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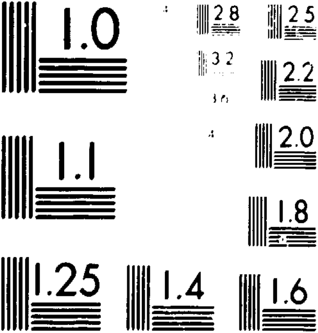

MICROCOPY RESOLUTION TEST CHART

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PROGRESSIVE KILNS AND DRIERS - SOURCE OF ENERGY CONSERVATION

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1. Introduction

The word "economics" is in the course of the contemporary world-wide power crises being articulated in perhaps all its forms, above all in connection with the search for possibilities of reducing the fuel and energy consumption. In the ceramic industry, the largest consumers of thermal energy are on one hand drying installations, but above all kilns.

The firing of ceramic goods represents the last phase of the technological process, in which the products acquire their final properties. The chemical and physical processes which take place during the firing of ceramic products, are given by the composition and properties of the individual components of the body, by their relationship, both the dimensions and shape of the grains and their mutual distribution. From the mutual interactions then follow changes of both weight and volume of the product that are influenced by processes which take place during the firing operation, and the final properties of the products are given by the phase and chemical composition, the ratio of the individual raw-material components, the dimensions and shape of the fired products, the distribution of pores, etc.

The firing is also the most complicated phase of the technological process, in the course of which occur a number of phenomena which can take place both simultaneously and individually, and the conditions, under which these processes are taking place, influence the physical and chemical composition of the product, the size of the crystals, the contents and composition of the melt, and thus also the resultant properties of the products. Upon an unsuitable conducting of the firing operation there can then arise, due to non-uniform and rapid heating or cooling, the setting up of stresses in the body, and thus the formation of cracks which sometimes may lead up to the destruction of the compactness of the product. Therefore maximum attention should be paid to the control of the firing process.

Before we are going to discuss the details of firing and compare the kiln designs from the point of view of operating economy, before assessing the advantages and disadvantages of the individual types and seeking possible ways of [illegible] the individual basic terms, i.

order to eliminate potential misunderstandings and inaccuracies.

The most frequently employed term is "firing" or "[illegible]". Because the field of ceramics includes in the broadest sense of the word bricks, earthenware, refractories, sanitary ceramics and kitchenware, porcelain, abrasives, technical pastes, wall tiles, floor tiles, etc. and certain types of ceramic ware can additionally be divided into subgroups, e.g. refractories are divided into fireclay, silica, magnesite, etc. the expression "firing" has also several meanings.

By thermal processing in ceramics is understood:

- the removal of moulding additives (used e.g. in pressing),
- the removal of mechanically bound water (both in dryers and kilns),
- the expelling of organic additives in the mass,
- the obtainment of the required qualities, the aim of which is to provide the object with properties that are necessary for further handling. Into this group belongs the calcination which is the removal of water of crystallization, the decomposition of carbonates and other compounds which can be decomposed by heat (as a rule no new compounds are formed), biscuit firing which is the thermal processing of the ceramic semi-product in order to obtain the properties which are required for further processing, firing (glost firing), during which the body attains its final properties, decorating fire which is the post-treatment of the body by the application of further materials (decorating, metallizing, dyeing, etc.).

In order to make the thermal processing of ceramic wares not only of a good quality, but also economical, it must be carried out under optimum or nearly optimum conditions. The optimum thermal processing mode is the shortest thermal processing mode at the lowest possible temperature, at which the object of the thermal processing acquires the most suitable properties. The optimum mode is the shortest, because the required plant has smaller dimensions, the lowest temperature is the optimum one, because a temperature increase leads to a steep rise in the fuel consumption without any substantial [illegible] in the utility qualities.

It still remains for us to explain, what is meant by the most suitable properties of the product. This implies that the properties of the thermally processed object still correspond to the requirements for the further handling of the latter, or to the requirements of the quality standard. For example a casting tube from fireclay has after firing to 1400 °C a cold compressive strength of 15 MPa and an absorption capacity of 8 %. (15 MPa are approx. 150 kp.cm^{-2}). After firing to 1100 °C it exhibits a strength of 7 MPa and an absorption capacity of 15 %. But even with these qualities it can be utilised without further measures. Thus for this tube the optimum firing temperature is 1100 °C. At this temperature the tunnel kiln exhibits roughly half the specific heat consumption in comparison with the temperature of 1400 °C. Since, however, are at the same time also being fired products that require a higher firing temperature, the operating mode of the kiln must be adapted to the most unsuitable product.

It is not generally known that the optimum operating mode is not exclusively determined by the composition of the thermally processed mass, but that it is also being determined by the size and shape of the products, by the method of moulding, by the kind and type of the kiln and, last but not least, also by the fuel employed. Products of large dimensions, with a thick body and of a complex form, must be thermally processed more slowly than small, thin-walled products of a simple shape.

On the contrary, continuous tunnel kilns of a small profile allow more rapid firing than batch kilns of a large volume, even if the heating system of the large kiln would permit rapid firing. This is given by the heat sharing mechanism between the kiln and the fired ware.

Under practical conditions it is quite exceptional to be able to operate in the optimum mode. This is being most frequently prevented by the fact that either the kiln does not allow the maintenance of this mode, or that at the same time are being processed several types of products or semi-products with differing optimum operating modes. Then it is necessary to realize the actual operating [illegible] the [illegible] [illegible] compromise. It should [illegible] [illegible] [illegible], however, [illegible] [illegible] [illegible] of the opti[illegible] operating modes for the [illegible] dividual products. Otherwise a large deviation could occur which would lead to the creation of defects or to an unproportionally high fuel and power consumption.

Even a small deviation from the precise thermal processing mode will manifest itself by a deterioration of the mechanical, electrical, magnetic and other properties. Deviations from the specified dimensions and shapes are generally caused by the non-observance of temperatures, thermal processing periods or by an unsuitable composition of the atmosphere. In this respect a lengthening of the holding period at the maximum temperature has as a rule the same effect as a temperature increase. Also the presence of reducing components in the atmosphere, as long as it does not cause complete destruction, manifests itself in a similar way.

The above mentioned facts explain, why it is necessary to devote maximum attention and care to the thermal processing. The bad thing about defects caused by thermal processing is that the kiln rejects can generally not be used for any purpose (in certain cases only as grog). There obviously occurs also a waste of all the expanded thermal and electrical energy, and above all human effort.

For this reason can be observed all over the world the endeavour

1) to give preference to small single-purpose kilns which operate in an optimum thermal processing mode,
2) to design thermal processing modes on the basis of the results of theoretical and detailed calculations, supplemented by laboratory tests and pilot-plant trial firings in special test kilns or already verified kilns,
3) to design the technological lines in such a way that in the kilns are fired products with similar optimum thermal processing modes,
4) to automate as far as possible the kiln operation, in order to eliminate the human factor from their attendence.

In the observance of the above requirements can be sought sources of savings of both thermal and electrical energy, as well as savings of human work. Only in this way it is possible to increase the economy of the entire operation of a ceramic plant.

2. KILNS FOR THERMAL PROCESSING OF CERAMIC WARE

The firing of ceramic ware is carried out in kilns which can be divided in accordance with a number of view points. The individual points of view can be summarized as follows:

1. According to the technology	- 1.1	- single-firing (one-fire process)
	- 1.2	- biscuit firing
	- 1.3	- firing of glazes (gloss firing)
	- 1.4	- firing of decor
	- 1.5	- other thermal processing
2. According to the type of operation	- 2.1	- continuous with stationary fire
	- 2.2	- continuous with moving fire
	- 2.3	- periodic (batch)
	- 2.4	- other
3. Kiln system	- 3.1	- chamber (one- or multi-chamber, bell kiln, shuttle kiln , etc.)
	- 3.2	- annular
	- 3.3	- tunnel
	- 3.4	- shaft (co-current and counter-current)
	- 3.5	- rotary (co-current and counter-current)
4. According to the type of transport	- 4.1	- car
	- 4.2	- with sliding plates
	- 4.3	- roller or ball type without plates
	- 4.4	- roller or ball type with plates
	- 4.5	- with conveyer belt
	- 4.6	- with chain conveyer
	- 4.7	- with air cushion
	- 4.8	- step-by-step
	- 4.9	- other
5. According to the type of heating	- 5.1	- with direct heating
	- 5.2	- with indirect heating
	- 5.3	- semi-muffle
	- 5.4	- with combined heating
	- 5.5	- other
6. According to the source of energy	- 6.1	- for solid fuel (coal, wood, plant waste)
	- 6.2	- for liquid fuel (oil, kerosene)
	- 6.3	- for gas fuel (producer gas, town gas, natural gas, liquefied pro- [illegible], etc.)

7. According to the type of fired ware
   - 7.1 - for brick products and civil engineering ceramics
   - 7.2 - for refractory products (fireclay, silica)
   - 7.3 - for civil engineering and chemical earthenware
   - 7.4 - for wall tiles, floor tiles and mosaic
   - 7.5 - for sanitary ceramics
   - 7.6 - for kitchen porcelain
   - 7.7 - for electrical porcelain
   - 7.8 - for technical masses (oxide and oxide-less ceramic, ferro-ceramic, etc.).

The individual types and design solutions of the kilns, their advantages and disadvantages, the comparison of their operational economies, will be discussed in the following chapters which are divided in accordance with the type of fired ware.

2.1. <u>Ceramic kilns for firing heavy-clay products</u>

After the Second World War up to approx. the sixties there prevailed almost in all the European countries the opinion that the production of fired brick products is no longer perspective, since ~~as~~ the intention was to replace bricks with reinforced concrete. Only in the second half of the sixties there occurred an abrupt change in the opinions, and in brick products were again positively evaluated their fundamental, highly advantageous properties, such as e.g. a satisfactory and permanent strength, thermal insulation qualities with a sufficient accumulation, frost resistance, etc. The brick products attain these final properties in the course of the thermal processing in the ceramic kiln.

The firing of brick products was first of all carried out in periodic (batch) kilns which were characterized by the fact that the fire, ware and the kiln had an unchanging position. These constructions were later on superceded by a system which made possible continuous firing, the fire or the ware moving during the firing process. To a further stage of technical development has contributed a kiln with built-in fixed burners and a movable setting - thus the car-type tunnel kiln.

In the course of the thermal processing the brick raw material is gradually losing its entire plasticity and the microstructure of the body is moulded into its final and permanent form. There occurs a series of complicated physical and chemical processes, out of which should be mentioned the liberation of the mechanically and chemically combined water, the burning out of organic materials, volume transformations of the quartz, transformations of carbonates, etc. Through the action of the above and quite a number of further processes comes about the final mineralogical transformation of the body. This process is terminated in a range of maximum temperatures which lie in accordance with the type of the raw material between 900 and 1100 °C. The laws and relationships which hold true for heat transmission, determine what quantities of the required heat input and during which period should be supplied and in turn removed from the given quantity of the brick product. This heat transfer rate should, however, only be such that the products are not damaged. The maximum non-damaging heating rate depends on the permissible temperature gradient. Through heating tension is set up which has its maximum value between the surface and core of the product. When the permissible temperature difference between the surface and centre of the product is exceeded, there follows its mechanical damage, reduction of strength, etc. A similar situation is during cooling. The permissible temperature gradient depends on a number of factors, such as the shape of the product, its dimensions, strength, elasticity, thermal conductivity, instantaneous temperature, etc. Great attention is required especially when firing more exacting products (ceiling joists, roofing, etc.) around 575 °C. At this temperature occur crystalline transformations of the quartz. Upon heating its volume increases (by approx. 2 %) which with too rapid a temperature rise sets up the hazard of the formation of cracks and the loosening of the structure. In the descendent temperature phase (during cooling) there occurs at a temperature of 575 °C the retransformation of free quartz, combined with a very rapid volume shrinkage (approx. 5 %). The tensions in the product which are set up during a rapid temperature drop [illegible] in the form of the so called hair cracks.

The determination of the non-damaging maximum rate of heating and cooling, including the determination of the firing temperature, is carried out experimentally and analytically in laboratories, and the thus obtained results are verified by pilot-plant tests. The result of this work is then the <u>limit curve</u> and the <u>optimum firing curve</u> which is determined from it.

One of the factors which markedly influence the character of the processes and the economy of the the thermal processing, are the <u>flow conditions in the kiln</u>. The air and combustion gases that flow through the kiln, create conditions for the oxidation of combustible materials, for the exhaustion of burning and reaction products. Almost in all ceramic kilns for the firing of bricks the combustion gases represent in the entire preheating zone the only source of thermal energy. And because heat transmission takes place here primarily by convection, very much depends on the flow rates and on their distribution over the kiln cross section. Therefore are introduced in modern kilns for enhancing the heat transfer into the preheating zone burners with a high outflow velocity, they can also be combined with air nozzles that facilitate the circulation of combustion gases.

Another significant factor which creates conditions for the formation of the desired microstructure, is the firing environment. In order to permit the perfect execution of all the required oxidations of organic materials and further chemical transformations, firing must be carried out with a sufficiently high amount of excess air. Exceptions form here only special firing operations aimed at the attainment of a certain colouring of the products where for a predetermined and tried out period of time reduction firing is carried out. The provision of the required values in the firing zone, i.e. above all the rise and maintenance of the maximum temperature in the entire cross section of the kiln, and the necessary holding period of the products in the heat, are the essential preconditions for faultless firing operations.

The intensity of the air flow in the cooling zone with an optimum arrangement of the temperature decrease supplement and complete the list of thermal and technological requirements for the firing of brick products. In the cooling stage exist sections, in which it is possible to cool at a considerable rate without the risk of damage. The utilization of these possibilities means a considerable shortening of the required firing time, and thus also the length of the kiln. It is, however, again necessary to draw your attention to the temperature region around 575 °C which requires gradual cooling due to modification changes of the quartz which have already been mentioned.

