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TECHNOLOGY OF NON-METALLICS [x]

Information Package

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ABSTRACT

The paper deals briefly with production technology of different ceramic products as well as with their application and future technological trends.

Raw materials used in ceramic industry and classification of ceramic products are also given concisely in this Information Package. For other information and the more detailed study, bibliography reflecting the described topics is brought as well.

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I. INTRODUCTION

Ceramic production belongs to the most important areas of the human material production for hundreds of years. It includes a wide scale of products which are necessary both for the civilized human life and the action and development of different industrial branches. Technology of non-metallics is the basis of building materials industry and there is no single society which would be able to exist without ceramics at present.

This publication was elaborated as the response to the increasing number of inquiries from developing countries to UNIDO concerning this topics. The Information Package should assist companies, investors as well as individuals by providing them with the concise information on technology of non-metallics. In the final stage, the aim should be in establishing a new or extension or modernization an existing ceramic facility in developing and the least developed countries.

This package is based on compilation of six publications edited by the UNIDO-Czechoslovakia Joint Programme for International Co-operation in the Field of Ceramics, Building Materials and Non-metallic Minerals Based Industries in Pilsen, Czechoslovakia, in several past years on this subject. It describes the most common ceramic technologies of production ranging from tiles and dinnerware to refractory materials exploitable e. g. in metallurgy. Due to the extensive character of diverse ceramic technologies the chapter dealing with machinery and equipment had to be presented only informatively.

This Information Package should serve as the preliminary information on the technology of non-metallics. The information contained in this package is by no means exhaustive nor should it be considered a replacement of technology profiles. Any contribution from our readers for updating of, or inclusion in the package would, of course, be welcome.

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II. RAW MATERIALS USED IN CERAMIC INDUSTRY[2]

Non-metallic raw materials and their utilisation are the topic of another information package where they are dealt in detail. Owing to the fact that these materials stand just in the beginning of the technology of non-metallics they are described briefly in this chapter as well.

There are many outstanding monographs and papers presenting a wide spectrum of different non-metallics which can be utilized for production of ceramics[3-5]. Within these books the topic is dealt in a more or less specialized way with respect to genesis, geology, mineralogy etc.

Ceramic raw materials belong to the group of non-metallic raw materials, though some of them can be used in the production of metals such as aluminium. Based upon their behaviour at 20°C, ceramic raw materials are classified into two main groups: plastic raw materials and non-plastic raw materials.

Plastic raw materials. The most important plastic raw material for ceramic production is the mineral kaolinite (Al_2O_3-SiO_2-$2H_2O$). Plastic raw materials form plastic paste when mixed with a proper amount of water. From this paste, various semi-products can be formed. De-watering of plastic raw materials during drying creates a change in volume, called drying shrinkage, and increases the strength of semi-products. Plastic raw materials are prone to cracking during drying. Semi-products lose their plastic deformation ability and become fragile. The strength of semi-products increases during firing. The first volume increase, due to thermal expansion, is followed by a volume reduction, called firing shrinkage. The porosity usually decreases and bulk density increases with the increasing firing temperature.

The plastic raw materials used in ceramics have their origin in the hydro-thermal decomposition of parent rocks, mainly feldspar. The products of decomposition either remained at their original places (primary raw material deposits) or were transported and sedimented in more or less distant places (secondary raw material deposits). The primary deposits are known to be of higher purity than the secondary ones. The products of hydro-thermal decomposition, i. e. quartz and kaolinite, sometimes contain traces of the parent rocks.

Contamination of plastic raw materials occurred during the movement to secondary deposits. The least contaminated clays are used for the production of non-vitrified light-coloured porcelain or sanitary ware products, or for the production of refractories. Depending on the degree of contamination, the more contaminated clays are used for the production of stoneware, bricks, or for other ceramic products for which colour is not important. In addition to the degree of contamination, primary and secondary plastic raw materials also differ in the size of clay particles. Primary raw materials are usually more coarse and, therefore, are also of lower platicity and lower strength after drying and firing. They usually vitrify at higher temperatures.

Non-plastic raw materials. Non-plastic raw materials are classified into two main groups according to their behaviour during firing: grogs and fluxes. Mixing plastic raw materials with non-plastic ones lessens the plasticity, drying shrinkage and cracking during drying and firing.

Grog reduces or sometimes eliminates drying and firing shrinkage of plastic raw materials. In some cases, it can even cause the expansion of products, e. g. if quarts is used as grog due to its $\alpha - \beta$ modification transformation. This effect is important in the production of silica. The most frequently used grog is quarts (SiO_2), ground reject of fired products, various types of shales including high-alumina, natural high-alumina materials, such as sillimanite (Al_2SiO_5), kyanite (Al_2SiO_5) and some special grog, such as corundum ($\alpha-Al_2O_3$), silicon carbide (SiC) and zirconium silicate ($ZrO_2 - SiO_2$). A higher portion of grog in a body forms the skeleton of semi-products and products and determines the properties of products to a considerable extent.

Fluxes, during firing, function in a body as a grog until their fluxing effect, which lowers the temperature of sintering, sets in. They reduce the absorption and increase the strength of products. Traditional fluxes are mainly orthoclase and microcline ($K_2O-Al_2O_3-6\ SiO_2$), dolomite ($(CaMg)CO_3$), cryolite (Na_3AlF_6) and witherite or natural barium carbonate ($BaCO_3$). The non-traditional fluxes, such as albite ($Na_2O-Al_2O_3-6\ SiO_2$), tuffs, tuffites, nephelines (K_2O-3 Na_2O-4 Al_2O_3-8 SiO_2), nepheline-syenites, phonolites, perlites, basalts, calcites ($CaCO_3$), marls, plagioclase, feldspars and magnesium raw materials are used increasingly. Industrial wastes and their concentrates, ground glass, slags and light ashes, are also used as non-traditional fluxes.

Some developing countries have no reserves of ceramic raw materials with sufficient plasticity. Organic or inorganic plasticizers are successfully applied together with fine grinding of some constituents and with new shaping methods.

III. CERAMIC PRODUCTS [6]

Ceramic products are made from non-metallic raw materials which form a considerable part of earth crust. They obtain their typical properties during final thermal treatment - firing. Ceramic materials represent a large scale of products, which are applied for building, chemical, machine and electrical industries, metallurgy, agriculture, as utility and decorative products, in pollution controll equipment and in many other fields of human activity. Due to their wide field of application ceramic products and raw materials are indispensable to successfull development of national economy of a country.

Many aspects are being taken into account to classify ceramic materials, for instance, the used production technology, the final use and respective body component share. A simplified classification of ceramic products is presented in Table 1.

