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RESOURCES FOR THE ANTICIPATED DEVELOPMENT 1/

by

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Mexico

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When it then comes to rural areas, to the world of villages and small agricultural settlements, the full handicraft manufacture will in most cases be quite appropriate. Same must, however, be energically promoted and rationalized.

II. RAW MATERIALS

Clay is one of the greatest resources of man. There are millions of tons of it practically everywhere. Left in the gound it does not look like much, nor is it good for much except stick to your boots on a rainy day when you happen to walk over it. But exploit the right way and convert it into building material and it will give work to thousands and provide livable shelters for millions. And properly used it may even produce objects of beauty and of aesthetic enjoyment.

But what is this material which we call clay in English, "argille" in French, "Ton" in German, "Arcilla" in Spanish. For us in the structural clay products industry it is any fine grained material possessing that peculiar property which enables it to be shaped by means of conventional methods. This statement is not, of course, strictly true as we know many non-plastic materials which are clays without any shade of doubt.

In one sense what people call clay may be characterized by its particle size. Same is difficult to assess in the case of some consolidated materials as shales, which do not desintegrate or "slake" in water. Let concern us first with clays that readilly desintegrate in water and whose particle size may be determined by a more or less simplified procedure. Clay as it is found in the nature, may contain a whole range of particle sizes from say, a fist size to a fraction of a micron. The nomenculatur which we apply to these sizes depend somewhat on the discipline of the men who interpret the particle size analysis. In geology the classification of plastic sediments of Wentworth (Jour. Geol. 30, 377-392,/1922/) is usually followed, in which clay properly speaking is defined as anything with a particle size under 4 microns. In the soil sciences, on the other hand, the tendency has been to reduce this size limit to 2 microns. Above this, a range of sizes exist, which are classified into several groups with definite size limits. They range from 1.27 to 12.7 mm for what is called gravel, from 0.107 to 1.27 mm for so-called sand, from 0.063 to 0.107 for fine sand and finally from 0.01 to 0.063 mm, called silt. We may, however, just as well forget about the name of these fractions, as they are entirely artificial with little relation to the clay's mineralogy.

For practical purposes the clays' particle sizes are best divided into sievable and subsieve fractions. The approximate useful limit for sieving is said to be 45 microns which corresponds more or less to the opening of the 325 mesh Tyler or U.S.S. sieves. For practical purposes, however, the finest sievable particle size is the one retained of standard sieves, the openings of which range from 0.060 to 0.066 mm. This would be the following sieves:

Opening	Mesh number	Authority
0.063 mm	200	I.M.M.
0.066 mm	240	B.S.I.
0.061 mm	250	Tyler
0.062 mm	230	U.S.S.
0.060 mm	100	DIN
0.063 mm		AFNOR

The subsieve fractions, normally determined by any of the sedimentation methods based on Stoke's Law comprise all particles below 0.060 mm (60 microns).

We have said before, that soil investigators consider all particle smaller than 2 microns as clay. Whether this is justified or not is hard to decide. Grim (Clay Mineralogy, McGraw-Hill, 1953) himself claims that since non-clay minerals are not present in particles much smaller than about 1 to 2 microns, there is a fundamental reason for placing the upper limit of the clay size grade at 2 microns. This may very well be so. I recall however, that Koster's (Ber. deut. Keram Ges. 33, 146-150) /1956/ results obtained from several German common clays show, that such clay minerals as Illite and Clorite may be found even in the particle size range of 63-200 microns, and most of them in the range of 2-20 microns. Even for kaolinite, the maximum particle size was found to be in the range of 2-20 microns. Consequently we could not do better than to abstain ourselves from attaching particle size significance to the term "clay" and give our results strictly in terms of sizes only. It seems, furthermore, that most workers who deal with clays as raw material follow this procedure.

Clay Minerals

Clays, meaning again those materials as they are found in the nature, are composed of clay mineral and non-clay particles. Fundamental clay minerals research has greatly enlarged the number of identifiable clay minerals. This is not the place for a thorough discussion of the different clay minerals that may be found in common clays.

Everybody knows now that they differ fundamentally on the way how the structural "sheets" or layers formed from the fundamental construction units, such as the silica tetrahaedron, and aluminum and magnesium octahaedrons are combined, superimposed etc. We also know that some fundamental clay properties depend a great deal on isomorphous substitution of one ion for another in the above layers and on the ensuing imbalance which cause adsorption and fixation of a cations either between the layers or on the particle's surface, depending on the location of the imbalance causing substitution.

We also know that adsorption of ions on the surface of clay mineral particles may be, apart from the above attraction, due to imbalance within the sheet, by what we call broken bonds. As a matter of fact, a normal clay mineral particle, being a fragment, may be entirely surrounded by them. Due to the nature of the broken bond, a clay mineral particle may exhibit both positive and negative adsorption sites and this may be considered as one reason of interparticular attraction.

We also know that the ions sorbed on the clay mineral particle surface are interchangeable, that is they may be exchanged for others by means of suitable treatment in aquous media, following a well-known order of preference. The nature and magnitud of the exchangeable and exchanged ions affect the properties of the clay in the raw state. The literature on this subject is inmense and can not be reviewed here.

The clay minerals found in common clay may belong to either of the known clay mineral group, that is that of kaolinite, Illite, Montmorillonite or chlorite. As to the particle shape, the most common are platelets, flakes or foliae, less commonly found are laths, ribbon and fiber type habits associated with some minerals of the Montmorillonite group like Hectorite, attapulgite, Nontronite, Palygorskite, Sepiolite, etc.

Due to the structural similarity of clay minerals, there exist interstratified varieties in which individual crystals are composed of elementary layers of two or more different types. Their existence has been known since a long time but the fact that they were among the commonest types to be found in clay fractions, has been discovered only recently. My own experience with one representative of this clay mineral type will be related in a later context.

Non-clay minerals

Non-clay minerals present in common clays are mostly fragments of the original rock. The most frequently encountered non-clay mineral and by common consent the coarsest is naturally quartz, followed by Calcite, Mica, Feldspar and Pyrite. The size of the residual quartz depends to a considerable degree on the nature of the mother rock. So it is said that clays derived from granite contain quartz particles mostly in the range from 0.06 to 2 mm, whereas in those formed from porphyry, the quarts particle size is much smaller, generally from 0.02 to 0.06 mm. Granodiorites produce even smaller quartz particle sizes. In general, however, the data of different investigators vary considerably. In one of Grim's reports the average quartz particle size was 0.03 to 0.06 mm. In Köster's (Ber. deut. Keram Ges. 33, 146-150 /1956/) the largest proportion of quartz was found in the 2-6 micron size.

Some common clay contain crystals of calcite that are sufficiently large to be recognized by the unaided eye and it may form concretions of considerable size. Most of the limestone, about which complaints are heard as being the cause of lime-blowing, is usually not intimately associated with the clay matter but comes from irregular bands of variable thickness which may occur at unpredictable intervals within the clay deposit. These bands are sometimes so small that they can not be removed by hand sorting. Some otherwise red burning clays derived from the weathering of limestones, frequently contain large particles of residual limestone while being substantially free of fine grained calcium carbonate so characteristic of clay of the calcareous type. In the former clay the size of residual limestone may vary from 1 to 6 mm.

A particular case is that of the true calcareous clays, such as those of Iraq, in which the degree of subdivision of the calcium carbonate is so great that it even reaches clay matter sizes and in such a state actually may contribute to the material's workability.

Also pyrite is frequently recognizable with the unaided eye. Grim found that in some cases the proportion of pyrite may be even larger than that of quartz. The minimum size so far found by him was 0.06 mm. Individual crystals may form nodular aggregates that reach sizes up to several millimeters. Extremely small particle sizes, is however, rather rare, as they easily succumb to oxydation.

Organic matter

Organic matter is an important part of all common clays. That portion of it that is capable of imparting to the clay its grey or black color is probably not higher than 2.5%. The largest part of the organic matter will be found in the 2-20 microns range with a maximum between 3 and 4 microns. In shales, one part of the organic matter is so small that it can not be individually recognized under the resolution of the petrographic microscope. Sometimes one finds, however, black opaque particles about 10 microns in size. More important are remnants of wood and roots, which may interfere with extrusion and must be removed therefore.

Evaluation of clays according to the particle size distribution

Graphs showing the cumulative particle size distribution are chronically difficult to evaluate, compare or relate to the fundamental clay properties or to its behavior in actual use. The same may be said of the remaining methods of graphical particle size distribution, such as when the frequency is plotted against the particle size. A method much followed today in Europe consists in dividing the particle sizes into three groups, for instance less than 2 microns, 2-20 microns and above 20 microns. A triangular diagram may then be constructed with the three particle size groups at each of the apexes of the triangle. The particle size composition is then represented by triangular coordinates.

It is the properties in the raw state that may most likely be correlated with the particle size distribution, as represented by a point in the diagram, and it has been found that it is above all the "extrudability", that is ease with which either extremely thin-webbed hollow tiles, roofing tiles or full brick may be extruded from a given clay, which most frequently correlates with the relative proportions of the three above gractions. Areas may then be marked off enclosing compositions suitable for given type of clay product. So for instance according to Winkler (Ber. deut. Keram. Ges. 31, 337343, 1954) thin webbed hollow tiles suitable for light-weight ceiling constructions (hourdis) may be manufactured from clay whose particle size composition falls within the following limits:

Minus 2 microns	24 - 49 %
2-20 microns	30 - 47 %
Over 20 microns	6 - 34 %

(Fig. 1) this certainly looks like the fulfillment of an old dream - to be able to determine the suitability of a clay for a given manufacture by a simple laboratory test and express it by a dot on a diagram.

Experience shows, that the degree of correlation with actual working properties is far from absolute and a blind dependence on it may well be dangerous in some cases at least. A great deal depends on the particle size distribution of the minus 2 microns fraction itself and on the identity of the present clay mineral. As to the first parameter, it is well known how far down to colloidal sizes clay minerals particle may range and it might be well to recall that Bray, Grim and Kerr divide the whole colloidal range into coarse colloids, 0.5 - 0.06 microns, fine colloids, 0.03 - 0.06 microns, and superfine colloids under 0.03 microns.

As to the identity of the clay minerals, it should make conside rable difference whether illite or kaolinite is the main clay mineral present. And when it comes to the minerals of the montmorillonite group the difference in behavior will be even larger.

The underlaying principle, however, is sound. What we call workability of the clay is almost certainly also a function of particle size distribution. An adequate balance between the coarse, medium and fine particles is needed so that the "lubricating" action of the clay colloids is fully taken advantage of. The better, the more intimate the packing between the coarser particles, the less of the colloidal fraction will be needed to achieve a given workability. And the idea certainly should be to obtain the best results, as regards workability and mechanical strength, with the least possible proportion of the ultrafine clay fraction, which as we know, if present in excessive amounts, causes difficulties such as high shrinkage and poor drying properties. Clays too high in ultrafine particles lacking a balanced particle size distribution are sticky rather than plastic and do not flow well through the die.

As its best, however, particle size distribution is a valuable tool in evaluating common clays from the same region or of the same origin, whose general characteristics are well known, so that there is only a question of an a priori selection of the clay that offers the best possibilities. But the general practice of using it as a sole arbitre of the clay's suitability must be definitely discouraged.

The particle size distribution as tool for evaluating brick clays is useless with such clays that do not slake in water as with them, any attempt to obtain a particle size distribution must involve fine grinding, the intensity of which bears

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no relation to that which the material may undergo in actual use. In such cases, therefore, the particle size distribution indicates the intensity of grinding more than anything else. Here we have to depend on other methods of evaluation. Such clays, furthermore, may be the most valuable.

Clay Testing

I should like now the audience to have a look at the Clay Testing scheme before them. (Fig. 2) Its complexity does not escape us and its usefulness is beyond question. It was designed for a survey of clay resources in the New York State. (The Clays and Shales of New York State, Published by State of New York's Department of Commerce, Albany, N.Y.) We should, however, be content with a lesser number of the more meaningful tests. I shall, therefore, attempt to enumerate and discuss such tests through which a satisfactory answer to the fundamental questions could be obtained as to

(1) whether or not brick or any other structural clay product could be elaborated from it and what their quality is likely to be,

and

(2) what is to be done to the clay to make it amenable for the manufacture of a particular product, how its working properties may be improved etc.

We should now try to put ourselves into the position of an engineer wanting to test the amenability of a series of clays for brickmaking. As likely as not he will have to begin with little more equipment than that which might be found in an average chemical analytical laboratory. Nevertheless, there is a great deal of information he might be able to secure even with such limited resources.

He will usually start by determining the proportion of particle above 1 mm in size. That point of separation is chosen on the assumption that any particles under 1 mm are usually quite harmless. The best way to do it is to desintegrate the oven-dry clay by means of a rubber covered pestle making sure that only lumps of caked clay are so affected and none of the pebbles. The so prepared clay is then soaked overnight in 200% of water and the slurry washed through a 1 mm opening sieve. The residue on the screen is then dried weighed and a screen analysis made of it.

The retained portion will then indicate that part of the clay which must be either removed from the clay or rendered harmless. The percentage of fraction passing the 1 mm sieve but retained on the 0.06 mm one below will also be determined. The fine fraction passing the 0.06 mm sieve will be collected and made into a determined volume. From this stock suspension, samples may be pipetted away (after thorough stirring) for use in the sedimentation analysis.

Sub-sieve particle size distribution

The various methods for determining the particle size distribution have been rather well investigated especially by the soil investigators. The most commonly used methods are based on sedimentation under gravity and are quite suitable for the range from 100 to about 0.5 microns. Size distribution curves are obtained and the sizes computed are those of the equivalent particles diameter defined as the diameter of the sphere of the same material which would fall at the same speed as the particle in question. This means, naturally, that especially with clay minerals particles there must be a discrepancy between the effective particle size and the equivalent particle size, because most clay minerals occur in flakes, platelets or scales, less frequently laths, ribbons, fibers etc. Particle shape, however, also affects the rate of fall. It was above all Kunkel (Jour. Applied Phys., 19, 1056-58) 1948) who found that for thin plates and needles, the error thus introduced is greater than 50%.

In our case all this may be disregardes as in our work we will be looking not for absolute values, being quite satisfied with comparative results. We need not go here into the discussion of Stoke's Law on which all sedimentation measurements are based.

Undoubtedly, one of the most rapid test methods providing a size distribution curve is the hydrometer method. A standardised procedure was adopted by the ASTM under its designation D 422-54 T and fundamentally the same procedure is also used by the Technical Association of Pulp and Paper under its suggested procedure T 649 SM-54., which even provides a handy nomographic chart for solving Stoke's Law. The hydrometer method depends on the difference in specific gravity of the medium and the suspension.

The hydrometer method has been severely criticised and in my opinion justly so, as the introduction and removal of the hydrometer agitates the suspension and interferes with free settling. Nevertheless, satisfactory agreement with the pipette method has been frequently reported.

I have been using myself the pipette method of Steele and Bradfield modified by Bray (Jour. Amer. Ceram. Soc. 20, 257-261, 1937). The method consists in taking 5 ccm samples from a diluted clay suspension at specified times and depths. In other words, no special apparati are required excepting those available in every chemical analytical laboratory.

Unfortunately, all the gravity sedimentation method is good only for determining particles size down to 0.5 microns. Then sedimentation times become unrealistically long. Unfortunately again, it is precisely the extremely small particle sizes that affect the properties of the clay most. It is possible to supplement the gravity sedimentation method by the centrifugal one, as has been done by Steele and Bradfield (Rept. Amer. Soil Survey Assn. Bull. No. 15, 88-93, 1934). Using this method, particle sizes down to 0.0625 microns may be determined. This method is very useful as any commercial laboratory centrifuge using tubes and working at 2200 RPM may be used. Such centrifuges are, however, not always available in developing countries.

The next important step will be to determine the so-called technological properties of the clays. By now, our engineer will have known whether his clays slakes in water or whether it will require grinding to develop a siutable workability. He will also know whether, if the first condition applies, they will have to be or can be removed or rendered harmless by grinding. A simple test with hydrochloric acid will tell him whether the pebbles are limestone or not.

In the case of pebble-containing clays it will be best for him to make duplicate tests with (a) the clays freedof the pebbles and (b) the clay in which the pebbles were ground to a size not exceeding 1 mm. Condition (a) is best achieved by slaking the clay in 200% of water and then passing it through a 1 mm opening sieve making sure that the residue on the screen contains only pebbles and no un-slaked lumps of clay. He will then leave the slurry to dry until proper consistency for molding is obtained.

Both, the slakable and unslakable but soft (the lumps may be crumbled between the fingers) should be ground and screened through a 1 mm opening screen. The equally unslakable but hard clays (the particles can not be crushed between the fingers) will be ground to pass a 3 mm sieve. By doing this, we will be simulating conditions prevailing in the preparation of the different clay varieties for the extrusion process. Resuming, we have now the following scheme:

Type of clay	Treatment
Slakable, pebbles-containing clays	Eliminate pebbles by screening slurry through a 1 mm sieve
Slakable, pebbles-containing clays	Dry grind and screen through a 1 mm sieve
Slakable clays without pebbles	Dry grind and pass through a 1 mm sieve
Non-slakable but soft clays	Dry grind and screen through a 1 mm sieve
Non-slakable and hard clays	Dry grind and screen through a 3 mm sieve

Molding

Our engineer will now have to mold his clays, prepared in the above way, into specimens easy to fire. The size of the briquettes will depend on the type of the available kiln. In most capital cities there are small kilns normally used for calcination of precipitates in the course of analytical analysis. These kilns usually work at temperatures not much above 1000°C but in most cases, this is just what we need. Some of these kilns are even equipped with more or less precise temperature indicators. A size 5 x 5 x 1 cm is a good general purpose one. A mold may be of hard wood, perhaps steel sheet lined, but metal is better. For easy de-molding it may be hinged at one of 1 cm sides, or a steel plunger may be provided to eject the molded specimen from the mold. To prepare the molding "mud" the above ground sample will be mixed with amount suitable for easy molding and the engineer will try to achieve at all times the consistency in which the clay will no longer stick to his hands. Some clays, however, never achieve this stage and if they do, they don't posses the right consistency for easy molding. Such a circunstance will be noted, however. The molded briquettes will be dried in the open air and then in a drying oven of the usual type, which is also available everywhere.

