residual No. 5 oil, the heat consumption being 2,300 kJ/kg of fired bricks. The plant is equipped with a substation for 300 kVA and a subterranean concrete tank holding 100,000 litres of oil. In addition to that there will be a cylindrical elevated tank with a capacity of 5,000 litres for the day-by-day consumption of the kiln. The required capacity is manufactured in one shift, five days a week, 50 weeks a year. Production schedules and raw material requirements are given in annex VII.

In the Hoffmann kiln plant the cut bricks are hand set on larger racks that are carried to the open-air drier by a lift truck. After they have hardened sufficiently to withstand stacking, they are moved again by the lift truck and deposited in the chamber drier. This drier has four chambers and uses waste heat from the Hoffmann kiln. The drying time assumed is 20 hours.

After the moisture content of the bricks has been reduced to not more than 3%, the lift truck removes the racks from the chamber drier and the bricks are unloaded and formed into packs outside the kiln. The packs are placed in the Hoffmann kiln by a fork-lift truck, which is also used to remove the fired bricks from the kiln and to transport them to the yard. To enable the fork-lift truck to enter the Hoffmann kiln, the kiln is of the type with cut-off heads. It is fired by wood from the top. Figure VII shows the schematic layout of this plant. Raw material requirements and production schedules, which are the same as for the tunnel kiln works, are given in annex VII.

Quality and production controls

Raw materials and quality controls are usually neglected in small and medium-sized brick plants because they are considered too expensive. A plant with a capacity of 60 tons per day on which the examples given are based merits at least some such controls.

Mechanical strength being the outstanding characteristic of any structural building material, most clay-testing laboratories are equipped with machines to test for this characteristic. Since determination of crushing strength must be made on full-sized bricks, these machines are usually large and, therefore, quite costly. Their acquisition cannot be recommended, at least not at the beginning. However, since there is an almost linear relation between porosity and strength, much can be learned from a determination of porosity. Once the relation between strength and porosity of a clay or a clay mix has been established (which can be done by sending representative brick samples to an institute to determine the crushing strength), checks on porosity, especially combined with the observation of fired colour, permit good control of the clay's uniformity and of the properties of the final bricks. Therefore, the control of the sample brick plants will be confined to the determination of porosity, shrinkage and firing colour.

The uniformity of clay supplies is of overriding importance. The raw material must be checked before the clay reaches the plant, usually at least one month before the plant requires it. Therefore, the control laboratory should work with samples taken by the pit foreman from those parts of the pit expected to be exploited one month later. Since it is always advisable to plan the pit's operation far in advance, samples from those areas to be affected in a year or two should also be tested. Again, these samples will be obtained and submitted by the pit's foreman.

The investment

The total estimated investment costs for each type of plant are given in annexes VIII and IX. Considerable caution must be exercised in using these figures, since their degree of reliability varies a great deal. Only the figures marked with an asterisk are based on actual quotations submitted by several equipment manufacturers and represent the level of prices prevailing at the end of 1975. They have been increased by 40% to represent the cost of transport to an overseas country plus duties, fees and other expenses. This percentage may vary, however, from one country to the other according to the import duty levied. Some countries, to promote industrial growth, forgo import duties entirely.

Figures marked with a double asterisk, essentially costs of land, are based on what is believed to be the minimal requirements. The costs per square metre tend to be on the high side and represent the top prices that should be paid. Still less reliable are the figures marked with a triple asterisk. No universal validity is claimed here, since civil engineering costs vary sharply.

It is equally hazardous to estimate labour costs. The calculation of overburden clearing and removal and clay-winning costs are based on experience in several developing countries, but they may not apply in every case because of the variations in the configuration of the clay strata, nature of the overburden, wage level etc. Electric power costs vary widely but tend to be high. The estimate of $0.048 per kWh and the estimates for diesel oil and gasoline prices are believed to be on the low side. However, since in all cases the estimates are based on units such as man-hours, tons, and square metres, adjustments can be made on the basis of real costs and prices in each locality or country.

Annexes VIII (1) and IX (1) list expenses incurred from the time the brick plant was first conceived until the required land was purchased and the equipment ordered. During this period equipment specifications are prepared, quotations obtained and all the clay prospecting and testing carried out.

Section 3 in annexes VIII and IX lists salaries and expenses of the administration personnel needed during the construction period and salaries of technical personnel while they are being trained. The salaries of the technical personnel during the construction period are charged to "Equipment", section 7 of annexes V and VI, since they represent legitimate installation expenses, which are part of the final cost of equipment.

The investments required for each of the two plants are summarized below.

Tunnel kiln plant

(Dollars)

Fixed capital investment (annex VIII)	
(1) Pre-investment and preparatory expenses	46 000
(2) Clay pit and its development	106 600
(3) Wages, salaries and other expenses during the construction period	47 720
(4) Utilities	50 400
(5) Office equipment	10 000
(6) Land and civil engineering	464 300
(7) Manufacturing and other equipment	1 361 000
Total fixed capital investment	2 086 050
Working capital	
Manufacturing, administration and sales expenses for approximately 2 months	95 000
Total investment tunnel kiln plant	2 181 050

Hoffmann kiln plant
(Dollars)

Fixed capital investment (annex IX)

(1)	Pre-investment and preparatory expenses	46 000
(2)	Clay pit and its development	106 600
(3)	Wages, salaries and other expenses during the construction period	49 520
(4)	Utilities	35 400
(5)	Office equipment	10 000
(6)	Land and civil engineering	608 150
(7)	Manufacturing and other equipment	1 003 700
	Total fixed capital investment	1 859 370

Working capital

Manufacturing, administration and sales expenses for approximately 2 months	90 000
Total investment Hoffmann kiln plant	1 949 370

The Hoffmann kiln plant is roughly $150,000 cheaper than the tunnel kiln plant. This relatively small difference is due to the fact that in spite of the considerable difference between the costs of the tunnel and Hoffmann kilns, the latter plant requires almost 70 % more covered area.

Personnel requirements

Annexes X and XI show the personnel requirements for the two plants. Although the number of workers is somewhat higher for the Hoffmann kiln plant, this increase is due chiefly to the use of wood for firing, which requires manual stoking as well as hauling of the fuel. If it were not for this operation, somewhat fewer workers would be required for the Hoffmann kiln than for the tunnel kiln plant.

The managing director should have a thorough knowledge of general business administration, and preferably be a graduate of a college that includes this subject in its curriculum. He should have a firm grasp of modern marketing methods. A background in either building materials or the construction industry is desirable. A sales manager may frequently be dispensed with, depending on the interest of the general manager in marketing and the character of the market. If only a few but important clients are to be served, the managing director may act as his own sales manager, perhaps assisted by a senior salesman working on a commission basis. However, if a sales manager is engaged, he must have a background either in the building materials or construction industry.

