OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

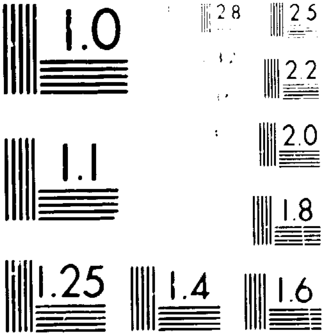
Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org



MICROCOPY RESOLUTION TEST CHART

[illegible]

12928 → PEMBLETON

UNIDO-Czechoslovakia Joint Programme
for International Co-operation in the Field of Ceramics,
Building Materials and Non-metallic Minerals Based Industries
Pilsen, Czechoslovakia

Distr.
LIMITED SAGE

JP/55/80
September 1980

ORIGINAL: English

Technical Workshop on Energy Conservation
in Silicate Industries
for the Least Developed Countries

Pilsen, Czechoslovakia
October 1981

HEAT CONSUMING UNITS IN CERAMIC INDUSTRY

by: Jiří Kout +/

967

+/ PREFA, National Enterprise, Brno, Czechoslovakia

55

Contents:

1. INTRODUCTION.

Many important articles about heat consumption and fuel policy in ceramic industry have been written in the last few years. All this due to the substantial increase of all types of fuel price and especially due to the oil crisis which has burst upon many countries with a sudden shock.

It is evident that the fuel policy is different in individual regions of the world in connection with fuel resources and reserves. But with the exception of some few countries rich on fuel reserve the main part of the world has to look very carefully on the selection of the fuel.

When discussing the fuel policy in ceramic industry it is of importance what percentage make fuel costs of total production costs which differs substantially in heavy clay industry on one side and the white ceramic industry on the other side.

The firing process of ceramic products is the main heat consumer in every ceramic plant while the drying can be done with lower heat consumption and sometimes even in the open by natural air circulation at prevailing temperature. Very often the waste heat taken from the cooling zone of the kiln is the only source of the heat for drying.

There are many ways to fire ceramic products. Some of them, mainly heavy ceramic products as brick, stoneware products and refractories and some fine ceramic products as sanitary ware, porcelain insulators and others are fired in one-fire process. On the other side many other products belonging to structural and white ceramics as wall tiles, tableware, some types of technical ceramics, etc. i.e. ware which is to be glazed or decorated may be fired twice or even many times to become the final product.

As to the products which have to be fired in two or more steps, one of the methods is to fire the ware to a sufficiently high temperature to mature the body without the glaze in the so called bisque fire and then the glaze is applied and fired to a lower temperature in the glost firing.

Another method is to initially fire the ware to a low-temperature bisque fire,apply the glaze,and then mature the body and glaze together at a high temperature.

Modern tendency is to eliminate the second firing in order to reduce the fuel consumption and to finish the ware in one firing even for that ware which has been traditionally twice fired as e.g.wall tiles,earthenware and porcelain tableware.To reach this goal both body and glaze composition for this firing must be carefully adjusted and the use of homogeneous raw materials of suitable properties is one of the basic conditions.

During the firing process the ceramic body or clay mix consolidate and reduce porosity due to the development of a viscous liquid or sufficient mobility of atoms in the solid state.Many different reactions and changes take place during the firing in accordance with the body composition,firing conditions,etc.

With the exception of some few products most ceramic bodies shrink on heating process,the shrinkage being equivalent to the porosity decrease and varies from a few volume per cent to 40 per cent depending on the type of body,the manufacturing process and ultimate density of the fired ware.

The shrinkage proceeds mainly at an uneven rate during the firing process which has to be taken into consideration when adjusting the correct firing cycle to avoid excessive internal stresses in the ware which can lead to failures as warping and cracking of the ware.Special care has to be taken as well in setting the ware to avoid the friction with material on which it is set.

To prevent the failure of the ware the time and temperature level of the firing process must be adjusted and controlled to give a satisfactory product.A suitable design and type of the kiln has to be selected including all electrical and controlling equipment to reach the proper result of the firing process.

2. CHOICE OF FUEL.

Before coming to the description of the use, design and economy of individual types of kilns let us have some few words on fuels and materials for the construction of kilns.

There are very many sources of heat which can be used for firing in ceramic industry:

1. Wood
2. Charcoal
3. Peat
4. Agricultural wastes
5. Lignite
6. Coal
7. Coke
8. Natural gas
9. City gas
10. Coke-oven gas
11. Producer gas
12. Propane, butane
13. Liquid fuels-oils
14. Electricity

The selection of the proper fuel for firing ceramic products is governed by many different conditions, the most decisive of which are:

1. Availability of the fuel
2. Type of the products to be fired
3. Price per unit of heat
4. Investment and maintenance cost of the firing equipment

As to the Europaen heavy clay industry till 1956 the main fuel was coal, the consumption of liquid fuels constituting only approximately 5 to 10 %. Thenafter the popularity of oil steadily increased and reached its peak in 1970 to 1972 of around 50 % of the total energy input not only for heavy clay industry but also for refractories.

The advantage of oil fuel in improved working conditions and its superior physical properties and as well as competetive price compared with the coal in those years were the reason of the fuel oil popularity. Some disadvantages of fuel oil consisting in high sulphur content and difficulty to operate oil burners at a low thermal input rate at lower temperature in the kilns were the reason that even many heavy clay and refractory producers switched to gas firing in those countries where gas became available and of attractive price.

Many well known advantages of gaseous fuels as

a/ freedom of sulphur

b/ increase in output due to the low temperature combustion

c/ reduction in labour requirement

d/ the potential direct use of kiln combustions for drying purposes

were pointed out to promote this type of fuel in heavy clay industry. But the fuel price increases in recent years in general and of high grade fuels as gas especially have changed the situation in the fuel policy of heavy clay industry in Europe and as well in many other regions of the world.

Due to this situation many countries must now, when following the correct fuel policy economise and exploit other fuels which have previously been overlooked and use them in improved and more efficient process.