Majority of ceramic products is formed by alumino-silicates in the whole range of ratios of both components, i. e. from almost 100% of silicium oxide (silica products) to almost 100% of aluminium oxide (corundum, vitrified Al_2O_3). Mutual ratio of both oxides defines refractoriness of ceramic material of corresponding composition according to the phase diagram Al_2O_3 - SiO_2 (Figure 1). The validity of this diagram is limited to the pure raw materials without contaminating impurities, which usually lower melting temperatures between solids and liquids. This effect is exploited to reach desirable properties of some types of products when fired at lower temperature, e. g. for production of porcelain, stoneware and utility ceramics, with the exception of refractory products.

Aside aluminosilicates, special ceramic materials are produced based on vitrified MgO, CaO, MgO, $ZrSiO_4$, ZrO_2, carbides, borides, nitrides, graphites, ferroelectric materials ($BaTiO_3$, $SrTiO_3$), piezoelectrical materials, semiconductor materials ($BaTiO_3$, $ZnO.Bi_2O_3$, V_2O_5, SiC), ion conducting materials, translucent magnesium, gas and humidity sensors, electrodes, cutting tools, bioceramics, dentoceramics, ceramic enamel coatings used in industry, high performance bearings, etc. The position of special ceramics in ceramic products classification is also presented in Table 1.

The frost resistance of ceramic materials is usually not required in climate conditions of the vast majority of developing countries.

According to the purpose of their use, ceramic materials can be classified in accordance with the United Nations International Standard Industrial Classification (ISIC) into three main groups:

- structural clay products
- pottery, China and earthenware
- other non-metallic mineral products not classified before.

IV. DEVELOPMENT OF TECHNOLOGIES [2,6]

Manufacture of structural ceramics

Bricks

The favourable properties of ceramic materials in comparison with those of other building materials, especially for the construction of residences, have helped the brick industry to gain a good position in national economies of several countries and have contributed to the availability of low-cost housing during previous decades. Decorative bricks, used frequently for constructing fences and for decorating gardens, have also gained popularity. The contemporary production of roofing tiles is characterized by the development of new shapes and glazed tiles, resulting in mass reduction and improved aesthetic qualities. The production of drainage pipes is decreasing at present. Plastic pipes, which are easier to lay are produced in only some developing countries. The raw materials are usually heterogeneous, relatively impure red-burning natural clays, sometimes combined with sand or ash. No burnt greg is used in the mixture. If necessary, siliceous sand can be added.

The feasible level of mechanization depends mainly on available capital, market potentiality and labour costs. Capital expenditures and labour productivity grow simultaneously with the level of mechanization. Charcoal heaps, down-draught of chamber kilns are used by cottage and small-scale industries for firing bricks, while production plants of higher capacity usually use Hoffmann and tunnel kilns. Firing temperature varies from 900°C to 1150°C, depending on the type of clay used.

The anticipated technological trends in the manufacture of bricks are:

- increasing production of hollow blocks, accelerating the construction and improving the thermal insulating properties of brickwork
- production of glazed roofing tiles
- new shapes of roofing tiles with reduced mass
- artificial aging of the clay instead of natural aging
- waste-heat utilization from kilns in driers, sometimes open-air drying to reduce energy consumption
- substitution of tunnel kilns in production plants with higher capacities
- construction of counter-current tunnel kilns in which two lines of kilns cars move in opposite directions. (The heat from cooled bricks is transferred to these heated in the other line and specific energy consumption is lowered considerably).
- waste-heat utilization, e. g. by joining periodical kilns for preheating bricks
- application of stain and wax pastes in order to improve product appearance
- production of clay floor tiles and facing tiles as a comlementary product in brickmaking plants, vastly improving their entrepreneurial economy.
- application of pulverized coal as a substitute for gas and oil.

Stoneware pipes

Stoneware pipes are produced as salt-glazed, earthen-glazed, unglazed or glazed (on the internal surface only). The raw materials used are: vitrifying clays with low shrinkage and grog, such as fired shales, ground stoneware reject, quartz sand or a fine grain by-product of kaolin washing that can also act as a flux if a higher portion of parent feldspar rocks is present.

Stoneware pipes are manufactured either by semi-dry processing or wet processing. Pipes of diameters up to 300 mm are shaped either on vertical or horizontal worm de-airing presses. The type of presses depends on production capacity and assortment. Horizontal presses have higher output and usability for diameters up to about 300 mm. The moisture content of the green body for horizontally extruded pipes is usually lower, with 16 per cent as a maximum. The pipes with diameters above 300 mm are extruded on vertical worm de-airing presses. These presses use a higher relative moisture content of the clay, usually 17 per cent to 18 per cent. Bend pipes, angle pipes, breeches pieces and some other accessories are pressed on a specially adapted horizontal de-airing worm press. Some special fittings, produced in small amounts, are manufactured manually by bending segments, cut according to templets.

Internal glazing is done either during extrusion by spraying the glaze on the internal surface of pipes or after drying by special glazing equipment that is inserted into the pipe and sprays the glaze on its internal surface. Complete glazing is done by dipping the pipes into a tank filled with the glaze slip. Before glazing, the edges of pipes are dipped into melted paraffin to keep them unglazed for firing. Glazing by salt is done by inserting the salt (for cooking, industrial salt) into the kiln at maximum temperature. The salt is decomposed in the kiln temperature.

Decomposition of salt proceeds in the water vapour atmosphere (from combustion products) forming hydrochloric acid (HCl) and sodium oxide (Na_2O) that react with the body of pipes creating the glaze. The Seger formula of typical salt glaze - $1.0\ Na_2O-0.67\ Al_2O_3-3.33\ SiO_2$ - determines the necessary 3:1 ratio of $SiO_2:Al_2O_3$. Apart from this condition, the minimum temperature for salt glaze formation is 1120°C. Improvement of the surface and appearance of the glaze can be achieved by the addition of up to 10 per cent of borax ($Na_2B_4O_7 \cdot 10\ H_2O$).

Green pipes are dried in chamber or channel driers by waste heat from kilns and usually by an auxiliary steam heater. Uniform drying is important to prevent bending of pipes. Open-air drying can be applied in productions with lower capacity in order to save energy in countries with warmer climates. The firing of stoneware goods has been done mainly in chamber and Hoffmann kilns. In modern production plants, depending on the market potentiality, shuttle kilns or tunnel kilns are used for firing stoneware. Firing temperature ranges between 1150°C and 1280°C.