As for the technical employees, the staff is limited to one plant superintendent, one chief of quality control and a foreman. The first two posts should be occupied by engineers, the first preferably by a mechanical engineer and the second by a chemical or ceramic engineer. With suitable training a secondary-school graduate could occupy the second post, since knowledge of chemistry is not absolutely indispensable. His work will consist in checking the uniformity of clay supplies and of the fired product.

The plant superintendent, who is in charge of all operations, reports direct to the managing director. He oversees and controls the clay pit operations and raw material supply through the pit foreman and the manufacturing side of the works through the production and kiln foreman. The production foreman is the key person in any successful operation, and much will depend on his character and leadership ability. He trains and directs the workers, takes care of the installations, supervises the planned production both as far as quantity and quality are concerned. He also prepares the production and payroll reports. A man with a mechanic's background and a natural feeling for handling of tools should, with appropriate training, make a good foreman.

The pit foreman should have most of the qualities required of the production foreman. Three kiln foremen are required; a fourth substitutes for the three on their days off. During the remaining three days he attends to repairs of the Hoffmann kiln or in the tunnel kiln works, and assists in the maintenance of the tunnel kiln car tops.

Personnel training

No previous specialized training is normally required for the managing director and for the sales manager. However, specialized training for the plant superintendent is absolutely necessary. He should be sent to a large modern brick plant for this training, preferably in one of the developed countries. He should spend at least six months there familiarizing himself with all aspects of brick manufacture, including organization of the clay pit, clay testing, control of manufacture and maintenance. Since, however, procedures used in developed countries cannot be blindly applied to developing countries, he should also be given the opportunity to work for three months in a modern brick plant in a developing country.

After he has returned and the construction of the plant has begun, he will act as counterpart of the crew that will supervise the construction of the plant and will, therefore, have ample opportunity to familiarize himself with the equipment and its requirements. This will broaden his knowledge and prepare him for taking over his duties as plant superintendent.

The technical employee in charge of raw materials and quality control will also profit from six months' work either in a brick and clay institute or in some large brick plant where quality control is practised. For carrying out his functions in a tunnel kiln plant he should have some knowledge of maintenance of pyrometric equipment (thermocouples, voltmeters, ammeters, potentiometers). Such knowledge is not difficult to acquire and is invaluable because reliable servicing facilities are not always available. Such knowledge, however, is best acquired at the instrument manufacturer's plant, but most good clay research and testing institutes can give such instruction.

The works foreman should also receive at least six months of thorough training in a modern brick plant. He should be trained in all types of maintenance, in particular, preventive and corrective maintenance, and its scheduling.

The pit foreman should also receive at least three months' training in a large brick plant that does not use excavating machinery in winning its clay. He should be instructed in the correct way of using hand tools, such as picks and shovels, and the precautions to be observed in handling and employing explosives for blasting. He should be familiar with the way clay strata run, bend and outcrop.

The four Hoffmann foremen are normally trained by the engineer contracted to build the kiln. However, such training is seldom sufficient because learning to judge the temperature by eye and observe and determine the fire's progress takes a long time. Three months' training in a Hoffmann kiln brick plant that uses wood or a similar material as a fuel is necessary for at least one of the kiln foremen. Such brick plants, however, are more likely to be found in developing countries. The situation is radically different in the tunnel kiln brick plants. Since tunnel kilns are instrumented and provided with automatic temperature controls, the training given by the engineer in charge of the kiln construction is usually sufficient.

Costing

The various manufacturing expenses that make up the production cost are shown in annexes XII, XIII and XIV. The cost of raw materials is believed to be fairly representative of the situation at the end of 1975. Of course, the level of wages may affect the final cost significantly. The depletion allowance should be mentioned of $0.50 per ton. This allowance is normally fixed quite arbitrarily following common usage and is credited to a special depletion reserve to be used for purchasing new clay land in case of necessity, after the land currently worked has been exhausted. The allowance is fixed at a higher level than the cost of currently worked land because of the tendency of land prices to rise, especially if it is known that clay, valuable to a presumably prosperous brick plant, is found on it.

The expenses and costs of labour depend of course on the level of wages in each country. The price of fuel oil represents the international level it reached in 1975. The price of wood is subject to considerable variations depending on whether the country concerned produces lumber. In a lumber-producing country, wood for burning is likely to be reasonably cheap because mostly waste wood from sawing operations and perhaps even sawdust is used. The costs given here are taken from a sparsely wooded country where gathering, cutting and sawing the wood come to about $1.00/m^3

Somewhat more debatable is the amount of interest on capital charged to the cost of manufacture as shown in the last item of annexes XIII and XIV. This figure is the amortization of the interest that would have been earned by the capital during the pre-investment and construction periods had it been invested elsewhere. Since, however, not all of the capital to be invested will be needed from the very beginning but only gradually as funds are required, only interest on the funds actually disbursed should be charged. Trying to anticipate the rate at which funds will be needed is risky, so that the expedient was adopted of halving the current rate of interest. Interest rates vary from one country to another, and those in developing countries tend to be higher than those in developed ones. Five per cent is thought to be a fair approximation.

However, in most countries the internal revenue authorities are unlikely to approve the above-mentioned practice as a valid deduction for tax purposes. Annex XV gives a summary of production expenses. The share of the six major expenses that represent over 80 % of the manufacturing costs is given below.

	Tunnel kiln plant (%)	*Hoffmann kiln plant* (%)
Clay	18.5	20.1
Direct labour	9.2	12.3
Fuel	11.7	10.1
Depreciation	30.2	27.9
Electric power	7.3	7.6
Interest	4.2	4.1
Total	81.1	82.1

It will be appreciated that the largest share of the manufacturing costs is taken up by depreciation of equipment and building and that labour is a rather minor item compared with the former. Therefore, in any investment of this kind, the cost of equipment should be kept down as much as possible.

Little can be done about the fuel bill. The calculations do not show much saving when wood is substituted for oil. Substantial savings, however, can probably be obtained by burning agricultural wastes as discussed earlier, but unfortunately no information is available on the cost of these waste materials.

The second largest expense is for clay. On the basis of data given in annex XII, this large expense may be broken down as follows (%):

Winning	38
Hauling	16
Overburden removal	29
Depletion allowance	17

Here the winning of clay is the largest outlay. The remedy would be to mechanize the clay pit, but the present high cost of earth-moving equipment would considerably increase the equipment depreciation, and as annex XII indicates, amortization accounts for over 50% of the cost of hauling. Overburden removal is the second largest expense. Little can be done here, since few clay deposits are entirely devoid of overburden.

Unit costs can be reduced through increased output. As annexes V and VI show, the cost of equipment per million bricks per year decreases with increased capacity. The share of equipment depreciation in the total manufacturing cost can be expected also to decrease sharply with increased output. Clay, direct labour, fuel and power consumption will rise proportionately, while the remaining expenses, which in the examples given account for less than 20%, will remain stationary or will increase slightly.

