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Organización de las Naciones Unidas para el Desarrollo Industrial

Curso práctico [illegible]
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Pilsen, [illegible]

13 - [illegible]

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La monografía que aquí se resume trata principalmente de los problemas que plantea la fabricación de productos refractarios de sílice y de arcilla refractaria.

Tras haber definido l[illegible] refractarios de sílice y de arcilla refractaria, se analizan brevemente las principales propiedades que se exigen a los productos refractarios.

Al analizar los [illegible] de la fabricación de ladrillos de arcilla refractaria, se describen en primer lugar las materias primas y se tratan todas las posibilidades técnicas de preparación de la pasta, [illegible] el proceso de extrusión, el proceso de prensado en seco y el proceso de colado. Una vez analizados los problemas fundamentales del secado, se examinan los procesos de cocción, incluso en los aspectos relativos a los hornos [illegible] problemas [illegible]. Se muestran las diferentes [illegible] de una planta de arcilla refractaria mediante análisis financieros [illegible] de diferente capacidad de producción.

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BODY COMPOSITION AND PROCESSING OF FIRECLAY AND SILICA BRICKS 1/

Z.A. Engelthaler*

SUMMARY

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This document is mainly concerned with the manufacturing problems of fireclay and silica refractories.

After the main types of fireclay and silica refractories are defined, the main required properties of these refractories are briefly analysed.

In analysing particular steps of fireclay bricks manufacture, raw materials are first described. All basic body preparatory possibilities are shown, i.e. the stiff-mud process, the dry-press process, as well as the casting process. After basic problems of drying are analysed, firing process - including kilns and problems of choice of fuel - are discussed. Different stages of the development of a fireclay plant are shown in condensed financial analyses of two plants with two different yearly production capacities and projected jointly in two different variants: as fully automated plants and as plants utilizing maximum labour.

A similar schedule has been used for the silica manufacturing problems which, at the same time, have been extended with the brief description of super-duty silica refractories and semi-silica products.

The establishing of the refractory industry in any country must be weighed very sensitively, since it would depend not only on the availability of raw materials but also on the market potential and the feasibility of such a venture.

On the other hand, fireclay manufacture can help settle many of the problems of the industrialization of any country, developing industrial plants comprising heat transfer and firing, baking or heating operations.

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United Nations Industrial Development Organization

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Seminar and Training Workshop on
the Production of Refractories

Pilsen, Czechoslovakia

[illegible] June 1974

BODY COMPOSITION AND PROCESSING OF FIRECLAY AND SILICA BRICKS [1]

Z.A. Engelthaler*

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TABLE OF CONTENTS

1. Definitions and scope of the lecture.

Certain materials have the capacity to withstand high temperatures without deforming or melting. Such substances are termed refractory materials.

Refractories are materials with the softening point of SC 26, i.e. 1580°C or above, up to cone 42, i.e. 2000°C. They are subdivided mainly according to their refractoriness by their chemical composition and other physical properties.

Refractory materials cover a wide range of compositions, based on different minerals and additives. In this lecture, those refractories, which are called alumino-silicates, will be discussed.

Alumino-silicate minerals occur frequently in nature. All mixtures of the two components system /silica-alumina/ show a high melting point, as their lowest eutectit has been accepted as the limit for the refractoriness. It is not surprising that this class of refractories is frequently employed in industrial practice. Although compositions ranging practically from 100% silica to 100% alumina are commercially manufactured, the range 22% to 42% alumina predominates because these compositions are formulated from natural clays. These products are called <u>fireclay refractories</u>, and, in establishing a manufacture in any country, fireclay refractories are to be considered as the first types of refractories, which can be applied and commercially produced on an easy way. The manufacture of fireclay refractories is one of main topics of this lecture.

The ratio of alumina-silica largely determines the refractoriness of materials, as shown in Fig. 1. It is understood that presence of other fluxes and impurities, can decrease the presented refractoriness which is valid for two pure components only.

Fig. 1 shows the alumina-silica equilibrium diagram, representing crystallographic changes and the melting behaviour of compounds, mixtures and solid solutions under conditions of chemical equilibrium. The most important points are:

a. The melting points of three compounds are shown, namely, that of silica /1723°C/, mullite /1850°C/, and alumina /2050°C/.

b. There are two eutectics, that between silica and mullite melting at 1580°C /after other scientists 1595°C/, and that between alumina and mullite melting at 1840°C.

The same diagram shows the range of fireclay bricks, of silica bricks and that of high alumina products. While problems of the fireclay and silica manufacture have been incorporated into this lecture, high alumina and lightweight products' problems will be explained within one of next lectures.

Silica refractories contain not less than 92% silica with only very small amounts of alumina, which decreases the melting point of silica rapidly /see Fig.1/. They are manufactured from naturally occuring quartzites or ganisters and form another important class of refractories. However, in comparing silica with the fireclay refractories manufacture, it is obvious that the silica manufacture does not occur to be so common as the fireclay production. This fact depends on the reality that the silica manufacture is more specific than that of fireclay products. Super-duty silica bricks are silica refractories with strictly controlled flux content /alumina less than 0.5%, alumina plus alcalis not exceeding 0.7% from total/.

Semi-silica products show the silica content higher than 88% from total. They represent a compromise between silica and fireclay produts in order to improve low thermal shock e resistance of silica bricks and large after-shrinkage of fireclays.

Main Required Properties of Refractories.

This matter has been included into this lecture to demonstrate main required properties of fireclay and silica refractories.

1. Refractoriness.

The grade of refractoriness is determined by the purity of raw materials used. As explained in Chapter II. of this lecture, refractories are all materials with a melting point corresponding at least to Seger Cone No 26 /1580°C/.

Fig. shows the Pyrometric Cone Value of fireclay and silica refractories, including a table of Seger Cones and Squatting Temperatures in Centigrades.

During the operation of furnaces refractory materials are exposed not only to the heat but also to the effect of the pressure of the brick-work or strain as a result of thermal expansion. This pressure under heat causes the bricks to soften at a lower temperature than that corresponding to their refractoriness.

In many cases, therefore, it is more important, for operational purposes, to know the refractoriness under load. According to different types of refractories, their refractoriness under load can differ considerably from the refractoriness defined by Pyrometric Cone Value.

2. Refractoriness under Load.

This property is defined as the ability of a material to withstand specified conditions of load, temperature and time. Details of variations in this test can be found in different national standards. It is usual to show the result of this test as a curve relating the expansion /contraction/ to the temperature. Fig. 3 shows the refractoriness under load of selected refractories determined according to Czechoslovak Standard Specification.

3. Crushing Strength.

The Crushing Strength of refractories shows the maximum load per unit area, applied at a specified rate, that a material will withstand before it fails. Fig. 4 shows the crushing strength of different fireclay and silica bricks. In ordinary kinds of fireclay bricks a crushing strength of at least 1[illegible]0 kp per sq.cm and in silica bricks a minimum strength of 140 kp. per sq.cm is considered to be sufficient, as the load on bricks in industrial furnaces amounts, as a rule, to only a few kiloponds per sq.cm. The crushing strength also differs according to the quality of fireclay bricks, reaching up to 1000 kp per sq.cm in the manufacture of superduty products.

4. Porosity.

Metal and glass melting furnaces need to be lined with refractory materials capable of resisting erosion and corrosion by molten metals, slags and glasses. In other applications, an ability to prevent the excape of gases or to retain heat, necessitates close textural control of the refractories.

The porosity, as a measure of the proportion of pores in a ceramic material, can be defined as

- Apparent Porosity. The ratio of the open pores to the bulk volume, expressed as a percentage
- Sealed Porosity. The ratio of the volume of the sealed pores to the bulk volume, expressed as a percentage
- True Porosity. The ratio of the total volume of the open and sealed pores to the bulk volum , expressed as a percentage
- Absorption /Poresity according to weights/. The ratio of the weight of water, absorbed by the specimen, to the weight of the dry specimen, expressed as a percentage.

Fig. 5 shows porosity of different fireclay and silica products, expressed as the absorption and the apparent porosity.

2. Thermal Shock Resistance.

Sudden changes of temperature which are sometimes a necessary condition to operational methods or the degree of the capacity to withstand fluctuations in temperature, can lead to an inner strain in the material and may cause it to crack. Depending on their nature and structure, different types of refractories are more or less resistant to the thermal shock. While fireclay bricks usually withstand sudden changes of temperature well, silica products are very much sensitive to any change of temperature, which is close to temperature of quartz modifications changes. More details will be given in the Chapter IV/4.

6. Linear Thermal Expansion.

Is the reversible increase in dimensions of a material when it is heated. Normally, the linear expansion is quoted, either as a percentage or as a coefficient, in either case over a stated temperature range.

The linear thermal expansion of refractories depends on the properties of the material and has to be taken into account in the construction of furnace linings. It is partially absorbed by the vertical and horizontal joints between the individual bricks, and is completely checked by the expansion joints.

The average linear thermal expansion of a fireclay refractory may be quoted as 0.6% or as 6×10^{-6}, between 0° and $1000^{\circ}C$, while that one of a silica refractory, for the same interval, reaches 1.2%, i.e. 12×10^{-6}.

7. Volume Stability in Heat.

Refractory materials must be processed and fired so as to undergo under normal service temperatures only slight additional changes in volume /contraction or expansion/, corresponding with changes in their structure.

While fireclay bricks, after being refired, show a permanent linear contraction, silica products, under the same conditions, prove a permanent linear expansion.

8. Thermal Conductivity.

is expressed by the quality of heat transmitted through a material in unit time, per unit temperature gradient along the direction of a flow, and per unit of cross - sectional area.

The thermal conductivity of refractories depends expecially on the quality and the chemical composition of the brick. The higher the bulk density of the material and the lower its porosity, the better is its thermal conductivity. On the other hand, the best thermal insulators are light weight materials.

III. Fireclay Refractories.

1. Raw materials:

Fireclay refractories are produced usually from natural raw materials, In some cases some of raw materials are refined before used in fireclay blends.

Each blend is composed from two basic parts

a. plastic part, such as clays and kaolins

b. non-plastic part, such as grog /culls and fired clays/, flint clays and sand.

Refractory clays /china clays, ball clays, fireclays and others/ are classified into two major groups, namely residual clays - where the material is found in the location in which it is formed, and, sedimentary clays, when the clay has been transported in some way and deposited elsewhere. The basic component of refractory clays are alumino-silicates minerals, usually, so called clay minerals. These minerals show the workability and can be transformed /by addition of water/ into a plastic blend.

The most important substance of refractory clays is the group of minerals of kaolinite, with a chemical composition corresponding closely to $Al_2O_3 . 2\ SiO_2 . 2\ H_2O$. Such minerals confer both a refractory character and plasticity to clays in which they are present. Refractory clays are contaminated by only small amounts of alcalies, iron and titanium compounds and other fluxes. Their properties fluctuate in respect of chemical composition, refractoriness, plasticity, drying and firing shrinkage, so that it is normal practice to use several plastic clays mixed together or with flint clays and kaolins for any particular product. Refractory clays also contain, in smaller or bigger amounts, silica minerals, namely quartz. In addition to quartz, other crystalline, amorphous or noncrystalline hydrated silica may be present but all have the chemical composition SiO_2.

