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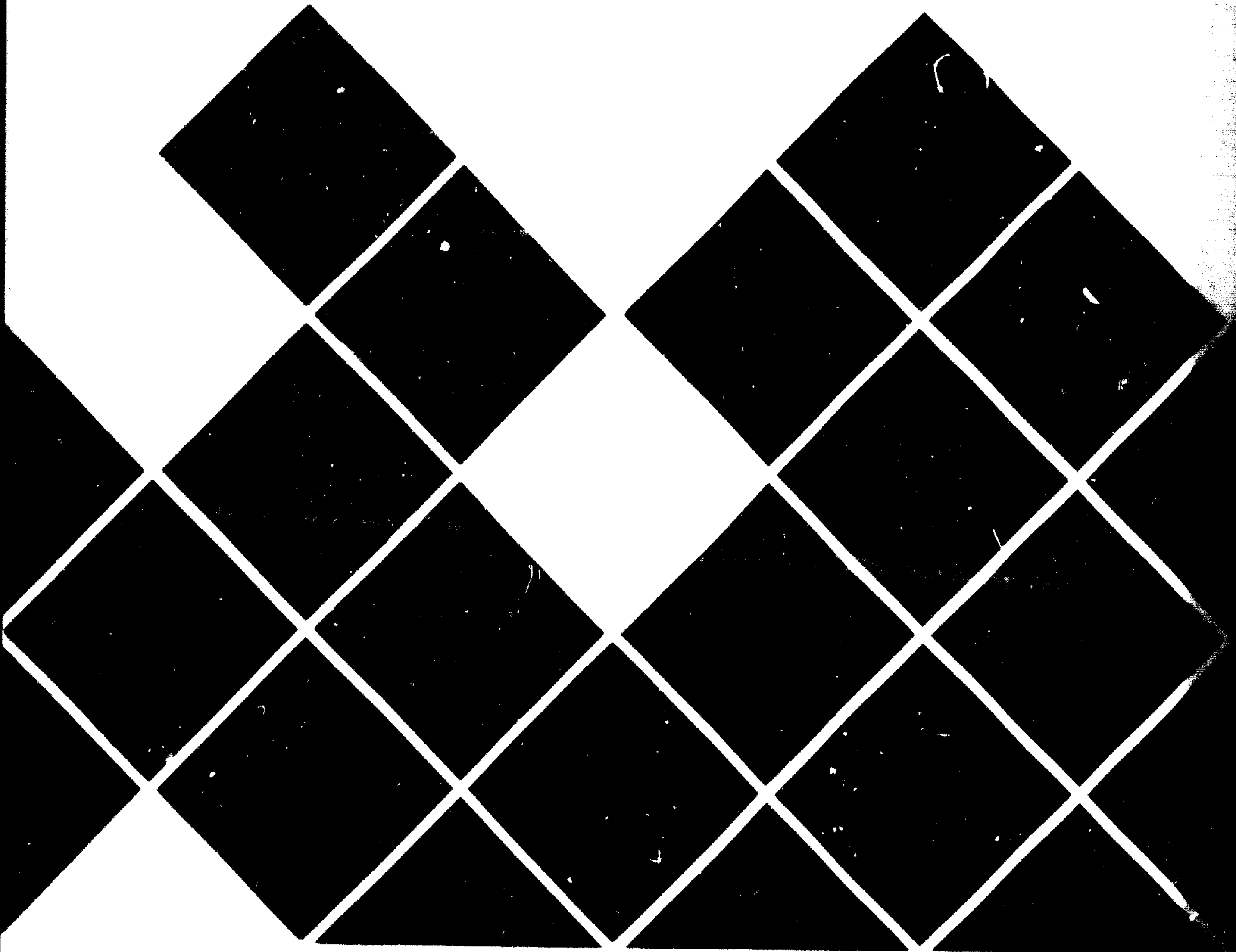
THE ESTABLISHMENT OF THE BRICK AND TILE INDUSTRY IN DEVELOPING COUNTRIES



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Preface

THIS PAPER was prepared by H. W. H. West of the British Ceramic Research Association, as consultant for UNIDO, for the Interregional Seminar on the Development of Clay Building Materials Industries in Developing Countries, held in Copenhagen, Denmark in August 1968. The Report of this Seminar has been published under the symbol ID/28.[1]

The Seminar brought together responsible representatives of developing countries from both policy-making and technical sectors to discuss all aspects of plants producing clay building materials. The recommendations of the Seminar defined specific forms of technical assistance and offered guidance to the participants.

The present paper was also submitted by UNIDO as a background document at the Workshop on Organizational and Technical Measures for the Development of Building Materials (Moscow, USSR, 25 September—19 October 1968).

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

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[1] *The Development of Clay Building Materials in Developing Countries*, United Nations Publication, Sales No. E. 69. II. B. 18.

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Introduction

THIS PAPER is concerned with the establishment of the brick and tile industry in developing countries. It seeks to give sufficient information about the characteristics of raw materials and of alternative manufacturing processes to permit developing countries to take the decisions necessary to establish heavy clay industries of their own.

The clay brick is as old as history. In the primitive process of brickmaking, river silt, straw and cattle refuse in equal parts are mixed in a pit by the treading of men and animals until a uniform mud is obtained. [1][1] The hand-moulded bricks may be merely sun-dried or fired in scove kilns using wood for fuel. The organic material serves as a non-plastic diluent and reduces cracking during drying; indeed straw may be regarded as a primitive form of fibre reinforcement. This process is essentially a local one and is confined to small work places producing only enough for immediate needs.

When developed commercially, the process is similar, but rather less organic material is used and mud of a stiffer consistency is prepared. After drying in hacks the bricks are fired in clamps or scove kilns, and coal may be imported for clamp firing. The next stage involves machinery for preparation and making of more regularly shaped soft-mud or soft-extruded bricks. The raw material may still be river mud, or alternatively older deposits specifically exploited for brickmaking. This process is still seasonal. Open-air drying in hacks is used, but some attempt is made to control the firing conditions more closely by the use of trench kilns or above-ground Hoffmann kilns.

In the early stages of developing a brick and tile industry, quality is relatively unimportant. A fired-clay brick is better than adobe, although in dessicated climates adobe may be adequate. The basic problem at first is to provide adequate shelter, but eventually it becomes necessary to distinguish different classes of bricks for particular purposes. Tiles have common performance requirements, and these are more rigorous than those of brickwork between damp-proof course and eaves which, except on very exposed sites, is relatively protected by the overhang of the roof and also by the proximity of other buildings. Hollow blocks are not usually exposed to the weather. Rather it is common practice to render the outside and plaster the inside, so that quality in these is less important, provided that minimum standards of strength and durability are met. Thus, while the output is undifferentiated at first, quality becomes important eventually, and prices must be adjusted to take account of supply and demand.

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[1] Figures in square brackets refer to references listed at the end of this paper.

Variation in the quality of handmade goods is inevitable, and it is characteristic of craftsmen to sell their products at a price related to average quality. In England as late as the last decade clamp-fired, handmade bricks were being sold "as they rise", that is, an average batch from the whole clamp not sorted into best, underfired, overfired and waste. A class of businessmen who recognize the financial advantages of selling a sorted product and who are prepared to take responsibility not only for the quality of the grade sold but also to dispose of the less popular grades of seconds seems to be necessary. This implies a marketing ability, which distinguishes manufacturers who are concerned with a purely financial operation from craftsmen who are concerned only to make a living by their manual skills.

The emergence of manufacturers of this kind, and the recognition of the need to make particular kinds of products, leads to the construction of factories. In developing countries the need for new production resources may be readily seen, but action to fill this need may have to come from the government as the only source of adequate capital. Thus a gap tends to arise between the indigenous original craft and improved-craft technology and the imported technology of modern clayware factories. Under some circumstances this is inevitable, as for example, when the economy is strongly polarized between one or two large centres of population and dispersed rural communities. However, while it may not be necessary to follow the step-by-step historical course of European plants, it may still be possible to employ intermediate technologies appropriate to developing countries.

The term "developing countries" covers a wide spectrum of economic conditions and available technical expertise. The 70 countries usually lumped together as "developing" had a population in 1962—excluding 700 million in China (mainland)—of 1,400 million with an average *per capita* income of some £50. Of the total, 470 million in India had less than £26 per year. In Latin American countries the income was nearly four times that of the countries of the Far East. While there are wide differences among individual developing countries, the crucial gap is between the developing and the developed countries. Thus 340 million in Western Europe have an average *per capita* annual income of about £350, while in North America 205 million have nearly three times this income, about £1,000 per year. [2]

Since it is neither possible nor desirable to discuss at every point the different stages of development in the various countries under consideration, this paper will deal with a single problem. The solution may be difficult, but the problem may be stated quite simply: to develop viable manufacturing industries in predominantly agricultural communities, where capital is scarce and labour is plentiful, without altering the whole economic balance for the worse. More than this, a manufacturing industry implies an organization and method of work which may be at variance with the culture and social mores of the developing countries. For example, the regular working habits of an industrial community may be impossible to attain in a township where every able-bodied man is needed on the family plot at sowing or harvesting time. Thus before the kind of organization that characterizes the western industrialized countries can be created, the whole framework of society must change. The logical limit of this process is the fullest use of

365 days a year for production, each worker labouring only one of three daily shifts, then enjoying leisure and cultural activities, cinema, restaurants, television etc., which must thus be provided throughout the twenty-four hours. This has not yet been reached even in Europe, although it is approached in the United States.

The problem of scarcity of capital resources in the developing countries was noted in 1953 by the Director-General of the International Labour Organisation (ILO):

> "Whatever progress is achieved with capital formation, either from domestic sources or from foreign borrowing, it is certain that capital is going to remain scarce for many decades. The methods of production based on high capital investment per unit of labour which prevail in the advanced countries would surely be uneconomic for countries of Asia today. These methods of production have been developed in countries where labour is scarce and dear, where savings are high and where effective demand has kept ahead of what can be produced with existing techniques and labour forces. It is labour which has to be economised. In Asia labour is plentiful and cheap, and it is capital which has to be economised. This is a new economic problem and demands new technical methods for its solution. The search for these methods, and their application, will not be easy. It calls for a sustained effort of imagination and ingenuity, using the creative energies of the whole community, to produce new technologies which will be genuine innovators."[3]

This advice was not taken, and aid to developing countries took the form of the installation of highly advanced industrial technologies, some of which, admittedly, have been very useful in some countries. On balance, however, the hoped-for improvements in the over-all economies have not taken place. It is now becoming fashionable to recommend "intermediate" or "appropriate" or "progressive" technologies, by which is meant emphasizing the progressive and gradual improvement of the existing levels of technology in the country concerned using the available resources of men, money and materials, concentrating on the development of labour-intensive industrialization, and especially recognizing the interdependence of the different crafts and industries within a region with the object of achieving a self-sustaining local economy.

This philosophy has been well explained by E. F. Schumacher. [4] It finds practical expression in the Intermediate Technology Development Group and needs no further elaboration here. The application of this philosophy in establishing a heavy clay industry has important consequences for developing countries. In a primitive country with no brick industry, the first step is to make bricks from local clay or mud by hand. Such activity starts near the large centres of population and then spreads to the smaller towns and villages. Ready availability of bricks and tiles for building is aided by the production of storehouses that are more nearly verminproof than bamboo and straw-walled or thatched huts. Well-ventilated, weatherproof houses provide protection not only from the elements but also from nocturnal marauding insects that transmit tropical diseases.

Mortar materials are necessary for the development of a brick and tile industry. Cement production requires high capital investment, but wherever there is limestone or calcium carbonate in some form, lime burning is possible, and adequate sand-lime mortars may be produced. If pozzolanic materials are available, good mortars should be possible. In a land wholly devoid of cementitious alternatives dry walling or mud bonding may still be a better alternative than no shelter at all, but in general a brick and tile industry should be established first in areas where the units can be assembled into broadly conventional brickwork.

The establishment of a brick and tile industry can be justified because it permits durable walling and roofing materials to be produced wherever suitable raw material and fuel are available. In practice this means that at worst the process is confined to areas in which mud from the river-bed can be used. Each little community can produce its own building materials, and the cheapness and convenience of this must be contrasted with the capital expense necessary for setting up cement works.

In favourable circumstances clay building materials and concrete may be produced with equal facility, but the cost of transporting cement to enable local concrete block industries to be developed is considerable. Suitable aggregates are less widely distributed than possible clays for brick and tile making.

Making durable building materials widely available creates a demand for shelter. As a country becomes more industrialized, better and larger accommodation is eventually desired. Marion Bowley, however, has shown that in the development of industrialized countries as exemplified by Great Britain:

> "The basic improvements demanded have been the generalisation of standards of accommodation, that is weatherproof and sanitary dwellings, etc., according to standards habitually accepted, and provision of some increase in actual space and privacy per family and per person. Demand for improvements of these types is not a demand for new technically superior materials which would provide improvements over the technical standards achieved by the well-to-do. It is simply a demand for sufficient materials of the standard type. The second phase in improvement over this shelter and space minimum has taken the form of demand for increases in internal amenities in terms of fittings, hot water, etc., and has led to the development of a mass market for fittings. At some stage in the struggle upwards, outward visible signs of social standing [come to have greater value] than further improvement in technical standards, and hence there has emerged an extension in demand for elaboration in appearance and variety. The criterion, as in the other stages of improvement, has obviously been in terms of the established fashions of the next higher social class.
>
> "These are not, then, conditions in which new materials are required, but conditions in which mass production of existing materials is required. They are thus conditions providing opportunities for innovations in methods of production of materials and for the industrialisation of production; they reinforce the influence of general increases in numbers of dwellings required." [5]

It is towards this end, to provide sufficient building materials to house substantially the whole population, that the development of a brick and tile industry is aimed.

The history of the brick and tile industries in industrialized countries may provide some pointers towards possible trends in developing countries. It should be observed, however, that the nineteenth-century Industrial Revolution tended to compress development into a comparatively short space of time, and the increased markets provided by industrial constriction and the needs of urban housing were a spur to innovation which the general mechanistic climate was able to satisfy by a spate of inventing new machinery. Before this developments were remarkably slow. Brickmaking was introduced by the Romans but ended when they left. The Flemish weavers who emigrated to England in the thirteenth and fourteenth centuries had to import bricks from Belgium and Holland. By the fifteenth century bricks were manufactured locally, and after the Great Fire in 1665 all buildings in London had by law to be erected of brick or stone. This spur to production did not, however, result in any change in production methods, which remained until the nineteenth century hand-winning, weathering and hand-making with hack drying and firing in primitive kilns. The first machine was probably built in 1825, Lyne and Stainford's pug mill, with moulds designed to make fifteen bricks at once. This was the beginning of the soft-mud process. In 1835 Jones' machine with the moulds on a rotating table followed. [6] Until 1782, very few bricks were made in America, since they were convenient ballast for ships travelling light from Great Britain; but developments in brickmaking machinery in Britain and Europe were paralleled in America from about 1835, when Adams invented an improved moulding machine, worked by horse, and subsequently in 1840 one driven by steam.

Possibly the most important invention in the history of brickmaking was that of the Hoffmann kiln in 1858, which changed the whole operation of the European industry. Subsequently the principle of the continuous kiln has been adopted in a more primitive form in developing countries with outstanding success. The tunnel kiln had been known much earlier, but it was difficult to control. The Hoffmann kiln was preferred because it was easier to operate, and this led to the development of the annular kiln. In America, car tunnel kilns directly superseded intermittent kilns, probably because of the generally cheaper sources of fuel, which made fuel-saving less important.

The Hoffmann kiln, with the invention of the stiff-plastic process that enabled hard colliery shales to be made into good bricks, was especially important in the industrialization of the coalfield areas of Lancashire and Yorkshire and in the expansion of the railway system, with its need for high-quality bricks for cuttings and tunnels. There are still some brickworks in England that owe their origin to an enterprising railway engineer who knew he would shortly need bricks and recognized a good brickmaking clay when he saw it in his excavations.

As a result of employing Coal Measure shales in the stiff-plastic process, chain haulage, dry pans with perforated bases, bucket elevators, and rotary and other screens appear to have come into use. [7] Somewhat earlier (in 1840) a dry press had been introduced to make floor tiles in Staffordshire; it was followed around 1860 by the semi-dry press process of brickmaking. Successfully begun in

Accrington this latter process was a disaster in Nottingham because the bricks were not durable; but by 1880 it had become the foundation of the Fletton brick industry in Peterborough.

Tunnel dryers had been tried in England in 1845, and another system in America in 1867, but only in the last decade of the nineteenth century in Germany were real advances made with contra-flow and recirculation systems, and the use of waste heat from kilns.

Noble records that at the turn of the century modern methods were rapidly replacing traditional ones, but all the clay was still being won by hand, with the assistance of blasting where necessary. [7] The earlier works were small, built to meet local demand; for larger building schemes bricks were made on site. Although the railways and canals provided transportation for bricks, the horse and cart was still used to transport them in loads of 350 to site from the railway or barge. Steam lorries could carry 3,000 bricks, but the roads were hardly adequate and the maximum speed permitted was only four miles per hour. Only after modern means of transportation—a prerequisite for industrialization—had been introduced was the expansion of the brick and tile industries possible.

Apart from a period of depression in the early 1880s the brick industry's output showed a steady rise up to the First World War. Figure 1 is plotted from data given by Noble. [7] The dotted line shows the growth up to 1907 and gives an indication of the rate of increase in production required in an expanding economy. From 1921, when production again rose to 3,900 million, growth was much more rapid, reaching nearly 7,000 million in 1938.

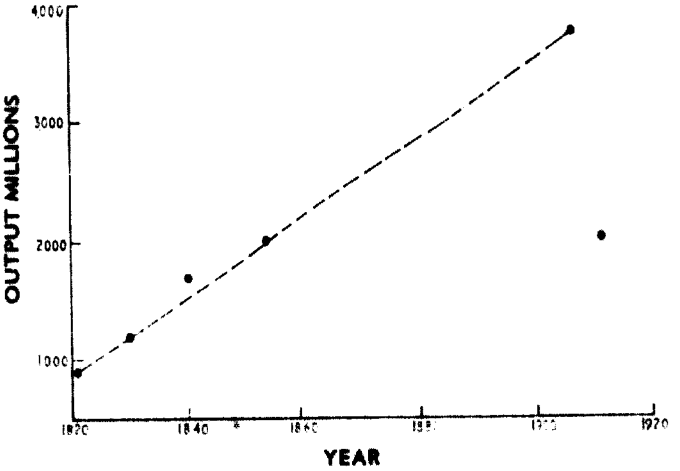


Figure 1. Output of bricks in Great Britain, 1821–1912 [7]

During this time the processes invented in the nineteenth century were being vastly improved. Winning and haulage were extensively mechanized with the introduction of the power shovel early in the century and the dragline in 1930. Clay-preparation machinery was increased as the necessity became apparent, and pans became larger and more robust with heavier mullers. The semi-dry press and stiff-plastic machines were also made more robust and effective. The roller-bat process, which is the stiff-plastic process for making plain roofing tiles, became important in the British market. Its success, however, prevented the development of a single-lap tile industry and hence allowed the concrete tile in Britain to capture the market for a more economical tile capable of being laid at lower pitches. In Europe the clay roofing tile industry maintained until a few years ago complete supremacy with the clay single-lap tile.

The soft-mud process developed little until the turn of the century, when first the Berry machine appeared and then the Monarch with an output of over 2,000 bricks per hour. The Autobrick machine, incorporating automatic setting of pallets on cars, was extensively used in the United States.

The extrusion process was well established by 1900, and most of the developments up to 1939 were improvements in the mechanism of the extruder or of the wirecutter. De-airing was introduced, although its full implementation came later. In drying and in firing the pre-1939 developments were essentially improvements on existing principles. More important is that in the United Kingdom only 7 per cent of the output was made in seasonal plants, and only some 10 per cent was dried naturally. Table 1, abstracted in simplified form from data given by Miller, shows how completely the mechanized processes had become established, with annular continuous kilns firing almost 60 per cent of the total production. [8]

Production in the United Kingdom fell to about 1,000 million bricks from 1939 to 1945, but by 1960 it was again almost 7,000 million. In the last two decades production of facing bricks has increased at the expense of common bricks. This is true for Great Britain, as shown in table 2, for the United States to an even more marked extent, and for Europe to a somewhat lesser extent.

All the important new processes have aimed at reducing labour to the minimum. Winning is all by machine, and increasingly it is tractor and scraper on outside contract. Haulage systems are moving predominantly to dumpers or tipping lorries. The stiff-extrusion process, using low moisture content and high horsepowers, has brought about new extruders, invariably fully de-aired, and better clay preparation, including high-speed rolls. This stiff-extrusion process is steadily replacing the stiff-plastic process. New plants usually produce perforated bricks because they can be more effectively and rapidly dried and fired. A number of mechanical setting machines have been patented so that the bricks need not be handled manually. Intermittent air-flow drying systems speed up drying and reduce waste to negligible proportions, while steam tempering allows very rapid drying. Large soft-mud machines operate automatically, and even the handmade process is now mechanized to the point of supplying the moulder with a preformed clot. Car tunnel kilns are the preferred system of firing in new works, and both they and existing kilns are being changed to oil firing and gas firing as soon as it becomes economic to do so. Similar changes in technique have occurred in the roofing tile industry in Europe.

In the United States packs of about 100 bricks are customarily delivered to site by special lorries incorporating handling equipment. This procedure is being followed now in Great Britain, and some packaging is being used in Europe. The fork-lift truck is the ubiquitous transport system in works, and packs of bricks loaded by fork-lift can be off-loaded onto large building sites by tower

Table 1

METHODS OF DRYING AND FIRING BRICKS MADE BY DIFFERENT PROCESSES

(Per cent United Kingdom 1938 production)

	Non-seasonal					*Seasonal*			*Total*
	Semi-dry press	*Stiff-plastic*	*Extrusion*	*Soft-mud*	*Hand-made*	*Extrusion*	*Soft-mud*	*Hand-made*	
Drying process									
In kiln only	31.0	26.2	0.1						57.3
Hot floors	<0.1	0.4	14.3	<0.1	0.4	0.1	<0.1	<0.1	15.2
Tunnel dryers	0.2	0.4	7.3	<0.1	0.2	<0.1	0.3		8.4
Chamber dryers		0.2	2.4	0.1	<0.1	<0.1			2.7
Hacks or unheated sheds			0.4	<0.1	0.5	0.9	1.1	2.2	5.1
Not specified	3.1	1.4	4.3	0.8	0.8	0.3	<0.1	0.7	11.4
TOTAL	34.3	28.6	28.8	0.9	1.9	1.3	1.4	2.9	100.1
Firing process									
Clamps or downdraught		<0.1	0.7	0.1	0.3	0.1	0.8	1.6	3.7
Clamps and/or periodic and/or continuous	4.5	3.3	4.6	0.3	0.2	0.1	<0.1	<0.1	13.2
Periodic downdraught	0.1	2.1	4.4	0.2	0.6	0.9	0.3	1.0	9.6
Semi-continuous	5.5	0.1	0.2						5.8
Annular continuous	20.0	21.4	16.8	0.3	0.3	0.2	<0.1	<0.1	59.2
Car kilns (tunnel or chamber)	0.1	0.2	0.5		<0.1		0.3		1.2
Not specified	4.1	0.5	1.0	0.1	0.5	<0.1	<0.1	0.3	6.7
TOTAL	34.3	27.7	28.2	1.0	2.0	1.4	1.7	3.1	99.4

crane. The final stage has been reached with prefabricated brick panels, which are delivered to site ready to install as a walling unit.

Since the beginning of the nineteenth century the clay industries in industrialized countries can be considered to have passed through three phases broadly separated by the two world wars. The first phase was one of invention, the second, one of development of these processes with the incorporation of useful mechanical aids from other industries, and the third, once again a most fertile period of innovation and invention.

The unifying theme in all these phases has been an increase in productivity achieved by the investment of capital leading to a reduction in labour. For many years works set up in the late nineteenth century and early twentieth century were allowed to continue operating with no reinvestment of capital because they were completely written down. By making no allowance for depreciation the owners could make a satisfactory profit from a basically inefficient and costly process. Now works are planned and built on the basis of a useful working life of 20 to 25 years during which an adequate return on the investment will be provided and sufficient capital will be generated to build a new works at the end of the period.

Table 2

CLAY BRICK PRODUCTION IN MILLIONS IN GREAT BRITAIN

Type	*1938*	*1948*	*1958*	*1960*	*1964*	*1967*
Commons	5,750	3,582	4,348	4,659	4,641	3,971
Facings	850	869	1,865	2,321	2,989	2,846
Engineering		147	228	302	324	391
TOTALS	6,600[a]	4,598	6,440	7,283	7,954	7,208

[a] Engineering brick output not available.

Countries now developing may avoid the mistakes of the nineteenth century by choosing only the best methods that survived during the stage when brickworks were supplanting craft industries. Where this has already taken place and if capital and raw material resources are available, it is now possible to erect a plant to produce substantially any product required. For bricks this can be done for a productive labour cost of no more than two man-hours per 1,000 bricks, or about 0.6 man-hours per ton. Whether such plants are appropriate, or whether a more labour-intensive process should be deliberately chosen, will depend upon the circumstances in each case.

I. Raw materials

FORMATION AND COMPOSITION OF CLAYS

THE RAW MATERIALS of the brick and roofing tile industries are usually heterogeneous, relatively impure buff or red-burning natural clays. In general the works of the heavy clay industry is likely to be located on, or close to, its source of raw material. Only in highly developed communities with a market for specialized and highly specified products is it economically feasible to transport desirable clay great distances. However, since suitable clays are widespread, the choice of site for large works can often be made on the basis of propinquity to the market as well as to the raw material.

Clays are sedimentary rocks formed by the breakdown of pre-existing rocks—originally the primordial igneous crust of the cooling planet—under the chemical and mechanical agencies of surface weathering and also by pneumatolytic action, which is attack by chemically active gases and solutions from lower in the earth's crust. While the purer clays, such as ball clays, used for pottery manufacture may be uniformly fine-grained, the heavy clays consist of a range of particle sizes from quartz grains several millimetres in diameter to clay minerals of sub-micron size.

The characteristic property of a clay is plasticity, the ability to be shaped under pressure in the presence of an appropriate proportion of water and to retain that shape when the pressure is removed. The very fine particles impart this property. Although the size fraction less than two microns is referred to as "clay" it is composed not solely of clay minerals but also of fine particles of the constituents found in coarser sizes, especially silica flour and micas.

Primary clay deposits have been formed in the same place as their parent material—the China clays of Devon and Cornwall are typical examples—while secondary clays have been transported by the action of wind, water, or ice. Brick and tile clays are generally secondary, and their properties are determined by their geological history. especially by the environment of deposition.

The process of weathering breaks down the high temperature silicate minerals of igneous rocks, such as felspars, leaching out the alkalis to form clay minerals, which are more stable under surface conditions, and leaving the resistant materials quartz, muscovite mica and some accessory minerals. The chief transporting agent is water, which carries the fine particles in suspension and rolls the coarser particles along the stream bed, thus providing a sorting effect. This sorting is further enhanced when the river slows down in its lower reaches and deposits the coarser particles. By the time it reaches the sea only the finest particles are in suspension;

the dissolved salts in sea water flocculate this fine material and cause it to deposit, thus giving rise to a delta formation. Where the river empties into a fresh-water lake, however, no such coagulation occurs, and coarse-grained deposits form near the mouth of the river while the clays form further out in the lake.

Floods and changes in the nature and proportion of the material carried give rise to the alternations of sand and clay that are typical of lacustrine sediments. In glacial lakes "varve clays" show rapid alternations of sand and clay representing respectively the floods of spring and the still conditions under the frozen surface of winter. Glaciers grind away the rocks over which they pass. Besides a large quantity of very fine material they also pick up bigger pieces so that the glacial clays deposited when the ice melts tend to be fine-grained but to contain some large rock fragments. Such deposits are known as boulder clay. At the end of the ice-age in the northern hemisphere the finest material in the extensive deposits of boulder clay was transported by the prevailing winds to form thick deposits of fine-grained siliceous "loess" in a belt across central Europe and Asia.

Clays deposited in water are consolidated by the weight of subsequent sediments. Earth movements consolidate these further to form shales and in extreme cases slates. During these processes secondary minerals, calcareous or ferruginous nodules may be formed from percolating solutions, and eventually by uplift or denudation the deposit becomes accessible at or near the surface as a source of brickmaking raw material.

It has been estimated that the upper ten miles of the earth's crust consist of 95 per cent igneous rock, 4 per cent shale or clay, 0.75 per cent sandstone, and 0.25 per cent limestone. [9] While a typical clay shows considerable individual variation, it would be surprising if it did not have a chemical analysis approximating to the average composition of the crust. Table 3 compares the average composition of the crust obtained from more than 5,000 analyses from different parts of the world with the average of 77 analyses of different samples of glacial clay from southern Norway, and one typical English Keuper Marl. [10] Table 4 lists the chemical composition of a range of clays.

The chemical composition of a clay is the combination of those of its constituent minerals, the main ones of which are quartz, mica and the clay minerals. These last fall into three main groups: kaolinites, illites, and montmorillonites, together with a fourth group that includes palygorskites and sepiolites. The nature and proportion of the clay mineral greatly affect the properties of the clay, as do subsidiary constituents among the more important of which are:

Iron oxides:	haematite, limonite, goethite, magnetite;
Carbonates:	calcite, dolomite, siderite;
Sulphates:	gypsum, barytes;
Sulphides:	marcasite, pyrites, chalcopyrites;
Carbonaceous material:	coal, lignite etc,;
Phosphates:	calcium phosphate.

In the chemical analysis the SiO_2 is contained in the clay mineral, micas and free quartz, while the Al_2O_3 is from the clay mineral and micas and the micas also contain the alkalis Na_2O and K_2O; TiO_2 is from residual titanium minerals from

Table 3

CHEMICAL ANALYSES OF THE EARTH'S CRUST COMPARED WITH A KEUPER MARL [10]

	Clarke and Washington	*Goldschmidt*	*Keuper Marl*
SiO_2	60.18	59.12	56.73
TiO_2	1.06	0.79	0.98
Al_2O_3	15.61	15.82	16.09
Fe_2O_3	3.14	6.99	6.27
FeO	3.88		
MgO	3.56	3.30	4.31
CaO	5.17	3.07	3.60
Na_2O	3.91	2.05	1.11
K_2O	3.19	3.93	4.03
P_2O_5	0.30	0.22	n. d.[a]
		H_2O 3.02	Loss 7.04
TOTAL	100.00	98.31	100.16

[a] n. d. = not determined.

the parent rock. Fe_2O_3 is present not only in the iron minerals but may also form part of the structure of the clay mineral and mica. Small proportions of CaO and MgO arise from the clay mineral and mica, but when greater than 1 per cent, calcite, dolomite and gypsum are probably present. The sulphate noted is present as gypsum, barytes or soluble salts. Ignition loss includes the combined water present in the clay mineral and mica, the water of crystallization of the gypsum, the loss due to oxidation of carbonaceous material and carbon dioxide from the breakdown of carbonates and sulphur oxides from sulphates.

The compositions given have been for average specimens, but in all heavy clay deposits variation is to be expected both vertically and laterally. These variations can cause considerable processing difficulty either because they markedly modify the characteristics of the clay or because the discrete mineral species are themselves deleterious.

COMMON IMPURITIES AND BENEFICIATION OF CLAYS

In general any heterogeneity in raw material is to be avoided, but the economics of brick and tile production permit very little "beneficiation". The cheapest and most effective beneficiation is to leave those areas of the pit where unwanted constituents occur. In old hand-winning operations of surface deposits a series of shallow pits frequently can be found that testifies to the acumen of the diggers or more likely the insistence of the makers on a clay easy to mould. In large-scale mechanical winning such practices are clearly undesirable, and contaminated areas may have to be stripped and discarded.

Table 4

CHEMICAL ANALYSES OF DIFFERENT TYPES OF CLAY [10]

	Coal Measure fire-clay	*Coal Measure shale*	*Etruria Marl (non-calcareous)*	*Etruria Marl (calcareous)*	*Keuper Marl (illitic)*	*Keuper Marl (sepiolitic)*	*Oxford clay*	*Weald clay*	*London clay*
SiO_2	64.5	53.69	58.12	51.39	42.74	55.85	43.96	54.98	57.13
TiO_2	1.2	0.20	1.35	1.27	0.95	0.54	0.30	1.01	1.08
Al_2O_3	20.6	20.50	22.40	23.10	16.32	10.26	17.51	18.43	17.18
Fe_2O_3	2.8	Fe_2O_3 6.95 FeO 0.86	7.55	10.02	6.55	3.83	Fe_2O_3 2.76 FeS_2 2.60	10.37	7.98
CaO	0.7	0.30	0.40	2.00	9.46	5.66	8.14	2.66	2.41
MgO	0.8	2.41	1.28	0.96	6.23	11.30	1.59	0.91	2.82
K_2O	1.7	2.73	1.65	1.79	3.57	3.01	2.66	3.25	3.27
Na_2O	0.1	0.62	0.14	0.10	0.83	0.19	0.72	0.46	0.27
Li_2O	n. d.[a]	n. d.	n. d.	n. d.	n. d.	0.03	n. d.	n. d.	n. d.
SO_3	0.3	0.37	n. d.	n. d.	n. d.	n. d.	1.30	n. d.	n. d.
Loss	7.3	11.14	7.40	9.09	13.58	9.62	18.46	7.71	8.00
CO_2 from carbonate . .	1.0	n. d.	0.1	1.3	n. d.	3.9	5.92	n. d.	2.1

[a] n. d. = not determined.

In alluvial and lacustrine clays alternating bands or pockets of sand are common. Often the sequence of strata is satisfactory for brickmaking when won together, since some proportion of sand added to very plastic clay improves the drying and firing characteristics. However, too much sand reduces the plasticity, making moulding difficult, and also markedly reduces the strength of the fired product. Sand and clay should, wherever possible, be mixed in known and predetermined amounts, and this is best accomplished by separate winning of the two materials and remixing.

In older rocks, especially the Coal Measures of Britain, massive deposits of hard sandstone may have to be removed by blasting before the clay can be won.

Pebbles of various types occur in recent alluvial deposits, and, while always a nuisance, are a positive danger when they consist of pieces of limestone, which cause lime blowing noted below. Boulder clays contain pebbles of various sizes, some so large that their removal is important for the mechanical safety of the plant. A large proportion of pebbles, even if finely ground, reduces the plasticity of the clay in the same way as sand; but a smaller proportion of pebbles, if not broken down, causes drying and firing troubles by the localized differential thermal expansion and contraction effects. Current national standards usually require bricks and tiles to be free from large pebbles and deleterious impurities.

"Lime" includes all forms of calcium carbonate—limestone, chalk, calcite nodules and crystals and fossils, as well as the mixed carbonates dolomite and ankerite. They have the common characteristic that during the course of firing the calcium carbonate breaks down to calcium oxide, which may further react with clay to form complex calcium aluminosilicates. The more finely divided particles and the surface of coarser particles combine with other minerals, and when the products are drawn from the kiln any remaining calcium oxide in the coarse particles slowly reacts with atmospheric moisture to form calcium hydroxide. This reaction is accompanied by an increase in volume, so that particles near the surface expand and "blow off" a small piece of face with a result at best unsightly. Finely divided lime is a flux and may cause the goods to slump out of shape during firing. It may also modify the fired colour and is deliberately added to produce yellow bricks. Small calcite crystals may act as nuclei around which calcium phosphate deposits to form hard phosphate nodules, and some fossils are phosphatic. In either case the nodules behave like pebbles and are difficult to grind.

Calcium sulphate occurs in the anhydrous form as anhydrite, and hydrated as varieties of gypsum of which the crystalline form selenite is widespread throughout the geological column. While they may be broken down during firing if the temperature is high enough, any residual sulphate is soluble in water to some extent and can give rise to efflorescence and mortar decay caused by the reaction of the soluble sulphate with the tricalcium aluminate in set cement.

The commonest sulphides are those of iron, pyrites and marcasite, but the copper, lead and zinc sulphides, chalcopyrite, galena and sphalerite may also be found. Pyrites are oxidized during firing, and the resultant sulphurous oxides may attack the alkali and alkaline earth metals in the clay to form the soluble sulphates of sodium, potassium, magnesium and calcium and hence give rise to efflorescence in work. Pyrites can cause bloating during firing.

Iron carbonate (siderite) occurs alone or with calcite, dolomite, pyrites, etc. in clay ironstone bands and concretions and in ironstone nodules. Like calcite it can lead to blows and like pyrites give iron spots on the face, while the ferrous residue in the brick when wetted by acid rain water can cause brown staining of the mortar joints.

Carbon is common in clays. It occurs as roots in recent surface clays, as beds of peat, as lignite both disseminated and, like coal, in seams, and finely dispersed throughout the clay as in the carbonaceous shales and oil shales. It may be positively helpful in acting as a fuel or markedly deleterious, especially when varying in quantity and quality. In the latter case it is necessary either to slow down the rate of firing or to oxidize the carbon completely or to accept a product that is black cored or even bloated.

Soluble sulphates have already been mentioned, and to these must be added chlorides, especially sodium and potassium chlorides, and nitrates, which arise in many countries from the use of fertilizers but which occur in quantity in the soil of certain countries, notably Algeria, India, Iran, Spain and the United Arab Republic. All cause efflorescence, and coloured efflorescences have been reported that contained iron, chromium, molybdenum, nickel and vanadium, although some of these may have had their source in the fuel used for firing.