However, in most developing countries even if the need for the product exists, the economic situation of the population as a whole does not permit consumption in the desired quantities, the reason being, of course, the relatively high price of machine-made bricks. Thus the establishment of a brick plant with huge capacities only for the sake of securing favourable manufacturing costs is not always desirable. In fact, more brick plants have failed because sales lagged behind output than for any other reason.

Statement of profit and loss

After the production cost figures have been arrived at, the profit-and-loss statement can be prepared. First, however, the sales price must be set. It must be sufficient to produce a fair return on the invested capital. Here it is set at $92.00 per 1,000 bricks.

The yearly output of the brick plant given in annex VII is 8 million bricks, but since at least 1 in every 400 must be considered a reject, the above-mentioned output shrinks to 7,980,000. At the assumed sales price, gross sales come to $734,160. To complete the statement and to arrive at the net operating profit, the administrative and sales expenses must be calculated, as shown in annex XVI. The resulting profit-and-loss statement is given in annex XVII.

All purchase returns or rebates must be subtracted from the gross sales to arrive at net sales. In the present case there are none. Net sales less sales cost (production expenses in annex XV) yield gross profit, from which operating expenses are subtracted. The figures thus obtained represent operating profit, which here is identical with pre-tax earnings.

If there is any non-operating income, that is, income deriving from operations unrelated to the brick plant's main business (i.e. making and selling bricks) such as sale of land belonging to it, disposal of scrap iron or obsolete equipment, it must be added to the operating profit to arrive at pre-tax profit. Annex XVII indicates profits of $137,218 and $164,600 for the tunnel kiln and Hoffmann kiln plants, respectively. These figures represent returns of 6.29 % and 8.4 % on invested capital, respectively.

VII. Marketing

The marketing strategy to be worked out and put into practice will be indicated by the results of the market research. Few countries are entirely devoid of a building materials industry. There will always be at least some adobe type of product (a straw and mud brick or block), the drawbacks of which are readily recognized by all. In many developing countries the switch from dried mud brick to more permanent building materials is regarded as an economic and social advance and implies a degree of prestige. The real competition mechanically made bricks face comes from the handicraft product on the one hand and the sand-cement block on the other. Both of these products compete with the machine-made brick on the basis of price alone, even though a certain confidence is sometimes placed in the sand-cement block because the well-known virtues of portland cement and concrete are erroneously associated with it.

The true concrete block, made from properly graded gravel, sand and portland cement under controlled factory conditions, seldom represents much competition for the larger sizes of bricks, since it costs about twice as much as a sand-cement block of the same size.

More of a threat than the competition of factory-made sand-cement blocks is offered by small handicraft manufacturers who make their products right on the building site of the customer. This situation is common in countries blessed with abundance of clean sand.

Some years ago it was calculated that on a wall-surface basis even the cheapest kind of handicraft-fired earth brick was about 50% more expensive than the sand-cement block; although the absolute prices may have changed since then, the ratio of 2:3 probably has not. This large difference between the two products is due above all to the small size of the clay brick, which in the above-mentioned case was 29 x 14 x 6.5 cm whereas that of the sand-cement block was 40 x 20 x 15 cm. The influence of size on the ability of bricks to compete with other structural building materials has been mentioned earlier. Table 1 shows that under identical conditions large fired-clay machine-made bricks may not only hold their own but undersell the sand-cement product; the data come from an African developing country.

TABLE 1. COST OF MACHINE-MADE BRICKS AND SAND-CEMENT PRODUCT

Product	*Size (mm)*	*Wall area (cm^2)*	*Cost of 1 m^2 (dollars)*
Sand-cement block	403 x 101 x 202	869	1.57
Clay brick	252 x 126 x 151	380	1.55
Clay brick	353 x 101 x 202	713	1.38

Table 2 shows the rather disadvantageous position of machine-made bricks vis-à-vis handicraft ones. Even though the data were obtained in one developing country, the ratios probably apply to other countries as well. Indeed they may be even more unfavourable in densely populated countries such as India.

TABLE 2. COMPARISON OF MACHINE-MADE AND HANDICRAFT BRICKS

Bricks 240 x 120 x 60 mm	*Price per 1,000 (dollars)*	*Percentage*
Handicraft bricks "at kiln"	36.00	55
Handicraft bricks delivered	46.00	71
Machine-made bricks, delivered	65.00	100

The large difference between "at kiln" and "delivered" prices arises because these handicraft bricks are obtainable only through dealers who contract with the small manufacturers for whole kilnloads in advance.

The disadvantageous position of machine-made bricks becomes even more evident when it is pointed out that the survey on which the table is based, revealed that the manufacturing cost of these bricks was the equivalent of $23.00. In the country, however, handicraft and machine-made bricks were used in a proportion of 4 to 1.

Again, however, size maintains its importance in determining the competitive position of machine-made bricks vis-à-vis handicraft ones. Unquestionably a brick larger than 24 x 12 x 6 cm will be better able to compete with the handicraft product. The introduction of a larger brick into a market that is accustomed to a smaller one will surely encounter resistance. Resistance will come first of all from the masons, who, being used to laying the small brick, will certainly lose some of their speed if forced to work with the heavier large brick. The organization of training courses for masons will be the answer here.

Some sales resistance is also to be expected from private customers and perhaps even from architects. This type of resistance will almost certainly arise because the appearance of an unrendered wall built from large bricks is considered unappealing aesthetically. Imaginative treatment of such walls by means of raked, weathered, concave, convex or struck joints, recessed or salient courses, and horizontal or vertical articulation of the wall surface provides the kind of balance of highlight and shadow that helps make the appearance of an unrendered brick wall interesting.

In a developing country where handicraft and machine-made bricks are used about equally, consumers were asked to list the advantages and drawbacks of machine-made bricks as against the handicraft product. Their replies are summarized below.

The advantages are:

(a) Mechanical strength is higher;

(b) Edges and corners are well defined;

(c) Dimensions are uniform;

(d) Deliveries are dependable, even during the rainy season, when most handicraft operators close down or curtail their output; thus it is possible to keep to a predetermined schedule;

(e) The price does not fluctuate according to supply and demand;

(f) Their use makes for sounder, more durable and better-looking construction;

(g) They may be used in unrendered constructions, which effects considerable saving;

(h) Unrendered brick walls need almost no maintenance.

The drawbacks are:

(a) The price of the bricks are high. To offset this drawback, advantage *(g)* should be stressed;

(b) Skilled masons are needed for laying the bricks.

The shortage of good masons in developing countries is likely to be acute. If there is a handicraft brickmaking tradition in the country, the masons may have become careless because of the poor quality of bricks produced. If the sand-cement block is the only structural building material available, a true bricklaying tradition will be non-existent. Relatively little skill is needed for erecting structures from sand-cement blocks with their thick walls and heavy mortar joints. Any irregularities may always be hidden under thick rendering. Considerably more skill is needed to lay solid or perforated bricks, especially if they are to be left unrendered.