The permissible firing rate always holds true for a specific case, given by the properties of the raw material and the shape of the product. But the actual firing rate in an industrial kiln depends on the kiln construction, on the method of placement of the products on the kiln car, on the concrete distribution of the temperature field and on the actual pressure-suction conditions in the kiln. All these circumstances should be carefully considered when determining the operating curves for the firing process and the operating periods. In classical multi-layer tunnel kilns it is usual that the operating curve is up to five times longer than the limit curve. The main factor which influences the magnitude of the elongation, is the character of the product arrangement in the stack and the distribution of the stacks on the kiln car.

An index for the suitability of the placement of goods on the kiln cars is the so called permeability factor which is the quotient of the sum of free surfaces inside the stack (larger than 1 dm^2) and the sum of free surfaces of the kiln cross section. The permeability factor (ratio air : brick) should in the ideal case be equal to 1. The larger the difference of the areas air-brick, the greater will be the differences in the kiln cross section, and vice versa, the smaller the permeability factor, the denser will be the placement and the larger the temperature gradient between the centre and fringe of the block. The results of flow research as well as experience from the operation of brick kilns indicate that the optimum size of the gap between the placement and the kiln wall should be approx. 5 cm, between the individual stacks then approx. 6 cm. In practice it is, however, very difficult [illegible] in the above dimensions (with the exception of using automatic charging equipment).

[illegible] ...ial charac[illegible] of the production of bricks, with [illegible] large specialization, is only possible only by a continuously operated tunnel kiln. Progress in the automation of the placement of pressings onto kiln cars has made possible the construction of high-performance kiln units. Giant tunnel kilns with a kiln channel width of up to 7.6 m have been implemented. The economy of operation of such kilns requires, however, an absolutely regular supply of products for firing. Kilns of large dimensions place already considerable demands on the maintenance of the homogeneity of the firing process.

Contemporary developments in tunnel kilns for the firing of brick products are aimed at the attainment of maximum economies in the consumption of fuels and power, with the utilization of full automation of the operation. The endeavour to increase the thermal efficiency lead in brick tunnel kilns to the successful implementation of new constructions which make possible the utilization of up to 50 % of the total thermal input of the kiln for drying purposes. A tunnel kiln in connection with a drive-through tunnel dryer reduces very substantially the fuel consumption for drying and firing. Whereas in tunnel kilns in combination with batch operated chamber dryers specific heat consumptions for drying and firing of 2.5 - 2.8 $MJ.kg^{-1}$ of ware are being obtained, for tunnel kilns with drive-through dryers values around 1.7 $MJ.kg^{-1}$ are being achieved.

A lot of effort has recently been devoted to the utilization of the heat contained in the exhausted combustion gases by recuperation and the utilization of hot gases e.g. in boiler plants, respectively. In this way it is possible to reduce the specific heat consumption almost down to the limit of the theoretical consumption. No exception is the attainment of a specific heat consumption (after the deduction of the heat obtained from the combustion gases and the heat from the cooling zone of the kiln) of 0.9 $MJ.kg^{-1}$ (200 kcal/kg) of the fired ware. The heat distribution flow sheet is shown in Fig. 1.

For example Messrs. Lingl are placing many hopes into the principle of the two-tunnel counter-current tunnel kiln (see Fig. 2). The counter-current tunnel kiln has two or more [illegible] of rails, along which are counter-currently trans[illegible] [illegible] the principle of a counter-current heat exchanger; but whereas in the normal tunnel kiln type are being transported in one direction the goods and in the opposite direction the ballast material - air, in the counter-current kiln is being transported in one direction the ware and in the opposite direction also ware to be fired. Only through this principial change is attained double the counter-current efficiency. In principle, the counter-current tunnel kiln is built symmetrically. On one end is next to the cooling zone of track 1 the heating zone of track 2, and vice versa. The heat transfer takes place directly from the fired ware which is being cooled, onto the heated ware, without circulation by means of a fan. The canals are separated from one another by a wall which is provided with openings at the top and at the bottom. The difference in the weights of the air causes spontaneous movement. The larger performance of the fluid bed means a larger circulation performance and thus also smaller differences in temperature. The burners are installed roughly in the centre of the kiln and can operate with an excess air coefficient of 1.1 instead of 4 - 6 which is the usual value for normal kilns. The quantity of the waste gases is thus small, and through this also the stack losses, so that the specific heat consumption of a two-canal counter-current kiln represents 1/3 to 1/4 in comparison with tunnel kilns, i.e. 420 kJ/kg (= 100 kcal/kg). Prototypes of these kilns are already operating in Europe, but up to now no practical results from measurements on such kilns have been published.

The specific performances of tunnel kilns can be enhanced, besides by increasing the density of placement, only by shortening the firing cycle through the utilization of the so called placement with reduced stacking (up to the phase of single-layer placement). The system provides certain advantages in the possibilities of automating the loading and unloading of the products and in the first-class and uniform quality of the products, thanks to the homogeneity of the firing environment with an absolute automation of the operation of the whole system. The implementation of rapid firing requires, however, special preparations of considerably heterogeneous brick raw materials which are not necessary in the classical multi-layer firing. Also the specific heat consumption is with regard to the auxiliary materials for single layer firing higher. Therefore the utilization of such kilns must always be very carefully considered, above all in agreement with the overall concept of the brick plant.

I should also like to mention one concept of brickware production, in which it is possible to reduce the specific heat consumption, mainly through the utilization of waste rocks and overlaying clay from the winning of coal which contain high percentages of combustible materials.

It is a well known fact that the fuel burns out in the fired ceramic semi-product as a consequence of three processes - through the burning of gaseous products liberated during the heating of raw materials, through the oxidation of certain parts of combustible materials (coke rests) and through the burning out of coke rests of the fuel which is contained in the raw material.

The Brick Research Institute in Essen (FRG) has carried out the laboratory determination of the optimum curve for the firing of bricks from coal washing plant wastes, from which followed the typical characteristics for the firing behaviour which are given below:

110 - 450 °C	insensitivity to heating,
450 - 500 °C	sensitive to crack formation, partial oxidation of the burning out materials occurs,
600 - 700 °C	requirement for long holding period to attain complete burning out of the carbon fraction,
700 - 1040 °C	not sensitive to heating,
1040 - 40 °C	favourable behaviour during cooling, the sensitivity in the quartz modification transformation region (575 °C) is for normal brick firing insignificant.

The resultant optimum firing curve is shown in Fig. 4.

The parameters of the kiln developed in France are as follows:

Kiln performance/year	82 500 t
Length of kiln	150 m
Width of kiln	3.4 m
Length of passage through kiln	85 hours
Specific heat consumption	0.6 - 0.7 MJ.kg^{-1} = 140-170 kcal/kg
[illegible]	40-50 kW/t product

The waste rock contains 14.3 % C. The combustion air volume for attaining oxidation firing in the preheating zone represents the value of 60 000 $m^3.h^{-1}$. The quantity of discharged waste gases is 102 000 $kg.h^{-1}$ (75 $m^3.s^{-1}$) with a temperature of 450 °C which can be utilized via a suitable recuperator for drying purposes. The kiln equipment, especially the required air engineering and control equipment, are highly exacting for the attainment of high-quality firing, but above all with regard to the possible regulation of the specified curve in the preheating zone in connection with the fluctuating contents of combustible materials in the fired ware. With regard to limited localities of the raw material base there will occur no general expansion of this production technology for the entire brick firing sphere. But as long as a suitable raw material is available, very good product quality is being attained and with regard to the occurring self-firing also the operation is highly economical.

I should like to take this opportunity and mention briefly also the possibilities of improving the operational economy of existing chamber or annular kilns. One of the largest positions of the heat balance are the heat losses through the kiln walls and through heat accumulation into the kiln lining. If, however, the inner lining of the kiln is provided with a layer of highly insulating fibrous material, it is possible to attain through this measure alone fuel savings of 20 - 25 %, and to improve on top of that the quality of the firing operation. Through the introduction of burners with a higher outflow velocity of the combustion gases can be obtained a more perfect homogeneity of the temperature field which leads not only to a shortening of the firing cycle and to an increase of the performance, but again to an improvement in the quality of the products. Obviously the possible reconstruction of the thermal plant must be assessed individually and the actual reconstruction carried out only after a technical and economic analysis which has been prepared in advance.

The endeavour for a maximum speeding up and simplification of erection work in the construction of new kilns has [illegible] to the [illegible] of so called [illegible] kilns. In the manufacturing plant of the kiln supplier are prepared [illegible] modules [illegible], provided with the necessary valves and fitting, openings, etc. On the building site the modules are joined together and the assembly of the remaining valves and fittings is completed. By means of this technology it is possible to erect on the foundations which have been prepared in advance, the new kiln in the course of 2 - 3 weeks, and thus to shorten the building time to 1/5th of the original period. Also in case of a possible reconstruction it is possible to replace a module with a new one, without having to shut down the kiln for a considerable period of time.

The economy of operation of ceramic kilns depends to a considerable degree on the quality of the employed heating system. In the first tunnel kilns solid fuel firing was used (coal or wood, etc.). Later on, these fuels were being replaced with liquid fuels, for the combustion of which impulse burners have been developed. A more or less perfect atomization occurred here by the passage of the oil through a nozzle with a small circular opening, at a high pressure. The atomized fuel was injected in an interrupted manner without any premixing with air whatsoever through openings located in the kiln ceiling onto the placed ware. All the required oxygen for burning had to be supplied through the kiln itself - by the air flowing from the cooling zone of the kiln. After the preset temperature has been attained, the relevant group of burners was switched off and after the temperature has dropped, the group was switched on again automatically. The control was thus of the on-off type. On a qualitatively higher level are the today considerably widespread gasification burners, the development of which has been made possible by the introduction of gas fuels in the heavy-clay industry. Later on they have been perfected also for the combustion of fuel oils. In contrast to the impulse burners, the gasification burners utilize for the atomization of the fuel primary air which is generally supplied by a high-pressure centrifugal fan. The mixture of fuel with air is driven through openings in the kiln ceiling into the kiln space. The flame is softer and mildly radiant, the flame length can be readily controlled. The automatic control operates on the principle of full or partial performance, through which the unpleasant temperature impacts in the kiln space have been eliminated.

A further firing system for brick-making kilns is the utilization of burners located in the kiln walls. The newest systems of high-velocity burners, equipped with automatic flame guards and ignition facilities, replace in the preheating zone the recirculating fans, and with checker-board arrangement a perfect temperature homogenization even in relatively wide kilns can be obtained. This system makes possible to speed up the firing cycle, to increase the kiln performance and to improve the quality of the resultant product with a lower specific fuel consumption.

Beside the traditional fuels for the heating of ceramic kilns (liquid and gaseous), in connection with the world-wide energy crisis have in recent years again been used solid fuels for the firing of brick kilns. Quite a number of heating systems with a more or less satisfactory function have been developed. In principle it can, however, be stated that the return to solid fuel firing has been successful and that it has been possible to fully mechanize the pulverized coal transport to the individual burners. Some users even claim that there has not only been obtained an improvement of the operating economy, quality and increase of performance, but also a reduction of the specific fuel consumption. This claim can be taken at face value only under the assumption that prior to the reconstruction the kiln has not been pro[illegible] adjusted, so that during the reconstruction of the he[illegible]system was carried out also a partial reconstruction of [illegible] kiln body (sealing of canals, pipelines, etc.), the kiln car lining, etc.

One of the ways of utilizing solid fuels for kiln firing is their pressing into the moulded body (approx. 3 - 10 %) which leads to an improvement of the firing economy. It is, however, necessary to take into account that this will reduce the strength of the bricks and increase their absorptivity.

2.2. [illegible]IC KILNS FOR FIRING REFRACTORY AND INSULATING MATERIALS

Refractory products take up in the ceramic industry an important position, since they serve for the making of refractory constructions in situations where protection against the action of high temperatures is required.

In refractory products we come across porous, dense, up to sintered bodies. This fact gives the refractories a special position among the other ceramic products, because no other ceramic product is comparable with them as regards the body variability from both the physical and chemical points of view.

Refractory and insulating materials are generally divided in accordance with the chemical and mineralogical composition into:

1. siliceous (silica)
2. alumina-siliceous (fireclay, silimanite, corundum)
3. magnesium (periclas)
4. magnesium-calcium (dolomite)
5. spinel (magnesite-chromium, chromium-magnesite, chromite)
6. magnesium-siliceous (forsterite)
7. carbon (graphite)
8. siccarbide (carborundum)
9. zirconium
10. oxide
11. oxideless
12. metal-ceramic.

Further classification points of view are e.g. according to refractoriness, degree of compaction, method of production, thermal processing, etc.

The most important part of the technological process of the production of refractories is the firing operation. This is an irreversible process which provides the products with their required properties.

For the firing of refractory materials are employed two main types of kilns:

a) Periodic (batch) kilns, into which the products are charged all at the same time. The actual firing process then proceeds in accordance with a certain time and temperature program. After cooling, the ware is removed from the kiln and in its place comes a new charge.
To this group belong all the chamber kilns (single as well as multi), shuttle kilns, bell kilns, etc. The older kiln constructions exhibit relatively low efficiencies, because they have to be reheated for each charge, and the employed [illegible] exhibit a considerable heat accumulation. [illegible] heat up to the firing tempera-

ure and also difficult to cool. The walls of modern periodic kilns are made from materials with a very low thermal accumulation and a high insulation, so that after cooling down there remains in the light lining relatively little heat, and the insulating lining consumes very little thermal energy for heating up. The entire heating and cooling process is equipped with a fully automatic system, so that the operator sets up on the control panel the predetermined firing and cooling program, whereupon the latter is being implemented by the control instruments. The heat contained in the exhausted waste gases is being utilized in special recuperators, so that the actual specific heat consumption, after the deduction of the sensible heat in the recuperators and upon utilization of hot air from the cooling phase, does not differ too much from the classical tunnel kilns with cars.
In order to improve the thermal efficiency, these kilns are often built in series, the warm air from one kiln being transferred through flues into the second kiln where it is utilized for preheating the ware. This system reduces substantially the specific heat consumption and thus improves also the economy of operation.

b) Continuous kilns, to which belong beside the type Hoffmann or Mendheim kilns all the tunnel kilns. In the type Hoffmann or Mendheim continuous kilns we are dealing with thermal processing, in which the charged ware remains stationary, whereas the heat moves. In tunnel kilns the opposite is true, i.e. the charge moves (generally on kiln cars) and the heating system is permanently in the same position (in approx. 1/2 the kiln length).