As noted above impurities are best left in the pit either by selective winning or by selection from the won material. Unwanted large stones, timber and large roots may be picked out by hand when clays and shales are won relatively dry—the most effective way is from a conveyor belt as the material passes by—but plastic clays tend to coat these impurities, certainly the smaller ones, and they cannot therefore be detected. Machines are, however, available. Rolls with helical grooves (figure 2) break down the plastic clays, the larger stones travel along the top of the helix and are discharged as waste at the end of the roll, while the clay passes through the gap between the two rolls and on into the process. Pugs with a perforated barrel section are extensively used in Europe to remove roots and stones. From the feed point, rotating knives cut and mix the clay, which is forced forward to the perforated section. Clay extrudes through the holes onto a conveyor into the process, while any stones larger than these holes pass forward into

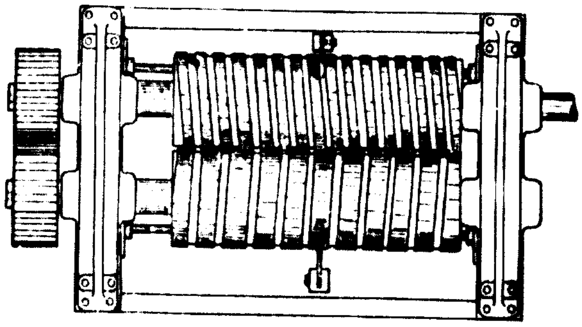


Figure 2. Stone-separating rolls [18]

the end section, which is closed by a gate, which can be opened from time to time to let the unwanted material run off.

Where the process permits it, an effective way of cleaning clay is to use a wash-mill and wash-back as in the English stock brick process. The brick-earth, won in a plastic condition, is tipped into a wash-mill, mixed with a large quantity of water, and agitated slowly and continuously by rotating paddles to form a thin slurry. To one side of the mill is a grid of any desired fineness through which the slurry but not stones, roots and other matter passes. The slurry is pumped to the wash-backs, large pits in which it is mixed with a chalk slurry and allowed to settle and dry out before being re-won as a soft mud suitable for hand-making or moulding in a soft-mud machine. The stones and other material are periodically cleaned out of the wash-mill between charges.

In any winning operation there is always the possibility that tramp iron may be taken to the works. If a discarded bolt or digger tooth reaches the processing machinery disaster may result. Often tramp iron can be taken out by hand from the picking-belt; alternatively it can be removed by magnets. These may be in the form of a magnetic head pulley on a conveyor belt or feeder, mounted above the conveyor as an overband magnet, or as a magnetic chute. Of these the magnetic head pulley is the cheapest and most effective.

After the above-mentioned methods have been used, any small-size impurities remaining will be ground fine enough in the subsequent process to ensure their distribution throughout the body. In most cases this will be satisfactory, but finely ground lime can still cause blowing, and soluble salts are, of course, unaffected by this kind of preparation. Both can be treated by additives, lime by the addition of common salt (sodium chloride) and soluble sulphates by the addition of barium carbonate. The barium carbonate added to plastic clay reacts with the soluble sulphates to form insoluble barium sulphate. Reaction depends upon the barium carbonate being intimately mixed, and precipitated material is more satisfactory than ground witherite, the natural barium ore. It is usual to add twice the theoretical quantity required, and this quantity can be found readily by analysis. Only those sulphates present in the raw clay are inactivated by these additions; there is no effect on sulphates subsequently formed by the reaction of sulphur oxides in the kiln gases with the clay. The most effective way of minimizing soluble salts in the finished product is to fire to as high a temperature as the clay will permit. Despite the heterogeneity of the clay sources used for brick and tile production, adequate clay preparation and mixing minimize the risk of large localized impurities, and proper control of firing gives the most durable product obtainable from the particular raw material.

EVALUATION OF CLAY RESOURCES

The nature of the clay and the amount available depend upon the structure and lateral variation of the strata. Information may be available from the national geological survey organization; but since heavy clays are not of great economic value, adequate mapping of their location may not have been carried out, especially in areas where more valuable minerals receive first attention. In existing pits the clay face may give considerable information about the distribution of the strata, and many plants have worked successfully without prior geological knowledge, dealing with problems as they arise. The evidence of the outcrop at the surface, however, may have quite different meaning at depth as the examples in figure 3 show. Capital investment, therefore, should invariably be preceded by a survey, including bore-holes or test-trenches, by a competent geologist. Further, neither the plant itself nor stacking grounds for the product or for waste materials should be located on valuable clay land, but many prematurely closed works testify to the failure of their owners to avoid this situation.

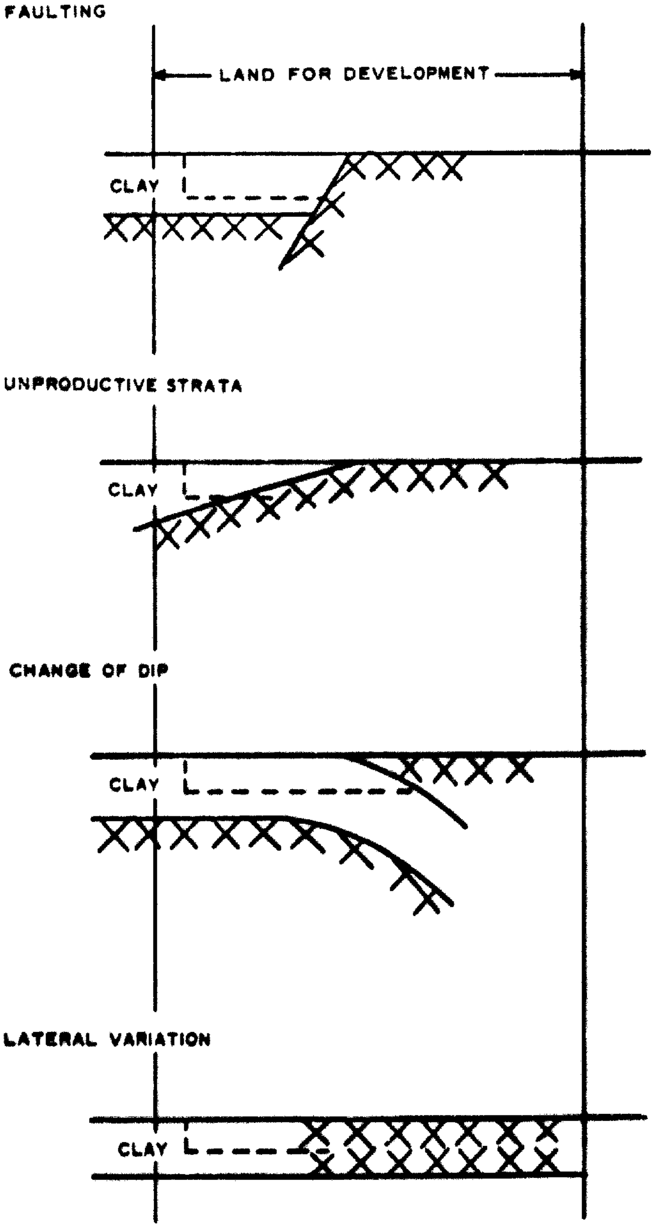


Figure 3. Possible difficulties in the working of clay pits [10]

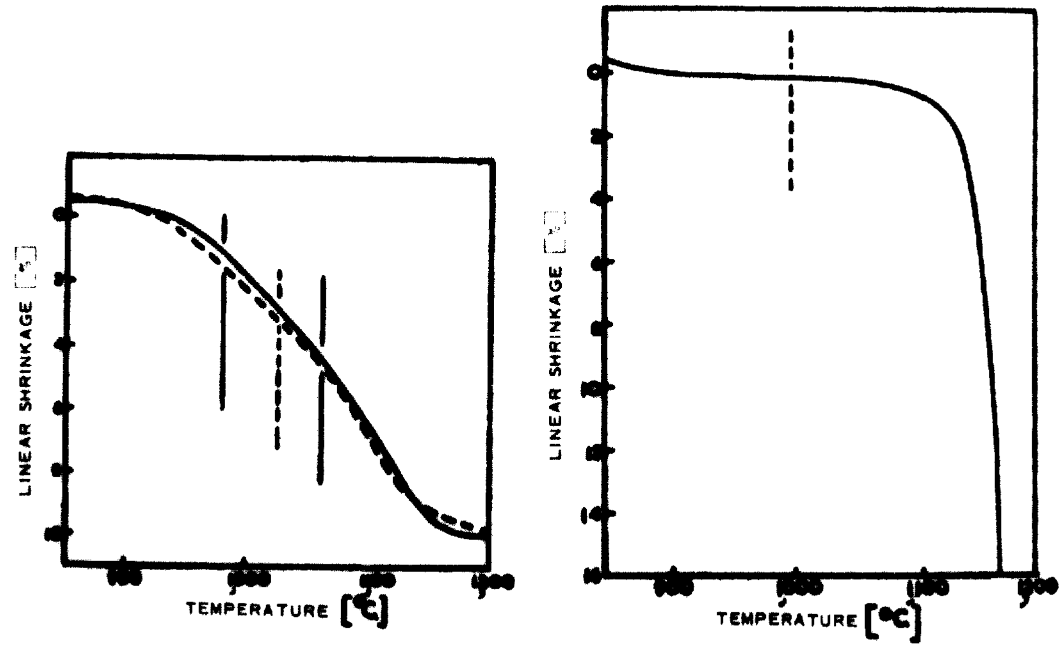
Not only the quantity but also the quality of the clay reserves is important. Where the beds are steeply dipping a much greater stratigraphical range—and hence a greater range of material—is available than in gently dipping beds. Steeply inclined beds result from strong earth movements, so that faulting, accompanied by zones of broken rock, bands of highly plastic clays and veins of minerals, such as calcite, is common. Clay working may, therefore, be difficult because the clays range in properties from plastic material to hard indurated shales and are interspersed with bands of unusable material.

The important property of clays is plasticity. While this depends on the nature and proportion of the clay minerals present—indeed it is the large surface area of fine clay particles and their ability to hold water films more or less rigidly at their surfaces that causes the phenomenon—it also depends on the state of compaction of the clay. Thus, clays which have been involved in earth movements or those in which the particles have been cemented together by percolating solutions of carbonates or silica have lower plasticity than might be expected from the nature and proportion of the clay mineral present, while at the other extreme organic colloids in the clay may enhance the working properties. The other minerals in clays act as non-plastics and merely dilute the properties of the clay in the wet state; beyond a certain quantity they may so markedly affect the rheological properties as to make the clay unworkable.

The Testing Department of the British Ceramic Research Association carries out a "Clay Report", a complete series of tests on unknown clays. These tests include: mineralogical examination; chemical analysis; particle-size determination; making characteristics; drying characteristics, volumetric drying shrinkage, empirical drying test; fired strength, water absorption and volumetric firing shrinkage; and fired colour. The results are evaluated in terms of the use to which the clay is to be put, and the type of process to be used is recommended.

The various test methods have been described. [10, 11] While all the tests contribute to the final evaluation, special attention should be drawn to the under-load test, since it provides an indication of the behaviour of the clay during firing and enables an optimum firing temperature to be assessed. A small setting of six briquettes is heated in a special furnace at a constant rate while under an applied load of five pounds per square inch, which is equivalent to that at the base of a kiln setting. A means is provided of recording expansion and contraction on a rotating drum, and characteristic curves are obtained. A slight thermal expansion is recorded up to about 850° C, but above this temperature firing shrinkage starts and the curve falls, steadily or in steps, until at a still higher temperature plastic deformation commences, and the curve descends more steeply. If bloating occurs it may show as an expansion at this point. Typical curves are shown in figure 4, and bloating can be detected in the Lias clay between 1,150° C and 1,200° C.

Some firing shrinkage must take place to develop adequate strength, and it is usual to look for a linear firing shrinkage of 6 per cent, though this is not always possible to attain. A temperature range in which the shrinkage does not increase rapidly is desirable to avoid marked variations in the size of the product caused by the inevitable temperature differences within a kiln. Furthermore, the temperature should not be so high that plastic deformation is rapid; otherwise the goods will

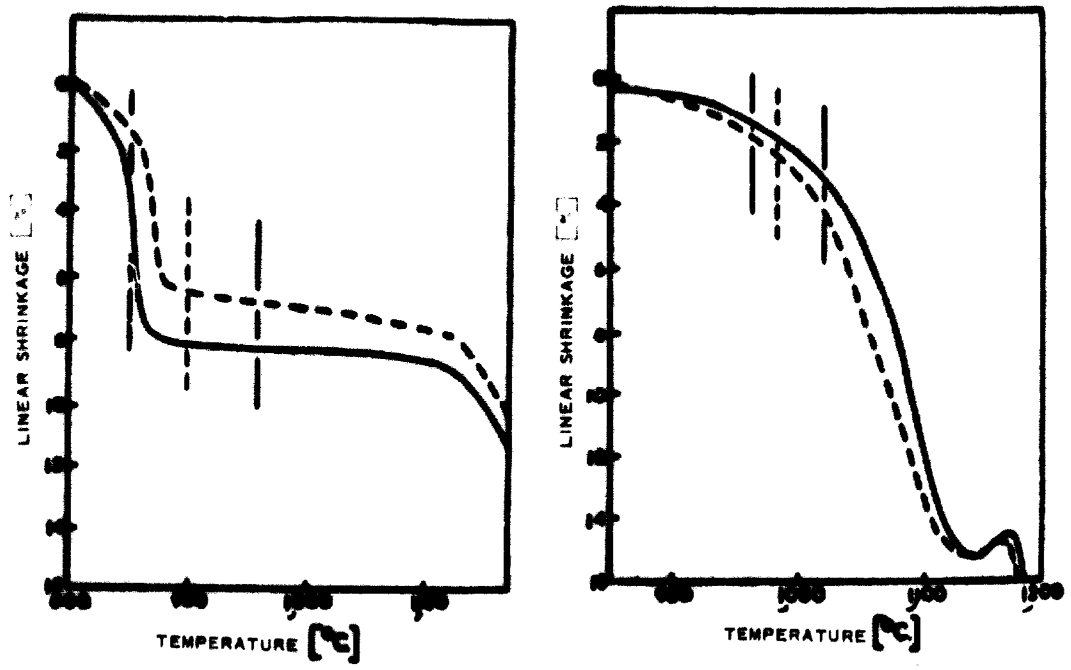


A

CARBONIFEROUS SHALE

B

KEUPER MARL



C

GAULT

D

LIAS

Figure 4. Shrinkage under-load curves for different kinds of clay [11]

be misshapen or even melted together. High lime clays show a characteristic flat portion on the curve between about 900° C and about 1,100° C before deformation starts. For example, the Gault clay in figure 4 C has the same shrinkage at 1,050° C as at 900° C, so fuel could be saved by firing to the lower temperature.

Other considerations may be important, however. For facing bricks, the higher temperature may have to be used to minimize difficulties caused by soluble salts and moisture expansion. For dense, well-vitrified, high-strength engineering bricks of accurate shape and dimensions, a clay with a long, steady vitrification range as the Coal Measure shale in figure 4 A is required. The Keuper Marl curve, on the other hand, is clearly less suitable. At 1,100° C little contraction and hence little development of strength has occurred, and above this temperature the vitrification is so fast that industrial production becomes hazardous.

CHARACTERISTICS OF DIFFERENT MANUFACTURING TECHNOLOGIES

Since wide ranges of properties are found in different clays, the production technology must be matched to the raw materials available. Alternatively, if a particular product is required, the raw material must be chosen accordingly. Clays for heavy clay manufacture are won over a great part of the geological column in the United Kingdom. As table 5 shows, the *in situ* moisture content increases at the rocks get younger, and the hardness decreases in the same direction. This affects the technology. Since the old, indurated rocks are hard and brittle, they often need blasting to loosen them from the face; and because of their massive nature positive kinds of winning equipment are necessary, usually face shovels. Heavy primary crushing equipment, jaw crushers or cubing rolls, is necessary to break the material down to a reasonable size for feeding and grinding. There may be very hard impurities, siliceous, calcareous or ferriferous bands and doggers. The rocks may be mineralized and ore minerals found such as pyrites or concentrations of gangue minerals, silica as quartz veins, which is a nuisance, felspar, which acts as a flux, or gypsum or calcite, which may be positively deleterious. Carboniferous clays contain variable amounts of carbon, and this makes accurate burning difficult.

The older clays need considerable work to produce plasticity, except in the weathered zone where very plastic clays may be found, and they are generally prepared by dry grinding. In Great Britain this method is certainly used for all clays older than Trias. Keuper Marl clays are often ground in wet pans. The very important Fletton brick process, which comprises 40 per cent of the total output of British bricks, operates on Oxford clay, which is dry ground. Some Weald clays are dry ground; some are prepared in wet pans; and the more recent clays are prepared in the plastic condition except in special cases.

These plastic clays require no blasting. They can be won by dragline or multi-bucket excavator. Although kibbling rolls are sometimes used to reduce the size of the primary feed it is possible to have a clay preparation line consisting only of smooth rolls. Boulder clays, in particular, contain pebbles and rock fragments that should be removed, but some of these clays are so plastic that sand is added as a diluent. The high moisture content and high plasticity may give processing problems. For example, high-drying shrinkage may lead to cracking difficulties. Fine-grained alluvial clays may be very siliceous and actually lacking in plasticity. However, in general they are suitable for tile manufacture.

Table 5

Geological column in the United Kingdom

Geological age	Raw material	Age of base of formation (million years)	Usual method of brick manufacture	Type of roofing tile	Usual method of tile production	
Recent	Alluvium		H. M.	Single-lap	H. M. Pug or stupid extrusion	↑
	Brick-earth		S. M.			
Pleistocene	Glacial clays	1	W. C.			
Pliocene and Miocene . .		25				
Oligocene and Eocene . .	London clay	60	H. M.	Plain	H. M. Pug extrusion	
	Reading beds		W. C.			
Cretaceous	Gault	120		Plain	H. M. Pug extrusion	*Moisture content*
	Weald clay					*Hardness*
Jurassic	Oxford clay	145	S. D. P.			
Triassic	Keuper Marl	170	W. C.	Plain	H. M. Pug extrusion	
Permian		210	S. P.			
Carboniferous	Etruria Marl		S. P.	Plain	Roller-bat	
	Coal Measure shales and fire-clays	280	W. C. S. D. P.			
Devonian	Shales	325	S. P.			
Silurian	Shales	350	S. D. P.			
Ordovician	Shales	410				
Cambrian		500				↓

Key: H. M. = handmade; S. M. = soft-mud; W. C. = wirecut; S. P. = stiff-plastic; S. D. P. = semi-dry press.

Table 5 also shows how the type of clay affects the choice of technology. Modern technologies will be discussed later, but in their more traditional forms the processes may be described as follows:

Handmade

In essence the hand process has changed little in 4,000 years of brickmaking. In its simplest form a man digs clay in the autumn, allowing it to weather in heaps throughout the winter. Then in spring he sets up his mould table near the heap, mixes some form of fuel with each batch of clay, places the moulded bricks on to a barrow and wheels them to his drying ground, where they are dried in hacks by the summer sun. When sufficient bricks are dry he builds them into a clamp on an adjacent site and fires them. His customers collect the bricks in their own transport.

Larger works dig the clay by machine and stack it to weather in curfs. The fuel may be added in a wet pan and the clots delivered to the makers by a machine feeding directly onto the making table. Hacking is still greatly favoured, although in some works the bricks are set by the makers onto dryer cars and dried in tunnel dryers. Firing is accomplished in clamps, downdraught or continuous kilns.

It has always been considered essential to weather the clay for handmaking, but whether any actual "weathering" takes place in the short time available is difficult to prove. What certainly does happen, however, is that the clay receives an extra mixing by being placed in the curf in horizontal layers and won by vertical cuts. Water is added at least to the top layers. Better distribution of moisture generally throughout the mass may also occur, and this is clearly important.

Soft-mud

The soft-mud process marks the first stage of mechanization of brickmaking by introducing a machine to replace the hand-moulder. The methods of winning, drying in hacks, and firing in clamps may be identical with the handmade process; in fact until the making shop in a works is reached it may be impossible to tell which process is in operation. Many plants operate the two processes, since the same clay preparation is adequate for both; although normally the better clay is reserved for hand-making, and the individual makers may require—or believe they require—variations in the temper of their clay.

The soft-mud process is of considerable importance as the basis of the stock brick industry, where large outputs lead to low labour figures. In a typical works of this sort the brick earth is dug by dragline and transported to the wash-mill, where it is formed into a slurry with water and pumped to the wash-backs at the works, which may be some distance away. Here chalk slurry is added and after being left to drain and dry for some months to attain the correct consistency, the mixture is re-won, coke breeze or "town-ash" being added, and is fed to the brick machine via a pan or mixer. The bricks are demoulded automatically onto pallets and the pallets loaded mechanically onto a dryer car. After drying, the bricks are re-set onto the tunnel-kiln cars by hand.

Extrusion, or wirecut

The extrusion, or wirecut, process may be regarded as an early attempt to produce a clearly "machine-made" brick. With the stiff-plastic process it characteristically produces in Great Britain the bulk of common bricks outside the Fletton industry.

Hand-winning may remain, but weathering can be dispensed with. Clays unsuitable for the softer methods can be processed through the wet pan and pug to produce a column stiff enough to handle and which may be set on a hot floor to dry. The dry bricks are fired in a Hoffmann kiln. For common bricks very little sorting is necessary, although underfired and grossly mis-shapen or broken bricks are usually excluded.

This process covers a wide range of operating moisture content and is used for the production of bricks, hollow blocks and roofing tiles. Soft extrusion at 20 to 25 per cent approaches the high moisture content of the soft-mud process, while de-aired stiff extrusion at around 15 per cent is close to that of the stiff-plastic process. Those works that have replaced the stiff-plastic process by stiff extrusion have found that with the same clay about 1 per cent more moisture content must be used to permit extrusion. Such bricks can be set directly onto tunnel kiln cars for drying and firing. The stiff-extrusion process is the most versatile and efficient, in the sense of low labour content, of all the processes in operation today and is characteristically chosen for new, highly mechanized works, the products of which are often perforated to permit faster drying and firing.

De-airing, the process of passing shredded clay through a vacuum chamber to remove much of the air before the clay is consolidated in the die, is often used to obtain a denser column. This yields a brick of lower water absorption and higher strength than would be the case without de-airing. In modern auger machines very high horsepowers are used (up to 650 h. p. on the big American machines) and output rates are proportionately large, up to 30,000 United States-size facing bricks per hour.

The extrusion process enables considerable flexibility in size and shape of the product to be achieved. By a simple adjustment of the cutter wires different thicknesses of bricks or lengths of hollow blocks may be cut, and by using specialist cutters like the Frey, various patterns of tiles may be cut from a simple extruded column. Facing effects may be achieved by treating the column with coloured sands and stains or coloured engobes or glazes. The surface may be textured or "rusticated" by a wire or plate if the column is relatively soft, or by rotating brushes, blades or textured cylinders or variants of these if the column is stiff. The kinds of attractive effects that can be achieved on an extruded column seem nearly limitless; considerable ingenuity can be seen in the many home-made devices that are to be found on works in many countries.

This process spans the whole range of technological development. It is used to produce low-strength common bricks by labour-intensive methods as well as high-strength facing bricks in the most modern works in the world. It is probably the most useful first step to be taken in developing a national brick industry from a handmade craft.

Stiff-plastic

The stiff-plastic process is an example of the late nineteenth century genius for mechanical contrivances. It was a great advance at the time of its invention, for it considerably reduced the labour in making and completely eliminated a separate drying process. It was ideally suited for colliery brickworks, since the raw material was waste shale and the product was cheap enough to be used extensively for underground construction. It is now also used to produce facing and engineering bricks, usually though not invariably, from shales won above ground.

The process is suitable for relatively hard clays and shales, which are ground in a dry pan, usually to pass a 7's mesh screen (with a 0.0949 inch opening, British Standards Institution). In its simplest form the dust falls through the screen onto a "dust floor", which is a loft set above the stiff-plastic machine. A man is employed to shovel the screened clay dust through a hole in a floor and down a chute to the mixer of the machine. Here water is added by a temperer, and the plastic material passes into a vertical pug, which squeezes it into clot moulds set in a circular table rotating beneath. These clots are ejected at a later point in the rotation and pressed in a mechanical press to give an accurate shape to the brick. One or sometimes two "frogs" – indentations in the bed face of the brick – are impressed, and this causes the clay to flow within the press mould and fill out the corners to produce a well-shaped, dense brick.

Semi-dry press

Although the stiff-plastic process uses a sufficiently low moisture content to permit the bricks to be made hard enough to set in the kiln, considerable amounts of water must still be removed. The semi-dry process dispenses with the costly process of adding water at one stage only to remove it later. In general the clay is ground and used with its natural water content, although some hard shales from the older geological formations may require small additions of water at the pan to achieve efficient pressing.

Most semi-dry presses are mechanical toggle presses and appear to operate at pressures too low for efficient working. Hydraulic presses may be more satisfactory both in the more even application of pressure and in the maximum pressure attained, but their outputs are lower. The actual operating pressures of mechanical presses are not indicated, and no accurate values have yet been established. It has been shown that there is a critical relationship between pressure and moisture content, such that the higher the pressure the lower the moisture content necessary to produce a product of given density. [12] Clearly, if presses were available with higher operating pressures, dusts of a lower water content might be used, with consequently less expenditure on fuel for drying. Nevertheless a balance must be struck between higher first costs and operating horsepower and the saving on drying.

This process is used by the largest brickworks in the world, the Fletton industry, which produces a considerable proportion of all the common bricks manufactured in Great Britain. The industry at its best uses large-scale winning by dragline, with haulage to the works by conveyor. Preliminary screening on a large grisly allows material of suitable size to pass directly to the clay-storage hoppers, while the oversize material is roughly crushed. Before the pans, clay is stored in one enormous hopper, but each pan is fed separately from it. Then the clay is usually processed by a unit consisting of separate pan, screen, and dust hopper to each press. From the presses the bricks are conveyed or taken on stillages to be set in fork-lift packs of half-chamber size, which are lifted directly into the transverse arch kilns and drawn in the same way.

Choice of technology

Before a works is established the market must be investigated and a decision taken on the kind of products to be made. When a suitable clay source is found it inevitably determines the technology. Although there may be several sources of clay equally well situated with respect to the market, not all the processes are equally suitable for all products; and in practice the possible courses of action are few.

The wirecut process provides the most freedom. Wet-ground plastic clays or dry-ground hard shales can be used as raw material for this process. Between low horsepower, low output, unde-aired soft extrusion on the one hand, and high horsepower, high output, de-aired stiff extrusion on the other, there are really a large number of separate processes, all wirecut extrusion. These can be adapted to make common, facing and engineering bricks (either solid or perforated), hollow blocks and roofing tiles.

In the other processes there is inherently less freedom. Apart from handmaking, they are confined to the production of bricks, although these may be perforated or cellular if produced by the stiff-plastic or semi-dry press process. While the most attractive facing bricks are handmade, and some of the strongest bricks are stiff-plastic, pressed bricks of poor quality are readily produced if the presses are not maintained properly. In the end the success of any process depends on appropriate raw materials. Too much care cannot be taken to ensure that the source is suitable and the reserves proved before an investment is made in plant and machinery.

II. Winning and haulage of clays

FACTORS AFFECTING THE CHOICE OF METHODS OF WINNING

THE CHOICE of winning methods is affected first by geological conditions, and second by economic ones. It is essential to make the best use of the natural advantages of the site and to avoid its obstacles, if the best return is to be achieved. The more important factors to be considered are: the nature of the deposit, the depth to be worked, contour of the surface, output required, amount of blending and sorting required, type of existing or proposed haulage system, capital available, and maintenance facilities and supply of spares.

Nature of the deposit

An important consideration in determining the viability of an otherwise satisfactory clay deposit is the nature and amount of the overburden. There is a limit to the thickness of overburden that can be removed economically, and at this limit mining must be resorted to if the clay resources are valuable enough to compensate for this most expensive method of winning. Overburden includes material varying from loose sand to massive rocks, and its removal may accordingly add negligibly or considerably to the cost of winning. Table 6 gives representative figures for five works from an early survey by the British Ceramic Research Association. [13]

Table 6

LABOUR USED FOR REMOVAL OF OVERBURDEN

Works	*Method of removal*	*Depth of overburden (ft)*	*Tonnage removed per week*	*Man-hours per ton of fired product*	*Man-hours per ton of overburden*
I	Dragline and dumper	6–20	175	0.2	0.2
II	Blasting, excavator and 2 lorries	20	293	0.3	0.6
III	Blasting and hand loading	19–44	133	1.0	1.2
IV	Hand	1	17	0.4	1.6
V	Hand	1	15	0.5	2.7

At Works I the dragline used for winning and loading also strips the overburden from time to time. This method is convenient and economical and ensures a high machine utilization, but the extent to which the overburden can be stripped back from the face is limited. The highest figures are for seasonal works where the removal of overburden provides a means for employing the labour in winter. Although this is unnecessarily expensive, some such stratagem may be necessary to keep craft labour when other industries in the same area are competing for workers.

The most economic method of overburden removal is by outside contract. Sufficient material for at least one year's working may be bared in a short time by bulldozers and scrapers at a very low cost. If the winning facilities have been properly planned, spare machine resources will not be available for overburden removal during normal plant operating times; but as an overtime operation at week-ends or during the annual works shut down the winning equipment is often used on older works for removal of overburden, cleaning up, and repairing roadways. Current thinking about new factories is moving towards three-shift operation 365 days a year. Under these conditions, no spare machine time is available.

The *in situ* moisture content and hardness of the clay are important, as is the distribution of unwanted materials. Thus multi-bucket excavators and shale planers can only operate on soft, plastic clay or friable shale. Since they work the whole face over the length of their boom, they can be used only where there is no unwanted material and all the clay in this depth can be used as a mixture. To win hard, indurated materials from the face requires a positive action machine, an excavator of face shovel, while plastic clays or shales broken up by weather or efficient blasting can be dug by dragline. Hand-winning is not limited by the nature of the clay.

Depth to be worked

The depth to be worked is linked not only to the thickness of usable clay but also to the total area of resources available. In thick deposits a decision has often been made to win only that depth which can be won in a single lift during the early years of the plant when depreciation is highest and go back to win the lower depths by the more costly method of benching at a later date. Deep faces can, of course, be won in a single lift by blasting and loading from the base, or by a dragline working from the top. If the seams of clay are themselves thin and selective winning is necessary, then either they must be won by hand or a skimmer must be used to take shallow cuts.

The depth of the water table influences the method of winning. While some works operate draglines or multi-buckets partly under water, the marked variation in moisture content hardly makes for consistency in production. It is usual to conserve water supplies by law, and in England, for example, working within certain depths of an underlying aquifer is forbidden.

Contour of the surface

The configuration of the surface in relation to the material to be won determines the direction of digging and the way in which the deposit will be developed. These in turn influence the choice of winning method and the type and layout of haulage system. Wherever possible the deposit should be worked so that water drains away from the face. Wet bottoms add to the cost of bottom working, and top working may be impracticable, especially on steep hillsides. Alteration of the contour of the surface by extensive earth-moving operations may be worth while when the clay requirements are large and the difficulties great.

Output required

Different outputs require different equipment, and at any level the equipment must be more than just adequate in order to ensure down-time for maintenance, and time to clear slips and other fortuitous occurrences.

Amount of blending and sorting required

In thin seams where unwanted strata are intercalated or interdigitated only hand-winning can achieve real selection. In some circumstances skimmers and horizontally-operating bucket excavators may be used. In thicker seams of even pitch and wider horizontal extent tractors and scrapers or bulldozers may be used successively to win and discard; but this process is wasteful, since at least a foot of good material must be left to avoid contamination. In any case the equipment must be capable of dealing with the impurities (usually hard) and the desirable material (possibly soft).

When blending is to be carried out in the pit, either the whole face must be won together roughly mixed, or parts must be won separately and then mixed together in heaps, or mixed by loading the appropriate number of shovels of each into the haulage waggons. The amount of blending thought to be required at this point determines the kind and number of machines used and the method of working. In heterogeneous strata several faces may be opened to provide different clays for the blend. In large works there is now a tendency to operate a number of pits at the same time, mixing the sources in large storage sheds so that variations in the properties of one clay source are mitigated proportionately.

Type of existing or proposed haulage system

Winning, loading and haulage should be integrated. New digging equipment may well make a new haulage system desirable. In general the transport unit and digger should be related so that the tub, dumper and lorry take an integer number of buckets from the digger. When the clay land is very close to the making unit, for low outputs, a front-end loader may be used both to dig and deliver into the preparation unit, especially when winning soft surface clays for handmade bricks or tiles. In seasonal yards, where temporary making facilities are moved around as the clay is used up, this method may be found useful. Fixed haulage systems, either tubs or rails or conveyors, provide special problems, but in general it should be noted that the most efficient utilization of digger time is in digging, not in moving to load or transport.

Capital available

While the best use should be made of the site, limitations on capital investment may make it essential to choose a system that is less than the optimum. In all operations capital and labour are linked. Capital is invested in mechanical plant to reduce labour, and higher than necessary labour content means increased running costs. In winning, the advantage is with hand operations, for these provide selection and control of raw material blends where mechanized methods would be impossible or at best less effective. The penalty for this greater control may be, in extreme cases, over two man-hours per ton instead of one tenth of this. In more concrete terms, at present British rates, about £0.8 per ton could be saved by mechanizing this process. Capitalizing this, at £2,500 per man replaced (based on recovering the investment in three years from the wages saved) on a works producing only 50 tons per day makes almost £30,000 available. In developing countries, of course, the economics are vastly different and the availability of capital more limited.

Maintenance facilities and supply of spares

In industrialized countries fitters and electricians may be easily obtained. Even the most isolated brickworks is rarely more than 24 hours from an indigenous source of spares. Developing countries, however, may expect, initially at least, to have to import machines. Care should be taken to order at that time, and maintain, an adequate supply of wearing parts and of those most likely to break down. Trained mechanics may be scarce, and inexperienced machine operators may cause unexpected damage. For these reasons, choice of winning equipment may have to be restricted to the simple, robust and easily maintained.

METHODS AVAILABLE FOR WINNING

Hand-winning

Surface clays of high moisture content are readily won by hand, and labour figures as low as 0.5 man-hours per ton for winning and throwing forward for weathering have been reported. Mechanical aids such as pneumatic shovels increase productivity.

Hard material can also be worked by hand, and in this case pneumatic picks may be used. Often the face is benched in steps one to two feet wide and from two to three feet high. The face is stripped vertically, starting from the top. As it is won, the material is cleared from each bench in turn by shovelling it over to the bench below, until eventually a heap forms at the base. This method can be used on deep faces and allows seams to be won separately, and the material to be won in small pieces, so that impurities can be cut out. By delaying loading weathering is carried out without extra labour. Because of the multiple handling, labour is 0.8 to 0.9 man-hours per ton without loading. Bad weather may destroy the bench system, and further labour is required for reinstatement.

Blasting is useful for winning hard materials or for working deep quarries. The fallen material may be allowed to lie for natural weathering. This method gives poor mixing. Sorting, breaking up large pieces and loading must be done by hand. This adds up to 0.75 man-hours per ton. The labour requirement for blasting alone, including drilling and setting charges, is about 0.15 man-hours per ton.

Multi-bucket excavators and shale planers

For plastic clays or friable shales, these machines have the advantage of producing a continuous supply of small pieces of clay taken from the whole face, thus providing good mixing. They operate over a fixed traverse on rails or caterpillar tracks and hence integrate well with a conveyor haulage system to the works.

The multi-bucket excavator has a series of buckets with sharp leading edges carried on two endless chains mounted on a gantry or jib, which may either be elevated to run upwards when the machine is located at the base of the pit, or pointed down when the machine is at the top. The angle of winning may be varied up to 45° from the vertical or horizontal respectively. The rails have to be moved when the face has been traversed once, and since this is costly the face should be as long as possible. There are advantages in working from the top of the pit, since it is usually easier to drain than the pit bottom. Since these are heavy machines, with the added burden of the counterweight to the jib, a good solid base is essential. The strata should either be horizontal or run at right angles to the dip so that variation from one end of the face to the other is minimized. These machines have the additional advantage of a wide range of outputs from small ones at 5 yd^3/h to ones delivering 50 yd^3/h. The labour requirement is 0.02 to 0.05 man-hours per ton depending on the output and the layout of the pit.

The shale planer has been extensively used in the United States, but much less so in the United Kingdom. It is similar in concept to the multi-bucket except that the clay is dug by knives carried on the endless chain and either falls into buckets on the same chain or falls onto a conveyor belt mounted on the machine below. The machine works only from the bottom of the face with its jib almost vertical and rotating through an arc to make a circular cut in the face. It then moves on its tracks to a new cut. To the extent that it can be selective in winning a small area at one time, it is less necessary to work near-horizontal strata.

Face shovels and draglines

These machines (figure 5) are the most widely used excavators in the heavy clay industries. The face shovel has a rigid jib with an arm at about the mid-point capable of extending and retracting and carrying a bucket at its end. This configuration of rigid boom and arm allows pressure to be applied to the bucket in digging, and this positive action allows the machine to deal with most materials, including hard shales won directly from the face. The machine has the additional advantage of being readily used for mixing clays by turning over and stockpiling.