Kaolins are other plastic raw materials which are used in some fireclay body compositions. They contain practically pure clay mineral kaolinite. In comparison with clays, kaolins show higher purity, white color after firing, coarser particles and, therefore, lower plasticity. Kaolins occur in the nature as raw kaolins, containing usually 15% to 60% of the mineral kaolinite, balance being represented by quartz sand with smaller amount of feldspars, mica and other minerals. Raw kaolins can be commercially exploited in the manufacture of siliceous and low duty fireclay refractories. If washed and refined, kaolins are valuable raw materials not only for high and superduty fireclays, but also for other types of industrial activities, such as fillers in the manufacture of paper, rubber and cosmetiques.

Fig. 6 shows properties of selected clays and kaolins used in refractory blends.

To control shrinkage during drying and firing and to regulate properties of finished products, fireclay bodies must also contain the non-plastic part. This non-plastic portion of the siliceous and low duty fireclay blends can be represented by natural minerals /such as quartz sand/, added to blends or present in clays or raw kaolins. Culls, fired clays and flint clays are added into medium, high - and superduty fireclay bricks in the amount of 30% to 60% from total, referring to the quality of fireclay bricks produced. In general, to produce a fireclay brick under normal industrial conditions, total non-plastic raw materials in the fireclay blend have usually to amount at least to 50% from total.

Culls are firebricks, which may already have been used in furnace lining or elsewhere, crushed to a size suitable for incorporation in a batch. Also wasters from the own fireclay manufacture is used in the same way for remaking into bricks. As the porosity of culls always is higher than that one of fired clays, the addition of culls into a fireclay blend is limited according to the quality of finished products.

Fired clays and flint clays.

All types of high- and super-duty fireclay bricks must contain fired clays and/or flint clays. Flint clay is non-plastic refractory clay, which is kaolinitic, with possibly contaminated with diaspor or boehmite. After firing, flint clays contain 42% to 45% of alumina. Their refractoriness reaches Pyrometric Cone Equivalent 34 to 35. These are materials of an extremely hard dense texture. Although they are rich in kaolinite they are consolidated to such an extend that even fine grinding will not develop any significant plasticity. Fired clays are fired in a rotary, shaft or tunnel kiln. Fired clays strenghten the skeleton of the body, decrease the plasticity of a green body as well as its shrinkage after drying and firing. The higher amount of fired clays in the blend the more accurate dimensions of finished products.

Sands can be added into blends of siliceous fireclay materials in order to increase the amount of natural non-plastic materials. Any of quartz sands is suitable for the technology provided it is not contaminated by other fluxing materials.

Fig. 7 shows properties of selected non-plastic refractory raw materials.

Aside basic raw materials, different organic matters can be used as bonds to increase the plasticity and crushing strength of green products.

2. Body Preparation.

There are three main processes in the manufacture of fireclay refractories.

a. Stiff mud process

b. Dry-press process

c. Casting process.

a. Stiff mud process.

Fig. 8. shows a typical flow diagram for the manufacture of stiff-mud bricks. Stiff mud bricks are formed by forcing the plastic material through a die from which it comes out as a more or less homogeneous column that can be cut off into required lengths. This column is generally produced by a deairing auger, consisting of a propeller-shaped screw running in a through, which forces the clay with high pressure through a die.

To receive a plastic body, water is added to the mixture with either a wet pan or a pug mill. The latter is generally preferred, because it is a continuous process and better adapted to feeding the auger.

The pug mill is a long, through-shaped container with usually two horizontal shafts running down the center, having attached to them suitable blades for kneading and mixing the clay and propelling it gradually toward the exit end. Water can be added to the material in a pug mill to bring the mixture to the proper consistancy.

The auger must be designed so as to prevent laminations, which often occur in the center of the column as a crack. The die itself is generally lubricated with oil to reduce the surface friction, and often it is steam heated for the same purpose. It has been found that if the clay is mixed in the auger in a vacuum chamber, the air is readily removed and a more dense and homogeneous column of clay is produced in passing through the die. Deairing of clay has become a common practice in stiff mud brick making and it enables the production of good quality bricks with a denser structure. However, to reach the required effect, vacuum has to reach up to 700 to 730 mm of Hg.

The column of clay from the auger is cut into uniform sections with a wire cutter. Some of cutters work with one, the other with two wires. The latter ones provide sections of more accurate length. For the same reason, some of producers prefer sizing of sections before they are repressed.

Re-pressing of clay sections makes up the required shape to the brick. After being re-pressed, bricks are quite firm and can be readily handled and stacked on the drier cars.

For hand shaping softer clay is prepared in order to be workable with lower force.

Ageing of the prepared clay sections is a useful operation to increase the plasticity of the mixture and to decrease the sensitivity of some blends to cracking during the drying process.

b. Dry-press Process. Fig. 9 shows a typical flow diagram for the manufacture of dry-press fireclay refractories.

In the dry-press process of making fireclay bricks the clay [illegible] y of a [illegible] powder containing 6 to 10% water. Only by high pressure such clay can be consolidated into a homogeneous body.

The preparation of parti[illegible] similar to that one in the stiff mud process. The modern technology, however, seems to be favoring the more careful control of the sizing of the grog by screening and recombining in definite proportions. The mixture of dry materials is moistened in a pan mixer and brought up to the proper consistency. They are different types of mixers used for this purpose. The mixed material is delivered to a hopper over the dry press, where the mixing action is continued and permitted to flow into the dry press as needed.

They are different types of dry presses used in the dry-press processing of fireclay refractories, such as toggle type, hydraulic presses or friction presses, pressing one or more presslings in one stroke. In order to make uniform bricks, it is essential that the mix be uniform that the same amount of the material be always charged into the dies each stroke, and that it be evenly distributed in the die box.

Fig. 10 shows the variation of main fireclay bricks properties with the pressing power. It is obvious that the quality of fireclay refractories is influenced distinctly with the pressing power, up to the limit of about 500 kp/sq cm.

c. Casting Process.

In preparing the body, casting process is used usually for special types of fireclay products only. Considerable experience is needed to make up a good casting slip. The type and amount of the clays are important as well as the sizing of the grog. The amount of deflocculant must be carefully adjusted. The casting process is less productive than other molding methods.

Therefore in establishing the fireclay industry in a country it is not recommendable to start with the casting process unless local technicians are trained satisfactorilly.

Note:

It is necessary to mention that, in many countries, siliceous and low duty fireclay refractories are also produced in a red brick plant, following basic operation of the red brick flow diagram. To add fireclay manufacture as a by-production of red bricks is a good compromising step in the developing period during the establishing the refractory industry. However, kilns for red brick making can never afford the firing temperatures needed in the manufacture of good quality fireclay bricks. In case fireclay products are to be produced in a brick plant, at least one chamber kiln should be added suitable to fulfil conditions for firing process of fireclay products.

3. Drying Process.

In the manufacture of dry-press fireclay bricks the drying problems are becoming quite simplified. However, those products, produced by soft-mud, stiff-mud processing, by hand shaping or those of a large shape must be dried carefully to obtain efficiency in the operation.

Before the green product can be fired, its humidity has to be decreased bellow 2%.

During the drying process the clay shrinks while water is being evaporated. As shrinkage, which causes cracking, is equal in volume to that of the water removed during the constant rate period, i.e. most of it, it is clear that the more water in the body the more occasion there is for drying cracks. The water is chiefly bound up with plastic clays.

Fig. 11 shows the typical drying rate curve for two different clays. During the constant period AB and DE, drying takes place at the exposed surface only, by diffusion of the vapour through an adhering stationary layer of air.. The water from the interior of the piece moves towards the surface, constantly replacing that which has evaporated. The rate of drying depends only on external conditions, unless it becomes so great that the surface dries before being replenished from the interior.

During the linear first falling-rate period the water still evaporates from the surface, but as this is beginning to dry out the rate falls. The second falling-rate period involves evaporation within the pores of the body followed by movement of the vapour to the surface. It is not very susceptible to external conditions.

Fig. 12 shows how an enlarged section of the clay looks at various stages of the drying process. In A, the clay particles are well separated by a water film, which also runs continuously over the surface. In B, the amount of water has decreased until the particles touch one another, but there is still a continuous surface film. These stages reflect to the linear period of the drying rate curve. In C, the water has decreased until the surface layer is broken and the level resedes into the capillaries with some air in the structure. Water is brought to the surface by a capillary flow and as vapor. In D, the water has still further decreased until it is found only in a few places where the particles come closest together. Here all the transfer of water is in the form of vapor.

Practically, however, it is never necessary to remove the last trace of water. On the other hand a dry piece is to be hard to be handled. The crushing strength amounts usually to at least 10 kp/sq.cm.

In installing drying equipment a lot of factors are to be taken into consideration, such as amount and type of products to be dried per day, the available space, man-power need, fuel and time efficiency and the maximum rate of safe drying. Main types of dryers used in the ~~d~~ fireclay manufacture are:

a. Unheated Dryers. Fireclay products can be easily dried when exposed to the atmosphere in warm and dry climate.

b. Heated Dryers, when the heat is supplied to the bricks by convection, conduction and radiations. Heated dryers can be constructed as

- **Hot Floor Dryers.** Fireclay products are placed in a single or several layers on a heated floor using the kiln waste heat. Such floor, in the same time, can be the crown of the kiln. Hot floor dryers are very easy to be installed and they fit to smaller capacities of the plant, but their disadvantages are many, such as high man-power need, large space needed and uneven drying.
- **Chamber Dryers.** Products are placed on pallets of the same width as the chamber, as soon as they are made. These are then loaded on a car which carries pallets in the dryer. After products are dried unloading is undertaken in the same way. Chamber dryers are usually built up to dry products of a plant with higher manufacturing capacity.

- **Continuous Dryers.** In the firecly refractories manufacture tunnel dryers is the most common type of dryers applied to dry products. The ware is moved through the tunnel on track trucks. The direction of the air flow may be either counter - or concurrent with the car motion. The countercurrent air flow tunnel dryers are more usual in the fireclay manufacture. They have an air inlet where the bricks are removed and an exhaust stack where they are put in. Tunnel dryers represent a modern type of dryers, as temperature, time and humidity control can be effectively maintained by various dampers and can be made automatic to comply with a predetermined drying curve.

Tunnel dryers usually are applied in a fireclay plant of a high capacity.

4. Firing Process.

The firing process of fireclay refractories is the most essential part in the technological flow. This process of heat treatment is applied in a kiln to develop a vitreous or crystalline bond, thus giving the product the required properties which differ from properties of green products distinctly.

The usual required firing temperatures of fireclay refractories are:

Type of fireclay	Firing temperature °C
Siliceous	1250 - 1350
Low duty	1350 - 1410
Medium duty	1380 - 1410
High duty	1410 - 1450
Super duty	1450 - 1500

In general, fireclay materials should normally be fired to a temperature well above that at which it will be used. This rule is valid for the majority of different fireclay refractories.

New properties of the fired fireclay product, created during the firing process by different physical and chemical reactions, can be demonstrated, in principle, in the following:

A. Kaolin. When the kaolin $Al_2O_3.2\ SiO_2.2\ H_2O$ is heated, nothing happens until 450°C is reached, at which point an intermediate product, so called metakaolinite $Al_2O_3.2\ SiO_2$ starts to be formed. In the same time there is a loss in weight of 14% and an endothermic reaction by absorbing of 170 cal per gram. At about 950°C there is a sharp evolution of heat and a new cubic crystal phase with a spinel-type structure appears. Above 1050°C this spinel structure gradually breaks down into mullite and cristobalite with an amorphous or glassy phase. At the temperature of about 1350°C the mix consists of 30% mullite, 15% cristobalite and 55% glass.