Due to its high effectiveness, the car tunnel kiln is considered to be the most suitable kiln type for the mass production of refractory ceramic materials. Only for the firing of special and complicated shapes from materials which require a special firing mode and whose yearly capacity is relatively low, it is more advantageous to use kilns with a periodic firing mode, naturally of a modern construction, [illegible] application of the newest findings in the field of thermal [illegible].

[illegible] of the relevant kiln construction is imfluenced by quite a number of factors:

- by the range of fired products
- by the required performance of the kiln
- by the method of ware placement within the kiln
- by the employed type of fuel
- by the required degree of control of the firing mode
- by the conditions for the location of the kiln in the production hall, etc.

For selecting the construction of the kiln is decisive among other things the number of kinds of masses and their shapes which are to be fired, because with this are linked also further parameters of the kiln, such as firing temperature, firing period, method of ware placement in the kiln, dimensions and shape of the kiln space, possibilities of mutual chemical reactions at certain temperatures in the kiln, etc. Also the course of the temperatures in the kiln need not be satisfactory for all the types of products. This must be carefully considered not only by the designer of the kiln, but also by the user, since it can happen that in the given kiln type it will not be possible to fire the required capacity and range, or that from the point of view of economy of operation the system will be unsuitable. In this connection is of importance also the question of kiln life which is always the longest, if the kiln operates in a mode which does not change. If products of a similar shape and one kind are to be fired (fireclay, silica, etc.), then the most suitable type is the car tunnel kiln. With the required performance is linked its length and the size of the kiln profile. The kiln lengths for the firing of refractory materials lie between 60 and 160 m, the width of the kiln space is generally 2 - 3.5 m. The height of stacking is determined by the deformability of the bottom layers of the stack at the highest temperatures and lies between 0.7 and 2 m. In connection with the gradual increase of the firing temperature (for obtaining better quality materials) is reduced load-carrying capacity of the material in the heat, so that the height of the kiln space in new kilns with a firing temperature above 1500°C is around 1 m and is still less for the firing of grog.

Similarly as in the case of brick kilns, also here [illegible] the endeavour for a maximum reduction of the [illegible] of fuels and energy. The kiln walls and ceilin[illegible] are made from highly refractory materials which are, however, supplemented by insulating materials. Also the kiln cars are provided with linings from a very lightweight structural insulating material in order to minimize the heat accumulation during the passage through the kiln. All over the world can be observed the endeavour for the maximum utilization of the heat which is leaving the kiln (in the form of combustion gases or hot air from the cooling zone of the kiln). With regard to the relatively high temperature of the exhausted gases have proven themselves very well recuperators which operate periodically or continuously. Through the utilization of these forms of heat not only for the purposes of drying, but also for other purposes, can be obtained a very low fuel consumption for the production of 1 kg ware. The following Table contains a comparison of several types of kilns with regard to the specific heat consumption for firing fireclay to 1300 °C.

Table No. 1

Type of ceramic kiln	Specific heat consumption $MJ.kg^{-1}$	(kcal/kg)
Chamber kiln, classical	16.7	(4000)
Chamber kiln, whose inner walls are provided with insulating material	12.9	(3100)
Bell kiln without recuperator	8.3	(2000)
Bell kiln with recuperator	6.2	(1500)
Car tunnel kiln with recuperator and utilization of heat from cool. zone	3.3	(800)

2.3. SELECTED KILNS FOR FIRING STRUCTURAL STONEWARE

The production of structural and chemical stoneware includes the following products:

- sewage pipes
- sewage shapes (branches, bends, etc.)
- tanks, sinks, plates, vessels, filter inserts, fans, pumps for handling chemical materials, etc.
- stoneware linings and floor stones.

The firing of sewage stoneware has been carried out in Europe up to 1951 in chamber or annular kilns. The first firing in a tunnel kiln took place in Czechoslovakia in 1951. Since then occurred a rapid expansion in the use of tunnel kilns for the firing of most stoneware kinds. Only certain complicated shapes and chemical stoneware products of [illegible] dimensions and complicated shapes are being fired in periodic, today already modern car-chamber or bell kilns.

For the firing of stoneware a process should be selected which corresponds to the composition of the raw material and the shape of the product. In the first, finish-drying phase is removed from the body the mechanically bound water. In accordance with the heating intensity, this period lasts up to approx. 300 °C, sometimes up to 490 °C. Upon further gradual heating there occurs the burning out of organic materials and the evaporation of the chemically combined water. From temperatures above 900 °C commences the gradual sintering of the body. This process, accompanied by a compacting of the body, culminates during the holding period at the final firing temperature which lies in the range of 1150 - 1300 °C, in accordance with the raw mix composition.

During the first ware cooling period in the range from the maximum firing temperature down to approx. 750 °C, the products can be cooled very intensively, since in this temperature range the products are in the so called "pyroplastic" state and are thus not sensitive to steeper temperature drops. But during the next cooling period the temperature decrease interval must take into account the presence of free quartz in the body and its transformations which are associated with rapid changes of volume. When determining the firing mode, it is also necessary to take always into account the technical possibilities of the thermal plant. In the course of both heating and cooling of the semi-products, are set up due to the non-uniform temperature distribution in the entire kiln profile smaller or larger stresses in the body which can, upon exceeding the permissible heating or cooling rate, lead to a complete destruction of the products. The required data for the determination of the permissible heating and cooling rate can be obtained on one hand by physical, chemical and physico-chemical analyses (by analysis of the DTA, VTA, DKTA curves), on the other hand experimentally. It is understandable that the firing intensity depends on the type of product, on the composition of the production mix and on its physical and chemical properties, furthermore on the method of [illegible], on the construction of the kiln, on the selected moulding technology, etc. Thick-walled products do not provide great possibilities for shortening the firing period, and are therefore often fired in separate periodic kilns, in which the firing period may represent even several days. On the contrary, thin-walled tiles can be fired with the placement of the products into one layer within several hours. In modern progressive car tunnel kilns pipes with a dia. of 100 - 150 mm are fired in 28 hours, 300 - 400 mm dia. pipes in 32 - 36 hours.

The kiln construction and the firing technology must thus start out on one hand from the theoretical knowledge about the course of sintering, on the other hand from the properties and behaviour of the production mixes during the firing process. The kiln equipment should guarantee the set up optimum curve, derived from the range composition, and a homogeneous temperature over the entire kiln profile.

Of great importance is the balancing of temperature differences both in the preheating and cooling zone. The heat transfer by convection and and the transfer from the radiating components of the combustion gases is increased by the use of special burners with a high outlet velocity (approx. 100 m/s). The side location of the latter in the preheating zone facilitates the heat transfer onto the products, especially in the bottom part, where the heat is being taken up by the kiln car lining.

Also in the firing zone is desirable an intensification of the heat transfer from the heating medium onto the fired ware. Some tunnel kiln suppliers are installing ceiling burners and claim that they attain a lower heat consumption and a better uniformity of the temperature. These claims should be taken with a pinch of salt and as long as better firing results are being obtained, this need not only be a matter of burner location, but follows from the whole complex of conditions, under which the actual firing operation is being carried out.

The air engineering equipment of the tunnel kilns must provide perfectly controllable and effective cooling, with the possibility of the [illegible] utilization of [illegible] heat from the cooling zone for drying; the tunnel kiln should also be [illegible]
[illegible]

The laws of flow and heat transmission dictate the requirements for the optimum density of the stacks, for the uniformity of placement, for filling the kiln profile and the suitability of the placement combination of the range produced. By an operational verification and supplementation of the theoretically designed stacks can be obtained an optimum placement and thus a maximum performance. The filling of the cars in accordance with these verified arrangements represents means of faultless and economic firing.

When stacking stoneware pipes, the pressings are not placed directly onto the receiving grid surface of the kiln car, but onto support rings, prepared from the same mix. These rings correspond with their diameter and thickness approximately to the fired pipes and prevent damage of the products themselves due to different thermal expansions of the kiln car grid and the stoneware products. A perfect utilization of the kiln space is attained with straight pipes through a suitable composition of the individual diameters and by placing the pipes alternately onto the "socket" and onto the "tip". Another economic method of placement is the so called "nesting", i.e. the insertion of pipes of smaller diameters into larger diameter pipes. The space underneath the roof is topped up with shapes and other small products which are placed onto carborundum plates. The placement of chemical stoneware requires special attention. Larger vessels and tanks are placed in the centre of the car, smaller products are located in accordance with their size and shape onto the storeys.

Glazed stoneware tiles are placed onto special ceramic setters which are put together to form columns in such a way that the combustion gases can flow through them in an optimum manner and thus provide perfect firing. For the firing of this range of products have proved themselves especially single-layer gap kilns which are discussed in the chapter devoted to ceramic linings.

The strive for operating economy and new findings about the behaviour and properties of production mixes have [illegible] in the firing of stoneware to firmly stabilised [illegible], above all in car tunnel kilns.

[illegible] performance range between [illegible] heat consumption of 3.35 - 4.5 $MJ.kg^{-1}$ fired were. The fluctuation is influenced by the stacking density (range composition of the products) and the travel speed of the kiln cars.

An increase in the kiln performance enforces an enlargement of the kiln width. In accordance with most recent experience of stoneware manufacturers, the optimum kiln width is 3 m. Values of 5 - 6 m are, however, no exception. But their operation is already highly exacting as regards the maintenance of optimum operating conditions.

The ever more frequent demand for longer pipes (above 1.5 m) has forced designers to raise the kiln ceiling. This leads, however, to new problems in maintaining the homogeneity of the temperature field. For the new tunnel kiln constructions are no longer sufficient the previously employed low pressure burners, and therefore are being introduced with success for these purposes high-velocity burners with a variable, cyclically repetive flame length. In this manner it is possible to master quite reliably also a kiln space width of around 5 - 6 m.

Considerable progress in the intensification of cooling was made possible by the theoretical deepening of the knowledge about the behaviour of the products and the properties of the stoneware production mixes. If we want to shorten the cooling period and not cause at the same time changes in the body in the form of both macro- and micro-cracks which lead to a reduction of the strength of the products, we must rigidly respect the permissible cooling rates. With modern systems incorporating the blowing in of cold air through laterally mounted nozzles, cooling with effective steel as well as ceramic registers or a water cooling system, with which especially excellent results are obtained, the temperature drop can be brought up to the limit of the maximum, with a sufficient operational safety.

Through the use of new refractory materials in combination with progressive fibrous materials and modern air engineering components can be provided optimum cooling of the kiln shell, the kiln canal, as well as the ceiling. The considerable thermal value of the thus obtained air is being [illegible] in drying plants which leads to an improvement of the heat balance of the kiln and thus the entire plant. With regard to the relatively large volume of the exhausted combustion gases, a number of designers have begun to introduce combustion gas recuperators, through which also this heat can be utilised for drying. Even though the recuperators require higher first costs and are made from high-quality stainless material, their influence onto thermal energy savings can be clearly demonstrated and it it is possible to state that the investment will be returned in the form of fuel savings within 1 - 2 years. But also in future both the kiln designers and users will devote their attention to the reduction of the fuel consumption through the application of high-quality insulating materials for the building of the kilns and kiln cars, with the aim to minimise the heat accumulation during the firing process.

And what are the perspective directions and trends of the technical development of ceramic kilns for the firing of stoneware? In the majority of the ceramic fields can be expected a more radical introduction of single-layer high-speed firing kilns of diverse designs. But in the field of stoneware pipe firing will probably remain unchanged the system of car tunnel kilns, above all for mass production. Only in case of special products, above all of large dimensions, these kilns will be supplemented with modern shuttle kiln or bell kilns.

In stoneware pipes can be observed the trend towards products with the highest possible lengths and an increase of diameters, with the possibility of a rapid and reliable connection of the pipes. The requirements for chemical stoneware are aimed especially onto products that are highly resistant to chemical influences, mechanical destruction and temperature changes. Modern technology is striving for the production of stoneware that is sufficiently sintered and impermeable, with the gradual leaving out of the hithorto quite current glazing. Another direction which is being investigated, is the drying and firing in one machine. But this technology requires production mixes that contain larger quantities of non-plastic components and that must be [illegible]. The fi[illegible] structure and high compaction does [illegible] make possible a reduction of the [illegible] thickness of the products.

A highly progressive and top standard fully automated stoneware production process has been developed in Belgium. This involves automatic glazing onto the raw body by dipping a set of products in an arrangement in accordance with the kiln car dimensions. The pipes are pressed simultaneously with the slit setter ring. This represents one of the substantial advantages of this system, since all the handling of the product is carried out on that ring and not on the pipe body itself as hitherto. The products are then transported into the dryer, for firing and for shipment.

Theoretical papers which clarify scientifically the physical and chemical processes that take place in the stoneware mass during moulding, drying and firing, are aimed at the relation of the properties of this mass to the resultant properties of the product. It still remains to finalize the working mass preparation in such a way that drying and firing can proceed still more rapidly and without the risk of destruction.