The jib of the dragline is hinged at the base to permit its angle to be varied, and the bucket is attached by wire ropes wound in by a winch. This configuration

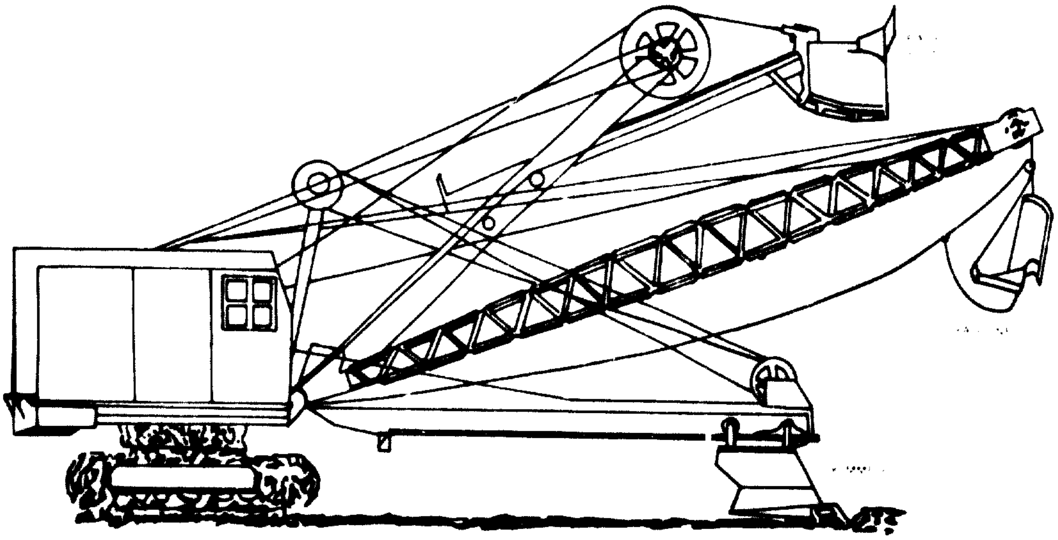


Figure 5. Composite drawing of some excavators [11]

allows the bucket to be thrown, thus increasing the working radius of the machine. They are worked from the top of the face, which is often advantageous in wet pits, and they can even win material below water. Because of the lack of positive action they are not suitable for very hard materials. Draglines provide for some mixing of the different strata but are not suitable for breaking up large hard lumps, unlike the face shovel, which can use its bucket as a sledge-hammer.

A third machine is the skimmer, with a fixed horizontal jib along which the bucket runs to make a shallow horizontal cut. It is useful for selective winning seam by seam, but its output is limited. It is not widely used in the heavy clay industry.

Only one man is required to win and load with an excavator. Hence the labour requirement is fixed by the output of the machine and in typical cases is 0.02 to 0.1 man-hours per ton.

Bulldozers, tractors and scrapers

Bulldozers are used for overburden removal and massive earth-moving work. They are less suitable for winning, since they can only load by pushing over the end of a ramp unless fitted with special shovel blades. They can be used, however, when fitted with rippers, to loosen and break up hard rock at the top of a face, which can then be removed by dragline or pushed down into the pit to weather and be re-won.

Tractors and scrapers can be employed on relatively soft materials when large areas are available. A uniform mixture of different seams is obtained when the scraper operates over a slope extending the full height of the usable material. With care pockets of impurities may be removed separately by hand. The machine wins and loads simultaneously and is best used to transport the clay to a weathering heap close to the works, where it can be readily re-won and transported into the plant by a front-end loader. The labour requirements for scraper operation are negligible. Because the scraper has such a large potential output it is not practicable to keep one fully employed; the usual practice is to have one on contract for a week or two during good weather to win and stockpile for a year's working.

FACTORS AFFECTING THE CHOICE OF METHODS OF HAULAGE

Great diversity is possible in haulage systems, for to some extent each pit is unique. Just as with winning, certain critical factors can be distinguished. The more important ones are: type of raw material and method of winning; length of haul; output required; nature of the ground, gradients and pit bottom; and capital and labour costs.

Type of raw material and method of winning

Hard, abrasive material requires special feeding arrangements to prevent damage to conveyor belts, and large lumps may jam in the feeder. The moisture content of plastic clays is important, since wet, sticky clays do not feed well on conveyors and may give difficulty in emptying from certain types of tubs. The average size of the raw material and the maximum size of lumps affect the width of the conveyor belt required and the angle at which it can be elevated.

It has been noted above that the size of haulage unit should be an integer number of digger buckets, and the cycle time of the haulage must similarly be related to the winning cycle. If several faces are being worked at once the haulage system must be designed to blend the materials in the appropriate proportions. This may mean no more than ensuring that alternate tubs delivered to the plant come from the separate faces, or alternatively that the different clays reach a central blending point before transmission to the works. In either case timing is important.

Length of haul

The important distance is the maximum length of haul when the pit is being worked out. If the haulage system is intended to last this long unchanged, it must be capable of being lengthened accordingly. Alternatively, a system may be installed suitable for short-haul conditions but which can eventually be replaced by one more economic over long distances. Fixed systems, conveyors and rope haulage, are generally more suitable for short distances, while free-ranging systems, lorries and dumpers are better for long hauls or for feeding to the end point of a fixed system. Aerial ropeways are uneconomic over short distances but rather better on long ones.

Output required

The haulage system must, of course, be balanced to accept the rate of delivery of the loading equipment and itself be able to deliver to the plant at the rate required by production. The loading, unloading and transit times of free-ranging equipment should be calculated to permit the correct number of units to be installed. In fixed systems belt and tub sizes and rope speeds are chosen to suit the output desired and the nature of the terrain. With aerial ropeways flexibility is achieved by altering the spacing of the buckets to give different outputs at constant rope speed.

Nature of the ground, gradients and pit bottom

Haulage routes are often confined to the works' own land, and then only difficult terrain and water are likely to be important. But from more distant quarries the course of the haulage system is determined by obstacles (roads, rights of way, land, etc.), which must be avoided. For this reason aerial ropeways are used for extended systems.

Gradients change as the pit deepens, so that the haulage system should be planned to accommodate this without difficulty. The maximum gradient is limited for free-ranging transport, and mention has already been made of the limitations on the angle of a conveyor to prevent clay from running back and balling up.

While modern dumpers can travel over poor terrain, the roads must be kept in a reasonable state to achieve the optimum turn-round time. The nature of the pit bottom and access roads is therefore important and influences the cost of haulage if much material has to be imported to maintain the surface. In some countries it is an offence to deposit clay on a public road, so facilities may have to be provided to wash the tires of vehicles before leaving the pit area. Fixed systems also need good bottoms, and where well-drained beds are not provided, considerable labour may be necessary to pack up rails or relevel conveyors. Where the raw material allows it the simplest solution in wet pits is to win from the top.

Capital and labour costs

The systems requiring the highest capital investment, conveyors and aerial ropeways, have the lowest labour costs. Labour requirements are inversely proportional to output over the main haulage stage and increase with the length of haul. The maintenance labour is particularly important in haulage, whether employed in restoring or moving rope haulage or conveyors, or maintaining roads and vehicles for free-ranging systems.

METHODS OF HAULAGE AVAILABLE

Haulage systems can be divided into fixed and free-ranging systems. In the first the material is transported along laid out lines by continuous flow on conveyors and as unit loads by aerial ropeways, or tub haulage. As the working face recedes, either the system is extended or a free-ranging system is installed at the end of the fixed system.

Free-ranging systems comprise units with their own motive power, capable of travelling freely in any direction over a suitable surface (which may nevertheless have to be provided and thus induce an element of fixity). Included are hand-barrows, animal transport, lorries, dumpers, bulldozers and tractors and scrapers.

In many pits combinations of methods will be found representing extensions of the original fixed system by more recent free-ranging additions.

Fixed systems

Hand-tramming

Hand-tramming is the usual link in hand-winning operations between the several work places and a central turntable where the tubs are clipped onto the main haulage system. Tubs vary in size of load from 5 cwt to over 1 ton, but there is no clear correlation between tub size and labour requirements. On level track, however, tubs are usually one half-ton capacity or more and where possible a down gradient should be provided from the working face.

This method is prodigal of labour: 0.25 man-hours per ton has been recorded for distances up to 30 or 40 yards. This figure increases roughly proportionately with distance until it may be almost trebled at 120 yards. Longer distances may be covered by horse-tramming at somewhat lower labour cost (about 0.5 man-hours per ton over a distance of 300 yards).

Rope haulage

Single and continuous rope or chain haulage systems are included. Large tubs (1 yd^3) are usually side tipping or bottom emptying, but smaller ones are up-turned in a cage-tippler. Single rope systems operate intermittently by hauling in a tub or train of tubs on the end of a rope. The empty tubs return under gravity. The method is restricted to straight-line operation and is usually used on steep gradients, often as the last stage of the haulage up the gantry into the works. It can also be used in deep pits close to the works where the gradient is very steep by having one large captive tub which, hauled to the top, tips automatically and returns to the base of the pit to be refilled.

In continuous haulage systems, the rope or chain may be overhead, when the tubs are fixed to it by means of V-notches, or, on long hauls particularly, beneath the axles when the tubs are clipped on by friction clips. To free tubs on the overhead system the rope is elevated and the tub runs clear; on the under-tub system the clips are knocked off manually or automatically. Within its limitations it is a most effective system, one which can operate long and short hauls over irregular ground following winding routes. It can be made quite efficient, but if the route to the works is not straight, transfer points are necessary and at each a man may be employed. Where this is not the case labour costs are independent of the distance covered.

Tub haulage by prime movers

In the development of clay haulage, hand-tramming was first replaced by horse-drawn tubs, and the natural successor to the horse after the First World War was the diesel or petrol locomotive. The added weight makes heavier rails desirable, and they operate best over the longer hauls (more than 220 yards), on level surfaces or at most slight gradients. When the layout of the pit bottom is properly designed, they are an economical form of transport.

Aerial ropeways

Aerial ropeways are used for transporting raw materials over long distances. They are not suitable for short distances nor for low outputs, since they have a high initial cost, although this is compensated for by low maintenance charges. The loading terminus has to be of substantial construction and hence is not easily moved, but most of the other haulage methods can be used as a secondary system, including the aerial ropeway tubs themselves carried on rail trolleys to the face.

Simple systems require labour at both the loading and unloading points, although automatic tipping arrangements can be readily installed. The effect on the labour content of the tonnage carried is seen in table 7, which refers to a medium-size tile works and a larger brick unit.

Table 7

MEASURED LABOUR COSTS FOR OVERHEAD ROPEWAYS

Fired output (tons/wk)	*Distance (yd)*	*Man-hours/ton of fired product*
216	2,200	0.41
1,100	500	0.16

Conveyors

Like aerial ropeways, conveyors are expensive to install, but under favourable circumstances they do not need an operator. Some labour for maintenance and clearing spillage is, however, essential to their continued proper functioning. In clay pits the belts are normally troughed to minimize spillage, but even so it is important to have a belt sufficiently wide to cope not only with the normal load but with any fluctuation inherent in the system of loading. Thus, means of even feeding from hoppers should be provided when excavators that dump large bucket loads are used. Multi-bucket excavators or shale planers can discharge directly onto the face conveyor. Feeding arrangements should also be designed to minimize damage to the belts by hard, abrasive material. Hoppers are rarely satisfactory for feeding wet, sticky clay, and in this case a box feeder may be used.

It is usual to install a loading conveyor parallel to the working face. The main labour involved in operating conveyors is in moving this face conveyor forward periodically to follow the working.

Free-ranging systems

They are mobile, flexible and can be made to operate at relatively high speeds. Since they deliver unit loads intermittently, hoppers and feeding arrangements must be provided at the plant and possibly also at the loading point of this transport. They have the merit of ready extension to cope with increased output requirements.

Hand-barrows and animal transport

In developed countries hand-barrows are uneconomic except in the case of a few very small works where a single gang is used half a week for winning, haulage and making and for setting and drawing the rest of the week. Labour requirements are higher than for hand-tramming, no doubt partly because of the smaller size of the barrows. The labour requirements appear to vary from 0.5 to 0.9 man-hours per ton as the distance increases from 50 to 100 yards.

Porterage with baskets is extensively used for earth-moving activities in labour surplus communities. It is completely flexible and may be useful in some circumstances.

Animal transport has a long and creditable history. Indeed in more recent times the name of "ball clay" was derived from the one hundredweight "balls" of clay shipped on pack horse by Josiah Wedgwood from Devon to Staffordshire in the eighteenth century. Pack and draft animals may provide the cheapest and most efficient form of haulage in the first stages of developing a heavy clay industry.

Front-end loaders and traxcavators

These small units of up to one and one half cubic yards, although primarily loaders, may be used for very short hauls, for example from the face to a primary loading point. Front-end loaders have pneumatic tires and are frequently used also within the works, especially for feeding from weathering heaps established close to the plant. Traxcavators are tracked vehicles useful on difficult pit bottoms.

Dumpers

Dumpers are an economical and reliable means of transport, even over rough and wet ground and up steep gradients. The provision of reasonably well-prepared road surfaces in the quarry extends the life of the dumpers and reduces turn-round times.

The robust construction is advantageous for loading by dragline or face shovel directly at the face, and a wide range of sizes is available to suit varying needs. The maximum economic haulage distance is about one mile for a six-cubic-yard dumper, less for smaller sizes.

Dumpers tip directly into a hopper or box feeder to discharge, and because of their fast operating speeds over rough roads the labour requirement is very low. It can be reduced further at low outputs by having only one man operate the digger and drive the dumper.

Tipper lorries

Large dump trucks of the Euclid type are specifically built for pit operation and are extensively used for clay haulage. Such vehicles should perhaps more correctly be considered under dumpers, since they have all their advantages except prime cost. Conventional tipping lorries, however, are the most economical haulage unit over long distances, but they require good roads and are therefore better operated when the pit is worked from the top.

THE ECONOMICS OF WINNING AND HAULAGE

Layout and drainage

Bricks in England are delivered into the centre of London at less than £3 per ton, the cheapest manufactured product in the country, far cheaper even than cement. Traditionally costs of production may be roughly divided into three parts: (1) for overhead; (2) for firing; and (3) for winning, making and drying. Actual cost exercises have shown about 7 per cent debitable to winning and haulage, with one case as high as 10 per cent. If there is no intermediate storage, a breakdown in the pit may mean a complete stoppage of the making plant so that one tenth of the total plant operation can actually affect one third. Hence, there is little margin for inefficiency. Whether the works is small or large, the proper operation of the pit and the maintenance of a regular supply of good clay to the making plant are central to effective production.

Mention has been made of the importance of a proper geological survey of the area before opening up a pit. When the structure of the area has been established, the layout of the pit should be planned to provide the most effective working conditions, and a well-laid-out pit is essential for efficient and economic operation. Often the topography is the determinant, but where the direction of working can be chosen, it is preferable to work down dip, so that the beds do not slope out of the working face. Otherwise the bedding planes of the rocks would act as drainage courses, and when lubricated by water the beds could move one over another causing landslides at the face.

The working should be compact and tidy. The faces should be laid out to make working and loading easier and to match the haulage system used. If impurities are to be left in the pit they must be dumped in areas not needed for clay winning. Each pit presents unique problems, but every pit should be laid out to best advantage according to a predetermined plan and not allowed to develop in a haphazard fashion.

While men can work in wet and difficult conditions, machines cannot. An adequate drainage system is therefore vital to mechanical working from the pit floor. Rain water partly runs off the surface and partly percolates to the rocks beneath. Run-off should be directed away from the pit by drainage ditches constructed above the face. Water that percolates into the bedrocks may issue from the face as a spring, and in suitable conditions a large part of the surrounding land acts as a catchment area to feed it.

Under conditions of normal European rainfall properly designed drainage ditches, or better, buried land drains, are adequate to lead surface water away from the face. In monsoon conditions, however, special problems arise, and seasonal clay working may be the only practicable solution.

Unless the pit can be drained directly into a stream a drainage pit or sump dug to a deeper level is necessary. In favourable circumstances this provides a soak-away into bedrock, but it may be necessary to pump out to some pit-top drainage system to keep the level down. Pit water can often be satisfactorily used as process water for boilers and sometimes for tempering. In the latter case, however, difficulties can arise, since salts from the rocks are taken into solution and the concentration may be sufficient to cause scumming and efflorescence.

Labour requirements

To provide statistics on labour that may be applicable to developing countries, the figures used have been extracted from surveys carried out in 1947 [14] and 1951 [13] in the United Kingdom and do not represent the best possible performances, although for very large outputs they approach it. Since that time the considerable use by small works of tractors and scrapers on contract to stockpile clay has greatly reduced winning costs and at the same time eliminated the need for haulage gear. The level of output markedly affects the labour content, and it has been shown that a reasonable curve can be drawn for excavator operations (figure 6). [14]

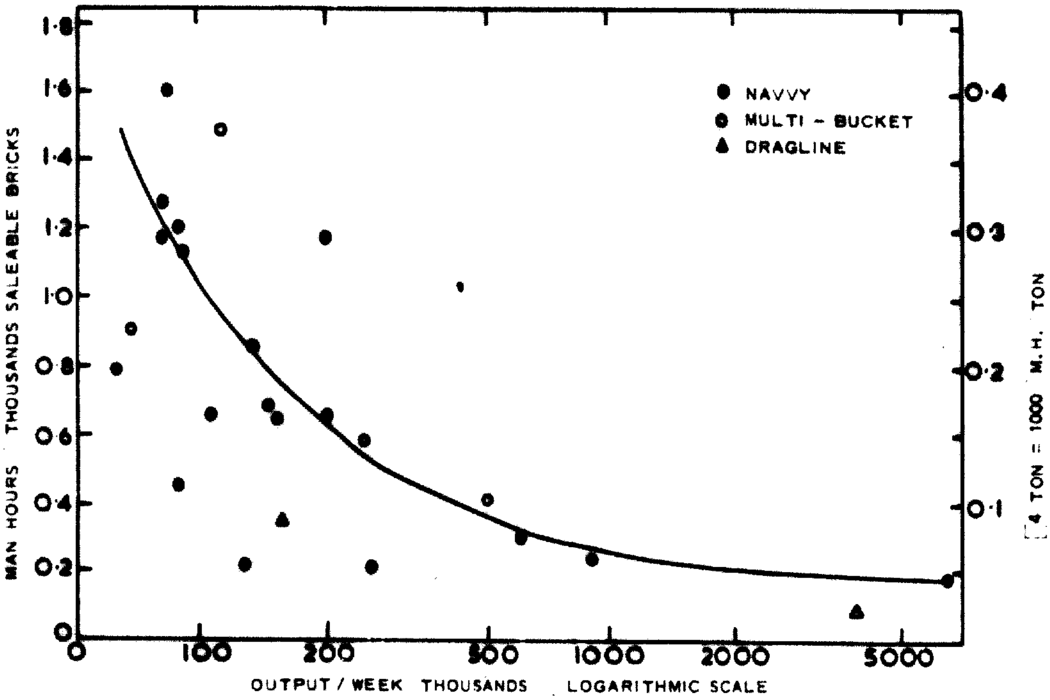


Figure 6. Influence of output on labour associated with excavators

Some explanations for the works deviating markedly from the curve have been offered. An interesting feature is the low labour figure for the two draglines, which is at least partly due to the elimination of the need to clean up the bottom when the plant operates from the top of the face. For this reason the labour requirement for draglines is considered to be only two thirds that of face shovels.

The smallest size of face shovel can produce sufficient clay for about 180,000 bricks per week, and for this two men are required, one to drive the excavator and one to clean up. At higher outputs the number of men required increases but the productivity improves, as shown in table 8.

Table 8

EFFECT OF OUTPUT ON LABOUR REQUIREMENTS FOR WINNING WITH FACE SHOVELS [15]

Output per week		*Number of men*	*Man-hours per 1,000 bricks*	*Man-hours per ton of fired product*
Thousands of bricks	*Tons of clay (approx.)*			
200–350	800–1,400	3	0.6–0.34	0.2–0.11
350–600	1,400–2,400	4	0.46–0.27	0.15–0.09
600–850	2,400–3,400	5	0.33–0.24	0.11–0.08
850–1,100	3,400–4,400	6	0.28–0.22	0.09–0.07
1,100–1,500	4,400–6,000	7	0.26–0.19	0.09–0.06
1,500–2,000	6,000–8,000	8	0.21–0.16	0.07–0.05

Table 9

MINIMUM LABOUR REQUIREMENTS FOR WINNING AND HAULAGE IN MAN-HOURS/1,000 BRICKS [15]

	Output per week (thousands of bricks)			
	100	*200*	*500*	*2.000*
Winning	1.0	0.5	0.3	0.2
Haulage	0.5	0.25	0.2	0.2

The minimum labour requirements for mechanized excavators and appropriate haulage are likely to be as shown in table 9 for various weekly outputs of bricks. The requirement in man-hours per ton of raw clay is given by dividing these by four and per ton of fired product by dividing by three.

There remains the case of the very small works operating hand-winning and hand-barrowing. For a distance of about 100 yards from the face to the works, the barrowing requirement is about 0.9 man-hours per ton of fired product, while winning and loading takes about 1.0 man-hours per ton. In all, 2.0 man-hours per ton of fired product may be expected, so that in an eight-hour day one man can win, load and barrow four tons. Two men working together will improve this somewhat, and a total of 10 tons per day may be expected.

MECHANIZATION OF METHODS PREVAILING IN DEVELOPING COUNTRIES

Although stratified deposits may be found in some areas of developing countries, the characteristic raw materials are soils and alluvial clays, typified by the black and the red soils of the west and peninsular regions of India, and the alluvial soils of northern and eastern India. In some areas suitable raw materials are found in the silt of deltas. Alternatively they may be obtained by preparing beds that are flooded by the river and then drained; this precipitates the fine clay and silt held in suspension. The clay is typically dug by hand, mixed with water and kneaded by treading, then hand moulded and dried in the sun at the pit site. The dry green bricks are transported to the kiln instead of the clay being transported to a making area adjacent to the kiln. Where the clay is transported, hand-barrowing and animal transport are most frequently used.

In the developing countries wages are so low that labour is a much smaller proportion of the total costs of production than in more industrialized societies. Thus the enormous differential between the wage rates in developed and developing countries enables labour-intensive processes to survive competitively in the latter, especially when the difficulties of financing and maintaining imported capital plant are considered. Thus mechanization of production, especially of winning and haulage, presents difficulties.

Where there are advantages in hand-winning to enable selection of good clays and rejection of impurities, the pit is likely to be mechanized only at a late stage. Similarly in small brickyards little mechanization may even be desirable. Bricks dried on the ground need a fairly large area, so for the handmade, hack-dried process, hand-winning and hand-making at the pit may be the most economic. The high wastage reported, however, suggests that damage is caused by transporting the bricks to the kiln, and it might be better to transport the clay and set up the making area near the kiln. Where larger outputs of machine-made bricks are envisaged, however, particularly near urban centres, larger-scale winning becomes possible.

Machinery used on any brickworks must be robust; machinery installed in clayworks in developing countries should also, at least at first, be simple. One solution is a tractor and scraper employed on contract to visit the larger works in an area in turn, stockpiling clay near the making plant, whence it can be re-won by front-end loader.

A universally useful tool that can be adapted to take a loading-shovel attachment is the simple agricultural tractor. This requires the minimum of maintenance and care in handling and can be utilized both as a digger and as a prime mover to tow a set of tipping tubs.

It seems unlikely that, as a first step in the mechanization of winning and haulage, any more complicated digging equipment should be considered. The logical steps in winning the more recent, broadly horizontal strata, which are likely to form the chief raw material sources, would be first to provide one or two agricultural tractors for towing tubs where necessary, and second, to contract for scrapers to win and dump the material near the works for the tractor shovels to load into the plant.

As noted above, two men can win, load and wheel for 100 yards clay sufficient to make ten tons of fired product per day. A tractor with a bucket of even one-half cubic yard will load and transport over the same distance perhaps 50 to 100 tons per day. This requires, however, two men, a driver and a mechanic for maintenance and repair. The running and maintenance costs will vary with the cost of fuel and spares, and they may well amount to as much as the two men's wages. If, then, the minimum total of these running costs is taken as being equivalent to the wages of four men it is clear that mechanical winning becomes attractive only when the output required is more than the 20 tons per day that four men can win and haul.

If the first stage of mechanization is to be at 40 tons per day, can assistance be provided to hand-winning? Pneumatic shovels increase output, but a source of compressed air is needed in the pit. The possibility of improving the method of working or even the technique of hand-winning and loading should not be ignored, but it is more logical to provide for better haulage arrangements. [16] Hand-barrowing should be replaced first, perhaps, by tubs towed by animal power; but these must be tipping tubs, since carts require labour to unload. Only for haulage over long distances will carts be economic.

To conclude: at an output of five tons per day the works will usually use hand-winning and haulage; at 50 tons per day loaders on agricultural tractors become economic; and at 300 tons per day tractors and scrapers may stockpile at the works for re-winning by front-end loader. Alternatively, digging equipment coupled to one of the haulage systems described above will be possible. While each case must be considered on its merits, in general the most versatile machinery for this output will be a simple form of digger and dumper transport.

III. Clay preparation and product manufacture

Clay preparation is the essential sequence of processes needed to bring raw clay into a form suitable for the making process. Fine-grained clays, won in the plastic state, need very little grinding and tempering, and traditionally only kneading after the addition of water is carried out. With more difficult clays a combination of processes is required starting with sorting, blending and weathering; crushing and dry grinding and screening; "tempering" the mix by the addition of water and the "souring" or "ageing" the moist dust or plastic clay; fine grinding of the plastic material in high-speed rolls and even re-pugging and multiple de-airing. The variety of methods indicates the range of properties of clay that have to be accommodated, but the object of each process is to minimize the original variations in the clay so that the product going into the making machine has a uniform clay content, constant size-grading analysis and a constant and correct moisture content for the process used. The better and more uniform the quality of the product required, the greater must be the control exercised, either manually or automatically, over the various stages of the clay preparation. It is possible to make indifferent ware from adequately prepared clay; it is not possible to make good ware from inadequately prepared clay.

Primary treatment and storage

Weathering

This traditional process of breaking down the harder clays and shales to improve their working properties is thought to improve plasticity by changing the particle-size distribution. Certainly when assisted by frost action it has been considered to be more effective than fine grinding. Rain tends to wash out some of the soluble salts, but by prolonged weathering, pyrites and other sulphide impurities may be oxidized to the soluble sulphates. The action of bacteria has been regarded as beneficial, and some homogenization of the water content has been claimed. The beneficial effects of weathering on the quality of the product have been recognized since historic times and were thought to be so firmly established that the weathering of tile clays was required by law. [17]

It is difficult to reconcile these views with the realities of the situation. The impervious nature of clay prevents weathering effects from penetrating far; when heaps are built ten feet high the proportion of clay receiving the full benefit of weathering is comparatively small. Possibly the most important effect of making weathering heaps is that the opportunity can be taken of wetting the layers as they are put down; and since they are laid down horizontally and re-won vertically, some mixing takes place.

Weathering is an extra process and involves double handling. Except in the special case of scraper winning and haulage where a curf is in any case made close to the works, it adds to the labour cost, up to 2.75 man-hours per ton in some cases.

Alluvial clays are usually sufficiently plastic not to require weathering, although frequently in developing countries the clay is wetted at the pit and possibly kneaded by treading. Two different clays may be mixed, watered and left for two or three days to "age" or spread out up to a foot deep on the ground, watered, allowed to dry and turned, watered again and the process repeated until the mix is plastic enough to use. In India the clay may be broken up, softened by mixing with water, kneaded and then covered with mats and left to dry gradually to the right consistency for moulding. Around Baghdad pits are prepared, flooded with water and allowed to stand for three or four weeks so that the water penetrates into the mass, which is then hand dug. These processes are essentially short-term, lasting days or at the most weeks, and thus are more a "souring" of the plastic clay than a weathering process.

Primary crushing and shredding

In recent years there has been a tendency to discount the effect of natural weathering and to give more attention to providing extra horsepower for clay preparation. To get the highest efficiency in the secondary grinding equipment, primary crushers are used to reduce the lumps as they are won to rough cubes of approximately three inches or less. Material in this form is more easily and uniformly fed and proportioned; thus when two or more clays are to be blended they should be in the prepared state.

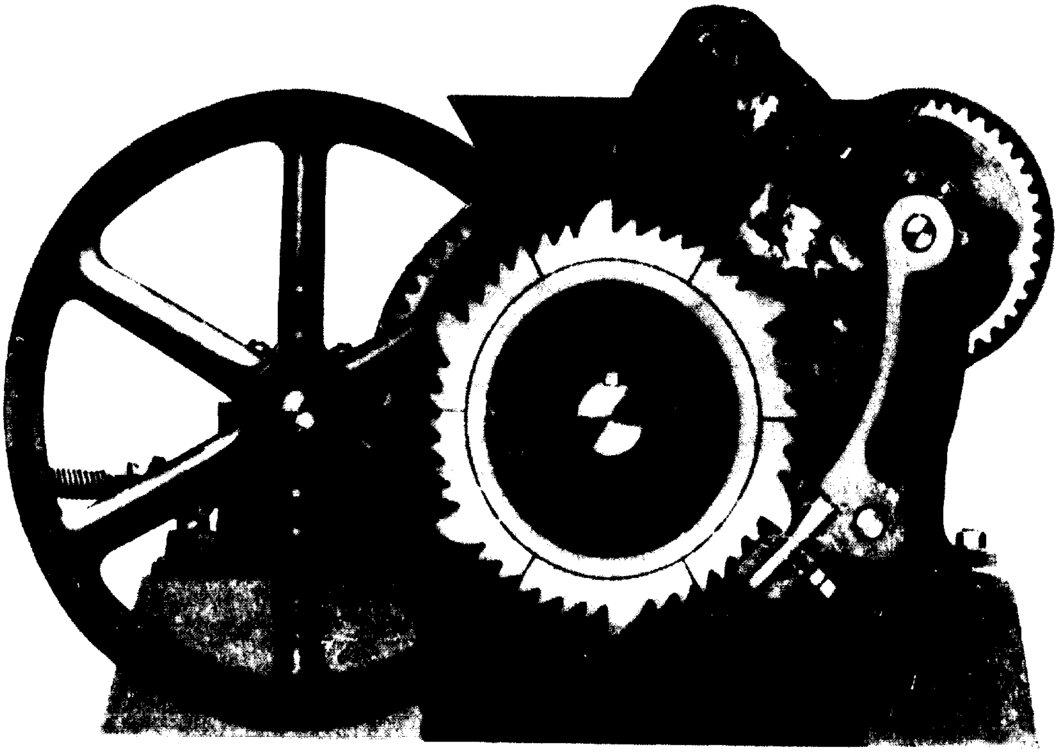


Figure 7. Single-roll crusher [18]

Crushers are used for hard materials and shredders for plastic clays, although kibbling rolls are also used for softer clays. Jaw crushers and gyratory crushers can be used for friable clays showing no tendency to pack between the jaws. Single-roll crushers (figure 7) with an oscillating breaker plate and roll, toothed to suit the material, perform a similar function. The use of these three types of crusher is declining however. Swing-hammer mills (figure 8), also used for friable materials, function by breaking the clay on impact with the hammers or the sides of the machine, although a good deal of breakdown arises when one clay lump hits another. The most important and widely used crushers are some form of double-roll. The rolls may be, but rarely are, smooth; more usually they have bars, projections, corrugations or teeth on their surface. All of these types of rolls are frequently called "kibblers", differentiated as "bar kibblers" and other kinds,

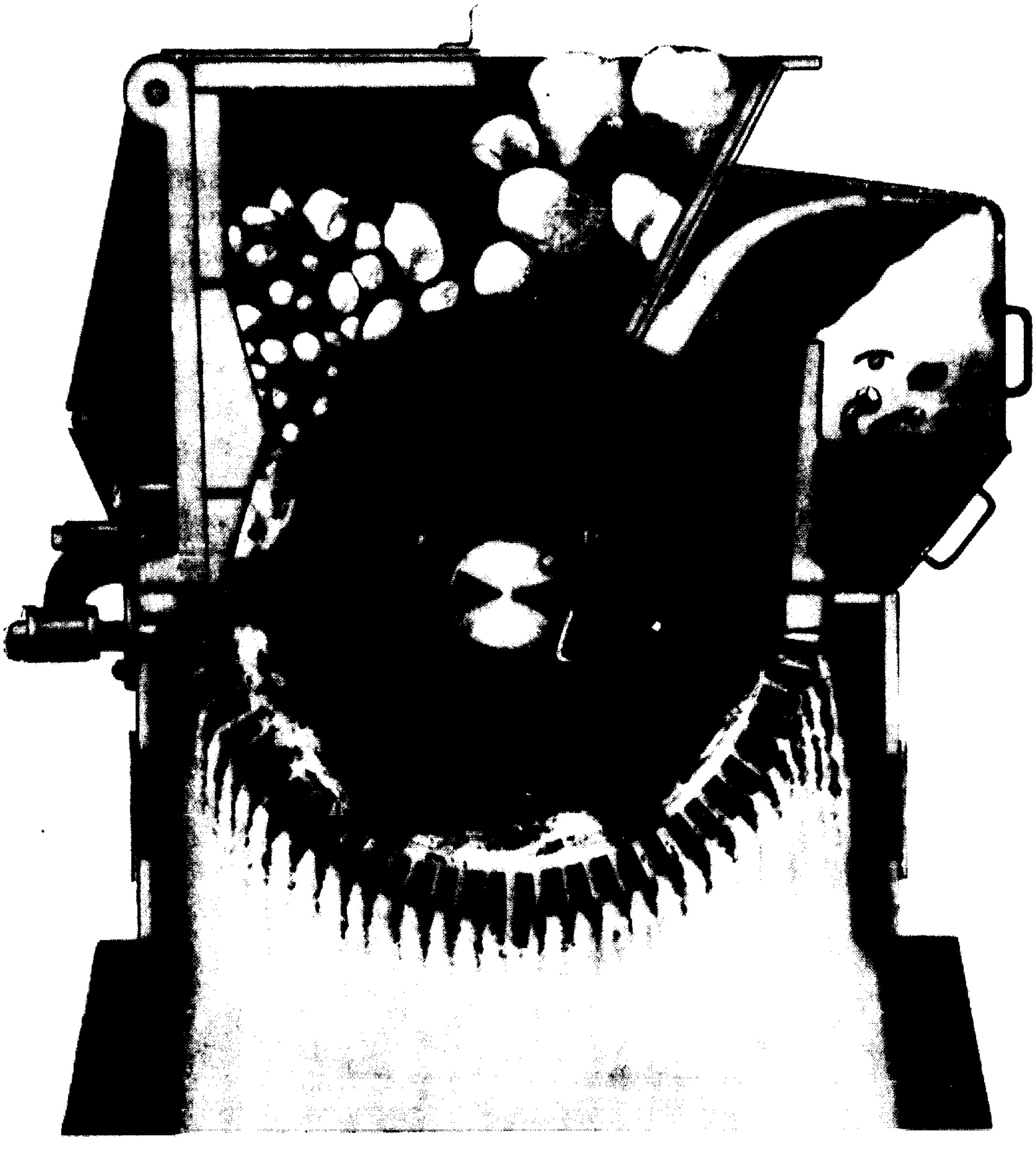


Figure 8. Swing-hammer mill [18]

although strictly speaking kibbling rolls have two sets of interspaced toothed rollers (figure 9). Rolls with projections, which are used for breaking down hard slab-like pieces into more cube-like shapes, are properly called cubing rolls (figure 10).

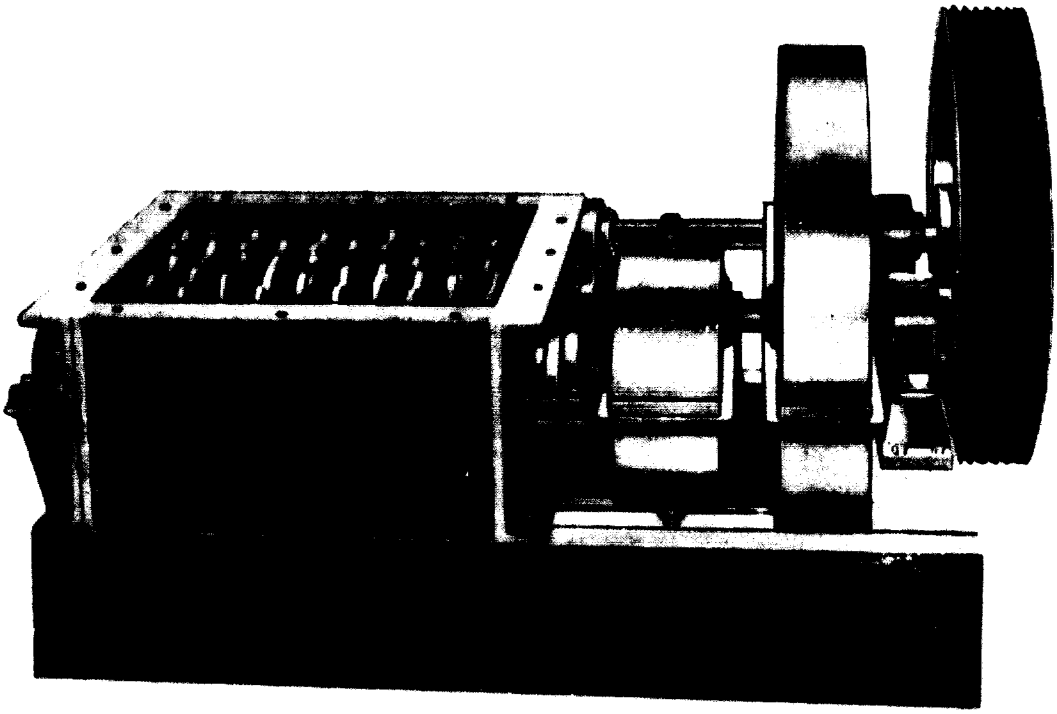


Figure 9. Kibbler rolls

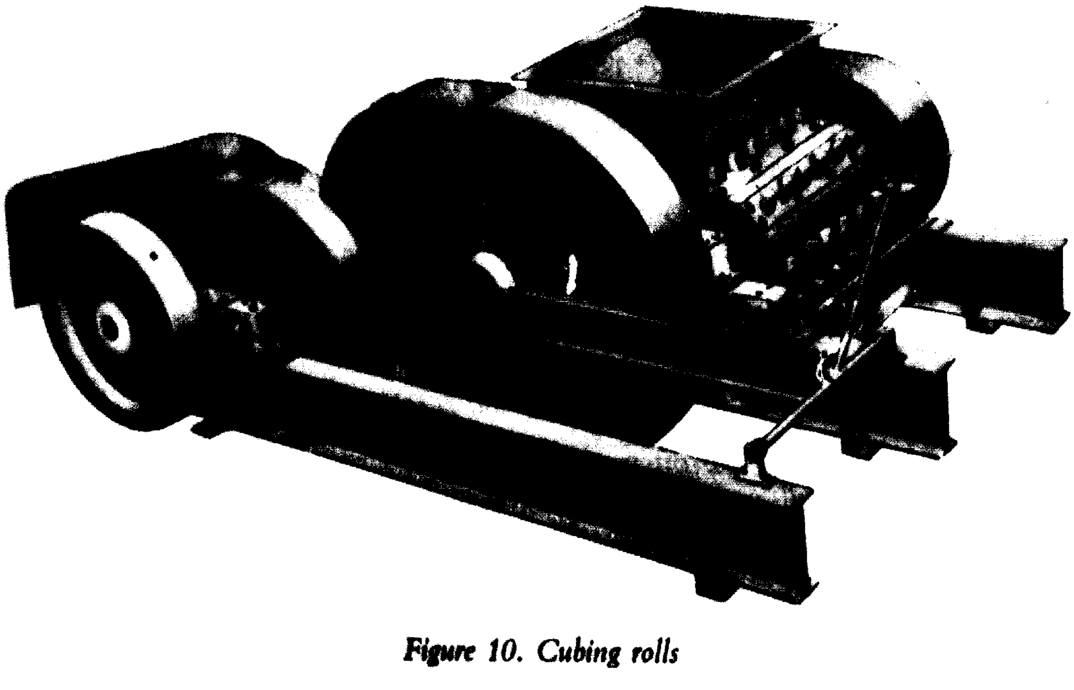


Figure 10. Cubing rolls

Mention has been made of corrugated rolls, which cut up plastic clays and also remove stones. Soft clay can also be prepared for the grinding plant and especially for blending and storing by using a clay shredder (figure 11). The rotating base has slots in which are fitted adjustable cutting knives so that the shreds of clay one-thirty-second to one-half inch thick fall through the slots onto a collector disc from which they are ploughed off.