The anticipated technological trends in the manufacture of stoneware pipes are:

- production of socketless pipes; special couplings are used while laying these pipes
- firing of socketless unglazed or inside-glazed pipes in kilns with a sloping floor. (The pipes roll slowly through the kiln. The firing cycle can be shortened by up to 1 hour with parallel reject reduction and very low specific consumption).
- lowering of firing temperatures through body compositions
- waste-heat utilization e. g. in joint periodical kilns
- production of other ceramics in stoneware production plants, widening the assortment and making the production flexible in meeting market requirements. (Numerous other products, such as cable ducts; decorative ceramics; clay floor tiles; non-fired refractories with hydraulic, chemical or ceramic bond; siliceous fireclay and chemical stoneware can be produced parallel with stoneware pipes).

Clay floor tiles

Dense, vitrified tiles the colour of natural clays are frost- and erosion- resistant. They are used for exterior tilings of balconies, pavements, squares, terraces, garages and workshop floors, but generally not in housing interiors due to their rough surface. They are mainly produced from vitrifying clays, either by extrusion by worm de-airing presses from semi-dry mixture. Clay floor tiles can be manufactured in brick-making, stoneware or fireclay production plants. Their production requires simple manufacturing equipment and is suitable for developing countries. Firing temperature, depending on raw materials, varies from 1000°C to 1200°C.

The anticipated technological trends in the manufacture of clay floor tiles are:

- further reduction of specific energy consumption, either by use of raw materials with low vitrifying temperature or by use of non-traditional fluxes
- balanced application of fine-ground fluxes in view of total energy consumption. (Fine grinding and mixing with the clay, which is indispensable, is an energy-demanding process).
- reduction of thickness of tiles
- production of clay floor tiles as a supplement product in brick-making, stoneware or fireclay production plants, improving the economy of production with regard to a more favourable selling price per kg. (Its introduction requires no or negligible additional investment).
- production of relief tiles that are interchangeable with facing tiles
- bigger dimensions of tiles
- extrusion in pairs, quadrangles, etc. up to dodecagons that are split into individual tiles after firing.

Facing tiles for exterior applications

Dense, vitrified tiles are used for exterior tiling of house-walls or their parts, slaughter-houses, public buildings, comfort stations, etc. They are produced from vitrifying clays that are either the colour of natural clay, unglazed or salt glazed, with glazed, coloured engobes. Production of facing tiles is simpler than that of wall tiles and can be done in stoneware production plants, sometimes in brick-making plants or in refractories production, improving the economy of these plants. The tiles are either extruded by worm de-airing presses (coarse-ground raw materials) or pressed from semidry mixture on hydraulic presses (fine-ground raw materials).

The anticipated technological trends in the manufacture of facing tiles are:

- production of relief tiles for application in architecture
- firing of tiles in single-layer, multi-passage kilns or in conveyor kilns with low specific consumption and a short firing cycle (1 hour or even less)
- greater economy of stoneware, brick-making or refractory production plants by parallel production with clay floor tiles
- bigger dimensions
- parallel production of artistic ceramics.

Wall tiles

Wall tiles are produced from different raw materials; kaolinite, quartz, feldspar a limestone. Selected types of wall tile body compositions with corresponding firing temperatures and raw material requirements are given in Table 2. Kaolinitic bodies, used originally for wall tiles, have two main disadvantages. In addition to a high firing temperature, they show high firing shrinkage, e. g. a small difference in firing temperature causes a great difference in product dimensions. The body compositions presently used, such as lime-siliceous, undergo minimum shrinkage between 1000°C to 1060°C, and desirable physical and mechanical properties are reached by firing tiles at these temperatures [10]. Calibration is therefore not necessary. Moreover, high thermal expansion of lime-siliceous body makes possible the use of low-melting glazes with high quality finish for temperatures ranging between 960°C - 980°C.

Lime-siliceous, magnesium-lime-siliceous or magnesium siliceous bodies are the most suitable compositions for earthenware production in developing countries because of the large availability of raw materials.

Glazing of wall tiles[11] is done mainly by a waterfall of the glaze. This method shows the best results in the quality of final surface. Low profile, semi-muffled kilns or modern single-layer passage kilns substitute for muffled kilns used in the past.

The anticipated technological trends in the manufacture of wall tiles are:

- energy conservation by decreasing the water content in a slurry using efficient slurry plasticizers. (It is recommended that the minimum proportion of dry matter to water be 60:40. A 1 per cent decrease in the portion of water in a slurry production plant with an annual output of 1 million m^2 of tiles results in an energy saving of more than 720 000 MJ, i. e. 17 500 kg of fuel oil per year which represents about 3 per cent energy conservation during drying.
- introduction of single firing, bringing about 40 per cent energy conservation. (This task is rather difficult due to high quality requirements of products. Wollastonite-type bodies are most suitable for single-firing production).
- development of new decorating techniques and improved quality of glazes
- production of bigger tiles, sometimes of rectangular shape
- large variety of designs
- utilization of lower quality body raw materials and opaque glazes
- reduction of necessary kiln furniture during firing
- bisque firing of double-fired wall tiles in tunnel kilns, glost firing by fast-firing in single layer
- dwindling differences between wall and floor tiles as they are applied interchangeably.

Floor tiles

There are two types of ceramic floor tiles: unglazed (dense, fully vitrified, coloured or white) and glazed (vitrified or semi-porous, with opaque glazes). Unglazed floor tiles are produced with two basic types of body: porcelain and clay. Body compositions with vitrifying temperatures are presented in Table 3. Porcelain floor tiles are composed of kaolin or white firing kaolinitic clays, quartz, feldspar and dolomite or limestone. They are used for white floor tiles and those whose colour is developed by blending stains into the white clay, such as blue and grey. Clay floor tiles are composed of vitrified clays, whose properties can be regulated by adding quartz, feldspar or feldspar pegmatites. The firing temperature varies from 1120°C to 1280°C, depending on the body composition. Glazed floor tiles are produced either as double-fired or single-fired. Double-fired floor tiles are produced by the earthenware technology used for wall tiles. Single-fired tile technology is similar to that of facing tiles but with raw materials ground to the requested fineness. Firing temperature of single-fired tiles fluctuates usually between 1100°C and 1200°C. Bisque firing of double-fired tiles is done at temperatures ranging between 1050°C and 1200°C; glost firing ranges from 960°C to 1000°C. Production of glazed floor tiles is suitable for developing countries with frost-free climates, enabling wide application of floor tiles that can be produced easily in wall-tile-producing plants. Glazed floor tiles are applied interchangeably with wall tiles.

The anticipated technological trends in the manufacture of floor tiles are:

- increasing production of glazed floor tiles and decreasing production of unglazed ones
- bigger dimensions
- single-layer firing
- single firing of glazed tiles
- large variety of designs of glazed tiles that are easy to decorate to meet market requirements
- opaque glazes enabling application of lower quality clays for glazed floor tiles
- parallel production of glazed floor tiles and wall tiles
- dwindling differences between glazed floor tiles and wall tiles in application.