2.4. C[illegible] KILNS FOR FIRING CERAMIC TILING MATERIALS

Every ceramic mass is transformed through thermal processing (drying and firing) from a more or less plastic state into a solid state, thus obtaining its permanent shape and at the same time new physical properties. In accordance with the number of firing operations, through which the semi product must pass, before the final product is obtained, we divide ceramic linings which include wall tiles, floor tiles and mosaic, into:

a) double firing - at present the currently employed technology in the production of wall tiles and glazed decorated floor tiles,
b) single firing - a technology which will be used more and more often also in the firing of other ceramic tiles than only sintered raw pavement and glazed mosaic.

In the so called double firing technology for ceramic tiles, each semi-product is fired twice, wherein during the first firing (biscuit firing) the dried semi-products are converted into a form which already has the properties of the body mass of the final product (through [illegible] processing [illegible] change [illegible], porosity, etc.), and has the capability of receiving a glaze. During the second firin (so called glost firing) is fired the applied glaze, possibly also with the decor. Through the second firing which is with wall tiles and decorated floor tiles carried out at a lower temperature (950 - 1100 °C) than for the first firing (1050 - 1150 °C), is obtained the final product.

In the so called single firing technology the semi-product is fired once only - at the present time are being fired in this manner above all raw dense up to sintered floor tiles and/or mosaic. The endeavour to simplify the production technology, especially to reduce the thermal energy consumption necessary for the double firing of ceramics, has lead a number of manufacturers to a transfer to the single firing technology also for wall tiles and decorated floor tiles. It can be said that ways and means have been found for adapting the mass and glazes for the new technology. The results obtained in terms of the quality of the final products are not, however, on such a high level as when the double firing technology is employed, and therefore still a lot of work will have to be done by process engineers in the plants, as well as designers of suitable thermal equipment, in order to attain the required quality in the single firing technology of porous tiles.

What are the requirements onto the semi-products entering the kiln and what are the demands onto placement on the kiln cars ?

One of the first prerequisites for the attainment of high-quality ware is the availability of a well prepared semi-product which is to be thermally processed. With biscuit firing this includes beside a suitably composed mass also the attainment of a thorough homogeneity of the mass with a suitable fineness (in order to prevent the formation of cracks through non-uniform tension in the non-homogeneous body), furthermore accuracy of shape, given by the function of the press tools (straightness, perpendicularity, uniform thickness, etc.), and a uniform drying of the pressings. Also as regards the placement of semi-products, especially in car kilns, there exist great demands onto stability (the height of the stack is [illegible] around 1 m), and these must [illegible] the uniform firing [illegible] cooling. With [illegible] semi-products without mechanical damage accurate in shape and dimensions, provided with a glaze of suitable properties, applied uniformly onto the body. The glaze surface must be absolutely clean. The stack must be stable and the firing furniture must contain no visible defects.

And now some details about the construction of kilns for firing ceramic tiling materials

For the firing of ceramic tiles have been used in the course of a long period of time quite a number of kilns of the most diverse types and design solutions. If we leave out in our enumeration the periodically operated kilns, then one of the first kilns used for biscuit firing of tiles were the car tunnel kilns, directly fired with producer gas. With regard to the then required capacities (around 300 000 m^2 per year), these were kilns with a high stack (above 1.2 m) and 5 columns of tiles placed in the lateral profile of the kiln. The period of passage was, with regard to the impossibility of obtaining a temperature field homogeneity in the lateral kiln profile (1.1 x 1.5 m), relatively long (around 80 hours). The non-uniform temperature distribution in the stack lead to a large dimensional tolerance of the biscuit fired tiles (a kaolinitic body was used), and the biscuit fired tiles were before glazing calibrated by grinding to a unified dimension.

In glaze firing, where above all cleanness of the fused glaze was required, there occurred a very rapid transition from the directly fired kiln to the muffle kiln. There exists a whole series of solutions of the ceramic muffles, into which mouth the individual burners and the combustion gases do not come into contact with the fired ware (heat is transferred only through muffle wall radiation). The oldest are the Dressler muffles which have the shape of the Greek letter "delta". These muffles facilitated by their construction the lateral circulation of the atmosphere in the kiln space. But due to the complexity of form their production was expensive. Therefore a number of designers have tried to simplify the original muffle construction. Some are using adapted Dressler muffles even at the present time, but these [illegible] a [illegible]. The latter has been replaced by normal [illegible] from a refractory material. The muffles of

Anglo-American designers are formed by plates that lean freely against a protruding roof wedge or plate. In their bottom part they are wedged into the kiln masonry. In order to increase the heat transfer surface, the plates are corrugated. The Karabedarf type muffles are of a box type, put together from individual profiled shapes. Through a suitable design solution can be obtained a lateral air circulation which is essential for a better temperature uniformity between the bottom and top part of the stack. The construction possesses, however, a larger number of joints, and thus it exhibits more leaks. The replacement of the shapes in comparison with the plate muffles is much more laborious.

All the muffle kilns exhibit the following disadvantages in comparison with directly fired furnaces:

1) with the same kiln profile and method of placement, the performance is approx. 20 - 30 % lower which is given by the radiation heat transfer capabilities of the ceramic muffles.
2) For the same reason the firing cycle must be prolonged by approx. 30 %.
3) Ceramic muffles and kiln wall linings increase first costs by 20 %.
4) Due to indirect heat transfer, the specific heat consumption is 30 % higher.
5) Muffle kilns have limited possibilities for controlling the temperature field distribution, especially in the preheating zone.
6) Limited possibilities in varying the placement of products, etc.

The disadvantages of indirect firing can, however, be partly overcome by using highly conductive carborundum materials with a minimum wall thickness and a form arrangement for the most effective heat transfer by radiation. By replacement of the material corundum with carborundum can be obtained a fuel consumption reduction of up to 20 %.

Since the medium-profile directly-fired kilns for the biscuit firing of tiles could not guarantee the quality improvement of the fired ware ([illegible] was from the economic [illegible] advantageous), it was also not possible [illegible] for these kilns the present time, and the muffle kilns did not prove by their technical solution their worth for biscuit firing, the process engineers devoted great attention to the preparation of a new working mass which would not display volume unstability (volume changes) due to the influence of differing firing temperatures. Thus was created the calcium-siliceous mass which has the advantage of volumestability, but which is on the other hand considerably sensitive to the cooling rate, especially in the region of the quartz modification transformations.

The designers of ceramic kilns were therefore forced to design car tunnel kilns with smaller profiles, lower stacks (max. 4 columns with a height up to 1 m), with a very well controllable cooling rate. With regard to the requirement of reducing the fuel consumption (a disadvantage of the muffle kilns), was developed in due time a new firing system with the so called semi-muffle.

The principle of semi-muffles is the formation of a whole series of large combustion chambers provided with controllable gates for regulating the inlet of combustion gases either into the kiln car grate or, conversely, immediately below the ceiling roof. Into each chamber leads 1 burner, generally of the low-pressure type, for the combustion of high-grade gaseous fuels (remote gas or natural gas). By a suitable adjustment of the control gates for bringing the combustion gases into the kiln space can be attained the greatest possible temperature uniformity in the kiln which is one of the main conditions for high-quality firing.

Beside car kilns (with a stack height of approx. 1 m) have been designed in the course of the development of kilns for ceramic tiles as well as other ceramic ware, and still are being designed, carless kilns, in which the ware to be fired is not placed onto kiln cars, but onto other transport equipment. These carless kilns make possible a considerable speeding up of the firing cycle, the maximum mechanization and possibly automation of the loading and unloading of the goods, etc. and thus to increase the effectiveness of the entire production.

As has already been stated, there has [illegible] already for a number of years the [illegible] [illegible] technology for [illegible] introduction of fully automatic production lines which include the preparation of raw materials, pressing, drying, biscuit firing, glazing, decorating and glaze firing, or to replace the field of double firing technology by a single firing technology.

The creation of the above conditions depends above all on the working out of high-speed modes for the thermal processing of the mass and from the development of thermal equipment which makes possible the practical implementation of these high-speed modes. It has already been proved today that under production conditions it is possible e.g. to shorten the drying time for tiles to 7 - 9 minutes and the double firing time from 60 - 80 hours to 40 - 50 minutes. Now it is also a fact that for the high-speed modes a selection of masses and glazes must be carried out. A condition here is the working out of new low-temperature and non-shrinking masses with the utilization of components that allow a reduction of the ceramic lining firing capacity, a lowering of its deformation and an improvement of the face surface quality.

Which were the actual reasons that lead to such a concentrated endeavour to reduce the firing period and thus also the period of duration of the entire production cycle? These are reasons not only of an economic, but also a commercial and social nature. Tests of the industrial operation of lines that have been hitherto carried out indicate their considerable advantages in comparison with the old laborious method of production. These advantages include:

1) The production of ceramic wall tiles or floor tiles is fully automated, the manual transshipment has been eliminated, the productivity was increased 2 - 3 times.
2) A marked reduction of the losses through rejects (by up to 20 - 30 %), an increase of the proportion of first quality products, the attainment of exactly the same colour hue, an increase of the stability of the properties of the ceramic products.
3) A reduction of own costs (by more than 20 %) due to penetrating [illegible] savings, the introduction of a high degree of [illegible] of the production process, then as a consequence of the improved efficiency

of the thermal equipment also savings of fuel and energy.

4) Smaller demands for production floor-space which exerts a favourable influence onto the reduction of investment costs.
5) Great and ready adaptivity to changing market demands.

These have been, at least very briefly, some of the reasons leading to the striving for mechanized up to automated production lines; but now let us turn to actual types of kilns which are being developed in the world for the high speed firing of ceramic linings, some of which are obviously suitable also for a different range of products.

Essentially it is possible to speak at the present time about 6 types of modern carless kilns. These differ from one another in the method of ware placement, in the system of its transport in the kiln, and also in the equipment for mechanizing the charging and discharging operations. From the point of view of the technical solution, the following can be said about the individual types on the basis of available information.

1. Roller kilns

The transport of wall tiles or floor tiles is carried out in this kiln type by means of rotating rollers (ceramic or metal). The material to be fired is set on ceramic plates from cordierite or a similar material. The kilns are designed either as gap or multi-channel type, most frequently in the execution 12-16-24 channels. In gap kilns there are generally 2 tracks above one another. The progress of the ware in the rows is either counter-directional or uni-directional. The latter method has prevailed in recent years which has been made possible by the use of natural gas, where the cheaper energy unit, in comparison with electric heating, eliminates the increased thermal consumption in kilns with uni-directional transport. The uni-directional shift also means an advantage for charging the kiln with ware.

As regards the basic technical parameters of these kilns, the following orientational values can be given:

Length of kiln	25 - 45 m
Firing period	2 - 4 hours
Kiln performance	1000 - 1500 m²/day

The above kiln type is quite popular in many parts of the world. A considerable operational disadvantage has, however, been the large consumption of refractory setters which cracked during operation. Therefore ways were sought, how to carry out high-speed firing in roller kilns without setters. Gap kilns of the second generation were developed, in which it is no longer necessary to place the tiles onto setters, but the tiles are moving directly along the roller track. For example the SITI kiln can fire eight 150/1[illegible]0 tiles beside one another. The burners are located below and above the roller track and are grouped into 10 self-contained controllable zones which facilitate a very easy adaptability of the firing curve.

The parameters of the line can be characterized as follows:

Performance	1200 m^2 tiles/day
Firing time for wall tiles	30 minutes
for floor tiles	40 minutes
Specific heat consumption for firing floor tiles	3.7 $MJ.kg^{-1}$
Firing temperature	1040 - 1060 °C

In Czechoslovakia was developed a conveyer line for the one-layer single firing of floor stones, the transport equipment being metal rollers. The line is fully automatic and from the press the floor tiles are conveyed into the gap dryer, then the floor tiles are glazed or provided with a spray decor, and conveyed along the roller track through the kiln. After cooling they are automatically classified and stacked into cartons. The technical parameters are as follows:

Length of kiln	59.2 m
Kiln performance	200 000 m^2/year
Firing cycle	55 minutes
Specific heat consumption	4.1 $MJ.kg^{-1}$
Firing temperature	1060 °C

2) Belt Kilns

The transport of wall tiles or floor tiles is implemented in this type of kilns by an endless screen belt made [illegible] material to be fired is [illegible] directly [illegible] conveyor which moves in comparison with the original roller kilns the advantage of doing away with the refractory setters. In order to maintain a sufficiently long life and operational efficiency, it is, however, essential to observe strictly certain principles, such as:

- low surface loading
- oxidation atmosphere
- prevention of contact with oil and grease

There exists quite a number of kilns of this type and the parameters of one of them can be given as follows:

Capacity	200 000 m^2 tiles/year
Heating	electrical
Length of kiln	30 m
Width of useful space	1800 mm
Height above belt	100 mm
Firing period	40 - 50 minutes
Max. firing temperature	950 - 1050 °C

The heaters are located both above and underneath the conveyer belt. With this type of kilns there occurs a very frequent cracking of the special conveyer, the repair of which requires equipment for welding refractory alloyed materials.

On a somewhat different principle has been developed in Czechoslovakia a line for firing glazed floor tiles. The floor tiles are placed onto refractory wires which move across the kiln that is heated by electric current. To prevent a possible sagging of the support wires, additional rotating rollers are located in the kiln. The advantage of this construction is a very low specific heat consumption, the repair of a broken wire is much easier than in belt kins and is carried out without taking the kiln out of operation.

3. Sled kilns

The transport of the ware through the kiln is realized in this case on multi-layer kiln plates which are provided on the bottom part with two metal stripes (so called sleds) that slide by gliding along small rails both inside and outside the kiln. The loading and unloading of the ware is mechanized (e.g. with the aid of pneumatic equipment). The auxiliary refractory materials (saggers, etc.) are mounted [illegible] or in a portable manner. The dimensions of kilns of this type are limited by the [illegible]-

nitude of the resistance to the sliding movement of the slab (around 30 - 40 m). The heating is generally electric or gas. This kiln type is mostly used also for the firing of household ceramics or porcelain.