In many developing countries the decline in the use of bricks coincides with the lack of good masons, which frequently leads to high labour costs in laying.

VIII. Conclusions and summary

Process

The soft extrusion process, if clay characteristics permit its use, is still the most suitable for most developing countries.

Two examples of brick plants, both based on soft extrusion but one equipped with an oil-fired tunnel kiln and the other with a wood-burning Hoffmann kiln, have been presented in this study. Equipment, space, personnel and investment required have been indicated and an administrative structure suggested. The approximate production costs have been calculated and a profit-and-loss statement elaborated for each brick plant. The calculations are based partly on information gathered in several developing countries and partly on estimate. Even if the results are no longer valid because of inflation, the presentation of the calculations shows how to project production costs and what data must be obtained to arrive at a realistic forecast.

Training

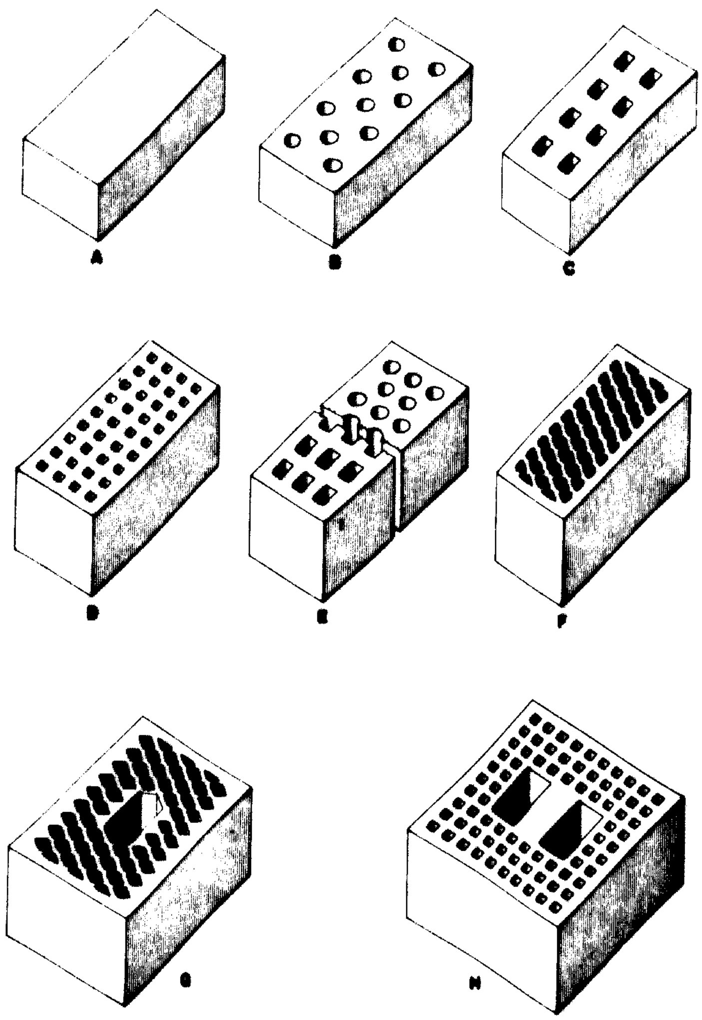
In view of the shortage of qualified masons, bricklaying courses should be organized even if an instructor has to be brought from a country with a long tradition in brickmaking, such as Denmark, Sweden and the United Kingdom. Alternatively, a mason could be sent to one of these countries to be trained as an instructor.

Marketing

In promoting the sales of bricks, the consumer's attention should be called repeatedly to the traditional virtues of fired clay bricks as the ideal building material. The stress should always be on "liveability" of brick structures as compared with those built with substitute materials. It is a good policy to erect experimental structures from bricks for use as "show-cases". The conventional information media such as cinema, advertising leaflets, and billboards should be used efficiently.

Annex I

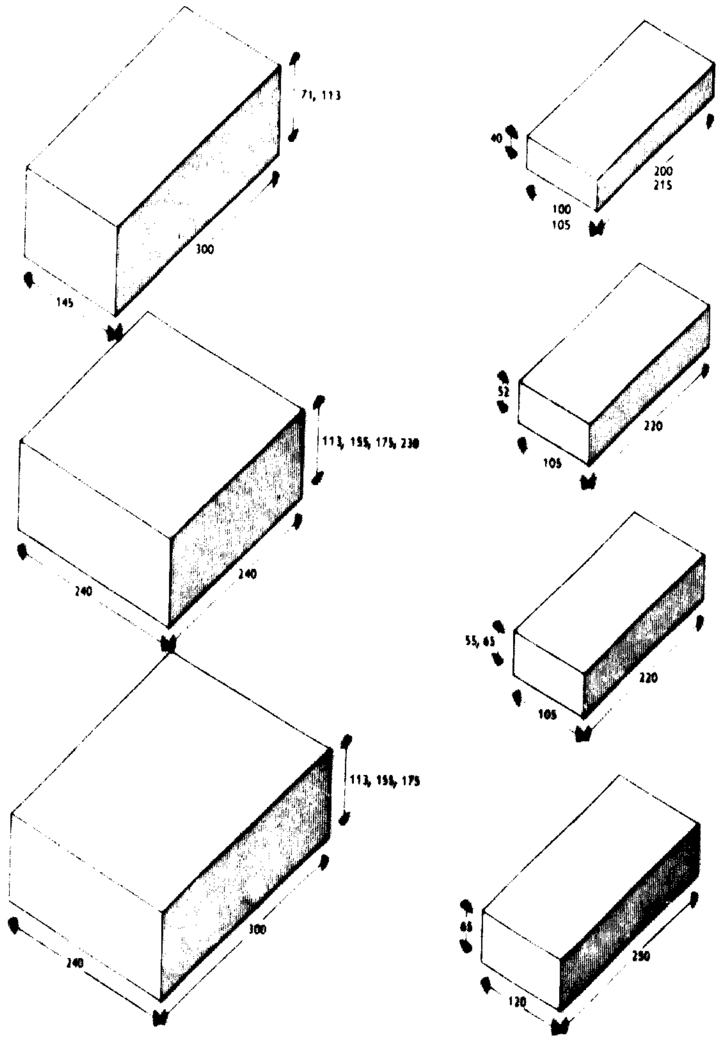
FORMS AND PERFORATIONS USED IN THE FEDERAL REPUBLIC OF GERMANY



Source: F. Hart and E. Bogenberger, *Der Mauerziegel* (Bundesverband der Deutschen Ziegelindustrie, 1964).