Manufacture of utility ceramics

Dinnerware and decorative ceramics

A large variety of dinnerware and decorative ceramics can be produced, of which the most important types are stoneware, earthenware, vitreous china and porcelain. Body compositions with corresponding firing temperatures are presented in Tables 4 and 5. A large number of body compositions are used for dinnerware production. The use of highly variable raw materials enables production of utility ceramics in those countries that have deposits of plastic clays. Production can be done on a small scale, with minimum technological equipment, as well as in modern automated production plants, using single-firing and double-firing technology. Therefore, these ceramics are suitable for the majority of developing countries, from the least developed ones to traditional ceramic producers, depending on market potentiality.

Production of dinnerware and utility ceramics has passed through three stages of innovation in developed countries. The first one, after World War II, was characterized by substituting tunnel kilns firing gas for round down-draught kilns firing solid fuels. The second stage, in the late 1950s and early 1960s, introduced mechanization into production lines (mechanization of casting and shaping, introduction of glazing machines, grinding machines, sorting lines, decorating lines etc.). The third stage of innovation in the 1970s was characterized by complex automation lines, including technological operations from shaping to glost firing.

The anticipated technological trends in the manufacture of dinnerware and decorative ceramics are:

- in porcelain manufacture, preparation of the blend in spray driers and isostatic pressing of flat pieces
- production of dinnerware and utility ceramics jointly with wall-tilemanufacture. (Countries with little experience in ceramic production are recommended to start with the manufacture of earthenware dinnerware and, after sufficient experience and skill is gained, then follow with porcelain, stoneware and vitreous china, depending upon raw-material availability. Production of complete dinnerware sets brings about difficulties with regard to the variety of shapes and decorations. It is recommended that the production of complete sets commence after sufficient experience is gained in production of plates and cups).
- similar problems are involved in decorating techniques. (Decalcomania (transfers) should be imported first and later production should start jointly with other types of decoration).
- mechanization and automation to increase capital expenditures and productivity of labour, taking into consideration market

requirements and variability of assortment produced.

Sanitary ware

Four types of sanitary ware are produced: earthenware, vitreous china, fireclay sanitaryware and stoneware. Principal sanitaryware products, such as wash-basins, bathroom fitments, closet bowls and sinks, are marketed both for household and communal utilities. Individual types of sanitary ware differ with respect to raw materials, firing technology (either single or double-firing), absorption, bending strength, crushing strength and firing temperature. The vireous China sanitary ware body compositions with corresponding firing temperatures are presented in Table 6. Vitreous china is the prevailing type of technology applied in sanitary ware manufacture. Sanitary ware is produced by slip casting, ranging from manual production for smaller capacities (which are labour-intensive, demand skilled workers, produce sophisticated shapes, permit assortment adaptability and offer a high rate of return on investment with regard to low-capital expenditure on equipment) to automated casting lines in high-capacity production plants (which have a high labour productivity and better working conditions, but demand high capital-expenditures and higher energy consumption.

For vitreous china sanitary ware production, the single-firing technology is applied [12]. Firing temperature in tunnel kilns ranges from 1200°C to 1300°C.

The anticipated technological trends in the manufacture of sanitary ware are:

- continued production of vitreous china sanitary ware due to lower investment costs and single-firing technology
- pressure casting of clay slip into synthetic moulds with high-quality castings, high durability of moulds, lower production costs and higher flexibility of production
- movement from high-capacity glazing lines to manual glazing or application of robots to meet market requirements for colour variability
- further energy savings during firing as a result of improved construction of kilns and equipment, waste-heat-utilisation

and decreased kiln furniture

- parallel production of artistic and utility ceramics, improving the economy of production.

Electroporcelain

Electroporcelain is classified according to low tension (used for voltages up to 440 v) and high tension (used above 440 v). Low-tension electroporcelain is unglazed for interior application and glazed for exterior applications. It can be produced jointly with sanitary ware or utility porcelain. Plastic clays, washed kaolins, talc, quartz and feldspar or pegmatite are used as raw materials.

High-tension electroporcelain is produced by more sophisticated technology form pure raw materials such as washed kaolin, high-quality clays, orthoclase and microcline, pegmatites, quartz sand or vein quartz and, if need be, flintstone or limestone and talc. Impurities, especially oxides of metals, lower the voltage resistance. Production of high-tension electroporcelain is possible only in countries with the necessary raw materials and market demand. Firing temperatures rang between 1380°C and 1420°C. Laboratories for testing final products to comply with relevant standards are indispensable in the production of high-tension insulators. These insulators are usually completed with steel fittings in production plants.

The anticipated technological trends in the manufacture of electroporcelain are:

- automated or mechanised shaping of mass-produced types.
- isostatic pressing of big, high tension insulators from spray-dried clay
- drying big insulators with high-frequency electricity. (It is recommended to start with low-tension insulators and follow with high-tension insulators or with special ceramics after experience is gained).
- firing in tunnel kilns in high capacity production plants and in shuttle and hood-type kilns in smaller plants
- completion of high-tension insulators with steel fittings in production plants
- parallel production of artistic ceramics, improving the economy of a plant.

Manufacture of refractories and other ceramic products[13,14]

Fireclay refractories

Fireclay refractories are the most common refractories and they are usually the first type to be manufactured in developing countries. Medium- and low- grade fireclay refractories can be produced by equipment similar to that used for stoneware or even bricks. Steel and iron production and production of other industries are conditioned by the application of fireclay refractories.

Fireclay products are manufactured from refractory clays and grog (fired shales, fired kaolins and ground fireclay reject)[15]. There are two basic methods of body preparation: plastic process (soft-mud) and dry process. The soft-mud process uses a ratio ranging from 30:70 to 10:90.

Lowering firing temperatures cannot be used to achieve energy savings, since low-fired fireclays would lose their quality and refractoriness. Firing is done in tunnel or chamber kilns at a temperature ranging from 1250°C to 1450°C, depending on the type and quality of final product.

The anticipated technological trends in the manufacture of fireclay refractories are:

- the use of non-fired grog in order to conserve energy
- application of shaped and unshaped non-fired raming masses and refractory concretes. (Jointless lining made of these refractories is more corrosion-resistant since corrosion occurs mainly in joints. Non-fired refractories account for up to 40 per cent of total production in industrialised countries).
- parallel manufacture of thermal insulators for high temperatures produced by the technology of combustible materials
- parallel production of refractory concretes
- parallel production of clay floor tiles and facing tiles to improve the economy of production.