Fig.13 shows, schematically, chemical reaction of such process; Fig. 14 then shows the typical Differential Thermal Analysis of the kaolin, with endo- and exothermic reactions.

b. Fireclay. The changes in less perfectly crystalline kaolinite or fireclay are somewhat differen , for the transformations are less sharp and there is usually only little alignment between the kaolinite starting materiel and the resulting mullite.

c. Impurities. Most fireclays contain impurities that can have important effects on the firing properties. These impurities, mostly carbonates and sulfites, break up themselves to form oxides which then react with the clay. Alkalies, iron compounds, fluorides, and alkaline earths often are the cause of the increased reaction rate when heating.

d. Silica. Although silica is an undesirable mineral in medium-, high- and superduty fireclays, it plays an important role in low duty and specially in siliceous fireclay refractories. In refractory clays and raw kaolins, silica usually occurs as a quarts sand.

Quarts can be transformed by heating into a number of polymorphous modifications /see Fig. 15/.

There are at least seven cristalline varieties of silica α - and β - quarts, α, β and γ - tridymite and α - and β - cristobalite and quarts glass. Many of writers call these modifications low - and high temperature modifications. The density of tridymite and cristobalite are very similar, but they differ considerably from those of quartz.

Firing shrinkage of fireclays is of great interest, the greater the shrinkage the greater the difficulty in holding dimensions of finished products. Also, high shrinkage can cause cracking during the firing process. This is the reason why each fireclay blend must contain non-plastic portion /see Chapter III/2 of this lecture/. Fig. 16 and 17 show some typical firing shrinkage curves of ceramic raw materials and blends.

A number of theories have been suggested for the cause of firing shrinkage when a glassy phase is present. It can be assumed that the shrinkage forces are due to the glassy phase acting in the surface capillaries. It is certainly true that high shrinkage rates occur in clay only when some glassy phase is present.

In the practice the firing process of fireclay refractories is devided at least into three periods:

a. the preheating period, which is necessary to remove volatile compounds /such as mechanical or chemical water, and organic matters/ by heating and/or oxidation.

b. The heating period to develop a strong body as a result of reactions, which ensure that no further significant change will take place when fireclays used in service

c. the cooling period to cool products down to the room temperature.

Fig. 18 shows a typical temperature-time curve for fireclays refractories firing operation.

5. Kilns.

While red bricks can be fired even on the simplest way, such as in clamp, fireclay refractories, due to the requested firing temperature, are fired in two main types of kilns

a. Periodic kilns /such as round or rectangular ones/

b. Continuous kilns /such as Hoffmann or Mendheim kilns and tunnel kilns/.

a. Periodic kilns can be operated on the up-draught, horizontal-draught or the down-draught principle. The best results are obtained in the operation of kilns on the down-draught principle. The firing process of fireclays in a periodic kiln is based on placing ware in the kiln, on the gradual heating up of the kiln, on keeping at maximum temperature for a necessary period and on cooling the ware. The ware can then be removed and a fresh setting can be put in.

It is clear that appart from inefficiency by heat losses through walls, a periodic kiln must use a large amount of fuel to heat up the structure for each batch of ware, all of which is lost during the cooling. On the other hand, periodic kilns can be used for very small manufacturing yearly capacities.

Car-bell kilns or shuttle kilns are a special and modern type of periodic kilns. They are used successfully for firing of special refractories because of the easy of setting and drawing and the very flexible firing cycle, which can be adapted in accordance with requirements of products fired. There is often a considerable saving in fuel and labor over the older type of periodic kilns. They are used for smaller capacities and often fired up to 1600°C to 1700°C. They also show high degree of flexibility in applying different firing cycles according to the product fired.

b. Continuous kilns, such as of Hoffmann or Mandheim type, utilize the waste heat given off during cooling. In the reality, continuous kilns consist of a number of periodic kilns connected in a circuit. The fresh air flow passes first through ware that has been fired and is in the cooling operation and then, the preheated air moves on to the kiln that is being fired. The hot waste gases pass on to ware, which is to be fired. Green products are preheated so that they need less fuel for their own firing process. The main principle of this type of continuously working kilns is based on the fact that the fire always keeps moving, while products remain in the same position. Waste heat is utilized for preheating of green products but the kiln structure still has to be heated and cooled for each batch.

In the tunnel kilns the reverse process is applied. A tunnel structure is devided into fields at constant, different temperatures corresponding the required firing curve. The ware is slowly pushed through the kiln on kiln trucks. Because of its high efficiency the tunnel kiln has been recognised as the best kiln for mass production of uniform products, although improved intermittent kilns can continue to be used for small or indivudual batches, speciously of heavy pieces.

6. Choice of Fuel.

The choice of fuel depends usually on following factors:

- availability and price unit of heat
- capital and maintenance cost of equipment necessary to use fuel
- labor requirement
- hygienic conditions

The following sources of heat can be used for fireclay refractories firing

- lignite
- coal
- coke
- antracite
- natural gas
- town gas
- propan
- producer gas
- oil

Electricity does not come into consideration for fireclay firing because of its very high net cost per kcal. In comparison with coal, net cost per kcal of electricity is in average 10 times higher than that one of coal.

Lignite or brown coal is usually pressed into briquettes before use.

Coal as well as lignite are not used for heating of tunnel kilns while they can be successfully utilised for heating of periodic of Hoffman kilns. All coals and lignites contain a certain amount of sulphur, varying from 0.5% to 3.5%. Sulphur is present either as iron pyrites /FeS_2/, or as calcium sulphate or in various organic compounds. In refractories making, however, sulphur does not make any bigger harm to products. If the smoked gases temperature sinks under the due point, corrosion of metal parts of the kiln will occur /piping, ventilators, etc./ Anthracite and coke represent the purest type of solid fuels and they can be used [illegible] with [illegible] and coals.

Gas fuel has great advantages over solid fuel. The burning of gas fuel is much more easy controlled than that of solid fuel. The flow of fuel to the burner is continuous, it can be automatically controlled to follow the requested firing curve. Gas fuel also shows much greater cleanliness both inside and outside the kiln. Town gas is also free of sulphur and natural gas often has a very low sulphur content.

Many of manufacturing companies prefer to utilize producer gas, manufactured from coal, lignite, coke or antracite. In average, if gas used to fire a modern tunnel kiln, 1 ton of coal needed to be carbonised to fire the same amount of ware corresponds to 1.2 tons of coal needed to fire the same in a periodic kiln. There can be therefore a considerable fuel saving aside other advantages mentioned in the foregoing paragraph.

Kilns for fireclay refractories firing, may be economically supplied with heavy fuel oils. Their characteristic may varry considerably according to the crude oil from which they are produced and the extent to which distillation has been taken.

Practically all heavy fuel oils contain sulphur up to 3% to 4%. Fig. 19 shows main properties of heavy fuel oil in the comparison with medium and light fuel oils. It is clear that two most important properties of heavy fuel oils are: viscosity, which is too high under room temperature. However, by suitable preheating a more viscous oil can be made to flow satisfactorilly. Calorific value of heavy fuel oil is high enough to provide temperatures needed to fire fireclay refractories.

Different writers have specified the following advantages of using fuel oils in ceramics firing:

- uniform quality of the fuel, which does not fluctuate from day to day supplies
- cleanliness, without dust or ash
- labour saving, supply of oil as well as kiln regulation can be automised
- flexibility in the kiln regulation
- high flame temperatures, reaching up to 2080°C, with lumineous flames and, therefore, with a high radiating power
- high kiln efficiencies with greater outputs from furnaces because of fast heat transfer.

However, final choice of fuel will obviously depend on the following determining factors:

/a/ Local possibilities for supply and transport of the fuel
/b/ The cost of the fuel delivered to the plant
/c/ The calorific value of the fuel
/d/ Local reserves or continuous supply possibilities
/e/ Installation and storage costs

7. Different Stages of the Development of a Fireclay Plant.

In order to show an estimated picture of different stages of the development of a fireclay plant the feasibility of two different plants at two manufacturing levels is roughly calculated. In considering the establishing of a new fireclay plant, the minimum economic capacity is to be determined at first. The minimum economic capacity will depend, primarilly, on the market poteciality with average prices as well as on total costs of the new manufacture. Different studies show that as average yearly capacity of 10,000 tons of fireclay products can be the possible economic minimum. However, commercial conditions between particular countries differ so far that it is impossible to determine one over-all valid minimum economic capacity.

Two different plants are being compared. /Fig. 20 and 21/. The fully automated plant /a./ is provided with all modern equipment, such as loading raw materials cars, feeders, transporting belts, conveyors, modern hand-moulding equipment, different transfer cars, automatically working presses, with a modern dryer, with a tunnel kiln with the pre-dryer, cars and control and with loaders, fork lifts and pallets.

On the other hand, the plant, utilising maximum labour, can produce the same planned yearly capacities, i.e. 10,000 tons and 50,000 tons, in the same products assortment, but the flow of the manufacture does not include different elements of mechanization, but prefers to employ maximum labour, without a modern dryer, and, instead a tunnel kiln, periodic kilns are applied.

Comparing both Fig. 20 and 21 one can see that to employ full mechanization at the lower manufacturing level leads to economic losses. The yearly capacity of 10,000 tons per year can be considered to be the economic minimum for a simply projected plant in a country with the cheap direct labour. An automated plant of the same capacity shows lower return on total capital due to higher both total manufacturing costs and administrative costs, as automation, modern dryers and kilns can not be exploited economically in a low capacity. Full advantages of automation, however, come into account in plants of higher capacities, as shown on the example of 50,000 tons yearly capacity. While the capacity of an automated plant grows five times, the return on total capital grows 5.5 times. In a plant which utilizes maximum labour, the same growth of the capacity shows the growth of the return on total capital to be only 1.21.

Therefore, the market potentiality with the specific requirements on fireclays assortment are together with the availibility of refractory raw materials the most important factors for the consideration on establishing fireclay refractories in any country. The more potential market, the more positive assumptions to establish a new plant.

Fig. 22 shows labour requirement for fireclay plants at different manufacturing levels. It is seen that both the mechanisation and automation decreases the direct labour need about four times. The more numerous workers, the more supervisors and foremen in the manufacture are needed. However, each automated unit increases requirements on skill maintenance.

Summarizing the foregoing paragraphs, we can say that

a. the establishing of a fireclay manufacture can be an economic venture provided the market is potencial and at least some of fireclay raw materials are locally available

b. the manufacture of silicious and low grade fireclay materials can be applied, as a temporary solution, in a red brick plant on assumption of acceptable firing conditions

c. the minimum economic capacity of a fireclay plant can be, in some cases, considered the yearly capacity of 10,000 tons. Such manufacturing unit can not be based on full automation, which is too expensive for such low capacity. For such cases it is recommendable to utilize maximum labour. In other cases the minimum economic capacity can be even lower than that one of 10,000 tons per year.

d. full advantages of automation come into account in plants of higher capacities, established in countries with the expensive labour.

IV. Silica Refractories.

Compared with fireclay products, silica refractories show the following main advantages and disadvantages:

1. Silica refractories show high refractoriness under load. Because of this property, silica bricks are good for use in metallurgical furnaces, operated at high temperatures.

2. Silica bricks do not contract on reheating but show an after-expansion, which means that they can be well applied in the construction of roofs with large spans.

3. In temperatures above 1000°C, silica products show a 50% higher thermal conductivity than fireclay materials. This property makes them suitable for gaswork and coke ovens, of which the carbonisation chambers are heated externally by conduction of heat through the walls of chamber.