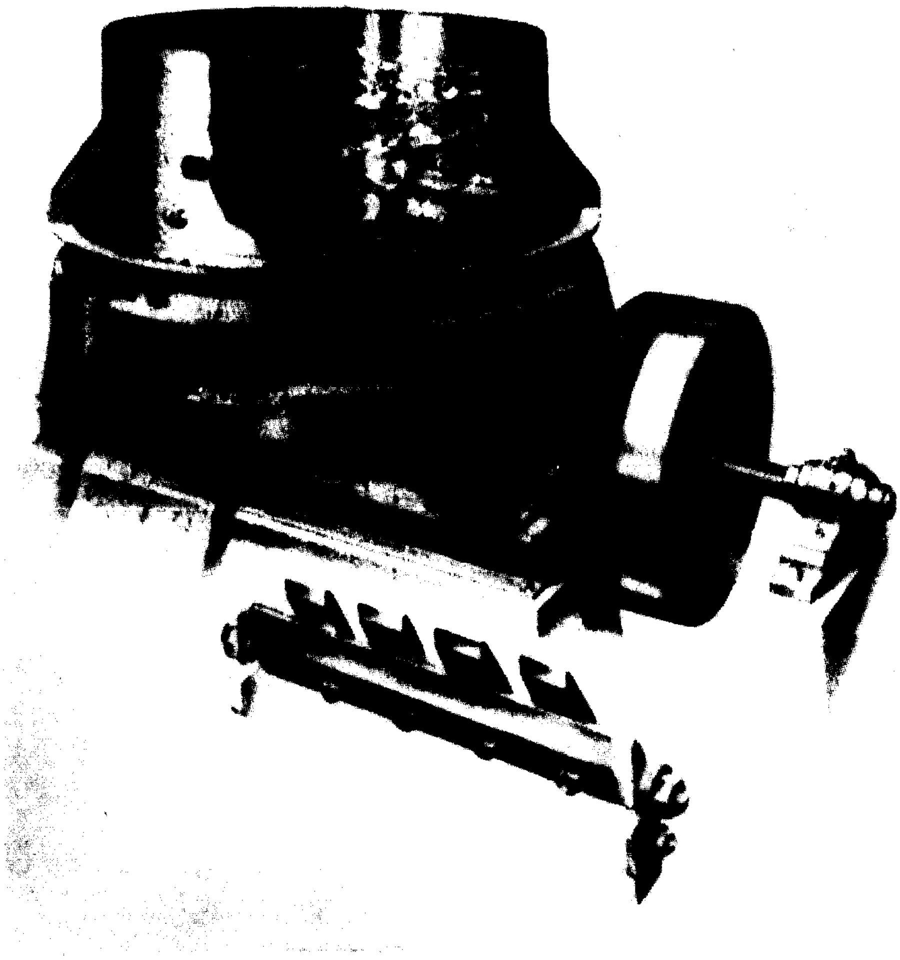


Figure 11. Clay shredder [18]

Bulk blending and storage

Since heavy clays are often markedly heterogeneous and consistent raw material is basic to effective mass production of a satisfactory product, the process of mixing and blending is important. To reduce variations, the whole face may be won in a single pass, as with a multi-bucket excavator, or, somewhat less effectively, with a dragline. Face shovels may be used to mix heaps of different materials at the face or put set proportions of each into each vehicle load.

It has already been noted that weathering is a means of blending and mixing, and, incidentally, of storage. Bulk blending in large storage heaps is extensively practised in the United States; 50,000 tons is not unusual at large works. The clay should be crushed before it is laid down in successive horizontal layers over the whole surface of the storage shed. The heap is re-won vertically, and thus some evening out of both the vertical and lateral variation of the pit is achieved.

The store is usually roofed in with some light construction so that no weathering takes place, although already weathered clays may have been used to form the heap. The store also provides an insurance against breakdowns in the pit, and those periods when the weather prevents digging. Alternatively contract winning and laying down in store enables sufficient clay for a year's working to be got in a short time during a spell of suitable winning weather.

DRY GRINDING AND SCREENING

Secondary grinding reduces the clay lumps from the pit or primary crusher to the final particle size for processing. Depending upon the moisture content of the clay this process is either dry grinding or plastic preparation. Dry grinding, which normally includes clays up to about 12 per cent moisture content, will be considered first.

A variety of secondary grinding equipment is available, including secondary hammer mills with a screen in the base to keep material above a certain size in the system; disintegrators, which are a form of high-speed, double-roller mill; and impact mills of various kinds, including attritors used for very fine grinding with air separation, which when hot air is used also give a dried classified product. The most important machine, however, and the one simple enough for general use, is the dry pan.

Within the rotating pan are set two large-diameter heavy rollers (mullers), which run on renewable dead plates of wear-resisting metal. Material is fed onto these dead plates and guided into the track of the mullers by scrapers. When the clay has passed under the mullers, the rotation of the pan causes the crushed material to be thrown towards the circumference of the pan. The area between the centre dead plates and the periphery is filled with perforated grids. The diameter of the holes in the grids (typically one-quarter inch) determines the size of the particles leaving the pan. The oversize is fed back under the mullers by the scrapers.

The speed at which the pan rotates determines the output, and hence speeds have increased over the years from about 22 rev/min to 30 rev/min or more. At high speeds screening on the grids is less effective, and this has led to inclined grids (figure 12) that slow the material down as it passes over, and rim discharge pans with solid bottoms and a gap at the periphery adjustable to vary the fineness of grinding. The gap is not adjusted to the final size required but rather to about one-half inch, so that much oversize gets through and there is perhaps a 50 per cent recirculating load.

The efficiency of dry grinding is influenced by the efficiency of screening, so the two processes should be considered together. From the pan, material falls

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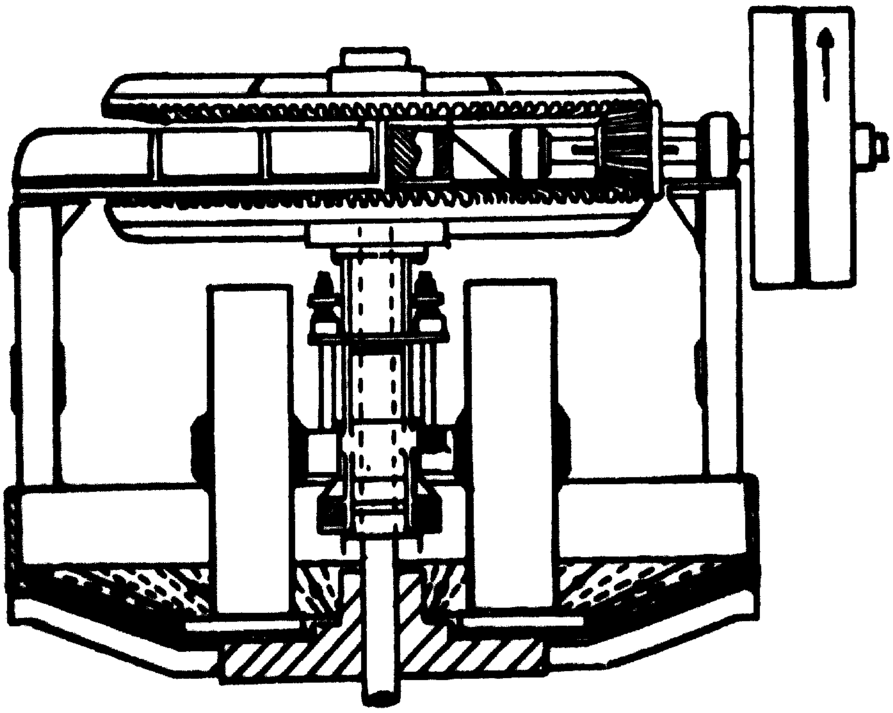


Figure 12. Dry pan with inclined grids [11]

into a hole from the bottom of which it is taken by bucket elevator to the screens. The oversize from the screen is usually returned to the same pan, although in multiple pan set-ups it may be returned to a separate grinding unit, such as pan, disintegrator, impact mill or even rod- or ball-mill to produce a very fine product.

In the heavy clay industry the most common size of screen is about No. 7 mesh (with a 0.0949 inch opening), that is, one that permits the passage of particles of almost one-eighth inch diameter and less. For stronger or finer textured products sections or whole screens of half this diameter (14 mesh = 0.0474 inch opening) may be used, but this of course reduces the output. In conventional plants screens finer than this are rare. The simple form of screen is an inclined perforated plate of steel. The holes are larger than the maximum size required because the particles only just small enough to pass through are often carried over by their momentum. Furthermore, large particles tend to carry a proportion of fines along with them so that the screen is not particularly efficient. Nevertheless, if the angle is properly adjusted perforated plate screens need no maintenance beyond replacement when the holes wear.

Variants of the inclined stationary screen include piano wire screens in which high-tensile steel wires are stretched taut the length of a frame and set apart at the screening diameter required. There are no cross wires, and it is possible for oversized wedge-shaped pieces to force the wires apart so that coarse particles pass through and the wires eventually break. Frequent inspection is therefore necessary. An improvement is to use more robust wedge wire screens that are profiled to allow a particle entering the space between two wires to fall away without danger of clogging.

From stationary screens rotating screens developed. In these an inclined cylinder of woven wire mesh is rotated, clay is fed in at one end, the fines drop through and the coarse is discharged at the bottom end. This is a dusty and basically ineffective process, since less than 25 per cent of the screen area is in use. The preferred alternative to a stationary screen is a mechanically or electrically vibrated one. Such a screen, fitted with woven wire mesh, provides a positive barrier to particles above the hole size. It is effective with dry clays, and blinding by moist clays can be eliminated by electrically heating the screen cloth.

Such heated vibrating screens not only improve the efficiency of screening but also the efficency of grinding by reducing the amount of fines returned to the pan with the oversize. Labour for cleaning is eliminated; only occasional inspection for screen wear is necessary.

BLENDING OF CLAYS AND ADJUNCTS

Mention has already been made of bulk blending and storage. The blending of two or more plastic clays, or clay and sand, grog or combustible matter can be done best by a proportioning box feeder (figure 13). This enables discrete loads of clay from the pit to be dumped intermittently without affecting the continuous discharge of the mixed materials. A box feeder is therefore a type of surge hopper, consisting of a rectangular box of conveniently large size with one or more compartments (marked 1, 2 and 3 in the figure) and having a slat conveyor base moved forward in regular increments at an adjustable rate. Besides its proportioning capabilities the box feeder is suitable for feeding a primary crusher with lumps of clay or a secondary grinder with crushed shale or plastic clay. To get a constant discharge rate with plastic clay, "hayrakes" are fitted to the front of the feeder as shown in the figure.

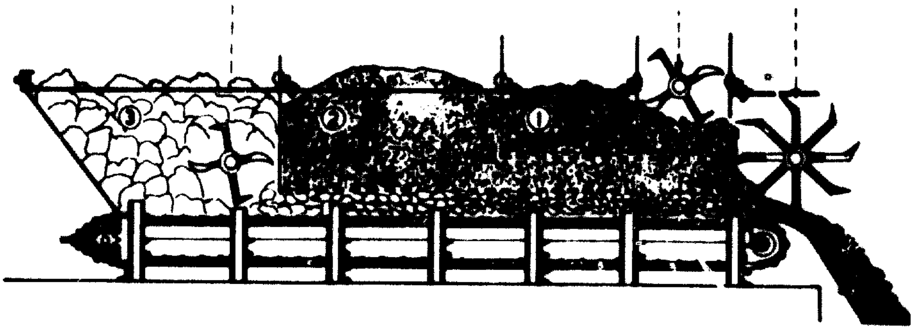


Figure 13. Box feeder [18]

Dry-ground clay dust is most readily blended by storing the separate components in hoppers and recombining them on a single conveyor belt by means of synchronous feeders. These feeders may be simple volume-proportioning devices controlled by a manually adjustable gate on the discharge orifice of the hopper or more sophisticated automatic weight-proportioning devices.

Additions of sand, grog or fuel in relatively large proportions may be accomplished from separate hoppers in a similar way. For smaller percentage additions, however, volume proportioning is inadequate, especially if the additive is expensive and the right amount critical, as is the case with barium carbonate to control soluble salts, or stains added to change the body colour. When such chemicals also create unpleasant working conditions, as dry-ground manganese dioxide does, a more attractive and more accurate method of addition is as a suspension in water, which can be metered through a pump.

A wide range of mixers, made for use in the chemical and food industries, are available for mixing the proportioned material. These include for dry powders, batch mixers of the double-cone blender type, and for tempered materials, ribbon mixers and various kinds of pan mixer, but in the heavy clay industry the most widely used and effective mixer is the double-shafted mixer (figure 14).

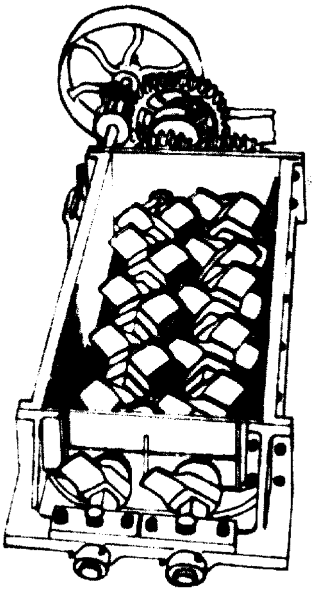


Figure 14. Double-shafted mixer [18]

Single-shafted mixers are also used, but they are little more than conveyors. The shafts are contra-rotating so that the knives cut and knead the clay and pass it forward; and by choosing the length of the mixer and by adjusting the pitch of the knives or even reversing some, the length of mixing time to which the clay is subjected can be varied. Such mixers may be used for tempering dry-ground clay, the water being sprayed into the entry end of the mixer, or for further wetting already plastic clay. They may be equipped for steam tempering through pipes in the base of the trough. Different materials fed as discrete layers onto a conveyor feed to this type of mixer can be effectively mixed and tempered.

Double-shafted mixers find particular favour because they are continuous. In the normal mass-production process of brick and tile making, batch production is inefficient. However, for the production of special body mixes either of different materials, or the same material at different moisture contents, for example, wirecut and handmade, a pan mixer may be employed. This consists of a rotating pan within which a set of blades rotates on an axis offset from the centre of the pan. After the appropriate period of mixing, a gate is opened in the base and the material suitably discharged.

PLASTIC PREPARATION AND STORAGE

Double-roll disintegrators and types of swing-hammer mill are available to break down dry or moist plastic clays, but they are less satisfactory for wet soft clays. The characteristic machine for plastic preparation is the wet pan (figure 15). Unlike the dry pan, this pan is stationary; the mullers rotate about the vertical axis and are often set at different distances from the centre so that their tracks cover a major part of the base. The whole of the base is gridded except, in some cases, for a short dead plate area where the feed enters, or a

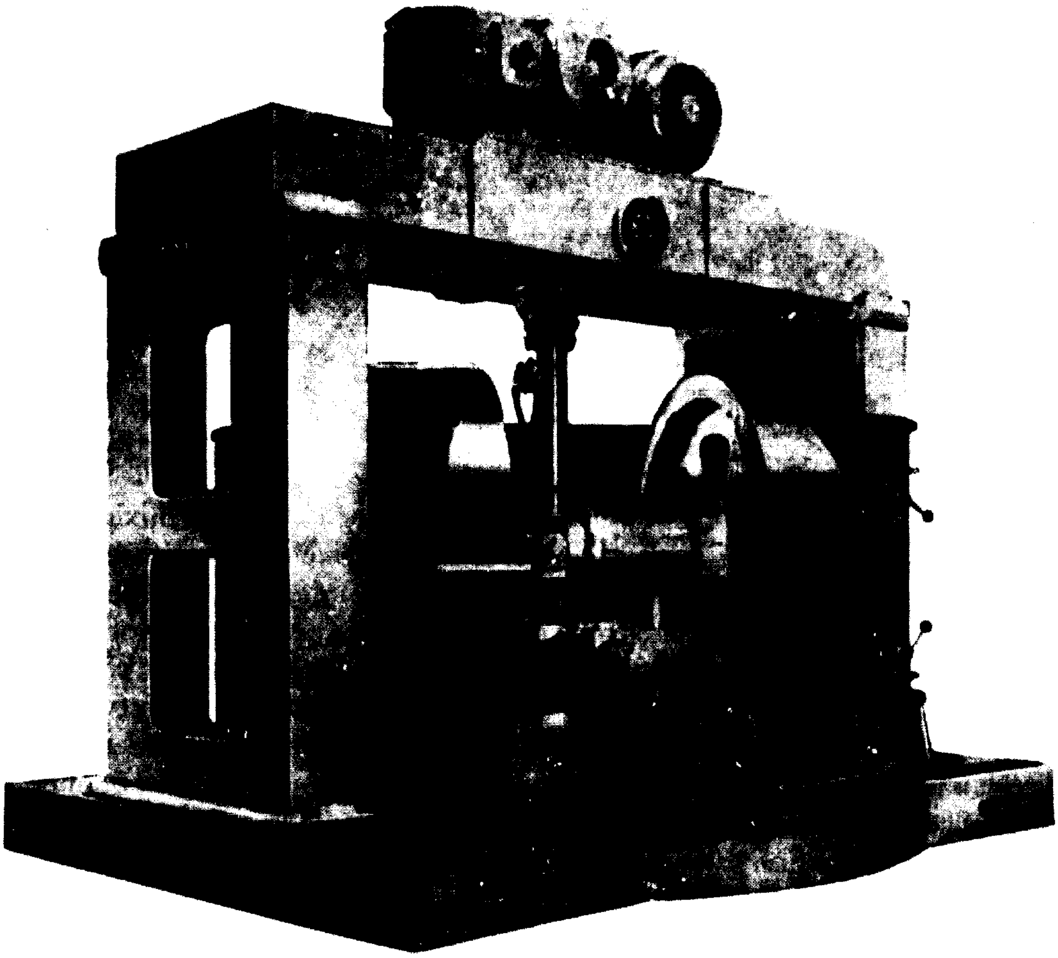


Figure 15. Wet pan

variable area depending upon the hardness of the clay and hence the amount of true grinding necessary. The mullers grind the clay and force it through the perforations, while the scrapers fold the clay upon itself and hence provide mixing. Water is frequently added at the wet pan, and at this point additions of barium carbonate or stain may also be made. It is the most effective form of mixing and tempering, and the degree of preparation given can be adjusted by altering the size of the slots in the perforated base.

The preferred way of collecting the output beneath the pan is by means of a Mauk mixer (figure 16), which not only collects the clay to a single point for discharge onto a conveyor but also provides a further element of mixing. Clay from the wet pan falls over the whole area of the mixer pan, which is moved around intermittently to give one complete rotation in about ten minutes. The continuously rotating screw discharges either at the centre or periphery of the pan.

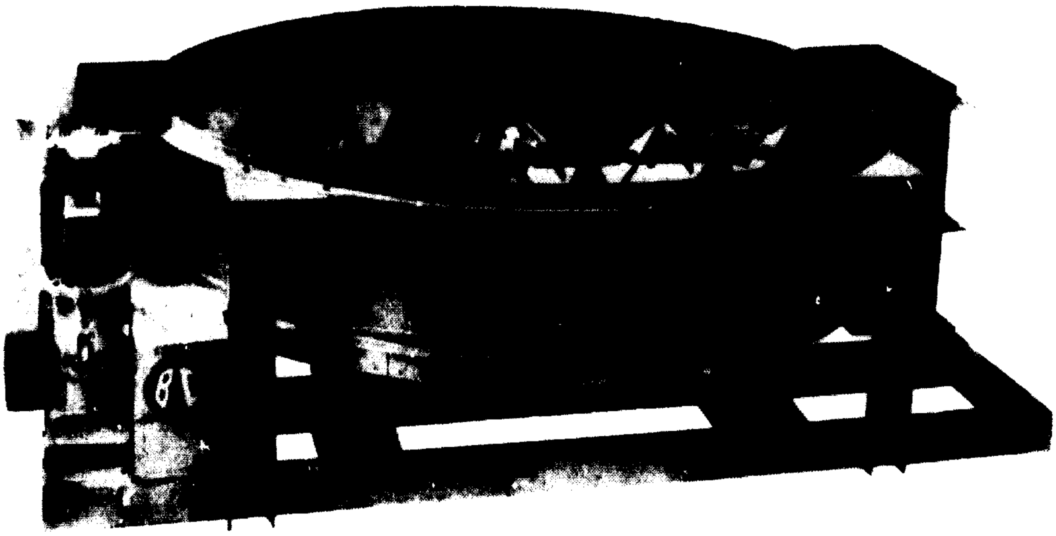


Figure 16. Mauk mixer

The grids in the base of the pan usually take the form of slots that vary from about four inches long and three eighths of an inch wide to more than twice that length and a width of one inch. Inevitably some coarse material passes through, and it is usual to pass the output from the pan through one or more pairs of smooth rolls. The gap between the rolls in each set is progressively decreased and the speed increased until the final pair of high-speed rolls, which are set tight-up and run at different speeds. The speed of the faster roll may vary from 130 to 250 rev/min, that of the slower from 115 to 225 rev/min. This differential speed breaks down the clay particles by a combination of crushing and shearing, while low-speed rolls, both of which operate at the same speed, perform by crushing alone. Modern works tend to use bigger wet pans with heavier mullers and to have only one or at the most two sets of high-speed rolls following. The chief purpose of high-speed rolls is to ensure that any residual lumps, especially lumps of hard material like limestone, are broken down into fragments too small to be deleterious. The output of the rolls is a thin ribbon of clay, which breaks off into small pieces suitable for feeding the making machine, although often a double-shafted mixer is installed to break up the ribbons and feed the making plant.

In Europe tons of tempered clay—10,000 or more—are frequently stored in "sump-houses". The material is laid down in horizontal layers through a system of conveyors. After some period of maturing it is continuously and automatically re-won by multi-bucket excavators feeding onto conveyors into the plant. This store of prepared material enables the plant to operate when extreme winter weather conditions make winning impossible. It is also claimed that the souring process evens out the moisture distribution through the mass, although there is little evidence for this. What does happen is that each clay particle becomes thor-

Figure 17. Souring tower [18]

oughly wetted by the water slowly percolating from the surface of the particle. One of the more interesting features of sump-houses is that, although massive capital expense is involved, quite short periods of souring are regarded as sufficient in some cases. [19]

The continental "*Maukturm*", or souring tower, has been developed for short-term plastic storage and souring (figure 17). It provides sufficient storage for one day's make, so that the clay fed in at the top is conditioned under the pressure of the superimposed load throughout the 24 hours it takes to reach the bottom. It is then discharged, via a mixing and conveying screw in the slowly rotating base, similar to that in the Mauk mixer.

Not all clays benefit from this short period of souring, but even so it may be advantageous to have hopperage of this kind to prevent delays in production. Indeed, the storage of partly prepared plastic raw material before it is formed into a clay shape is fundamental to maximum output in the extrusion process. At a given knife-setting and a given speed of shaft rotation the output of a pug is determined by the rate of feed of the raw material. If the pug is choke fed the maximum output is obtained, and if this quantity of raw material is not supplied, the production will fluctuate, often over a large range.

Since the ease with which even a so-called "constant" raw material can be ground through a wet pan varies from moment to moment according to the precise conditions in the wet pan, such as moisture content, depth of bed, and hardness of individual clay lumps, the output is not constant. If the material from the pan passes directly to the pug without some intermediate "storage" absolutely constant brick production is impossible. A double-shafted mixer before the pug may be sufficient to eliminate minor variations in feed, but a more elegant machine, which has the virtue of performing an additional preparation operation, is the continental circular screen feeder (figure 18). The bottom portion of the

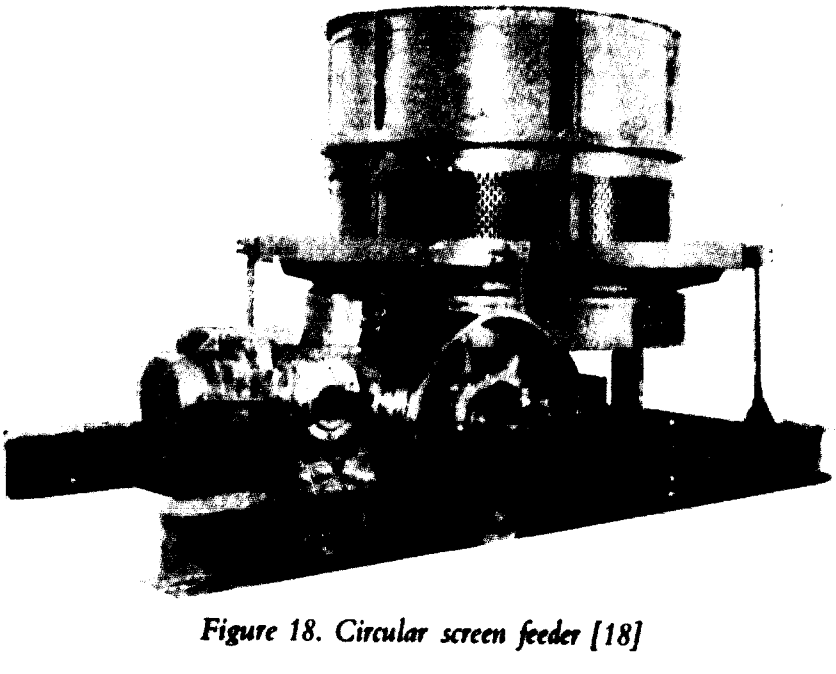


Figure 18. Circular screen feeder [18]

cylinder has perforations of any desired diameter, and the raw material is forced through these in the form of spaghetti-like pieces by means of a central rotating stirrer arm. The pieces are collected on a rotating disc base and ploughed off to be transported to the pug. The upper portion of the machine is blank. The height of the perforated portion is adjusted to give the exact output required, and the clay is maintained at a higher level. Momentary fluctuations in the pan output raise or lower the level of clay in the blank portion only, and the actual output to the pug remains constant. Incidentally, over-feeding of the pug resulting in either feeding back into the pug entrance, or excessive rate of production with consequent difficulties with the automatic handling plant, is impossible.

The methods of plastic preparation and storage discussed above range from the simple and cheap to the sophisticated and expensive. In developing countries a proportion of the works employ some means of hand kneading as the preparative operation, and for very small hand-moulded works this may be sufficient. The first stage in mechanization, however, might well be the use of the "sludge pan", or tempering tub (figure 19). This is a shallow pan with a vertical pug attached to the base. The centre shaft carries four radial arms with blades that mix the clay and water in the pan and direct it in towards the centre. The vertical shaft passes

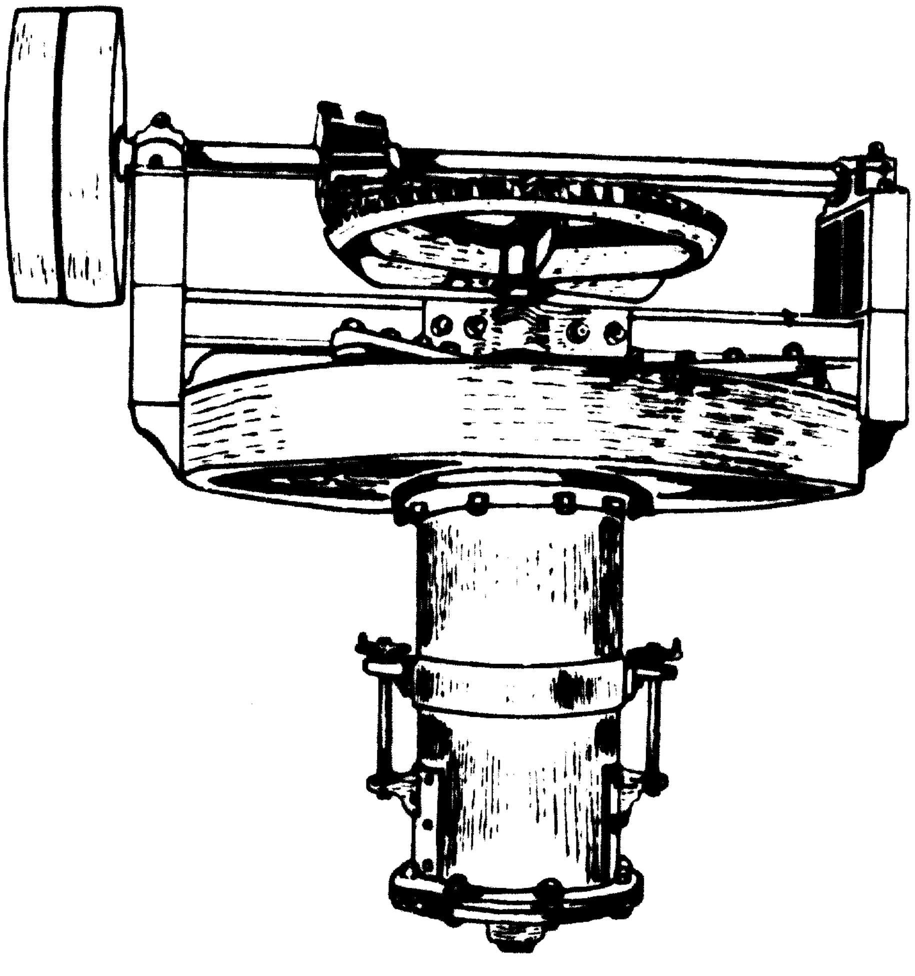


Figure 19. Sludge pan [18]

directly through the vertical pug, and here pug knives knead the clay and force it down to the discharge point at the bottom of the barrel. Such machines are suitable for outputs of around 50 tons per day, and the material can be used for hand-moulding or for extrusion of bricks and tiles.

MAKING MACHINERY

Some improvement in the labour requirement of the handmade process can be achieved by providing prepared clay at the maker's table. The Lintott machine tempers and delivers such clay to three makers' tables simultaneously from three orifices, while in the Aberson system an enclosed soft-mud type mixer is used to produce clots that fall onto a conveyor passing all the making stations. However, the real improvement in hand-making is to mechanize the moulding operation, and the soft-mud process must be regarded as a simple and effective step to increase production.

Soft-mud process

The basic brickmaking machine consists of a horizontal or vertical pug that extrudes clay into a multiple mould of usually four or six bricks. Figure 20 shows the Berry machine, a simple horizontal form with a cylindrical barrel in which rotating knives move the clay to the discharge end, where other blades force the clay through steel dies into the sanded mould that has been fed in immediately below. The filled mould is then pushed forward by the empty one behind, and the surplus clay is struck off. The mould is jolted to loosen the brick and inverted so that the bricks are discharged onto individual thin wooden pallets.

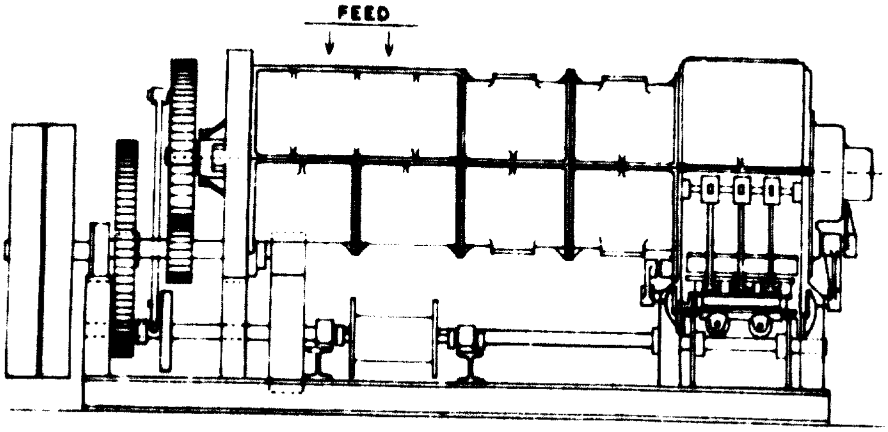


Figure 20. Berry machine [18]

The four-mould Berry machine has a rated output of 1,400 bricks per hour and is conveniently small. Three such machines make a viable and efficient works. Larger machines with six to ten brick moulds are available, however. The American Lancaster Autobrick machine demoulds automatically onto pallets (figure 21) and can be fitted with an automatic car loader, which places the pallets

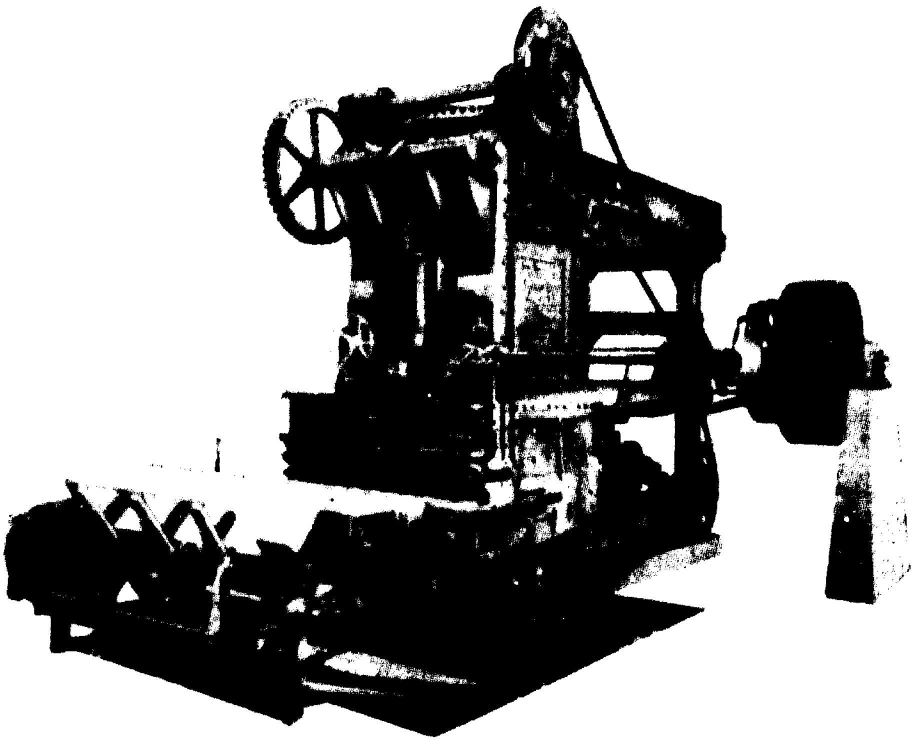


Figure 21. Lancaster soft-mud brick machine [18]

directly into tunnel dryer cars and returns pallets automatically to the machine. The Dutch Aberson and De Boer machines have outputs ranging from 5,000 to 15,000 bricks per hour. These can be made completely automatic when used in conjunction with a pallet ascender and chamber dryers.

In such dryers the pallets are placed upon racks, and similar racks can be erected in the open air for natural drying. Extensive rack systems are required, but this is a technology for large-scale production, which is perhaps almost directly transferable to developing countries.

Extrusion of bricks and hollow blocks

Extrusion is the process of forcing plastic clay through an orifice or die to produce a shaped column that can be cut into lengths by appropriately spaced wires. This gives the process its alternative name of "wirecut". It is a basic method of shaping that can be applied to a variety of clays at different moisture contents to produce all the heavy clay products—solid and perforated bricks, hollow blocks, land drains and sewer pipes, roofing tiles and floor quarries.