4) Car kilns

For the transport of the semi-products to be fired are used small kiln cars which are provided with travel wheels. The setting is of the single-layer type, on the car surface. The cars are naturally provided with a thermal insulating lining which prevents heat losses. The method of setting and handling during loading and unloading are similar as for the sled kilns. With regard to the fact that through the use of wheels the coefficient of friction is reduced, the kiln lengths can be larger than for sled kilns.

An example of this type of kiln are e.g. the "Fakir" kilns. The car, made from rolled sections (see Fig. 3), is provided with ceramic arbors, onto which are placed automatically wall tiles or floor tiles. The car frame is filled with a highly insulating, generally fibrous material which prevents heat losses. The furnace may be heated either electrically or with a gas fuel. Some parameters of a two-channel type "Fakir" car kiln are given below:

Length	60 m
Width of kiln space	2x1.95 m (for 6 tiles)
Max. performance	2 x 600 000 m^2/year
Firing period	45 - 60 minutes
Firing temperature	1100 °C

5) Step kilns

The feed of the fired material is carried out in this type of high-speed firing gap kilns either with the aid of a refractory setter or also without a setter which represents a certain advantage of the step system. The mechanism which provides the feed, is controlled by an excenter, generally hydraulically. In accordance with the information obtained a firing period of 40 - 90 minutes was achieved. Highly favourable results were attained in the heat consumption which approaches the theoretical value. There exist, however, still [illegible] regarding the scaling of the firing [illegible] lift [illegible]. The [illegible] are heated electrically or with natural gas. [illegible] to increase performance, several conveyer zones are connected beside one another.

6) Air cushion kilns

In this type of kilns, the movement of the ceramic to be fired is secured in the kiln space with the aid of an air cushion, along which moves the plate (tray) which carries the products. Messrs. Shelley from England have devoted considerable attention to the development of this type of kilns. They served first of all for decor firing on household porcelain, later was tested the firing of wall tiles onto a temperature of 1160 °C.

Length of kiln	13 m
Heat consumption	3.97 MJ.kg^{-1}
Performance at 30 minute cycle	360 m^2/day

Minimum practical results have so far been obtained with this type of kiln.

One of the concepts of the accelerated firing of ceramic tiles is a compromise between the hitherto current firing and high-speed firing. It is based on the firing of products set at the height of one sagger (approx. 30 cm), whereby up to 16 saggars are placed on a wide kiln car. The firing period is around 3 - 10 hours in accordance with the kiln cross section. The loading and unloading of the products into the saggars and of the saggars onto the cars and from the latter is close to automatic handling. The promoters of this concept are of the opinion that this represents the most practical and the most economical kiln type at the present time. The social problem is eliminated which is associated with running the third shift that is required for fully automated lines. The concept facilitates the automatic „putting" together of the cars in the course of one shift, thus forming a stock-pile, and during the following two shifts they are charged into the kiln. Of advantage is also the possibility of using current mass compositions.

The further development of kilns for firing ceramic tiles will be influenced by the following factors:

- [illegible] for reducing the fuel and energy consumption,
- [illegible] for [illegible] product quality,
- [illegible] demands for the automation of the operating
- [illegible]

- ever growing requirements for mechanizing and automating the loading and unloading operations,
- requirements for minimizing the firing period,
- possibilities of using new technologies - through a gradual transition to single firing also for glazed products,
- possibility of using more progressive refractory materials and insulations for kiln and kiln car linings.

On the basis of the above can be assumed that the further technical development in the field of wall tile and floor stone firing will proceed in the direction towards fully automatic single-layer gap furnaces, inserted into a production line - from the presses right up to shipment.

2.5. CERAMIC KILNS FOR FIRING SANITARY AND HOUSEHOLD CERAMICS

Sanitary ceramic products which include washdown WC's, wash-basins, bidets, urinals, etc. and further supplementary ware (paper-holders, soap-holders, etc.) belong with their dimensions in the field of fine ceramics to the largest. At the same time the thickness of the body lies between 1 and 2 cm. These conditions obviously place considerable demands on their handling, but above all on their faultless firing.

Household ceramics includes such products that have white bodies provided with a glaze or engobe, and are in the majority of cases ornated with an additional decor. We are concerned here with dinner sets, kitchen and household vessels, as well as various decorative extras (small vases, ash-trays, etc.).

All that has been said about the necessity of knowing the fundamental chemical and technological processes that take place in the body in the course of its thermal processing already in the chapter devoted to tiles, holds doubly true here with regard to the dimensions of the sanitary ceramic products.

The firing of sanitary ceramics is a typical example, how through a suitable composition of the casting body and the selection of glazes it is possible to change over from the double firing to the single firing. The original tra[illegible] technology for sanitary ceramics was of the [illegible] firing type. Onto the biscuit fired body was applied [illegible] after drying out, the second firing was done.

The both economically and time demanding technology forced the manufacturers to set up more suitable compositions of the casting body and to find also more suitable casting technologies, and today practically nowhere in the world is carried out double firing of sanitary ceramics. Onto the partly dried cast body is sprayed (either manually or automatically) the glaze, and after it is dry, the semi-product can be thermally processed.

Different is the situation in the <u>firing of household ceramics</u>. Here is still being used in the majority of cases the double firing technology, possibly also the supplementary decor firing. But even in this field of production technology is the endeavour to gradually introduce the single firing technology. Especially in cases, when this is made possible by the raw materials. The attained product surface quality is, however, still poorer and a higher percentage of rejects must be reckoned with, caused by the handling of the green body. The moulding technology itself (by casting or jiggering) resembles rather the technology used in the production of household porcelain. But the differences lie above all in the composition of the body and thus also in the method of thermal processing - oxidating atmosphere, firing temperature up to 1200 °C, thicker body. As has already been mentioned, the sanitary ceramics production technology has undergone in the course of its development a number of changes. The original periodic kilns have after the introduction of continuous kilns been rapidly replaced by the economically and operationally more advantageous car tunnel kilns. With the aim of attaining maximum performances large profile kilns were built - with two and more storeys. They were fired either directly (under the kiln car grate) or indirectly (into muffles) with producer gas which was replaced later on by high grade gas fuels. With regard to the impossibility of balancing the temperature in the lateral kiln profile, the firing periods had to be maintained at approx. 50 - 60 hours. Also the specific heat consumption was relatively high, with regard to the high percentage of the employed firing furniture (storeys and various setters). Especially in muffle kilns this value was around 21 MJ.kg^{-1} of the fired ware.

The endeavour to shorten the firing period, with the possibilities of using a better quality fuel (especially natural gas) and the endeavour to reduce the specific heat consumption have lead ceramic kiln designers to the reduction of the height of the stack and thus to a transition from multi-storied kilns to single-storied kilns. With regard to the requirement to increase the kiln performance, it was necessary to make the kiln wider, since kilns with a length of more than 100 m are from the point of view of the suction-pressure conditions already more difficult to control. A thorough knowledge of the chemical and technological processes which take place during the thermal processing of sanitary ceramics, and the perfect technical mastering of the firing process, have enabled the designers of the thermal equipment to decrease gradually the firing period which represents in today's car tunnel kilns around 10 - 15 hours.

Where the quality of the liquid fuel (fuel oil) prevents the use of direct heating (influence of sulphur and contamination in the fuel), it is necessary to fire sanitary ceramics in muffle kilns. The design solution of the latter corresponds essentially to what has been communicated in the chapter devoted to tiles. The disadvantage of muffle kilns lies in the difficulties associated with the shaping of the firing curve in the preheating zone, in the limited capacity of the kiln (given by the width of the kiln space and the thermal performance of the muffles), in every case the heat consumption is higher in comparison with directly fired kilns, and the investment costs are higher due to refractory materials that are required for the manufacture of the ceramic muffles.

Beside muffle and directly-fired car kilns are appearing in many places kilns with semi-muffles, whose description, advantages and disadvantages have been presented in the chapter about tiles. A mutual comparison of the technical and economic parameters of all 3 car kiln types is given in Table 2.

Beside car kilns fired with technical fuels, can be used for firing sanitary ceramic products also electrically heated kilns. These are suitable above all in locations with cheap electric power. The hot zone in these kilns is equipped with heaters - either spirals or suspension elements. The Swedish company Kanthal, one of the world's leading manufacturers of heating elements, is supplying them in the form of wire or spirals (so-called Kanthal wire) or in the form of suspension elements - [illegible] ([illegible] Kanthals).

Table 2

		directly fired	semi-muffle	muffle
Length of kiln	[m]	100	100	100
Width of kiln space	[m]	2.1	1.6	1.4
Performance	[t/year]	7800	4500	3300
Firing cycle	[h]	12	16	28
Specific heat consumption	[$MJ.kg^{-1}$]	8.19	9.6	14.6

A great advantage of electric power is the easy and accurate regulation of the firing curve in the hot zone and the clean operation. A disadvantage is the limited kiln performance given by the kiln space width, because the heat in transferred only through radiation, so that the kiln space width can not be too large. The introduction of any form of air movement in the kiln (in order to attain heat transfer through convection) leads to a steep rise of the electric power consumption. Further disadvantages are the high first costs (especially for equipping the hot zone of the kiln), a somewhat lower life (especially with a permanent and high current loading) and the electric power costs. As regards the air engineering equipment of the kiln, the electric kiln is simpler in comparison with fuel fired kilns.

The strive for increasing the efficiency and speeding up the technological process for the firing of sanitary ceramics is forcing designers of ceramic equipment to develop various types of automated lines, from the preparation of the body, via pouring plants, automatic glazing lines, high-speed firing kilns, right up to automatic shipping lines. The further development of car tunnel kilns which form part of production lines, is, however, hindered by the great difficulties associated with the automation of the loading of the ware onto and its unloading from the kiln cars. Therefore attention has been paid in the further development of sanitary ceramics production to those kilns that make this automation possible.

At the present time the leading position in the field of [illegible] sanitary ceramics products with full automation of the [illegible] is [illegible] e.g. by the English company Gibbons [illegible] line.

[illegible] is a [illegible] tunnel plate kiln of the roller type, heated either electrically or gas fired, to which is linked a large bin for glazed semi-products and a bin for the fired ware. The entire operation of the equipment is computer controlled. The dried glazed semi-product is removed under system program control by automatic equipment from the large capacity bin, set by the charging equipment onto the roller track and through impulses from a photoelectric cell placed into the high-speed firing kiln. The tunnel kiln which is always destined for firing one type of product only, is at its beginning and end provided with a roller track, in the hot zone the plates (with the dimensions 930 x 559 x 32 mm) with the set dried semi-products exert a sliding movement along a layer of fireclay balls. The kiln is heated with Kanthal or Superkanthal heating spirals, or gas burners could be used. The cooling zone is equipped with a multi-stage cooling system which provides an absolutely troublefree operation with perfectly cooled ware. After the fired product runs out from the kiln, it is automatically inserted into the large-capacity shipping bin. The refractory ceramic plate is returned back into the production process. The tunnel kiln is fully automatic in its operation and requires no attendance. The monitoring system sends fault messages into the central control room, should the production flow be interrupted for a period longer than 2 seconds. If the rating of the bin is sufficiently large, the kiln can be operated continuously even over the weekend. The kiln construction can be assembled from individual modules which have a length of approx. 2 m. Should the technology require this, the kiln can be lengthened or shortened at any point. The outer shell of the kiln is sheet-metal clad.

Some parameters of the "Viking" tunnel kiln:

Kiln performance	124 plates/24 h=1300 t/y
Length of kiln	35.36 m
Width of channel	0.834 m
Height of channel	0.711 m
Firing cycle	12 hours
Specific heat consumption	6.98 MJ.kg^{-1}

A considerable disadvantage of this in other respects perfect [illegible] lies in the fact that it is [illegible] for [illegible] the kiln [illegible] be fired only one type [illegible], in another one [illegible], etc.

supplementary equipment and special products must be fired in separate kilns (mostly in shuttle or bell kilns).

Quite a number of constructions similar to the type Viking line have been designed, and their technical parameters are frequently quite different. But as long as with those kilns is arranged a large-capacity bin, controlled by an automated system, the first costs for the entire line are quite considerable; due to this they are not being used very widely in the ceramic industry.

Recently have been carried out in certain types of sanitary ceramic products for economical reasons so called <u>correction firings</u>. Should after the firing in the tunnel kiln be found on the product defects that can be repaired (unglazed points, bad retouching, etc.), the product is repaired and again subjected to the so called correction firing. For these correction firings are mostly used bell or shuttle kilns, in which the required firing curve can be obtained (different from the current firing in the tunnel kiln). In this way can be repaired defects on products which otherwise could not have been sold and meant a loss of profits.

<u>Household ceramic products</u>, as has already been mentioned, are generally fired using the double firing technology. For both biscuit firing and glost firing analogical kilns can be employed which only differ from one another in the firing temperature. In certain cases, when a highly suitable composition of the body and the glaze has been selected, it is possible to fire in one kiln on one car both product types. The semi-products are set onto the kiln cars either into combs (for porous bodies) or into saggars (for semi-sintered bodies). The ratio of the weight of the ware and the firing furniture influences the fuel consumption in the kiln, and thus also the overall economics of the plant. Therefore quite a number of manufacturers of ceramic firing furniture are striving for the smallest possible weights and dimensions with a maximum durability of the material.

The car tunnel kilns are with regard to the required performances designed with a small and medium profile, fired either directly or indirectly (with liquid fuels). With advantage are used electrically heated kilns in areas where sufficient supplies of electricity are available. Beside car kilns can for the firing of household ceramics naturally be employed also further earlier kilns (e.g. sled, plate, roller types, etc.). The construction of the kiln must guarantee high-quality firing, uniform along the entire profile of the kiln space, with a well molten out glaze, without mechanical damage, cracks from the cooling zone and/or deformations of the products.