4. In spite of high refractoriness under load, silica bricks rapidly deform after initial softening, i.e. the overheating of the construction above its critical point can lead to the collaps of the work.

5. The other disadvantage of silica bricks is in their sensitivity to thermal changes at lower temperatures /up to 700°C/. Therefore the heating of kilns newly lined with silica materials must be gradual, expecially around the temperatures of 230°C and 575°C. Furnaces and kilns with silica refractories roofs must not be cooled under 700°C.

1. Raw Materials:

The chief refractory component in silica products is silica - SiO_2, which occurs in several modifications. The basic modifications are: quartz, tridymite, cristobalite and quartz glass, each of which may transform into any of the others /possibly also into meta-stable forms of SiO_2/, at various temperatures /see Fig. 15/. Each transformation is accompanied by a change in volume bringing a change in the specific gravity of the individual modifications of SiO_2.

Silica is widely distributed in minerals and rocks. However, the most suitable raw materials for silica products are quartzites, sandstones and ganisters, containing at least 95% SiO_2 and alumina less than 1% to 2%. It is necessary to add a suitable bonding agent that will hold the non-plastic silica grains in both the raw and fired state. Hydrated lime is usually added in the amount of 2% from total, as well as sulphite lye to increase mechanical properties of green products.

The conversion of low temperature quartz modifications into high temperature ones can be accelerated by the presence of mineralisers, such as iron oxides.

Quartzites, as well as sandstones and ganisters are sedimentary types of quartz. The shape of sand grains depends on the amount of erosion they have undergone and any other matter that may have coated them. Fine grained quartzite, with a large content of amorphous or microcrystalline basalt cement, are excellent for their quick and easy transformation into high temperature modification /Fig. 23/. The other type of quartzite, showing bigger grains, practically with the minimum of errosion and missing the basalt cement, needs, usually, the addition of mineralisers and more specific granulometric composition in order to prepare a suitable body composition /Fig. 24/.

2. Body Preparation.

Fig. 25 shows a typical flow diagram for the manufacture of silica bricks.

Quartzites are first crushed in a jaw crusher or Symons granulator into smaller pieces up to about 60 mm. Fine grinding is usually realised in dry pan mills. In order to enrich the finest particles in the blend /below 90 microns/, part of the quartzites is ground in vibrating or other mills.

Silica wasters are ground separately. Hydrated lime as well as sulphite lye are diluted and added into the mixer at the beginning of the mixing operation. If mineralisers are to be added they are either mixed with the hydrated lime or blended into ground quartzite in the mixer before it is moistened.

The moisture content of the mass differs for dry pressing and for hand shaping. While the blend for dry pressing requires the moisture content of 5 to 7%, for hand shaping 8 to 9% are necessary.

The majority of silica products is manufactured by dry pressing. Successful pressing operation is very important for the quality of finished products. The bigger pressing force, the lower porosity, the lower permeability and the bigger crushing strength of finished products. Fig. 26 shows the variation of selected silica refractories properties with the pressing power. Therefore, some of high silica products are pressed by several strokes during the pressing operation. They are different types of presses used, such as friction presses, toggle presses and hydraulic presses, pressing one or more bricks in the same operation. In order to make uniform bricks, it is essential that the mix be uniform, that the same amount of the material be always charged into the dies each stroke, and that it be evenly distributed in the die box.

Before pressed silica bricks are dry they must be handled carefully because of their low green strength.

3. Drying Process:

Drying process of silica products is much simplier than that one of fireclay bricks as, more or less, they occur no volume changes. While water content is decreased the green strength of products grows up to 30 to 50 kp/sq.cm. The growth of the mechanical strength is caused by the sulphite lye as well as by the cristalisation of hydrated lime.

Drying process of silica bricks is operated by high temperature, which, sometimes, exceed 200°C. While floor dryers are mostly used for drying of hand shaped products, chamber or tunnel dryers are applied usually for dry pressed products.

3. Firing Process and Kilns:

Silica bricks must undergo the firing process, which, converts the green products irreversibly into a hard product of required properties.

The usually required firing temperature of silica products amounts to 1400 - 1480°C, i.e. Seger cone 13/14 to 17. The soaking temperature must be regulated in accordance to the quality of silica bricks manufactured. While silica bricks for the steel industry can be fired at lower temperature, the same products for coke ovens and gasworks are to be fired at higher temperature in order to secure better conversion of quartz modifications. Very slow firing, including prolonged soaking, is necessary to allow for the solid-state reactions to be completed, and to prevent rapid volume changes during inversions.

Fig. 18 shows a typical temperature-time curve for silica bricks showing the regions where slower firing is necessary as well as faster firing is permissible. The firing schedule must be regulated very carefully in the temperature interval below 600°C.

The firing process is divided at least into three main operations:

a. preheating

b. firing

c. cooling

An average fired silica brick is a mixture of different quartz modifications, containing about 45 to 60% of cristobalite, 12 to 25% of tridymite, 5 to 10% of unconverted quartz and

10 to 15% quartz glass.

Different types of kilns are used for silica firing. All of them, however, must be well regulatable, absolute evenness of temperature is essential and the required firing temperature, which exceeds usually that one for fireclay bricks firing, must be reached.

For bigger plant capacities /20,000 tons to 50,000 tons per year/, a tunnel kiln is recommendable, as the slow rate of heating and cooling can be realized easily. The firing cycle of a tunnel kiln can take 6 to 10 days.

Calculations show that for smaller plant capacities /5,000 tons to 10,000 tons/, periodic kiln can be more economic, although their firing cycle can take up to 3 to 4 weeks.

While tunnel kilns are heated by gas or fuel-oil, some of periodic kilns for silica firing can also be fired by coal.

5. Super Duty Silica Bricks.

Super duty silica refractories are silica bricks with strictly controlled flux content. As a result of that superduty silica refractories can be used under load in higher temperatures than normal silica bricks, sometimes even higher than 1700°C.

To produce super duty silica bricks, the body composition must be strictly controlled. Only selected quartzites or ganisters are used together with other additives, such as hydrated lime and sulphite lyes. More careful selection and washing is usually required in order to keep the flux content as low as possible. Different standards show different limits for the content of fluxes in the super duty silica blends.

Silica bricks, containing not more than 0.5% alumina and with a total of alumina plus alcalis not exceeding 0.7% are super duty silica refractories.

The other manufacturing processes of super duty silica bricks are the same as those of normal silica refractories. The increased refractoriness, refractoriness under load, cold crushing strength and the decreased permeability and porosity f super duty silica refractories increase life of different kilns of 10 to 30% over normal silica bricks.

6. Semi-Silica Products.

The group of semi-silica refractories was developed as a compromise between silica and fireclay bricks, in order to improve low thermal shock resistance of silica and large after shrinkage of fireclay. Semi-silica products are also highly resistant to slag attack.

The manufacturing flow of semi-silica bricks can be realized in both fireclay as well as silica processing.

If fireclay technology is to be applied in the manufacture of semi-silica bricks, mixtures of different quartz sands and refractory, mostly silicious clays are main components of the body. In this case shaping and drying is realized under the same conditions as for fireclays. Because of a very high content of silica /usually higher than 88% form total/, firing of semi-silica bricks corresponds more to silica refractories firing than to fireclays.

Semi-silica bricks can also be manufactured as a by-product in a silica plant. In such case, low-grade quartzites or ganisters are crushed, ground and screened and then mixed with deflocculated clay slip. Shaping, drying and firing process correspond to processes of normal silica manufacture.

Semi-silica blends are used for the manufacture of checker bricks for openhearth furnace checker settings.

V. Final Note.

The presented lecture does not represent highly scientific analyses of the problem how and under which conditions the manufacture of fireclay and silica refractories can be realised. It shows, however, main and practical headlines to be respected in considering the establishing a successful manufacture of the fireclay or silica materials.

One of the important factor of refractories is the quality of products, manufactured, which can influence the life of kilns considerably. Refractories in service are exposed to great heat and other different conditions which they are expected to resist. Therefore, proper choice as well as right application of refractories is one of important conditions for the successful management.

In weighing the possibility of establishing any of refractory manufactures, it is necessary to evaluate the feasibility of such venture, taking into consideration not only the availability of different refractory raw materials, but also the market potentiality and to compare the production, administrative and sales costs with the expected sales. As mentioned in foregoing paragraphs, the expected plant capacity will also influence the manufacturing equipment considerably /such as type of dryers and kilns/. Automation of the process will then depend not only on the man-power costs, but also on the skilled service and investment costs.

Refractory materials are needed in all countries for many different reasons: all manufacturing factories using heat transfer, applying firing, baking or heating operations, need different types of refractories. Therefore, the development of the refractory manufacture can be one of solutions to industrialise the country.

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VII. Table of Figures.

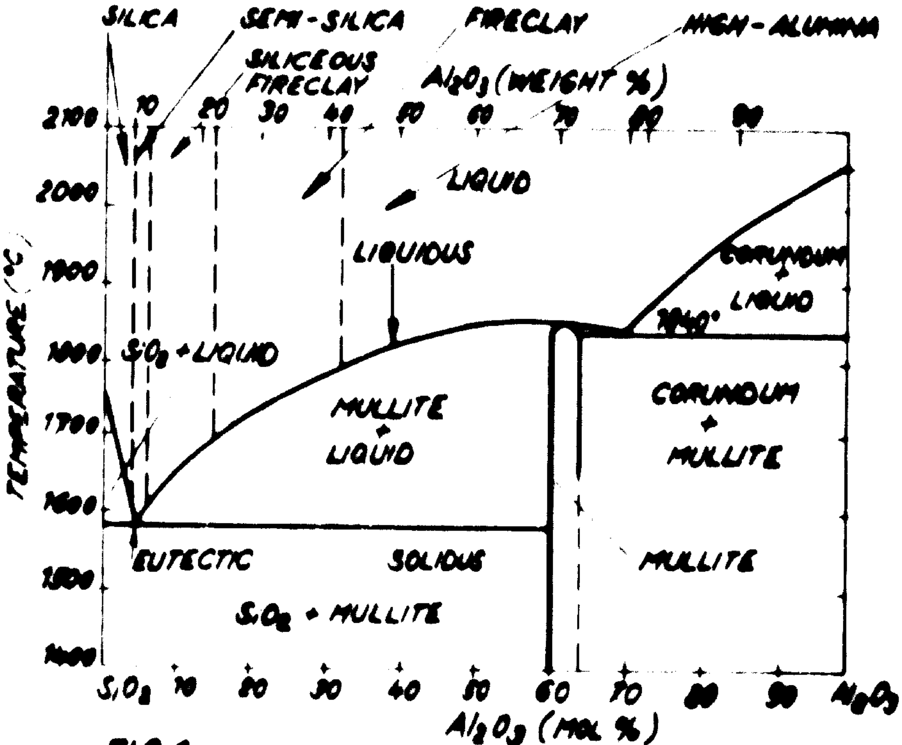


FIG. 1 - EQUILIBRIUM DIAGRAM Al_2O_3 - SiO_2 SYSTEM

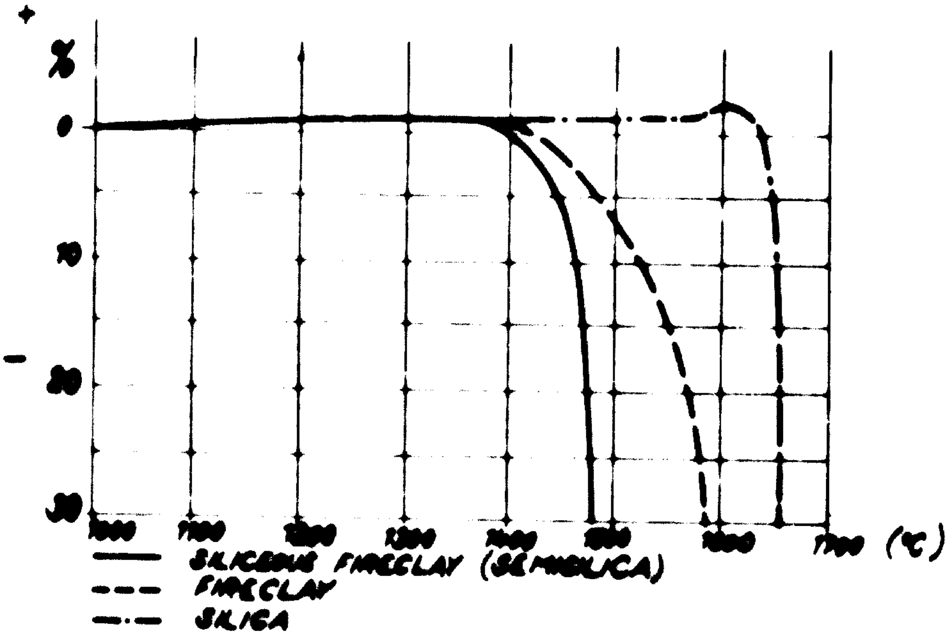


FIG. 3 - REFRACTORINESS UNDER LOAD OF FIRECLAY AND SILICA REFRACTORIES

Fig. 2.