The three instruments for moving clay through the die are piston extruders, or stupids; expression rolls; and screw extruders, or augers. The stupid is the oldest and on a small scale can be hand-operated, as were the transportable stupids for roofing tiles, which used to be wheeled around the drying sheds so that the tile was made and placed straight on the rack. When the piston reaches the end of its stroke it has to be withdrawn and the machine refilled with clay; hence the process can never be continuous, although in the operation of pneumatic stupids for making land drains the process is fast enough to be commercially viable.

Two expression rolls fixed one above the other are used to force a column, roughly shaped in a double-shafted pub, through a tapering die placed in front of the rollers. A complicated pattern of laminations folded in the direction of extrusion is formed, and it has been claimed accordingly that clays that could not be satisfactorily extruded in an auger machine could be formed by this process.

The most important and in Great Britain now practically the only form of extruder is the screw extruder, or auger machine. This is used for soft extrusion at 20 to 25 per cent moisture content, for de-aired stiff extrusion at 15 per cent moisture content, and for all grades of extrusion between these two. In its simplest form it consists of a cylindrical barrel within which rotates a close-fitting helix mounted on a central shaft. Material is fed in at an opening on top of one end, and at the other is an orifice or die often preceded by a short tapering spacer section. Clay is forced along the cylinder by the flights of the helix and consolidated both within the flights and eventually by the tapering section of the spacer and the constraint of the die.

To produce perforated bricks and hollow blocks, clay is extruded from the parts that are to be hollow by means of core pieces in the die. At the back of the die a bridge piece is fixed, and from this project metal tines with cores on the end shaped to the outline of the hollow required (figure 22). Often modifications have to be made to this bridge work to balance the die and ensure that a good even column is produced.

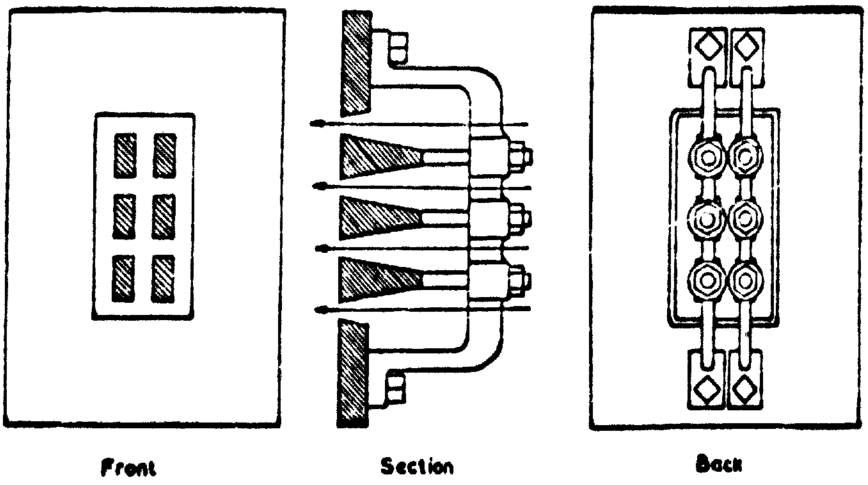


Figure 22. Hollow block die [11]

Another important type of extruder is the de-airing extruder. Figure 23 shows four different designs but a common principle: *(a)* and *(b)* are "stepped barrel", or "double-deck" extruders, while *(c)* and *(d)* have co-axial barrels and are "in-line" extruders. Clay entering the first barrel is forced through a shredder plate into a chamber where a vacuum (V) is applied. The clay then falls into, or

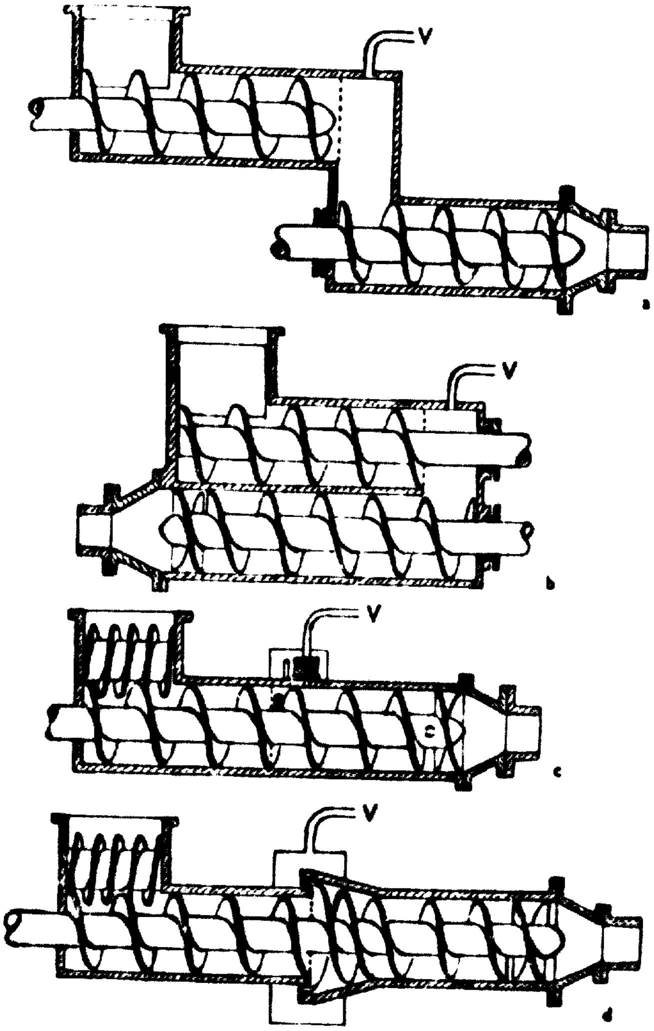


Figure 23. Four designs of de-airing extruder [18]

passes forward to, the second barrel, where the now de-aired material is consolidated and extruded. A so-called "full" vacuum applied is usually about 28 inches of mercury. This should really be applied as a predetermined percentage of the atmospheric pressure at the particular time, but in practice minor variations in vacuum are not important. With this full de-airing the plasticity is increased, a denser, stiffer column is produced, and eventually a denser, and hence stronger, fired brick with lower porosity results. Some clays produce extrusion faults when fully de-aired. While a stiff column is desirable for direct setting on tunnel-kiln cars, it makes rustication of the surface more difficult and can make problems in drying. Hence partial de-airing is sometimes applied.

The auger extruder produces a range of bricks from soft-extruded facing bricks with crushing strengths of 2,000 pound-force per square inch, to stiff-extruded, de-aired engineering bricks with crushing strengths almost ten times as great. It is at once the most versatile and most carefully controlled process and is in the stiff-extrusion form characteristically chosen for modern brick factories.

It is the chief process for producing perforated bricks; and although a few clay hollow blocks are now being pressed in the United States, it may be said to be the only process for block making.

Where clay is won with an *in situ* moisture content such that a wet process must be used, the extrusion process should be considered for large plants. However, the clay must be sufficiently plastic to produce a good column, and alluvial clays may not be satisfactory. The possibilities of difficulties are probably greater with extrusion than any other process, since there may be extrusion faults, drying faults, and firing difficulties with dense bricks. It is thus vital to make full examination of the characteristics of a clay before a decision is taken to install this process. Nevertheless, when properly operating on good and consistent raw material, extrusion produces first class common, facing and engineering bricks and hollow blocks at relatively low operating cost.

Stiff-plastic process

The stiff-plastic machine invented in England combines extrusion and pressing. It is suitable for hard clays and shales prepared by dry grinding. The clay dust is usually tempered in two consecutive mixers and fed into the top of a vertical pub that extrudes into a clot mould. The clot mould is either one of a number in a circular table rotating about a vertical axis, or one of a number in a drum rotating about a horizontal axis, or one of a pair of reciprocating moulds. The essential point in the process is that immediately after being roughly shaped, a clot is passed to where it receives its final shape, although it is sometimes re-pressed. The press mould is larger in the bed face dimensions than the clot to permit the latter to fall in easily and to allow for the escape of air; but the clot stands higher, and the action of pressing squeezes it out to fill the mould. Escape holes are provided in the bottom die plate to allow excess clay to leave the mould. In the re-press mould there are no vent holes. This operation is carried out to improve the finish and increase the density of the brick.

Stiff-plastic bricks are characteristically dense and strong, with sharp arrises. Their typically machine-made appearance is aesthetically and physically more appropriate to industrial building than to modern housing.

Since the bricks can be set directly in kiln without drying, there are superficial attractions to the process. One dry pan and screen with two single presses or one double press and a Hoffmann kiln makes a neat clayworking unit with the tidy output of 100,000 bricks per week. This is a convenient size for a local brickworks, and there have been many in Great Britain to testify to their profitability. In terms of modern capital requirements, however, such a small unit is not favoured, and new works are now laid down on the basis of outputs over three times as great.

In developing countries, however, the stiff-plastic process might find favour if suitable hard clays and shales are available. A possible disadvantage is that a good fitter, preferably trained by the machinery manufacturers, and an adequate stock of spare parts are required. Probably the optimum conditions for using this process will exist only rarely.

Semi-dry press process

The ground dust usually has a moisture content of 6 to 10 per cent, although Fletton bricks contain up to 20 per cent. Press operation is of three types: crank or eccentric, cam and toggle. In all cases the mould is filled automatically with dust by a reciprocating feed box. In crank-operated presses the top die comes down to consolidate the dust, and at its lowest position the bottom die plate is given two impact pressures by a cam, and then the brick is ejected by the top and bottom die plates rising together. When the bottom die is level with the table the feed box moves forward to push the brick clear, the bottom die falls, the mould fills with dust and the cycle repeats. The process is entirely automatic, and one double-mould machine produces 1,200 bricks per hour. Re-presses are also fitted, and the trade mark "Phorpres" of the London Brick Company emphasizes that four pressures are applied.

The sequence of operations on cam and toggle presses is similar. A further type of press is the rotary table, in which a number of moulds rotate to be filled at one point, pressed at another and ejected at a third. Somewhat higher outputs up to 2,000 per hour are claimed for these, but they are more costly than the simple eccentric press.

The same maintenance requirements arise in this process as in the stiff-plastic; nevertheless if suitable clays are available it should be considered for its economy. Fletton clays, with their excellent pressing characteristics and high content of carbon providing free fuel, are able to produce the cheapest bricks in developed countries. Although that fortunate combination of properties is rare, it is worth looking for.

Roofing tiles

The traditional method of making tiles is by hand from clots. The type of mould varies in different regions and with the type of tile, but the simplest type for plain tiles consists of a frame of metal of tile thickness placed on a flat block on the maker's bench. A clot is cut from the stock heap, wedged on a sanded board and thrown into the sanded mould with enough force to fill it completely. Excess clay is cut off level with the top of the mould and struck off with a rod. The frame and tile are slid off the bench onto a pallet, and the frame is removed. At this time the tile is quite flat with two lugs at one end, which are later bent up to form the nibs. Nail holes are put in with a hollow punch. Some reduction in the labour element of hand-making can be achieved by extruding bats, that is blanks about the size of the tile, which are then finished by hand in a mould.

Plain tiles are "cambered" either with soft mixes, by drying on cambered drying racks, or for stiffer methods by placing them face up in bungs of ten on a "horse" shaped to the camber and striking the top with a cambered plate.

Plain tiles are also extruded from an auger machine with a continuous nib, and may be sold in that form, or alternatively special cutters are employed that shape the nibs and nail holes and profile the ends for beaver tail tiles and special shapes. Mention has been made earlier of stupids for extruding pantiles and shaping them on special cutting tables attached.

Pantiles and interlocking tiles are pressed from extruded bats in plaster moulds, complicated shapes being produced and placed on pallets automatically by vacuum lifting devices. The pallets can be automatically handled to dryers. Relatively little labour is used, so that in Europe the clay roofing tile is a viable proposition.

Another form of bat making for plain tiles is the roller-bat process, which is basically a stiff-plastic process. Moist clay dust is fed between two wheels and compressed in the gap where it is constrained at the sides by a flange on the bottom wheel. A continuous ribbon of tile thickness is produced, oiled and cut off to form tile-size bats. The rated outputs of different machines are 4,000 to 12,000 bats per hour. The bats are either re-pressed into the final form immediately or left to sour in bungs for two or three days first.

The mechanization of tile making is not easy, as the declining number of works in most developed countries testifies. Since better clay preparation and more careful processing are necessary to avoid high waste in drying and firing these thin shapes, the process is inevitably more expensive than brickmaking. Plain tiles can readily be extruded, but more are needed to cover a given area of roof than single-lap tiles. Simple types of these, like normal roll Romans can be extruded from stupids, but this is little advance over hand-making. Spanish tiles can readily be extruded as an oval section pipe with a score mark at the ends of the long diameter so that it can be split after firing into two tiles. This provides perhaps the simplest way of developing larger-scale production. The ultimate is the re-pressing of bats to make interlocking tiles, but this might well follow on the establishment of an extensive plain or Spanish tile industry.

IV. Drying

THE PROCESS OF DRYING CLAY

THE OBJECT of drying ceramic articles is not only to remove water, which might otherwise cause difficulties in firing, but also to stiffen them up sufficiently to permit them to be set in the kiln. It is not necessary to reduce clays to zero moisture content but only to some point below the leather-hard moisture content, which is the point at which most of the shrinkage ceases. The remainder of the moisture is removed at the beginning of the firing cycle. There are in fact disadvantages in drying to very low moisture contents. The ware becomes brittle and easily damaged, and since dry clay is an excellent desiccant it can re-absorb moisture from the atmosphere. With some types of raw material re-absorption cracks occur, which show as waste after firing.

Three processes must take place concurrently for effective drying: transfer of heat to the ware; vaporization of the liquid water in the piece; and subsequent removal of the water vapour produced.

In the heavy clay industries these processes are carried out by the passage of warm air over the surface of the wet clay. Between this moving air and the wet surface of the piece lies a thin layer of still air through which the water vapour must pass to be removed by the main air stream. Evaporation causes the temperature of the surface to fall below that of the drying air, and at that point heat flows to the surface by conduction through the stagnant air film. The rate of conduction, and (because all this heat is used to evaporate water) the rate of evaporation, is directly proportional to the thickness of the layer of still air and the difference in temperature between the wet surface and the drying air.

The temperature of the drying surface is not affected by the velocity of the drying air when this exceeds about ten feet per second but depends only on the temperature and humidity of the air. At constant temperature and humidity, however, increasing the velocity of the air increases the rate of evaporation because the thickness of the film of still air is reduced. The amount of this increase is difficult to predict, since the direction of the air flow in relation to the drying surface is critical. The different faces of a rectilinear article like a brick dry at different rates depending upon the brick's orientation in the air flow.

The difference in temperature between the drying air stream and the wet surface of the ware can be measured by a wet- and dry-bulb thermometer. This consists of two thermometers side by side in a suitable case, the bulb of one of which is covered by a wick saturated with water. This wet-bulb thermometer records the temperature of the wick as the water evaporates, while the dry-bulb thermometer records the actual temperature of the air. The wet-bulb temperature then is the temperature of a drying surface under those conditions, and the difference between this and the dry-bulb temperature, called the wet-bulb depression, is a measure of the moisture content of the air. If this moisture content is high the rate of evaporation is low and the wet-bulb depression will be small; if the humidity is low the opposite will be the case. In Great Britain dryer temperatures are invariably measured in °F and drying calculations carried out in these units. The practice has accordingly been followed here.

At constant air velocity the rate of drying is proportional to the wet-bulb depression but independent of the actual temperatures, provided that the surface of the piece is covered with a continuous water film (true for clay until shrinkage ceases) and that all the heat transferred to the drying surface is supplied by convection from the surrounding air. In industrial dryers some heat may also be supplied by conduction and radiation.

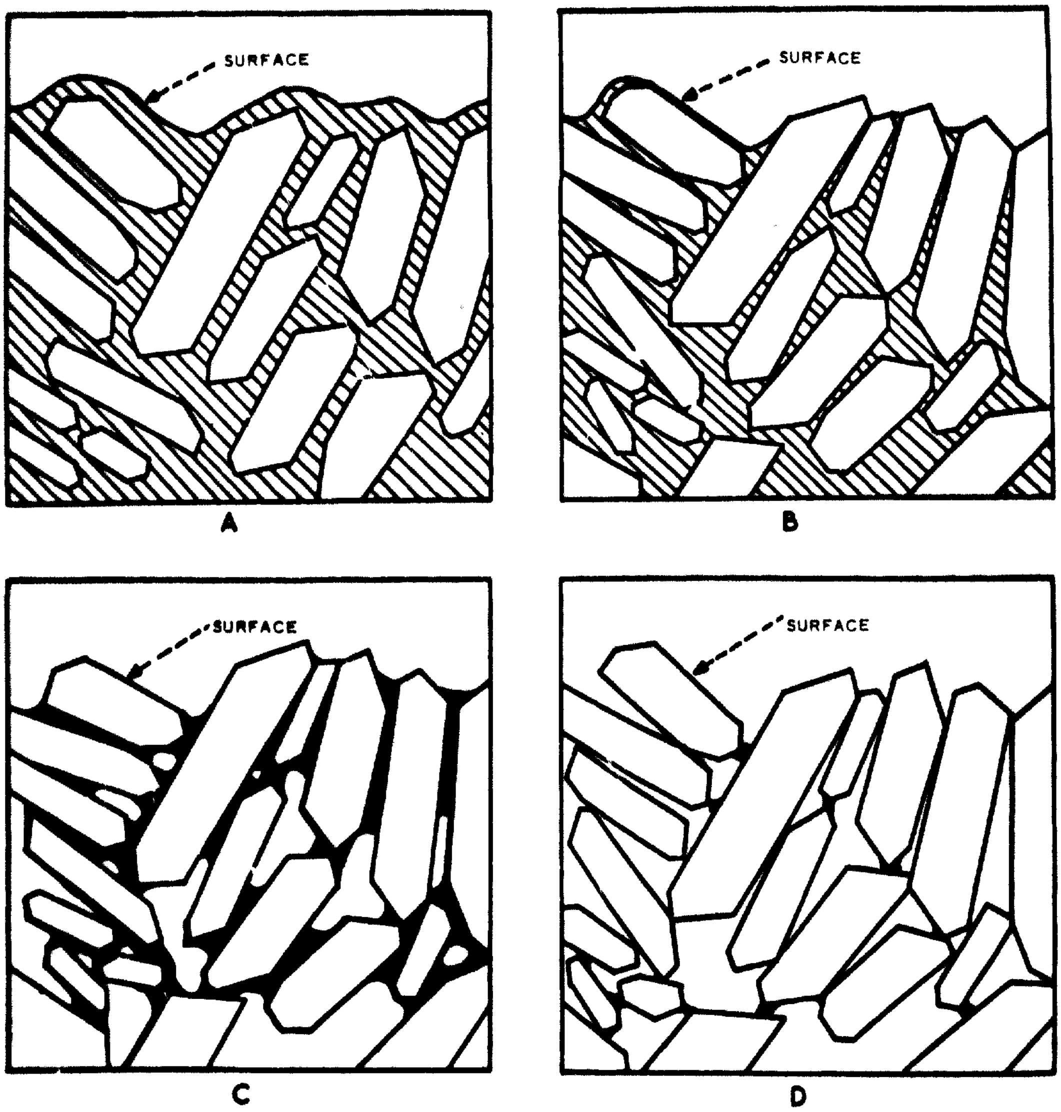


Figure 24. Clay at various stages of drying [20]

Plastic clay is usually regarded as a conglomeration of solid particles separated by water films completely surrounding the particles, so that, as shown in figure 24 A, the surface is a continuous film of water (shown shaded). As water evaporates from the surface it is replaced by water flowing through the capillaries from the inside of the ware. The particles move nearer each other; and this contraction, which is equal to the volume of water lost by drying, continues until the particles touch—the leather-hard state (figure 24 B). Flow of water to the surface now stops, and the drying surface retreats into the piece. Air spaces begin to appear in the wider parts of the capillaries (figure 24 C). The surface colour of the ware changes when the water film disappears, and this gives rise to the expression "white hard" for drying to this point. Finally the water films at points of contact between particles disappear (figure 24 D).

Since a free water surface exists on the clay down to the leather-hard state, the rate of evaporation is constant, and this is called the "constant rate period". Below this, water has to diffuse to the surface in the vapour phase, and this becomes progressively more difficult, as the water vapour is formed further from the surface. The rate of drying at constant temperature and humidity decreases, and this is known as the "falling rate period". The removal of water is influenced now mainly by the size of the capillaries and the temperature of the brick.

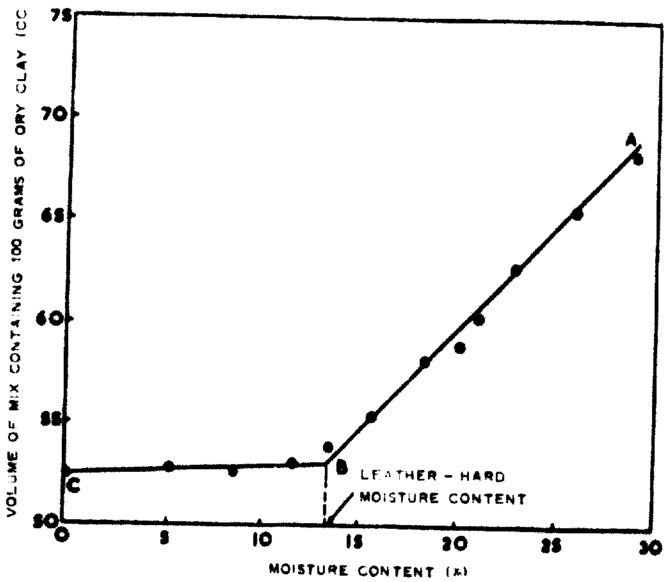


Figure 25. Changes in volume of a clay during drying [20]

The changes in volume are shown in figure 25. *A* is the initial moisture content (dry basis) of the clay, in the case quoted 29 per cent; *B* is the leather-hard moisture content, usually shown as M_L (13.4 per cent), which varies for different brick and tile clays usually between 8 per cent and 14 per cent, the higher value being associated with finer particle size; *C* (usually written V_D) is the volume of dried clay and represents the total volume of clay particles plus the volume of pores. Figure 24 above assumes all the pores are completely full of water, but in fact a small volume of air is present. When the mix is de-aired the graph in figure 25 is displaced downwards by an amount equal to the volume of air removed so that the denser product is indicated by a lower value of V_D. The more dense structure produced by de-airing makes drying more difficult, especially during the falling rate period, and a wet centre may be left under conditions that would adequately dry an unde-aired piece. This wet centre may lead to damage in firing.

It will be apparent that the amount of shrinkage is largely determined by the difference between the moisture content as made and M_L. The amount of water required to produce the best making moisture content varies with the proportion and type of clay mineral present and figure 26 shows the making moisture content plotted against the "clay" size fraction for a series of boulder clays [20].

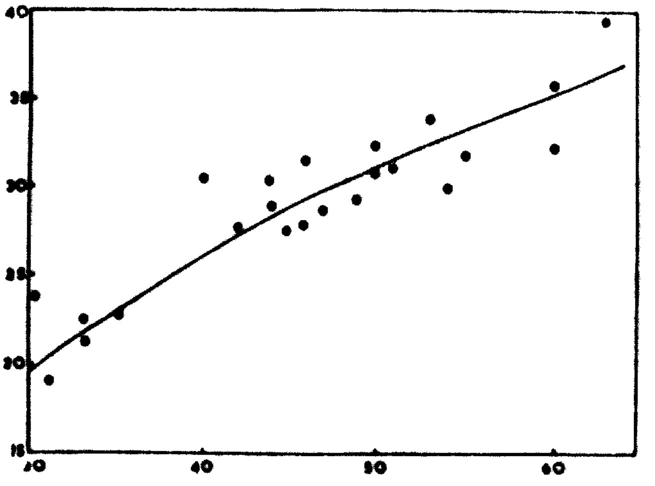


Figure 26. Effect of grain size on the making moisture content of clays [20]

Although it is the volumetric drying shrinkage of clays that is usually reported, in practice it is the linear shrinkage that is important; and this may be taken as roughly one third of the volumetric shrinkage. It is not, however, the same in all directions. In extruded bricks or tiles the shrinkage parallel to the direction of extrusion is greater than the shrinkage in a direction at right angles because of the alignment of the flat clay particles under pressure in the process of extrusion through the die. The application of a load to drying ware increases shrinkage in the direction of application of the load so that bungs of tiles may shrink more in the vertical than the horizontal direction.

Because a clay piece dries from the surface, the moisture content there is always less than that of the interior. The establishment of moisture gradients as drying goes on causes water to flow from regions of high moisture content at the centre to regions of low moisture content at the surface. These moisture gradients depend on the resistance of the body to the flow of water, and this resistance differs with the clay and can be modified by the addition of non-plastics, such as sand or grog. The curves in figure 27 illustrate this for bars dried from one

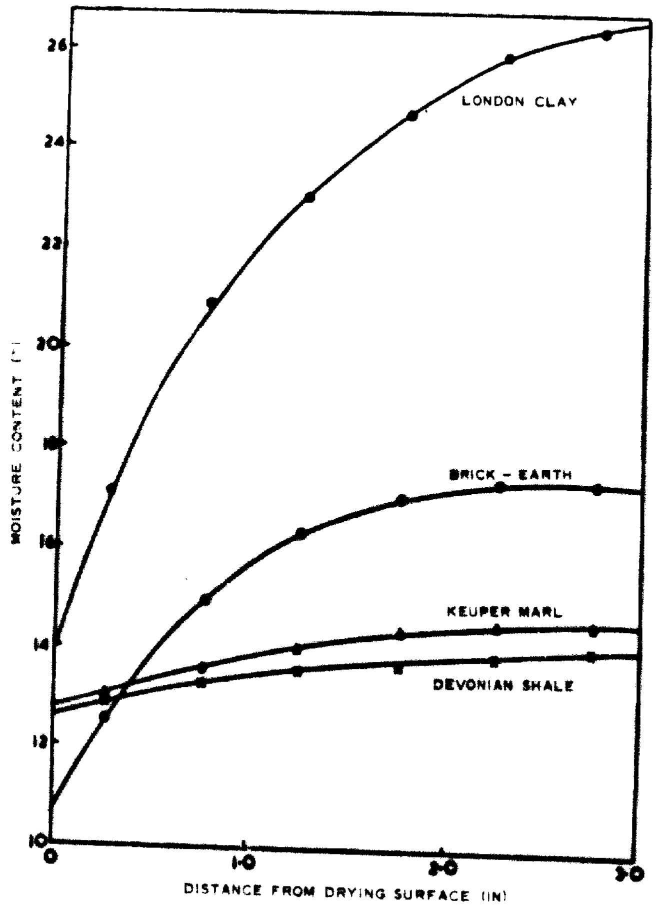


Figure 27. Moisture distribution in different clays drying under the same conditions [20]

end only. The less plastic clays, such as Devonian shale, offer little resistance to the movement of moisture, so that the gradient is small, while the fine-grained, highly plastic, London clay shows a marked gradient. When the rate of evaporation is increased the moisture gradient increases in any clay.

Since the viscosity of water decreases with increase in temperature, if the temperature of the piece as a whole is raised water will flow to the surface more readily. This is the principle of humidity drying, in which the ware is warmed up in an atmosphere of high humidity, often by circulating warm air within a chamber but allowing none to escape to exhaust. Smaller moisture gradients between centre and surface reduce the chance of cracking, and the process is therefore to be favoured for clays or special shapes, such as hollow blocks, which are difficult to dry.

Humidity drying may also give shorter drying times, but more startling reductions have been claimed for steam tempering. Steam is used instead of water for tempering, and the hot extruded shape is transferred immediately to a dryer, thus eliminating the warming-up period. The process has been used in France and Italy mainly for hollow blocks, and for these thin-walled units reduction of drying time to a few hours is possible with an extrusion temperature of 140° to 180 °F.

Above leather-hard there is a tendency for the surface layers to contract more than the centre. This differential shrinkage sets up tensile stresses in the surface which, when they exceed the strength of the clay, result in cracking. Since the shrinkage at a particular point is related to the moisture content at that point, the magnitude of the moisture gradient limits the rate at which drying can proceed without cracking. Below leather-hard shrinkage practically ceases. Although the centre may still be quite wet when the surface reaches this point further shrinkage will be largely restrained by the rigid outside, and at very fast rates of drying the total shrinkage is reduced. With thin pieces such as tiles, which dry from the edges, however, the shrinkage of the centre is greater in the later stages of drying. When the moisture content becomes too low for the clay to accommodate by plastic deformation, a crack starts wide in the middle and narrower towards the edge of the tile.

Since the tensile strength of a clay increases as the moisture content falls, drying rates can be progressively increased, and at any stage of drying there is a safe rate that avoids cracking. This can be determined for small settings of bricks in the laboratory, but on a works the schedule will usually have to be longer because of the difficulty of controlling the conditions in a dense setting.

The safe rate differs markedly for different clays as figure 28 illustrates. It

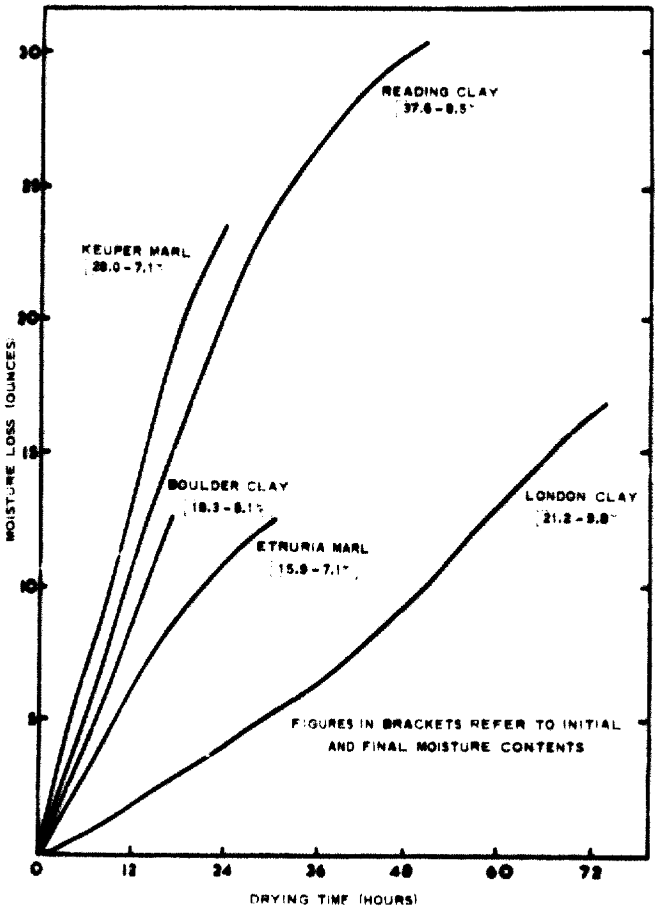


Figure 28. Maximum safe rates of drying of various bricks as determined in the laboratory [20]

has been shown that the cracking tendency of clays can be established by empirical drying test, and that the order in which different clays fall in the test is the same as is found in practice. [21] It was found that the clay mineral type has a critical role in determining the drying properties of clays and that this is more important than either the particle size of the material or proportion of clay mineral present. To summarize: kaolinitic clays are easy to dry and illitic clays very difficult; clays between these two extremes, which may be regarded either as disordered kaolinite or as a mixture of kaolinite and illite with properties intermediate between the two constituent minerals, show intermediate cracking tendencies.

It follows from this and from what has been said about drying shrinkage that when two or more clays are to be blended, the mixing must be thorough enough to ensure that the clays mix at the particulate level. Lumps of one clay in another will exhibit differential drying shrinkage, and this may lead to cracking. Although cracking is seen at the dryer exit, it may have been initiated further back in the process by inadequate grinding and tempering so that besides an inhomogeneous mix of clays there is an uneven making moisture distribution.

HEAT REQUIRED FOR DRYING

Heat for drying in artificial dryers is required not only to evaporate water but also to raise the temperature of the clay, water and structure on which it rests, such as pallets or dryer cars, from ambient or the entry temperature to the temperature at which evaporation is to take place. The heat required to raise the temperature of each material in British thermal units is given by the general equation:

$$\text{Heat required (Btu)} = \text{Weight of material (lb)} \times \text{Temperature rise (°F)} \times \text{Specific heat of material}$$

Separate calculations can be made for the clay, residual water in the brick at the end of drying, and dryer cars, etc., and summed to yield a total.

To this must be added the heat required to evaporate the water, that is the latent heat of vaporization, which at 212 °F is 971 Btu/lb of water, but in dryer calculations the figure usually taken is that at 100°F, which is 1,050 Btu/lb of water. This is almost ten times the heat required to raise the wet clay from 50°F to 100°F.

The heat losses from the dryer structure are difficult to estimate and depend not only upon the construction of the walls and roof, for which thermal transmittance values are available, but on the degree of exposure to weather, the moisture content of the structure, and the temperature distribution in the dryer. Attention to design is important when building a dryer to minimize losses, and correct operation, especially the prevention of loss of hot air through badly fitting doors, is essential. Over-all heat losses from the dryer structure may be expected to fall within the range of 200–1,000 Btu/lb of water evaporated.

The exhaust air from the dryer carries away some residual heat, which can be calculated from the temperature and wet-bulb depression of the exhaust air and its initial moisture content at atmospheric temperature before being heated up to enter the dryer. For good thermal efficiency the exhaust air should leave the dryer substantially saturated with moisture and at a high temperature. In practice, in temperate climates, the wet-bulb temperature is usually 80–95°F and the wet-bulb depression 5–10°F giving residual heat of about 500 Btu/lb of water removed from the dryer. In less efficient dryers with larger wet-bulb depressions or lower exhaust temperatures it may be as much as 1,500 Btu/lb.

Adding all these calculated heat requirements together and expressing the heat required to evaporate one pound of water as a precentage of the total gives a measure of the thermal efficiency of the dryer. Table 10 gives the minimum and maximum values for a typical convection type dryer.

The hot air provided for drying should not contain high proportions of sulphur dioxide, since under the humid conditions of a dryer this both corrodes the structure and, by reaction with the clay, forms sulphates, which cause dryer scum. In general the air should be provided from a heat exchanger, fired by coal or oil or alternatively by a steam heat exchanger. A steam air heater at 55 per cent is somewhat less efficient than a coal-fired air heater at 70 per cent. Steam is also used as a source of heat beneath hot floors and in gilled pipes in the base of some dryers as an addition to the hot air source. This was particularly the case when steam engines were used for the main works drive, and the exhaust steam was a cheap source of "waste" heat.

Table 10

HEAT REQUIREMENTS OF DRYING [20]

	Btu/lb of water evaporated	
	Minimum	*Maximum*
Heat withdrawn in hot bricks, pallets etc.	340	340
Heat losses from dryer structure	200	1,000
Residual heat in exhaust air	500	1,500
Heat to evaporate one 1b water	1,050	1,050
TOTAL	2,090	3,890
Thermal efficiency percentage	50	27

Although the products of combustion from coal or heavy fuel oil are not suitable for passing directly into a dryer, a low sulphur fuel, such as gas oil, may be used with high dilution of cold air. Alternatively exhaust gases from kilns have been used to pass under the floor of dryers in sealed flues before being expelled to atmosphere via a fan and stack.

The chief source of hot air for drying is by recovery of so-called "waste heat" from the cooling zones of kilns. Although the kiln fuel consumption is somewhat higher when hot air is withdrawn, the total fuel consumption for drying and firing is less than when auxiliary air heaters are used. Indeed on modern tunnel-kiln factories the heat recovered from the space over the crown together with that drawn through the fired goods to cool them is sufficient without further addition to dry as many bricks as the kiln can fire.

On continuous kilns heat is withdrawn from the cooling chambers starting two or three chambers behind the fire, and either ducted to external dryers, or, in the case of semi-dry press and stiff-plastic plants, passed forward to the drying chambers of the same kiln. Unlike tunnel kilns, where the temperature of the hot air remains sensibly constant, on continuous kilns the temperature drops as the goods cool. At that point the ducting is moved on to the next forward chamber and the last cool chamber taken off. By arranging to have three or more chambers in circuit at once the temperature of the air can be maintained; since in any case it is diluted with atmospheric air, constant temperature at the dryer can be achieved by adjusting the dilution.

Because of the high fuel consumption and labour cost intermittent kilns are used only for the most expensive bricks, but extensively for tiles. Unless heat is recovered on cooling, it is lost completely from both the bricks and the kiln structure. The amount of heat stored at the end of firing may amount to 20 per cent to 30 per cent of the total heat input to the kiln, so its recovery justifies some thought. The chief problem with recovery from intermittent kilns is that their relatively small capacity results in an extensive layout; hence heat losses from the ducting tend to be high. Because the temperature of the air from kiln falls continuously from the moment it is connected, some auxiliary source of heat is usually necessary.

COMPARATIVE EFFICIENCY OF DRYERS

As dryers become more sophisticated, the capital costs of the structure and instrumentation rise, and the running costs in labour and fuel fall. The total efficiency of a drying system is derived not only from the cost in fuel, labour and capital charges but also from the proportion of first-quality dry products it produces; hence the moisture content of the clayware ex-dryer and the level of waste are essential parameters in this equation. Moreover, in tropical countries "fuel" for drying is free, at least for part of the year, and this may weigh heavily in the choice of drying system.

Open-air dryers

The traditional method of drying bricks and tiles is to allow them to dry naturally in the open air. Protection against wind, rain and occasionally frost is necessary, and in tropical countries protection may be required against the sun. In general lean clays may be dried under more rigorous conditions than highly plastic ones, which need to be dried in the shade in open sheds.