To determine the shrinkage, the freshly molded specimen are best provided with reference marks several centimeters apart. This is better than measuring the outer dimmensions of the specimen or using the inside measurements of the mold.

The specimens are re-measured after drying for 24 hours at 110°C. If the available kiln is equipped with a temperature indicating instrument, the specimens may be fired at different temperatures, thus obtaining a sort of a firing curve. At any

We regret that some of the pages in the microfiche copy of this report may not be up to the proper legibility standards, even though the best possible copy was used for preparing the master fiche.

rate, the porosity and water absorption is then determined by boiling the specimens in water for 2 hours and weighing them afterwards. We don't have to go into the corresponding procedures too deeply.

Some clay workers prefer to determine the drying and firing shrinkage on the volumetric basis. (which by the way is much more exact than direct measurements). The freshly molded specimen is first weighed in air and then suspended in kerosene. The difference between these values divided by the specific gravity of kerosene gives the so-called "plastic" volume. After drying at 110°C the specimen is saturated in kerosene and the above procedure is repeated to obtain the dry volume. Volumetric shrinkage is then computed by means of equation (1):

$$D_s = \frac{V_p - V_d}{V_d} \times 100 \qquad (1)$$

where D_s = Volume shrinkage

V_p = Plastic volume

V_d = Dry volume

The percentage of linear shrinkage is then calculated from the percent volume shrinkage by the equation (2)

$$S_1 = 1 + \frac{D_s}{100} - 1 \quad \times 100 \qquad (2)$$

where S_1 = Linear Shrinkage

D_s = Volume shrinkage

To determine firing shrinkage one proceeds in the same way except that dry volume is substituted for plastic volume and fired volume for dry volume in equation (2).

While sophisticated clay testing at a specialized laboratory may involve a great deal of equipment available at any average laboratory or that may be locally constructed with relative ease.

The Atterber Plastic limit method for instance, has by now been thoroughly discredited by generations of ceramists. The fault, however, lies less with the method itself and more with those who interpret it. Most ceramists have so far forgotten the Atterberg procedure and it may be well to re-state once more its essential features. Atterberg (Intern. Mitt. Bodenkunde I. pp. 4-37, 1911) divided what he called the range of plasticity into five stages which were as lately as 1942 redefined by Allen (Public Roads, 22, 263-265, 1942) as follows:

(1) "Liquid limit is the moisture content, expressed as a percentage by weight of the oven-dry soil, at which the soil will just begin to flow when jarred slightly".

(2) "Plastic limit is the lowest moisture content, expressed as a percentage by weight of the oven-dry soil, at which the soil can be rolled into threads 1/8 inch in diameter without breaking into pieces. Soil which can not be rolled into threads at any moisture content is considered non-plastic".

(3) "Plastic index is the difference between the liquid limit and the plastic limit. It is the range of moisture contents through which a soil is plastic. When the plastic limit is equal to or greater than the liquid limit, the plastic index is recorded as zero.

It should be noted here that Atterberg stage included three more, which are generally not used any longer. They are:

(1a) Lower limit of fluidity, at which two portions of the clay will not flow together if jarred, and

(3a) Cohesion limit at which the grain cease to cohere.

The different limits are relatively easy to determine even though a great deal of experience is necessary to secure reproducible results. They tell a great deal about the clay if interpreted in accordance with the now known criteria as being related to the sorption capacity of the clay mineral, to the specific surface and thus to the particle sise. The data obtained by White (Amer. Mineral. 34 508-512, 1949) with pure clay minerals may be important in interpreting the plastic limits obtained with common brick clays.

	Plastic Limit	Liquid Limit	Plastic Index
Illites	25 - 55	50 - 115	25 - 60
Kaolinites	25 - 40	30 - 75	0 - 35
Montmorillonites	80 - 250	115 - 700	35 - 600+

It goes without saying that plastic indices above 50 probably indicate the danger of drying troubles for the clay involved. In which way the limits indicate particle size is also borne out by White's figures. The plastic index rose from 25.5 for the whole sample of illite to 51.38 for the 0.5 micron fraction. With kaolinite the increase was less spectacular (22.06 to 32.[illegible]). In other words high plastic indices are indicative of a high proportion of fine particles which may cause troubles. Ultra-high values indicate the presence of montmorillonite which may be even more dangerous.

Some clay workers prefer to use the Rieke's Index. (Ber. deut. keram. Ges. 4, 182-3, 1923-24) in which the difference in the moisture contents between two consistencies is determined. One of these is the Atterberg's Plastic limit and the other the stage at which the clay stops adhering to the hands. It is, therefore the "sticking limits" and the property determined is another version of what is called "water of plasticity" determined of course within a more significant range. It should be observed here that such an authority as Howink (Elasticity, Plasticity and Structure of Matter, P. 346) concedes that the Rieke's Index, due to its excellent correlation with the water sorption capacity, which in turn depends on the nature of the clay mineral and particle size seems to have considerable significance and deserves further study. Data obtained by Endell, Hoffman and Wilm (Z. angew. Chemie, 47, 539, 1934) indicate that it is only with montmorillonites that the Rieke's index rises above 10 whereas with normal kaolinitic clays these indices remain at 4 - 10. This is important for us.

Returning now to the so-called "water of plasticity", what is meant by that expression is that amount of water which is required to produce maximum workability in the clay. Since this condition is difficult to assess, as Macey (Trans. Brit. Ceram. Soc. 47, 291-326, 1947-48) was to find by himself, and considering that what is called 'water of plasticity" is a valuable and meaningful characteristic, the exact stage at which the water content is determined should be determined more exactly than mere "feel". Any rheological property will do. The easiest to determine is the deformation under compression. The Pfefferkorn method, (Sprechsaal 25, 297-299, 1924) in which the moisture content of clay body that under the condition of the method has suffered deformation by 33-1/3 % of its height, is considered as the "molding water" (Anmachwasserbedarf). (Ber. deut. keram. Ges. 34, 14, 1957). The corresponding apparatus, though simple may not be easily available.

When using these old methods, we should do well to forget all about their old association with what is called "plasticity", about which we know very little. High Atterberg or Rieke's plastic indices do not necessarily mean that the clay, exhibiting it, will work better in extrusion. Instead, we should concentrate on the fact that the higher these indices, the higher are also likely be the contents of colloidal particles and that above certain values the presence of montmorillonite should be expected. Another of these simple tests, which nevertheless yields a great deal of information, is the Moisture Adsorption as determined by Keeling (Trans. 6th Intern. Ceram. Congress 195-203). The method consist essentially in determining the moisture adsorbed by oven-dried clays when exposed for 24 hours 75% relative humidity atmosphere at 25°C. The required relative humidity is conveniently maintained by means of a saturated solution of common salt. Since the moisture adsorption is roughly proportional to the specific surface area the meaning of the test is clear. However, Keeling introduced another refinement by establishing an Ignition Loss/Moisture Adsorption Ratio which, as he claims, is characteristic of the clay mineral. Since in brick clays we are rarely dealing with pure clay minerals but with mixtures of these non-clay minerals and generally not productive of ignition loss, whose concentration, furthermore, is generally difficult to establish, the LI-MA Ratio is of doubtful value to the practical brickmaker. But the sole Moisture Adsorption test, as indicator of the particle size of the clay fraction is of positive value, chiefly on account of its ease and simplicity.

Drying characteristics

One of the most important property of the clay is its drying behavior, that is the ease or difficulty with which it may be safely dried. I have seen quite a few brick works going down the drain because the drying characteristics of the available clay have not been determined. It may be said in general terms, that most losses, which occur in the manufacture of extruded brick, originate in the dry state eventhough they might not have been noticed until they have been fired. Of these losses, those caused by defficient drying properties are among the highest.

We shall talk more extensively of these clays later, but it is important that they be detected as early as possible in the process of evaluation, because at this stage the advice of an experienced brickmaker could still be taken. "The most economic thing to do with such sticky clays so difficult in the drying is not to use them".

The unfavorable drying properties are due to their high proportion of colloidal matter. Most of them contain, furthermore, the clay mineral Montmorillonite, whose swelling properties are so well known to us. As we have seen, the presence of Montmorillonite in the clay is usually detected through its high sorption capacity and high plastic index. The drying difficulties, which manifest themselves by the deficient rate of removal of water during drying, causes surface cracking. The latter defect is due to the fact that at normal drying speeds and humidities the surface of the clay body dries out, and becomes more or less impermeable before the moisture from the interior could have migrated to it and evaporated. Differential shrinkage sets on because the interior of the body, which has lost little moisture, does not shrink whereas the surface layer does. Cracking is the normal outcome of this process.

The two methods, normally used to detect difficult drying clays are based on the two symptoms mentioned above. In the first method, the behavior of a small freshly molded specimen, for instance 5 x 3 x 1 cm is observed during its drying in an atmosphere of known relative humidity. This is best done by placing the freshly molded specimen on a perforated plastic or aluminum sheet over a saturated solution of certain salts in an ordinary dessicator. The dessicator is then placed in a water bath whose temperature may be controlled as required. The relative humidity within the dessicator may be controlled by the choice of the suitable saturated solution from say 28.5 to 99. One usually starts with a low relative humidity, say 30%, achieved by means of a saturated solution of $MgCl_2$ at 60°C. Normal drying clays will survive this treatment without troubles. With tender drying clays the relative humidity in the dessicator will have to be gradually raised until no cracking occurs. The higher the relative humidity required for the trouble free drying of the specimen, the higher is the drying tenderness of the clay. The cracks usually appear already after 30-45 minutes. The clay that does not require a relative humidity over 60% is considered reasonably safe. The second method consist in determining the humidity gradient through the body of the drying clay. In one version of this method (Improving the Properties of Clays and Shales, Canada Department of Mines and Resources, No. 793) a test pieces in the form of a cube 5 cm square are dried for 3 hours at 65°C. After removing them from the dryer, a core 12.5 mm is cut out of the cube and sliced in sections 4 mm thick, which are carefully weighed and then dried at 110°C. Afterwards the percent moisture contents are calculated and plotted against the distance from the drying surface. The figure 3 shows a group of clays showing different drying behavior. In a normally drying clay the moisture gradient would be an almost straight gently sloping curve. The more steep the curve the worse are the drying characteristics.

In a refinement of this method extruded, 15 mm diam. rods 10 cm long, are wrapped in tinfoil, leaving only one end exposed. After drying at 60°C for 6 hours, the rods are sliced into 1 cm sections in which the moisture content is then determined, Again a moisture gradient curve may be constructed by plotting the individual moisture content values against the distances from the open end of the rod.

Also very useful is the determination of the Bigot curve, obtained by plotting the values of the drying shrinkage against the respective losses of moisture. The steeper the curve, the more difficult is the clay supposed to dry. Also the so called "turning point", that is the point at which the curve begins to have a linear run is significative. It has been found, however, that exceptions are common so that the conclusions of the Bigot curve are not be taken as dependable as far as the drying tenderness is concerned.

Extrusion

Actual extrusion tests are naturally invaluable and there really is no substitute for them. But in order to be meaningful, they should be conducted with auger diameters at least 15 cm. Anything smaller does not give representative results, mainly because the auger takes up a too large a share of the available barrel space. The clay helical coil, which is then the result of the auger's rotation, is consequently too thin and the resulting degree of lamination unrealistically high. Augers of that size are unlikely to be available in many developing countries.

Much better results are obtained by means of a plunger press, which may easily and cheaply be built almost anywhere. It consists fundamentally of a length of 40 cm diam. flanged steel pipe to which the front and rear templates may be bolted. The front template is provided with a 5 x 2.5 cm straight die, the rear one with the opening for the shaft. The plunger attached to the shaft is activated by means of a flywheel or a four-armed capstan. A more sophisticated but also easy to build extrusion apparatus was designed by Fréchette (Jour. Amer. Ceram. Soc. 19, 233-34, 1936). (Fig. 4) while one may not determine with any degree of exactitud the lamination tendency of a clay, by means of this apparatus, there are other deffects which do become apparent in the course of the tests. Torn corners is one of them. Furthermore, it provides handy briquettes to be used in most of the tests that have been just described.

One of the most important tests is the shrinkage and deformation behavior under load. Unless one has some kind of kiln which permits access from the top, it is quite difficult to improvise. I have myself used the principle adopted by the ASTM for testing firebrick under load at high temperatures, but adapted it for use with specimens 5 x 5 x 5 cm, loading them by means of a 13½" firebrick placed "on end" and protruding through the kilns crown. The protruding end of the 13½" brick was then loaded to give the total load required by the 5 x 5 cm surface of the specimen and it was calculated that a total load of 10 kilos is required to simulate setting conditions in an average kiln. The test must be conducted at various temperatures and the results plotted.

The tests which have been described so far are such as may be conducted with simple, frequently home-made equipment. The obtained results should enable the engineer to decide whether the available clays are suitable either for mechanized or handicraft manufacture. After the completion of these tests he will also know what is to be done to the available clays to render them suitable for either manufacture. He will also have learned by this time that clays of different characteristics may be combined to achieve the desired results. Also a decision might have been reached as to the most convenient technological process.

At this point, the clay samples are usually sent to a specialized clay laboratory for further testing and evaluation. Most institutes of this kind have their own standardized testing schemes and methods and this is not the place to deal with them in any detail. It may be said, however, that the information which will be sought will be more or less the same as we were trying to secure by means of our primitive methods. However, the testing method will be more refined and the equipment much more sophisticated and highly specialized. Some of the usually conducted tests will now be briefly discussed:

Physical and Chemical Tests

(1) Particle size distribution
(2) Moisture sorption
(3) Dehydration behavior
(4) Chemical Analysis
(5) Petrographic Examination
(6) Differential Thermal Analysis

Technological Tests

(1) Grinding Behavior
(2) Pugging behavior
(3) Extrusion behavior

(4) Drying behavior
(5) Progress of vitrification as indicated by changes in porosity, shrinkage and mechanical strength and color.

We have already dealt with particle size distribution at some length so that there is little to be added here. As to the dehydration curve, it yields results that are interesting in themselves but the correlation of which with the fundamental brick making properties is vague at best. Much the same may be said about the Differential Thermal Analysis. It is certainly important to know the nature of the clay minerals present. So for instance a clear kaolinite type of curve presages less troubles than another indicating the presence of Montmorillonite. However, most common clays contain more than one clay mineral and the resulting curves may be very difficult to interpret. And when it comes to mixed layer clay minerals, the interpretation difficulties are multiplied. Chemical analysis may be considered one of the more useless discipline as a simple firing test conveys much more practical information.

A petrographical examination is very useful as it permits to appreciate the presence of non-clay minerals, whose particle size is large enough to permit their identification, and sometimes even to estimate their relative proportion. I would say that more can be learned from a petrographic examination than from a chemical analysis. In order to observe the extremely small particles of clay minerals, electron microscopy must be resorted to. Particle size measurements effectuated with the aid of an electron microscope are very dependable but the conclusion as to their distribution uncertain at best, chiefly due to the possibility of segregation which may occur in forming the mount. The practical value of the lectron microscope for the clay worker must be considered as rather small.

When it now comes to the strictly technological tests, one of the more important is the clay's behavior in grinding. What must be decided here is whether the clay can be made into an extrudable body by means of wet preparation or whether it will require dry-grinding and sieving to produce a workable body. The slaking test fives the first indication. A clay that slakes in water will, of course, give no problems in the wet preparation. There are, however, great many clays that do not slake at all but are soft enough to produce an extrudable body by wet preparation. This property of a clay is, however, difficult to determine by other method than those that actually simulate the action of the corresponding production machines. Well equipped clay laboratories should count with one or two sets of smooth rollers through which the clay samples may be passed. The number of times the clay in question has to be passed through such test rollers are then taken as indicative of the ease or difficulty of the clay to be worked by that method.

A particular case of those clays that are soft enough to be worked by the wet method is the one when pebbles are present. About 5% of pebbles under 6 mm in diam. may usually be tolerated as they may be quite effectively ground between the smooth rollers. But their presence does increase the wet milling difficulties.

If dry grinding is required, the clay should be run through a dry-pan and a screen analysis made of the product. Some of these hard and brittle shales produce too little fines if ground under normal conditions. They must, consequently, be ground finer or other means for obtaining the desired fines provided. With hard shales about 30 to 40% must be finer than 0.3 mm.

Extrudability

The clay's extrudability is perhaps its most important property, next to that of the drying characteristics. No clay should be declared fit for the manufacture until full sized bricks have been extruded from it, dried and fired under either fully industrial or closely simulated industrial conditions. Extrusion tests supply a great deal of information, which may not be detected by any other means. Nor are these amenable to being expressed numerically.

One of the first things observed when a given clay is being run through a full size extrusion machine is the so-called pugging range. This means that a little more or a little less water does not notably affect its consistency. This property is important as clays possessing a short pugging range are difficult to keep just right for the operation of an extrusion machine. Incidentally, this property of clay is susceptible of being evaluated by a rather simple laboratory test. So for instance, is some rheological property of the clay is determined in function of its water content and the results plotted in this way, a curve is obtained the slope of which is roughly proportional to the rate of change of the clay's consistency with water. The Pfefferkorn compression figures at different moisture contents may be used for that purpose.

The best way to conduct an extrusion test is to extrude a full brick size column, without de-airing and using a dry die. It must be remembered that the purpose of the extrusion test is to determine the qualities of the clay and not to show how good a product could be made out of it with careful manipulation.

The defects to be observed are the following:

(1) The smoothness of the extruded surfaces
(2) The appearance of the corners, that is the presence or absence of tearing,
(3) Absence or presence of lamination and its degree.

Good extrusion clays produce a very smooth surface even with a non-lubricated dies. The more roughness is produced, the less satisfactory are the clay's extrusion characteristics. Furthermore, a good-working clay will run through the dry die without any tearing at the corners. A less suitable one will produce some tearing but the fault may be overcome by applying back pressure to the column (such pressure will be usually offered by an automatic brick cutter). A bad clay resists all efforts to overcome the torn corners A properly lubricated die will naturally offer less resistance than a dry one and by using such a die a satisfactory column may be obtained even from an unsatisfactory clay. But is is to be expected that torn corners will inevitably appear at irregular intervals in the course of a day's operation

By far the most important observation is one that concerns the clay's tendency to produce internal structure, mostly called coring or lamination. While this defect is a consequence of the extrusion process itself, the clay's response to this inherent cause may vary to considerable degree from one clay to another. Nor is there any possibility of determining this tendency in the laboratory. Ellis Lovejoy, the well known american brick consultant used to use the figure 5 to illustrate five degrees of lamination severity from practically none at the bottom (No. 1) to excessive (No. 5) at the top. To make comparison, the column extruded from the tested clay is broken and the exposed interior compared with the examples in Fig. 5.