Annex II

SIZES OF BRICKS USED IN THE FEDERAL REPUBLIC OF GERMANY



Annex III

SIZES OF BRICKS AND HOLLOW BLOCKS USED IN FRANCE

Dimensions (thickness x height x length)	*Approximate weight of element (kg)*	*Quantity* Per m² On edge	Per m² Flat	Per m³
Ordinary bricks				
Wire-cut or pressed Solid or perforated				
10.5 x 5.5 x 22	2.2	38	68	565
10.5 x 6 x 22	2-2.6	38	62	540
11 x 6 x 22	2-2.6	36	62	520
Selected bricks				
For facings, intermediates or industrial flue work				
10.5 x 4 x 22	1.6	38	87	730
10.5 x 5.5 x 22	2.2	38	68	565
10.5 x 6 x 22	2-2.6	38	62	540
11 x 6 x 22	2-2.6	36	62	520
12 x 6.5 x 23	3.1	–	51	390
Re-sized, re-pressed and extra-pressed bricks				
High strength				
10.5 x 5.5 x 22	2.4	38	68	565
10.5 x 6 x 22	2.4-2.6	38	62	540
11 x 5 x 22	1.8	36	72	600
11 x 6 x 22	2.4-2.6	36	62	520
Perforated solid and re-pressed bricks				
10.5 x 3 x 22	1	38	108	950
10.5 x 4.5 x 21.5 or 22	1.4-1.5	38	87	760
10.5 x 4.5 x 22	1.6	38	80	700
10.5 x 5 x 22	1.7	38	72	600
10.5 x 5.4 x 21.5 or 22	1.8-1.9	38	68	590
10.5 x 5.5 x 22	1.9	38	68	565
10.5 x 6 x 21.5 or 22	2-2.2	38	62	540
13.5 x 5 x 28	2.5	24	56	396
13.5 x 10 x 28	5	24	31	216
Hollow blocks				
To be rendered				
12 x 9 x 25	3.5		39.5	
14 x 9 x 29	4.1		31	
18 x 10.5 or 13 x 25.28 or 30	6.5-9		31.5-21.5	
19 x 9 x 29	6		31	
22 x 10.5 or 13 x 25.28 or 30	7.5-10		31.5-21.5	
24 x 13 x 28 or 30	9-12		23-21.5	
25 x 13 x 25 or 28	8.5-11.5		26-23	
Facing blocks				
2 visible faces				
18 x 10.5 or 13 x 25	6.5		26-31.5	
22 x 10.5 or 13 x 25	7.5		26-31.5	
25 x 10.5 or 13 x 25	8.5		26-31.5	
27.5 x 10.5 or 13 x 25	9.5		26-31.5	
Hollow plasterwork bricks				
3 x 15 x 30	1.4	19		
3 x 20 x 40	1.6	11		
3.5 x 15 x 30	1.6-2	19		

Dimensions (thickness x height x length)	Approximate weight of element (kg)	Quantity Per m² On edge	Quantity Per m² Flat	Quantity Per m³
Hollow plasterwork bricks (continued)				
3.5 x 20 x 40	1.7	11		
4 x 15 x 30	1.8	19		
4 x 20 x 40	1.9	11		
4 x 25 x 40	2.1	9		
4.5 x 15 x 30	2	19		
4.5 x 20 x 40	2.1	11		
5 x 15 x 30 or 40	2.2-2.8	11-19		
5 x 16 x 30	2.4	18		
5 x 20 x 30 or 40	2.5-3.5	11-19		
5 x 40 x 50	7.5	4.7		
5.5 x 15 x 30	2.7	19		
5.5 x 20 x 40	3.5	11		
6 x 20 x 40	3.5	11		
7 x 20 x 40	4	11		
Hollow bricks, normal and large dimensions				
8 x 15 x 30	3.3	19		
8 x 16 x 30	3.4	18		
8 x 20 x 40	4	11		
10 x 15 x 30	3.4	19		
10 x 20 x 40	4.2	11		
10 x 25 x 40	4.6	9		
11 x 11 x 22	2.8	34	34	
11 x 15 x 22	4.3	19		
11 x 20 x 40	7.5	11		
11 x 22 x 40	8	10		
15 x 20 x 40	9	11	14.5	
18.5 x 20 x 38.5	11	11	11.5	
20 x 20 x 40	12.5	11	11	
22.5 x 15 x 40	12.7	10	14.5	
22.5 x 20 x 40	13.5	10	11	
25 x 15 x 40	14	9	14.5	
25 x 20 x 40	16	9	11	
30 x 15 x 40	17	7.6	14.5	
30 x 20 x 40	18.5	7.6	11	
Hollow joint-break bricks				
20 x 15 x 40	10.5		14.5	
20 x 18.5 x 40	12.5		11.5	
20 x 20 x 40	13		11	
22.5 x 15 x 40	12.5		14.5	
22.5 x 18.5 x 38.5	13.5		11.5	
22.5 x 20 x 40	14		11	
25 x 15 x 40	13.9		14.5	
25 x 18.5 x 38.5	16		11.5	
25 x 20 x 40	16.5		11	
27.5 x 15 x 40	15.5		14.5	
27.5 x 18.5 x 38.5	18		11.5	
27.5 x 20 x 40	18.3		11	
30 x 15 x 40	17		14.5	
30 x 18.5 x 38.5	19		11.5	
30 x 20 x 40	20		11	

Source: Fédération des fabricants de tuiles et de briques de France.

Note: Nearly all brick plants make half-bricks. Some that specialize in facing products also supply shaped bricks such as quarter-rounds or bevelled-edge bricks.

Annex IV

CLAY RESEARCH AND TESTING INSTITUTES

British Ceramic Research Association, Queen's Road, Penkhull, Stoke-on-Trent, ST4 7LG, United Kingdom
Centre technique des tuiles et briques, 2, avenue Hoche, 75008 Paris, France
Centre national d'études et recherches céramiques, 23, rue Cronstadt, 75013 Paris, France
Institut für Ziegelforschung Essen E.V., Am Zehnthof, 4300 Essen-Kray, Federal Republic of Germany

Annex V

COST OF MANUFACTURING, FIRING AND DRYING EQUIPMENT FOR TUNNEL KILNS OF VARIOUS CAPACITIES

(Dollars)

Item	*Tons of bricks per day*[a]				
	40	*50*	*60*	*80*	*100*
Manufacturing equipment[b]	154 500	154 500	154 500	266 700	266 700
Tunnel kiln and drier equipment	320 400	373 400	426 800	589 800	694 700
Construction material and labour	188 000	230 350	274 850	338 700	432 900
Total	662 900	758 250	856 150	1 195 200	1 394 300
Investment for million bricks/year	118 375	108 321	101 923	106 714	99 593

[a] Size: 24 x 11.5 x 7.5 cm; weight 2.5 kg.
[b] f.o.b. port prices considered.