Following the conditions in Europe we can see from the statistics that in many countries coal is the cheapest fuel and taking into consideration that the world's resources are 5 times bigger than we know in the time being there will be enough coal on the world for about 150 years. As to the other fuels- the reserves of oil and natural gas are considered to be under same conditions for about 50 years.

Looking at one part of ceramic products-brick, or materials used in walling in general-it is evident that the production of a ceramic wall needs roughly 3 times more energy than a sandlime wall and 4 times more than a wall made from concrete blocks. Because of this influence of energy on production costs ceramic building materials could loose their market in case that no improvement would be reached at this field.

Due to present day fuel problems an increasing number of heavy clay manufacturers in Europe are looking to coal in different forms to solve their fuel problems. This situation called out a new research in coal usage for firing of ceramic kilns and progress has been already made by some equipment manufacturers in the development of firing systems which assure that all previous problems of this type of firing as e.g.enviromental problems due to smoke,smog,dust,etc.were succesfully solved.

The use of milled coal in new developed systems of different manufacturers or of producer gas are the ways how the coal may be in many countries where available,the correct and economic fuel of every brick,refractories and stoneware pipe manufacturers.

But still it has to be taken into consideration that as the shortage of energy and high energy prices are affecting ceramic building materials much more than their competitors/cement,plastics/the price gap between them and ceramics will be becoming bigger as energy prices as well as coal prices are increasing.

To minimize the energy cost for brick manufacture other low grade fuels can be adopted as e.g.coal slurries,coke breeze, wood pulp and sawdust,etc.and in some countries even agricultural wastes as coconut,rice and groundnut husks,chaff and straw. The use of these types of fuels is unfortunatly limited to be applied only in internittent kilns or sometimes in moving-fire continuous kilns.Another problem could be the collection and the transport of the fuel to one spot.

That what was said here concerns mainly the manufacture of heavy clay products and a somewhat different situation is in tiles and white ceramic products manufacture where the energy cost makes a substantially lower proportion of the production costs.But also in this field the energy cost with increasing fuel prices starts to be one of important items which cannot be overlooked.Therefore many efforts have been exerted in last years to improve the production process and save the energy consumption especially in heat consuming units.

Coal or other low grade fuels cannot be used for direct firing of white ceramic kiln.Nevetherless producer gas made of coal or other low grade fuels is one of the answer in saving the energy cost.Due to the changed world's energy situation during the past few years the use of producer gas has been considered again for ceramic firing in more detail as it was 15 to 20 years before.

The advantage of this fuel is that producer gas can be generated from many kinds of solid fuels-coal,wood,peat,straw,etc. The calorific value of producer gas depends on the kind of the above materials but due to the very high nitrogen content this value is always low when compared with other types of gas fuels and therefore producer gas is classified as "poor gas".

On the other side producer gas is suitable for the firing of ceramic products as to its chemical composition and calorific value as it creates a soft and mild flame.Moreover modern type two-stage gas producers can be operated semi-automatically or fully automatically and can achieve with coal rates of efficiency upto 90 %.The final product is then a clean gaseous fuel which can be piped without the tar deposition associated with the old type of gas producer.

It is therefore general opinion that coal may in many countries be the surest source of fuel especially for brick,refractories and stoneware pipe manufacturers and with new two-stage process technique of gas producing also for all other branches of ceramic industry.

3. REFRACTORIES AND INSULATING MATERIALS FOR KILNS CONSTRUCTION.

The durability and economics of any kiln depend largely on the suitable choice of correct quality and the installation of the refractory and insulating materials as main parts of the kiln masonry. We give in few words just a short description as to the quality of different materials for designing and constructing of kilns for ceramic industry.

The first refractory bricks were manufactured probably by the Chinese and were probably made of ceramic clay. The refractoriness and other qualities of these bricks were rather poor but sufficient to meet the requirements for the construction of modest type furnaces for melting of glass and / or metal. During the centuries coming the technical progress of thermal processes required further development of the refractories used. It was necessary to use raw materials of better quality and to develop wider range of refractory products suitable for specific purposes as iron and steel industry, glass industry, gas works, boilers, etc.

Small workshops with manual methods of manufacture were changed step by step to factories with more mechanisation of manufacturing processes. The increasing demand of consumer industries after the first world war and particularly after the second world war on the improved quality of refractories urged a scientific research on this field which led to the development of high quality products.

The main property of refractories is their refractoriness sometimes expressed as P.C.E./ pyrometric cone equivalent/. Those materials having the refractoriness higher than 1580° C are called refractory materials. This temperature corresponds to Seger cone No. 26 or Orton cone No. 23. Other properties determined and limited by different Standard Specifications which are also of importance for the qualification of refractories are mechanical strength, refractoriness under load, thermal conductivity, etc.

Various production methods are nowadays employed in refractory industry but it is not the purpose of this course to describe the manufacturing processes of refractories - just let us have a review of different types of material used for the construction of ceramic kilns in brief.

Constructional refractory materials are subdivided according to their refractoriness, chemical nature or kind of industrial use.

Fireclay bricks.

The main refractories applied in the construction of kilns in ceramic industry are fireclay bricks. From the chemical point of view they consist of two main components-alumina and siliciumdioxide. The raw materials for the manufacture of fireclay bricks are refractory clays with clay minerals and up to 5-6 % impurities mainly quartz, iron oxid, feldspar, etc. Further constituents of mixtures for the manufacture of fireclay bricks are kaolin, shale and refractory grog /chamotte/.

There is a wide variety of fireclay products suited to particular applications in accordance with the origine of the raw materials, their treatment, shaping method and other parts of the manufacturing process.

Firing. Depending on the raw material and the final product the firing temperatures of fireclay bricks are generally in the range of 1250°C to 1500°C. Those fireclay bricks with application for higher temperature processes made with raw materials low in fluxing agents require firing temperature of 1500°C and above.