2.6. CERAMIC KILNS FOR FIRING HOUSEHOLD PORCELAIN AND ELECTRO-PORCELAIN

Not so many years ago in porcelain plants was available only the periodically operated round kiln. Demands for the improvement of the working environment, for the reduction of manual work, the acceleration, quality and economy improvements of the firing lead after the Second World War to the general expansion of continuously operated kilns - above all car tunnel kilns.

At the present time not even these facilities can fully cope with the requirements that are necessary for the introduction into production lines with the automatic ware loading and unloading in a continuous production flow. But the car tunnel kilns remain, and probably will remain for still a long time to come, due to their universality towards the changing range of products and the demands of the production technology the most frequently employed firing equipment.

The firing of household porcelain is a typical example of the double firing technology, i.e. during the biscuit firing (at 800 - 900 °C) the dried out semi-product is strengthened to such an extent that it is capable of accepting the glaze, without being deformed upon further handling. Only during the second, so called glost firing, is obtained at a temperature of 1390 - 1410 °C the sintered whiteware body which has its characteristic properties (transparency of the thin-walled body, white fracture, low absorption capacity).

The firing of electro-porcelain is carried out for the majority of products by the single firing technology. This is given by the shape and thickness of the body and also by the method of moulding. If the household porcelain is characteriz-[illegible] thin-walled body, moulded by [illegible] casting or jiggering, [illegible] the body [illegible] thick-walled, so that glazing can be done di-[illegible], without [illegible] of deformations.

The porcelain firing technology is one of the most exacting ones in the field of ceramics firing, and is essentially the same for both types of products. During the glost firing of porcelain must namely be added to the current requirements, such as the maintenance of the temperature curve and the uniform temperature distribution in the entire cross section of the kiln, still the requirement for the accurate maintenance of the composition of the atmosphere. From temperatures of approx. 1050 up to approx. 1250 °C must be maintained a reducing atmosphere, and towards the end of the firing process must be maintained a neutral atmosphere.

The maintenance of the appropriate atmospheres is a condition for attaining the required whiteness and transparency of the porcelain. In the oxidation zone must burn out perfectly the organic admixtures as well as the carbon from the fuel, in the reduction zone must be reduced the ferric oxide Fe_2O_3 which would adversely dye the porcelain yellow, to FeO. The change from an oxidating atmosphere to a reducing one of the reducing one to the neutral must be carried out within the shortest possible section, and the division between the atmospheres must not "migrate" with regard to the temperatures. The practical methods for solving this technological requirement will be discussed later.

A further technological requirement concerns the exhausting of the combustion gases behind the hot zone; these gases could namely due to a positive pressure flow into the cooling zone. This measure prevents the reoxidation of FeO to Fe_2O_3 (the so called formation of "positive pressure yellow" and a milky deposit on the glaze - cloudy glaze). The design solution will be described later.

Besides those two firing operations, the household porcelain is in most cases provided with an above-glaze decor, fired in general in single-purpose small-profile kilns with a continuous operations. They have to satisfy above all the following requirements:

- clean operation,
- attainment and maintenance of constant temperature conditions given by the type of decor,
- [illegible]
- [illegible] with minimal losses,
- [illegible]

As has already been stated in the introductory part of this chapter, the original round kilns have been replaced by car tunnel kilns which have made possible an improvement of the working environment, have reduced manual labour and above all speeded up and increased the economy of the technological process of thermal processing.

Even though the first tunnel kiln constructions satisfied the technological requirements better than the periodic kilns, their attendance was with regard to the required quality of the products still considerably exacting. Especially the fluctuating quality of the producer gas exerted a negative influence onto the firing quality and necessitated an almost incessant inspection of the firing mode. In due course producer gas was replaced with high grade gas fuels (town gas, natural gas or propane-butane), the tunnel kilns were being equipped with automatic control facilities, the undesirable heat value fluctuation of town gas was eliminated by the introduction of the automatic regulation of the so called Wobbe number, i.e. the maintenance of a constant ratio of the heat value of the fuel and its density. Concurrently with the growth of knowledge about the processes in the body it was possible to begin with the gradual shortening of the firing period, and through a suitable selection of lining materials and insulations, with the utilization of new structural elements, the specific heat consumption has been reduced.

The only still unsolved question concerns the problem of mechanizing and possibly automating the loading and unloading of the ware which is very laborious for relatively small ware. This requirement finally lead to the development of high-speed firing kilns generally of the carless type which have partly been mentioned already when discussing the firing of ceramic linings. But we shall still come back to certain details.

But since the car kilns exhibit a number of benefits, above all their universality, their relatively large specific performance and reliability of operation, they will still for a long time compete with single-passage kilns which form part of production lines.

[illegible] technical [illegible] of the individual kiln types for the fir- [illegible] and electro-porcelain.

The <u>tunnel kiln for biscuit firing of household porcelain</u> represents with its technical solution and equipment a generally non-exacting piece of equipment. The crux of the matter is, as has already been pointed out previously, that the dried body is uniformly thermally processed within the shortest possible time, so that it attains a sufficient strength for further handling and is capable of accepting a glaze.

The semi-products are set into storeys, with the aim of a maximum utilization of the given space, plates can be placed one on top of the other and stacks can be formed out of them, the height of which is adapted to the strength of the dry body. The advance in the kiln is generally provided by a hydraulic advancer with a continuous feed. The preheating zone is for the intensification of the heat transfer into the dry semi-products and for the maximum balancing of the temperature field in the lateral profile of the kiln provided with modern burners that create a larger turbulence of the combustion gases and are supplemented with air jets, located in a checkerboard manner underneath the roof. This arrangement provides a lateral circulation of the atmosphere in the kiln space and a perfect balancing of the temperatures. The hot zone is often equipped with side burners for the combustion of gaseous fuels. Should there be only liquid fuel available (or when fear of contaminating the body surface exists), indirect heating should be selected by installing some type of muffle or semi-muffle. Where electric power is cheap, can be employed with success some kiln type with electric heaters (silite kilns, kilns with resistance heaters, etc.). Into the cooling zone at the end of the kiln is blown cold air. Warm air from the cooling zone is generally utilized for the purposes of drying.

Apart from car kilns can be used for biscuit firing of household porcelain also other types, mostly high-speed firing executions which are suitable for insertion into the technological line. There exists quite a number of conveyer systems, and since we are concerned with low temperatures, it is possible to utilize also belt kilns, roller kilns with metal rollers, etc. Their design solutions, advantages and disadvantages have [illegible] (in the chapter devoted to [illegible]).

[illegible]

cessing technology - to maintain the sharply terminated transitions between the individual sections of the hot zone - one of the most complicated pieces of equipment in the field of thermal equipment for ceramics.

- 1st zone - oxidation up to 1050 °C (excess air approx. n=1.8)
- 2nd zone - reduction 1050 - 1280 °C (excess air approx. n=0.9)
- 3rd zone - neutral 1280 - 1410 °C (excess air approx. n=1.1)

Each zone must have its separately controlled inlet of fuel and combustion air. The fuel is generally conveyed in a steel pipeline which is equipped with a number of measuring, recording and control instruments. Also the combustion air which is supplied through a sheet-metal pipeline or ceramic ducts in the kiln casing, must be continuously metered, controlled and maintained in constant ratios with the fuel.

The change from a reduction atmosphere to an oxidizing one (considered in the direction of the flow of the combustion gases - that against the direction of movement of the kiln cars) must be carried out in the shortest possible section, and the division between the atmospheres must not change with regard to the temperatures. Essentially the following three methods of solution can be employed:

a) specially adapted burners which supply excess air along the the entire circumference of the kiln space,
b) or in the division zone a separate fan supplies air along the entire circumference,
c) an interesting solution of the division of the atmospheres is contained in a Czechoslovak patent, in accordance with which the reducing gases are exhausted from the kiln space by an injector and transferred into the burners in the oxidation zone, where they finish burning. This method is, however, quite exacting from the point of view of both the construction and operation, and is employed more for the firing of electro-porcelain.

The atmospheres are maintained by a perfect, preferably automatic control of the draft conditions in the preheating zone and the pressure conditions in the cooling zone.

The cooling zone is in the majority of the tunnel kilns [illegible] of several individually controllable sections. [illegible] [illegible] the cooling zone is generally [illegible] [illegible] [illegible] to the [illegible] the hot zone be returned into the cooling zone and endanger the quality of the products. In the region of the first cooling registers can be utilized the so called pyroplastic state - an insensitivity towards sudden temperature changes - and cold air can be blown into the kiln ("shock cooling"). Through this redesign it is possible to shorten the cooling period and thus also the length of the cooling zone. The cooling zone of the kiln is mostly equipped with ceramic and steel recuperators for indirect cooling. At the end of the kiln is an exit curtain which prevents the entry of false air into the kiln space.

The kiln must, especially in the hot zone, be made from high-quality refractories and thermally insulated. Also the kiln car lining, incl. the multi-stories superstructure and the grate, is executed from several layers of high-quality refractory and insulating materials in order to prevent the escape of heat into the gangway underneath the kiln.

With regard to the fact that in the firing of porcelain a reducing atmosphere must be maintained, it is not possible to utilize in these kilns electric heating or indirect heating into a muffle. As long as for the firing of porcelain only liquid fuel is available, it is necessary to sagger all the ware and to take into consideration that the quality of the resultant product will always be lower.

With regard to the exacting firing technology and the high demands onto the quality of the fired ware, the car tunnel kilns for glost firing are equipped with the following basic measuring and control instruments for:

- the automatic maintenance of the adjusted draft-pressure conditions,
- the automatic temperature control in the individual zones,
- the automatic maintenance of the air-fuel ratio control in the individual zones,
- the automatic maintenance of constant pressure in the fuel supply,
- the measurement of the fuel and combustion air quantity in the individual zones,
- the measurement and recording of the oil pressure in the hydraulic [illegible] (inspection of the regular movement of the kiln cars and their troublefree passage through the kiln),
- [illegible] of electric power supply interruption, pressure drop [illegible] draft drop, etc. [illegible] kiln automatic safety closing devices,
- [illegible] kiln atmosphere in the indi-

vidual zones are installed automatically and continuously operating gas analysers.

Beside the classical car tunnel kilns which can be assessed as universal for the firing of ceramic goods of any type, are being used more and more frequently the so called <u>single-burner single-layer high-speed firing kilns</u> which are suitable for the inclusion into automatic production lines. One of them is the sled kiln.

The glazed products are placed either manually or by an automatic device in one layer onto highly insulating refractory plates. The plates are brought from the return track by the lateral traverser in front of the gap kiln entrance. The feed of the plates in the kiln is provided by the hydraulic advancer. The plates which are provided in their bottom part with steel belts (skids), skid through the kiln along two steel girders. In order to make sliding easier, the metal parts are additionally lubricated by a special high-temperature resistant grease. The kiln is equipped in the hot zone from both sides with high-velocity burners. The cooling is very intensive, without influencing negatively the quality of the ware. After firing, the plate with the ware is transferred by the lateral traverser onto the return track, where the ware is removed either manually or mechanically.

<u>Tunnel kilns for the firing of electro-porcelain</u> start out on the technological side from analogical constructions as for the gloss[1] firing of household porcelain. With regard to the considerably different production range (from small electrical engineering components right up to giant insulators), also the dimensions of the firing facilities differ. For a small range of products is used to advantage some type of a small-profile car or carless kiln which is suitable for inclusion into a technological line. Somewhat different is the situation in the field of high-voltage and extra high-voltage insulators which are fired due to their considerable mass exclusively in tunnel kilns or possibly in periodic kilns. The kiln space dimensions are naturally adapted to the dimensions of the fired range of products. With a higher kiln space arise automatically also higher demands for the balancing of the temperature in the entire profile and the maintenance of the required distribution of the atmospheres in the three

tenns. With regard to the much greater thicknesses of the body in comparison with household porcelain, the attainment of a reduction is of a paramount importance. Also the firing periods are differentiated in accordance with the thickness of the body and represent for some products up to around 100 hours.

Decor firing kilns for household porcelain

Since household porcelain is in the majority of cases additionally provided with a suitable decor (given by fashion and the taste of the user), also this type of kilns will be mentioned briefly.

With regard to the high demands onto the purity of the fired ware are employed for firing above-glaze decor in the first place small-profile high-speed firing tunnel kilns, generally carless, heated with electricity and gas, respectively. Since we are here concerned with oxidation firing, also certain types of oil fired indirectly heated (muffle) kilns can be employed.

In accordance with the employed methods of transportation can be differentiated step, belt, sled, roller, car, etc. kilns. Their constructions have already been discussed in the chapter dealing with the firing of tiles. The requirements for their operation are as follows: troublefree, clean operation, observance and maintenance of the required temperature in the entire profile, maximum performance with minimum production losses, and optimum economy of operation.

With advantage are being employed for the firing of above-glaze decor basket kilns. The ware to be fired is placed into baskets which are made from refractory steel. The baskets move along a roller track, electric heating is generally used.

A special type of decor is the decoration with cobalt. With regard to the fact that cobalt must be fired at temperatures above 1300 °C, either car or sled kilns are used for firing.

And now in conclusion a few words about the perspective directions and trends of the technical development of kilns for the firing of household and electro-porcelain.

The world-wide endeavour for the creation of conditions for the introduction of automated lines will lead designers of thermal equipment to the development of more and more suitable constructions of single-purpose high-speed firing gap kilns of the car or endless types. With regard to the endeavour to reduce in the thermal equipment the consumption of fuels and power, to minimize the firing period, are being carried out at some research stations experiments with the single firing of household porcelain. This was preceded by a thorough preparation and selection of bodies and glazes, a new moulding and glazing technology onto a relatively thin body of the green semi-product was developed. But the results are not comparable with the classical double firing technology, and therefore this production is for the time being applied to thick-walled products of the "hotel" type. Technology is, however, steadily pressing forward, and perhaps one day it will be possible to single-fire also high-quality thin-walled porcelain.