Silica

Silica is cheaper than high-alumina refractories but is only suitable for continuous kilns. It is produced with special qualities for individual applications such as silica for coke ovens, metallurgical silica and silica for glass. Suitable raw materials are amorphous, cemented or, at least, fine-grained quartzites with a low content of alumina that acts as a strong fluxing agent[15]. Its content in raw materials for high-quality silica must not exceed 1.0 per cent. The firing process must be carefully controlled due to the crystallographic changes of silica.

Silica is fired at temperatures ranging from 1400°C to 1500°C. Because of high requirements for raw material quality, technology adapted to the properties of raw materials and a usually limited market, silica production in developing countries is rare.

The anticipated technological trends in the manufacture of silica are:

- production of silica from grained quartzites
- parallel production of silica with high alumina and magnesite
- high-purity raw materials for products applicable to temperatures up to 1700°C
- application in glass, metallurgical and ceramic industries
- joint production of light-weight insulating silica bricks and silica in the same plant.

High-alumina refractories[16,17]

High-alumina refractories contain a higher percentage of alumina than metakaolinite ($Al_2O_3 - 2\ Si\ O_2$), i. e higher than 45.9 per cent. Raw materials rich in alumina, such as pure alumina, vitrified alumina, sillimanite, andalusite, kyanite, bauxite or high-alumina synthetic grog, which is prepared from a mixture of kaolin and alumina, are used in the production of high alumina refractories. Natural alumina raw materials, such as andalusite, bauxite, allophane, kyanite (disthene), diaspore, gibbsite and boehmite, frequently represent the possibility for a successfull venture. Kaolinite, pure refractory clays or special inorganic or organic binding agents, such as phosphoric acid, alumophosphates and sulphite liquor, are used as binders.

High-alumina refractories are resistant to oxidizing and reduction atmospheres, some of them up to 1700°C, abrasion, slags and glass batch.

Technology of high-alumina manufacture is similar to the manufacture of fireclay by the semi-dry method. The exact body composition and high-pressure pressing are characteristic of high alumina production. The firing temperature depends on the type of product and varies from 1500°C to 1600°C. High-alumina can be produced also by casting from melted raw materials. Such technology, however, is more sophisticated, and it is not recommended to start with this technology.

With regard to the requirements for special raw materials and the applications for special purposes, production of high-alumina refractories in developing countries is possible after a higher level of development is reached.

The anticipated technological trends in the manufacture of high-alumina refractories are:

- application of high-alumina refractories as non-fired and non-shaped plastic and ramming masses and refractory concretes, monolithic linings of kilns, furnaces and other heating aggregates
- utilization of natural, up-graded high-alumina raw materials
- production of high-alumina refractories parallel with magnesite or silica refractories
- precise dimensions of final products

Corundum materials

Corundum materials represent a special group of high-alumina products, with more than 80 per cent of alumina content. High resistance to oxidising and reduction atmospheres up to 1900°C, abrasion, slags and glass batch is characteristic of corundum, kaolins or refracotry clays are used as raw materials, together with either chemical or ceramic binders. Corundum products are made either by isostatic or hot pressing and are fired at temperatures ranging from 1600°C to 1700°C. They are also manufactured by casting from a melt.

The anticipated technological trends in the manufacture of corundum materials are:

- application of natural high-alumina raw materials
- use for special purposes, mainly spark-plugs and burner stones, once fireclay production is established in developing countries according to the market, which is usually limited.
- possible parallel production in fireclay production plants equipped for this purpose by shuttle kilns.

Basic refractories

Basic refractories are special refractories such as magnesite, chrome-magnesite, olivine and forsterite products. Raw-material requirements amount to dead-burnt magnesite clinker, chrome ore with a maximum Al_2O_3 content of 12 per cent, olivine rocks, and sulphite liquor as a bond. Firing temperature varies from 1550°C to 1700°C.

Basic refractories are highly resistant to basic slags and melted metals. They are applied in the production of non-ferrous metals, such as copper, brass, nickel alloys and aluminium alloys. Production of basic refractories in developing coutries is possible when a relatively higher level of development is reached. The availability of raw materials and market demand are necessary prerequisities for basic refractories production. Basic refractories can be produced parallel with silica and high alumina. Purity of raw materials is indispensable for products applied in high temperatures.

Special refractories

The three most important examples of special refractories are: (1) graphite refractories (high thermal conductivity and high thermal shock- and chemical- resistance, except for oxidation), (2) silicon carbide bricks and shapes (high mechanical strength, resistance to spalling, good thermal conductivity, resistance to reduction and to mechanical abrasion) and (3) zircon refractories (uniform thermal expansion and good thermal shock-resistance, used for the aluminium and glass industry and for calcium phosphate production). Production of special refractories is rare in developing countries and only occurs in countries that have a developed ceramic production (especially fireclay and high-alumina), the relevant raw material and market requirements.

Thermal insulators

Thermal insulators are classified into three categories according to the maximum temperature of applieation: Low-temperature, medium-temperature and high-temperature insulators. Low-temperature insulators are applicable for temperatures ranging between 600°C - 700°C, such as glass wool and slag wool. Medium temperature insulators are applicable for temperatures up to 1200°C, such as vermiculite, expanded clay products, diatomite, perlites and insulating fireclays. The light weight of materials is frequently achieved by the addition of organic materials (sawdust, coal dust, granulated coke, peat, cork or other combustible materials) in the clay mixture in order to decrease the bulk density of the product since they are fired out during firing. The body is usually prepared by wet mixing to desirable plasticity, either manually or mechanically. Extrusion or rough pressings on worm presses, overpressing, drying and firing follows. Some fired products are calibrated. Production of medium-temperature insulators is suitable for developing countries because of the availability of raw materials. Moreover, these insulators can be produced in brickmaking plants, plants for refractories or sotneware products. High-temperature insulators are applicable for temperatures up to 1600°C and are manufactured by several processes using the following materials:

- combustible materials, used in a similar way as in the production of medium-temperature insulators.

- foam-building materials, such as soaps and sodium resinates. This method produces fine-pored refractory insulating bricks with fine spherical pores, low thermal conductivity and relatively high mechanical strength. Pores are made by inclusion of foam into the ceramic slurry (fireclay or high alumina, depending on temperature of application). Calibrating of burnt products is a condition for their successful use.

- bubble-creating materials, such as aluminium dust, peroxide of hydrogen H_2O_2 and calcites, in acid or alkali milieu. The gas produced by chemical reaction forms bubbles in the slip. After hardening, the porous body is achieved.

- Hollow clay or corundum balls, bound either by a refractory clay or by a chemical bond.

- sublimating matters, such as naphtalene and polystyrene. They sublimate out of the body before product maturity is reached, creating regularly distributed pores.

- insulating ceramic fibres, produced either by air blowing to a stream of a melted refractory mixture or by a centrifugal effect. Insulating folies, mats, felt, blocks and special shapes are produced from ceramic fibres. They have excellent thermal insulation properties and can be used for furnaces and kiln insulation.