The fireclay refractories are classified differently in individual Standard Specifications. The conventional and still mainly used classification is according to alumina content and refractoriness. The refractory products with alumina content upto 44 per cent are conventional fireclay products and with alumina content above 44 per cent are called high-alumina products.

High-alumina bricks require for their manufacture different raw-materials as e.g. sillimanite, kyanite, andalusite and bauxite. Due to the lack of these natural raw materials some synthetic materials as sintered mullite, calcined alumina and adjusted production process these types of products exhibit a higher refractoriness as well as all other improved characteristics.

In the construction of kilns for ceramic industry the fireclay brick is the most used material and for kilns with firing temperature upto 1300°C(as most ceramic products require with the exception of porcelain tableware,insulators and some special technical ceramic products)is the only material for the construction of refractory masonry of these kilns.

For porcelain firing kilns the fireclay refractories make upto 95 % of refractory lining,the combustion chambers of burners being made of high-alumina bricks with Al_2O_3 content above 44%.

Some types of refractories related to fireclay brick where alumina is parially or completely replaced by other refractory materials as zirconium,carbon,graphite,etc.have practically small use in the construction of common kilns for ceramic industry.

On the other hand refractories with silicon carbide are of important use for some parts of kilns as muffle tiles and kiln furniture as slabs,bats,saggars,etc.Silicon carbide refractories have a high thermal conductivity and a slight thermal expansion which results in an exceptionally high thermal shock resistance. In order to decrease the oxidation of silicon carbide the products are covered with a protective coating.

Magnesia bricks.

This group of refractories includes magnesia bricks,magnesia-chrome bricks with 5 to 15% of chromic oxide,chrome-magnesia bricks with 15 to 30% chromic oxide,chrome-ore bricks and sinter dolomite bricks.These types of products have high refractoriness and good resistance to basic slags.Due to these properties they become increasingly important especially for iron and steel industry.

As to their use in ceramic industry these refractories make the inside lining of some kilns for high temperature use,burning chambers and also as the lining for rotary kilns for firing high-temperature grog or sinter magnesite.

Silica bricks.

Silica bricks consist mainly of silicon dioxide-SiO_2-which in the origine material is present as quartz,quartzite,etc. and during firing is transformed irreversibly into other forms of silica which results in volume expansion of bricks during firing.

Due to special behaviour of this material consisting in reversible volume changes especially under 800°: these bricks are very rarely used for construction of ceramic kilns their application being in glass melting furnaces,coke and gas producing units and electric furnaces roofs i.e.in those continuously working units where no temperature changes especially its decrease bellow 800°C occur.

Nevetherless in spite of the above mentioned behaviour some designers and manufacturers of ceramic kilns make use of silica bricks for the construction of continuosly working kilns vaults in order to make advantage of the superior refractoriness under load of this material.

Refractory insulating bricks and materials.

Refractory insulating bricks with the porosity between 40 to 75 % are determined mainly for thermal insulation purposes of all types of kilns and furnaces.

The following groupes of insulating materials are used in the construction of ceramic kilns:

-insulating firebricks/subdivided-fireclay,diatomaceous earth, vermiculite,cordierite,zirconia/
-insulating castables/with similar subdivision/
-insulating plastics
-mineral wool
-ceramic fibre

The common insulating bricks are generally used as back-up brickwork due to their refractoriness.But some types of products which are described as light-weight firebricks have a refractoriness upto Seger cone 18/1520°C/ and can be installed as the inside lining of kiln walls providing there is no mechanical stress, flying dust or slag attack.Like that especially modern types of ceramic intermittent kilns as bottom-car kilns,top-hat kilns,etc. are inside lined with light-weight firebricks of different kinds in order to decrease the total mass of the kiln and thus save on fuel.

In addition to conventional refractory brick materials and more developed insulating brick materials there is a wide range of insulating products nowadays used in construction of ceramic kilns. From many of them especially ceramic fibres with extremely low thermal conductivity,low density and specific heat are ideal material for many applications.Insulation with ceramic fibre has assumed increasing importance with the reappraisal of the question of fuel conservation in all energy-consuming industrial kilns and furnaces.It includes such secondary products as blanket,board, shapes,sprays,etc.

4. FIRING AND KILNS.

Let us illustrate the principles underlying the firing in ceramic industry and the construction and operation of some types of kilns employed in this industry.

4.1 Intermittent kilns.

The earliest type of kiln was the intermittent or periodic kiln in which the process consisted in ware setting in the kiln, firing to the temperature,cooling and then the ware drawing from the kiln.Fireboxes for different types of fuel were left bellow the ware and hot gases generated in the fireboxes rised through the setting upward by natural draft to the top where they escaped through installed flues.This type of kiln is called the updraft kiln.

The temperature uniformity in these kilns is very poor and the proportion of underfired ware normally very high.Almost any type of fuel can be used for firing in this kiln as coal,oil,wood and even agricultural wastes as coconut or rice husks.As the heat economy when using some of the cheapest fuels in large kilns of this type could be fairly good still some updraft kilns are being constructed.In some regions they can have a number of points to their favour as lower capital investment and maintenance cost in new small ceramic plants whenever no enough capital is available and the labour is cheap.

The lack of temperature uniformity of updraft kilns was corrected to some extent by introducing downdraft kilns in which the hot combustions passed horizontal or down through the ware and then up a stack.There are many types of these kilns for firing ceramic products.One of the most used in Europe for firing heavy ceramic products as well as pottery was the Kasseler kiln(see Fig.No 1).This kiln was normally 5 to 8 m long,2 to 3,5 m wide and 2,5 to 3,4 m high.

Another typical example of a downdraft kiln is the double-decker round kiln which has been used for many years in porcelain industry in many countries in Europe.This kiln represents a partial progress as it fires the ware at two different temperatures(see Fig.No 2).