2.7. [illegible] KILNS FOR FIRING SPECIAL PRODUCTS

This field of ceramics includes oxideless and oxide ceramics, ferro-ceramics, etc. With regard to the special requirements for their thermal processing and with regard to the very small production capacities, will be empoyed for the firing of these products above all periodical kilns of an atypical execution, adapted to the fired range of ware - chamber, bell, box and possibly other kilns, heated with high-grade fuels or electrically. To this group belong e.g. ladle kilns for the firing of frits, cylindrical kilns for firing pyrostat tubes, etc.

3. C E R A M I C   D R Y E R S

Ceramic dryers are the second largest consumer of thermal energy, and therefore rightly attention should be devoted to the economy of their operation. Before we are going to discuss certain dryers, it would be expedient to carry out the basic classification of the ceramic dryers.

Classification of ceramic dryers

1) According to the employed drying medium:
   - hot air
   - combustion gases
   - with preheated steam
   - other types
2) According to the operating pressure:
   - positive pressure
   - [illegible]

- negative pressure
- vacuum

3) According to heat transmission for drying the material

- convection
- radiation
- contact
- dielectric
- electric resistance

4) according to the nature of operation

- periodic
- continuous - counter-current
  - co-current
  - cross-current
  - reversing
  - impact
  - rhythmic
  - other types

5) According to the drying medium flow around the dried material

- circulating
- with longitudinal flow
- with lateral flow
- impact
- blow through

6) According to the movement of the dried material

- at rest
- grate
- chamber
- box
- movement due to the influence of the kinetic energy of the drying medium
  - flow
  - eddy current
  - fluid bed
  - spray
- movement on the conveying equipment
  - car
  - belt
  - roller
  - suspension
  - wire or on belts
  - pallet
  - other types

- mechanical movement
  - drum
  - plate
  - cylindrical
  - vibrating
  - other types

As can readily be seen, there exists quite a number of drying installation solutions for drying both ceramic bodies and products, and for the drying of by-products in the manufacturing process (e.g. plaster moulds, etc.), respectively. In my paper I am going to mention only some typical examples.

3.1. DRYERS FOR DRYING HEAVY-CLAY PRODUCTS

The most advantageous facilities for drying brick and refractory products are drive-through, continuously operated dryers, in which it is possible to introduce full mechanization of both transport and the drying mode and that utilize the heat from the cooling zone of the tunnel kiln and also the heat from the waste gas recuperators, respectively. The pressed semi-products can be set by automatic devices into metal storeys which are inserted by an automatic system, into the drying channel. Continuous transport in the drying channel can be provided e.g. by a chain conveyer, hydraulic advancer, drive roller bed, etc. After removal from the dryer, the dried semi-products are automatically taken out from the storeys and set onto the kiln cars. In order to save floor space, the dryers are built as multi-channel facilities, with one common return track (see Fig. 1). The actual drying is provided by the so called "rotomixers" which move along the passing metal storeys and blow onto the semi-products warm air exhausted from the kiln. According to requirements, the warm and dry air is mixed with cold and moist air, in order to maintain the necessary drying curve. The entire drying process can for the mass production of one type of product range be fully automated and controlled by measuring instruments from the control panel.

For your information is presented Table [illegible] which expresses the influence of the dryer construction onto the specific heat consumption.

[illegible] is being manufactured a wide range of products as to shape, dimensions and weights, it is necessary to choose the less progressive chamber dryers, in which must be taken into account longer drying periods (3 - 4 times), a higher specific heat consumption for drying out the water (2 - 3 times), and smaller possibilities of automating the drying cycle.

Table 3

Type of dryer	Specific heat consumption for evaporating 1 kg water [MJ]
Chamber with steam registers	13.0
Channel with recirculation fans	6.7
Progressive channel with rotomixers	3.8

Even though it would seem that the cylindrical [shape] with both internal and external surfaces of the stoneware pipes will facilitate an easy removal of water vapour from the body, under practical conditions it is not so. For the drying of stoneware pipes are mostly used drive-through drying installations with a vertical guidance of the drying medium, in combination with rotomixers. This technology makes possible a shortening of the drying period in comparison with the older chamber dryer types to 1/2 - 1/3.

3.2. DRYERS FOR DRYING FINE CERAMIC PRODUCTS

The permanent boom in the manufacture of ceramic [illegible] leads to maximum endeavours concerning the intensification and automation of the entire production. For the finish drying operation, the thin-walled semi-product with small dimensions, with a low moisture content, represents an ideal example for the inclusion of single-layer dryers with surface set ware onto a gas-permeable belt, roller bed or a similar conveyor. Where classic car kilns, with the stacking of products into columns, are used, a much longer drying period must naturally be reckoned with (see Table 4). The necessary heat can be taken from the cooling zone of the tunnel kilns, or from the combustion gas recuperators or separate combustion chambers.

Sanitary ceramics products have in the past been dried mainly in open spaces. In the endeavour to go over from the manually existing production to fully automated production lines, prerequisites were given for the combining of continuously operated tunnel dryers with air or suspension chain conveyors. The heat required for drying is obtained either from the cooling zone of the kiln or from separate heat exchangers or liquid fuel fired combustion chambers. The drying period with a directed air stream and with the utilization of modern high speed drying systems can for sanitary ceramics be reduced to approx. 8 - 10 hours.

Table 4

Type of dryer	Drying period [hours]
Car tunnel dryer	46
Roller high-speed dryer	0.5

Household porcelain and electro-porcelain are mainly being dried in era dryers which with their parameters fully satisfy the requirements of the manufacturers. If they are supplemented with automatic loaders and unloaders, possibly with belt dryers, preconditions are given for their inclusion into fully automatic production lines: moulding - drying - firing. The drying period naturally depends upon the thickness of the body, the type of raw material, the moulding system and also upon the actual shape of the semi-product.

3.3. SPECIAL METHODS OF DRYING IN THE CERAMIC INDUSTRY

Due to the depletion of high-quality gypsum stones and thus an increase in their price, certain foreign companies (Morton, Roderick, etc.) have begun to take an interest in the problem of drying gypsum plaster moulds, with the aim of attaining a more progressive drying mode. In the classical drying system, the optimum drying medium temperature is around 50 - 55 °C. When this temperature is exceeded, there occurs a rapid destruction of the plaster mould through cracking. It has been proved by research work that with an organized drying mode, i.e. with a certain moisture content and maintenance of a temperature increase in the plaster mould, it is possible to use hot air with a temperature even above 100 °C, without destroying the plaster mould. The research results have been successfully applied under practical conditions, and the obtained plaster savings for the ceramic ware manufacturers are considerable. It is understandable that each type of gypsum plaster requires its own mode of drying which must, however, be accurately determined in the laboratory and [illegible] in practice.

Due to the requirement for increasing productivity and thus automating the production process, we are coming across very frequently in the preparation of the moulding mass in the ceramic industry the so called <u>spray dryers</u>. Spray dryers have found already some time ago considerable applications in the food and chemical industries. The favourable experiences were applied in the preparation of masses in the tile plants and also in the dressing of clays in other branches of the ceramic industry. By including the spray dryer in the production line was increased the hygiene of the operation and a practically unlimited throughput was obtained. The resultant product has the required constant grain size and moisture content and fills prefectly the press mould. The drying principle is as follows: The material is in a pumpable state conveyed to the given spraying equipment, where it is atomized in the form of a fine mist into to hot drying medium stream. Due to the large contact area of the droplet cloud and the drying medium, there occurs a very intensive and rapid evaporation of the moisture from the atomized material. The obtained product is a fine powder. Atomization can be carried out either through atomizing disks or pressure nozzles. Both methods have their advantages and disadvantages. With atomizing disks the atomization is more perfect and the operation is highly flexible, but the powder has a much finer grain size distribution and the operating costs are higher than for pressure nozzles. The latter give particles of larger dimensions, but the atomization is not so uniform. A source of trouble are generally the pressure pumps. In both cases the erosive effects of the ceramic suspension must be reckoned with. Therefore the nozzles or disks are made from cemented carbides, tungsten carbide, etc. As the drying medium are used combustion gases from a gas or oil fired furnace. The temperature is generally approx. 450 - 550 °C.

The <u>belt dryer</u> represents a progressive and high-performance facility for drying ceramic raw materials. It surpasses all the hitherto employed channel dryers by a substantially better utilization of the heat. It guarantees a constant moisture content of the dried ware with a reliable, hygienic and [illegible] [illegible] drying is used either [illegible] air or a mixture of air and combustion gases from [illegible]

The drying installation consists of several drying chambers (in accordance with the required throughput). On the ceiling are located recirculation fans for intensifying the drying process. The material in the form of noodles passes through the dryer on three corrosion resistent wire belts, the speed of which can be continuously controlled in accordance with the type of the dried material. The incoming moisture content can be up to 30 %, the outgoing moisture content is adjustable between 1 and 18 %. The heat consumption for the evaporation of 1 kg water is 4.2 MJ. The performance of the unit is 1 - 18 t/h.

The drying hammer mill is designed for the simultaneous drying and grinding of coarse, low abrasive ceramic materials (various types of clays). The output of the grinding mill, the fineness of grind, as well as the degree of drying, depend on the given material and the setting of the classifier. The drying medium is obtained from a separate combustion chamber. The incoming grain size is up to 50 mm, the outgoing up to 0.09, the incoming moisture content up to 30 %, the outgoing up to 5 %. The temperature of the drying medium can be up to 500 °C.

4. C O N C L U S I O N

In my paper I wanted to concentrate above all onto the progressive thermal facilities in the ceramic industry, with the aim to mutually compare the advantages and disadvantages of the design solutions and their share in the consumption of fuels and power. With regard to the very wide complex of problems of thermal processing in ceramics, I could only deal with the most essential items and select out of a wide range of kilns and dryers only the most widely used types. Nevertheless I belive that the paper has made possible to acquire at least a global summary of the contemporary thermal technique in the ceramic industry.

Firing in the ceramic industry will also in future remain the most costly part of the production process. Through the tenacious of purpose cooperation of specialists for the building of ceramic kilns and dryers, the manufacturers of [illegible] and ceramic process engineers who are engaged in the [illegible] of [illegible] materials, it will be possible to attain a still higher [illegible] in the field of thermal procoating of ceramic products. And therefore it is necessary to give also in future the greatest possible support to technical developments in the manufacture of ceramics. The utility values of the ceramic products rightly deserve it.

5. LIST OF ENCLOSURES

Fig.1 - Air distribution flow sheet between the tunnel kiln and the channel dryer

Fig.2 - Arrangement of a two-channel counter-current tunnel kiln

Fig.3 - Sketch of a single-layer setting onto the type "Fakir" kiln car

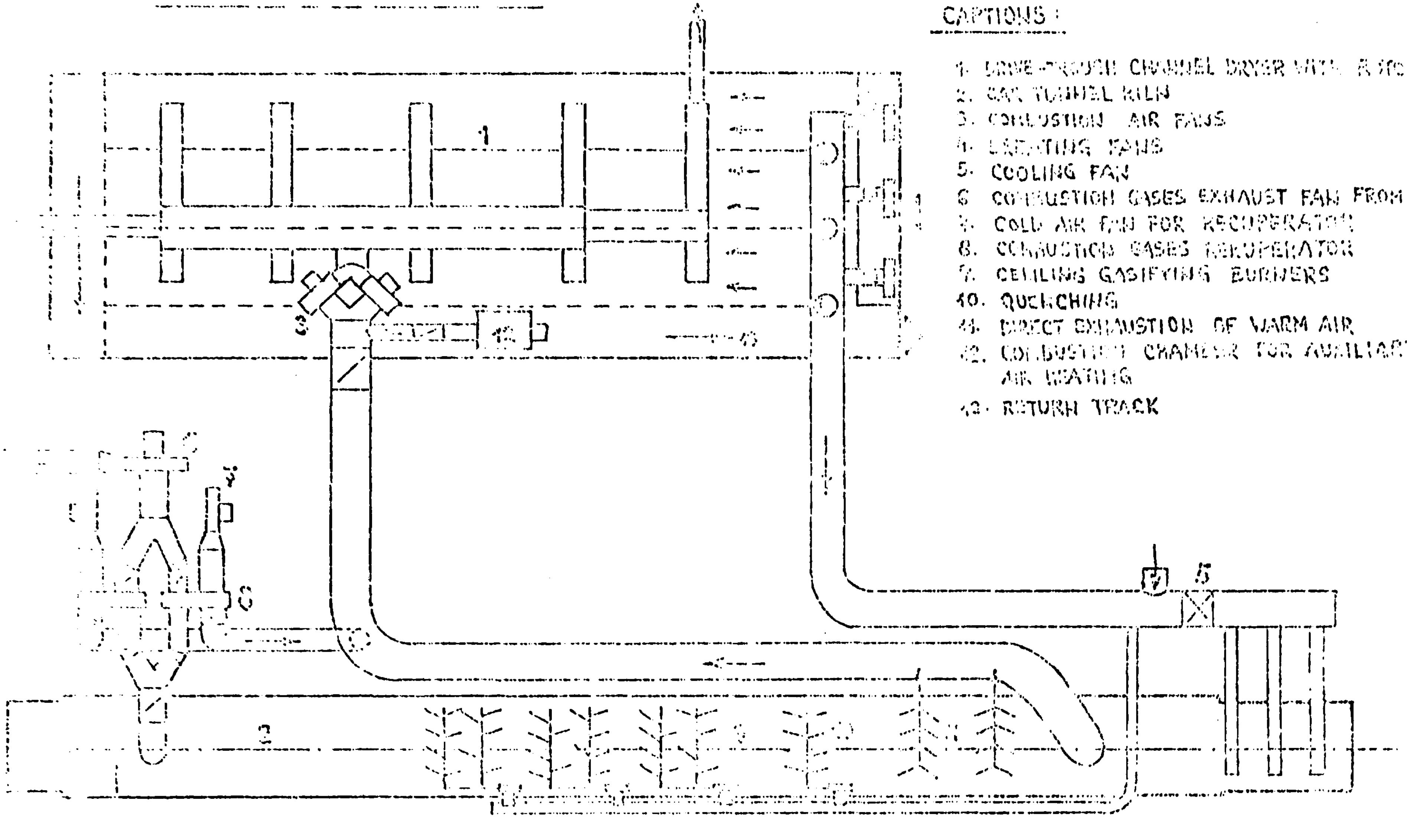
Fig.4 - Optimum firing curve for overlying clays