Pyrometric Cone Value of Fireclay and Silica Refractories.

	Seger Cones	/°C/
Fireclay Bricks	26 - 35	/1580 - 1770/
Siliceous Fireclay Bricks	28 - 33	/1630 - 1730/
Silica Bricks	32 - 34	/1710 - 1750/

Seger Cones and Squatting Temperatures in Centigrades.

SC	°C	SC	°C	SC	°C
26	1580	32	1710	38	1850
27	1610	33	1730	39	1880
28	1630	34	1750	40	1920
29	1650	35	1770	41	1960
30	1670	36	1790	42	2000
31	1690	37	1825		

Fig. 1.

Crushing Strength of Different Fireclay and Silica Bricks.

	Crushing strength kg . sq.cm
Fireclay brick - ordinary	100 - 150
Fireclay brick - duty	250 - 350
Fireclay brick - superduty	400 - 1000
Silica brick - ordinary	150 - 250
Silica brick - duty	300 - 400
Silica brick - superduty	900 - 1000

Fig. 2.

Water Absorption and the Apparent Porosity of Different Fireclay and Silica Bricks.

	Water absorption %	Apparent porosity %
Fireclay brick - ordinary	12 - 15	23 - 28
Fireclay brick - duty	8 - 11	17 - 22
Fireclay brick - superduty	6 - 7	13 - 16
Silica brick - ordinary	13 - 15	23 - 26
Silica brick - duty	10 - 12	19 - 22
Silica brick - superduty	8 - 9	15 - 18

Fig. 6

Properties of Selected Clays and Kaolins Used in Refractory Blends

Selected Properties		Raw Kaolin	Washed Kaolin	Siliceous Clay	Ball Clay	Flint Fireclay	Claystone
Refractoriness	S.C. (°C)	32 (1710)	33/34 (1760	26 (1580)	33 (1730)	33/34 (1760)	32/33 (1720)
Chemical Composition	%						
Loss on Ignition		4,30	11,66	6,30	13,77	12,84	12,46
SiO_2		[illegible]	51,39	72,00	48,30	48,50	50,80
Al_2O_3		9,47	34,62	17,90	32,80	34,40	32,80
Fe_2O_3		0,18	0,45	1,04	2,39	1,99	2,13
Water Plasticity	%	13,6	37,8	22,2	39,3	25,3	20,3
Shrinkage after Drying	%	2,6	3,1	6,1	8,3	4,4	4,1
Shrinkage after Firing	%						
1150 °C		0,6	2,4	7,2	8,7	6,2	5,8
1350 °C		0,7	7,2	7,8	12,3	8,3	7,3
1400 °C		0,7	12,4	5,4	11,9	10,8	9,3
Waterabsorption after Firing	%						
1150 °C		15,7	23,4	10,1	10,8	13,8	14,2
1350 °C		15,2	13,8	1,7	1,8	9,2	10,2
1400 °C		14,8	6,2	1,0	0,7	2,6	4,9

Tab. 7.

Properties of Selected Non-plastic Refractory Raw Materials.

Selected properties		Flint Fireclay	Clay Calcinated	Siliceous Sand
Refractoriness	/S.C./	33/35 /1760/	33/34 /1740/	34/35 /1760/
Chemical Composition %				
Loss of Ignition		14,09	0,80	0,00
SiO_2	%	44,78	53,70	96,06
Al_2O_3	%	35,11	40,40	0,05
TiO_2	%	2,22	1,50	0,00
Fe_2O_3	%	2,00	1,99	0,16
CaO	%	0,77	0,45	1,90
MgO	%	0,55	0,32	0,30
Na_2O	%	0,29	0,30	0,00
K_2O	%	0,44	0,50	0,00