Generally speaking, we distinguish two kinds of lamination. The series of striae or layers near the surface of the column, more or less parallel to it and rounded at the corners are due to the friction of the die which retards the flow of clay at the surface while below the clay moves along at greater speed, thus causing slippage. These are, therefore, die lamination planes. Auger lamination, which is seen in Fig. 5 example 5 as a large core, twisted, bulging in one half of the brick and correspondingly concave in the mating half brick. This lamination is caused by the fact that the clay leaves the auger in the in form of a helical coil, which is compressed and conso lidated in the spacer and finally the die itself. However, the surfaces of the helical coil of clay do not knit together to form a homogeneous extruded column.

Page ', para 2, line 3

Change: "to imbalance within the sheet, by " to read "to imbalance within the sheet, caused by . . ."

Page 7, para 2, line 4

Change: "remaining methods of graphical particle .. " to read "remaining methods of graphical representation of particle . . "

Page 7, para 3, line 4

Change: "that is case ...." to read"that is the case .. ."

Page 11, para 5, line 1

Change: "Both, the slakable and unslakable but soft" to read "Both, the "slakable" and "unslakable but soft" clay . . "

Page 13

Insert in the second line of para 5: " equipment, there are many things about a clay that may be learned by using commonplace equipment available . ."

Page 14, para 2, line 1

Change: " . . that Atterberg stage " to read " . that Atterberg stages . "

Page 1', para 2, line 1'

Change: "......particle size seems to have considerable significance and deserves further study." to read "......particle size is significant."

Page 15, para 3, line 8

Change: "........should be determined more exactly....." to read "........should be defined more exactly......"

Page 16, para 1, line 7

Change: "........are also likely be the......" to read ".....are also likely to be the....."

Page 16, para 1, line 14

Change: "......24 hours 75% relative humidity" to read ".....24 hours to 75% relative humidity"

Page 16, para 1, line 23

Change: "........non-clay minerals and generally......" to read ".....non-clay minerals and materials generally....."

It is probably impossible to eliminate lamination altogether so what remains to be done is to render it harmless. How this is done will be dealt with in another context. The fact remains, however, that different clays vary greatly in their tendency to produce laminations.

Behavior in drying

Drying behavior is also preferably determined in full sized bricks. While extreme drying tenderness is in most cases detected before the testing reaches the stage of full size brick, it is necessary to submit the freshly extruded brick to a normal drying cycle. It is a well known fact that lamination faults are frequently discovered in the dryer, where they manifest themselves in more or less severe cracking. As a matter of fact, such cracks are sometimes attributed to bad drying characteristics whereas they are in reality the consequence of lamination. Lamination, however, may in some cases aggravate the effects of bad drying properties.

In some tests with full size bricks the clays may be classified either as "Fast", "Medium", "Slow" and "Impractical", depending on whether they can be safely dried in 24 hours or less, in 72 hours, in 96 hours and finally, if they can not be safely dried in 120 hours. In a more sophisticated test, hand-molded specimens 80 x 40 x 24 mm are subjected to severe drying in a specially designed oven. The clays are classified according to the time it takes to produce the first indication of cracking. The following scale might be of interest: (Ziegeltechnisches Jahrbuch, 1958, pp. 145).

Time in minutes until the first appearance of cracks	Classification of drying tenderness
0 - 2	extraordinary sensitivity
2 - 4	very high sensitivity
4 - 6	high sensitivity
6 - 8	sensitive
8 - 10	still sensitive
10 - 12	low sensitivity
12 - 20	very low sensitivity
over 20	not sensitive

The importance of extrusion tests with full size brick can not be overemphasized, especially as regards the processes of preparing, extruding and drying, because once a product has been successfully dried, there is little that can go wrong with it except that it may be improperly water-smoked or overburned. Most of the time these defects are caused by negligence. And as have been said before, even cracking, which is sometimes observed in firing may be frequently traced back to lamination or other causes originating in the manufacture of the raw product.

The justification for my insistence on full scale extrusion tests may best be illustrated by the following "true life" story, which involved the use of a combination of two particular raw materials. A well known European research institute was retained to determine the most favorable proportion. Then, the Bigot Curve was prepared, drying sensitivity assessed, the optimum firing curve established, the shrinkage behavior investigated by means of a thermal expansion apparatus etc. In other words, no effort was spared to secure a thorough knowledge of the materials. Then we proceeded to extrude a number of brick under actual manufacturing conditions dried them in the available chamber dryers, Inspite of the fact that laboratory results indicated drying sensitivity, no troubles were encountered in the course of the industrial-scale drying operation. Then we set the dry brick in the available Hofmann kiln together with the normal output of the works and produced exactly one hundred percent breakage.

Testing the clay's firing behavior

A rather good idea of the clay's length changes on heating may be obtained by means of an ordinary thermal expansion apparatus. Although the data here obtained are not directly applicable to the practice, valuable information about the clay's behavior on heating are obtained here nevertheless. That is for instance the magnitude of the initial expansion, and the rate of shrinkage, the first indication of the vitrification range is also obtained here, as the expansion-shrinkage curve at the end of the contraction period may either produce a more or less prolonged trough or suddenly turn up after reaching the highest shrinkage point. The latter feature naturally indicates a short vitrification range.

Most clay testing laboratories fire either hand molded or extruded specimens at various temperatures and determine in them the water absorption and porosity, shrinkage and mechanical strength. The last property is best determined in flexion and expressed as Modulus of Rupture. These properties may then be plotted against the firing degree, expressed either in degrees C or in pyrometric cones. Such curves are good indicators of the clay's firing properties. A sharp bend in the porosity and shrinkage curves indicates, as has been said, dangerously short vitrification range whereas a trough in the porosity or absorption curve at values close to zero indicate long vitrification range and therefore a safe burning clay. Most unwelcome are those clays that never really reach the neighbourhood of zero absorption but start to bloat before reaching full vitrifications.

Most valuable for the manufacture of common clay products are such clays which conserve say 10% porosity during a long tempera- ture interval. Such clays are hard to overburn - they just get progressively harder.

Very useful for determining the clay's firing properties is the Temperature Gradient Method developed by Stone (Jour. Amer. Ceram. Soc. 36, 140-42, 1953) based on an idea by Steger (Ber. deut. keram. Ges. 17, 177-82, 1936). Here a test bar about 20 cm long is exposed to a temperature gradient in a specially constructed electric furnace. The temperatures along the bar are measured at 10 points during the firing. After completing the test the bar's width is carefully measured with a caliper at the point where temperature measurements were made and shrinkage calculated. The corresponding values may then be plotted against temperature and a curve constructed. The bar may also be sliced by means of a thin diamond blade and the porosity of each piece determined. A porosity - temperature curve may then be constructed. The advantage of this method is its rapidity.

Clay Prospecting and Exploration

In prospecting for clays there is no easy substitute for honest leg work. The country must be explored on foot and it pays to send out "scouts" who would "comb" it so to say, searching for outcrops exposed in streams, road cuts etc. It is also well to interview farmers who usually have a pretty good knowledge of them. Eventhough untrained scouts may be used at the beginning, a knowledge of Geology, preferentially Clay Geology and particu- larly the Geology of the region are of considerable help. These are somewhat difficult to secure.

In a hilly country an experienced clay man is aided in tracing clay beds by the contours of the hills. A clay or any soft material will be indicated by a relatively flat bench in the hill and such benches will be followed for a long distance and are easily picked out in passing from one hill to another. Having located them it remains to open them and sample them. Beside benches, conclusions may be drawn from the shape of the hills. Steep slopes indicate hard materials, gentle slopes softer materials.

I used to know a practical clay man whose knowledge of the rela- tion of topography and even the type of vegetation and clay occurrence was uncanny. He would start his prospecting by flying over the region in a small plane or a helicopter and would pick out features of the land below him and mark them as possible clay sites on his map. He was right in 8 out of 10 cases. Such talents, I recognise it, are rare and of course imply a thorough knowledge of a particular region.

When sampling outcrops it pays to discard the upper part of the clay to a depth of at least 20 cm. This upper part of the exposed clay stratum will most probably have been leached out and oxidized and will unlikely represent the characteristic of the deposit.

Having located a sufficient number of outcrops, indicating a good sized deposit of acceptable quality, the stage, which I shall call "exploration" will start. This, however, should be an engineer's job and the advices of a geologist will be most useful. The located clay region must now be drilled, but the question how closely one must drill will depend on what one will find. The first drilling, usually called exploratory or "wildcat" drilling is usually done on 250 meters centers. If sufficient clay of the desired quality is found in several adjacent holes, the area is then drilled on 100 meters centers. The results being promising, the drilling is continued on successively decreasing centers and finally on 20 meters centers before the location of the pit may be decided.

Drilling Equipment

The type of drilling equipment will depend first on its availability, next on the nature and depth of the overburden and hardness of the clay. For use in structural clay products one will look for clay deposits with little or no overburden, because stripping in an expensive operation. The overburden should also be soft. Underground mining is seldom practicable in the case of most structural clay products. With these limitations in mind the most suitable equipment is an auger drill.

Truck mounted, gasoline engine driven 4-6" diameter augers are frequently used in clay exploration, but they are not easily available in most developing countries. Three and four inch hand rotated auger drill are used and they are not expensive. They are usually attached to sleeve-jointed pipe. In the deeper holes the apparatus is lowered and hoisted by means of block tackle attached to light tripod. The deepest hole on record was drilled to a depth of about 42 meters. This is more than what is normally required in the case of even very large common clay deposits. The average speed is reported to be about 60 cm per hour and the cost of labor about US $6.00 per meter (in the US), for boring and sampling.

Smaller but quite satisfactory augers may be manufactured by a skilled blacksmith. One example of these "home-made" drills is a double twisted auger 1-1/4" in diam. with a pitch of 2-3/4" and 1/4" face. The threaded part is about 13" long terminating in a 6½" long, 3/8" rod threaded at one end and attached by means of a coupling to about 40" of iron pipe 3/8" to which a crossbar to serve as handle is fastened by means of a tee. Additional lengths of pipe are screwed on as required. One may use this hand drill to a depth of some six meters, although the record seems to be 18 meters. It is also possible to use a carpenter's single twist bit of the same size as above, welded to a section of a ½" pipe to which additional pipe lengths may be screwed on as needed.

The usual procedure is to start by digging a hole by means of a spade to prevent surface soil from dribbling back into the hole. For sampling the auger has to be withdrawn from the hole and the clay that has collected between the twists of the auger carefully removed. The amounts of clay collected in this manner are not large but quite sufficient for the determination of a few of the fundamental characteristics of the clay. Samples should be taken at regular depths, when necessary even at 30 cm intervals. A record showing the depths drilled and samples taken must be filed away and kept together with the report of the clay's characteristics.

It is also worth the effort to prepare three dimensional models of the explored clay field with wooden sticks representing holes on which the existing strata are painted in different colors according to their qualities.

Finally a note regarding other types of drills. Auger drills are useless with most hard clays such as shales. Here either rotary core drills or churn or percussion drills must be used. Rotating core drills, because of their dearness will seldom be found in developing countries and their purchase for the exclusive purpose of clay exploration will rarely be entertained. Sometimes, however, they might be borrowed from some mining enterprise in the country. Rotary core drills provide more clay per sample but also require about 50 liters of water per minute. This is continuously pumped through the core barrel to flush out all cuttings.

A churn of percussion drills use no water and may be used with all kinds of overburden and with all types of clay. But again, as in the case of rotary core drills, they are unlikely to exist in most developing countries.

When no drilling equipment is available, the only way out is to dig wells or sink shafts at uniform intervals. These must be at least 2 x 2 meters. A six meter depth is usually the maximum. Casing is required with poorly consolidated clays. This is the most time-consuming and expensive exploration method. If however, no drills are available and the need for assessing the available clay reserves pressing, there is no other way out.

Valuation of clay deposits

The valuation of clay has been the subject of much discussion. What is usually done is that all expenses connected with acquiring and developing a clay property are charged to it. That involves all expenses incurred in prospecting, exploration and testing. Road building costs to make the property accessible must also be included. Most brick makers believe that this is not enough and argue that a clay that is being used in an existing factory should be worth more than it was before the factory was built, because its value was enhanced by the expenses involved in perfecting the product and establishing it on the market. They also argue, sometimes, that coal lands have differential values, one for virgin coal land and another for the operating property.

Anyway, the amount charged to the product for the clay used in its manufacture should not only include the cost per ton arrived at as stated above, but also what we call depletion charge or allowance, which is meant to provide funds for acquiring new land after the one in use has been exhausted. This allowance should be higher than would correspond to the cost of the clay as calculated above, as it may be safely assumed that the price of land in the neighborhood of the plant will have increased during the time of its operation, not only as a consequence of the above enhancing of the clay's worth but also because of the general tendency of real estate to increase in price.

This is, however, something for the country's fiscal authority to establish or at least to approve. It may be interesting to mention in this context that the decision of a U.S. District Court puts the depletion allowance at 5% of the Gross sales price. (Bull. Amer. Ceram. Soc. 33, 223, 1954) of the product manufactured.

Use of Industrial Wastes

Although there might not be many industrial waste in most developing countries at the present stage of their development, occassionally the need to dispose of them may arise.

The use of coalwashing tailings will be a border case, as they consist mostly of clay. In one investigation (Trans. Brit. Ceram. Soc. 57 258-270, 1958) it was concluded that they should produce brick with characteristics similar to those made from clay. Furthermore, burnt-out pit shale and Fly Ash could be used as grog in connection with these materials.

Pulverized fuel ashes, of which huge amounts have been accumulat ing near large power stations which use pulverized coal, may constitute another raw material for the manufacture of brick. The nedd to dispose of these ashes, whose output in 1953 was estimated at over 2,000.000 tons per annum (Trans. Brit. Ceram. Soc. 53, 293-313, 1954) must have declined considerably due to the intro- duction of oil burning.

After an investigation effectuated in 1953 it was concluded that where a suitable plastic clay is available within a reasonable distance of a source of ash, the manufacture of fired brick containing 80 to 90% of this material and 20% clay is a distinct possibility. Both extrusion and semi-dry pressing were used here. Nevertheless, it seems that the particle size distribution of the used clay and its plasticity seem to have an important bearing on the effects of adding pulverized fuel ash and therefore this ash cannot be mixed with all clays and every clay must be carefully tested to ascertain whether the addition of ash would be of any practical value.

Use of non-clay raw materials

When the available clays do not possess the requisit properties, the clay technologist has to look for other sources of raw materials, reaching even into the non-clay field or devise new and unorthodox manufacturing methods. While some of these unorthodox manufacturing methods will be dealt with in another context, it should suffice here to say that the proper treatment to be given to a clay will be the result of the tests which were discussed in this chapter. So for instance a Montmorillonitic clay which can not be safely dried may be used in dry-pressing or its objectionable properties may be improved by a preliminary roasting. Hard and apparently non plastic clays may develop a degree of plasticity for extrusion by fine grinding and should even this fail, brick or blocks could be molded from it using the vibration-compaction method normally reserved for molding concrete blocks, using a properly "doctored" clay as bond. Such a method was developed some years ago by the Armour Research Foundation for Saudi Arabia (Bull. Amer. Ceram. Soc. 33, 218, 1954). While in the Armour process bloated aggregate is used because thermal insulating properties were desired for use in a hot desertic country, there is no reason why ground, non- plastic, calcined or raw materials could not be used. My own results with materials of volcanic origin seem to point in that direction. Satisfactory brick have been developed by me in the Valley of Mexico, where good clays amenable to extrusion are scarce, as the only available variety is an alluvial clay composed chiefly of montmorillonite with interlayered illite type layers, which exhibits extremely unfavorable drying properties. Here the great abundance of a pumice could be made use of in the manufacture of brick by means of the vibration-compaction method using as abound a small proportion of the above montmorillonitic clay.

On the other hand it was also demonstrated that excellent bricks could be manufactured from locally abundant volcanic scoria by bonding it with 10-20% of the montmorillonite clay and firing it at temperatures around 1000°C (Bull. Amer. Ceram. Soc. 35, 363-367, 1956).

Extrusion of limestone

The use of certain types of soft and impure limestones also belongs into the category under discussion. Such materials have been used for brickmaking in Havana, Cuba since a long time. In the absence of suitable clays, these limestones offer distinct manufacturing advantages. Only 10 to 12% water is required for extrusion and the material dries easily and when fired at 590°C, is has the strength of a clay brick fired at 870°C. (Bull. Amer. Ceram. Soc. 35, 275, 1956). About 10% of clay is added to the limestone to produce a yellow color.

That this is not an isolated phenomenon is shown by the fact that the use of limestone has been in Honolulu, where with addition of 5% of weathered lava, crushing strengths of 98 and 189 kg per sq.cm. were obtained with and without vacuum respectively. The firing temperature had to be at least 480°C otherwise the brick would slake, but if fired above 730°C the $CaCO_3$ would dissociate.

Another investigation (Bull. Amer. Ceram. Soc. 35, 286-288, 1956) showed that usable building brick may be produced from marls and dense limestone, the latter acting as grog. The requisite amount of clay mineral is in the order of 10%.

These examples have cited in order to show that the brick engineer has to display a great deal of imagination when dealing with brick raw materials, especially when the traditional ones fail.

III. THE TECHNOLOGICAL PROCESS

The engineer's ability to devise and design technological processes in accordance with the requirements of his raw material, the availability of mechanical equipment to meet these requirements and human capacity to use it efficiently, these constitute the second set of resources for the anticipated development of the clay brick industry.

Other participants have already dealt with the production technology in considerable detail. We shall concern us briefly with the selection of the preparation method and particularly with the reason that may induce us to chose either the wet preparation method as practiced in Continental Europe, or the dry grinding one as used predominantly in the U.S. and to some extent in the U.K. Our decision will depend chiefly on the characteristics of the available raw material and to a lesser extent on the product to be manufactured.