Annex VI

COST OF MANUFACTURING, FIRING AND DRYING EQUIPMENT FOR HOFFMANN KILN PLANTS OF VARIOUS CAPACITIES

(Dollars)

Item	*Tons of bricks per day*				
	40	*50*	*60*	*80*	*100*
Manufacturing equipment	154 500	154 500	154 500	266 700	266 700
Hoffmann kiln and drier equipment	220 000	260 000	310 000	388 000	465 600
Total cost of equipment	374 500	414 500	464 500	654 700	732 300
Investment for million bricks/year	66 875	59 214	55 298	58 455	52 307

Annex VII

PRODUCTION SCHEDULES AND MATERIAL REQUIREMENTS FOR TUNNEL KILN AND HOFFMANN KILN PLANTS

Total fired production (brutto)

Bricks per year	8 400 000
Bricks per week	168 000
Bricks per day	24 000
Tons per day	60

Bricks extruded (number)

Per year	9 333 333
Per week	186 667
Per day (shift)	37 333

Clay requirement (kg)

Per 1,000 bricks	3 333
Yearly	31 108 000
Weekly	622 200
Daily	124 430

Water requirement

Per 1,000 bricks	500 litres
Yearly	4 667 m³
Weekly	93 m³
Daily	19 m³

Fuel oil requirements for tunnel kiln plant only (litre)

Per 1,000 bricks	137.5
Yearly	1 155 000
Weekly	23 100
Daily	3 300

Wood requirement for Hoffmann kiln plant only (m^3)

Per 1,000 bricks	2.87
Yearly	24 100
Weekly	482
Daily	69

Assumptions:

Yield of clay	0.75
Drier losses	10%
Operating time	
Kiln and drier	50 weeks/year
	7 days/week
	24 hours/day
Manufacturing	50 weeks/year
	5 days/week
	8 hours/day
Heat requirements (kJ/kg brick)	
Tunnel kiln	2 300
Hoffmann kiln	2 500
Calorific value of fuels	
No. 5 fuel oil	42 MJ/l
Wood	2 190 MJ/m^3

(For wood containing 48% water and yielding 156 kg of dry substance per m^3)

Annex VIII

FIXED CAPITAL INVESTMENT FOR TUNNEL KILN PLANT

(1) Pre-investment and preparatory expenses

Item	*Number*	*Period (months)*	*Cost (dollars)*	*Total (dollars)*
Managing director	1	12	1 000	12 000
Secretary	1	12	200	2 400
Cashier-bookkeeper	1	12	200	2 400
Consultation fees				8 000
Rent of offices		12	100	1 200
Clay prospecting				10 000
Clay testing				5 000
Incidental expenses				5 000
Total				46 000

(2) Clay pit and its development

Item	Number or amount	Period	Cost (dollars)	Total (dollars)
Clay pit foreman	1	6 months	300	1 800
Workers for clearing overburden 1 m thick[a]		21 600 hours	0.50	10 800
Clay land	2 ha			40 000**
Removal of overburden by trucking	30 000 tons		0.45	13 500
Explosives				500
Diesel engine tipping truck	1, 10-ton capacity			40 000*
Total				106 600

[a]By digging, blasting and hand-loading.

(3) Wages, salaries and other expenses during the construction period

Title or item	Number	Period (months)	Cost (dollars)	Total (dollars)
Managing director	1	12	1 250	15 000
Counterpart engineer (later plant superintendent)	1	9	800	7 200
Cashier-bookkeeper	1	12	280	3 360
Secretary	1	12	200	2 400
Manufacturing foreman	1	6	400	2 400
Clay pit foreman	1	3	300	900
Chief of quality control and tests	1	9	500	4 500
Draughtsman	1	12	200	2 400
Warehouse clerk	1	8	150	1 200
Janitor	1	12	120	1 440
Night watchman	3	12	120	4 320
Office rent		6	100	600
Office supplies				2 000
Total				47 720

(4) Utilities

Item	Capacity	Cost (dollars)
Electrical substation	300 kVA	22 400*
Subterranean concrete tank for fuel oil	100 000 l	10 000***
Auxiliary fuel oil tank	5 000 l	5 000
Electrical installations and connections		8 000
Water supply installation		5 000
Total		50 400

(5) Office equipment

Office equipment	Cost (dollars)
Furniture	
Typewriters	
Business machines	
Total	10 000

Note: For an explanation of the asterisks, see p. 32.

(6) Land and civil engineering

Item	*Area* *(m²)*	*Cost per unit area* *($/m²)*	*Cost* *(dollars)*
Land[a]	6 000	5	30 000**
Buildings[b]			
Main	4 010	100	401 000***
Machine	45	100	4 500***
Laboratory	58	100	5 800
Offices	100	150	15 000***
Sanitary installation[c]	50	160	8 000***
Total			464 300

[a]This is the area strictly necessary for the proposed plant. Since, however, the output of the pressing equipment could easily be doubled by organizing a second shift, it would be necessary only to add drying and firing facilities to have a plant of twice the proposed production capacity. In this case an additional 1,600 m² of land would be required on the left-hand side of the plant shown in figure I.

[b]Concrete columns 6 m high, structural steel, trussed roof construction covered with corrugated galvanized iron sheets, 10 cm concrete floor.

[c]3 showers, 3 toilets, 3 washing bowls, 3 drinking fountains, 3 urinals, dressing room with 40 lockers.

(7) Manufacturing equipment

Item		*Cost* *(dollars)*
Making equipment		
1 Roll crusher		
1 Box feeder		
1 Set of laminating rolls		
1 Double-shafted mixer		
1 Extruder		
2 Inclined slat conveyors		
1 Single-wire automatic cutter		
1 Belt conveyor for cut bricks		
Total cost of making equipment		244 300*
Spare parts for making equipment		50 000
Machine shop equipment		20 000
Laboratory equipment		10 000
		324 300
Drying and firing equipment		
Drying racks	82 600	
Final drier equipment	41 580	
Tunnel kiln equipment	440 300	
Construction material and labour	274 850	
Total for kiln and drier		839 330
Engineering and supervision		90 000*
Travelling expenses for supervising personnel		15 000*
Final project expenses (drafting and calculations)		20 000*
Accessories (screws and nuts, various materials of iron and steel, welding rods, oil etc.)		24 000
Concrete foundation for equipment		10 000***
Electric energy during construction	125 000 kWh at $0.048	6 000
		1 004 330

Note: For an explanation of the asterisks, see p. 32.