In the most primitive form bricks are moulded, placed in the ground flat on the bed face, and after two or three days set on edge so that both bed faces receive heat and air. In developed countries when hack-drying was practised extensively, flat open spaces (hack grounds) were prepared and hack bottoms raised up above the general level. On these flat mounds two rows of ten-inch wide wooden planks were placed eight to ten inches apart. Bricks were barrowed from the making shop and set crosswise on the planks, and setting boards were used to space the bricks three eights of an inch apart. When this course had stiffened up sufficiently a second course was set brick-over-space and the process continued to eight courses high. Then on top, light roofs were set and lee boards placed against the side exposed to sun, wind or rain. After the bricks had dried sufficiently to be handled they were re-set skintled in a more open fashion so that the original eight courses became eleven, and left until dry enough to set in kiln.

A hack composed of two blades could hold 16,000 bricks. Other hacks would be built parallel to the first about nine or ten feet away so that ten hacks holding 160,000 bricks could be accommodated on three quarters of an acre. The total drying time in English conditions was three to four weeks so that about one million bricks could be dried in the six-month season. In India, with a drying period of eight to fourteen days depending on the weather, a comparable hack ground would produce two to three million bricks in the same period and perhaps four million in the extended time available in most tropical countries.

The efficiency of this process is clearly difficult to assess in terms of cost, but certain points can be made. Since these are handmade bricks with about 30 per cent moisture content, about one and a half pounds of water has to be removed from each brick. In a moderately efficient dryer this would require 4,500 Btu per brick. Assuming a heat exchanger efficiency of 70 per cent, about 6,400 Btu per brick need to be supplied by the fuel. Taking coal at 11,500 Btu per lb, 557 lb of coal would be needed to dry 1,000 bricks, that is approximately 190 lb of coal per ton of bricks. This has to be put on the credit side.

The labour requirement depends on how far the bricks have to be barrowed, but on average it is likely to be 2 man-hours per 1,000 for wheeling and hacking and rather less, perhaps 1 – 2 man-hours per 1,000 for picking up and wheeling to kiln. The process of skintling is unlikely to take less than one man-hour (m. h.) per 1,000, so that as much as five man-hours per 1,000 may be involved in all.

Finally it must be noted that freshly made bricks are easily damaged in hacking, and the secondary handling to skintle them gives a further opportunity for chipping and cracking, as does the long distance the dry bricks have to be barrowed. Unexpected changes in the weather may also cause warpage, cracking or softening of the bricks. These losses, directly debitable to hack-drying, are seldom less than 5 per cent and often much more.

The provision of large unheated sheds, sometimes with open sides that could be closed with louvres in bad weather, was an improvement over open-air hacks. The goods were placed by hand on racks or pallets. In America a rack-and-pallet system was practised with bricks on pallets placed upon permanent racks either covered in the open or in large sheds. This process was early mechanized by the installation of twin-rope horizontal conveyors between the rows of racks so that the loaded pallets of wet bricks were conveyed to a vacant space where they were taken off and placed in the rack. Similarly pallets of dry bricks were unloaded from the racks and conveyed to the kiln. This method in conjunction with the Lancaster soft-mud machine enabled American manufacturers to continue making common bricks long after conventional hack-drying would have ceased to be viable.

As wage rates rise, however, free fuel, which is the credit side of the hacking equation, ceases to be important in comparison to labour content and quality, and consideration should be given to artificial dryers.

Hot floors

In the nineteenth century open-air drying was too slow and uncertain in England to meet the need for increased output of bricks, and hot floors provided a means of drying all the year round. They are essentially floors, heated by coal or coke fires or steam, on which the bricks are set, with a roof over the top, which provides protection from the weather but allows the evaporated water to escape.

The floor may be of thin steel or cast iron plates, or three inches to six inches thickness of concrete, over the flues beneath. Metal floors heat up and cool down more quickly and have an operating temperature of 180°F, while the temperature of concrete floors is around 120°F. The bricks are usually set on end either singly, with finger space between, or in packs of two or three touching, with finger space to the next pack. Such settings on a concrete floor may take seven to ten days to dry in winter and four to six days in summer. On metal floors the time is shorter, but the limiting factor is the tendency to crack.

Hot floors have been used extensively in Great Britain for wirecut brickmaking, and some still exist. It used to be argued that waste heat was utilized in exhaust steam, but this was available only during the working day, and the provision of live steam at night was an expensive extra. Cooling air from the kilns has been introduced through ducting over the top of the floor, with propeller fans to force it down onto the bricks. While this is not a very effective way of using hot air, it does improve the rate und uniformity of drying on the floor.

Chamber dryers

There are two categories of chamber dryer. The corridor dryer was developed in Europe. Bricks on pallets are stacked on an ascender, taken by finger car and set in one of a number of corridors so that the pallets rest on ledges running the length of the corridor. The dried bricks are removed by the finger car and placed on a descender from which they can be transported to the kiln. The pack dryer, on the other hand, takes cubes of bricks loaded by stillage truck or fork-lift truck, and is usually equipped with a system of hot air supply capable of forcing the drying air into the dense pack setting.

Chamber drying is a batch process. The bricks are set in the chamber, the hot air put on and exhaust permitted according to a prearranged schedule. At the end of drying the heat is switched off and the bricks withdrawn. The simplest corridor dryer has hot air admitted at the bottom at one end and exhausted at the top at the other. It may have steam tubes below the floor for additional heating. One defect is that drying rates in different parts of the chamber differ; thus drying times have to be increased to ensure that all the bricks are dry.

Modern corridor dryers are interconnected so that exhaust air from chambers nearing the end of the drying cycle, which is at a comparatively low temperature and high humidity, can be passed into a chamber of freshly set bricks. As drying proceeds more fresh hot air and less recirculated air is admitted until eventually all fresh hot air has been used to complete the drying. A further improvement is the recirculation of air within individual chambers. In recent dryers the direction of air flow can be reversed at chosen intervals of time. This improves the uniformity of drying.

Pack dryers meet the need to dry the packs of bricks made by mechanical setting machines for transport by fork-lift or stillage truck to the kilns. The problem of getting air to the centre of the pack is overcome by using special fan units of the Rotomixair or Reciprojet type within the dryer chamber that circulated hot air (admitted to the fan unit through the crown of the chamber) at high velocity in such a way that the bricks are subjected to intermittent drying. The volume of hot air entering a particular chamber can be regulated, and if the bricks are difficult to dry the air can be recirculated in the chamber at the beginning of the drying cycle with no hot air entry or exhaust.

Modern chamber dryers are highly controlled, sophisticated plants that permit drying with no waste at all. The total heat requirement for drying need be no more than about 2,000 Btu/lb of water evaporated, giving an efficiency of about 50 per cent.

Tunnel dryers

Tunnel dryers provide a continuous drying process. The ware, set on cars, moves progressively through increasingly rigorous drying conditions from the entrance, or "wet end", to the exit, or "dry end". In the counter-flow type of tunnel the bricks travel in the opposite direction to the air flow. The hot air entering at the dry end at perhaps 180°F picks up moisture in drying the bricks and is exhausted to atmosphere as saturated air at 90°F at the wet end. The heated air is provided from an external source but may be supplemented in older dryers by steam pipes in the floor.

This simple statement hides the many difficulties involved in operating tunnel dryers successfully. Hot air should be fed in, not at a single point at the entrance to the tunnel, but rather bled in by means of a tapered duct in the floor in progressively smaller volumes over as much as one third of the length of the tunnel. The duct is set between the rails on which the cars move, and in this way the natural tendency of the air to rise immediately to the roof of the tunnel and flow horizontally is partly offset. Hot air is forced to rise up through the setting over a greater number of cars and hence to maintain the drying potential of the air over a greater distance.

Even so it is difficult to force the air to pass through the setting rather than around the sides and tops of the cars, although rather better air distribution is obtained when the bricks are set on pallets on rack cars rather than castled in even an open pack setting. Facing bricks are often set on pallets to prevent the damage that may arise in an eight to ten course castled setting, and any bricks made too soft to withstand the weight of superimposed bricks must be set on pallets. To improve the distribution the velocity of the air can be increased and the efficiency of drying maintained by recirculating air, taken off at the crown at the mid point of the tunnels to a secondary duct in the floor. Alternatively, fans may be arranged to provide cross flow of air. All the systems are devised to increase the contact of the drying air with the moist bricks and to provide control over the rate of drying throughout the tunnel in order to avoid drying conditions that would cause the bricks to crack.

The high velocity intermittent air flow fan units of the Rotomixair or Reciprojet type mentioned in connexion with chamber dryers may also be used in tunnel dryers to provide an inexpensive and simple zone dryer.

Even when the temperature distribution in a tunnel is the optimum and all the tunnels in a set are balanced, it is still easy to produce waste by faulty filling and emptying. [22] A schedule should be drawn up so that each tunnel receives the same number of cars, and only one dry car is drawn from a tunnel at a time. Otherwise, freshly set cars might be pushed so far forward as to be immediately subjected to temperature and humidity conditions that would not normally be reached for several hours.

Tunnel dryers should be fitted with doors at both the dry and wet ends. Provision must then be made for exhaust, either by means of a reek stack in the roof, which operates on natural draft at the wet end, or by exhaust fans, which draw the wet gases down to a duct at ground level at the same place. Because the temperature of the bricks entering the tunnel is lower than the temperature of the saturated exhaust gases, condensation may occur until the bricks warm up. The exhaust system is therefore often placed one or two car lengths in from the wet end. Where bricks are especially sensitive to condensation separate provision may have to be made to warm them up at this point by steam or hot water pipes.

When bricks are set directly onto tunnel-kiln cars a form of tunnel dryer is required to reduce the moisture content to about 2 per cent to 3 per cent for entry to the pre-heater section of the kiln. While a separate "conditioning chamber" may be provided for the storage of set cars and the reduction of the making moisture content by a few per cent, the main drying is usually carried out in a dryer section forming a part of the tunnel kiln.

Comparison of hot floors, chamber and tunnel dryers

All methods of drying except direct setting onto tunnel-kiln cars involve double handling in placing the bricks onto a car or pallet and removing them after drying for setting in the kiln, but hot floors have the distinction, shared by hacks, of requiring three handlings of each individual brick. If the movement of the pallets of ten or twelve bricks from the cutting-off table to the wheeling barrow, or the alternative case of placing packs of three or four bricks onto a standard crowding barrow for transport to the drying floor is included, there are four separate handlings. Since on traditional works of this kind the setters usually also wheel from the floors to the kiln as a relief from constant work inside the kiln, a skilled man is partly employed on what should be an unskilled task.

For the same output hot floors are less extensive than hack grounds in temperate climates, since the setting density is about the same (6/ft^2 at finger space on floors and 5-6/ft^2 over-all in hacks), while the drying time is only about a third or a quarter. The labour for wheeling and putting down and picking up and wheeling is therefore less, a total of about 3 m. h./1,000.

Modern chamber dryers with automatic pallet loading and unloading require only one finger-carman for outputs of 8,000/h so that the labour at 0.12 m. h./1,000 is minimal. In the traditional Keller form with ascender, hand-trammed finger-car, and descender unloaded by hand and wheeled on carousel cars to the kiln, for 4,000/h two finger-cars are required, with two men handling carousel cars to the kiln and two returning pallets and cleaning up. This gives 1.5 m. h./1,000.

For tunnel dryers, setting on pallets requires 1 m. h./1,000 and castling somewhat less, about 0.8 m. h./1,000. Machines are available to perform both these operations, and the labour content can be reduced to less than 0.2 m. h./1,000. Dryer cars may be set in the tunnels and dry cars taken to the kiln fork-lift truck for 0.25 m. h./1,000 or less, but hand-tramming requires 0.5 m. h./1,000. At best the process needs less than 0.5 m. h./1,000, while the traditional method needs 1.5 m. h./1,000.

Thus with high capital investment modern dryers have a negligible labour element. Traditional tunnels and chambers are about half hot floors. The more important comparison, however, is in thermal efficiency.

Table 11 gives some comparisons of good and bad dryers as quoted by Macey [23] together with typical values for good modern chambers and tunnel dryers from data provided privately by Ford.

The best hot floor is very little more efficient than the worst tunnel dryer. This is mainly due to the high proportion of heat used to heat air rather than to evaporate water; therefore a good tunnel or chamber dryer must always have an efficiency at least twice that of a good hot floor.

While the efficiencies of good tunnel and chamber dryers may be the same, the reasons for low efficiency are different. In a tunnel dryer the heat losses are low, but operation may be carried out at such a low temperature that large volumes of air are needed. In a chamber dryer the drying may be efficient, but the heat losses enormous owing to inadequate supervision, with such results as heat being left on in empty chambers, and badly fitting doors.

With respect to both labour and fuel efficiency hot floors are more expensive than other dryers. Nevertheless, it should be noted that they are cheap and simple to build—if they are of the underfloor flue type—and hence for intermittent operation they have certain advantages that expensive capital installations lack.

Roofing tile dryers

More care is needed in drying a thin slab than one more nearly a cube. With roofing tiles changes of shape, changes of section at nibs, and the presence of nail holes are all areas of weakness where distortion or cracking may occur. Shaping and drying to produce a camber raises yet more difficulties. In Great Britain tiles are set in kilns either leather-hard or white-hard, depending upon the type and the area in which they are made. The preponderance (70 per cent in 1952) of plain tiles, mainly machine-made of nominal size $10\frac{1}{2} \times 6\frac{1}{2} \times \frac{1}{2}$ inch, led to the continued use of hot floor dryers on which these tiles were dried in bungs. In Europe, on the other hand, the predominance of the single-lap tile led to drying singly on pallets, first in open-air or open-shed natural rack dryers and later in chamber dryers.

Table 11

Comparative heat requirements (Btu/lb of water evaporated) for different types of dryer

Process	*Macey*						*Ford*		
	Hot floor		*Chamber*		*Tunnel*		*Chamber*		*Tunnel*
	Good	*Bad*	*Good*	*Bad*	*Good*	*Bad*	*Corridor*	*Pack*	
Evaporating water	1,000	1,000	1,000	1,000	1,000	1,000	1,050	1,050	1,050
Heating air	2,000	3,000	600	1,000	600	2,000			
Heating bricks	50	50	70	70	70	70			
Heat losses from dryer	1,000	3,000	200	3,000	200	1,000			
TOTAL	4,050	7,050	1,870	5,070	1,870	4,070	2,690	1,950	2,280
Efficiency percentage	25	14	53	20	53	25	39	54	46

Historically in the North Midlands of England hot floors were used to remove only sufficient moisture from tiles made by the roller-bat process to permit them to be set in the kilns in high, bung settings. Drying in unheated ventilated sheds often took six weeks to remove five per cent of the moisture. Elsewhere the tiles were dried white-hard on floors and set on edge in the kilns. The tiles were not set directly on the floor but on cambered boards or bricks. Three to four per cent of badly cracked or broken tiles was not unusual in these systems, and minor cracks at nibs and nail holes might bring the total to between seven per cent and nineteen per cent dryer waste in bad cases.

Large sheds with sides open, or closed with hinged shutters or chequered brickwork, were used to dry single-lap tiles. Racks were installed just wide enough to take the maximum size of tile. The usual arrangement was to have a single rack against each long wall and one to four double racks inside separated by gangways five to six feet wide in which the tiles were made on hand-operated mobile stupids. The tiles were dried to the white-hard stage in four to twenty-eight days depending on their shape and whether artificial heat was supplied, factors that determined the rate at which they could be safely dried. Setting the tiles singly on racks meant that they could be dried more quickly than plain tiles in bungs.

The floor area covered by the racks amounted to no more than 30 per cent of the total roofed area, so that heating by hot water or steam pipes under the racks even when supplemented by hot air from the kilns tended to be expensive in fuel at about 2.3 cwt/ton (cwt = hundredweight = 50.802 kg).

A variant of these dryers was the drying of tiles set singly from four to ten tiles on cambered or flat trays. These trays were stacked up to 30 high on hot floors, kept apart by wooden lugs at the end of each tray. Drying was finished off on the cambered trays, but those set on flat trays were removed after a few days, cambered, and set in bungs on the floor. Tiles dried by this second method were found, not unnaturally, to have a higher incidence of cracking and distortion. The floor area needed for drying singly on trays was no more than that required for drying in bungs because of the faster drying time achieved.

Chamber dryers provide the most effective method of drying tiles, since the schedule can readily be adapted in individual chambers to suit the different patterns of tiles that make up the output of a normal works. Even so it may still be economic to dry special tiles naturally on racks adjacent to the making place.

In tile production waste is a critical factor. Attention to drying is therefore vital, and usually the problem is to dry uniformly. The traditional solution is to dry slowly using mainly natural heat sources; but even when tiles are dried singly on racks, cracking and distortion are by no means eliminated. The modern solution is not only to have adequately instrumented and intricately controlled chamber dryers, but also to invest considerable resources in clay preparation and large-scale storage and souring facilities followed by intensive secondary preparation and carefully controlled making. In Switzerland the same company has built a new tile plant and a new brick plant. Both are highly mechanized and efficient. The capital cost of the tile plant was twice that of the brick plant when both were brought to equivalent output.

V. Firing

THE ACTION OF HEAT ON CLAY

THE PROCESS of manufacture of ceramics has been described in these words: "Minerals of inconstant composition and doubtful purity, when exposed to immeasurable heat long enough to carry unknown reactions partly to completion, form heterogeneous non-stoichiometric materials known as ceramics."[24]

There is a basic truth concealed beneath the wit. Heavy clays are heterogeneous materials, and the process of preparation and making is an attempt to homogenize the gross disparities. But physical discontinuities are impressed by shaping, and in pressing and extrusion a polished skin is formed with properties different from the bulk of the piece. The first action of heat in drying is to remove some, often most, of the mechanical water, and this may cause cracks. The removal of the last traces of the mechanically held water is the first stage in firing proper. Throughout the process of raising the temperature to between 950°C and 1,150°C and cooling back to ambient temperature, the clay is subjected to a series of changes in its physical properties, while complicated chemical reactions occur both within the separate mineral constituents and between the different minerals.

During all this time, size changes occur, first by thermal expansion, later by contraction caused by a reduction in the pore volume on sintering and partial vitrification, then by changes in the number and size of the pores and eventually, if the temperature is allowed to rise too high, by melting caused by the formation of a complete gas phase.

Since the piece is of finite size, there is a time lag in the transference of heat between the centre and outside. The magnitude of this lag depends on the ratio of surface area to volume. With the same time temperature schedule, different effects are produced depending on whether the shape is a brick or a tile. Thus the same volume of clay, 108 in^3, will produce a brick of 9 in × 4 × 3 with a surface area of 150 in^2 or a tile of 24 in × 9 × ½ with a surface area of 465 in^2.

It is usual to speak of firing temperature because this is a convenient measurement to make, but the one usually taken is that within the gas flow at the crown of the kiln. This crown temperature is used as a relative indication of the progress of firing and a comparative measurement of this particular firing versus some arbitrary standard. Rarely do such temperature measurements yield any information about the temperature distribution in the kiln, and even in tunnel kilns differences of 100°C from top to bottom or inside to outside of the setting are by no means unknown.

The measure of the efficacy of firing is the heat work done. In a sense the properties of the fired object are a measure of this, but because the composition of each piece, indeed each part of each piece, varies, this information cannot be used for absolute comparisons. Heat work recorders are available, however, in the form of Bullers rings, Holdcroft bars and Seger cones. These provide a relatively accurate representation of the combined effect of time and temperature on the body of constant composition from which they are made, and hence by inference on the ware at that point.

The most important change in physical properties is the development of strength, which renders the shape permanent. When clay has been fired above about 600°C, its plasticity is destroyed and it can no longer be broken down in water.

Much higher firing temperatures are required, however, before the clay will resist the effects of long-term natural weathering. For most clays a firing temperature of 950°C is a practical minimum for acceptable durability. As the firing temperature is increased, more recrystallization of mineral species takes place, and glass and closed pores are formed. If a building clay can tolerate a temperature of 1,100°C or more without melting out of shape, then a high-strength product with low water absorption is likely to be produced which, in the case of a brick, will be of engineering quality.

The chemical and mineralogical changes that take place on heating are those of dehydration, oxidation, recrystallization and vitrification, and those important in affecting the firing process are summarized in figure 29. Stage I is the continuation of the drying process by the removal of the last traces of mechanically held water. Stage II starts at 150°C, and water combined in the montmorillonite

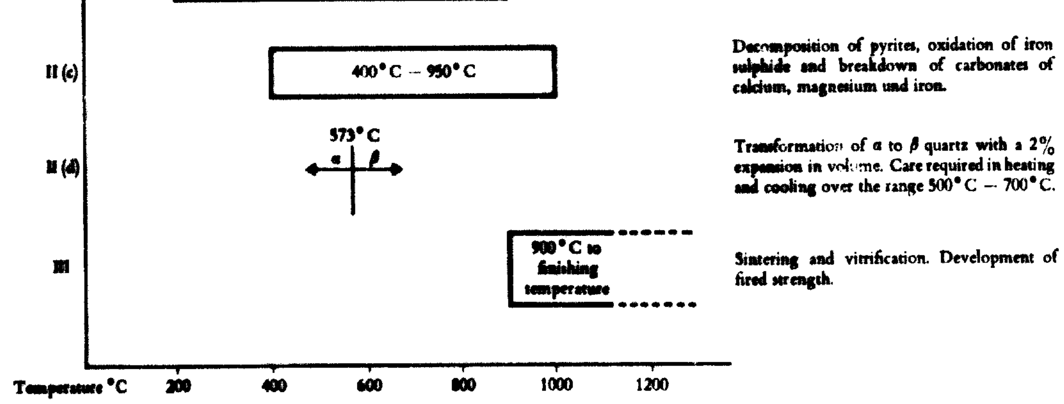


Figure 29. Action of heat on heavy clays

clay minerals starts to come off, at 200°C that combined in illite, and at 400°C kaolinite starts to decompose and may continue to 850°–900°C. Stage II(b) represents the range of temperature over which carbonaceous material is oxidized. To accomplish this, excess air must be present and sufficient time allowed for the reaction to complete. The decomposition of sulphites and carbonates occurs in the same general range. The evolution of sulphur gases may cause bloating unless time is allowed for oxidation before the surface has vitrified.

Stage II(d) is the very important α/β quartz change, which causes expansion at 573°C. This volume change is reversible and takes place again on cooling, and care is necessary to prevent dunting. In practice the heating and cooling rate should be reduced between 500°C and 700°C.

Stage III is the stage of sintering, when particles begin to coalesce at their points of contact, and some vitrification starts. The amount of glass formed depends upon the quantity of fluxes, lime, magnesia, soda, potash and ferrous oxide present in the clay.

To accommodate these reactions the process of firing is broken down into four stages, three of which are shown in figure 29.

Stage I is water smoking, or slow heating. The temperature of the kiln is gradually increased, and only when the bottom of the setting reaches 120°C is the process considered complete. At this time the crown gas temperature may be 300°C. The time taken in this stage depends upon the moisture content of the ware as set, but any sudden increase in temperature or too rapid an over-all rate of rise in temperature will result in cracking. Large volumes of excess air 1,000 to 1,500 per cent are admitted in the early stages to prevent condensation in the cooler parts of the setting and possible scumming.

Stage II is the pre-heat. If heating is carried out too rapidly steam may persist to temperatures at which it prevents oxygen from reaching the goods to complete the oxidation reactions, thereby causing discoloured, black-cored or bloated goods.

Stage III is full fire. As soon as the oxidation reactions are complete the temperature can be rapidly raised from 900°C to the finishing temperature, which varies with the raw material but for most building clays is a maximum of 1,150°C. The top temperature is held for a period to "soak" the goods. Essentially this is to ensure as far as possible uniformity of temperature throughout the chamber, and hence to minimize variation in the properties of the bricks.

Stage IV is cooling. This was traditionally allowed to take place at the natural rate, but the removal of hot air accelerates cooling. With most products cooling can be very rapid from finish of fire down to 700°C. Care is then taken over the quartz inversion period down to 500°C, when the cooling rate can again be increased.

The fired colour is affected by the firing conditions. Red products require oxidizing conditions. Blue products are produced by applying reducing conditions at about 1,000°C continuing until top temperature is reached and subsequently oxidizing on cooling. Alternate oxidizing and reducing conditions produce variegated effects. Basically the colour may be attributed to the iron oxide in the clay. With high iron 5 to 9 per cent, low alumina 10 to 22 per cent and negligible lime all shades of red are produced, with darker reds at the higher temperatures. When the CaO : Fe_2O_3 ratio exceeds 2.0 (that is in high lime clays or when lime is purposely added), cream and yellow colours can be obtained under oxidizing conditions. When the ratio is 1.5 : 1.8, yellow bricks are produced by a reducing period at 900°C to 1,000°C followed by oxidation. A moderate iron oxide content of 1.5 per cent to 3.0 per cent with about 25 per cent alumina gives buff colours. Fairly pure high alumina clays with low iron oxide give cream colours under oxidizing conditions at high temperature.

TYPES OF KILNS AND METHODS OF FIRING

Table 12 is a classification of the main types of kilns.

Intermittent kilns

Updraught, temporary structures

The clamp is the most ancient and most widely used method of firing, to which the addition first of side walls and later crown has led directly to the modern intermittent kiln. At its simplest it is a dense setting of bricks with fuel between the courses, which is lit at one end and left to burn progressively—and often haphazardly—to the other end. In England clamps are still used to fire stock bricks for the pleasing multi-coloured effects achieved by the random oxidation/reduction conditions during firing.

In this industry the clamps are large, containing one million bricks or more. The bricks themselves have added fuel, originally "town-ash", the carbonaceous residue of town refuse left to rot in city rubbish dumps, but now more usually coke breeze.

The floor of the clamp is saucer-shaped on bare earth, and on this a base course of spaced fired bricks is placed with coke or coarse breeze between followed by a layer of fine breeze. Above this, dry green bricks are set to a height of ten feet or more, with three courses of fired bricks at the top and sides. Narrow flues some eighteen inches high and three inches wide running down the length are left every three or four feet across the width. To ignite the clamp, fires are lit at one end by these flues so that the combustion gases travel into the clamp base and set it alight. At this point the ends of the flues are sealed and the clamp left to burn out, a process that takes weeks or months depending upon the size of the clamp. Frequently setting is still proceeding at one end while the other is firing, and conversely bricks are drawn from one end while the other is still burning.

The building of a good, tight clamp is an art, but once lit the results depend mainly on the weather, especially the strength and direction of the wind. For protection permanent side walls and roofs are built, even in some cases a wall at one end as well. A roof is, of course, essential for setting in other than dry weather. Nevertheless, although the proportion of first- and second-quality bricks may be increased, "place", or underfired, bricks are always found at the sides and top where heat losses are greatest, and overfired bricks, "roughs", or even melted-together bricks, "burr", are found in areas of gross overheating.

Table 12

CLASSIFICATION OF KILNS

Intermittent	*Semi-continuous*	*Continuous*
Updraught	Semi-continuous	*Annular* (moving fire)
(a) Temporary structures:		Barrel, or longitudinal, arch
Clamp		Transverse arch (chamber) kilns
Scove kiln		
(b) Permanent structures:		*Car tunnel* (moving ware)
Rectangular		
Round		
Horizontal draught		
Rectangular		
Downdraught		
Rectangular		
Round		

Despite the low yield of good bricks, clamps have advantages beyond the attractive colours produced. No structure requiring capital for its construction is necessary, and complete flexibility of size is possible. In rural works, clamps holding only 10,000 bricks may be made, and 50,000 to 100,000 is common. Indeed, on works with covered clamps when trade is good it is usual to increase output by building uncovered clamps on spare ground in summer. When trade is slack, unlike continuous kilns, which must be drawn at the due time, clamps can be left as a store of bricks. Works still exist where the first bricks were burnt in clamps and used to build the first permanent kiln.

The scove kiln is a form of clamp in which transverse fire flues extend across the kiln twelve to eighteen inches wide, ten to fifteen courses high on centre lines about three feet apart. A kiln of typical size is 60 bricks wide (40 feet), 100 feet long and 50 to 60 bricks high, holding over one million bricks. As with clamps, permanent side walls and a wall at one end may be built, but when there are no such walls the sides and ends are built of place bricks. The kiln takes its name from the practice of "scoving", daubing the outside with wet clay to make it airtight. The kilns are fired with wood, coal, oil or natural gas. With coal a grate is necessary, and permanent fire arches are sometimes erected to hold the grates.

Scove firing has been extensively used in the United States to fire common bricks set and drawn by large forks on an overhead crane. The same problems of non-uniformity of firing arise as with clamps, but it is an effective method of cheaply producing large outputs of low-grade bricks.

Updraught, permanent structures

Updraught kilns are in common use in different countries and are usually given local names. These kilns have permanent walls with fire-holes in the side walls at or below ground level. The hot gases pass up through the goods and are exhausted at the crown in the same way as in a clamp. The most primitive type, called in Great Britain the Scotch kiln, dates back to Roman times. It is simply four walls with fire-holes in the side walls connected by fire flues left in the base of the setting and a hole in each end wall as a wicket. A typical size is about 30 by 15 feet wide by 12 to 15 feet high. The top of the setting is normally covered with burnt bricks and a layer of ashes or earth, but there is a modification in which a permanent crown is provided with a number of small holes for exhaust.

The Suffolk kiln has fire-holes below kiln-floor level, so that the gases rise through a chequer brickwork floor of the kiln, exhausting through a number of crown openings. Stack kilns are a round variant with a brickwork cone rising above the kiln top. This produces some draught to exhaust the gases passing up through openings in the crown.

Updraught kilns have the advantage of having no permanent stacks or flues, and hence low capital cost. Control of the firing process is minimal, but updraughts must be considered less efficient than downdraughts.

Horizontal draught

Frequently called Newcastle kilns, they are simple rectangular chambers, fifteen feet long, with an arched crown, fire-holes at one end and exhaust ports at the base in the other. Double-ended kilns (figure 30) are twice the length and have a centre exhaust flue to stack. Since access to the side walls is not required, Newcastle kilns can be built in batteries side by side. This makes for cheaper construction. Although the draught is intended to be horizontal, the hot gases tend to rise to the crown and descend again to the exhaust ports so that the bottom of the setting tends to be underfired and the top overfired.

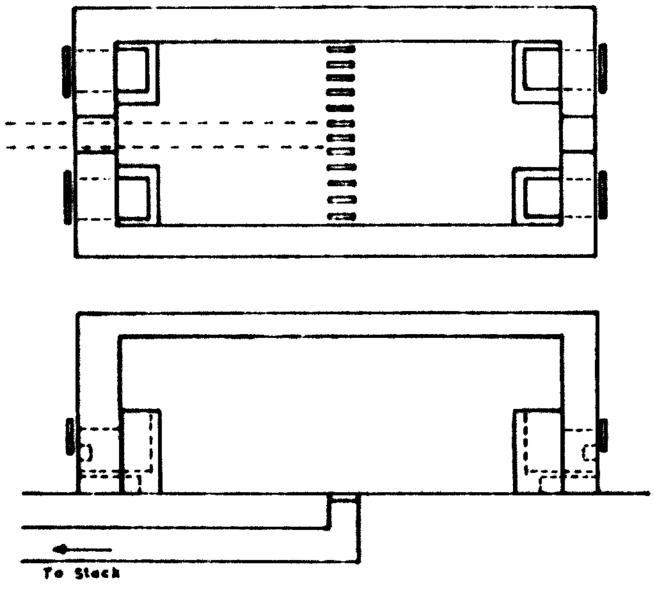


Figure 30. The double-ended Newcastle kiln [30]

Downdraught

Round or rectangular downdraught kilns are the most popular form of intermittent kiln. Capable of high-temperature operation, they are used to fire facing and engineering (including blue) bricks, roofing tiles, floor quarries, land drains, sewer pipes and refractory goods. They are more efficient than updraught kilns, and more flexible, though less efficient, than continuous kilns.

The hot gases rise from the fire-holes in the side walls or periphery through "bags" to the crown and then pass down through the setting to openings in the kiln floor that connect to flues and thence to stack (figure 31). The size of the kiln and the size and number of fire-holes depend upon the capacity, which may vary from 10,000 to 100,000 bricks, but is more usually around 50,000 bricks, or about 100 to 150 tons of ware. Rectangular kilns are easier to set, but need to be of substantial construction held rigid with buckstays and tie-rods. Even then the roof life is shorter than that of round kilns. Round kilns have a regular distribution of fire-holes and hence heat, but they still need to be banded with steel bands to

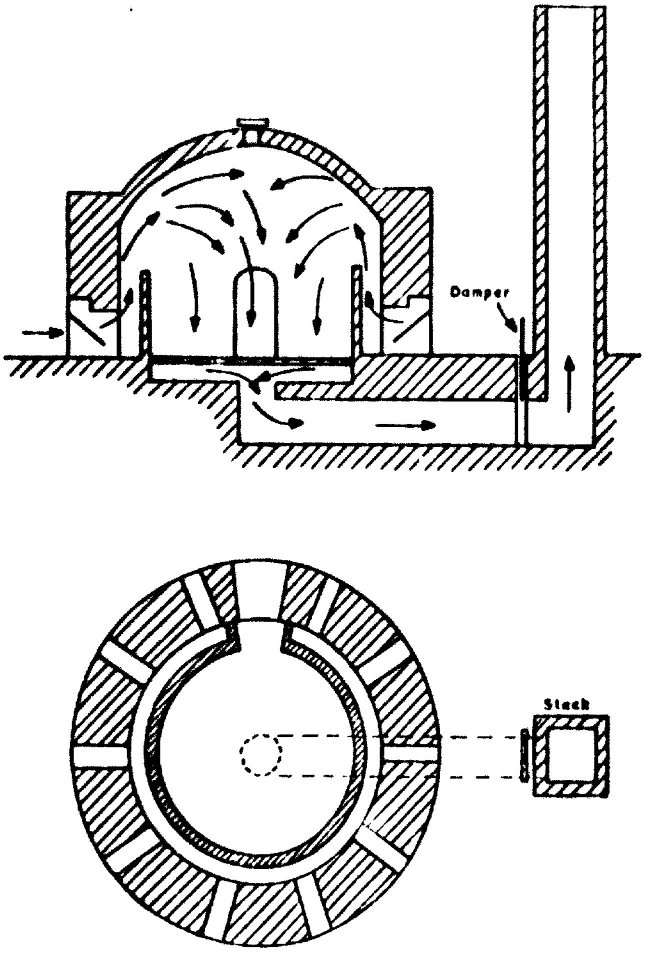


Figure 31. Round downdraught kiln [30]

prevent distortion and cracking of the structure caused by the thermal expansion and contraction associated with repeated firing and cooling.

Despite their high fuel consumption, two or three times that of a comparable continuous firing kiln, intermittent kilns continue to be used for their flexibility, which permits them to be fired to any schedule and also allows the atmosphere to be adjusted between oxidizing and reducing and for their convenience in enabling the number of firings to be adjusted to the demand for the product. The smallest continuous kiln has an output of 60,000 per week, and the more usual size is 100,000 per week, so that for very small works or for small outputs of several different products intermittent kilns are valuable.

Semi-continuous kilns

A semi-continuous kiln may be regarded as five or more rectangular intermittent kilns built side by side as a series of interconnecting chambers. Fire-mouths are provided in the first chamber to raise the goods to the finishing temperature, and during this time the hot exhaust gases are taken forward to dry and pre-heat the ware in subsequent chambers. When the temperature is sufficiently high in the second chamber it is top fed with fuel, and the fires in the first chamber are allowed to die out. The firing zone continues to move forward with top feeding until the last chamber is reached, and from this the gases are exhausted to stack. If the number of chambers is small, the kiln is then drawn completely, re-set and firing started again at the first chamber.

The size and number of the chambers may be varied to suit the production requirements, but the transverse arch construction permits large chambers to be built if required. Semi-continuous kilns, 80 chambers long with five firing circuits, have recorded outputs of one million bricks per chamber per year. These large kilns have fuel consumptions approaching those of continuous kilns, but small kilns of five chambers show a fuel saving of only about 15 per cent over intermittent kilns.

Continuous kilns

In continuous kilns the process of firing is not interrupted. At any time green bricks are being set at one part of the kiln and fired bricks drawn at another, while fuel is fed to the firing zone. This description is true of both types of continuous kiln, those in which the fire moves while the ware is stationary and those in which the ware moves and the fire is stationary.

It has been noted earlier that the continuous kiln is the most efficient way of firing. Intermittent kilns lose 30 to 50 per cent of the heat input in exhaust gases passing to the stack at temperatures that at the end of firing may reach 800°C to 1,000°C. A further 30 to 40 per cent is contained in the ware and kiln structure at the end of firing to be lost to atmosphere in cooling unless a separate system for recovering waste heat is installed. The operation of continuous kilns, however, is such that the combustion gases pass through the pre-heat zone to exhaust, thus progressively warming up the unfired ware before passing to stack at no more than 100° to 200°C. Air for combustion is pre-heated by being drawn forward through the cooling goods, thus recuperating heat that would otherwise be lost. As a result of these operations fuel consumption for a continuous kiln is only a half to a quarter that required to fire the same product in an intermittent kiln.

There are two broad categories of moving-fire kiln: longitudinal or barrel arch, and transverse arch. This refers to the construction of the chambers, which in the longitudinal arch, for example, a Hoffmann, are a continuous tunnel only notionally split into chambers by short drop arches in the crown and distinguished by the separate wicket entrances providing access to each one. In the transverse arch kiln the long axis of the chamber is at right angles to the direction of flow of the gases, and these are allowed to pass forward through openings in the inter-chamber walls. In both cases twelve chambers are a minimum and sixteen or over more usual.