As has been pointed out already, easily slaking clays and some none-slaking but soft and friable ones, lend themselves better for the wet preparation method, especially if they are highly plastic or sticky. For shales or some of the harder clay varieties, dry milling is the only reasonable answer. The nature of the product to be elaborated also has a bearing on the subject. One would be more inclined to use the dry grinding method in the manufacture of face or engineering brick, but the fact that these bricks are usually manufactured from hard clays or shales also has something to do with the above preference. The distinction between a common brick and a face brick, which is almost absolute in the U.S. becomes progressively more nebulous as we travel eastwards from that country. Furthermore, each method has its hard-core adherents who would not change their minds either way regardless of logical reasons that may be expounded.

Much depends on the climate. Clays that are permanently wet are difficult to grind efficiently in a dry pan as even a damp clay will pack on the bottom and none of it will pass through. This is one of the reasons why some technologists prefer to use the wet preparation method even at the cost of having to use several sets of smooth roll to get the grain size down to a reasonable figure.

When I said that easily slaking clays lend themselves better for the wet preparation method I realized that there are important exceptions to that general rule. That is there might be clays that slake too easily. The clays around Baghdad in Iraq for example are extremely fine grained and the brick extruded from them exhibit a great deal of lamination when prepared by the wet preparation method. The helical coil, about which we talked a little while ago, just does not knit well enough. We all know that it is possible to alleviate this defect by providing for a comparatively coarse particle size distribution. Since in Baghdad even the addition of sand, which would almost certainly alleviate the problem, was considered too expensive, I have suggested that the clay be ground in a dry pan to a comparatively coarse size, say 8 mm, tempered thoroughly but quickly before the coarse grains have had the chance to desintegrate.

Wet Preparation

The equipment used here would consist of a proportioning box feeder, a clay desintegrator to break up the lumps of clay and one or two sets of smooth rolls. This will be the very minimum and might work quite well with soft alluvial clays. More sophisticated installations may have in the first place a clay crusher or a shredder. The selection between the two depends on the softness or toughness of the clays and on the degree of humidity. A shredder will be used with the tough humid clays. This equipment will be followed by a wet pan where the clay is crushed, tempered and squeezed through the perforated bottom plates. Beneath the wet pan there is usually a collector which collects the clay as it passes through the slots and delivers it at single point for discharge into the first set of smooth differential speed rolls. Considerable homogenisation takes place in this collector (Maukmischer) and it is considered a good investment.

Then there are either one or two sets of differential speed rolls. The number depends on the response of the clay to this treatment and on the type of product manufactured. The important thing is to maintain the rolls in good conditions as they usually wear down quickly. Good rolls have attachments for grinding their surface. The connection between these machines is normally provided by slat type conveyors.

Whether the clay will go directly to the extrusion machine, usually combined with a short length of pug mill, or whether a double shaft mixer is installed between the last set of rolls and the extrusion machine depends on individual taste. My own experience indicates that some clay tend to produce an excessive amount of lamination if they are fed directly from the rolls to the extrusion machines. In these cases the double shaft mixers is of considerable help.

The Problem of Stones

A special problem is created by the presence of stones and pebbles. In the dry grinding process they are simply ground-up with the clay and then their effect, provided they are not limestone, is similar to that of sand. If on the other hand the wet preparation method is to be used, the situation becomes altogether different. Larger stones will be eliminated by the helically grooved rolls, but it is generally the smaller stones that create problems. About 5% of stones not over 10 mm in the feed may be handled by the differential rolls, but at least two sets with different settings must be used. Special attention must be paid here to the maintenance of the rolls as their

Page 16, para 2, line 1

Change: "..........important property of the clay..." to read "....important properties of the clay...."

Page 21, para 5, line 9

Change: "....instance, is some ..." to read "...instance, if some...."

Page 30, para 4, line 2

Change: "....has been in Honolulu,...." to read "...has been tested in Honolulu..."

Page 37, para 7, line 5

Change: "...must be a friffle than...." to read "...must be a triffle higher than..."

Page 38, para 4, line 3

Change: ".... powered by 250 HP motors..." to read "...powered by 40 HP motors...."

Page 39

Insert after the fifth paragraph the following:
"According to Pels Leusden, (Ber.Deut.Keram.Ges. 47, 345-351 /1970/) the length of the later should be 66-80% of the auger diameter, but in exceptional cases up to 150%. The cross-section of the spacer at the exit end should be 1.5 to 2 times larger than that of the entrance end of the die. I have found, however, many exceptions to this rule-of-thumb. Also important is the length and the taper of the die. It may be said in general terms that very workable clays require shorter and more highly tapered dies. On the other hand, leaner clays seem to require longer and straighter dies. Again, exceptions are many. It need not be stressed here that for a given clay there is a most satisfactory relation between the cross-section of the die, its length and its taper. The most convenient expedient, however, adopted by most dies and clay working equipment manufacturers, is the use of a design which would work satisfactorily with the greatest number of clays. Such a design may differ considerably from the ideal one."

Page 44, para 2, line 6

Change: "...shovelled out and place" to read "...shovelled out and placed"

Page 44, para 3, line 8

Change: ".....does not remain even wither." to read "... does not remain even either."

Page 44, para 3, line 11

Change: "the adges of...." to read "the edges of...."

Page 45, para 4, line 7

Change: "better job is gound." to read "better job is found."

surfaces quickly wears hollow in the center and let through too many stones.

A better solution is to use stone removers, which are quite common in Continental Europe. Here the clay is squeezed through a perforated barrel. These machines consume much power and their effectiveness is limited approximately to a 5 mm size. Everything else must be handled by the rolls. They will be normally installed before the rolls and after a double shaft mixer. In some installa tion the wet pan is dispensed with altogether.

The Slurry Method

A very effective way to eliminate pebbles was and perhaps still is practiced in England. Here the clay, usually won in the plastic state is made into a slurry which is then screened and finally thickened by flocculation by lime, then allowed to settle and dry-out to the appropriate consistency. A modernized version of this old method was devised some time ago for use with the Hudson River bank clay, which is normally too wet to be desintegrated mechanically. Here a slurry of 2.0 to 2.2 specific gravity is prepared by defflocculation with soda ash in a continuous ball mill which, however does not grind but only desintegrates the clay. A mill 180 cm in diam and 150 cm long is expected to handle 25 tons of dry clay per hour. There are several ways in which the slurry may be handled after screening: It may be either concentrat ed in rotary dryers and fed directly into the pug mill and soft-mud brick making machine. Or ground dry clay may be mixed with it and molded.

This method has some interesting possibilities for both the developed and developing countries. It is amenable to full mechanization and even automatization but it may also be precticed in countries blessed with plenty of sunshine. Drying a slurry in shallow pits dug in the ground is not much of a problem as I was able to demons trate in West Africa.

The Dry Grinding Process

After the primary crushers the clay passes to the dry pan. There has been a great deal of controversy about the type of equipment to be used in primary crushing. Jaw and gyratory crusher have been mostly discarded by now as they are easily clogged by moist clay. The type now generally used may be either a swinging hammer crusher or a double roll crusher. Incidentally, this last type of crusher was used at the modern Belden plant in the U.S. The two sets of crusher installed here may handle 25 tons in 12 minutes.

In better installations the clays as received from the pit are dumped into the hopper of an apron conveyor that feeds the crusher below. The crushed clay is then elevated by means of an inclined conveyor to a height of about 8 to 10 meters above ground and unloaded by means of a tripper over the whole length of the storage building. In other designs, the crushed material is deposited in bins, which may be connected by means of apron feeders directly with the dry pan.

If the crushed clay is stored on the ground, it is usually picked up by bucket loaders which drop their load straight into the pan. Refinements in this respect may comprise a hopper with another apron feeder which then feeds the pan at an uniform rate.

The largest size of lumps that may be fed into a say 9 foot dry pan is about 10 cm. Naturally, a modern dry pan, equipped with large size extra heavy mullers is normally capable of handling even larger lumps, but its grinding efficiency suffers. The smaller the size of the feed, or couree, the better the grinding efficiency.

Most pans are designed for bottom discharge, that is the material that has been crushed by the mullers is thrown by centrifugal force over the slotted screen plates and any material not passing through these slots is directed by means of strategically positioned scrapers into the path of the muller for additional grinding. The material that has fallen through the screen plates is transported to the screens and sieved to the required size. The oversize is normally returned to the pan. There must be, therefore, a delicate balance between the size of the screen plate slots and the openings of the screen.

The efficiency of a grinding-screening system may be judged in terms of (1) Percentage of Recovery and (2) Circulating Load. (1) is the percentage in the ground product of fines which will pass the screen and (2) the ratio of the ground material delivered to the screen to the amount of the screened product. To calculate the percentage of recovery at the point of separation, screen analysis of the feed and of the oversize (or tailings) returning to the mill are required. The following equation may be used:

$$R = \frac{100\ (c-a)}{(bc)}$$

where: R = Fractional recovery of fines in screening

R = 10R or percent of fines recovered in screening

a = percent of particle coarser than the point of separation in the feed to screen

b = percent of particles finer than the point of separation in the feed to screens

c = percent of particles coarser than the point of separation in the oversize after screening.

Under normal circunstances circulating loads vary from 1.5 to 2.0. The percentages of recovery may be as high as 95% but they may be also occassionally as low as 50%.

The sensible thing to do when starting a new operation, is to vary the width of the slots of the pan's screen plates until the correct particle size distribution in the ground product is obtained. The relation between the size of the grids and the amount of fines obtained will vary according to the "grindability" of the clay and the water content. Sometimes, the slots must be made so narrow that the mill's output is reduced. If, on the other hand they are kept too open with relation to the desired point of separation, the circulating load becomes excessive.

Sometimes it might be a good practice to keep the slots more open than customary and direct the now considerably increased oversise from the screen into a hammermill and grind it there to the required fineness. The pulverized tailings may the be transported back to the screen but sometimes discharged directly into the bin. In this way the circulating load is considerably reduced or even eliminated completely, and the output of the system greatly increased.

If several clays are used to make a single product, the blending may be done at the time of loading the pan, in which case all the materials are ground together and stored in a single bin. The proportioning may be done by means of bucket loaders or wheelbarrows. In more modern installations each material is ground separately to the required fineness and deposited in a bin of its own. The proportioning is then done either by weight using poidometers or by means of vibrating feeders. Other types of feeders, such as apron feeders, or rotary disc feeder may also be used. In each case the individual raw materials are unloaded on a single belt conveyor and discharged into the pug mill or into the double shaft mixer.

One of the most important features of the dry pan is its sturdiness, reliability, essential simplicity, high productivity and relatively low and easy maintenance. Most of the wearing parts such as mullers, running track plates, screen plates (grids) and even the Bevel wheels and pinions are easily replaceable and of such a simple design that they may be cast in any larger foundry. Properly maintained, most Dry Pans outlast men by a considerable margin.

Screens

Considerable attention must be paid to the screens. In the first place it pays to heat them electrically as the incidence of blinding is much reduced.

Until recently, there has been little new development in the design and construction of vibrating screens. In old installations the type of screen mostly used worked with a relatively steep screening angle of 33°. In the Belden plant mentioned above, it was possible to reduce screen area by 50% by the use of longer low angle screens. This plant, incidentally screens 90-95 tons per hour using 10-1.5 x 3.7 m - 4.8 mm opening screens.

Another development in this line is a screen that operates in a horizontal position made possible by an upward and simultaneously forward motion of the screen which impulses the grains to travel over the whole surface toward the discharge end. This screen is reported to be very efficient. At the Higgins brick plant in Chino, California, such a screen is even screening moist clay directly from the desintegrator. A horizontal screen offers many interesting possibilities in plant design. With the old high angle screens the necessary head room was always considerable. They were always hidden out of sight and not very accessible because of the height at which they were installed. I have heard many a plant superintendent complain about their inaccessibility which caused a chronic lack of supervision and maintenance. Now, these screens may be installed on the floor level where they are perfectly accessible for inspection and maintenance.

This was made possible furthermore by another new development in plant design. It is the preference for belt conveyors in substitution of bucked elevators, which, as has been recognised a long time ago, are wasteful of power and high on maintenance. Consequently, modern brickplants are now being designed entirely without them. The pugging operation should be as thorough as possible to assure a perfect distribution of moisture through the body. Sometime even two extra length pugg mills have to be used.

Shaping Methods

The shaping methods that may be utilised would be roughly the following:

(1) The soft Mud Method

(2) The Stiff-Mud extrusion Method

(3) The Dry-Presse Method

(4) The Stiff-Plastic Method

(5) The Vibration - Compaction Method

We shall not go into any detail as regards the constructional and operational features of the individual processes. The factors which will affect the selection of the shaping process will be in order of importance, the characteristics of the available raw materials as outlined in Chapter II and the exigencies of the market.

The soft-mud process is generally suitable for the manufacture of full bricks, especially if sanded surfaces are required for use in facing.

Another advantage of the soft-mud process is the large production capacity obtained from some of the available machines. The Dutch made machines now in operation at the new Belden Sugarcreek plant handle 27-28 ten-brick molds per minute thus producing around 16 thousand brick per hour with three operators.

Their drawback is the need to use pallets and the high proportion of moisture which must be removed. Special chamber dryers are required. This per se would not be considered a disadvantage in Continental Europe where this type of dryers is rather common. The other drawback is that while being versatile in terms of surface finishes obtainable with them, not much else but solid brick may be produced on these machines.

The stiff-mud extrusion process is the most widely used one and is thought to be the one most susceptible to mechanization. The equipment here used has considerable flexibility in terms of the products that may be manufactured with it.

As for the stiff plastic process, its use is limited to the U.K. The wear on the mold boxes is said to be high.

Dry-pressing, or as it is more properly perhaps, called in England, semi-dry process is from many viewpoints a very attractive one. The size of the product is more easily controlled in it but to obtain the same degree of vitrification the firing temperatures must be a friffle than would be the case with any of the other plastic processes. However, when proper clays are used, there should be almost no dryer losses and the drying itself is faster and cheaper because of the lower percentage of moisture used in this operation. There are exceptions to his general rule, however, I am told. The Fletton bricks in England are said to be pressed with 20% of moisture.

Also the manufacturing equipment is more simple. The grinding and tempering may easily be done in the dry pan. The drawbacks of the dry-press method are in my opinion two. The high rate of wear on the mold box linings and the relatively low output of the presently available presses. An output of 1500 brick per hour is all one can get even out of one of the modern rotary table presses. Inspite of these limitations, the famous Flettons of which 12.000.000 are turned out per week, are said to be all dry-pressed.

The vibration-compaction process is a relative newcomer in the ceramics field. But the large production capacities, ease of handling, versatility in terms of sizes and shapes and relatively low power consumption, make out of this process a thing of the future. It will be recalled that this method has been used hitherto only in the manufacture of sand-cement or concrete blocks.

The vibration-compaction method is not meant for handling normal plastic clays. But non-plastic clays, non-clay materials, calcined or bloated clay aggregates, they all may well be shaped in these machines using only a limited admixture of specially prepared clays. The manufactured product, which dries quickly, may then be fired in any of the many kiln types available, including up-draft ones.

For the time being the stiff-mud extrusion process offers the best possibilities. Its versatility is remarkable and production capacities amazing. In the U.S. extruders powered by 250 HP motors and producing as many as 18.000 per hour are not uncommon.

The extrusion process is at the same time one that puts the greatest demand on the clay's characteristics and on uniformity. Faults, such as lamination and coring are many. The product is also more difficult to dry that any of those produced by other shaping methods and there is a lot of water to be removed, even though in this respect the extrusion process is surpassed by the soft-mud one.

Everything considered, the auger extrusion process is not what we would call a very logical one. There is something odd about the fact that in order to extrude our clay we have to form it first into a coil that is, in comparison with the cross section of the product, relatively thin, and then compress it again into the extruded column. No wonder that the column, as it emerges from the die is full of tensions and inhomogeneities. This is the main reason why there is a greater likeliness of troubles in this process than in any other so far considered.

Where full or simply perforated brick are manufactured, the tendency has been to increase the stiffness of the extruded column. Less water is used and the product may be set directly on the tunnel kiln cars, or even stacked on pallets for lift-truck transport to the dryer and then to the kiln itself.

The situation is different when hollow products are extruded, which may not be stacked one on top of another. In these cases stiff bodies may do considerable damage to the rather weak bridges to which the die's cores are fastened. And finally, the economy obtained in drying, because of the reduced water content of the extruded product, may even be offset by the considerably increased power consumption.

There is normally very little a brick engineer in a developing country can do about the design and construction of his extrusion machine, as its characteristics will have been determined by the manufacturer. Recent studies in extrusion indicate that too many things about this complex process are still to be investigated.

The curious fact is that even such an essential feature as the optimum helix angle is still being discussed. Most authorities seem to agree on a 23° auger eventhough some still insist on a 30° angle. I even heard one clay machinery manufacturer sadly complain that most of his colleagues in the trade inherited their die and auger patterns from their predecessors fifty years ago.

The brick engineer in a developing country will have little to do with the design of an auger and even his extrusion dies will probably be purchased with the bulk of the equipment. Nevertheless if he encounters troubles in extrusion he will have to know just what is causing it. To suit his clays and to reduce the degree of lamination, he may have to vary the critical distance between the tip of the auger and the end of the die. While there must be numerous exceptions, it is my experience that very workable (read "plastic") clays require a shorter spacer and vice versa.

Bricks and tiles that emerge crooked from the dryer are almost always due to an uneven flow. Sometimes this trouble is caused by a deposit of hard clay in the spacer and sometimes the die is not centered well enough. If the defect persists even after having centered the die, the trouble may be remedied by installing brakes on the side where the flow is fast. These brakes may consist of 1/4" steel plates introduced between the die and the spacer, so that they protrude into the path of the clay.

The balancing of multiple hole or hollow tile dies is even more difficult. A new die usually shows an uneven flow and it is normally the center that runs slow. The easiest remedy is, of course, to increase the separation of the cores even if that means that the thickness of the web will be increased. Uneven flow of a die shows best when the column is cut flush with the face of the die while the machine is at standstill. As soon as the machine is started and the clay begins to flow, all the points of imbalance will show at once. The central webs or partitions may be retarded and the whole column may turn to one or the other side. It may be straightened by guiding it for a half meter or so and it will seem to be running straight, but the imbalance will be there and the tile will as likely as not warp in drying and it may even develop cracks. The imbalance must be corrected and the only valid indication that it has been achieved is that the column runs straight even without guidance or support. One experienced manufacturer once told me that more defects were caused by faulty dies than by any one of the remaining causes. He might have been exaggerating, however.