(8) Labour for installing equipment

Title or function	*Number*	*Period (months)*	*Salary (dollars)*	*Total (dollars)*
Counterpart engineer (later plant superintendent)	1	12	800	9 600
Manufacturing foreman	1	12	400	4 800
Mechanic	1	12	300	3 600
Electrician	1	6	300	1 800
Tunnel kiln foreman	1	6	300	1 800
Skilled and unskilled labour	90 man-months		120	10 800
Total				32 400

Annex IX

FIXED CAPITAL INVESTMENT FOR HOFFMANN KILN PLANT

(1) Pre-investment and preparatory expenses

Item	*Number*	*Period (months)*	*Cost (dollars)*	*Total (dollars)*
Managing director	1	12	1 000	12 000
Secretary	1	12	200	2 400
Cashier-bookkeeper	1	12	200	2 400
Consultation fees				8 000
Rent of offices		12	100	1 200
Clay prospecting				10 000
Clay testing				5 000
Incidental expenses				5 000
Total				46 000

(2) Clay pit and its development

Item	*Number or amount*	*Period*	*Cost (dollars)*	*Total (dollars)*
Clay pit foreman	1	6 months	300	1 800
Workers for clearing overburden 1 m thick[a]		21 600 hours	0.50	10 800
Clay land	2 ha			40 000**
Removal of overburden by trucking	30 000 tons		0.45	13 500
Explosives				500
Diesel engine tipping truck	1, 10-ton capacity			40 000*
Total				106 600

[a]By digging, blasting and hand-loading.

(3) Wages, salaries and other expenses during the construction period

Title or item	*Number*	*Period (months)*	*Salary (dollars)*	*Total (dollars)*
Managing director	1	12	1 250	15 000
Counterpart engineer (later plant superintendent)	1	9	800	7 200
Cashier-bookkeeper	1	12	280	3 360

Note: For an explanation of the asterisks, see p. 32.

(3) Wages, salaries and other expenses during the construction period *(continued)*

Title or item	*Number*	*Period (months)*	*Salary (dollars)*	*Total (dollars)*
Secretary	1	12	200	2 400
Manufacturing foreman	1	6	400	2 400
Kiln foreman	1	6	300	1 800
Clay pit foreman	1	3	300	900
Chief of quality control and tests	1	9	500	4 500
Draughtsman	1	12	200	2 400
Warehouse clerk	1	8	150	1 200
Janitor	1	12	120	1 440
Night watchman	3	12	120	4 320
Office rent		6	100	600
Office supplies				2 000
Total				49 520

(4) Utilities

Item	*Capacity*	*Cost (dollars)*
Electrical substation	300 kVA	22 400*
Electrical installations and connections		8 000
Water supply installation		5 000
Total		35 400

(5) Office equipment

Office equipment	*Cost (dollars)*
Furniture	
Typewriters	
Business machines	
Total	10 000

(6) Land and civil engineering

Item	*Area (m^2)*	*Cost per unit area ($\$/m^2$)*	*Total (dollars)*
Land[a]	7 000	5	35 000**
Buildings[b]			
Main	5 398.5	100	539 850***
Machine shop	45	100	4 500***
Laboratory	58	100	5 800
Offices	100	150	15 000***
Sanitary installation[c]	50	160	8 000***
Total			608 150

[a]This is the area strictly necessary for the proposed plant. Since, however, the output of the pressing equipment could easily be doubled by organizing a second shift, it would be necessary only to add drying and firing facilities to have a plant of twice the proposed production capacity. In this case an additional 2,772 m^2 of land would be required on the left-hand side of the plant shown in figure II.

[b]Structural steel columns, steel trussed roof construction covered with corrugated galvanized iron sheets, 10 cm concrete floor.

[c]3 showers, 3 toilets, 3 washing bowls, 3 drinking fountains, 3 urinals, dressing room with 40 lockers.

Note: For an explanation of the asterisks, see p. 32.

(7) Manufacturing equipment

Item		*Cost (dollars)*
Making equipment		
1 Preliminary roll crusher		
1 Box feeder		
1 Set of laminating rolls		
1 Double-shafted mixer		
1 Extruder (pug mill)		
2 Inclined slat conveyors		
1 Single-wire automatic cutter		
1 Belt conveyor for cut bricks		
Total cost of making quipment		244 300*
Spare parts for the making equipment		50 000
Machine shop equipment		20 000
Laboratory equipment		10 000
		324 300
Drying and firing equipment		
Drying racks	80 000	
Final drier	154 000	
Hoffmann kiln	200 000	
Total for kiln and drier		434 000*
2 Fork-lift trucks		48 000*
Engineering and supervision		90 000*
Travelling expenses for supervising personnel		15 000*
Final project expenses (drafting and calculations)		20 000*
Accessories (screws and nuts, various materials of iron and steel, welding rods, oil etc.)		24 000
Concrete foundations for equipment		10 000***
Electric energy during construction	125 000 kWh at $0.048	6 000
		647 000

(8) Labour

Title or function	*Number*	*Period (months)*	*Salary (dollars)*	*Total (dollars)*
Counterpart engineer (later plant superintendent)	1	12	800	9 600
Manufacturing foreman	1	12	400	4 800
Mechanic	1	12	300	3 600
Electrician	1	6	300	1 800
Kiln foreman	1	6	300	1 800
Skilled and unskilled labour	90 man-months		120	10 800
Total				32 400

Note: For an explanation of the asterisks, see p. 32.

Annex X

PERSONNEL REQUIREMENTS FOR TUNNEL KILN PLANT

Category	*Number*
Administrative	
Managing director	1
Sales manager	1
Accountant	1
Cashier	1
Secretary	1
Timekeeping and payroll clerk	1
Warehouse clerk	1
Janitor	1
Total	8
Technical	
Plant superintendent (engineer)	1
Chief of controls and tests (engineer?)	1
Production foreman	1
Total	3
Clay pit	
Pit foreman	1
Truck driver	1
Worker	16
Total	18

Category	*Number*
Plant	
Manufacture, loading and transport to drier	8
Setting tunnel kiln cars	6
Kiln foreman	4
Worker unloading tunnel kiln cars and loading trucks	4
Mechanic	1
Electrician	1
General worker	3
Yard foreman	1
Mason	1
Doorman	1
Night watchman	3
Laboratory assistant	1
Total	34

Direct plant labour	25
Indirect plant labour	9

Annex XI

PERSONNEL REQUIREMENTS FOR HOFFMANN KILN PLANT

Category	*Number*
Administrative	
Managing director	1
Sales manager	1
Accountant	1
Cashier	1
Secretary	1
Timekeeping and payroll clerk	1
Warehouse clerk	1
Janitor	1
Total	8
Technical	
Plant superintendent (engineer)	1
Chief of controls and tests (engineer?)	1
Production foreman	1
Total	3
Clay pit	
Pit foreman	1
Truck driver	1
Worker	16
Total	18

Category	*Number*
Plant	
Manufacture and loading of racks	4
Setting packs for the kiln	6
Drier foreman	1
Lift-truck driver for the drier	2
Kiln foreman	4
Kiln stokers	8
Fork-lift truck driver for the kiln	4
Mechanic	1
Electrician	1
General worker	3
Yard foreman	1
Doorman	1
Night watchman	3
Laboratory assistant	1
Total	40