The bisque firing of porcelain ware at Seger cone No 010 /approx.900°C/occurs in the upper deck of this kiln,whereas the glost firing in the lower deck at Seger cone No 12 to 15 /approx.1350 to 1430°C/.Many types of fuels especially coal, oil,wood,etc.have been used in these kilns.The porcelain ware when glost fired has to be set in refractory saggars to prevent direct contact of unburnt particles of the fuel in combustions with the ware and thus to protect the ware against dirt.

As the downdraft kilns have been improved in a number of ways during last years in the semi-automatic and automatic control of draft and temperature,these kilns are still in operation in many ceramic plants.

Some downdraft kilns of large size are suitable for firing of heavy ceramic ware as stoneware and refractories of special shape and large pieces.With some advantage these kilns are also suitable to fire the ware in the manufacture of a small and variable output and the ware which needs special conditions of atmosphere and firing cycle.Large downdraft kilns are still being used for firing of silica and basic bricks.

Besides the above mentioned conventional types of periodical kilns which are today in spite of their improvement technically obsolete and uneconomical as they consume normally 2 to 5 times as much fuel as a continuous kiln,there are many modern types of intermittent kilns as car bottom kilns,top-hat kilns, etc.the use of which is growing steadily for some special reasons in last years.These kilns are described in an other chapter bellow.

4.2 Continuous kilns.

In order to save fuel and labour many efforts were made to develop kilns with improved fuel economy and labour conditions i.e.continuous kilns reducing heat consumption through:

a/Utilizing the heat of combustion gases by drawing them through the ware still to be fired

b/Utilizing the heat content of the ware after firing either for preheating the air for combustion of the fuel or for drying purposes.

There are two main methods of continuous firing:

a/The first with stationary ware in an annular ring or in a series of interconnected chambers where the fire moves round the circuit

b/In the second the kiln maintains the temperature distribution in a tunnel and ware moves through the tunnel

Both methods have in common that the firing is never interrupted and the heat losses reduced to the conduction through the kiln walls and subsequent radiation.These losses can be minimized by insulating the walls efficiently or even by using this heat partially for drying.This type of heat loss can be deal_t with solely through the design of the kiln i.e.the type of refractory and insulating material applied,the thickness an properties of insulation of kiln wall and ducts,etc.

4.2-1 Moving-fire type kilns.

This type of kilns came into general use first with the ware in an annular ring or ina series of interconnected chambers and the fire progressing round the circuit.

The first successful kiln of this type was the hoffmann kiln /see Gig.No3/which was invented round the middle of last century.The original Hoffmann kiln had a circular firing c[illegible] but this original design has often been changed substa[illegible] so that we have had many types of so called hoffmann kilns with circular,annular,oblong and other different shape of firing chamber/Fig.No 4 and 5/as e.g.zigzag,Belgian,Ideal kiln,etc.

These kilns were designed mainly to fire engineering bricks and many of them are still in operation throughout the world. Fuel feeding holes are situated in the roof of the chamber and any type of fuel may be used,coal being used still most widely, following by oil,wood and agricultural wastes.

The design of a modern Hoffmann kiln/see Fig.No 6/consists of two straight series of chambers joined at the ends by rectangularly placed chambers or by connecting flues only.The chambers have a rectangular shape with straight suspended roof so that the whole cross section is a door for brick setting and drawing purposes. This is more economical as the chambers are easier to set as the inside of the kiln is accessible to the fork-lift truck.

In principle it could be said that a Hoffmann kiln can be built more cheaply than any other continuous kiln as e.g.tunnel kiln, the saving of investment cost being round 30 %. It is built of ordinary red bricks i.e. the same type of bricks to be fired later in it.

Another type of continuous moving-fire type kiln which was developed in Europe also during the middle of last century is a continuous kiln with chambers joined side by side with wall partitions, and connected with flues/see Fig.No 7/.This connection permits drawing the exhaust gases from the chamber being fired to the chamber to be fired next and thus preheating the charge of this chamber close to the final temperature. Further the gases after passing through this chamber can be used to preheat several more chambers ahead of the fire. At the same time the chambers on the other side of the fired chamber are cooling, and by drawing the air through them, preheat can be provided for combustion.

Thus, the firing moves along from chamber to chamber in a regular manner. In some cases these kilns were constructed with so many chambers that two or even three firing points could move around the ring simultaneously.

The firing is carried out either by dropping the fuel through holes in the roof of the chamber under fire or by fireboxes with oil or gas burners.

Thi type of kilns has been used mainly for firing of fireclay refractories and stoneware but also gas fired for technical porcelain especially large apparatus insulators.

4.2-2. Tunnel kilns.

The second type, and the most important in firing all kinds of ceramic products, is the kiln with fire remaining in one place and the ware moving continuously through a heated tunnel. In principle this type of kiln, called tunnel kiln, has two main advantages:

1/First, the kiln parts at any one point stay at the same temperature and are free of strain caused by a periodical temperature change

2/Second, the ware may be set on cars or other type of transport equipment and unloaded outside the kiln in a convenient place.

Thus in the tunnel kiln the nearest approach is made to the suitable firing method where heat energy is only consumed for the irreversible chemical changes and the heat used is recovered as completely as posible during the cooling.

General tunnel kiln description.

There are very many different types of tunnel kilns with extreme dimensions-the lenght being between 2 m to 210 m and corresponding dimensions of the internal area of the tunnel. In spite of this variety there is a number of features mutual to all ordinary types of tunnel kilns.

For illustration let us see the schemes of 3 tunnel kilns in Fig. No 8,9 and 10 for firing of sanitary ware, high refractory ware and ordinary fireclay ware with the longitudinal plans and time temperature curves.

Common to all these tunnel kilns is a rail system with cars conveying the ware through the tunnel in one direction/see Fig. No 10-A/and the counter current of air and combustions/2/. The described kiln in Fig.No 10 is of 105 m in overall length to hold a total of 35 kiln cars to fire refractory products. It consists of 3 main zones, the construction and operation of them being as follows:

a/ Preheat zone /marked P/.