As a matter of principles it is always better to speed up the slow sections than to retard the fast one. The man who said that was talking from the standpoint of power consumption. The above may be done, for example, by using core blocks of different lengths and of different tapers. One may then lenghten or shorten them to create more or less resistence to the clay flow.

A special cause of troubles are the bridges behind the dies to which the cores are fastened. Normally they cut the clay stream as it flows around them, but if the pressure in the dies is high enough, the strands are again united. But even so, a source of weakness will always be there. This, incidentally is believed to be one of the reasons while perforated or hollow tiles are mechanically more resistent in the direction of extrusion. To avoid the lines of weakness in the tiles or bricks, the tendency has been to make the bridges as thin as possible but there is then often the danger that they may buckle under pressure. The strength of a bridge may be increased by making it deeper instead of thicker. Some clay men believe in scoring the bridges in the expectation that this will "roughen" the cut surface of the clay stream thus facilitating subsequent welding.

The distance that the bridge is to be set back from the rear of the die must be determined experimentally. It has to be set back far enough to allow the clay to come together again before it enters the die liner but not so far back that the stems to which the cores are fastened become too long so that they might weave around under pressure and throw the die off balance. Eight to 10 cm between the bridge and the rear of the die seems to work quite well in most cases. Bridges may also help to balance a die, on the other hand. They may be placed across sections of the dies which run fast.

Wire Cutters

For cutting full or perforated brick there is nothing that can beat a Steele's automatic rotary cutter, which cuts up to 18 brick at a time. I have had one of them at a plant and it was already thirty year old when I first saw it. That was in 1942. It is still in perfect operating conditions I am told. The preference in Europe runs towards automatic single wire cutters. They are fine pieces of machinery. Under conditions of developing countries they appear to be somewhat difficult to adjust and to maintain. I have seen that by myself. Since the automatic rotary cutter, referred above, does not work well when the extruded column is not heavy enough, as happens with hollow tiles, I would use a rotary hand cutter working on the same principle and capable of cutting 32 - 30 x 30 cm tiles per minute. This would be the best cutter for developing countries.

Handicraft Brick manufacture

It has been said that of all human activities it is handicraft brickmaking that has changed the least since its invention. If what is meant by that is nothing else but the act of filling a mold with mud and depositing the so shaped object on the ground, then it might be so. After having seen this human activity in quite a few developing countries, I am inclined to say that they differ a great deal and that consequently, they must have also changed a great deal since the time, long time ago, when one of our predecessors in the trade molded the loaf-shaped brick which Kathleen Kenyon found in Jericho and which must be dated to at least 5000 years B.C.

Some brickmakers work singly, other prefer to do it in a group or in couples. Some brickmakers work standing, other squat on the ground.

It is India's handicraft brick industry that seems to me the most highly developed. (See Fig. 6). And it must also have by far the highest output. Although I have no figures regarding the total output in the whole of India, it should suffice to say that the three principal cities of the state of Gujarat, that is Ahmedabad, Baroda and Surat, produce between 300 and 350 million bricks per year. Even here; however, there are variation in the molding technique.

The most frequently employed is the table method. This is somewhat misleading as there is no table. Instead a cast iron plate which serves as the bottom of the mold is fixed to the ground. The plate usually bears the raised initial of the brickyard and is provided with two ridges along one of each of its larger and shorter sides, which help in centering the mold and prevent it from slipping-off the bottom plate. The rest of the molding equipment consists of several sheet iron plattens somewhat larger than the brick and a strip of iron 1/4² thick and some 8" long which is used to cut-off the excess of mud.

The molder squats on the ground in front of his mold, the inside of which is sprinkled with a mixture of sand and fine clay and then placed on top of the bottom plate. A bat of clay, which has been prepared by one of the helpers, is dropped into the mold, the excess of mud scraped off by means of the above tool and the scraped surface sprinkled with sand. Then one of the of-bearing sheet-iron plattens mentioned above is placed over it, the whole quickly turned over and the mold gently lifted, leaving on the plate the de-molded brick. The second platten is then placed on top of the demolded brick, the two plattens with the brick sandwiched between them lifted and carried over to the drying place where the brick is deposited edgewise on a level ground. The two plattens are brought back to the molder to be used again.

The usual division of labor is such that while one or two helpers prepares the bats, two other do the off-bearing. Frequently, however, there is only one man to prepare the bats and another for off-bearing. Very frequently also the whole family works together; the man does the molding with his wife preparing the bats and children doing the off-bearing.

Normally, when the off-bearing helper has returned, a second brick has already been demolded and is ready to off-born. For the initial drying the bricks are usually laid on edge in rows of 100 or so leaving approximately 10 cm space between adjoining bricks. The daily output, which naturally depends on the number of workers in the crew is said to be the following:

2 helpers	2000
3 helpers	2500
4 helpers	3000

In another method, also frequently practiced, the molder, squatting in front of his mold, continually changes his position as brick after brick is being molded and deposited flatwise on the ground.

Page 52

Insert in the second line of para 2: ".....by oil. (See Figs. S1 to S5)"

Page 53

Insert in the second line of para 6: ".....used in India. (See Figs. B1-B3)"

Page 59, para 1 line 12

Change: "...that a gap of flue..." to read "....that a gap or flue...."

Page 59, para 3, line 11

Change:"....kilns were provided..." to read "...kilns were not provided..."

Page 61, para 4, line 7

Change: "....under ware firing..." to read "...under-ware firing..."

Page 62, para 5, line 3

Change: "Rotary of gear..." to read "Rotary or gear..."

Page 66

Para 1 should read:

"products in an African country has already been given and conclusions drawn. The fact must be stressed that sand cement blocks are extremely permeable, whereas clay bricks, in virtue of their tortuous pore system, are much less permeable and can be used without rendering. The experience of Liberia is significant. Here, unrendered brick constructions have been found unequalled as far as duration, impermeability and low cost is concerned, inspite of the legendarilly heavy rains."

Page 67, para 1, line 3

Change: "...must probably..." to read "...most probably..."

Page 69, para 3, line 1

Change:"Fig 27 shows...." to read "Fig. 27 A,B,C show...."

* * * * *

In this case, however, the cast iron bottom plate is not fastened to the floor but is free. Its design is also somewhat different from the one described above in the sense that it fits into the mold like a lid. The molder then proceeds generally as described above but instead of de-molding the brick on a platten, discharges it directly on the ground by quickly turning over the mold and then lifting it gently to allow the brick to slide out. Then he shifts his position sidewise to mold and deposit the following brick next to the previous one and so on. There are usually three people in a crew producing 2000 bricks per day.

Regardless of the molding method, the bricks are left in their demolded position for three days. After that, they are stacked 6 high alternating headers and stretchers and leaving 5 cm spaces between neighbouring bricks and about 25 cm between adjacent stacks. The crew gets paid the equivalent of US $1.00 to 1.50 per thousand bricks, the price varying according to the locality.

The sales price is amazingly low. A 9" x 4½" x 3-1/4 brick sells for the equivalent of US $5 to $8 per thousand. Furthermore, 45 millions of modular size brick 19 x 9 x 9 cm were contracted for by the Capital Project Circle in Ahmedabad at a price of only US $4.40 per thousand. That was in 1967, however. As to the quality, out of a lot of 175 brick sampled at random, 90% showed crushing strength in excess of 35 kg per sq. cm, which is the minimum strength required by the Indian Standards. Fifty per cent had strength over 50 kg per sq. cm. The average porosity is around 15% but most of the brick have about 13%.

<u>Brickmaking in Mexico</u> (See Fig. 7)

In Mexico, hand molding techniques vary a great deal according to the region. In the neighborhood of the Capital, the brick-maker works with his mold on the ground. The mud is prepared usually in the late morning and is left soaking until the following day. The clay is won directly from the bank nearby by means of a hoe. Water is generously applied and worked into the clay with the hoe. The molding operation starts in the early morning. The six cavity mold is placed on the ground on which ashes from the kiln has been spread and levelled. The brickmolder works alone but is generally aided by a boy who carries the mud from the nearby pile. Two trips are usually required. The mud, which if fairly fluid, but highly thixotropic, is poured into the mold, each cavity thoroughly filled, the excess of mud cut-off by means of a rule and the surface polished with water. Then the mold is lifted leaving on the ground six well shaped bricks. The mud is of good quality, highly thixotropic so that inspite of its semi-fluid condition the freshly molded brick does not slump after the mold has been removed.

The bricks are dryed in full sunshine without cracking. One molder and his infant helper produce 500 bricks per day but they work much less than 8 hours as all the work is finished at noon time. He gets paid approximately US $6.50 per thousand. The brick size is generally 26 x 13 x 6.5 cm but major size variations are quite common.

Turkey (See Fig. 8)

In the country around Ankara in Turkey, considerable handicraft brickmaking takes place. As many as 200 small scale manufacturers or better to say contractors, because that is what they are, are said to operate. The dug out clay is placed into long trenches, thoroughly watered and left soaking overnight. No kneeding or treading is practiced. The mud is then shovelled out and place on the molding tables. A brickmaking crew consist of 7 men of which two do all the molding. They turn out 6-7 thousand bricks per day for which they are paid at the rate of 20 Turkish pounds per thousand. The molding table on which the mud is placed is provided with wooden "aprons" inclined at a degree of 45 degrees. It is this apron against which the bricks are molded. The mold itself is a flimsy affair consisting of two stretcher cavities. Water is used as parting material, that is the molds are inmersed in the muddy water contained in a wooden trough attached to the apron. The wetted mold is then placed on the same apron, and rapidly filled with the mud. One face of the brick is, therefore, formed against the water-drenched apron, the other by roughly wiping-off the excess of mud. This is done by hand.

Afterwards the mold, with its charge of mud, is off-born and the brick de-molded on the ground. That face of the brick in contact with the ground is always very rough and unequal. This is due partly to the uneven ground but the rough wiping-off of the excess of mud in the previous operation is also responsible for it. On the other hand, the opposite face, which has been molded against the surface of the apron, and which after de-molding is "up", does not remain even wither. The friction of the mud against the mold's walls during de-molding, causes certain retardation of the brick's surfaces as a consequence of which the edges of the upper face of the brick always remain somewhat raised. The result is a concave shape of the upper face of the brick. The crushing strength of these brick averages 25 kg per sq.cm. Curiously enough, the above molding procedure is repeated almost entirely in the brickyards around Lomé in Togo. Even the mold is the same flimsy two stretcher cavity mold. The only thing missing is the inclined apron.

Iraq, the country where brickmaking was probably invented, must be one of the largest brick producers ever. In 1958 there were

81 factories around Baghdad producing around 756 million bricks per year. They sell for about US $10 per thousand. Most of these brick are, strictly speaking, not handicraft brick, being produced by extrusion. In the meantime, however, the production of true handicraft brick has not died out as could have been expected. In 1958 the production of hand-made bricks was still estimated at some 1.2 million per day. By 1966 the production of handicraft bricks was limited to special square brick roughly 9" x 9" x 2" or even 12" x 12" x 2". They are, therefore, similar to those old Babylonian brick that one sees in the Museum of Baghdad.

Anyway, these Baghdad handicraft brick fetch a much higher price. The 9" square brick sells for approximately $25.00 per thousand and the 12" square ones get even as much as US $100. These bricks are used mostly for covering Baghdad's flat roofs or after cutting and smoothing the cut surface by means of vigorous rubbing, even for facing. For this purpose they are preferred even to the extruded brick. No doubt on account of their more regular shape and absence of lamination.

Defects of Handicraft Brick

The chief defects of handicraft brick, which seems to be common to all countries where they are manufactured, is their lack of uniformity and the great amount of deformation, warpage etc. These defects are generally due to sloppy molding. Sometimes, however, the molding is quite good, as for instance in some places in India and Mexico, but the brick are damaged, sometimes beyond recognition in the course of subsequent handling.

The main reason is, of course, the lack of experienced workers. In most countries, the work is seasonal and only very few are willing to learn it properly and do a good job. Turnover is very large and the workers normally do not stay long enough on the job to learn the trade. Nor are most of them interested in it as brickmaking is for them a temporary arrangement until a better job is gound. Brickmaking just is not a very lucrative occupation.

Partial mechanisation may be the answer in some cases. Since sloppy molding is one of chief causes of the poor quality of handicraft bricks, I believe that the introduction of small extrusion units will go a great way towards obtaining a better quality. We should, however, beware of the example of those 80 brickmakers of Iraq, all of them equipped with second hand extruders who turn out some 756 million bricks per year, most of them more misshapen and cracked than most of the handicraft bricks I have see elsewhere. If field extruders are introduced,

2000. Each of them should be equipped in the future with a field extrusion machine of this type. The market is indeed, extraordinarily large.

I should like to go even farther with my appeal to the clay working machinery people. The thing that really is needed is movable equipment, amenable to be used with animal power but susceptible for easy conversion to other type of drives, such as Steam or Diesel Engine and even electric motors.

The range of machinery to be developed would include:

(1) A self-contained brickmaking unit composed of a pug-mill, auger extrusion machine and a hand-operated wire cutter with a short length of belt conveyor to feed the pug mill.

(2) A mobile selfcontained soft-mud brickmaking unit.

(3) A horizontal pug-mill.

Of the two brick making machines, the second is to be preferred, as the soft-mud process, simulating the hand molding operation, is generally suitable for use with any clay that can be successfully hand-molded.

I am even visualizing small, two or three cavities soft mud brick machines that would be mounted on wheels and hand-propelled over the ground, on which they would deposit the molded brick and then be pushed to the next spot. They would work in the same fashion as the simple concrete block machines now on the market. There are people who say that what has been done for the concrete or sand cement block can not be done for the clay brick, but I doubt it. After all, who believed fifty years ago in the possibilit of a pocket wireless the size of a match book.

Perhaps we should change some of our attitude towards clays, clay products and brickmaking in general. I believe firmly that great m non-plastic materials may be bonded with a small percentage of specially prepared clay, molded in the same way as any sand cement or concrete block, and then fired in any of the kilns at our disposal. We should then be able to use the available hand propell vibration-compaction machines and would not have to invent a movab soft-mud machine which, admittedly, is not an easy matter.

IV. DRYERS AND DRYING

Drying clay products is an expensive proposition if waste heat from the kilns is not available. If heat for drying is to be generated, drying could even be more expensive than firing. The some kind of quality standards will have to be estaclished and a mechanism devised to enforce them. These standards must not be too rigid nor too high but they must at least guarantee a decent shape and a minimum crushing strength. The latter property will have to be specified in accordance with the established local construction methods.

Need for Simple Extrusion Units

As far as I know there is no extrusion machine on the market now, that would be cheap and simple enough but sturdy to take much abuse, and therefore suitable for field installations and work. Under these conditions, those enterprising brickmakers in develop ing countries who want to start on their road to mechanization have to turn to second hand extrusion equipment discarded by european brickplants fifty years ago.

The need for such simple extrusion units is very pressing. No de-airing is required and their output should be around 5.000 units per day. The brick should be extruded preferably "on end" and smaller auger diameters, perhaps not exceeding 20 cm, used.

I have seen a small stiff mud extrusion unit in operation at the Firestone Plantation company near Harbel in Liberia. It extruded end-cut brick through a 4¼" x 3-1/4" die. The brick although fired in up-draft kilns were of extremely good quality and were extensively used in the Company's contruction programmes. These brick needed no plastering nor inside painting and the exposed brickwork stands up to the elements remarkably well. There is said to be no maintenance over the year and even the heavy rains of this region do not stain the outside brickwork. In the words of Firestone officials, these brick were the outstanding building material for maintenance-free low cost housing. Getting back to the need for field extrusion equipment, a few words in connection with the pugging and grinding equipment to go with the above extrusing unit. The need for it will depend on local conditions. With some normal surface clays of the type used in India, in Mexico and in many other countries, no grinding is necessary, only soaking overnight and the mud may be shovelled directly into the pug mill of the extrusion machine. For more difficult clays, some type of a clay crusher may be required. A set of rolls will suffice to break up the clay and the soaking will be done on the ground or in souring pits.

Such a machine will have to be specially designed for these semi-mechanised brickworks and clay working machinery manufacturers around the world should start paying attention to this potentially enourmous market. It must be recalled that in India alone, the number of Bull's ring kilns is estimated roughly at amount of heat actually required to fire 1 kg of clay in a Hoffmann kiln to 1000°C is said to be approximately 320 kcal. (Rechnungsgrundlagen für den Entwurf und den Betrieb keramischer Brennöfen, Wilhelm Knapp, 1948). On the other hand the requirements of heat for drying may vary from 1000 to 2000 kcal per kg or water evaporated according to the efficiency of the dryer installation, so that to dry 1 kg of fresh brick, 200 to 400 kcal may be required. Unfortunately not even in the best designed of Hoffmann kilns is it possible to dry more than one third of the brick required alone by the waste heat from it. No wonder that most brickworks make extensive use of open air drying facilities. Of 21 mechanized brickworks in an uropean country I have visited in 1966 only 6 were equipped with artificial air heating facilities, however defficient they might have been, and fourteen did not even use the waste heat from their kilns.

The availability and amount of waste heat depends on the type of kiln used so that the problem should really be discussed in connection with them. We may say, however, that only a modern car tunnel kiln, with its efficient utilization of the heat imput, permits the drying of the whole amount of brick fired through it. Modern kilns of this type are very expensive, however, and it is still questionable whether the manufacture of common bricks and tiles in developing countries, with their dearness of capital, justify the huge investments required. More will be said about this in the next chapter.

At any rate, most African countries that are blessed with plenty of sunshine, will have to make efficient use of this commodity. Open air drying will therefore be used almost exclusively.

Whether or not permanent shed will be built or whether the piles of drying brick will be only covered by palm leaves and the like, will depend on local conditions and climate. Hand molded bricks are normally left on the ground until they reach the stage where they may be handled without damage to them and are then piled up for subsequent drying. During the rainy season they must be protected from the rain. Nevertheless the degree of protection depends on the rain's intensity and direction.

With machine-made brick of the continental European type, it is well to utilize pallet - or lath - loading automatic or semi-automatic equipment in combination with an elevator, gathering frame, finger car etc. This kind of equipment is well known. And even if the automatic loading system as a whole is not availa ble, the elevator, and the finger car are always a good investment. It is recommendable, however, that outdoor facilities for depositing the loaded pallets or laths be provided. They may be simply and cheaply made. All that is requ'red is a structure open from all sides but protected from the rain and capable of supporting the ledges on which the loaded pallet come to rest.