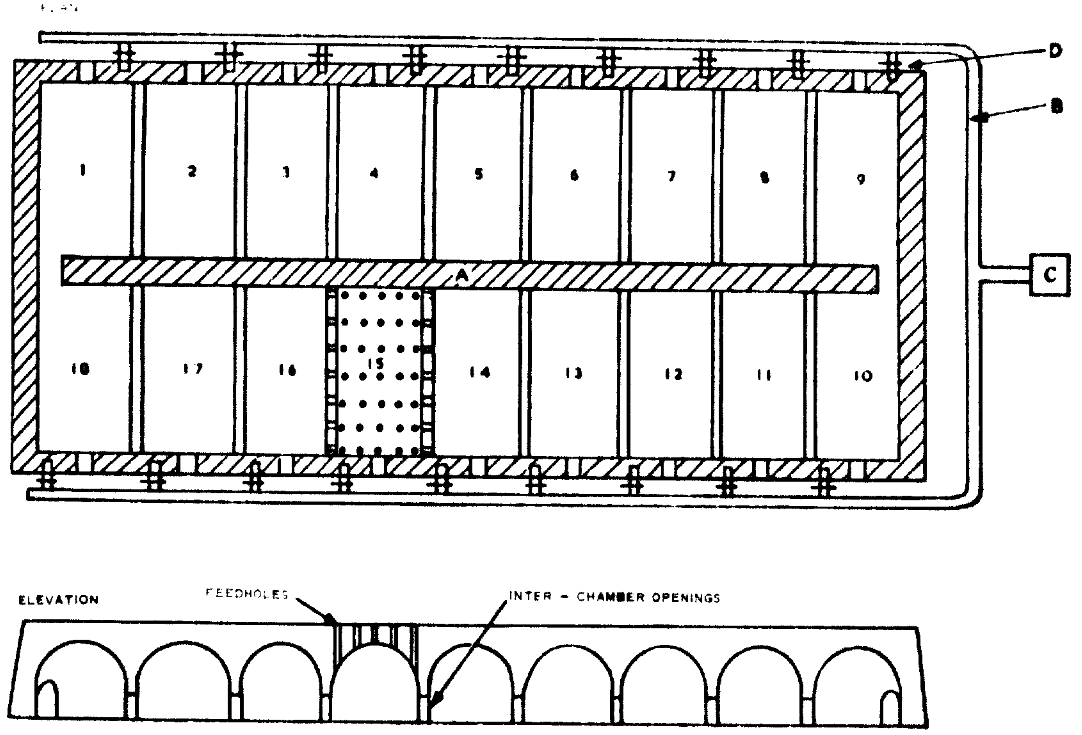


Figure 32. Eighteen-chamber transverse arch continuous kiln [30]

An eighteen-chamber transverse arch kiln is shown in figure 32. The main flue *(B)* is shown around the outside of the kiln below ground level although more often this flue is in the centre wall *(A)*. Each chamber connects to the main flue via a damper *(D)* and hence to the stack *(C)*, which may be 120 to 140 feet high. The whole cross-section of the chamber forms a large wicket providing access for setting and drawing. It is sealed during firing by a brick wall built and demolished at each cycle.

Figure 33 is a representation of the firing cycle with the chambers drawn in one line. From the three chambers under fire, 8, 9, 10, the products of combustion travel forward pre-heating the chambers 11, 12, 13, 14 before passing to

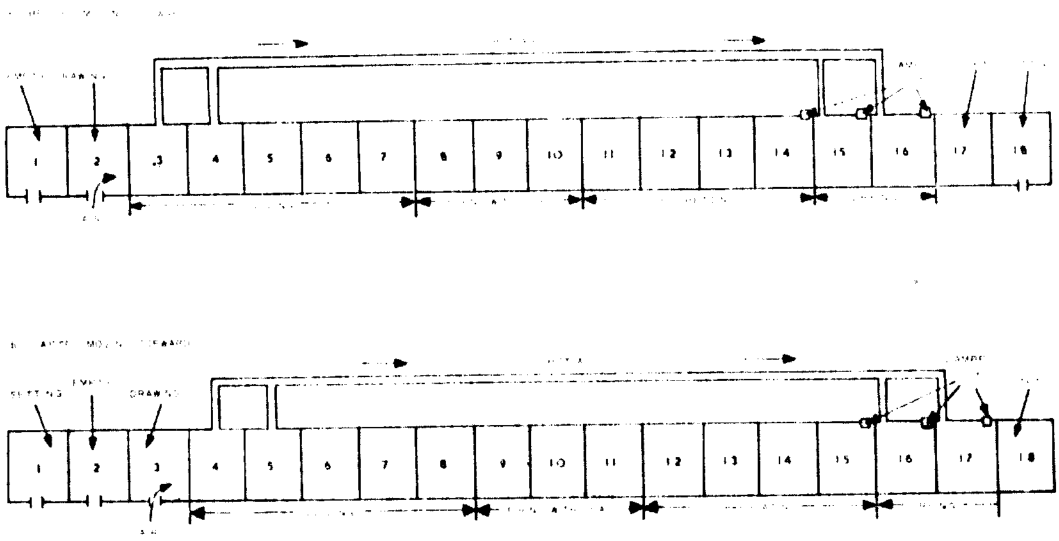


Figure 33. Diagrammatic layout of the working of an annular continuous kiln [30]

exhaust through the open damper of chamber 14. Chambers 3, 4, 5, 6, 7 contain fired goods cooling. Cold air enters through the open wicket of chamber 2, which is being drawn. It travels forward cooling the fired ware and itself heating up to provide hot air for combustion of the fuel being fed in the firing zone. The forward travel of the air from chamber 2 towards chamber 14 depends upon the pull of the stack through the open damper at chamber 14.

To dry stiff-plastic and semi-dry pressed bricks set directly in kiln, hot air is withdrawn from the cooling chambers into a hot air flue in the centre wall and passed forward to the drying chambers in front of the pre-heat. In figure 33 dampers have been opened to connect chambers 3 and 4 to the hot air flue, and the exhaust dampers opened on chambers 15 and 16 so that stack draught will pull the hot air forward. In this way the goods are dried with clean hot air before the products of combustion are subsequently allowed to reach them. The openings in the interchamber walls are papered over on the forward side in chambers 15, 16 and 17 to prevent in-leakage from the open wicket at 18.

When the maximum firing temperature is reached in the appropriate chambers of the fire zone, provided sufficient pre-heat has been achieved in chamber 11, the whole system is moved forward as shown in the lower diagram.

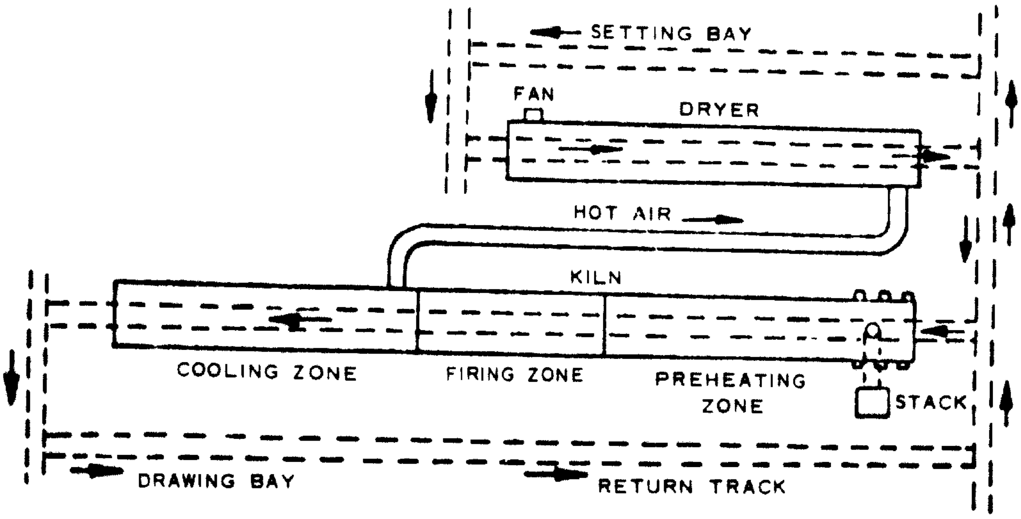
Most longitudinal and transverse arch kilns are built with round arches, but flat-arched kilns of both types have been built to simplify setting packs of bricks with a fork-lift truck. Considerable savings in labour are achieved in this way, provided the clay does not distort sufficiently to prevent the packs from being drawn in the same way.

The other category of continuous kiln, moving-ware or car tunnel, consists of a long tunnel through which pass refractory-topped cars running on a pair of rails. Figure 34 is a schematic diagram of a tunnel kiln and associated dryer. The set cars pass through the dryer, are moved to the kiln by a transfer track and enter the pre-heat. They pass through zones of gradually increasing temperature up to the firing zone and are then cooled gradually before leaving the exit. Air is moving in the opposite direction, heated by passing over the cooling ware and thus providing heated combustion air. In addition part of this cooling air is taken off to the dryer. The exhaust gases from the firing zone are pulled forward by a fan to exhaust ports near the entry end, heating the green ware en route.

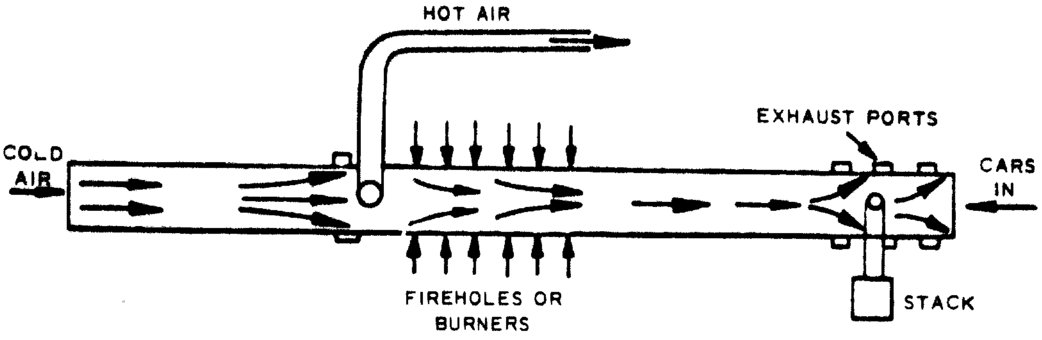
These general descriptions define the categories of continuous kiln, but within these categories there is a variety of kilns providing different firing conditions and top temperatures, and different degrees of control.

Top-fired barrel arch kilns

The best known is the Hoffmann kiln, developed as a twelve-chamber circular kiln with centre chimney in 1858 in Germany but later changed to elliptical form to achieve increased length. As mentioned earlier, this kiln can be said to have changed the whole technology of heavy clay manufacture in Europe, thus



[a] CAR TUNNEL KILN AND DRYER



[b] CAR TUNNEL KILN SHOWING GAS FLOW

Figure 34. Layout of tunnel kiln and dryer [30]

making possible the great expansion of the common brick industry in Britain in the nineteenth century. Fuel is fed from the top through a number of small feed-holes in the crown, usually four or five rows of four or five holes. Because no grate is provided on the base the maximum temperature is limited to 1,050°C. The usual output in the United Kingdom is 100,000 to 140,000 per kiln, but in Europe by using high draught conditions to fire perforated bricks or hollow blocks, higher outputs are achieved. The Hoffmann is simple and cheap to construct, with low fuel consumption; but the temperature distribution is not entirely uniform, with weak positions at the wickets, inside wall and usually in the end chambers.

Bull's trench kiln is basically a Hoffmann kiln dug out of the ground, suitable for less industrialized regions. The blades of bricks are set 18 to 20 courses high with a gap between each and longitudinal spaces also left in the setting. About twelve feet of trench forms a chamber, at the forward end of which is a damper opening formed in the side wall of the trench. This connects to a vertical flue on top of which a movable sheet metal chimney about 30 feet high is bolted when a chamber is taken into circuit. Holes are left through the setting to allow fuel to be fed from the top.

The zigzag, or Buhrer kiln, has its gallery length increased by making a zigzag path (figure 35). It is of small cross-section and operates on high draught and a high rate of fire travel so that greater output is obtained. It is widely used in Europe for hollow blocks and interlocking roofing tiles thoroughly dried before setting. The Habla kiln is a zigzag with no crown and the division walls built each time with green bricks. The setting is covered with fired bricks and ash, with feed-holes inserted appropriately.

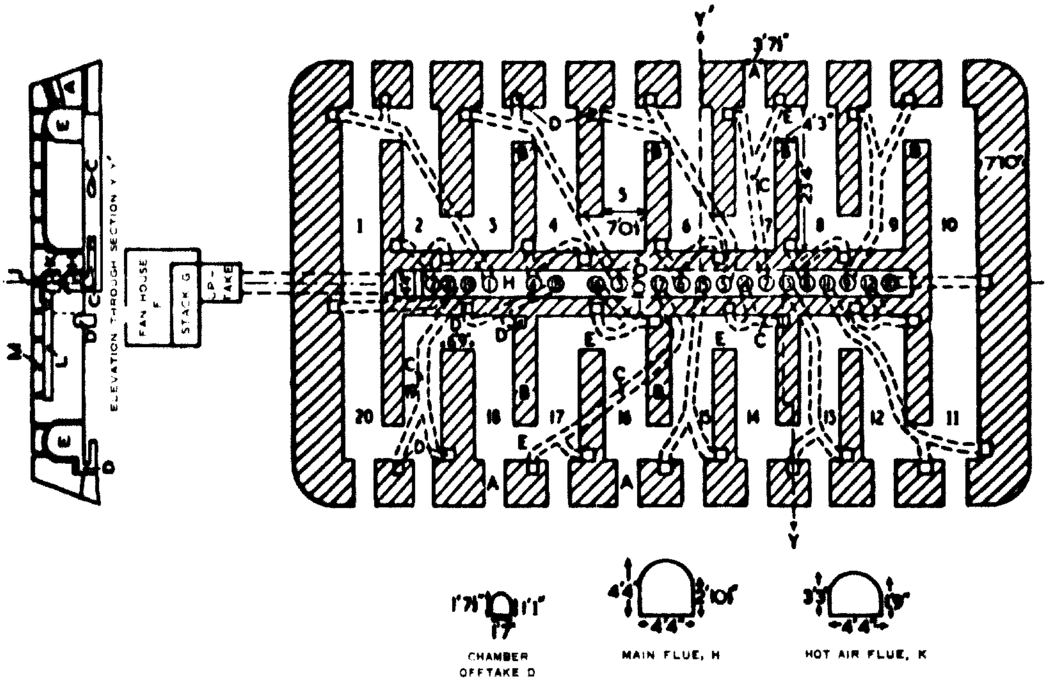


Figure 35. Plan and section of zigzag kiln [30]

Grate-fired barrel arch kilns

The Belgian kiln, and the somewhat similar Ideal kiln, are fed not from the top but through a fire door in the wicket, the fuel being thrown onto a grate extending the width of the kiln with primary air admitted beneath. This permits temperatures up to 1,300° C or more to be obtained and also allows multi-coloured bricks to be produced by partial reduction. The kilns normally have 22 to 28 small chambers holding 6,000 to 8,000 bricks, limited in width by the distance coal can be thrown uniformly onto the grate, and in length by the limitation of heat transfer from the grate. Fast rates of travel are used to give outputs of 80,000 to 150,000 bricks per week.

Transverse arch kilns

The chambers may be larger than barrel arch kilns, with capacities from 8,500 to 70,000 bricks, although the normal range is 20,000 to 40,000 bricks. The Staffordshire and Lancashire types of kiln are fired from the top onto the solid floor of the chamber. In the super-Staffordshire kiln the first row of feed-holes in front of the interchamber wall feeds coal on to a grate extending the width of the chamber with a primary air supply beneath. Two or three further rows of feed-holes feed into the bricks in the usual way. The provision of fenders allows temperatures up to 1,150°C to be obtained, so that the super-Staffordshire is extensively used for red facing and engineering bricks. Without grates the temperature attained is 1,050°C to 1,100°C, slightly higher than a Hoffmann.

Transverse arch kilns have somewhat better control than barrel arch kilns. If control dampers are fitted to the interchamber openings operation of these in the cooling zone will regulate the amount of excess air reaching the firing zone. Because of the extra control these kilns are popular for firing carbonaceous material and are the only type of kiln used for firing Fletton bricks. Fuel consumption is slightly higher than the Hoffmann because the interchamber walls have to be heated on each cycle, and they also tend to slow the fire travel.

Tunnel kilns

Until recently the tunnel kiln has been slow to be adopted in the brick and tile industry in Europe, although some have been in use for over 30 years. They are, however, common in America. The impetus to use tunnel kilns arises from the very much improved labour conditions when setting and drawing are wholly divorced from firing. These operations can be carried out in cool conditions, unlike the intermittent and continuous kiln, where the object is to draw and re-set without allowing the chamber to cool completely. Thus as wage rates rise and labour becomes more difficult to get because of competition from other technologies in an industrialized society, the tunnel kiln becomes increasingly economic. In Great Britain the situation has now been reached that a new brick factory not based on a tunnel is unlikely to be built.

Early tunnel kilns were top fired with coal; modern ones are top fired with heavy fuel oil ar gas, or side fired with the same fuels. The advent of cheap natural gas is likely to swing the balance towards gas firing because of the greater contol and ease of operation. With coal or heavy oil, fuel cannot be fed until the temperature is high enough to ignite it, whereas a small gas flame, or of course a flame of light oil, can be used to bring up the pre-heat.

The ware is set on cars with flues left in the setting. On top-fired kilns the car is pushed forward half a car length at a time so that the fuel burns in spaces left across the car at the mid-car and between-car positions. When a continuous push is used on top-fired kilns, flues are left down the length into which firing takes place. Side-fired kilns fire either into the transverse flues at the half-car positions or with continuous push either into a space below the car deck, or into combustion chambers in the kiln wall so that the gases do not impinge directly on the ware.

The side-fired kiln uses more fuel than the top-fired one, but more hot air is available for drying because on side-fired kilns some combustion air is supplied at the burner and so less cooling air is needed. This combustion air is cold, and more air is used in total, hence the higher fuel consumption. On a top-fired kiln all the combustion air has been pre-heated in the cooling zone.

Besides the better labour conditions, the tunnel kiln lends itself more readily to incorporation within a highly mechanized flow-line production layout. The most highly mechanized plant in the world, the "one-high plant" of General Shale Products Corporation at Knoxville, Tennessee, in which the bricks, set in a single layer on the kiln cars, are not touched by human hand until they reach the bricklayer on the building site, would be inconceivable without a tunnel kiln. Nevertheless, these kilns are highly controlled and to some extent delicate machines, needing considerable expertise to set them up and to keep them running at optimum efficiency. Experience in industrialized countries suggests that only when wage rates rise to the level of affluence are tunnel kilns viable in the brick industry. At that point, however, a properly designed and operated plant using the tunnel kiln is a worth-while commercial proposition, and the product is superior in quality and uniformity to any fired by other methods.

LOW-GRADE FUELS

In the total world energy picture, the consumption of low-grade fuels is small. Brown coal, peat and wood taken together represented only 10 per cent of the total in 1960 as shown in table 13. Nevertheless, for brickworks in developing countries local resources of fuel may be very important, and certainly wood is frequently used in these areas for firing heavy clay products.

Completely dry wood has a calorific value of 7,800 to 9,700 Btu/lb. It is normally used, however, in the air-dried state when its moisture content is up to 15 per cent and the calorific value accordingly lower. When freshly cut, wood may have 25 per cent to 50 per cent moisture. Wood has a low ash content—0.3 per cent to 0.6 per cent compared with 5 per cent to 10 per cent for coal—so no clinker forms on the fire-bars. It burns with a long, clean flame, giving temperatures up to 1,000° C. Larger fire-boxes are needed than for coal, and the consumption of wood is rather more than twice the weight of coal used. Since wood has a high content of volatile matter, about 90 per cent of the combustion air has to be provided as secondary air.

Peat is a recent growth composed of partly rotted vegetable matter. The source is mosses and similar plants growing in marshes in temperate climates. The moisture content varies, but may be 90 per cent, although many peats have a low ash content. Peat is a valuable local fuel in Scotland and Ireland and is important in some other countries, notably Canada, Finland, Norway, the Soviet Union and Sweden. It has been used for firing Scotch kilns, with a saving of some 25 per cent in fuel cost.

Lignite and brown coal are of great importance in many parts of the world including Australia, the Federal Republic of Germany, India, the Soviet Union and the United States. Although the nomenclature varies somewhat in different countries, the deposits may be regarded as forming a continuous series from peat to coal. Lignite may be considered as a more mature solid fuel than peat but with a recognizably woody structure, while brown coal is nearer to true coal. They all crumble on weathering and therefore cannot be stored for long periods. Lignites have a higher moisture content, up to 50 per cent compared with 30 per cent for brown coals. Lignites have a low calorific value, about 6,000 Btu/lb, but are a valuable fuel capable of satisfactorily firing heavy clay products.

Oil and gas firing

Because of their high fuel consumption and the necessity to use the cheapest fuel, the heavy clay industries everywhere traditionally use indigenous fuels and if possible local ones. Thus in Europe coal was everywhere used until the developments in oil refining in the 1950s made heavy fuel oil available at competitive prices. In the United States both oil and natural gas had been used earlier because they were indigenous fuels.

The per therm cost of fuel is not the only outlay. The labour cost of handling and feeding coal to kilns is considerable. As labour costs have risen the heavy clay industry has turned increasingly to heavy oil, not only because of lower handling charges, but also for the cleaner conditions on the kiln top and in the chamber that dust-free, ash-free fuels give. Now that natural gas and L. P. G. (the liquefied petroleum gases, butane and propane) are becoming available, the heavy clay industry is beginning to use them also for their greater convenience and control.

Despite the claims of convenience, however, cost remains a crucial factor. While the cost of fuels varies from country to country, it also varies from consumer to consumer, since the price is fixed in relation to the guaranteed consumption. Nevertheless, it is instructive to compare the per therm costs of various fuels in Stoke-on-Trent, England, in 1962 and 1966, the latest complete figures available (table 14). The rates include appropriate rebates for quantity, and where ranges are given these take account of reductions for off-peak demand.

Table 13

WORLD FUEL CONSUMPTION 1900—1960 [25]

	Millions of coal-equivalent tons				*Percentage of total*			
	1900	*1913*	*1938*	*1960*	*1900*	*1913*	*1938*	*1960*
Coal	701	1,216	1,212	1,956	73.5	76.9	57.4	40.9
Brown coal	28.6	51.5	105.6	257	3.0	3.3	5.0	5.4
Oil	29.3	76.9	390.1	1,503.2	3.1	4.9	18.5	31.4
Natural gas	4.9	22.6	101.3	578.7	0.5	1.4	4.8	12.1
Peat	6.5	6.5	16.6	29.5	0.7	0.4	0.8	0.6
Wood	166.8	164	168	189	17.5	10.4	7.9	4.0
Hydroelectric power	16	43	119.4	265.6	1.7	2.7	5.6	5.6
TOTAL	953.1	1,580.5	2,113.2	4,779.3	100.0	100.0	100.0	100.0

Table 14

Approximate cost of fuels in Stoke-on-Trent 1962–1966 [25]

Fuel	Cost per therm (pence) 1962	Cost per therm (pence) 1966
Coal graded and large	5.8	6.4
slack	4.4	4.7
Coke summer	6.0	8.1
winter	6.7	9.2
Town gas (thousands of therms per year)		
36	–	18.2
100	15.2	15.5–16.6
200	13.6	13.7–14.8
400	12.7	12.8–13.9
600	12.3	12.5–13.6
1,000	–	12.2–13.4
Electricity	29.7–40.5	30.7–69.0
Fuel oil 35 sec (gas oil)	8.7	6.60
200 sec	6.45	5.62
950 sec	5.75	4.78
3,500 sec	5.45	4.51
Paraffin	11.1	8.97
Liquid petroleum gas Butane	appr. 12.1	9.0
Propane	appr. 11.9	

The effect of these price changes can be seen in the changed utilization of fuels in the industry (table 15).

Table 15

Fuel consumption in the production of bricks, tiles, fire-clay and other building materials [25]

(Million tons of coal or coal-equivalent)

	1955	1960	1965
Coal	3.87	2.98	2.18
Coke, breeze and other solid fuel	0.47	0.32	0.24
Electricity	0.25	0.30	0.34
Oil	0.13	0.48	1.27
Creosote/pitch mixtures	0.02	0.03	0.03
Total	4.74	4.11	4.06

It will be noted that four grades of fuel oil, distinguished by their Redwood viscosity expressed in seconds, are given in the tables. The type of oil used depends on the method of firing as well as on the cost. Since price increases as the viscosity decreases, the heavier grades are in most common use. Gas oil is at present used mainly to apply heat at low temperatures, for the water smoking period in intermittent kilns or for boosting the pre-heat on tunnel kilns, but interest is developing in this fuel as an alternative to heavier fuel oils; 950 seconds oil is mainly used on atomizing burners for side-fired tunnel kilns, and for intermittents, although the more expensive 200 seconds oil, which needs less heating, is also used. For impulse or injection burners on top-fired continuous kilns, including tunnels, and side-fired Belgian kilns, 3,500 seconds oil is used.

The firing of intermittent kilns by oil is no easier than firing by coal, indeed at some points more careful control is necessary. Lengthy water smoking requires burners that can be turned down to give a low rate of heating, and if this is not possible only alternate fire-holes are lit. Nevertheless, labour is saved in coal wheeling, feeding and ashing out, and the kilns can be kept more tidy. Maintenance costs are less because there are no fire-bars to replace. The quality and colour of the product may be more uniform, and increased output may be obtained. Against this must be set the capital cost of the installation, the greater care needed to ensure uniform heating at all the fire-holes, and the necessity for regular inspection of the burners and the removal of carbon deposits, which impair burner efficiency. The use of atomizing burners is wholly dependent on the electricity supply; if this fails the system fails.

Top-fired continuous kilns can easily be changed from coal to oil. The first method used was to drip feed oil from small drums through a tap manually adjusted. In this simple system one drum is usually placed over each feed-hole. The rate of flow varies as the temperature of the heavy oil increases because of its location over a feed-hole, and also as the level in the drum falls. An improvement is to pump heated oil through a ring main on top of the kiln with branches to each row of feed-holes through which the oil is again drip fed. Frequent manual alteration of the tap settings to maintain a constant feed rate is necessary in both these systems.

Positive feed systems, that is impulse or injection systems, are an advance over drip feeding. Fuel oil is heated and circulated at high pressure in a ring main from which the oil is injected in measured quantities through lances in the feed-holes. The quantity of oil in a slug, and the number of slugs per minute can be varied to give a wide range of firing conditions. The differences between the available systems lie mainly in the details of the control system used.

Small slugs of oil fed frequently tend to give top heat, while large slugs tend to give bottom heat because some oil reaches the floor of the kiln and burns there. Similarly, hot oil burns at the top of the setting, colder oil lower down. Since this precision is available in feeding fuel, similar precision is needed in temperature measurement and automatic control of the burners by the thermocouple readings.

Most modern tunnel kilns are oil or gas fired. Impulse burners are used with heavy fuel oil for top-fired tunnel kilns, while side-fired kilns use atomizing oil burners. In general, fuel consumptions are less on top-fired kilns, 25 to 35 gallons/1,000 bricks compared with 35 to 45 gallons/1,000 on side-fired kilns. However, the hot air available is sufficient to dry the output from only about 10 per cent moisture content on top-fired kilns and from about 20 per cent on side-fired kilns.

Oil has considerable advantages over coal as a fuel for burning heavy clay products. First there is a saving in labour, not only in handling fuel on the kiln top, but also in the reduction in cleaning and ashing-out. The absence of hot ash in the chamber leads to cooler drawing conditions and less dust and dirt. Because oil is less variable in quality than coal there is better control of firing, more consistent firing with more uniform heat distribution, and the possibility of increased fire travel.

In general, the product is better and fewer bricks are lost on the bottoms through local overfiring and discolouration. The per therm price of oil may be higher than coal depending on the locality, but the actual firing cost, including labour, is lower.

Ignoring town gas, which is too expensive for heavy clay firing, other gas (L.P.G. and natural gas) has even greater advantages than oil. It is clean, easy to handle and control. It can be applied with great precision and to parts of the kiln that are at too low a temperature for oil to ignite, or where at best smoky flame conditions would result. The sulphur content of L.P.G. and natural gas is negligible, so that not only is kiln scumming less likely, but there is no problem with acid smut emission and acid attack on the fan and stack. The calorific value of butane is 3,200 Btu/ft^3, natural gas about 1,000 Btu/ft^3 and town gas 500 Btu/ft^3.

Piped natural gas has the advantage of not requiring expensive storage facilities like L.P.G., nor is maintenance required as with coal and oil. Kilns presently firing with oil can be readily converted to gas. Top-fired kilns have a ring main on the kiln top with air induction burners of heat-resisting steel. Similarly, on tunnel kilns the oil burner is replaced by a gas burner, and on intermittent kilns one burner per fire-hole is sufficient.

In industrialized countries a choice of fuels is available—coal, oil and town gas, if not natural gas or L.P.G. The ones used depend much more upon the price structure and value of labour than upon any intrinsic merit of the fuel itself. In developing countries it is the fuel at hand that finds use. For many purposes convenient and cheap low-grade fuels (wood chips, paddy husks, mixtures of coal dust and crude oil) suffice. When quality and uniformity in the product become important, then better fuels are required. Control of firing becomes progressively easier, and in some countries it will become cheaper, as firing moves from coal to oil to gas.

EFFICIENCY AND ECONOMICS

The thermal efficiency of different kilns can be measured, but the over-all efficiency and economics of different methods of firing is a complex of various cost items. Capital costs, fuel costs, labour costs and maintenance and repair costs are only one side of the problem. Of paramount importance is the yield of saleable goods, since this, in the end, determines the profit on the firing operation. In terms of quality there is a hierarchy of kilns, starting with clamps, passing successively through the various intermittents, barrel arch kilns, then transverse arch kilns and ending with tunnel kilns, which, with suitable raw material, can be controlled to produce waste in such negligible quantity that it may be disregarded.

In thermal efficiency too there is a similar ranking. Updraught kilns are less efficient than downdraught intermittents, and these in turn less efficient than semi-continuous and continuous kilns. All types of continuous kilns, however, show a variation of efficiency with output such that the lower the output the higher the fuel consumption. These changes are large—a tunnel kiln firing 120,000 per week nearly doubled the fuel consumption when the production was reduced to 60,000 per week. For this reason the rate of fire travel should be maintained as high as possible by keeping the kiln in good repair, ensuring an even setting of dry bricks, maintaining sufficient draught, and regular feeding of fuel, with possibly the addition of carbonaceous matter, such as pulverized fuel ash, to those clays in which this is beneficial.

Kilns should be properly maintained and air in-leakage kept to a minimum. Wet flues and kiln bottoms slow down the rate of travel, increase the fuel consumption and affect the quality as well. This situation can be avoided by providing storm drainage ditches all round the kiln. Drainage needs to be planned before the kiln is built, and sound foundations are important to prevent later difficulties. Flues should be inspected regularly and cleaned out to prevent them from becoming blocked with sand and brick dust. Extensive air in-leakage cools the kiln gases, reduces the draught and makes it more difficult and more prolonged to reach top temperature. The influence of the temporary brickwork built to close the wicket should not be ignored in this connexion. Notable improvements result from building two nine-inch walls with a cavity four inches or so wide between, both walls being well covered with clay.

On intermittent kilns particular attention should be paid to fire-holes and bags. Fire-bars should be replaced as necessary to prevent unburnt fuel from falling through. With lower grade coals more attention has to be given to the fires, and more ash has to be removed. Above about 800° C a better grade of coal is required to get a good rate of rise in temperature. Fuel savings are possible by reducing the time of firing especially at the higher temperature stage, but of course, the top temperature must still be attained. Underfeed stokers on intermittent kilns have given notable reductions in fuel consumption, up to 25 per cent.

In the calculation of thermal efficiency a balance is struck between the heat input and the heat output, including losses. The sources of heat loss and the magnitude of some examples investigated by the British Ceramic Research Association are given in table 16.

The largest heat losses are in the flue gases, but part of this loss is unavoidable. The amount lost in water vapour depends on the moisture content of the clay, both mechanical and combined, and on the hydrogen content of the fuel. The average stack gas temperature with natural draught should not be lower than 100° C if the draught is to be adequate, so that the loss of sensible heat in the stack gases at this temperature cannot be avoided. Similarly, because of the requirements for cooling and since some air in-leakage must be tolerated, 500 per cent excess air has been regarded as reasonable on annular kilns, particularly longitudinal arch kilns.

Table 16

HEAT LOSSES FROM SOME CONTINUOUS KILNS, EXPRESSED AS THERMS PER TON OF FIRED GOODS [30]

	Type of continuous kiln										
	Barrel arch (ring tunnel) kilns				*Chamber kilns*				*Car tunnel kilns*		
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
Sensible heat in fired goods and cars when drawn from kiln	0.14	0.30	0.13	0.47	0.0	0.08	0.08	n.d.	1.74	6.25	3.56
Potential heat of combustible matter left in fired bricks	0.16	0.34	4.35	1.11	0.0	1.30	0.10	n.d.	0.30	—	0.89
Heat required for irreversible thermal reactions:											
To decompose carbonates	0.01	0.82	1.45	0.45	0.14	0.02	3.14	1.77	0.02	0.36	1.97
To decompose clay molecule etc.	0.97	0.74	1.94	1.02	1.47	1.79	0.61	0.87	1.88	2.66	0.74
For reaction between lime, silica and clay	—	—	—	—	—	—	−1.15	—	—	—	−0.72
Flue gases:											
Total heat in water vapour	3.88	8.59	8.77	4.55	7.68	5.97	2.63	4.17	6.95	8.32	2.26
Sensible heat in dry gases	3.48	16.58	9.24	5.31	8.49	5.69	8.67	5.31	8.11	16.59	4.47
Potential heat in dry gases	0.60	0.15	1.86	0.0	0.0	0.0	0.0	0.0	0.87	0.0	0.28
Heat in hot air rising from open feed-holes	4.91	1.77	—	—	8.85	—	—	—	—	—	—
Heat in hot air withdrawn to dryer	—	—	—	—	—	2.59	7.15	7.00	8.28	—	1.67
Radiation and convection losses from kiln structure above ground level	5.01	1.73	n.d.[a]	1.29	9.52	3.80	4.79	n.d.	8.30	7.03	4.87
Total heat input	19.19	33.35	30.91	14.86	38.36	20.16	26.96	23.4	37.51	37.46	19.71
Total heat in flue gases	7.96	25.32	19.87	9.86	16.17	11.66	11.33	9.48	15.93	24.91	7.01
Output (thousands/week): Roofing tiles	65	—	—	—	184	—	—	—	—	—	—
Bricks	18	97	94	166	—	131	208	224	128	—	261
Firebricks	—	—	—	—	—	—	—	—	—	137	—
Firing temperature °C	980	1,025	1,045	1,010	1,115	950	950	1,005	1,125	1,405	985

[a] n. d. = not determined.

The heat losses by radiation and convection from the kiln surface above ground level do not include losses by conduction to the ground nor losses by radiation and convection from the ground surrounding the kiln. The car tunnel kilns shown in the table had low outputs, and modern large cross-section kilns might be expected to have lower losses.

The removal of waste heat for drying contributes to the over-all efficiency of the process. Some extra fuel has to be fed to an annular kiln to maintain the back heat when hot air is being taken off behind, but the total fuel consumption for drying and firing together is less.

The selection of the most economic kiln depends upon the production requirements of the particular plant. The nature of the raw material and the type of product determine the finishing temperature. The kiln must be able to attain this readily by an easily maintained schedule appropriate to the material. The output required fixes the size of kiln and affects the choice of type. The quality and uniformity of the goods desired is a determinant. The state of the market is important in that the price differential between first-quality goods and other saleable ware fixes the benefit to be derived from capital investment in better firing facilities.

In summary it may be said that clamps involve little or no capital investment and correspondingly little control over the firing process. The yield of first-quality products is low; uniform size is not to be expected; and some proportion of bricks (place bricks) are so underfired as to be unsuitable for use in external walls where frost is expected. Intermittent kilns have high fuel consumption but meet a need for flexible and high-temperature operation where demand is variable or specialized products are required. Hoffmann kilns are the cheapest continuous kiln to build, have fast rates of fire travel and show good thermal efficiencies. Their output ranges from about 100,000 to 150,000 bricks per week. They are designed to fire common bricks to a temperature of about 1,050°C. For facing bricks the more uniform conditions obtained in a transverse arch kiln are to be preferred. The top temperature is much the same, 1,050°C, unless grates are fitted, when 1,150°C may be reached. For firing temperatures above this in annular kilns, a Belgian type must be used. Car tunnel kilns require the highest capital investment but involve the lowest labour requirements and give the best working conditions. They have high outputs and produce high-quality, uniform products, if necessary at high temperatures, with negligible waste.

In the context of production efficiency and the economics of the total production process, a car tunnel kiln is the inevitable choice for a modern factory in industrialized countries. In the development of a brick and tile industry, however, it is difficult to escape the conclusion that the appropriate sequence of firing facilities is clamps followed by Hoffmann kilns with specialized facilities for the small proportion of special or high-quality products required. Only when the industry is thoroughly established and labour costs make the investment attractive should the wholesale introduction of more sophisticated methods of firing be considered.

VI. Productivity and efficiency

BASIC COSTS OF MANUFACTURE

Labour

THE BREAKDOWN OF COSTS in monetary terms is discussed below, but a convenient comparative index of productivity is given by the labour cost assessed as man-hours per thousand bricks, or in the case of other clayware units, man-hours per ton of fired product. This latter permits comparisons to be made between different products, but since in many handling situations the number of pieces moved is more important than their weight, the per thousand figure is the more informative.