Starting just beyond the entrance end door with a vestibule /1/ between the end door and internal door, to accomodate 1 car, These doors are of insulated steel construction and of vertical lift type. The vestibule chamber acts as an air lock for the introducing of kiln cars to the kiln without upsetting the pressure balances within the kiln. The masonry of this part consists of common brick and block construction.

The other part of the preheat zone is constructed near the vestibule of common bricks, then partially from low heat duty firebrick and partially from high heat duty firebrick as the furnace zone is approached. The walls can be insulated either with insulating powder near kiln entrance or with insulating brick near the furnace zone.

Hollow walls are designed on each side of the preheat-offtake zone /2/. These communicate from the kiln interior through refractory dampered exhaust flues located at car platform level and are connected with a sheet metal duct to the combustions exhaust fan/3/. Some other 2 or 3 fans are mounted on the top of the kiln for recirculation of combustions /4/ to keap the heat down in the load for better uniformity of heat distribution in all parts of the kiln.

In the following part of the preheat zone bottom burners ports are provided with burners suitable to the kind of fuel applied and of required output of heat. The first lower burners-so called preheat butners-are of the high velocity, jet excess air type to maintain the oxidizing atmosphere in the preheat zone /5/.

Furnace zone /F/.

The design of the furnace zone is such as to provide for firing the lower and upper part of the ware setting space and therefore lower and upper burners are installed in this zone.

Number of burners depends on the size of the tunnel kiln-for the tunnel kiln in the Fig. No 10 six lower burners and four upper burners are installed per side /6/. High pressure fans or turboblowers serve for air supply to the individual groups of burners.

The control of burners is normally through regulation of the fuel. only, thus minimizing pressure fluctuation in the kiln. The fuel regulator is cross connected to the air line. The temperature control can be automatic or for manual adjustment.

The masonry of furnace zone is constructed from corresponding high heat duty materials and walls are backed up with insulating bricks and insulating powder or layers of ceramic fibres.

Cooling zone(C).

The cooling zone is divided in two sections-the first being the rapid cooling zone(7)provided to produce a rapid drop in temperature to the critical cooling range.This zone is furnished with inner lining of thin wall pannel brick and enables a combination of direct cooling and/or regulated indirect cooling of the load of the car.

The other portion of the ware cooling zone can have first the cooling done indirectly by means of room air drawn from the outside into hollow walls and then through sheet metal duct with ware cooling fan(8)to the dryer.At the end of the cooling zone is air exit fan(9)and air curtain replacing the exit end door.The air from this fan flows through the ware cooling zone and is exhausted at least partially through the ware cooling zone fans.

The masonry of this zone is constructed from low heat duty bricks backed up with insulating material.

This is a description of an open-flame tunnel kiln for firing of fireclay refractories.

In Fig.No 11. are sections through the furnace zone of direct fired open-flame kiln,indirect fired muffle kiln and semi-muffle kiln.In the muffle kiln the burners discharge into chambers separated from the car load by refractory walls.The heat in this kiln is transmitted through the muffles mainly by conduction and radiation and subsequently by convection. This heat transfer necessitates higher combustion temperature and insulation and due to greater heat losses the fuel consumption is higher.The only and main advantage of muffle kilns is that no protection of the ware with saggars is required when fired with fuel oil and when without saggars more ware can be placed on each car.

Semi-muffle kiln represents a type of kiln to reach the following results:

a)To decrease the fuel consumption due to the partial heat transfer by convection in direct contact of combustions with the ware.

b)To keep the characteristics of the muffle kiln as to no contamination of the ware especially when fired with fuel oil.

c)To rech a homogeneous temperature throughout the entire kiln section.

For illustration see the furnace zone cross sections of muffle and semi-muffle tunnel kilns of main manufacturers and/or suppliers of kilns in Fig.No 12 and 13.

In Tables No 1,2 and 3 are given the characteristics of conventinal tunnel kilns constructed in last 10 years for firing of stoneware pipes(Table No 1),refractories(Table No 2) and tiles(Table No 3).

Table No 1

Characteristics of tunnel kilns for firing of stoneware pipes.

	Output tons/year approx.	Length of the kiln m	Tunnel section		Firing cycle hours	Fuel consumption	
			width m	height m		MJ/kg	kcal/kg
Factory I	25.000	107	3,07	1,90	42 - 60	3,35	800
Factory II	48.000	135	5,00	2,05	62	4,20	1.000
Factory III	15.000	114	2,44	2,45	50,5	3,35	800
Factory IV	20.000	114	2,44	3,00	62	3,27	780

Table No 2

Characteristics of tunnel kilns for firing of refractories.

Type of the ware		Fireclay refractories upto 45% Al_2O_3	high-alumina refractories	silica refractories	basic refractories
Type of kiln		Tunnel straight kiln, open flame			
Firing temperature °C		1.350-1.460	1.450-1.600	1.400-1.500	1.600-1.850
Firing cycle	hours	30 - 100	70 - 80	120 - 240	80 - 140
Output	tons/year	16 - 19.000	35 - 60.000	3 - 50.000	20 - 50.000
Dimensions of the kiln:					
Length	metres	65 - 180	100 - 160	120 - 200	100 - 160
Width	metres	1,4 - 3,2	1,4 - 3,2	1,4 - 3	1,4 - 3,2
Height	metres	1,1 - 2,1	1 - 1,2	1 - 1,6	0,6 - 1,1
Fuel		Gas or fuel oil			
Burners		Low pressure or jet with cold or preheated air supply			
Fuel consumption	MJ/kg	2,51 - 2,93	3,8 - 5,8	4,1 - 6,7	4,1 - 7,1
	kcal/kg	600 - 700	900 - 1.400	1,000 - 1,600	1.000 - 1700

Table No 3.