Where stiffer brick and tiles are extruded, they may be loaded on pallets up to a height which must be determined experimentally and which would be about eight courses high. These pallets may then be transported either manually or mechanically by means of the many available lift-truck (Fig. 9) or even by means of special Tilting Brick Trucks (Fig. 10) (see photo). They are no longer easy to obtain, nowadays but being so simple they may even be manufactured locally.

The ideal thing of course would be to set the brick for drying in the same way they would be hacked for firing. It would then be possible to pick them up by means of a lift truck and deposit them in the dryer. After drying the pack would be picked up again and deposited in the kiln. Unfortunately the large mass of brick required ror this operation to be efficient, requires drying by convection in artificial dryers of the chamber type and is not suitable for open air drying in outdoor sheds.

When it comes to artificial dryers, there seem to be room for much improvement. The most efficient system of course is loading stiff mud extruded brick directly on tunnel kiln cars and drying them through a continuous dryer. Unfortunately, however, unless we have a tunnel kiln operation, this excellent system can not be practiced.

We usually distinguish between continuous and periodic or chamber dryers. They may be of the tunnel type eventhough I have seen quite a few chamber dryers that were as wide as they were long. They were used mostly to dry packs on pallets by means of Rotomixair. I did not think much of them.

Most of the dryers using the pallet system and finger cars are of the periodic type, that is they must be loaded and then unloaded again, during which time they are out of operation. Much time is lost there. In addition to that, heat is lost in heating the structure of the dryer itself. The air distribution system of many of these periodic dryers still leave considerable to be desired. Sometimes there is just a series of round holes in the bottom through which the hot air is blown. The spent air is then allowed to leave by another series of holes in the ceiling, usually connected to a stack. No wonder some of the drying times are so long. There is some room for improvement. In one of the recommended designs there is a slot in the center of the tunnel's floor along its whole length. The slots have an "A" profile and act as injectors in increasing the upward velocity of the air. Since, however, the hot air is usually blown into this flue from one end, that part of the dryer closest to the air's entrance receives most of it and the points farthest from it the least. Therefore the width of the slots is varied being very small at the beginning and then gradually increasing towards the end of the flue. Furthermore, exit openings in the tunnel's ceiling are connected to an exhaust fan for the renewal of the air. This permits recirculation of the still warm but partially moist air from chambers nearing the end of their cycles to those just beginning on it.

Theoretically, at least, continuous tunnel dryers are to be preferred. Until something better is invented they depend on a train of dryer cars on which the brick are loaded. The train is gradually pushed through the dryer by means of a suitable pusher. Counterflow type dryers are usually better, above all for stiff-mud products, as in them the fresh ware comes first in contact with moisture laden air carrying the moisture removed from the drying bricks ahead. On the other hand there is some danger of condensation of misture on the frequently cold bricks. The exhaust of the moisture laden air is usually by means of a stack or an exhaust fan.

In order to operate efficiently, continuous dryers must be provided with wet and dry bulb thermometers and the humidity of the air controlled at strategic points. Controlling the humidity of the air is not enough, however, the amount of air going through the dryer must also be controlled. The adjustment may be made on the incoming air or at the dryer's outlets or stack. The adjustment should be made in accordance with a relative humidity reading at some point in the tunnel. For example a reading of 70% RH at a point three car lengths from the cold end might be set up as a standard. When the humidity at this point increases, the incoming air or the stack dampers are opened somewhat. It is desirable to manipulate these dampers so as to maintain a positive pressure in all parts of the tunnel in order to prevent cold air leakage into the system. (Bull. Amer. Ceram. Soc. 35, 471, 1956). With all that, it may be said that continuous dryers are not easy to control, especially if there are frequent changes in the size and weight of the products. And of course, they operate best 7 days per week. Week-end interruptions in the supply of course, throw the operation out of gear.

Another thing I dislike about continuous tunnel dryers is that they must use cars which must be loaded and then unloaded at the exit end and the dry bricks transported by some mean to the kiln. The empty cars must be returned to the extrusion machines to be loaded again. Return tracks are required and of course transfer tracks at each end of the tunnels. And dryer cars are bulky and awkward to handle. But then I might be prejudiced against them.

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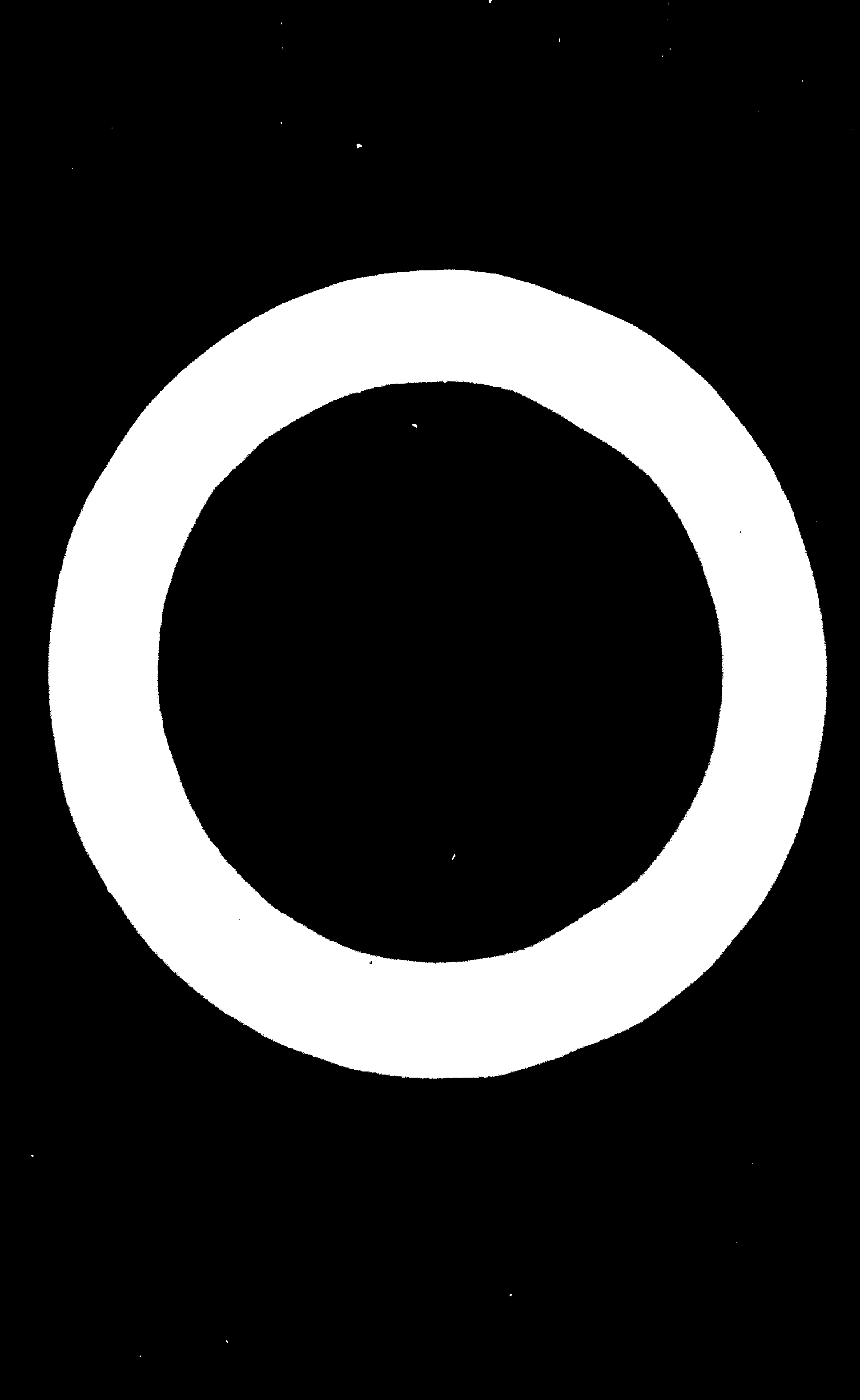

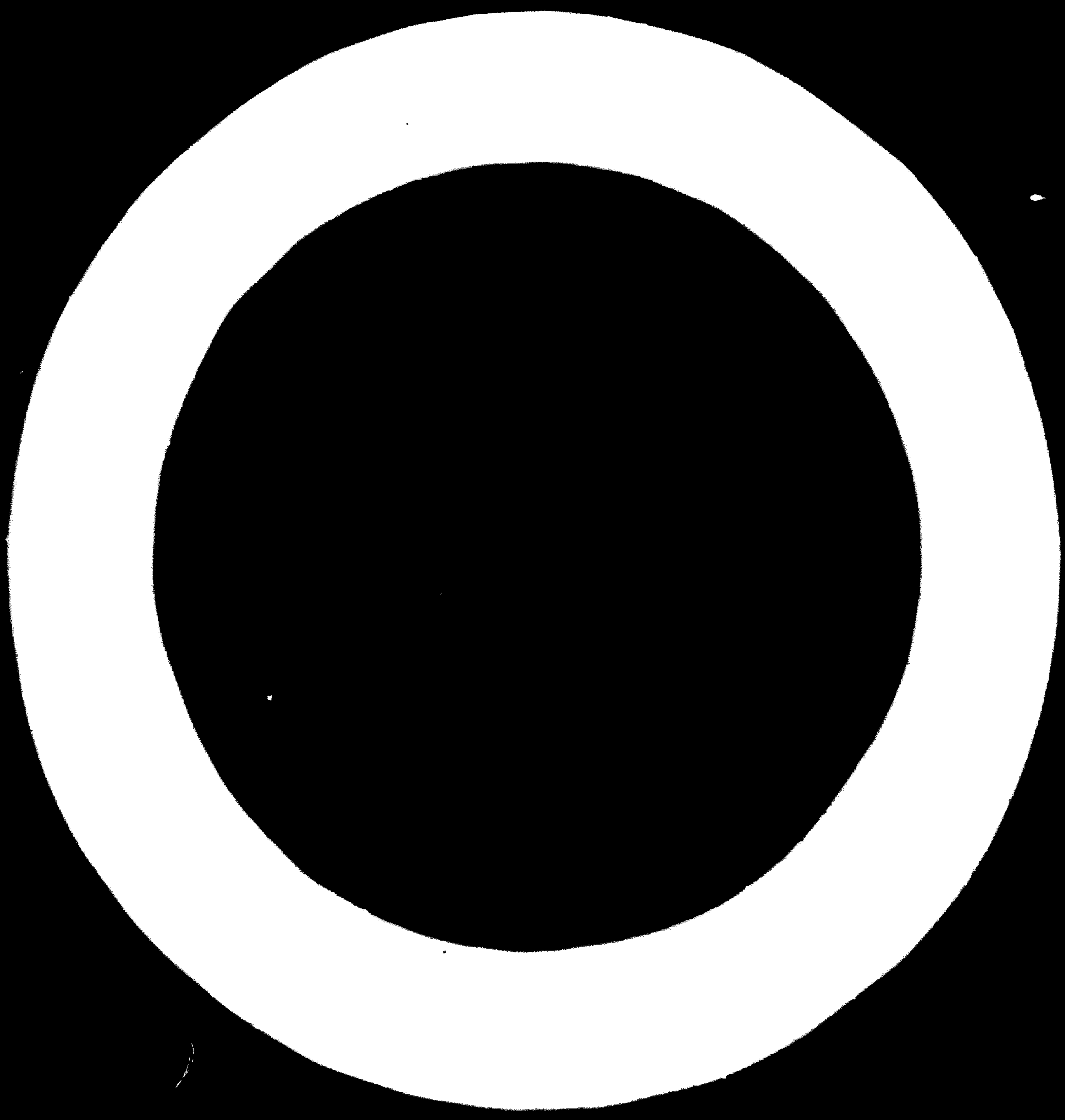

I. INTRODUCTION

A mechanized brickwork even of the traditional type may cost a million dollars and a modern one as much as 10 million. A handicraft brick manufacture may be started with less than 10 thousand. On the other hand a 100.000 brick per week output may require 19 men in a mechanized plant whereas five men turn out ten thousand handicraft brick per week. The manpower figures are West's (The Establishment of the Brick and Tile Industry in Developing Countries, Unido, 1969) and probably reflect conditions in the U.K. The expenditure of man-hours per 1000 brick will be roughly 8 for a mechanized brickplant against 20 for a handicraft operation.

In spite of this high difference in man-hours, industrially made full brick were never able to compete with handicraft ones under conditions of most developing countries. The price ratio in most countries I have visited is 1 : 1.5 to 1 : 2 for such countries like México, Turkey, Iraq and Togo. No comparison is possible for India where until recently no mechanized bricks production existed and 9" x 4½" x 3" handicraft bricks sold for as little as 40 to 60 Rs. per thousand or US $5.00 to 8.00.

The reasons for this may vary from one country to another, but the principals may be enumerated as follows:

(1) the labor is paid less
(2) there is no overhead in the handicraft operation
(3) there are few if any maintenance expenses
(4) there is little equipment to be amortized

However, the decision as to what type of manufacture is to be promoted and finally established, will depend on many factors among which the availability of the required capital is only one. What must also be taken into consideration is, that handicraft full brick will be under normal conditions considerably cheaper than machine made ones and, therefore, more accessible to the broader strata of the population.

One of the greatest attraction of clay brick in most climates is the possibility of using them unrendered, that is exposed, and it was precisely handicraft bricks that were highly appreciated for facing purposes because of the variety of interesting textures, range of colors and shades they were able to contribute to a construction. Very few of the handicraft bricks I have seen around the world would be suitable for facing purposes. The main reasons are their relative shapelessness high porosity and low mechanical strength. Furthermore, my own experience indicates that any serious attempt to improve their quality will almost certainly increase their cost to such an extent that the price will not be much below that of machine made bricks.

Then, when it comes to larger sizes, be it a hollow tile or a large brick with 30-35% of voids, the situation becomes different, because these products do compete advantageously not only with full brick of the artisanal type but also with the ubiquitous sand-cement block, if the comparison is made on the basis of the wall area. The following is an example from Liberia:

Product	Wall Area	Cost per sq. foot of wall
Sand-cement block, 16" x 4" x 8"	128 sq.in.	¢ 14.6
Clay brick, 10" x 5" x 6"	60 sq.in.	¢ 14.4
Clay Tile 14" x 4" x 8"	112 sq.in.	¢ 12.8

Some architects object on aesthetic grounds to the use of large brick or tiles for facing as it is believed that "thin" bricks (any brick the length of which is more than three times its thickness) give a much more pleasant impression. The appearance of unrendered walls made from tiles (or bricks) as large as 30 x 16 cm in France and Switzerland indicate the great range of possibilities open to the large size unit, and testify to great number of pleasing facades that it is possible to obtain with them. We should do wall to conclude, therefore, that a large size clay unit which is both cheaper to make and to use, should not constitute an obstacle to its successful employment in unrendered walls.

We might conclude, therefore, that for large and above all capital cities, some type of mechanized brickwork should be the most appropriate type of manufacturing installation. The mechanization does not need to be complete, but my own experience indicates that even partial mechanization should include either power extrusion or some other type of mechanical shaping method.

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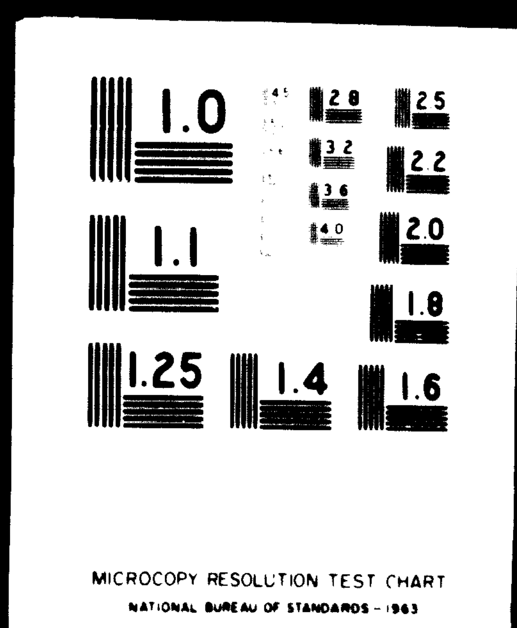
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963

refractory covering, which are then moved at a fixed rate through a tunnel. Thus the ware passes progressively through the water-smoking, preheat, firing and finally the cooling zone. The hot combustion gases, generated in the firing zone, are drawn through the setting of the advancing cars by means of a series of openings on each side of the kiln, situated near to its entrance. These openings connect the tunnel with the exhaust flues which are, in turn connected with a fan. The rate of exhaust and the speed of the exhaust gases may be regulat d by means of dampers. To secure firing uniformity the combustion gases must pass through the setting. To achieve that the setting is longitudinally divided into two halves in such a way that a gap of flue is left between them.

In most recent kilns the secondary air, which in some cases may represent 70% of the total combustion air requirement, comes from the cooling end of the kiln, being induced through the burner block by the action of the sealed-in burner. This secondary combustion air may attain temperatures as high as 650 to 750°C. In older installations the primary atomization air enters through the burners while the secondary air is induced around the burners openings and the rest drawn from the cooling zone. Apart from the hot air drawn from the cooling zone for combustion purposes, the waste heat obtained from the cooling ware is carefully husbanded fro drying. In most well designed kilns enough heat is saved to dry the totality of the imput of the kiln even when soft mud and stiff mud bricks are produced. Refinements including forced cooling, recirculation of hot air are now common features of most modern tunnel kilns.

Most English and U.S. tunnel kiln designs differ basically from those used on the Continent in one important aspect. The width of the firing zone is considerably larger in the former, the distance between the inside wall and the setting on the car being as large as 90 cm and with the burner being set still farther back, the whole distance between the burner's tip and the ware could be of the order of 150 cm. Even so, precautions are sometimes taken to avoid impingement of the flames on the ware by firing either (1) under the setting, (2) in the space between individual car settings. (3) above the kiln setting. Until recently, few U.S. designed tunnel kilns were provided with inspection pits in form of a tunnel under the whole length of the kiln. Originally these inspection tunnels were used mainly in the case of wreckage from overturned setting. The size of cars for firing structural clay products has grown increasingly large. Cars 3 meters square are no longer rare.

The modern tunnel kiln is naturally heavily instrumented. The output depends mostly on the length of the kiln. For solid and perforated brick, fired anywhere at 1000 - 1100°C, the daily output may be put at 500 kg per meter of kiln length for kilns under 60 m long and up to about 1500 kg per day per meter of kiln measuring 100 meters and over. The last figure will apply especially to the rather recent kilns.