The labour requirements given in the tables that follow are based on a 40-hour week, except that "Firing" is taken as three men working a total of 168 hours. The data represent the productivity that may be expected in the manually operated form of the process described, so that while machinery is used for making, the amount of handling equipment is minimal. The basic labour requirements have been synthesized by grouping together typical features found on a number of works, and the outputs are representative of the kind of works described. Taken as a whole the tables present a spectrum of efficiencies but generally illustrate the practices followed in Great Britain in times of relatively cheap labour before 1950. Only productive labour figures are given, that is for those processes directly associated with manufacture. Thus maintenance and transport are not included, nor is loading unless so stated. The amount of non-productive labour depends upon the views of the manager of each works, especially as men nominally held for yard work and other labour are really kept as spares against sickness and holidays. Hence only productive labour costs are capable of being compared.

Possible improvements of the basic processes and the gains to be made by rationalization and mechanization are considered later. Wherever possible labour is dispensed with, but the essential process is unchanged. This represents the kind of improvement possible in laying down a new works of the "basic" type. The final stage, not elaborated here, is the second generation works, examples of which are now being built, which represents a new technology and a new philosophy. In this labour is almost wholly dispensed with, and such men as are employed are supervisors trained not only in the process but also in the maintenance of the sophisticated control equipment required. While the number of men is reduced, their wages are higher. Indeed, the arithmetic of both improved processes and new factories involves recognition of the fact that considerable capital is needed to replace labour (perhaps £ 2,500 per man saved). While increased profits can be earned, this is only possible on large production units, which currently for new brick factories are 400,000 to 600,000 bricks per week, and will need to become even bigger as costs rise.

Handmade

In the seasonal operation of a small handmade yard, the clay is dug during the autumn and allowed to weather over the winter. In spring making begins; the bricks are hack dried and fired in clamps. Five men can operate this system to produce about 10,000 fired bricks a week during the making season. The distribution of labour is given in table 17. The digging and curfing operation has not been included, but in a seasonal yard the men may be kept on for this and removal of overburden, maintenance and loading from stock. This almost doubles the labour requirement.

Table 17

LABOUR FOR HANDMAKING OF BRICKS (SEASONAL)

(Output: 10,000 bricks per week)

	Men	*Hours per week*	*Man-hours per 1,000 bricks*
Preparing and wheeling clay and sand	1	40	4
Making (1,000/day/man) and wheeling and hacking	2	80	8
Skintling, wheeling and setting, drawing and loading	2	80	8
TOTAL	5	200	20

Since making is a skilled job and moulders are paid a high piece rate, it would be more economic on larger works at least to keep them on making and provide unskilled labour for wheeling away the bricks. However, it has been the accepted practice in the industry for the maker to wheel away his own bricks and thus obtain a break from continuous making.

Since hacking involves multiple handling, including skintling when the bricks have firmed up and the manipulation of hack covers and louvres, the use of artificial dryers would be an improvement. The waste in properly controlled dryers is less, so that there may be a net saving after allowing for the cost of fuel. There are also advantages to be gained by working throughout the year.

The bricks are fired in clamps, which are cheap, flexible and produce attractive colours, but which produce a relatively high proportion of waste and underfired bricks. Since the handmade brick is so expensive to mould, sufficient loss may be suffered to make it worth while to provide downdraught intermittent kiln facilities.

Soft-mud

The standard three-mould Berry machine requires four men to operate and load pallet barrows for an output of 1,000 per hour. The labour requirements for a very small works show little improvement over hand-making (table 18).

Table 18

LABOUR FOR SOFT-MUD MANUFACTURE OF BRICKS BY THREE-MOULD BERRY MACHINE

(Output: 40,000 bricks per week)

	Men	*Hours per week*	*Man-hours per 1,000 bricks*
Digging and curfing	3	120	3
Wheeling clay and sand	3	120	3
Making (1 machine)			
Temperer	1	40	1
Berry	4	160	4
Wheeling, hacking and skintling in sheds	3	120	3
Preparing clamps and wheeling and setting	3	120	3
Drawing and loading	2	80	2
TOTAL	19	760	19

Output has a big effect on labour. For a large stock brick works using a Lancaster machine with automatic loading of pallets onto dryer cars, tunnel dryers and a tunnel kiln, the labour requirements are considerably reduced, as shown in table 19.

Table 19

LABOUR FOR SOFT-MUD MANUFACTURE OF BRICKS BY LANCASTER MACHINE

(Output: 300,000 bricks per week)

	Men	*Hours per week*	*Man-hours per 1,000 bricks*
Mechanical digging and processing in wash-backs	4	160	0.53
Making	6	240	0.80
Drying	4	160	0.53
Setting	18	720	2.40
Firing	3	168	0.56
Drawing and sorting	15	600	2.00
TOTAL	50	2,048	6.82

In both these cases, town-ash was added to the bricks as fuel, and the variable carbon content may result in as much variation in the quality of the fired goods from the tunnel kiln as from a clamp. This increases the labour requirement for sorting.

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Extruded solid and perforated bricks and hollow blocks

There is no real distinction to be made between these different products as far as the extrusion process itself is concerned. In modern technology solid and perforated bricks are made at stiff consistency, while hollow blocks tend to be made somewhat softer, and in Europe are often steam tempered and rapidly dried. Hollow blocks were usually dried on pallets in steam-heated chamber dryers, for which an example is given. The labour figure is calculated in terms of brick-equivalents of the hollow blocks. Table 20 compares a simple form of wirecut process—hand-winning, chain haulage, hand-tripped side cutting table, hot floor dryers and one Hoffmann kiln—with alternative winning and drying systems.

Table 20

LABOUR FOR WIRECUT MANUFACTURE OF BRICKS AND HOLLOW BLOCKS
(Output: 100,000 bricks or brick-equivalent per week)

	Bricks Hot floor		*Bricks Tunnel dryer*		*Hollow blocks Chamber dryer*	
	Men	*Man-hours per 1,000 bricks*	*Men*	*Man-hours per 1,000 bricks*	*Men*	*Man-hours per 1,000 brick-eq.*
Hand-winning and haulage	15	6.0	—	—	—	—
Excavator and haulage	—	—	2	0.8	2	0.8
Wet pan	1	0.4	1	0.4	1	0.4
Extruder	2	0.8	2	0.8	2	0.8
Wheeling to hot floors and putting down	5	2.0	—	—	—	—
Taking up and wheeling to kiln	3	1.2	—	—	—	—
Tunnel or chamber dryer	—	—	5	2.0	8	3.2
Setting	3	1.2	3	1.2	2	0.8
Firing	3	1.7	3	1.7	3	1.7
Drawing	3	1.2	3	1.2	2	0.8
TOTAL	35	14.5	19	8.1	20	8.5

With small tubs and the provision of a suitable hand-operated tippler one man can feed the pan, but one-yard side-tipping tubs usually require two men to empty. The hand-tripped side cutting table needs two men, one to operate the bow wire and slide the cut column along and the other to trip the side-cutter and help the wheelers move the pallets of bricks onto their barrows. As the column is cut into ten or twelve bricks by the wires, an offcut is left at each end, which is thrown back into the pug. Up to 10 per cent of the column is being continually reprocessed in this way. Unless arrangements are made to return offcuts directly by conveyor, some spillage is inevitable, and one man is employed, at least partly, in cleaning up.

In the operation of the tunnel dryers two men are employed castling the bricks on to cars, two men push full cars into the dryer and assist in pulling dry ones out, and one other man returns empties. In the chamber-dryer system two men at the pug transfer pallets of blocks to the ascender, one man takes a finger car into the chambers, and another man on a second finger car takes dry bricks out to the descender. In addition two men take the bricks on carousel cars from the descender to the setters, and two others return pallets to the pug and clean up. Only two setters and two drawers are needed because the larger size of the hollow block units allows more brick-equivalents by volume to be handled.

A continuous kiln requires three shifts of burners. Although the same number of men can fire two kilns suitably sited, labour is required for coal wheeling, making and daubing wickets and cleaning ash from the chambers.

The wickets of old Hoffmanns are small, making access by mechanical handling equipment difficult, and the bricks are usually taken in and out on crowding barrows.

Stiff-plastic

Labour for winning and haulage, wheeling and setting, firing, and drawing are similar to the wirecut process, as is the output in the standard form of one double press (table 21).

Table 21

LABOUR FOR STIFF-PLASTIC MANUFACTURE OF BRICKS
(Output: 100,000 bricks per week)

	Men	*Man-hours per 1,000 bricks*
Excavator and haulage	2	0.8
Dry pan	1	0.4
Screen and dust floor	1	0.4
Tempering	1	0.4
Taking off double press	2	0.8
Cleaning up and press relief	1	0.4
Wheeling and setting	5	2.0
Firing	3	1.7
Drawing and loading	3	1.2
TOTAL	19	8.1

Without primary crushing and mechanical feeding one man is employed full time in feeding and tending the dry pan. An attendant is needed on the dust floor to keep a heap of dust over the outlet to the machine, and he also cleans the inclined screen at intervals. The man cleaning up escape pieces is one of the three-man gang who take turns to remove bricks from the press onto crowding barrows. One man is saved by the setters doing their own wheeling, and three drawers should also load.

Semi-dry press

The process and labour requirements are very similar to the stiff-plastic; but the basic output is somewhat higher, since three presses are used, each with an assumed saleable output of 1,000 bricks per hour. Table 22 gives details.

Table 22

LABOUR FOR SEMI-DRY PRESS MANUFACTURE OF BRICKS

(Output: 120,000 bricks per week)

	Men	*Man-hours per 1,000 bricks*
Excavator and haulage	2	0.7
Dry pan	1	0.3
Screen and dust floor...............	2	0.7
Taking off presses	3	1.0
Cleaning up and press relief.........	2	0.7
Wheeling and setting	6	2.0
Firing	3	1.0
Drawing	3	1.0
TOTAL	22	7.7[a]

[a] In all the tables the man-hours per 1,000 bricks is correct for the totals; the addition of individual items does not necessarily agree in the last place of decimals.

It will be seen that apart from the high-output, soft-mud process, semi-dry press needs the least labour, and, of course, there is no separate drying process. When the advantage of low fuel requirements for Fletton clay is added, it is not hard to see why this simple process, albeit highly mechanized, remains even today efficient enough to make common bricks competitively, provided the plant is big enough.

Roofing tiles

The process of roofing tile manufacture is complicated by the necessity to make a proportion of specials, ridge, gable tiles and others. Table 23 deals only with standard tiles and only four processes are given. The data are taken from the survey made in 1951–1952 and represent median values rounded off. [13] The labour is given in man-hours per ton for an output of six tons per hour, or approximately 50 tons per day for machine-made and one third of this for hand-made. The labour figures should be multiplied by three to get an approximate equivalence to the man-hours required to produce 1,000 bricks by the various processes.

Table 23

LABOUR FOR THE MANUFACTURE OF ROOFING TILES

Process	*Plain tiles*				*Single-lap tiles*			
	Handmade 80 tons/wk		*Extruded 250 tons/wk*		*Handmade 80 tons/wk*		*Extruded bats pressed 250 tons/wk*	
	Men	*Man-hours per ton*	*Men*	*Man-hours per ton*	*Men*	*Man-hours per ton*	*Men*	*Man-hours per ton*
Hand-winning and haulage including weathering	6	3.0	–	–	6	3.0	–	–
Excavator winning and weathering rope haulage	–	–	4	0.6	–	–	4	0.6
Wet pan	1	0.5	1	0.2	1	0.5	1	0.2
Clot production	1	0.5	1	0.2	1	0.5	1	0.2
Souring	1	0.5	–	–	1	0.5	–	–
Barrowing clots to makers	1	0.5	–	–	1	0.5	–	–
Making	–	–	4	0.6	–	–	8	1.3
Hand-moulding and setting in racks	10	5.0	–	–	16	8.0	–	–
Drying on racks	1	0.5	–	–	3	1.5	–	–
Placing pallets in ascender	–	–	–	–	–	–	2	0.3
Wheeling to dryer	–	–	6	1.0	–	–	1	0.2
Cambering and chequering	–	–	6	1.0	–	–	–	–
Loading and wheeling	2	1.0	4	0.6	2	1.0	4	0.6
Setting	2	1.0	4	0.6	2	1.0	4	0.6
Firing–continuous	–	–	3	0.7	–	–	–	–
or intermittent	4	2.8	–	–	4	2.8	9	2.0
Drawing and sorting	2	1 0	4	0.6	2	1.0	4	0.6
Wheeling and stacking	1	0.5	3	0.5	1	0.5	3	0.5
Loading	1	0.5	3	0.5	1	0.5	3	0.5
TOTAL	33	17.3	43	7.1	41	21.3	44	7.6

In the handmade processes clots are soured before being wheeled to the moulders who make the tiles in the drying sheds and place them directly on the racks.

The machine-made plain tiles are extruded first as clots that are cut off and passed by conveyor to two tile extruders where the tiles are cut and placed on pallets. After stiffening up they are cambered and chequered. In the single-lap process, the clots or bats are produced, pressed on four revolver presses, the tiles taken off and placed on pallets. These pallets are then put in an ascender and taken by finger car to corridor dryers. They are removed from the dryer in the same way. Such tiles are frequently fired in continuous kilns, but for simplicity intermittent firing is shown.

While plain tiles are easier to make, and have been popular in Great Britain, they give less cover than single-lap tiles. Indeed, plain tiles give treble thickness over 80 per cent of the roof and double thickness over the rest, while single-lap tiles give single thickness cover over rather more than 60 per cent of the roof. If the important objective is to provide the maximum roof cover for the minimum manufacturing cost, single-lap tiles are to be preferred.

Costs

Even within an industrialized community, the range of efficiency in brick and tile production is large. Production costs, therefore, vary widely In table 24 some data are given for different processes. These were works on which projects were carried out for complete reorganization, and while it was possible to recommend improvements, the general level of efficiency was at, or somewhat above, average. The costs have been rounded off and combined into the different parts of the process. They have been expressed as percentages to permit comparisons to be made.

Table 24

COST OF MANUFACTURE
(Per cent of total cost)[a]

	Process			
	I *Handmade*	*II* *Wirecut*	*III* *Stiff-plastic*	*IV* *Semi-dry press*
Winning and haulage	3.3	8.0	9.5	1.2
Clay preparation	6.9	0.5	5.0	5.8
Making (and drying)	27.5	12.2	7.0	13.7
Fuel and power (drive)	10.3	17.3	5.5	4.3
Total cost of green production	48.0	38.0	27.0	25.0
Setting drawing and firing:				
labour	9.1	21.4	21.0	18.2
fuel	5.9	16.6	19.0	21.8
Total cost of firing:	15.0	38.0	40.0	40.0
Overhead	37.0	24.0	33.0	35.0
GRAND TOTAL	100.0	100.0	100.0	100.0

[a] The outputs in millions per year for the four processes are: I—2; II—5; III—5; IV—13.

The low cost of preparation on Works II is due to the very simple system consisting of only a single-shafted mixer, feeder and two sets of medium-speed rolls. The high cost of making on Works I is due to the cost of hand-moulding. At Works I and II the cost of fuel and power includes steam for driving the main engine and for drying. Works I uses fork-lift setting and drawing. Some fuel is added to the brick mix. Overhead costs include depreciation and selling costs. The total is the ex-works cost and does not include transport.

It has been noted earlier that the large differential between wage rates in developed and developing countries enables labour-intensive processes to continue. In a factory in Pakistan producing for 22 man-hours per 1,000, the labour costs are only 16 per cent of the total costs, [26] whereas in a comparable works in Europe labour costs would be about 40 per cent.

In India surveys have shown wide disparity in costs in different areas. [27] Table 25 summarizes the information for four states and compares it with that given in table 24 recast in similar form.

Table 25

COMPARISON OF COST OF BRICK MANUFACTURE IN FOUR INDIAN STATES

State	*Cost in rupees per thousand*				*Cost in per cent of total*		
	Raw materials	*Fuel*	*Labour*	*Total*	*Raw materials*	*Fuel*	*Labour*
West Bengal	12	9.9	22.1	44	27.2	22.4	50.4
Punjab	1.3	6.8	9.7	17.8	7.3	38.2	54.5
Bombay	5	9.0	15	29	17.2	31.2	51.6
Madras	1.3	12.7	6	20	6.5	63.5	30.0
British works							
I					5.3	25.7	69.0
II					10.5	44.6	44.9
III					14.2	36.6	49.2
IV					1.8	40.2	58.0

The broad similarity is perhaps surprising, and it is interesting to note how close the proportionate costs of labour are for the Indian works except for Madras. Overhead costs are not included in these data, but other data show values ranging from about 11 per cent to 17 per cent, while the British overhead costs lie around 30 per cent. [28]

IMPROVED PROCESSES

Layout

When a new works is designed or an old one reorganized the labour costs given above can be cut considerably by ensuring that the layout is such that unnecessary handling is avoided, and by providing simple handling aids. It is important to recognize that the output of a plant is determined by the output of the critical machine—the one at which, because of its method or economics of operation, the minimum variation is possible. This will often be a press or re-press, and in the case of automatic loading, it will be the setting machine. The works must be designed in multiples of the output of the critical machine, and sufficient "hopperage" must be provided to ensure a constant flow of material to it.

To achieve best results from the pan and screen, a mechanical feeder should be provided to give a constant feed despite the intermittent arrival of clay. Large apron or box feeders may be provided into which dumpers or lorries can tip. Constant weight feeders should be installed for the addition of small quantities of additives, e.g. barium carbonate, but for larger additions of sand, grog, or breeze, a proportioning box feeder is preferable.

Pans should be so arranged that one man can supervise several at once. Heated vibrating screens should be used to eliminate the labour of cleaning. The dust floor in the stiff-plastic and semi-dry press processes should be replaced by hoppers over each press.

Temperers in the stiff-plastic process may be replaced, or at the least their duties greatly reduced, by installing a metering device for water additions linked to a constant weight feeder. In this way a constant proportion of water is added. Suitable catwalks will enable one temperer to deal with at least two presses.

Hoppers and magazine conveyors should be provided to take care of normal fluctuations in throughput, and the aim should be essentially constant output at the critical machine. The rated output is the normal output of the machine working continuously; the target output is that required from the machine and is about 10 per cent less than the rated output. The target output includes waste at all stages of the process but should not be regarded as an allowance for idle time.

Mechanical loading of dryer cars and stillages or the building of fork-lift packs is assumed. Fork-lift trucks can transport dryer cars to the dryers and kilns and return empty cars. In many situations fork-lift trucks are more useful and more efficient than transfer cars. This is particularly true of setting in clamps when the dryer cars can be lifted on to the first bench to enable the tops to be set.

The choice of kiln will depend upon the product and output required. It need not affect the efficiency if either one kiln large enough for the output is provided or two or more continuous kilns are situated side by side with bridges between them so that only one gang of burners is required. Oil or gas are the preferred fuels if available economically because of the labour cost in handling coal. Where practicable, fork-lift setting and drawing yields savings. Bricks should be stacked in fork-lift packs to avoid the heavy labour cost and loss when stacked and reloaded by hand. In the United States a very high proportion of bricks is now banded and delivered on lorries equipped with mechanical handling equipment, and this practice is spreading in Europe too.

Labour costs

Table 26 gives target labour figures for some variants of the basic processes. It should be emphasized that these are not the ultimate. They take advantage of existing simple handling devices and most importantly, the outputs have been chosen to suit the plant. The processes are not seasonal and adequate dryers are assumed. An example of the effect of an economic output is given under the wirecut process where the labour requirement for a plant designed for 160,000 per week has been recalculated at 100,000 per week. As an example of a simple mechanical aid, in the handmade process a clot-making machine is used to feed clots on a conveyor to the markets. After the bricks are made they are demoulded on to pallets and pushed down a roller conveyor to be taken away not by the hand moulder but by the dryer attendants.

While no allowance has been made for non-productive labour in this table, it will be seen that quite low productive man-hours can be achieved in these conventional processes. If advantage is taken of the latest developments in mechanized brickmaking, productive labour figures of less than two man-hours per 1,000 can be reached.

Table 26

LABOUR REQUIREMENTS FOR IMPROVED PROCESSES OF BRICK MANUFACTURE

Process		*Target output per week*	*Total men*	*Man-hours per 1,000 bricks*
Hand-made		100,000	33	14.1
Soft-mud	Berry plant clamp-fired	148,000	22	5.8
	Aberson plant clamp-fired	200,000	19	3.8
	Aberson plant kiln-fired	540,000	48	3.6
Extrusion	Unde-aired, Hoffmann-fired	160,000	17	4.6
	Plant as above	100,000	13	5.7
	Stiff de-aired, tunnel-kiln-fired	160,000	15	4.1
Stiff-plastic	Hand set and drawn	188,000	20	4.5
	Fork-lift set and drawn	198,000	12	2.8
Semi-dry press . . .	Hand set	260,000	23	3.7
	Fork-lift set and drawn	260,000	17	2.8

SEASONAL CHARACTERISTICS OF INDUSTRY

In temperate industrialized countries the need to minimize labour yet to provide year-round employment and the necessity to use the capital plant to the utmost in order to maximize the return has led to the almost complete disappearance of seasonal working. In tropical and sub-tropical countries, the advantages of natural drying and cheap labour outweigh these considerations, and in small, rural brickworks there is no incentive to become non-seasonal. In larger brickworks situated near cities, however, there may be more need to operate continuously. Nevertheless, non-seasonal operation is carried out not only to reduce manufacturing costs but also to provide a constant source of bricks for the builder. If climatic conditions prevent building over a continuous period or make it prohibitively expensive, there is little merit in making during this time.

Seasonal working in the brick and tile industry, however, has other disadvantages. Because continuity of employment is not assured the labour tends to be transient. In general it may be said that the standard of labour in traditional brickyards in industrialized countries has not been high. This affects quality and operating efficiency and hence is directly reflected in operating costs.

Intermittent working of machinery gives more than adequate time for maintenance. Each making season starts with an effective plant that should last until the next maintenance period. However, since it is known that the plant is going to be shut down, non-essential repairs are usually put off until this time, with the result that the plant may well be running at less than optimum efficiency for some time before the shut-down. Starting annually means that each year there is an effective "starting-up period" during which production will be less than normal, and although this period may not be lengthy it is an item on the debit side of seasonal working.

Seasonal working is either expensive in labour or expensive in capital to the extent that the plant lies idle. Considerations of quality and operating efficiency, including mechanical efficiency, are basically problems in management. While these problems may be made more difficult by seasonal working, they are not unavoidable. Only a local assessment can decide how much it is worth to establish non-seasonal working, but in the end all industrialized societies come to mechanical, continuous production.

VII. Establishment of a heavy clay industry in developing countries

REQUIREMENTS FOR BUILDING MATERIALS

BUILDING MATERIALS are heavy or bulky, and hence their transport to site is expensive. During the expansion of the heavy clay industry in Great Britain in the ninteenth century, brickworks were put down wherever a local market developed. In most areas no community was farther from a source of bricks than the distance a horse and cart could cover in a day. However, despite the availability of bricks at a distance, local building materials continued to be used, particularly stone and slate for roofing. The decline in the use of stone and slate seems to have come about, not so much because of a direct selling effort by the manufacturers of bricks and roofing tiles, as because the winning and shaping of stone and slate has become uneconomic for normal building, owing to increased wage rates of quarry workers.

It is the craft element in building construction too which is expensive. Bricks remain cheap, but the cost of laying them in the wall may be four times the cost of the material. Although the total cost of all the brickwork in a building is a small proportion of the whole, the tendency is to use larger units for internal walls and to use bricks for their aesthetic qualities and durability as a facing material. In countries where there is no facing tradition, hollow clay blocks are used for walling, rendered outside and plastered inside. The cost of laying an equivalent area of wall is less with large units than small ones, as table 27 shows. These data were published in 1964, [29] but the same kind of comparisons are valid today, although the cost of each item is higher.

Table 27

COST OF LAYING MASONRY
(Shillings)

Material	*Cost of material delivered per yd super 4 inch thick*	*Cost of material in wall per yd super*	*Difference due to labour, mortar, overhead etc.*
Common bricks	6.8	25.0	18.2
Hollow clay blocks	7.3	16.7	9.4
Breeze blocks	7.1	15.6	8.5
Light weight aerated concrete blocks	11.2	20.1	8.9

The cost of labour in developing countries is not likely to be a major consideration in establishing a brick industry, but a shortage of trained bricklayers may well be. Bricks have the great advantage that their size permits simple structures to be produced without much thought, but a viable brick industry requires good masons. That hollow blocks are a cheaper unit to lay than bricks will not weigh heavily, for the greater facility with which bricks can be made and used encourages the manufacture of bricks rather than blocks, except perhaps in large cities where a more varied demand for building products exists.

Where no indigenous brick and tile or concrete block industry exists, the demand for these products may well not arise spontaneously, and government initiative may be necessary to start the industry. Clearly the industry will begin in the largest city, but to become viable, it must spread into towns and villages. If the object is to provide dwellings, storehouses, and workshops, a complete network of rural industries is necessary, since bricks and tiles cannot be transported far economically. The raw materials for clayware production are widespread, and the traditional technology is simple, but some consideration should be given to the ultimate stage in the development of a building materials industry.

The United Kingdom may be regarded as approaching the ultimate in the use of structural ceramic products, and hence provides an indication of the maximum development of these industries. It is heavily populated; 90 per cent of the population of over 50 million is concentrated in about 60,000 square miles of England and Wales. It has a strong facing brick tradition, and although concrete tiles have now captured most of the roofing market, in other circumstances clay might have maintained its place.

In this highly developed industrial country, housing demand is limited more by the rate at which houses are built and the shortage of mortgage facilities than by the ability of the workers to pay either the rent for Local Authority dwellings or to repay the purchase price of their own house. The demand for new dwellings each year has been put at 500,000 (roughly 1 per cent of the population). Although it is government policy to build a proportion of these dwellings in materials other than bricks, nevertheless the above figures provide an indication of the size of the market in relation to population.

It should be noted, however, that this must be regarded very much as the ultimate. In all developing countries, including Great Britain in the nineteenth century, the first demand is for the construction on a broad scale of simple weatherproof shelters that give privacy to each family. When this demand arises, the development of large-scale mass-production facilities for building materials becomes not only possible but essential to keep the price for housing low. Until then, however, there is a need to encourage the spread of craft brickmaking, lime burning for mortar production, and bricklaying. Inevitably there will be a rural industry of small workshops and an urban industry of a few large works. The crux of this discussion is to ensure that both are as efficient as possible.

PROTOTYPE PLANTS

Neither the same process nor the same layout is appropriate for both rural and urban plants. The outputs required are of different orders of magnitude.

Consideration here will be given to plants with outputs of 5 tons per day, 50 tons per day and 300 tons per day. In terms of bricks, these are outputs of approximately 10,000 per week, 80,000 to 100,000 per week, and 500,000 per week based on the European working week of 5 days totalling 40 hours.

Five tons per day represents the output of the rural community plant. It is the first stage up from the single craftsman, and it remains a seasonal operation. The process is hand-making, with perhaps rudimentary preparation machinery driven first by animal power. Mention has been made earlier of the possibilities of the agricultural tractor as an implement for winning and haulage. Possibly such an implement could be made available on some sort of communal basis for agriculture and for brickmaking, but for this a necessary concomitant is a village blacksmith. The local production of durable building materials and the availability of metal working and mechanical skills are important steps on the road to industrialization.

At the other extreme, plants with outputs of 300 tons per day are factories, requiring all the facilities of urban civilization, power supply, large supplies of fuel, adequate reserves of raw material for at least 50 years at full output, a pool of trained operatives, and fitters and electricians to service the machinery. The first such plant to be erected is likely to be a plant near the chief city, one that supplies a range of clay products, bricks, tiles, and sewer pipes to accommodate the varied needs of the developing city.

As a brick unit, however, at this output, unless suitable clay for stiff-plastic or semi-dry pressed production is available when the plant could be non-seasonal, the choice lies between a soft-mud plant and an extruded plant, depending upon the raw material and the requirements of the market. For roofing tiles, either extruded Spanish tiles or re-pressed extruded bats is a likely choice. Winning will be mechanized, and haulage probably dumpers. The machinery will still be simple, with the minimum of mechanical handling equipment. This factory will need to be non-seasonal, and might be provided with artificial dryers to use the year round, since these give lower waste than hacks. However, advantage could be taken of open-air drying by providing racks in open-sided sheds into which finger cars, hand-propelled or animal-drawn, can place pallets of bricks from the soft-mud machines or the extruder.

Providing drying facilities during the rainy season is more difficult. Chamber or tunnel dryers would stand empty for perhaps nine months of the year. This is an expensive capital investment, and such a low utilization may well not be possible. Since rack drying is to be used in the dry seasons, a system compatible with this must be evolved. A simple method is to construct some of the drying sheds with flues beneath the racks through which the products of combustion from the kilns can be passed. Alternatively and additionally flues with fire-holes at one end and connexions to a stack at the other may be constructed to permit heat to be supplied to the floors separate from the kiln. Clean hot air from the kilns can also be discharged beneath the racks to assist in drying. This system is not markedly efficient, but it requires little capital for installation.

At this level of output, either Hoffmann or transverse arch kilns should be provided. For special products, intermittent kilns might be used, but for the mass production implied by this output, a continuous kiln is desirable. A tunnel kiln will rarely be necessary. If artificial drying is provided the year around, waste heat should be taken from the kiln, but even for the few months of operation of the system noted above, the investment in ducting and fans will be worth while.

The intermediate size plant of 50 tons per day was the standard unit in the development of the industry in the United Kingdom. If five tons a day represents a rural craft industry, started by a man making bricks himself, and if 300 tons a day represents essentially a venture requiring support, perhaps at governmental level, then 50 tons a day represents the entrepreneurial plant. Whether this type of plant will play a big part in future development is difficult to assess, but certainly it is a conveniently small commercial operation for one man to run. Such plants have often been started by builders to provide materials for their own operations. The parallel encouragement of brickmakers and builders is basic to the development of a strong industry.

All the plants of this output described in Chapter VI would be viable in the right circumstances, and the choice must depend upon the local raw material. Winning and haulage could be accomplished by an agricultural tractor with front-loading shovel. For wirecut production of bricks or hollow blocks and for the preparation of clay for roofing tiles, a sludge pan would be adequate and could be animal-driven. Drying will be in open-air racks or hacks, and the plant, at least at first, is likely to be seasonal. Firing may be in clamps or scove kilns for bricks, but at this output, one Hoffmann is suitable. Alternatively, a Bull's trench kiln may be constructed for less cost.

If sheds are provided for storage, extra ware can be dried during the making season and stored to burn in the kiln when open-air drying ceases. The green ware needs to be protected from the weather, so covered runways will be necessary to permit the bricks and tiles to be barrowed into the kiln without damage. Alternatively the simple hot floor flue system described above can be applied for year-round working.

Although some statement of general principles has been made, certainly each country, and desirably each plant, needs to be considered in detail before recommendations adequate to provide a basis for investment decisions can be made.

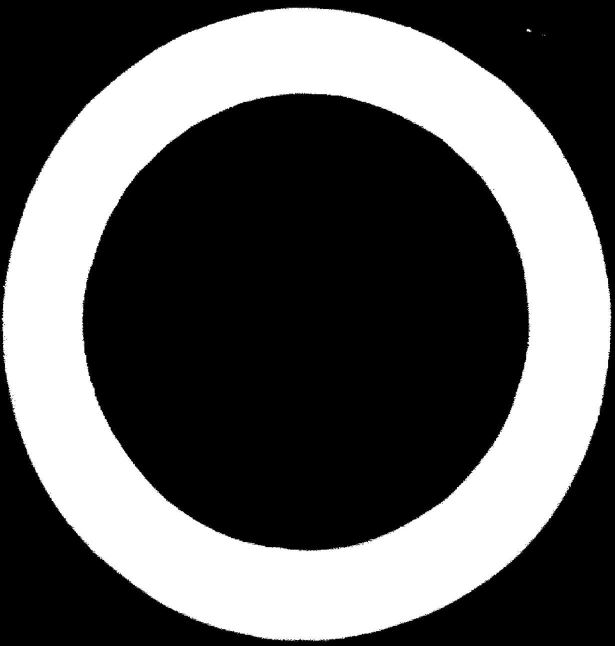
PROVISION OF STAFF

Even moderately mechanized brick and tile making processes need some engineering expertise. It is no accident that many managers of small works in Great Britain were trained mechanics. Clay is an abrasive material, and regular maintenance of machinery and replacement of wearing parts is an essential element in the process. It is at this level of trained fitter that management should be sought for the intermediate-size works. For the largest plants, engineering and technical staff will need to be provided, and the manager, though desirably trained in ceramics, is employed to manage.

A country with no history of brick and tile manufacture will lack operatives and technical staff. A training programme is essential under these circumstances, and instructors must be imported. The training of operatives is best done on the job. Although the process is initially inefficient, the setting up of a small training works under the managership of the instructor provides a nucleus of skilled labour for future expansion.

Such expansion depends essentially on general acceptance of clay units as building materials. This implies the widest possible dissemination of the products and of the skills to lay them. This situation is unlikely to occur without a nationally sponsored scheme of rural development spreading out from the towns and cities. Such a long-term scheme, aimed at stimulating the growth of rural industries, would result in the widespread use of readily produced local clay units suitable for building permanent shelters as well as economic growth, which would provide a market for enlargement of the size of producing unit.

It may not be necessary for every country to pass through all the stages of development experienced by the clay industries of Europe. However, the technology should fit the level of production, and sophisticated methods are only viable at large outputs. It would be unfortunate if developing countries were to invest in large factories that turn out to operate at a loss when smaller units with simpler processing would be adequate. If there is one single lesson to be learnt from the history of the brick and tile industries in developed countries it is that clay building units must be cheap, plentiful and everywhere available. This surely is the requirement of materials for housing in developing countries.



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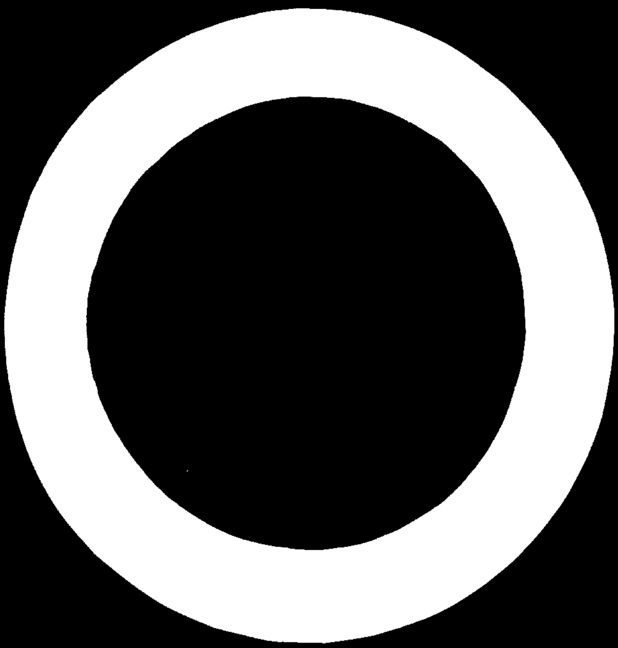

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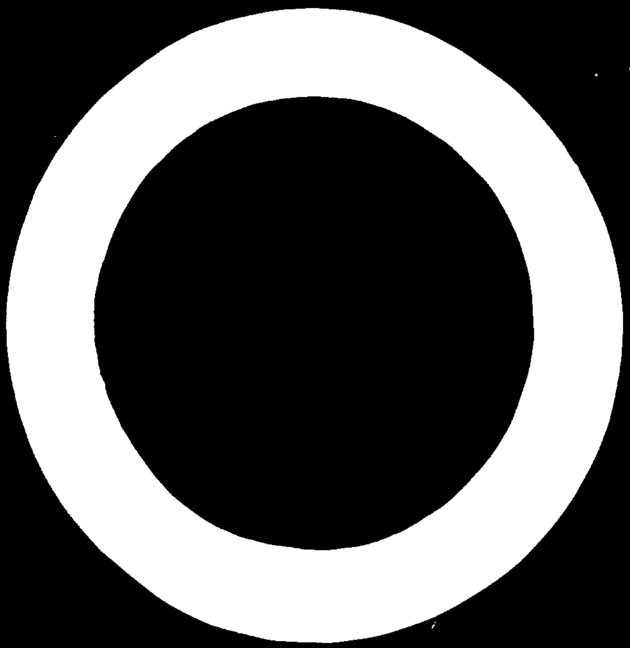

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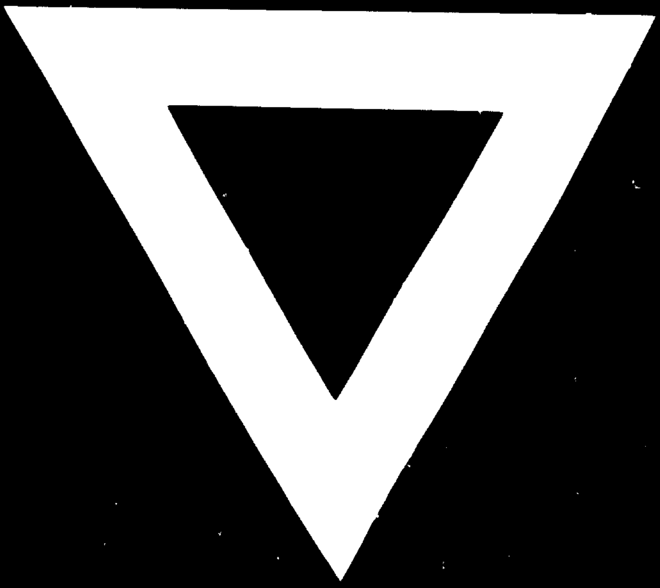

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