Characteristics of car tunnel kilns for firing of tiles.
(Twice fired technology)

Type of ware	Wall tiles		Floor tiles(glazed)	
Type of firing	bisque	glost	bisque	glost
Output sq.m./year	1,455.000	920.000	506.000	463.000
Type of the kiln	semi-muffle	muffle	open-flame	muffle
Dimensions of the kiln:				
Length metres	107	84	94	89
Width metres	0,92	0,92	0,92	0,92
Height metres	1,10	1,07	1,31	1,31
Setting width mm	760	760	730	770
Setting height mm	960	930	940	920
Firing cycle hours	45	17,6	50	18
Fuel consumption				
kJ/kg	3.768	4.815	3.350	5.440
kcal/kg	900	1.150	800	1.300

4.2-3 Rapid-firing tunnel kilns.

There is no doubt that in some branches of ceramic industry the rapid-firing tunnel kiln has recently become more important. This concerns especially the tiles and some fields of white ceramic production.

The proper performance of a continuous kiln depends on the relation of the static and dynamic mass of the kiln, to the mass of the ware. The static mass consists of the fixed parts of the kiln i.e. the kiln body, metal parts and outer insulation. The dynamic mass comprises the moving components such as kiln cars with kiln furniture and in rapid-firing kilns different types of conveyors. slabs, netting, etc. including the fired ware and moving atmosphere. Both the static and dynamic mass should be kept at a minimum with the exception of the part of the fired ware.

And from this point of view the rapid firing kiln has some advantages as regards the fuel efficiency. Besides small-section tunnel car kilns the schemes of different transport systems applied in rapid-firing kilns can be seen in Fig. No. 14.

1. Kiln car
2. Transport on rotating rollers with or without refractory batts.
3. Refractory batts sliding on sled.
4. Ditto sliding on balls.
5. Transport on metal screen or wire belt.
6. Transport on air cushion.
7. Transport on step-wise walking beam.
8. Suspended chain conveyor.

But even under these transport systems in rapid-firing kilns there is a difference, the first of which being the transport on cars or other carriages and the second in which the ware is carried without any supporting material as e.g. the tiles on rollers, air cushion or on walking beam. This second system may be considered as more energy saving as no heat is removed from the furnace zone in the respective kiln transport equipment.

In general the following aspects may be considered in favour of rapid-firing kilns:

1. Energy saving due to short firing cycle, less kiln furniture or none at all
2. Better work conditions due to the possibility of shutting-down the kiln over the week-end or even during the night-shift and thus keeping the kiln in the same No. of shifts as other factory departments
3. Easy start-up and shut-down due to the light weight of all parts of the kiln especiall when light fibre insulating material is used for the insulation.

But there are still some disadvantages of these kils:

1. Limited range of products
2. Requirements on better quality and homogenity of raw materials, prepared body and glaze composition
3. Mainly no utilisation of hot air recovered from the cooling of the ware for drying purposes.

Some comparisions of the efficiency of rapid-firing kilns with other kilns are listed in last chapter of this paper.

4.3 Modern low-thermal-mass intermittent kilns.

This article concerns the intermittent kilns of modern design applied mainly for firing of pottery, sanitaryware and technical porcelain ware.

Until 1930s the intermittent kilns of different design dominated for firing of practically all ceramic products in many European countries. It was only after this time that tunnel kilns were built in significant numbers replacing the old fashioned intermittent kilns with their disadvantages consisting in bad quality and uniformity of the ware, poor working conditions, higher fuel consumption, etc.

But with the improved quality of lightweight bricks and better control instruments and especially in recent years with introduction of low-thermal-mass materials the intermittent kilns have benefited and their use in ceramic industry has grown steadily. Moreover the reluctance of kiln operatives in developed countries to work over week-end 24 hour/7 day week on tunnel kilns has increased the attraction of intermittent kilns.

The suppliers of these kilns emphasize the following advantages when compared with continuous tunnel kilns:

1. The accurate temperature control obtainable throughout the programme controlled firing cycle ensures the correct time-temperature schedule for first quality results and elimination of firing losses.
2. The changing of firing curve only takes a short time whereas changing the firing curve of a tunnel kiln is a slow operation which can not be carried out without some losses.
3. The flexibity of operation is of great advantage when market demand varies, as only the required output needs to be fired and there is not the high running cost of a tunnel kiln operating beneath peak capacity.
4. Very little labour is required for setting, fire and empty the kiln and the ware once placed is not subject to vibration and movement. Placing and emptying can be carried out during the day shift only and not night work is needed.
5. Week-end run and week-end work can be cut out completely which

starts to be a basic condition in many countries.

6. Due to the decreased labor especially at night shift and week-end normal rates of pay are applicable which results in reduced labour cost.

7. The kilns are also of considerable use to firms who fire the bulk of their output in tunnel kilns. Their installation allows the difficult re-firing to be taken from the tunnel kiln and fired separately under more controlled conditions.

The modern intermittent kiln are offered today as bottom-car kilns, top-hat kilns, shuttle kilns, etc. in a wide range of standard sizes with guaranteed operational efficiency for all main kinds of fuel i.e. gas, oil and electricity.

5. FUEL ECONOMY AND CHOICE OF THE KILN.

The most important point for correct minimizing the energy cost on the field of fuel whether in developed or developing countries is that all the attention should be given to energy conservation in all existing plants or plants to be constructed. One of the way to reach this goal is to use the adequate type and design of all heat consuming units especially kilns.

As the whole ceramic industry has an enormous interest in fuel economy many measures have been settled to save and minimize the energy cost in existing brickworks and ceramic plants, the most important of which are:

1. Use optimal operational cycle and firing curve by applying automatic burning systems.
2. Modernize the old kiln design and construction.
3. Optimize hot air recovery when improving kiln insulation and keep heat accumulation of kiln cars.
4. Adopt other low grade and cheaper fuels.
5. In brickworks moreover:
   - Use exhaust gases for drying whenever possible or use the kiln as dryer to remove the last moisture as e.g. in case of stiff extrusion process.
   - Incorporate carbonaceous additives in clay mix.