The most favorable fuel is gaseous eventhough very satisfactory results are obtained with very heavy oils. When only coal is available, it is best to convert it into producer gas. In Europe, however, coal is sometimes fed directly into tunnel kilns from the top, thus simulating conditions in the Hoffmann kiln.

Eventhough, as has been already pointed out, the transport of brick and the setting of kilns are highly labor intensive operations, the development of setting machines has been rather slow. This has been largely due to the variety of sizes produced by most brickplants. Efficient setting machines have been already developed and several of them are being used successfully. They are, as rule, not very flexible. For this reason plants manufacturing an ample range of products have to fall back on more simple labor-saving devices. In the Belden plant, for instance, the brick are brought to the hackers by belt conveyors. For setting, the tunnel cars are placed on an elevator so that its level may always be adjusted according to the height of the courses being set. The hackers never change their position. This is a good system for face bricks where special care in handling is required. For more common clay products perhaps, pre-set packs may be placed either by overhead cranes or with fork-equipped lift trucks.

VI. OIL FIRING BRICK BURNING KILNS

Oil is one of the cheapest fuels and one of the most easiest to handl and to use. In one African country where I worked some time ago and which did not even produce oil, we proved that in terms of the calorific values it was about 50% cheaper than coconut husks.

Several grades of oil are available. The following classification is based on the commercial standards of the National Bureau of Standards of the U.S.

Number	Grade
1	Distilate oil for use in burners requiring a volatile fuel.
2	Distilate oil for use in burners requiring a moderately volatile fuel.

3 Distilate oil for use in burners requiring a low-viscosity fuel.

5 Oil for use in burners requiring a medium viscosity fuel.

6 . Oil for use in burners equipped with pre-heaters permitting a high viscosity fuel.

These oil differ in their specific gravity, flash point and above all viscosity. So for instance the Saybolt Furol viscosities (measured at 50°C) of the oils No. 5 and No. 6 the only ones that are presently of interest to us, are 40 and 300 seconds respectively.

For economic firing of brick the most important is of course grade No. 6. Its heat value is usually in the neighborhood of 10.000 kcal per liter.

The easiest and simplest way to burn fuel oil in firing bricks is to laddle it directly into the firing holes of a Hoffmann kiln. This is actually done in some Middle East oil producing countries. A better way is to mix it with chopped straw, rice husks, etc. Iraqui brickmakers around Baghdad and Basra use this method to a considerable advantage. Its only drawback is its messiness. A more sophisticated method used in modern Hoffmann kilns and in some top fired tunnel kiln is to inject the oil into the firing hole at predetermined intervals by means of special impulse valves operated by means of compressed air, Several designs, especially of Italian manufacture are in use in Europe and around the world.

Oil Atomization

For use in other kiln installations atomization is the only correct way to burn heavy oil. Incidentally, atomized oil does not work very well in Hoffmann kilns and above all it is not good for top firing. I have actually seen the firing of a Hoffmann kiln by means of atomized fuel oil and in this case the burner was situated in a shallow flue beneath the kiln floor. This was then what we would call under ware firing. I was also able to compare the results obtained in this particular case with those obtained in a kiln of the same design and using the same clay, but fired by means of impulse-injection from above. The results of the second plant were infinitely better - the proportion of over-fired ware much less.

Incidentally, the most interesting oil atomization method I have ever seen is being practiced in firing the so-called "Koora" up-draft kilns around Baghdad. Here the oil is fed by gravity to a burner tip inside the kiln and its atomization is achieved by means of steam, generated in a water-fed coil attached to the burner and heated by radiation from the firing chamber.

Considerable attention has to be given to the choice of the atomization method. The following table may give a good idea regarding the power required to atomize 100 liters of oil per hour for each of the possible atomization methods:

Low Pressure air burners, air at 0.07 kg/sq.cm.	2.75 HP
High Pressure air burners, air at 5 kg/sq.cm.	10.00 HP
Steam Pressure burners	3.00 BHP
Mechanical Atomizing Burners	0.85 HP

Assuming steam cost at US $2.00 per 1000 kg and electric current at ¢ 4 per Kilowatthour we have the following comparative hourly cost of operation per 100 liters of burned oil:

Mechanical atomization	¢ 2.5
Low Pressure Air at 0.07 kg/sq.cm.	¢ 8.0
Steam Atomization	¢11.0
High Pressure Air, 5 kg/sq.cm.	¢33.00

The above tabulation indicates the unsuitability of high pressure atomization. Mechanical atomization, though the least costly to use, is impractical for our type of operation as the high oil pressures involved cause a too rapid wear of the atomizing nozzles. Burners of this general type also show a limited turn-down capacity. We are, therefore, left only with low air pressure and steam atomization.

Although most of the less viscous fuel oils may be delivered to the burners by gravity feed, high viscosity oils No. 5 and 6 require pressures of at least 1 kg per sq. cm. Rotary of gear pumps are used for that purpose. To be pumped efficiently, the above two grades of oil must be heated at temperatures sufficiently high to reduce their viscosity. Burners will operate better when supplied with oil of constant viscosity which can more easily be obtained if the oil is heated at temperatures at which the oil's viscosity changes very little. This will allow the widest variation of temperatures with the least change in viscosity. For oil No. 6 for instance a difference of 10°C in the range of 100-110°C will cause the oil's viscosity to vary only from 80 to 120 seconds. The same temperature difference in the range of 55-65°C will cause the viscosity to fluctuate between 650 and 1260 seconds. There is a great variety of oil heaters on the market. Electric heaters are frequently used eventhough the most practical are steam operated ones.

If low pressure atomization is used the air pressure should be at least 0.07 kg per sq.cm. The amount of air required for atomization will depend on the draft conditions of the kiln, pressure of the atomizing air, maximum temperature to be developed etc. At 0.07 kg/sq.cm air pressure and moderate kiln draft, approximately 45% of the total combustion air should be used in atomization. The total combustion air requirement must be calculated from the oil's chemical analysis but it may be roughly figured by means of the following rule of thumb: Divide the B.T.U.'s per unit of fuel by 1000 and the result will be roughly equal to the cu. feet of total air required to burn that unit of fuel.

As for the burners, a great variety of them are available. The most simple consist of an inner oil nozzle carrying the oil, surrounded by an inside air nozzle which has a venturi bore. The oil leaving the oil nozzle opening encounters the stream of primary air as it passes through the venturi of the inside air nozzle. This primary air has a rotating motion imparted to it by means of the primary air supply openings which are tangentially arranged. This high velocity rotating primary air thoroughly breaks up and atomizes the oil. Refirements may include the utilization of secondary atomizing air through a hull enclosing the inner oil nozzle with its enveloping primary air nozzle. The pressure air is provided by a suitable blower. Both the amount of air and that of oil must be capable of being controlled very efficiently. A normal oil firing circuit will be operating on the closed circuit principle. That is approximately twice the amount of oil required for firing will be circulating at all times. The burners connected to it will take only the required amount of oil and the rest will be returning back to the storage tank. Each burner will be equipped with its own graduating valve and an oil strainer. The whole operation of such a system will become clear during the discussion of a complete burning system for use with scove kilns.

Before proceeding further, the problem raised by the absence of electric power at many of the handicraft brickmaking sites in most developing countries, must be discussed. As we have seen, power will be required here for the following purposes:

(1) To pump and to atomize the fuel

(2) To heat the oil.

If electric power is not available, the best thing to do is to use steam for atomization, and for heating the oil. Excellent steam heaters are available. They are easy to operate and very reliable. Steam may also be used to pump the oil. Piston operated pumps are easily obtainable. Personally, I prefer steam for atomization and for doing all the other chores, as with them there is less maintenance. Furthermore, a boiler is the least complicated of power equipment and boiler operators are easily trained. It may not be the most efficient thing to do, however, from a strictly engineering point of view.

Oil Firing Installation for Use with Scove Kilns

The oil burning installation which will now be described was designed for use precisely with a large size scove kiln. For the reasonswhich were already discussed, steam was selected for atomization.

When figuring the requirement of steam for atomization, it has to be born in mind that eventhough it may vary from 0.25 to 0.5 kg of steam per liter of oil, a careless operator may waste as much as 1 kg of steam per liter of oil. It is, therefore, safer to allow 0.5 kg of steam per liter of oil. Let us turn now to practical operators. In the U.S. The lowest Boiler HP required per burner is 2½ to 3 with 4 kg/sq.cm. steam pressure, but better results are obtained with dryer steam obtained at say 7 kg/sq.cm. pressure.

The oil for our operation will then be deposited in a say 50.000 liter tank. Its bottom will be one meter above ground level so that the oil may flow by gravity into the recirculating and auxiliary tanks. We will do well to install a steam coil inside this main storage tank for heating purposes. Its capacity will be about 4000 liter. A steam operated piston pump will take the oil from the auxiliary tank and pump it to the burners. A schematic view of the burning and distribution system is shown in figs. 18 to 26. As may be seen in figs. 18 and 19 each burner is provided with a needle-point valve to control the access of oil. Globe valve control the steam supply to the burners. The connections are made in such a way that by loosening the two universal joints on each side of the burner, the whole assembly can be swung out, leaving the firing opening free. This is important especially at the end of the operation when, having finished the firing, the openings have to be blocked. The oil line is oversize, at the start - but the diameter decreases by ¼" every five burners. The return line from the last burner is one inch. As regards the steam line, a single 2½" line leads from the boiler to one side of the kiln. There it forks off into two 1-5/8" lines running along each side of the kiln. (See Fig. 19).

The oil distribution and pumping station is shown in Figs. 20 and 21. As may be observed, the oil is pumped from the auxiliary tanks by means of a double-action steam operated pump through a strainer. Two strainers with the necessary gate valves are provided, in order that each may be cleaned without interrupting the firing operation. The oil then enters the cyllindrical air chamber, which is used to minimize pump pulsations and thus ensure steady oil flow to the burners. From the air chamber the oil goes to the oil preheater. This consists essentially of a cyllindrical steam chamber around a coil carrying the oil, which, after being heated, is directed to either one of the two kilns as required. A thermometer is installed in the "cross" which distributes the oil either to one kiln or to the other. The temperature of the oil is maintained between 100 and 110°C by means of a globe valve controlling the steam inlet.

A pressure relief valve must be installed at the hot oil outlet to relieve the thermal expansion of the oil into the return line in the event that the oil valves on either side of the preheater are accidentally closed.

Since about twice the required amount of oil is being pumped, the excess must be returned to the auxiliary tank, and its pressure must be maintained constant. This is actually done at the return end of the installation, which is shown in figs. 22, 23 and 24. As may be seen, the oil may return from either side, depending on whether the left hand or the right-hand kiln is in operation, access to each entrance being controlled by means of a gate valve. The line from either kiln is simply joined to the system by means of G.J. Unions. A bypass leads to the pressure regulating valve, which is pre-set for the desired pressure depending on the type of burner employed, but is generally maintained at around 1 kg/sq.cm. The return line is provided with a pressure gauge. From here the oil flows directly into the auxiliary tank.

It will be realized that the installation may be made more simple through the use of a lighter, free flowing oil that would not require preheating and that could be delivered to the burners by gravity. These oils are, however, much more expensive. The installation that has been briefly described is a simple unsophisticate one, suitable for field operation. More complex and precise systems may be devised but they might not always be suitable for field operations.

VII. PROMOTION OF BRICK CONSUMPTION

The brick's greatest competitor is the sand-cement block and less so the true concrete block. The price structure of these products in an african country will be compared and conclusions drawn. The fact will be stressed that much can be made of the fact that sand-cement blocks are extremely permeable, whereas clay bricks, in virtue of their tortuous pore system are much less permeable and can be used without stuccoing. The experience of Liberia will be cited. Here, unrendered brick constructions have been found unequalled as far as duration, impermeability and low cost is concerned, inspite of the legendarilly heavy rains.

The fundamental approach to the promotion of brick consumption will differ according to whether there is or is not a brick tradition in the country. In countries with a brick-making tradition, the problem in most cases is one of resisting and stopping the encroachment of the sand-cement block. In most cases this encroachment was made possible by deteriorating brick quality. The response in this case is obvious: The brick quality must be improved and the consumer's attention must be called again towards the traditional virtues of clay bricks as the ideal building material. This is best done by making use of mimesis. i.e. by erecting experimental structures for use as show-cases. It is also possible to make use of the conventional media of diffusion, such as cinema advertising, leaflets, billboard etc. One of the most important factors in promoting the uses of clay brick is an easy availability of good masons. Relatively little skill is needed for erecting a structure out of large sand-cement blocks with their thick walls and by the use of thick mortar joints. Any surface irregularity may be hidden under the mortar coating. Considerable more skill is required for laying-up hollow clay blocks. However, the greatest skill is needed in laying-up solid or even perforated brick which are left uncovered.

One of the most efficient tools in promoting brick consumption is to train, in the first place, efficient masons. During a mission in Liberia, for instance, it was found that the decrease in consumption, inspite of the high esteem in which brick structures were held there, was due to the lack of good masons and consequently high labor cost in laying.

It is necessary, therefore, to organize brick-laying courses. Frequently it even pays to send suitable candidates for training in foreign countries with a highly developed brick-laying tradition. Several countries, such as Sweden, Denmark etc. offer bricklaying courses for masons from developing countries and advantage should be taken of these facilities.

In countries with no brickmaking tradition, the promotional approach will vary according to whether it is directed towards the urban population or towards rural areas.

In the capital of largar cities, where a substantial market for brick may justify it, a more or less mechanized brickwork, might have been erected, must probably with governmental financing or with substantial governmental help. Or it might have been decided to supply the existing need from one or sever.. handicraft, but rationalized brick yards, initiated for that purpose. The promotion of brick consumption will take the form of persuasion through leaflets, billboards, cinema advertising etc. Again, the powerful effect of mimesis should not be forgotten and the persuasive power of an experimental structure erected for advertising purposes is not to be under-estimated. The establishment of Credit Unions for brick users, sponsored by the Government will also be a powerful promotional tool. In any promotional appeal, the accent will be on permanence, durability, economy, better "livability" and perhaps aesthetic appeal.

In rural areas, the promotion of brick consumption will be intimately associated with their production. In other words a brick manufacture must first be introduced. Even here, therefore, the government's assistance is indispensable. Details of the promotional campaign may vary from one country to the other according to its social organization, civil administration structure etc. but, in any case a group of clay brick "specialist" should be trained to enable them to visit rural area and demonstrate the manufacture of brick and their superiority to other, more traditional but less satisfactory building materials. What one should finally aim at would be to have a "building materials specialist" attached to every chief of district, province or department. He would be trained to give advice to prospective builders, teach simple brickmaking techniques etc.

Finally, a simple manual, outlining in a simplified form the manufacture of field brick, their uses and advantages, could be prepared for use by rural teachers, who would then be able to awaken in their pupils the consciousness of brick construction as a symbol of permanence and value. The United Nations Technical Assistance Organisations are well prepared to assist the governments of member states in this task.

VIII. IMPACT OF STANDARDIZATION

In the development of clay brick and even in improving the quality, both dimensional and quality standards are of supreme importance. Quality standards, Standard Specifications and Standard testing methods should be established as soon as possible. While adopting quality standards existing in developed countries appears to possess a great deal of attraction, blind acceptation is seldom advisable. Quality standards existing in other countries must be revised with a critical eye in order to make them conform to the realities and needs of the country. Absurdly high quality standards existing in European countries may not be necessary in some African countries because of climatic, structural and other differences.

On the other hand extremely heavy and prolonged rainfalls prevailing in some African countries may require different quality standards for exposed, that is unrendered brickwork. What is needed is a considerable amount of common sense, because too rigid standards may become an obstacle rather than a tool.

Dimensional standardization is, of course, almost a necessity in any attempt at improvement. It is not uncommon that brick of different sizes are manufactured simultaneously in a given country. While these differences are usually due to different social and political backgrounds, it is indispensable that a mutually compatible and complementary size series be adopted. Again a great deal of common sense is necessary and it is not always advisable to adopt dimensional standards used in other countries. However, regional preferences must be taken into consideration.

In some countries where a smaller, and from many standpoints unsuitable brick size has been used for generations, it might be unwise to insist on a more logical, but to the local consumer (and mason) uncommon and often unwieldy larger standards, while insisting at the same time on introducing modifications in the making technique.

On the other hand, when it is a question of introducing a manufacture of hollow clay tiles into a country where previously only sand-cement blocks have been manufactured, care must be taken to adopt sizes that will be complementary or interchangeable with those of the competing cement block. At all times, however, a range of sizes to be introduced must be logical and the individual tile sizes interchangeable for a given wall thickness.

While, therefore, dimensional standardization is important even since the early stages of the development, dimensional and modular coordination become increasingly more important as the technical development advances to more complex stages. Modular coordination, the basis of which is the modul of 10 cm (1dm) is relatively easy to apply in the manufacture of hollow tiles

As for the source of additional air, the cheapest way to do it is to use directly the products of combustion. This is easy with gas and some light oils. Even heavy oils might be used sometimes, provided they do not contain too much sulphur. Otherwise scumming may occur with red firing bricks as the sulfuric acid-laden air exhibits rather high dew point. Also corrosion of the metallic parts of the dryers is then frequent. With oils high in sulphur or when coal is used, heat exchangers must be used. They are expensive and of course the heat imput is not utilized in them as efficiently as in direct fired installations.

V. KILNS AND FURNACES

Strictly speaking the cheapest and simplest kiln for firing brick is no kiln at all. This is the "clamp" which requires no firemen as once the fire is started it propagates itself until all the fuel is consumed. The results, unfortunately are mostly in the hands of chance through its agents of wind and weather. The construction of a clamp is a difficult art requiring much experience and in most cases the proportion of underfired brick is high. Underfired brick are usually located around the interior well-fired core. This underfired shell may be up to 1 m thick. Overfired brick are believed to be due to the fact that certain parts of the clamp start to "draw" better than others. This increased draft causes the temperature in these parts to rise suddenly, thus melting the ash and fusing the brick and ash together in a worthless mess. This draft can only be caused by a vertical split in the setting as a consequence of faulty hacking.