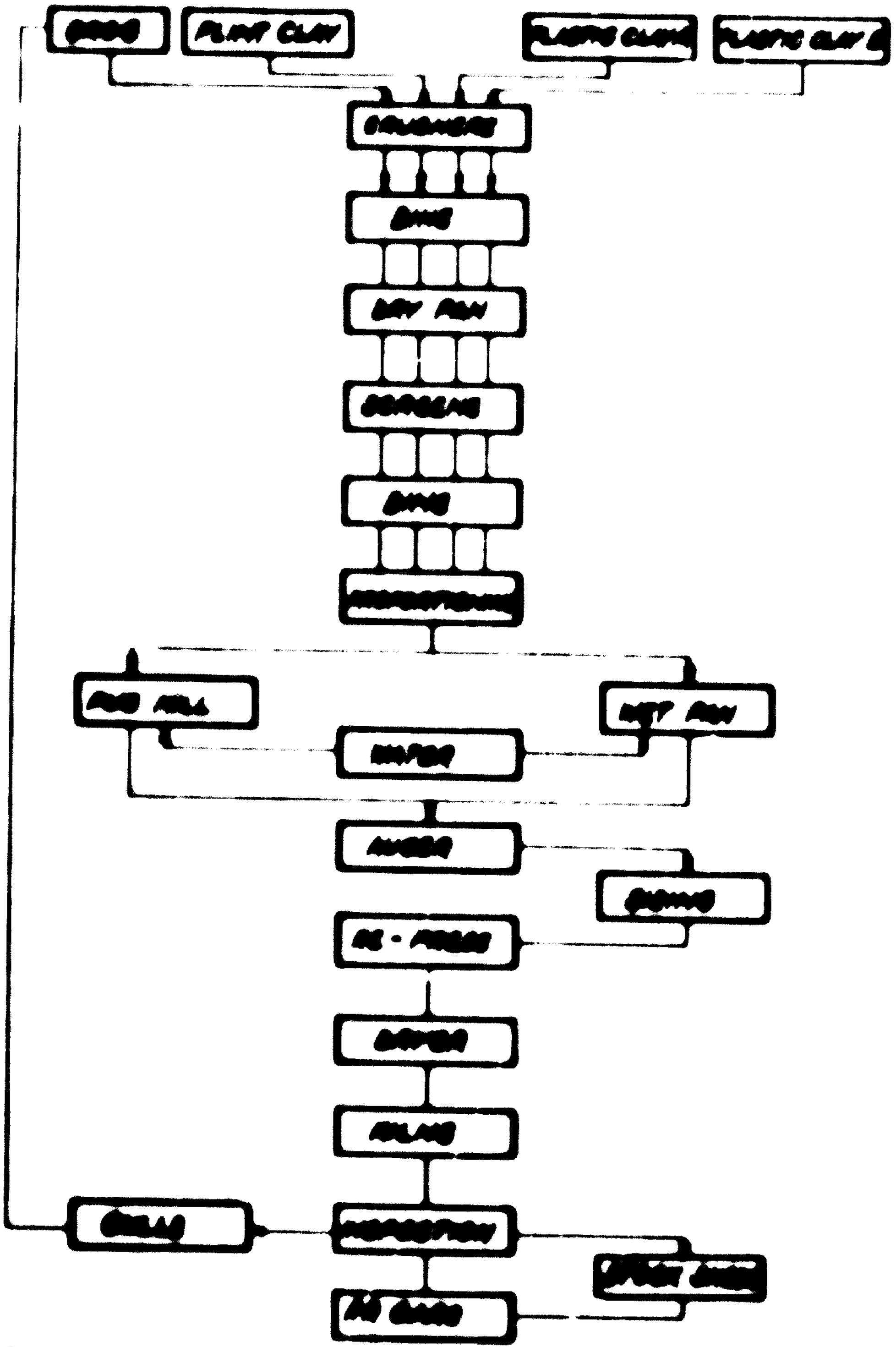


FIG. 8 – FLOW DIAGRAM FOR THE MANUFACTURE OF STIFF MUD FIRECLAY BRICKS

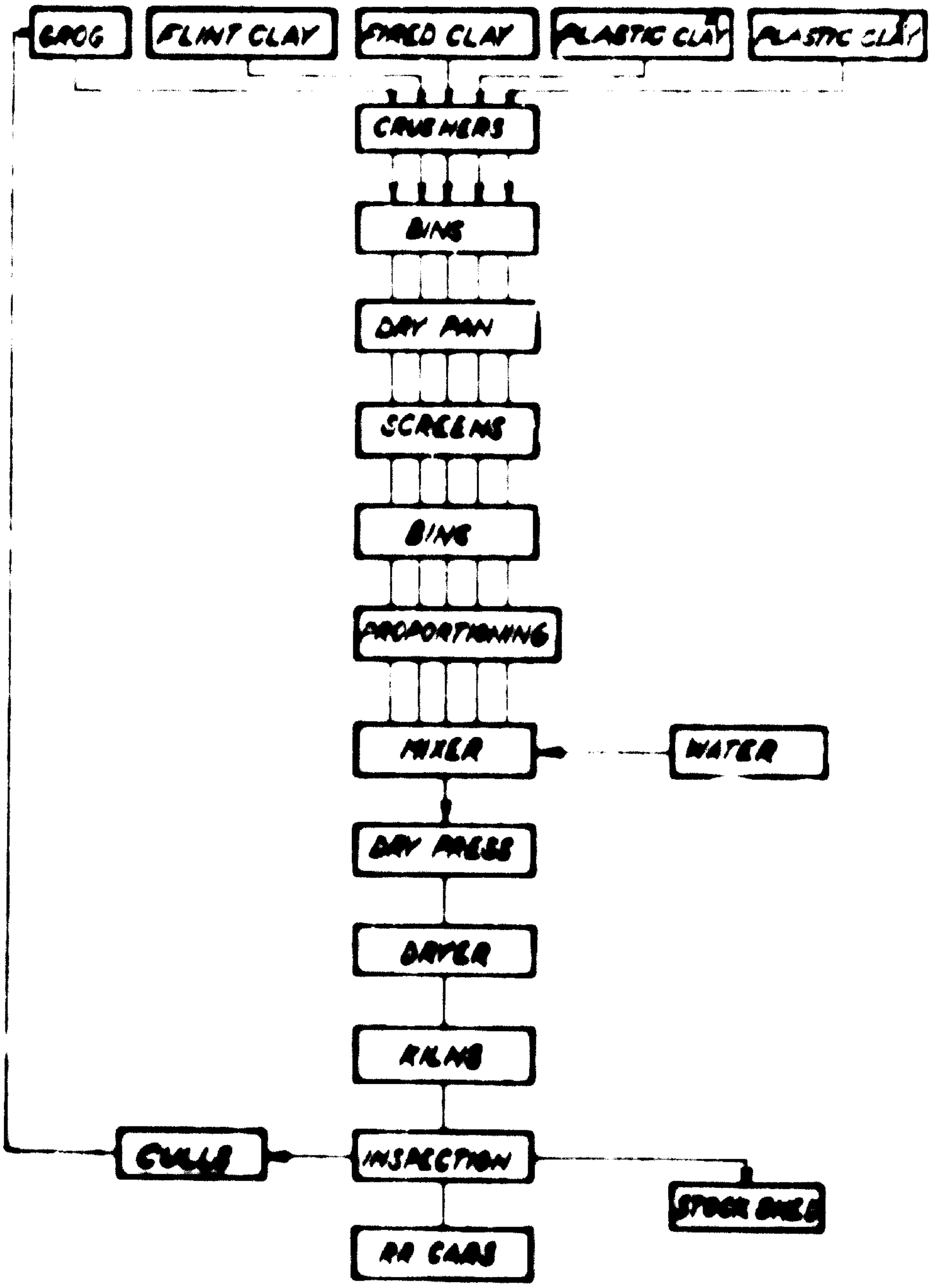
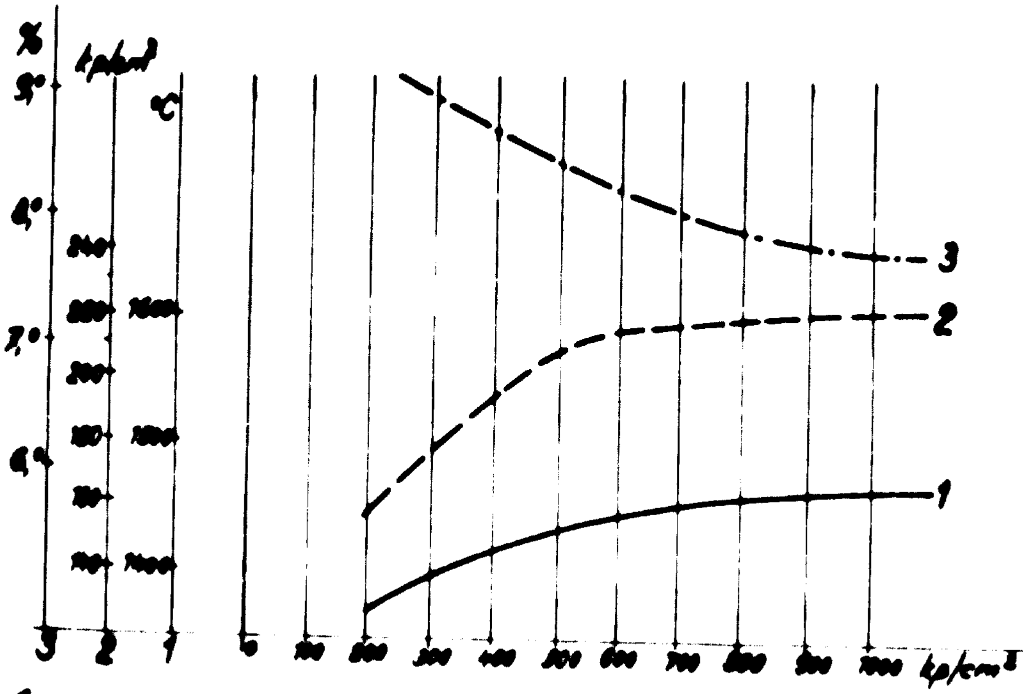


FIG. 8 – FLOW DIAGRAM FOR THE MANUFACTURE OF DRY-PRESSED FIRECLAY BRICKS



1 — REFRACTORINESS UNDER LOAD 2 - - CRUSHING STRENGTH 3 — — WATER-ABSORBTION

FIG. 10- VARIATION OF MAIN FIRECLAY BRICKS PROPERTICS WITH THE PRESSING POWER

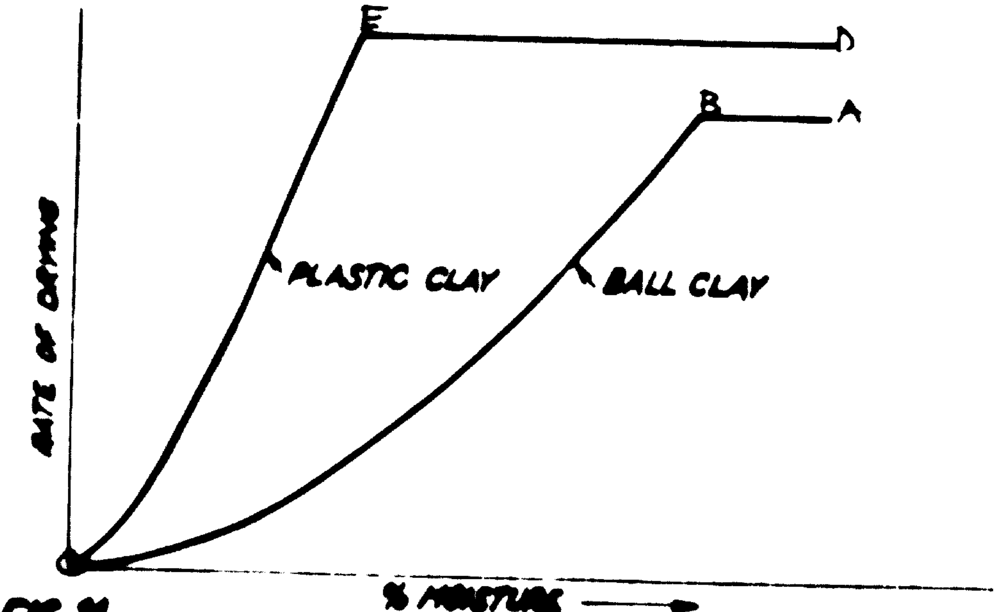
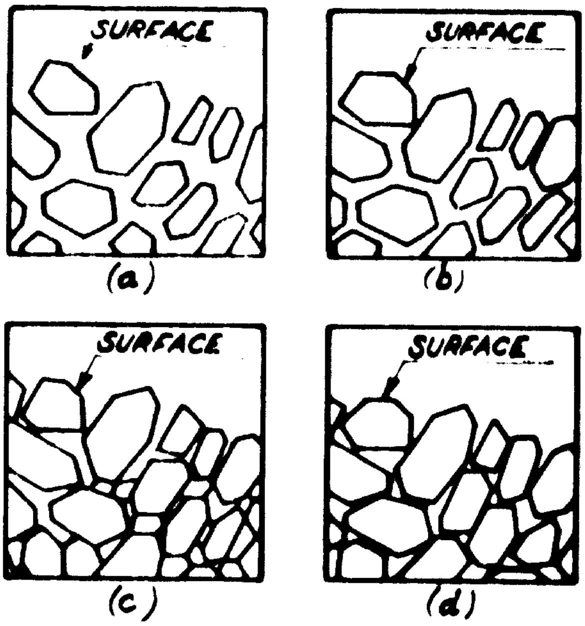


FIG. 11- DRYING RATE CURVE FOR TWO DIFFERENT CLAYS



(a) (b)
(c) (d)

FIG. 12- CLAY AT VARIOUS STAGES OF DRYING

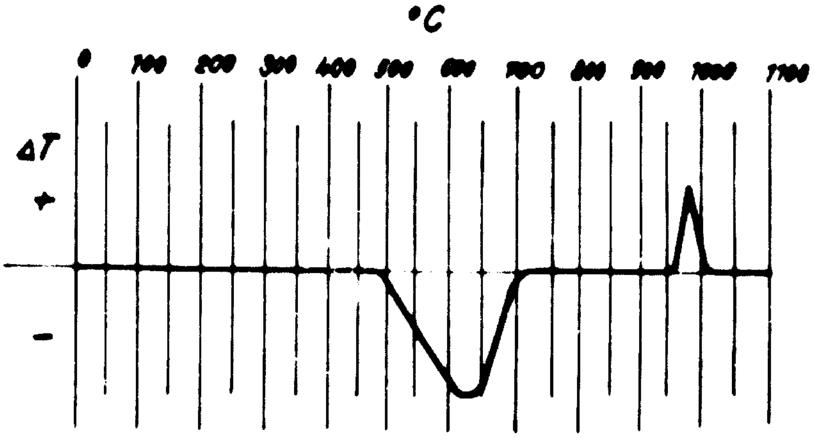


FIG. 14-DIFFERENTIAL THERMAL ANALYSIS OF THE KAOLIN

Fig. 13

Chemical Reactions of Kaolinite During Heating.

$$Al_2O_3 \cdot 2\ SiO_2 \cdot 2\ H_2O \xrightarrow{450-650^\circ C} Al_2O_3 \cdot 2\ SiO_2 + 2\ H_2O$$

Kaolinite Metakaolinite

When further heated:

$$2\ /Al_2O_3 \cdot 2\ SiO_2/ \xrightarrow{925-950^\circ C} 2\ Al_2O_3 \cdot 3\ SiO_2 + SiO_2$$

Spinel Phase Amorphous Oxide

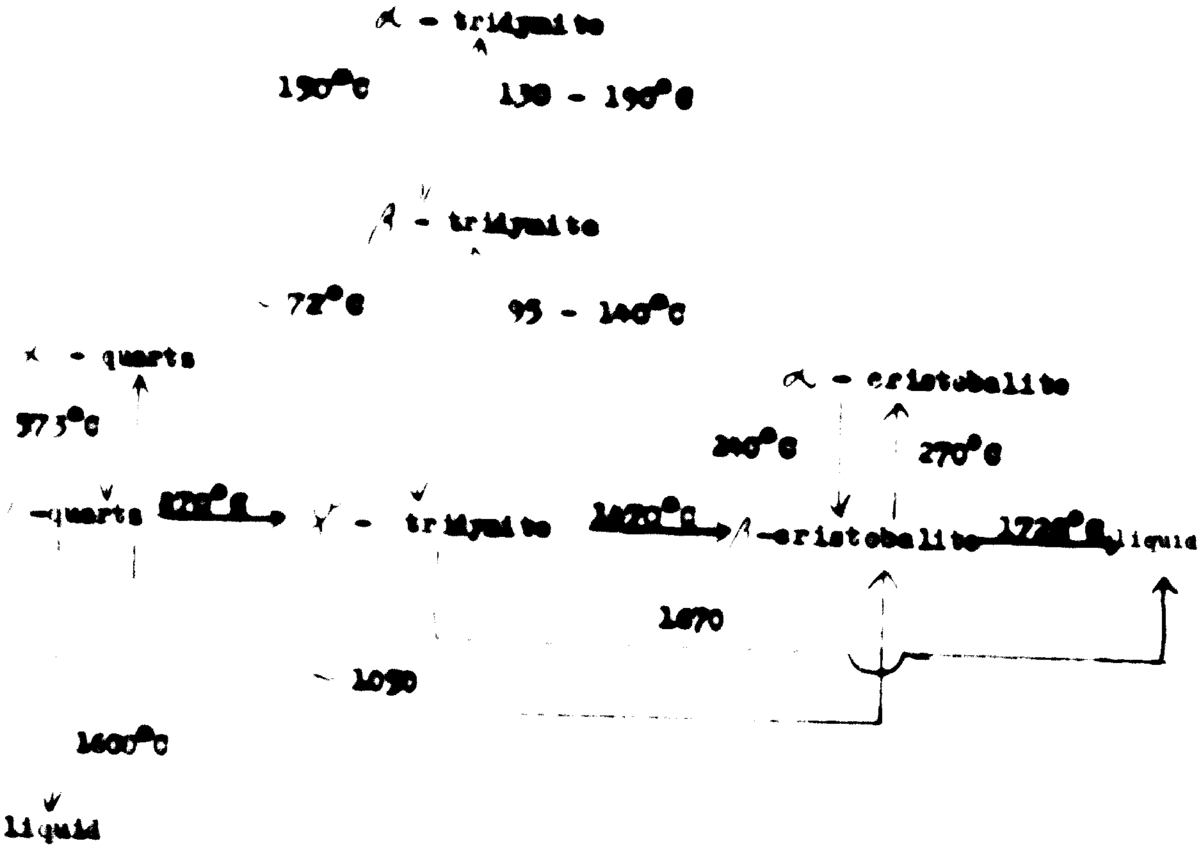
At final:

$$3\ /2\ Al_2O_3 \cdot 3\ SiO_2/ \xrightarrow{1050-1100^\circ C} 2\ /3\ Al_2O_3 \cdot 2\ SiO_2/ + 5\ SiO_2$$

Mullite Cristobalite

Fig. 15

Polymorphous Modifications of Silica and Their Stability Ranges.