The production and development of refractory insulators depend upon the level of industrialization of a country and the requirements of industry. They are important for any energy conservation programme.

V. PRESENT AND POTENTIAL APPLICATION OF CERAMICS [6]

Wide assortment of ceramic products is traditionally applied in the following fields:

- common bricks - in constructions, where appearance is of no importance. They are mass produced, in their manufacture no special care is taken to avoid surface blemishes
- facing bricks - produced with a view to structural use where appearance counts
- hollow bricks (blocks), decorative bricks - they are used for wall construction, especially where little weight or good thermal insulation is required. Decorative bricks are used for construction of fences, etc.
- roofing tiles - they are used for the roof construction or exterior wall covering as unglazed and glazed ones
- drainage pipes, field drains, agricultural drains - porous pipes, designed to withstand compression, used in land drainage
- stoneware pipes - salt glazed, earthenglazed, unglazed or glazed on the internal surface only. They are applied for sewage, chemical and surface water piping.
- clay floor tiles - dense, vitrified tiles with colour of natural clays, used for exteriors as coating of balconies, terraces, pavements etc.
- facing tiles (exterior) - dense, vitrified tiles, the colour of natural clays, produced unglazed or salt glazed and also with coloured engobes or glazes. They are used in exteriors as coating of house-walls and also in slaughterhouses, comfort stations. They find large application in architecture
- wall tiles - mass produced thin tiles with a porous body

covered by glossy or matt glaze. They are applied for tiling kitchens, bathrooms, washrooms, but also as decorative features in halls and entrance ways, but never in places liable to frost attack or frequent abrasion.

- floor tiles - dense, fully vitrified, the colour of natural clays or kaolins or with colour and textures achieved through additives. They are either unglazed or glazed by hard glazes. If glazed full vitrification might not be required. They are applied for interior floor tiling as well as for exterior decorative tilings.
- sanitary earthenware - produced primarily for general domestic use
- vitreous china - primarily for domestic use
- fireclay sanitary ware - strong ware, used in public lavatories, hospitals, hotels, restaurant kitchens etc.
- stoneware sanitary ware - it has great strength and is used for sinks, basins, wash tubs, urinal stalls and closets in factories and farms, public lavatories, etc.
- dinnerware - used as kitchen ware, dinner ware, souvenirs and decorative ceramics, with several types of body compositions
- low tension porcelain insulators - they have a vitreous body withstanding Voltage up to 440 V, used for Voltage insulation, either unglazed for the use in dry conditions or glazed for weather exposed pieces
- high tension porcelain insulators - made of completely vitrified material, covered by a glaze and having zero water absorption. Used for high-Voltage insulation they must have high resistance to high Voltage and to freezing.
- fireclay bricks - the cheapest kind of refractory bricks, used for temperatures up to 1450°C in furnaces, regenerators, soaking pits, kilns, glass and steel tanks, etc.
- silica bricks - refractory bricks, safely used at temperatures up to 1700°C, in continuously working kilns, such as in open hearth and electric furnaces, coke ovens, gas works and glass tanks

- high alumina bricks - having very high resistance to oxidation and reduction up to 1700°C, to acid slags and mechanical abrasion, they are used for muffles in ceramic kilns, burner blocks, high temperature gas or oil furnaces, etc.
- corundum materials - refractories with very high resistance up to 1900°C. Their production being expensive, they are used only for special applications.
- magnesite bricks - basic refractory bricks of high corrosion resistance and very dense structure, with extremely high thermal conductivity. They are used in open hearth furnaces, in furnaces for melting and refining of copper, tin. lead, and antimony, in firing zones of rotary cement kilns and lower side walls of soaking pits up to 1800°C.
- chrome-magnesite refractories - having great mechnical strength and stability at high temperature excellent to good resistance to spalling and high resistance to basic slags, they are used in non-ferrous metallurgical furnaces, i. e. copper, nickel, lead and aluminium production, roofs of basic open-hearth furnaces and soaking pits up to he temperature 1800°C.
- chrome refractories - characteristic by a high resistance to corrosion from basic and moderately acid slags and fluxes but having a relatively low refractoriness under load and low thermal shock resistance. Applicable up to 1700°C.
- olivine refractory bricks - bricks having practically no firing shrinkage and high resistance to fused iron and silicates up to 1650°C .
- forsterite refractory bricks - basic refractories, used in glass production, in lime and cement kilns and in production of dolomite and magnesite up to the temperature 1700°C.
- special refractories - wide range of refractories, of which mainly graphite refractories, silicon carbide bricks and shapes, cordierite and zircon refractories are used for special purposes and high temperatures.
- thermal insulators - wide range of thermal insulating materials used to a large extent in industries up to 1600°C.

Intensive scientific research having been done during the last decades enables new applications of ceramics in electronics as semi-conductors, insulation materials, ferroelectric and piezoelectric materials and ion conducting materials, in chemistry as gas and humidity sensors, electrodes, organic catalyst and catalyst carrier, in mechanical engineering as heat and wear resistant materials and cutting tools.

The present age is characteristic by wide transfer of technologies form industrialized to the developing and least developed countries. Numerous ceramic plants are constructed in developing countries improving employement of local people, infrastructure of local economy and utilisation of national raw material reserves. It is necessary to balance all the factors in terms of the level of sophistication of imported technologies to developing countries. High sophisticated technologies require high-qualified technical staff, high investments, modern equipment and developed market. In this connection, transfer of traditional and gradual development of non-traditional technologies respecting individual conditions seem to be the best way for developing countries in the field of introduction and improvement of ceramic industry. Feasibility of production usually depends on the market potentiality. If a ceramic plant of minimum economic capacity can be realized, its feasibility usually provides good prospects due to low raw materials and labour costs.

Ceramic raw materials are upgraded frequently in order to increase their useful value. Washed kaolin, up-graded diatomaceous earth, expended perlites, ground and separated quartz and limestones, bentonites, zeolites and upgraded clays then represent a wide scale of products which enlarge the use of ceramics and ceramic raw materials in numerous further non-traditional applications from agriculture, production of plastics, paper, rubber and chemistry to environmental protection and medicine. Thus the applications of ceramics and ceramic raw materials expand from traditional spheres to new, non-traditional ones.

The ceramics are pure, inert and resistant to chemical attack and frequently to high temperatures, too. They are produced from accessible raw materials in various shapes, with relatively low production costs. With regard to these aspects, the ceramics are going to find a wide field of new applications in the years to come.