Direct plant labour	32
Indirect plant labour	8

Annex XII

COSTING OF RAW MATERIALS FOR TUNNEL AND HOFFMANN KILN PLANTS (ONE-YEAR OPERATION)

(Dollars)

Winning		
16 Men at $5.00/day	29 200	
Shovels and picks	800	
Explosives	1 000	
1 Pit foreman, 12 man-months at $300	3 600	
		34 600
Hauling		
1 Truck driver, 12 man-months at $245	2 940	
Diesel oil, 8,ooo litres at $0.06	480	
One set of tires	1 600	
Truck amortization	8 000	
Spare parts, repairs etc.	2 000	
		15 020
Amortization of overburden		
Removal		26 600
Depletion allowance at $0.50/ton		15 554
Total spent on raw material		91 774

Annex XIII

COSTING FOR TUNNEL KILN PLANT, EXCLUDING RAW MATERIALS (ONE-YEAR OPERATION)

(Dollars)

Direct labour		
25 Skilled and unskilled workers at an average of $5.00/day		45 625
Fuel		
1 155 000 litres of No. 5 fuel oil at $0.05/litre		57 750
Manufacturing expenses		
(a) Supervision		
1 Plant superintendent at $1 000/month	12 000	
1 Foreman at $500/month	6 000	
(b) Raw material control		
1 Chief of controls at $500/month	6 000	
1 Laboratory assistant at $200/month	2 400	
(c) Equipment maintenance		
1 Electrician at $300/month	3 600	
1 Mechanic at $300/month	3 600	
(d) Spare parts		
2% of f.o.b. cost of equipment: $498 700	9 974	
(e) Kiln maintenance		
1 Mason at $200/month	2 400	
6 Man-months at $200	1 200	
Materials	3 000	
(f) Building maintenance		
(paint, replacement of roofing sheets etc.)	1 500	
(g) General manufacturing expenses supplies (estimated)	5 000	

Manufacturing expenses (continued)

(h) Security		
1 Doorman at $200/month	2 400	
3 Night watchmen at $150/month	5 400	
(i) Works administration		
1 Timekeeper and payroll clerk at $300/month	3 600	
1 Warehouse clerk at $300/month	3 600	
1 Yard foreman at $200/month	2 400	
(j) Medical expenses (estimated)	2 500	
(k) Insurance, 0.005% of the value of manufacturing, drying and firing equipment and building	8 977	
(l) Depreciation		
Equipment (10%)	136 103	
Buildings (5%)	21 715	
(m) Electric power: 755 000 kWh at $0.048	36 240	
(n) Water: 10 000 m³ at $0.30/m³	3 000	
Total manufacturing expenses		282 609
Amortization of organizational expenses: 5% of $93 720		4 686
Amortization of interest on capital during the preparatory and construction periods: 5% of $2 181 050 = $109 052, to be amortized in five years		21 810

Annex XIV

COSTING FOR HOFFMANN KILN PLANT, EXCLUDING RAW MATERIALS (ONE-YEAR OPERATION)

(Dollars)

Direct labour		
32 Skilled and unskilled workers at an average of $5.00/day		58 400
Fuel		
24 108 m³ of wood at $2.00/m³		48 216
Manufacturing expenses		
(a) Supervision		
1 Plant superintendent at $1 000/month	12 000	
1 Foreman at $500/month	6 000	
(b) Raw material control		
1 Chief of controls at $500/month	6 000	
1 Laboratory assistant at $200/month	2 400	
(c) Equipment maintenance		
1 Electrician at $300/month	3 600	
1 Mechanic at $300/month	3 600	
(d) Spare parts 2% of f.o.b. cost of equipment: $328 000	6 560	
(e) Kiln maintenance		
6 Man-months at $200	1 200	
Materials	2 000	
(f) Building maintenance (paint, replacement of roofing sheets etc.)	1 500	
(g) General manufacturing expenses accessories (estimated)	5 000	
(h) Security		
1 Doorman at $200/month	2 400	
3 Night watchmen at $150/month	5 400	
(i) Works administration		
1 Timekeeper and payroll clerk at $300/month	3 600	
1 Warehouse clerk at $300/month	3 600	
1 Yard foreman at $200/month	2 400	
(j) Medical expenses (estimated)	2 500	

Manufacturing expenses (continued)

(k)	Insurance: 0.005% of the value of manufacturing, drying and firing equipment, buildings	7 884	
(l)	Depreciation		
	Equipment	95 570	
	Buildings (5%)	28 658	
	Transport equipment (20%)	9 600	
(m)	Electric energy power: 755 000 kWh at $0.048	36 240	
	10 000 litres gasoline for two lift trucks at $0.35/litre	3 500	
(n)	Water: 10 000 m^3 at $0.30/$m^3$	3 000	
	Total manufacturing expenses		254 212
	Amortization of organizational expenses: 5% of $95 520		4 776
	Amortization of interest on capital during the pre-investment and construction periods: 5% of $1 949 370 = $97 468, to be amortized in five years		19 494

Annex XV

SUMMARY OF PRODUCTION EXPENSES (ONE-YEAR OPERATION)

(Dollars)

	Tunnel kiln plant	*Hoffmann kiln plant*
Raw material	91 774	91 774
Direct labour	45 625	58 400
Fuel	57 750	48 216
Manufacturing expenses	282 609	254 212
Amortization of organizational expenses	4 686	4 776
Amortization of interest	21 810	19 494
Total	504 254	476 872

Annex XVI

OPERATING EXPENSES FOR TUNNEL AND HOFFMANN KILN PLANTS

(Dollars)

Administrative expenses

(a)	Salaries		
	1 Managing director	15 000	
	1 Accountant	4 800	
	1 Cashier	3 360	
	1 Secretary	3 360	
	1 Janitor	1 460	
			27 980
(b)	Office supplies		5 000
(c)	Depreciation of office equipment: 10% of $10 000		1 000
	Total administrative expenses		33 980

Sales expenses

1 Sales manager	10 000	
Adversing expenses	12 000	
Commissions: 5% on total sales volume	36 708	
		58 708
Total operating expenses		92 688

Annex XVII

PROFIT-AND-LOSS STATEMENT

(Dollars)

		Tunnel kiln brick plant	Hoffmann kiln brick plant
Gross sales (7 980 000 bricks at $92.00 per thousand)		734 160	734 160
Less purchase returns, discounts etc.		–	–
Net sales		734 160	734 160
Cost of production		504 254	476 872
Gross profit		229 906	257 288
Operating expenses			
Administrative expenses	33 980		
Sales expenses	58 708	92 688	92 688
Operating profit and/or before tax profit		137 218	164 600
Return on investment (%)		6.29	8.44

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