α ...... low temperature modification

β γ .... high temperature modification

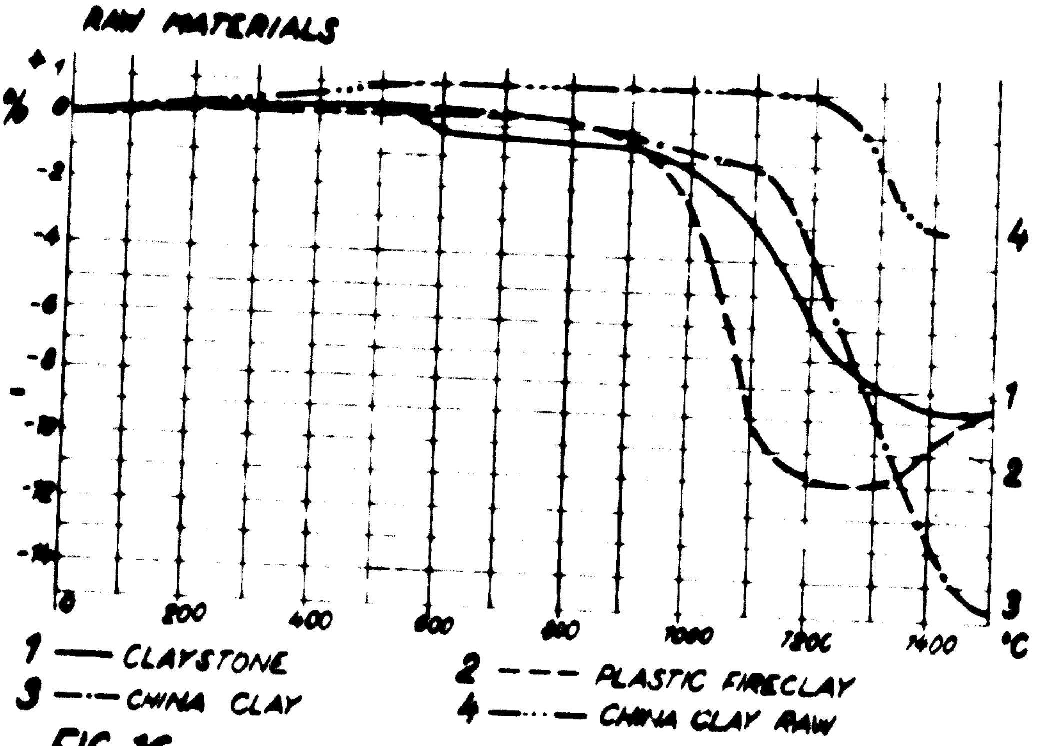


FIG. 16- FIRING SHRINKAGE CURVES OF SELECTED CERAMIC RAW MATERIALS

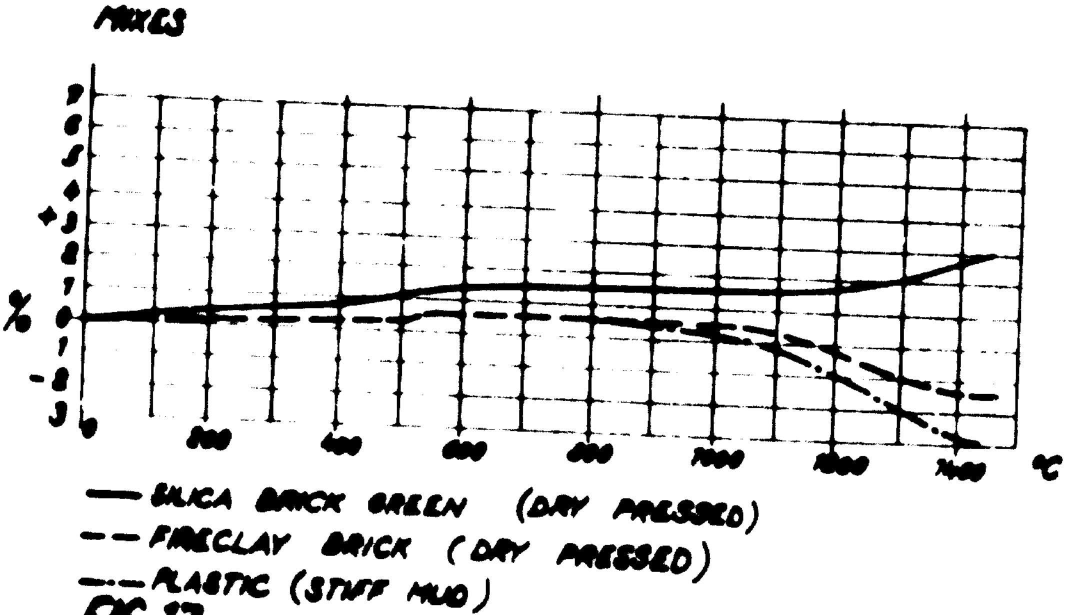


FIG. 17- FIRING SHRINKAGE CURVES OF SELECTED REFRACTORY BLENDS

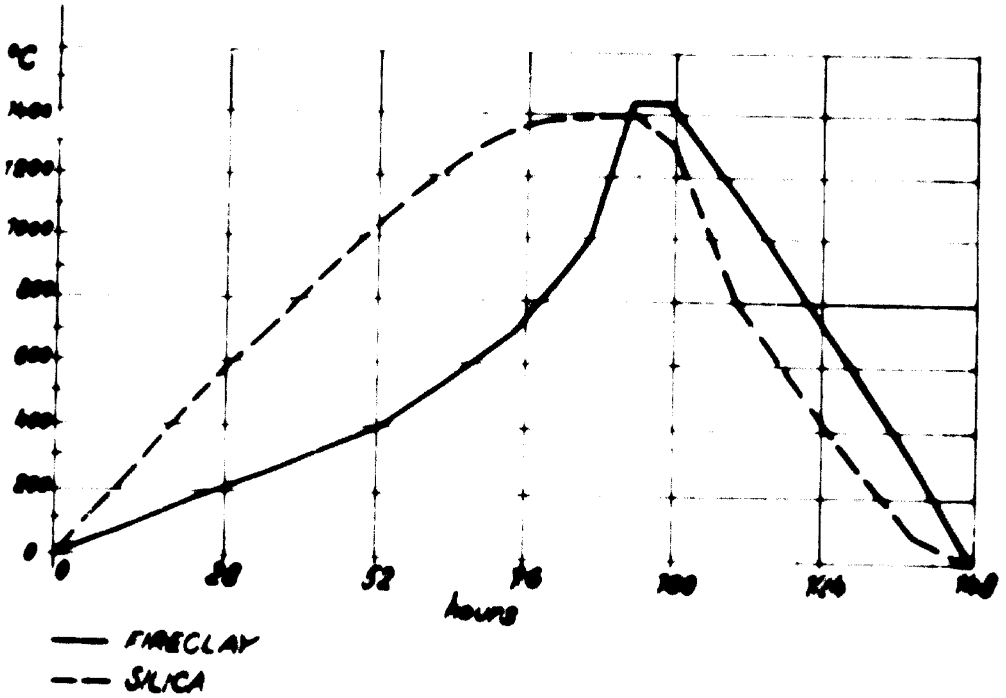


FIG. 18 - TEMPERATURE - TIME CURVE FOR FIRECLAYS AND SILICA REFRACTORIES FIRING OPERATION

Fig. 19. Characteristics of Three Grades of Fuel Oil.

Item	Light Fuel Oil	Medium Heavy Fuel Oil	Heavy Fuel Oil
1. Specific Gravity at 20°C	[illegible]	[illegible]	[illegible]
2. Flash Point /closed/, °C	[illegible]	[illegible]	[illegible]
3. Viscosity			
Kinematic /cSt/	2.5-11.5	17.4 max.	-
Engler °E /20°C/	1.17-2.07	2.5 max.	-
°E /50°C/	-	-	7.0
4. Gross Calorific value / kcal/kg/	[illegible] min	[illegible] min	[illegible] min
5. Oil Storage Temperature /°C/	10	[illegible]	[illegible]
6. Oil Temperature at Burners /°C/	[illegible]	[illegible]	[illegible]

Fig. 20.

Fireclay Plant: Condensed Financial Analyses at Two Different Stages of Development, 10,000 Tons per Year 1/

	US Doll. Equiv.	
	a	b
A. Annual Gross Sales	480,000	480,000
B. Total Manufacturing Costs	342,000	329,000
C. Total Administrative Costs	95,000	72,000
D. Sales Costs	25,000	25,000
E. Total Costs	462,000	426,000
F. Gross Profit before Taxation	18,000	54,000
G. Return on Total Capital based on gross profit	3.9%	12.6%

a. Fully automated plant

b. Plant utilizing maximum labour

1/ First year of full operation

Fig. 21.

Fireclay Plant: Condensed Financial Analysis, at The Different Stages of Development, 50,000 Tons per Year 1/

	US Doll. Equiv.	
	a	b
A. Annual Gross Sales	2.400.000	2.400.000
B. Total Manufacturing Costs	1.384.000	1.609.000
C. Total Administrative Costs	470.000	350.000
D. Sales Costs	125.000	125.000
E. Total Costs	1.979.000	2.084.000
F. Gross Profit before Taxation	421.000	316.000
G. Return on Total Capital based on gross profit	21,3%	15,2%

a. Fully automated plant

b. Plant utilising maximum labour

1/ First year of full operation

Fig. 22.

Fireclay Plant: Labour Requirements at Different Scales.