VI. PRESENT AND ANTICIPATED TECHNOLOGICAL TRENDS [6]

Traditional production technologies of ceramic materials have been based on processing of relatively considerable pure raw materials with prevailing content of minerals kaolinite ($Al_2O_3 \cdot 2\ SiO_2 \cdot 2\ H_2O$), quartz ($SiO_2$), orthoclase and microcline ($K_2O \cdot Al_2O_3 \cdot 6\ SiO_2$). With regard to the high purity of raw materials relatively high firing temperature is needed to reach desirable properties.

Non-traditional raw materials and technologies are with advantage and relatively easy applicable in ceramic productions, however, they are not commonly used yet.

There are two main reasons for the development of non-traditional technologies. The deposits of pure traditional raw materials are being gradually extracted and, therefore, their application is limited to such products where high purity raw materials are indispensable to reach required final properties (e. g. electroporcelain for high-tension insulators). The second reason for application of non-traditional technolo[illegible] and raw materials is the shortage of fuels and their high prices which force producers to lower energy consumption. Reduction of energy consumption is limited considerably when traditional technologies and raw materials are used.

Non-traditional technologies are also suitable. For the developing countries which are starting with or developing their ceramic production as non-traditional raw materials [illegible] usually cheaper and do not require sophisticated upgrading.

Perspective raw materials and technologies in connection with anticipated development will be used towards the end of this century and, therefore, it is necessary to pay attention to their industrial beneficiation in both developing and industrialized countries.

The attention of technologists at present is paid mainly to such non-traditional technologies which enable exploitation of local raw materials and rationalization of production parallelly with achievements of energy and material conservation. In this connection "Energy Management" is applied representing wide, control demanding complex of measures based on detailed analyses of current situation, studies of desirable goals and determination of gradual steps necessary for their realization.

Energy Management in ceramic industry is characterized by following fields of activities:

- non.traditional technologies with lowered energy demands
- optimization of thermal processes
- energy diagnostic of heat consuming units
- modernization of thermal equipment
- waste heat utilization
- calculation of respective climate conditions

In connection with energy and material conservation the most important technologies are those with lowered energy demands. Energy and material conservation in ceramic production can be achieved by a complex of measures the most important of which are:

Use of non-traditional fluxes

to which albite ($Na_2 . Al_2O_3 . 6 SiO_2$), tuffs, tuffites, nephelines, phonolites, perlites, basalts, calcites ($CaCO_3$), marls, plagioclase feldspars, magnesium raw materials, glasses, light ashes and slags belong. The optimal use of each type of non-traditional fluxes must be determined by physico-chemical test of the flux. The typical examples of applications of calcites and marls for compositions of lime-siliceous non-vitrified earthenware bodies show that in comparison with traditional kaolitinic body the bisque firing temperature is lowered by 200 up to 300°C while stable dimensions of products are reached and no additional costs for calibration, material losses and energy are needed.

The use of sodium fluxes for glaze compositions is indispensable to fine appearance of fast fired products.

Simplification of production technology

is characterized by single firing. Up to 40% of energy can be saved by the application of single firing of tiling materials. These technologies are fully applied for production of sanitary ware, they are typical for all stoneware products and are beginning to assert in production of utility ceramics and selected types of wall tiles.

Production and application of non-fired refractories

the share of which on total production of refractories in industrialized countries amounts to 30 - 40%, while in developing countries is much lower. About 60% of total energy consumption is saved by application of non-fired refractories technologies which can be realized in developing countries with lowe capital investments. However, know-how is usually needed for their manufacture and application.

Minimization of fired grog share in body compositions of ceramics and refractories
The natural grogs are used instead, e. g. quartz for production of fine ceramics and siliceous fireclays. Suitable choice of binding component influences positively the amount of fired grog in final products. Some technologies are known, as for example, shale bond in fireclay products, the application of which reduces the share of fired grog to as far as 20% from total or even eliminates fired grogs at all.

Use of proper insulations for the construction of heat consuming units and their parts, i. e. proper insulation of brickwork of a tunnel kiln, improved construction of kiln cars, their linings, etc. The highest improvement can be achieved in periodic kilns where lowered mass of the brickwork by application of suitable insulating materials brings about energy savings by 20 - 25% and, moreover, due to lowered heat accumulation the firing cycle can usually be shortened.

Lowering of material requirements of ceramic products can be achieved by numerous methods, such as for example:

- cheaper and available raw material substitution for deficit or imported ones
- application of bisque raw materials of lower value in combination with partly or completely opaque glazes
- application of reject in the body and/or glaze compositions
- reject reduction by strict observation of technological processes
- dimensions or mass of products kept in minus tolerance
- possible mass reduction of products according to functional requirements
- optimization of kiln output accrding to minimum energy consumption
- reduction of the consumption of auxiliary materials during production

Application of progressive production operations

- pressure casting of sanitary ware and utility ceramics into non-gypsum moulds. In comparison with traditional casting (depending on the type of products), the following savings can be achieved:

  40 - 60% of manpower

  60 - 75% of the cost of moulds and their drying

  50 - 75% of production area

  10 - 20% of production cost per unit
- dry pressing of utility ceramics by isostatic pressures substituting for plastic moulding by jiggering or casting. About 35% of electrical energy is conserved together with reduction of thermal energy consumptions.
- moulding under vibration of fireclay or high alumina products substituting for pressing or hand moulding. Special shapes, not workable before, can be produced. Labour is saved as well as sophisticated moulding devices.

Technical development is a continuous process. Achievements in one sector often open possibilities of development in another one. Non-traditional technologies and their products represent a large scale of products workable from raw materials all over the world.

VII. MACHINERY AND EQUIPMENT NEEDED

In the least developed countries and territories where insufficient infrastructure and market do not yet allow the establishment of industrial plants, a simple equipment for ceramic production can play an important role[18]. It takes into account the fact that some ceramic plants built prematurely in these countries failed to work properly also owing to insufficient experience in making ceramics where practical knowledge is indispensable. Starting the production of ceramics on a small scale with the very simple equipment has the advantage of low investment costs, possibility of experimenting, testing, training and getting familiar with the character of ceramic bodies and their transformations. This phase should facilitate later the transition to a industrial scale manufacture.

According to different types of ceramic products and technologies used there is a great variety of equipment needed. It is beyond the scope of this information package to list the whole spectrum of machinery. Generally, majority of technologies is based on following simple production scheme:
raw material store and processing, utilizing different storing facilities (boxes, silos), mills, crushers, conveyor belts and other transporatation, feeders, vibration screens, ...
body preparation and shaping with spray dryers (or scarcely filter presses), silos, pumps, screens, different types of presses, moulds for casting, ...
drying, where different types of dryers are applied (with suitable transpor facilities),
firing, utilizing proper types of kilns for different fuels, provided with transport mechanization, kiln cars with refractory furniture, ...
glazing, decoration and other operations - utilizing different technology lines, ...