5.1 Brick manufacture.

As to the brick manufacture it is evident that in modern plants the tunnel kiln has many advantages against fire-moving kiln consisting in firing uniformity, less reject, less supervision labour and in recently constructed kilns better fuel economy. But from the datas in Table No. 4 bellow it can be seen that under some special conditions when taking just the fuel consumption as a measure for comparision the fire-moving kiln could be a correct economical solution.

Heat consumption in brickworks. Table No.4

Characteristics:

Brickwork I -	Brickwork with open air drying and fire-moving Hoffmann kiln.
Brickwork II -	Brickwork with chamber dryer and fire-moving Hoffmann kiln
Brickwork III-	Brickwork with chamber dryer and tunnel kiln, constructed in 1930s till 1960s
Brickwork IV -	Brickwork with tunnel dryer and tunnel kiln of recent years with fully automatic production process

	Heat consumption			
	Specific for drying kcal/1 kg of water	calculated for 1 kg of ware		
		drying kcal	firing kcal	total kcal• MJ
Brickwork I	-	-	400	400= 1,67
Brickwork II	1800	500	350	850 = 3,55
Brickwork III	1400	300	250	550 = 2,30
Brickwork IV	1000	150	200	350 = 1,46
See notice		1/	2/	3/

Notice:

1/This value is the input of heat for drying purposes incl.the recovered waste heat.For Brickwork IV this heat is in total recovered from the tunnel kiln.

2.This value means heat consumption for firing purposes after reduction of waste heat transfered to the dryer.

3.This value is the total consumption of heat for drying and firing given in kcal and MJ for 1 kg of finished ware.

The datas in the Table No 4 prove that from the point of view of fuel saving the application of open air drying improve the energy balance.Furthermore taking into consideration the lower investment cost in favour of fire-moving kiln,availability of cheaper low grade fuel and most probably local cheaper labour,there is no doubt that in some regions of developing countries this manufacturing process could be selected as the most economical.And that moreover especially when no sufficient investment capital is at disposal.

From the last development of firing system in brickworks it is apparent that the design of modern brick tunnel kilns is directed to provide all hot air for drying as recovered waste heat from the kiln.There are many factors which influence the results in this matter as e.g.the moisture content of extruded bricks,firing temperature,range of products,etc.In brickworks with stiff-extrusion system with 10 to 13 % moisture content of green bricks this goal is normally reached.But with 20 % or more moisture in soft-extrusion most tunnel kilns do not provide the heat in sufficient amount.

5.2 Tiles and white ceramics manufacture.

There is today probably no subject in the tiles and white ceramic industry more discussed than the problems of merits of individual types of kilns to be introduced in new plants.It concerns the continuous tunnel kilns of modern design in comparision with rapid-firing kilns on one side and continuous and intermittent kilns on the other.

As far as the pure energy cost is concerned the tunnel kiln has certain disadvantage compared to the rapid-firing kiln and are sometimes dismissed by their oponents as unsuitable in terms of theirs inflexibility in the production and work over week-end.On the other hand,others emphasize the poor fuel economy of all types of intermittent kilns and theirs high maintenance costs.As the last experience show,there is still a need of all the above types of kilns in the ceramic industry,the final choice of the suitable type being dictated in accordance with many local factors.

What were the average conditions in white ceramic industry in Europaen countries in last years?

Breaking the total amount of fuel consumed in this industry into processes we find that about
50 to 60 % are used in high temperature firing process
20 to 25 % in drying
8 to 10 % in space heating
5 to 8 % for operating machinery
i.e.75 to 85 % of the total fuel used in the drying and firing processes.

Looking at the split in the way of fuel type there are differencies in individual countries but in general the main fuel has been the natural gas with its consumption reaching 60 to 75 % of the total amount,followed by oil,LPG,electricity and coal.

The aim to save energy in this industry in many countries in last years was first of all to cut out as much as possible all type of waste in the production.Further step was to improve kiln efficiency by introducing new equipment and methods on existing heat consuming units.The main steps were the waste heat recovery from the kilns which was very often previously in white ceramic industry neglected.

In intermittent kilns of older design the reduction of heat consumption has been followed by the use of low thermal mass fibre insulation and introducing of recuperative burners.Upto 50 % fuel saving has been reached by the combination of reduced firing cycles in reconstructed kilns with fibre insulation and high velocity recuperative burners.

These burners incorporate a high performance recuperator and simple flue combined in one compact unit.Hot combustions products issue from the burner head at 80 metres per second which results in good recirculation and improve heat transfer rates and temperature uniformity throughout the whole kiln section.

Proper energy recovery by waste heat has been also the main task in plants with tunnel kilns.Moreover the objective was to raise the ware to the maximum temperature as quickly as possible and to insulate the preheating and furnace zones of kilns to minimize heat loss by conduction.Additional insulation has been applied to the outer walls and roof of existing kilns and in some cases even at the hot face inside the furnace zone with low thermal mass fibre.

Further heat loss from tunnel kilns represent the hot kiln cars coming out from the kiln.The cars are heated and cooled every time they pass through the kiln which means a cyclic input and output of heat energy.The cars in most tunnel kilns are of massive structures for loadbearing qualities and need a lot of heat amounting to 5-10 % of the total heat supplied to the kiln to raise them to operating temperature.

To date,there are two ways of reducing this heat requirement:

1)Insulate the hot top of the car base and thus lower the temperature of the refractory mass.

2)Reduce the mass of the car lining so that less heat is required to raise it to operating temperature.

Both steps are achieved with ceramic fibre insulation of the kiln cars.Depending on the kiln cycle,operating temperature and fibre thickness a reduction in the kilns fuel consumption of about 5 % or even more can be expected.Due to the improved firing conditions in some cases,the firing cycle can be shortened and the output of the kiln increased which means generally further heat saving and reduction of fuel consumption.

Staying with the problem of fuel consumption in firing different types of ceramics let us see some datas in Tables No. 5 and 6 bellow.