Fig.5 - Sketch of high-speed dryer for household porcelain products with transshipping equipment

Fig.6 - Flow sheet of the Dorst spray dryer

Fig.7 - Flow sheet of a three-belt kaolin dryer

Fig. 8 - Diagram of the heat distribution and consuption inside the tunnel kiln

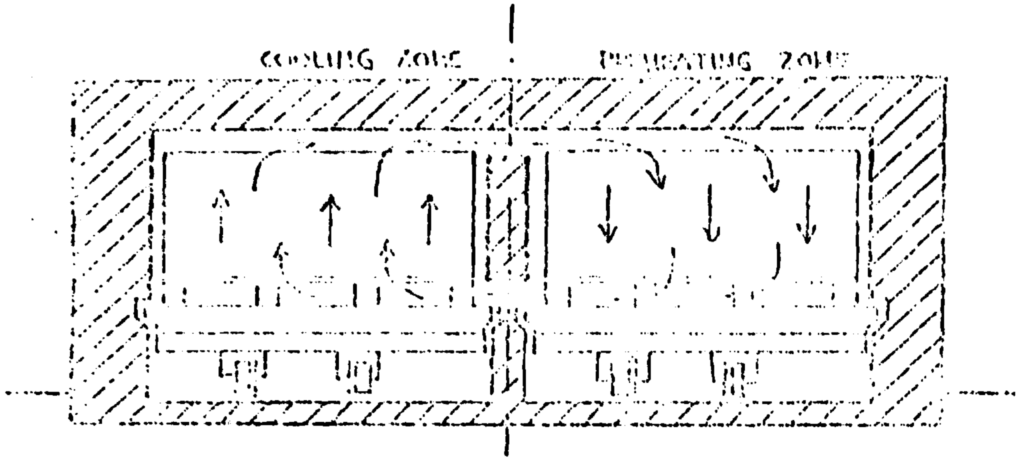


CAPTIONS :

1. DRIVE-THROUGH CHANNEL DRYER WITH [illegible]
2. CAR TUNNEL KILN
3. COMBUSTION AIR FANS
4. [illegible] FANS
5. COOLING FAN
6. COMBUSTION GASES EXHAUST FAN FROM KILN
7. COLD AIR FAN FOR RECUPERATOR
8. COMBUSTION GASES RECUPERATOR
9. CEILING GASIFYING BURNERS
10. QUENCHING
11. DIRECT EXHAUSTION OF WARM AIR
12. COMBUSTION CHAMBER FOR AUXILIARY AIR HEATING
13. RETURN TRACK

[illegible]

LATERAL SECTION THROUGH KILN



LONGITUDINAL SECTION THROUGH KILN

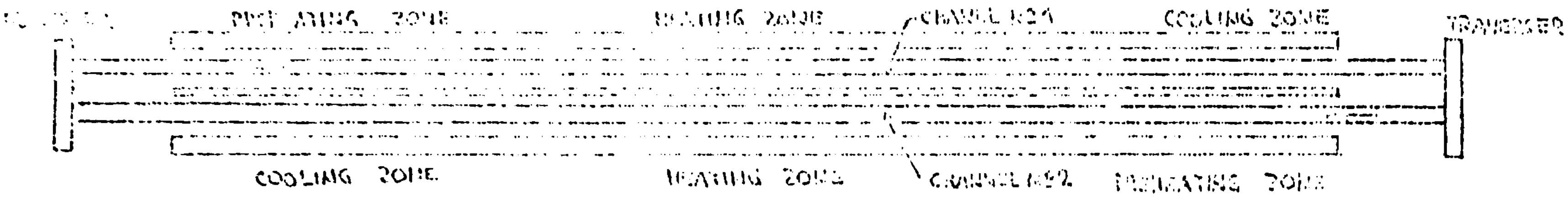


Fig. 3 : SKETCH OF SINGLE-LAYER SETTING ONTO THE TYPE [illegible] KILN CAR

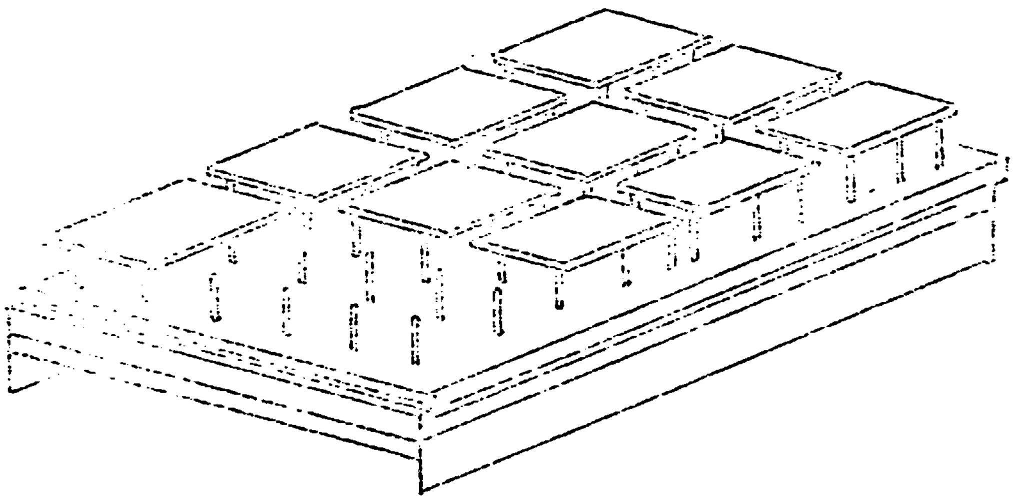


Fig. 4 : OPTIMUM FIRING CURVE FOR OVERLYING CLAYS

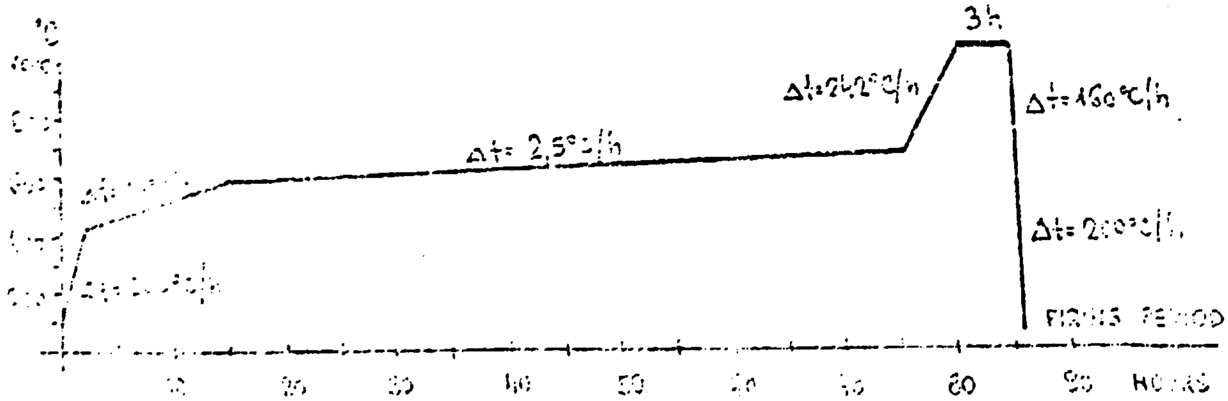
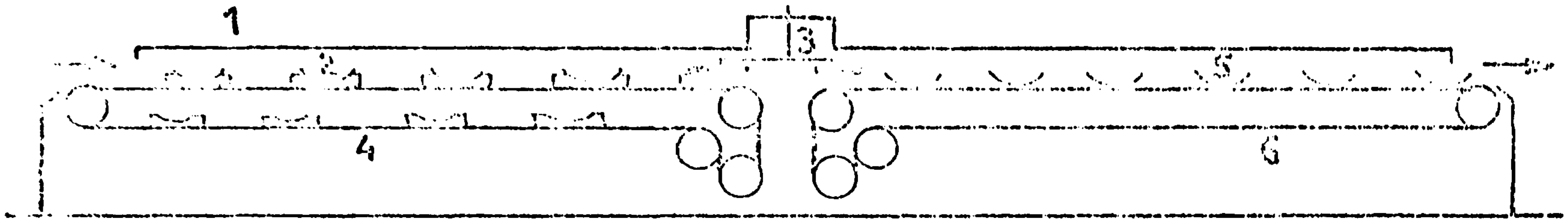


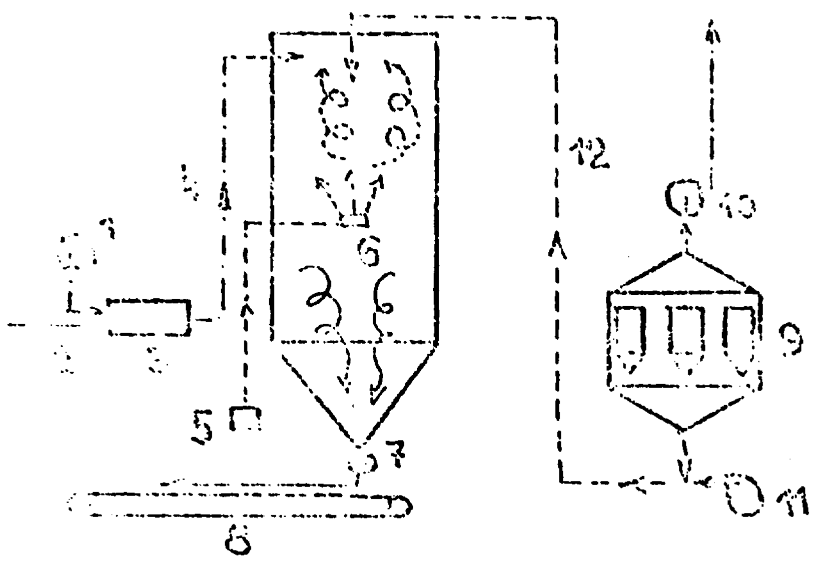
Fig. 5 : SKETCH OF HIGH-SPEED LINE FOR HOUSEHOLD PORCELAIN PRODUCTS WITH TRANSSHIPPING EQUIPMENT



CAPTIONS :

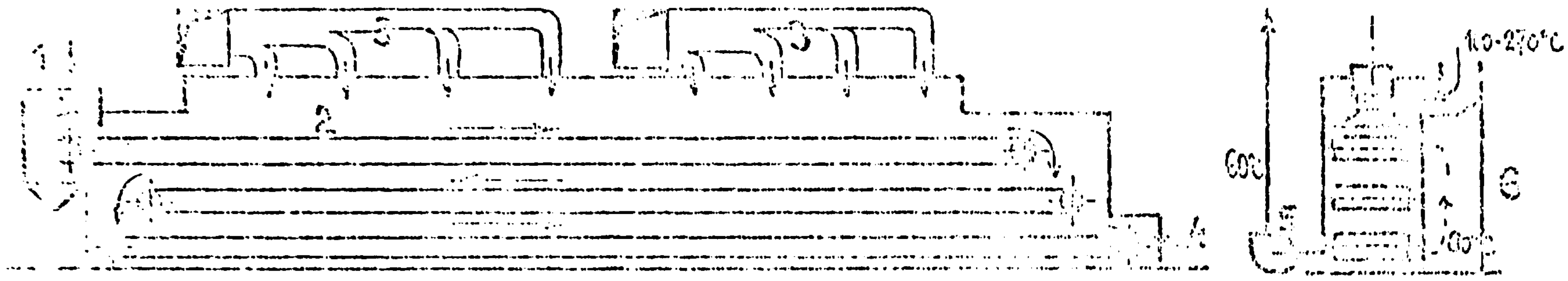
1. CONSTRUKTION OF ARM-TYPE HIGH-SPEAD DRYER
2. DRYING OF SEMI-PRODUCTS „ON THE MOULD"
3. PNEUMATIC TRANSSHIPPING EQUIPMENT
4. RETURN TRACK WITH EMPTY MOULDS
5. DRYING OF SEMI-PRODUCTS
6. RETURN TRACK OM ARM TYPE DRYER

[illegible] : FLOW SHEET OF [illegible]



[illegible] :

1. COMBUSTION AIR FAN
2. FUEL SUPPLY
3. COMBUSTION CHAMBER
4. HEAT CARRYING MEDIUM (COMBUSTION GASES OR AIR)
5. SLURRY PUMP
6. SPRAY DRYER
7. TURNSTILE SHUT-OFF ELEMENT
8. CONVEYER BELT
9. DUST CONTROL EQUIPMENT
10. MAIN FAN
11. AIR RECIRCULATION FAN
12. RECIRCULATION CIRCUIT



CAPTIONS:
1. NOODLE PRODUCING EQUIPMENT
2. METAL SCREEN CONVEYER
3. DRYING MEDIUM AIR ENGINEERING DISTRIBUTIONS
4. RAKING OUT EQUIPMENT
5. DRYING MEDIUM EXHAUST FAN
6. DRYING MEDIUM RECIRCULATION

1.0 DIAGRAM OF THE HEAT DISTRIBUTION AND CONSUMPTION INSIDE THE TUNNEL KILN