It has to be said that the complete machinery and equipment of a ceramic plant is closely linked with the proposed technology, e. g. in case of tiles production it differs considerably for once- or double-firing processes. Concerning ceramics, there are a lot of good and suitable equipment and machinery suppliers throughout the world. Some of them are specialized in different production technologies (structural ceramics, refractories, insulating materials, advanced ceramics, ...) some offer the general supply for the whole ceramic plant on a turn-key basis. An official UNIDO publication to help in orientation is to be recommended:

Information Sources on the Ceramic Industry
UNIDO Guides to Information Sources No.17
UNIDO Vienna, 1975.

VIII. FINAL NOTE

The presented Information package is far from being a complete technological manual. The aim of this publication is to describe briefly the production technology of main ceramic products including the raw materials processed and future technological trends. It should be a guideline for further orientation in technology of non-metallics.

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I. ANNEXES

Table 1 Ceramic Product Classification

2 Selected Types of Wall Tile Body Compositions with Corresponding Firing Temperatures

3 Unglazed Floor Tile Body Compositions with Corresponding Vitrifying Temperatures

4 Body Compositions of Selected Types of Dinnerware and Corresponding Firing Temperatures

5 Body Composition of Selected Types of Porcelain Products and Corresponding Firing Temperatures

6 Vitreous China Sanitary Ware Body Compositions with Corresponding Firing Temperatures

Figure 1 Equilibrium diagram: Al_2O_3 - SiO_2 system

Table 1

Ceramic Products Classification

Porous body <--> Vitrified body

Heavy ceramics <--> Fince ceramics

Brick products	Refractories	Earthenware	Stoneware		Vitreous China	Porcelain	Special
Single firing	Single firing	Double firing	Single (double) firing		Single firing	Double (single) firing	Single (double) firing
Coarse grained body	Coarse grained body	Fine grained body	Coarse grained body	Fine grained body	Fine grained body	Fine grained body	Fine Grained body
Brick	Silica	Wall tiles	Sewage pipes	Chemical stoneware	Sanitary ware	Tableware	Electronics ceramics
Roofing tiles	Fireclay	Tableware	Agricultural stoneware	Floor tiles	Tableware	Electro-porcelain	Electrotechnical ceramics
Drainage	High alumina	Artistic Ceramics	Chemical stoneware	Facade tiles Tableware	Artistic ceramics	Chemical ware	Bio-ceramics Dento-ceramics
Ceramic prefabricates	Refractory insulations	Glazed floor tiles	Artistic ceramics	Artistic ceramics		Dental porcelain	Non-oxides ceramics
Ducts	Magnesite Dolomite Chromium-magnesite Graphite Ceramic fibre	Kitchenware	Facade tiles Industrial tiles Paving tiles Ducts Garden ceramics	Glazed wall and floor tiles		Artistic ceramics	Hard ceramics Special requirement ceramics, Kiln furniture

Table 2 Selected Types of Wall Tile Body Compositions with Corresponding Firing Temperatures

	Type of body				
	kaolinitic	semi-kaolinitic	feldspatic	mixed	lime - siliceous
Rational composition %					
Kaolinite	80	65	55	50	48
Quartz	15	27	35	40	37
Feldspar	5	8	10	3	-
Limestone	-	-	-	7	15
grog, %					
total	60	60	50	55	55
fired grog	46	30	5 - 10	5 - 10	5 - 10
Main components	ball clays, stoneware clays, washed kaolins, fired grog, fired reject	ball clays, siliceous and stoneware clays, kaolins, pegmatite, fired grog, fired reject	ball clays, siliceous and stoneware clays, kaolins, pegmatites, quartz sands, feldspar, fired reject	ball clays, siliceous and stoneware clays, raw kaolins, marls, quartz sands, chalk, dolomite, feldspars, pegmatites, limestone, quartz, phonolite, nepheline, fired reject	ball clays, siliceous and stoneware clays, marls, wollastonite, chalk, dolomite, limestone, raw kaolins, fired reject
Firing temperature °C					
bisque	1280-1300	1230-1250	1200-1230	1140-1160	1040-1060
glost	1120-1140	1080-1100	1060-1080	1000-1040	960-1000

Table 3 Unglazed Floor Tile Body Compositions with Corresponding Vitrifying Temperatures

Type	Content %				Vitrifying temperature °C
	Washed Kaolins and Clays	Raw Kaolins and Clays	Feldspar	Phonolite	
Porcelain	70	-	30		1250 - 1280
Clay	-	70	-	30	1120 - 1160

Table 4 Body Compositions of Selected Types of Dinnerware and Corresponding Firing Temperatures

Stoneware dinnerware					
Type	Content %				Firing temperature °C
	Stoneware clays	Silica	Feldspar	Fluxes as feldspar, talcum and dolomite	
Body I	40-50	45	5-15	-	1250-1280
Body II	60	15	-	25	1200

Earthenware dinnerware						
Type	Content %				Firing temperature °C	
	Kaolins and clays	Silica	Feldspar	Limestone	bisque	glost
I.	50 - 55	35-45	6-12	-	1280	1120
II.	50 - 55	35-45	-	5-10	1080	980-1020
III.	75 - 85	15-20	0-5	-	1160	960-1020

Vitreous china dinnerware				
Type	Content %			Firing temperature °C
	Kaolins and clays	Silica	Feldspar and pegmatite	
I.	50	-	50	1250
II.	55	-	45	1300
III.	52	35	13	1250

..... to be continued

Table 4 - Continuation

Porcelain dinnerware				
Type	Content %			Firing temperature °C
	Clays	Silica	Feldspars	
Hard porcelain	35-60	20-40	15-25	1350-1450
Soft porcelain	25-35	20-45	30-40	1250-1350

Table 5 Body Composition of Selected Types of Porcelain Products and Corresponding Firing Temperatures

Type	Content %			Firing temperature °C
	Clays	Silica	Feldspar	
Hard porcelain	35-60	20-40	15-25	1350-1450
Electro-porcelain	37.5	37.5	25	1380-1420
Thin-wall type	49	29	22	1380
Soft porcelain	25-35	20-45	30-40	1250-1350
Dental porcelain	5	15-35	60-80	1100-1200

Table 6 Vitreous China Sanitary Ware Body Compositions with Corresponding Firing Temperatures

Type	Content %				Firing temperature °C
	Washed Kaolins and Clays	Silica	Feldspar	Other fluxes	
I.	40-60	30-40	10-20	-	1250-1300
II.	40-60	25-35	-	15-25	1200-1250

Figure 1 Equilibrium diagram $Al_2O_3 . SiO_2$ system