The Scove Kiln

The Scove kiln represents a considerable advance over the clamp. In the first place much less is left here for the work of nature. The brick are not placed close to another but space is left between adjacent bricks to facilitate circulation. The important fact is that fireboxes are built into bottom of the setting. The construction of scove kilns and especially the setting patterns vary somewhat from one country to another, especially according to the type of fuel available. One of the most important features is the contruction of the fireboxes.

In one developing country where coconut husks were used as fuel I have been able to develop a very successful construction pattern. Here the fireboxes were nine courses high and about 50 cm wide on centers of approximately 1.50 m. The construction and setting patterns that were gradually evolved may be observed in Figs. 11, 12 and 13. The setting pattern is intricate for the first nine courses as flues must be left for circulation and the construction must be stable enough to resist overheating. After and to what is now called "a large brick". However, difficulties have arisen due to the fact that 15 and 25 cm walls are widely used with acceptable results. Since modular coordination is said to be a system of addition and not one of subdivision, the use of 15 and 25 cm walls involves halving the modul which is not an ideal solution.

Even machine-made full or perforated brick may be successfully modulated as long as the width remains equal to 1 M. Its thickness may also be made equal to 1 M. thus satisfying the requirement that it should be possible to vary the height of structures by increments of one Modul. The length will then be either 2 to 3 M. with scoring for easy splitting the 2 M or 3 M sizes to produce 1 M x 1 M x 1 M pieces as required. The result then are bricks 290 x 90 x 90 mm, 190 x 90 x 90 mm or 290 x 140 x 90 mm or 190 x 140 x 90 mm. The first two sizes are quite handy as they are easily grasped by one hand. The second two are less convenient for one hand application as the 140 mm (1-2 M) width is not so easy to grasp with one hand. And, of course, the modulation principle is not strictly applied in the two last mentioned sizes as they involve splitting a modul.

Fig. 27 shows two types of modulated bricks, designed by the United Nations Experimental Housing Centre in Lima, Peru and now in full production. The brick are extruded each with two thin cores so that by splitting they produce smaller but equally modulated units one and two moduls long.

Considerably more difficulties are encountered when one tries to modulate hand-made brick. In the first place the 1 M (90 mm) thickness required by the fundamental modular principle is excessive for full brick and is likely to cause problems in drying and firing. One half of a modul (45 mm) will made the brick too thin and therefore too expensive. Furthermore a 3 M length by 1 M width is also not quite suitable for a hand made brick.

Nevertheless, the 1 modul thick brick 2 M x 1 M x 1 M is being successfully produced under the direction of the Capital Project Circle for the construction of the new capital city of the state of Gujarat where ultimately 580 million of them will be used over a period of five years.

It may well be remarked here that the German so-called "Normalformat" or simply NF 240 x 115 x 71 mm is a very satisfactory brick. This is, however, not a strictly modulated brick being based on the principle that four stretchers plus the corresponding mortar joints equal one meter.

Resuming then, one may say that careful thought and much investigation is required before a system of modular coordination is accepted, especially in countries which predominantly depend on handicraft manufacture for their supply of brick.

LIST OF FIGURES

TABLE I.

DIMENSIONS AND OPERATIONAL DATA OF 9 EUROPEAN HOFFMANN KILNS

KILN NUMBER	UNIT	I	II	III	IV	V	VI	VII	VIII	IX
GALLERY HEIGHT	m	2.20	2.20	2.20	2.40	2.50	2.60	2.75	3.00	3.25
GALLERY WIDTH	m	1.80	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50
GALLERY CROSS SECTION	m^2	3.60	3.95	4.80	6.20	7.40	8.65	10.00	12.30	14.55
MEDIUM GALLERY LENGTH	m	7.25	7.45	9.15	9.55	10.50	11.50	12.55	13.90	15.10
FIRE TRAVEL	m/24h	13.89	12.66	10.42	8.06	6.76	5.78	5.00	4.06	3.44
FIRING TIME FOR THE WHOLE KILN	days	6.05	6.64	8.06	10.42	12.42	14.53	16.80	20.69	24.42
COOLING TIME	hours	41.5	45.3	55.3	71.40	85.20	99.00	115.2	141.90	167.40

FROM: W. Avenhaus, "Rechnungsgrundlagen für den Entwurf und den Betrieb keramischer Brennöfen" Wilhelm Knapp, Halle, 1948

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these first nine courses a simple pattern of two and half headers over as many stretchers is used. Bonding of superposed brick is important for stability reasons. With coconut husks the right altitude was found to be 29 course followed by a flat course with the necessary flues and finally a layer of earth. These kilns may be naturally built infinitely long, one simply adds more fireboxes. The more, the better. In practice, the length of the kiln is limited by the economic potency of the brickmaker. In some countries the setting is not surrounded by an outside wall of underfired brick but the kiln is only scoved, that is daubed over with wet mud. This is a foolish way to economize as the relatively thin (one stretcher) outer shell materially increases the output of good quality bricks. As to the fuel consumption, with coconut husk we used about 500 kcal per kg of brick. When coal is used, grates have to be used. The size of the fireboxes and the setting height will also depend on the nature of the coal, its length of flame etc.

In the United States large amounts of bricks are fired in scove kilns, fired these days mostly by oil. Here the kilns are extremely large - containing at time as many as one million brick. They are up to 40 courses high and there may be as many as 20 fireboxes. (arches). The width is usually about 60 stretchers. For oil firing the arches must be considerably enlarged and the best width is equal to three stretchers and the height about 13 courses. The setting pattern varies somewhat but a very successful one may be appreciated in Figs. 14, 15 and 16. As may be observed, the setting pattern during the first 13 courses consists of a number of pillars one stretcher wide made more stable by alternating headers and stretchers in successive courses. There are free spaces corresponding to one brick's thickness between individual pilars to allow the combustion gases to distribute themselves evenly through the whole setting. Also to prevent them from short-cutting, the fourteenth course directly above the fireboxes is corbelled over entirelly. This forces the gases to divide and to flow to either side instead of rising straight up, thus contributing towards a better distribution of heat. One important feature of the oil-fired kilns is the middle partition wall or baffle built from fired bricks, in order to avoid the interference of the opposite burners. The consumption of heat in these large oil fired kiln varies with the type of clay and with the hardness of the product desired. The lowest consumption is said to be 340 kcal per kg of brick, the highest reported so far is 850 kcal. The quality is, in most cases excellent.

The beauty of the large scale scove brick kilns is that it can be set mechanically by fork lift trucks or even by overhead cranes. This is an important consideration. When the expenditure of manpower is analyzed, it is frequently found that the operations of transporting, setting and drawing take up as much as 40% of the total manpower required.

Permanent up-draft kilns are also used sometimes. The construction of one of them may be seen in Fig. 17. Their advantage is that on the long run labor, normally used in building the outside shell, is saved. In most cases, these kilns are provided with a permanent roof of clay tiles.

Special provisions must be made when firing brick made from clays with a narrow vitrification range. In this case only permanent kilns are used. Here a series of arched-over fireboxes at about 150 cm centers is built in such a way that transversal slot are left in them. The slots generally correspond to one brick' width and are spaced at intervals of 1½ stretcher. They are preferably built underground at such a depth that the top of the arches coincide with the outside ground level.

Any fuel may be used but as usual, with coal, grates are indispensable. The floor inside the kiln and between the arches is levelled off by means of rammed earth and sand.

A special case is the up-draft kiln used in Iraq, locally known as "koora". Much skill and ingenuity is displayed in the construction of these kilns. The side walls are built in the form of convex vertical arches conveniently butressed to take up their thrust. There is an ample firing chamber in the lower part of the kiln, frequently under ground, and a thick perforated arch above it. This arch supports the brick to be fired. The height of the firing chamber is considerable, certainly to avoid any direct impingement of the flames on it. This is a wise precaution as the kiln is built from the same calcareous clay exhibiting a short vitrification range as the ones being fired. The combustion gases pass through the flues in these arches into the brick setting above. The capacity of these kilns is 50,000 9" square bricks and the firing time up to 12 days.

The Bull's Ring Kiln

An important development in the firing of brick is the Bull's trench of ring kiln, so extensively used in India. Approximately 2000 of them are reported to be in operation. Several designs exist, all of them variation on a single theme with a greater or lesser degree of sophistication. Essentially they are roofless anular kilns. In its simplest form the Bull's ring kiln consists of an anular space roughly 6 meters wide and 2.5 to 3 meters deep, enclosed by two concentric walls variously thick. The inside and outside diameters are usually 35 and 48 meters respectively. Sometimes, however, for economy's sake, the anular space is partly

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dug out of the ground and the required height completed by brick. The kiln may also consist of two parallel "renches" some 6 meters wide, either dug out of the ground or built from brick, connected at both ends, thus acquiring the shape of a very elongated "O".

For firing the bricks are set in the kiln's anular space in a series of concentric stacks following the shape of the kiln. These stacks are built alternating headers and stretchers, their width is one stretcher across and there are 7 cm spaces between them for the fire travel. In the final three courses the brick are laid close together to bridge the gaps between adjacent stacks and to form a continuous cover. Lastly, the whole is covered with a 10 - 15 cm layer of coal ash. Square or rectangular holes 7 x 7 cm are left in the upper layer to provide openings for the access of fuel.

The brick setting in the kilns' anular space is divided into 28-29 section by means of sheet iron dampers which reach from top to bottom and completely seal one section from another. Each section contains 18.000 bricks 9" x 4-½" x 3" or 20.000 modular brick 19 x 9 x 9 cm. The simplest kiln may have one but generally two chimneys placed directly over the brick setting. For this purpose radially disposed longitudinal slots are left in the kiln's top covering and the two chimneys are placed over them. The lower part of these stacks is formed by elongated sheet-iron boxes (plenum), approximately 2.4 m by 60-70 cm, whose sides merge into the cyllindrical part of the stack, generally also 60-70 cm in diam. In more sophisticated designs the stack is placed over flues built into the outside but sometimes also the inside wall of the kiln. Again there are 28 to 29 of such uniformly distributed flue openings. Normally they consist of two vaulted horizontal openings, one at the bottom, the second near the top of the limiting kiln wall. These horizontal flues conne : the kiln's interior with a horizontal shaft within the wall, which is roughly 80 cm square. The movable stack is positioned over it.

The stack itself is approximately 15 meters high and consists of a bottom section 85 cm square, followed by a 1.20 cm high square to circular transition piece and finally a 12 meters high cyllindrical part 60-70 cm in diam. The lower parts are made of 1/4" boiler plate the upper cyllindrical part of 1/8" black sheet iron. It is reported to cost about US $270 and to last 2 years. Better kilns have two stacks, one over the inside and the other over the outside wall of the kiln. Furthermore, the stacks may be mounted on wheels to facilitate their shifting.

As to the firing openings, they are distributed on radial lines and there are five lines for each section or chamber. There are 11 openings uniformly distributed over the kiln's width. Four rows of holes are fed at the same time and the speed of travel is given at 9 lines each 24 hours. The dampers are lifted and the stack advanced to the next position as soon as the distance between it and the nearest firing hole in operation drops to 11 rows.

The fuel is coal and the feeding manual; the firing degree is judged by the brightness of the brick in the kiln. Six firemen, paid roughly the equivalent of US $10.00 per month, are employed. The completion of the whole circle, which will produce 560 - 580 thousand brick depends somewhat on the season. It is said to take 20 days in April-May and as long as 30 days in November. The fuel consumption vary from 275 to 450 kcal per kg of brick. Even allowing for the fact that the coal or rice husks added to the clay contribute some heat, the fuel consumption makes the Bull's ring kiln's fuel economy comparable to that of the normal Hoffmann kiln, certainly a most remarkable accomplishment. The firing uniformity is also quite good.

The Annular Kiln

Considering the poor fuel economy obtained in most periodic kilns the invention of the annular continuous kiln revolutionized brick making in Europe. The original annular kiln was conceived by Friedrich Hoffmann in 1861 in a round form, which appeared logical at that time. What was probably later considered as a nuisance was the necessity of setting wedge-shaped chambers at all times. Also probably the rate of fire advance was faster along the inner wall than along the outer wall. The design was then soon changed to an oblong one, so that it now consisted of two parallel tunnels or galleries connected at each end by semicircular parts of the same dimmensions. It may be appreciated that the necessity of setting wedge-shaped chambers persisted in these semicircular parts of the kiln. To eliminate them entirely, the semicircular communication parts were changed to straight ones. This helped to uniformize the setting but created new problems due to the defficient flow of the gases in these parts. Furthermore, the ware placed in the right angle parts of the kiln were consistently underfired. A partial remedy consisted in building the communicating end-parts of the kiln narrower while conserving the height of the main gallery. To avoid loss of velocity in them, the setting in there was kept more open. The final development then is that of two much smaller communicating flues that are kept free of ware entirely.

The Zig-Zag Kiln

The development of the Zig-Zag kiln constitutes a considerable deviation from the form of the original annular kiln. Here the direction of the galleries is being consistently changed by making them turn at a right angles. The setting in the connecting parts of the kiln is usually kept more open or is left out entirely, The width of the galleries in the Zig-Zag kiln is usually smaller because the expansion of the crown is not so easily taken up as in the normal annual kiln. The number of the chambers in a Zig-Zag kiln is always divisible by 4 so that the number of transitions is N-2 for N number of chambers. Due to the fact that at each transition the direction of flow is changed by 180° a stronger draft is necessary for best operation. This may be the main reason why fans are more frequently used in connection with this type of kiln than with any other. With a draft in the neighborhood of 35 mm W.G. speeds of travel in the range of 12 meters in 24 hours have been reported. With 60 mm W.G. even advances of 24 to 30 meters. Such rates of fire travel naturally lead to lower fuel consumptions. In view of the arrangement of the individual chambers, less heat is lost by conduction as the heat of one chamber is always at least partially communicated to the next chamber. The chief deffect of the Zig-Zag kiln is of constructional nature. The vaulting of the transition part is always less stable and consequently maintenance expenses may be higher. The dimmensions and some other characteristics of annular kilns are given in the following Table 1.

Other modification of the original annular kiln are the Transverse Arch Continuous kiln and the Belgian kiln. The transverse arch kiln is said to allow better control than the barrel arch one. The Belgian kiln differs from the Hofmann kiln by being grate fired thus allowing higher temperatures to be obtained. The kiln is described as follows: (Trans. Brit. Ceram. Soc. 41, 209, 1941-42). "The first sections of the kiln chambers are not set with ware but form the grates on which fuel is generally fired from the wicket. The grate is usually composed of refractory slabs spaced over the primary-air flue which runs beneath the floor and across the width of the chamber. Primary-air inlets are just outside the wicket openings. A short vertical continuation of the primary-air flue is built into the centre wall and communicates with the main flue via a bell-damper control thus the flue first serves as a chamber flue for withdrawal of steam and waste gases before the chamber comes into the firing zone and then it is used to distribute primary air through the fuel bed".

Although the essential features of the annular Hoffmann kiln are simple, complications are introduced in cases requiring the use of clean hot air from the cooling chambers for the drying and water smoking of freshly set ware. A separate system of flues has to be incorporated into the basic design. Drying and water smoking may be accomplished by other means but the above system is highly desirable.

Most Hoffmann kilns are fired by coal the size grading of which must be controlled. But it does depend somewhat on the particular working conditions of the kiln. The grain size should range from that of fine powder to about 3 to 6 mm. The firing is from the top through circular openings. Special shovels are used to permit some control of the evolution of heat but automatic stokers are used always more and more.

Firing circuits may vary considerably at different works, With kilns built for utilization of hot air from cooling chambers for water smoking, the following circuit may be used:

Empty	3 chambers
Reserve Zone	2 chambers
Cooling Zone	6 chambers
Firing Zone	3 chambers
Drawing Zone	4 chambers
Water Smoking Zone	2 chambers
Total	20 chambers

The firing holes are arranged in rows of three to four per row. The fire zone may comprise nine to eighteen holes.

Countries without coal may use agricultural wastes such as coconut or rice husks. The former are especially suitable on account of their content of oil and because of the soft flame they produce. Their heat value is around 3.500 kcal per kg. Wood has a heat value from 4000 to 5000 but the moisture content is usually very high thus depressing the amount of heat obtainable from it.

The oil firing these kilns will be dealt with in the next chapter. Gas firing offers particular problems and it may be said that it can not be done from the top. The best arrangement is under-firing in which the burners fire into a firebox located beneath the floor of the chambers to which it is connected by means of openings. If this system is employed the position of the exhaust flues must be changed as the combustion gases may short-cut to the flue-opening leaving the upper part of the kiln underfired. The second possibility of course is to fire through the wicket. Unless a very soft flame is used there is always the danger of local over-firing. Developing countries will have little use for gas firing unless brickplants are located near an oilfield.

Fuel Consumption of Annual Kilns

Fuel consumption will be influenced mostly by the rate of working the kiln. In order to obtain satisfactory rates of firing and lowest fuel consumptions the kiln must have a sufficient number of chambers, the least number being 18 to 20. This is especially the case where hot air drying and water smoking is carried out in front of the preheat zone.

With existing kilns the rate of fire travel, fuel consumption and uniformity of heating can be improved by proper setting. Trace flues through the setting should be in direct alignment from chamber to chamber and those at the sides should be built at such distances from the chamber walls that they are not obstructed by the drop arches. The trace flues should be sufficiently large to accomodate the accumulation of ashes. One or more steam flues should be provided across the chamber. It should stretch from top to bottom of the setting and the width should vary according to the number. If only one or two are provided per chamber at least 15 to 25 cm widths should be allowed. (Trans. Brit. Ceram. Soc. 41, 207-217 1941-42).

Under normal conditions and fire travel the fuel consumption should not be over 320 kcal per kg of brick at a firing temperature of 1000°C. The amount of waste heat that may be withdrawn from the cooling chambers is approximately 60 kcal per kg of brick.

The Car Tunnel Kiln

The car tunnel kiln is the last word in the long development of brick firing kilns. It is strangeto observe that its invention precedes that of the Hoffmann kiln by some twenty years.

Except in the U.S. the car tunnel kiln is seldom used to fire structural clay product eventhough the number of corresponding installations is on the increase. The main advanteges of this type of kiln are:

(1) High fuel economy
(2) Lower labor cost in setting
(3) Ease of operation
(4) High quality output
(5) Easy incorporation into an efficient factory set-up

Its chief drawback is the high initial cost. The basic principles underlaying the design of car tunnel kilns are well known and need not be discussed in any detail. Fundamentally then, the ware is set on top of especially designed cars provided with heavy