	Capacity			
	10,000 T		50,000 T	
	Automated Unit	Maximum Labour	Automated Unit	Maximum Labour
Direct Labour	35	126	148	608
Management				
General Manager	1	1	1	1
Production Manager	1	1	1	1
Technical Manager	1	1	1	1
Engineering Manager	1	1	1	1
Chief Chemist	1	1	1	1
Supervisors	2	4	4	8
Foremen	-	4	4	8
Plant's Accountant	1	1	1	1
Laboratory	2	2	6	6
Typist	2	2	4	4
Secretary	1	1	2	2
Store-keeper	2	2	6	6
Salesmen	1	1	2	2
Janitors	3	3	6	6

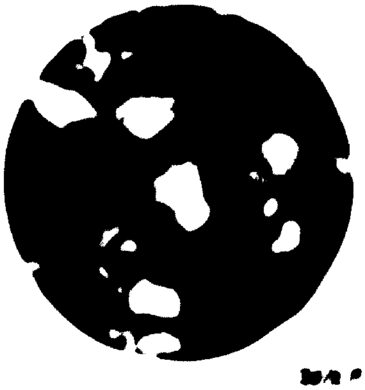


Fig. 23. Metallographical Slide of the Amorphous [illegible], Magnification [illegible]

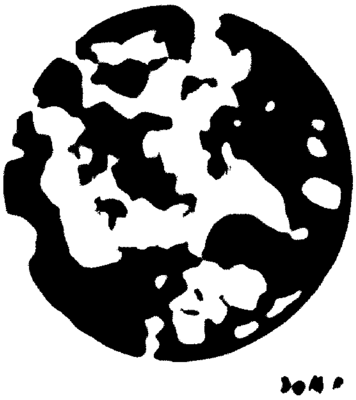


Fig. 24. Metallographical Slide of the [illegible] with Big Grains, Magnification [illegible]

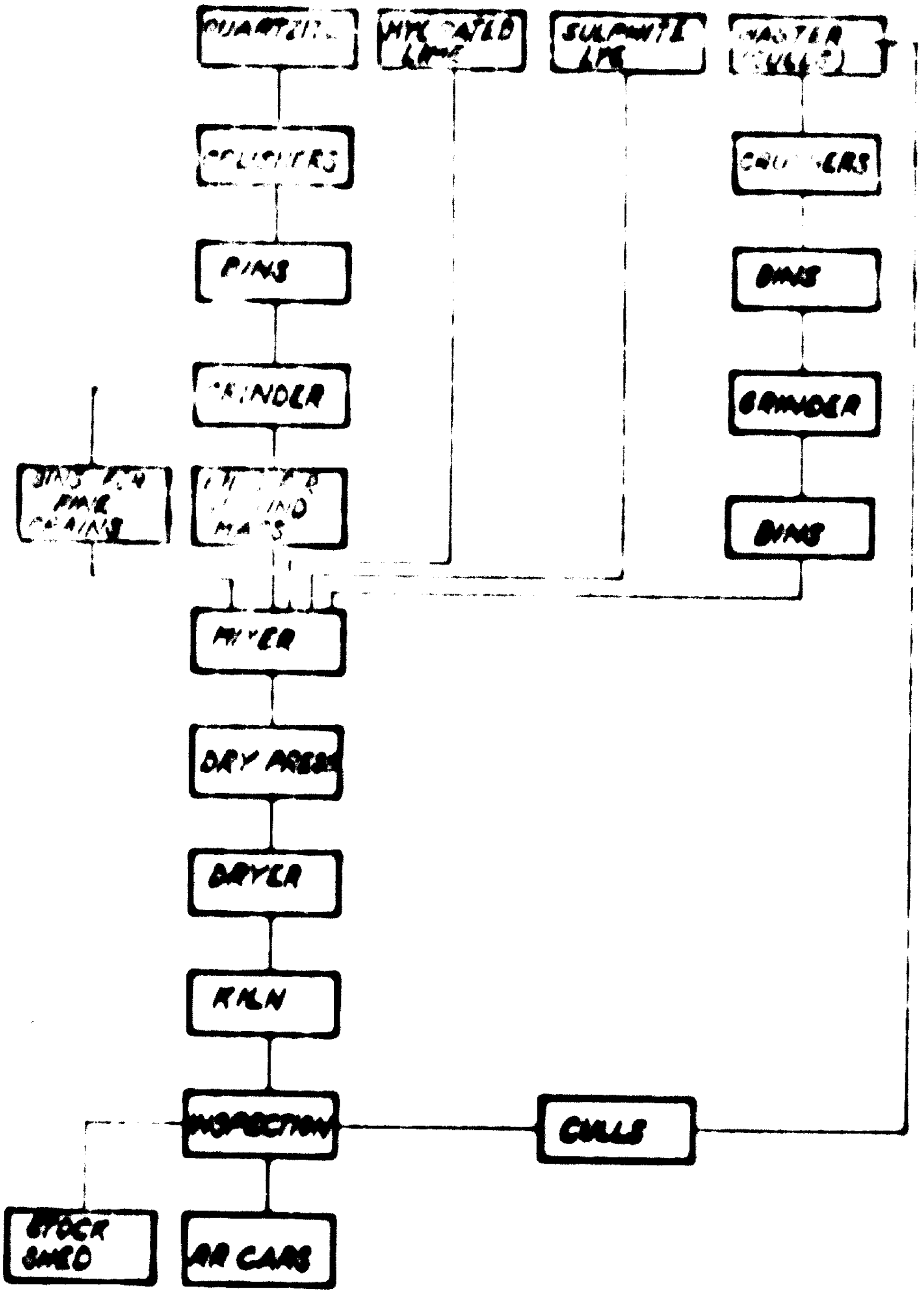
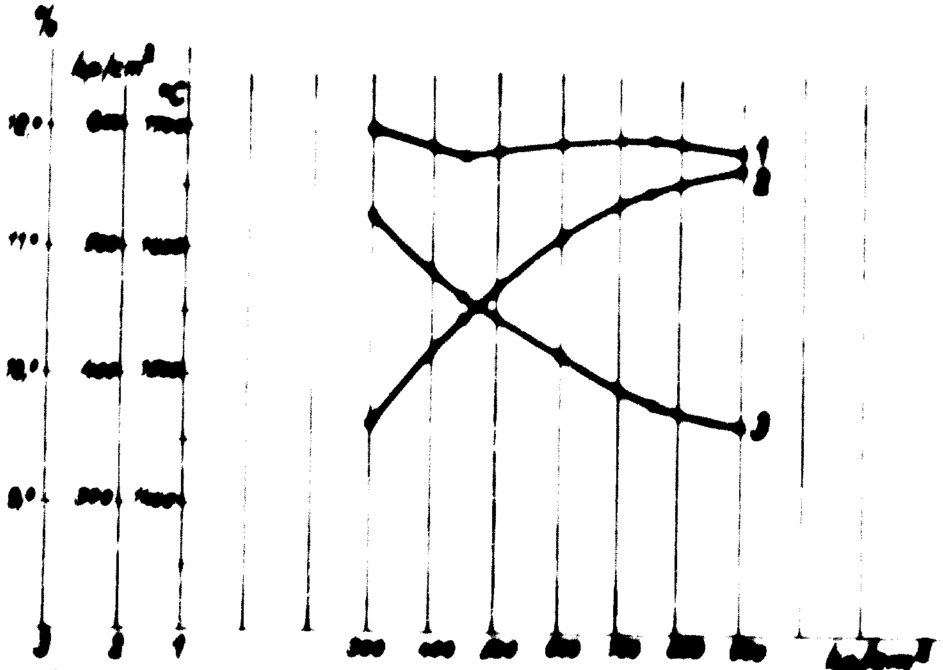
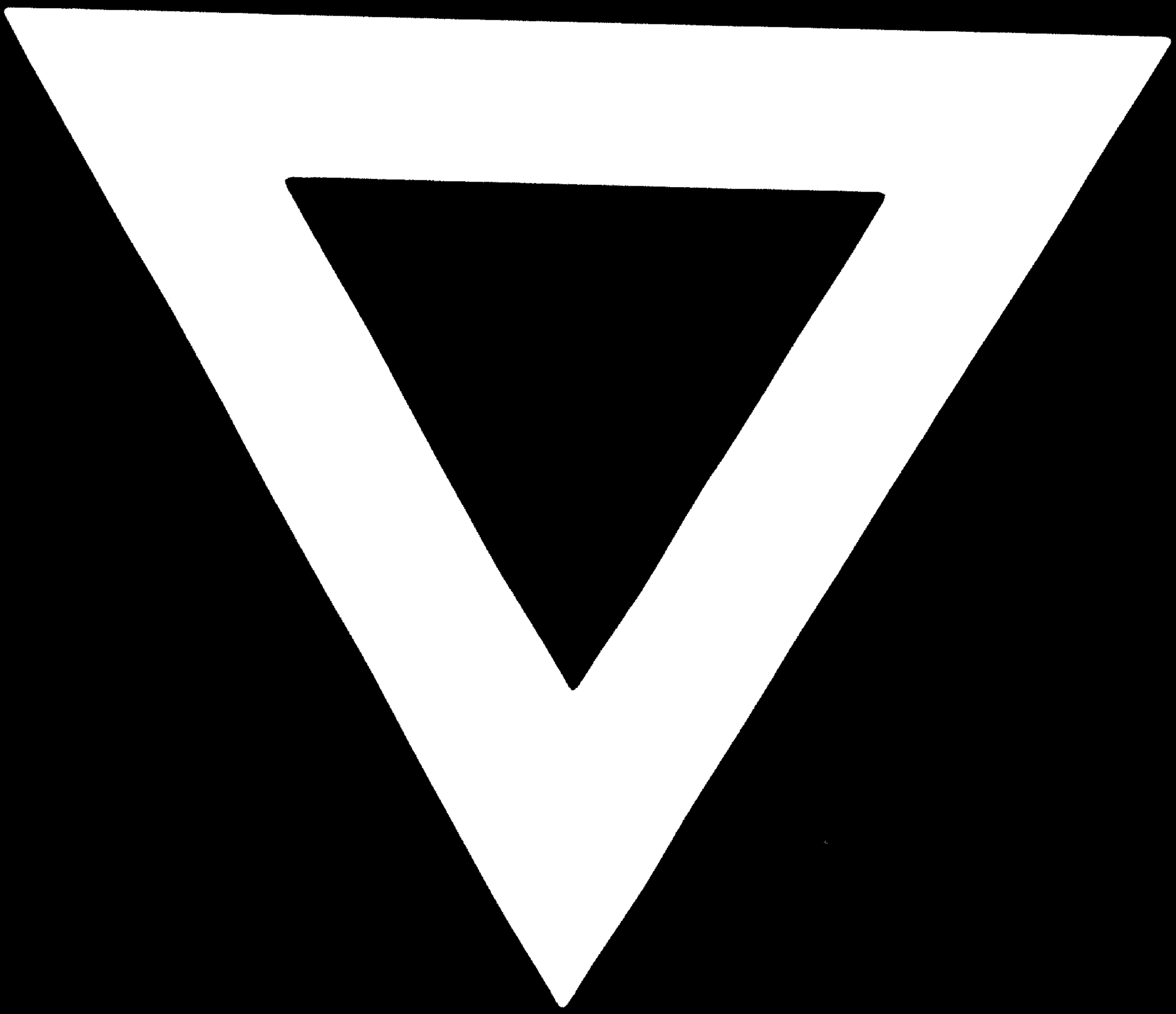


FIG. 25 - FLOW DIAGRAM FOR THE MANUFACTURE OF DRY-PRESSED SILICA BRICKS



1- REFRACTORINESS UNDER LOAD 2- CRUSHING STRENGTH
3- WATER - ABSORPTION

FIG. 20 VARIATION OF MAIN SILICA BRICKS PROPERTIES WITH THE PRESSING POWER



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