Wall tiles manufacture. Table No 5

Type of the kiln	Heat consumption kcal	MJ/kg
Bisque-muffle tunnel kiln	1.300kcal/kg	5,44 MJ/kg
-open-flame tunnel kiln	850	3,55
Glost-muffle tunnel kiln	1.500	6,28
-open-flame tunnel kiln	1.000	4,18
-rapid-firing kiln	650	2,72
Once-fire technology		
rapid-firing kiln	700	2,93

In spite of the fact that still many of tiles producers remain on the twice-fired technology the trends for single-fired wall tiles are increasing which is comprehensive from many points of view especially when taking into consideration the actual world energy situation and growing fuel cost.As there is today practically no difference between wall tiles and glazed floor tiles for the use in interiors and exteriors in many countries the same conditions are more or less valid for glazed floor tiles manufacture.

The heat consumption for firing of 1 kg tiles in different kilns can be seen from Table No 5.The heat consumption figures in this table are in favour of rapid-firing kilns in general an d, no doubt,in favour of once-fired technology.

When comparing the heat requirements in Table No 5 it has to be noted that there is no utilisation of waste heat recovered from the rapid-firing kilns which makes in case of other tunnel kilns about 20 % of total heat input and is used for drying of pressed tiles.

In spite of the above conclusions some tiles manufacturers prefere the firing of glazed tiles in gas-fired open-flame tunnel kilns of modern design and large cross section getting very good results as to the quality of ware as well as fuel economy.

The heat consumption in firing sanitaryware in different types of kilns is given in the following Table No 6.

Sanitaryware manufacture/vitreous quality/. Table No 6.

Type of the kiln	Heat consumption kcal/kg	 MJ/kg
Muffle tunnel kiln	4.200	17,58
Open-flame tunnel kiln	1.900 to 2.200	7,95 to 9,20
Rapid-firing tunnel kiln	1.500	6,28
Low-thermal-mass intermittent kilns:		
-gas fired	3.000 to 4.200	12,6 to 17,5
-electrically heated	1.800 to 2.000	7,5 to 8,4

From the Table No 6 it is apparent that even in the field of sanitaryware the heat saving is in favour of rapid-firing kilns of modern design. The rapid-firing cycle in sanitaryware manufacture is considered the cycle of less than 18 hours which is achieved in modern-type tunnel kilns with ware placed in one layer on cars or moving slabs.

In order to improve the work conditions together with fuel efficiency varying degrees of automation of kiln-car railway trackage have been succesfully introduced in the production of sanitaryware together with rapid-firing kilns to solve the problems over week-end in reducing the labour in this period to a minimum.

6. SUMMARY.

The following is a brief summary to the subject of individual kilns to be introduced in ceramic plants.

It is obvious that first of all it is necessary to distinguish between the existing plant and the setting-up of a new plant. Thenafter the choice may be influenced by many other factors taking into consideration especially the following:

1)The large-scale production of more or less fixed output is unlikely to be achieved efficiently without application of a continuous kiln which holds a number of advantages over the intermittent kiln:
a)Lower fuel consumption
b)Lower maintenance costs
c)More consistent quality of products
d)Easier integration of the kiln in a process flow-line

2)Rapid-firing kilns which represent a further step in fuel saving will be introduced when setting-up a plant with a fixed range of products. When making this choice the following has to be taken into consideration:
a)With the exception of some types of products manufactured in small scale and fired in small-section rapid-firing kilns (as e.g. laboratory and electro-technical ceramics) the introduction of rapid-firing kilns requires a large- or semi-scale production of a fixed range of products. This can be achieved only in tiles production and for firing of a definite type of product in pottery industry.
b)Before making the final choice the saving of fuel in rapid-firing kilns has to be compared with other factors influencing the economy as amount of second-class ware, re-fired ware, cost of kiln furniture, etc.

3.The intermittent kiln of modern design would be installed in a ceramic plant under the following conditions:
a)In existing plant
-either to increase the output with the minimum of disruptions to normal work routines especially when not enough space is available for accomodation of a continuous kiln

-or to enlarge the flexibility of the production to cover various demands of the market

b)For smal-scale production in whiteware industry.No continuous kiln will be costructed in a ceramic plant for an output under the limits bellow which such a kiln would be unnecessary(as e.g.the output of 300 to 400 tons of sanitaryware per year).

c)In case of limited capital due to lower cost of intermittent kiln.But it has to be carefully reconsidered in advance whether cost saving when constructing the intermittent kiln is really such as to maintain the economy of the whole production.

The above conclusions are valid only in generalities.As,in practice,every manufacturing unit is different,the final choice of heat consuming units will depend on local factors which will continue to have the basic influence on the final decision.

7. FIGURES.

Fig.No 1 The Kasseler kiln.

1 - firing chamber
2 - wickets
3 - flues
4 - chimney stack
5 - fire boxes
6 - perforated or solid flash wall
7 - accessory flues

Fig.No 2 Double decker round kiln

1 - glost firing chamber
2 - bisque firing chamber
3 - fire boxes
4 - flues
5 - chimney

Fig.No 3 Firing operation in a Hoffmann kiln.

1 - setting of ware
2 - 4 preheating
5 - 7 firing
8 - 11 cooling
12 - drawing of ware
A - entrance
B - firing chamber
C - movable flue
D - chimney stack

Fig.No 4 Hoffmann annular kiln

1 - firing chamber
2 - wickets
3 - flues
4 - smoke collecting channel
5 - dampers
6 - firing holes
7 - chimney stack

Fig.No 5 Hoffmann annular kiln

For description see Fig.No 4

Fig.No 6 Modern type of Hoffmann kiln

1 - firing chamber
2 - doors
3 - flat suspended roof
4 - flues
5 - smoke collecting channel
6 - firing holes
7 - movable partitions between chambers

Fig. No 7 Continuous chamber kiln Mendheim

1 - stack
2 - firing holes
3 - hot air flue
4 - smoke flue
5 - hot air exhaust

Fig.No 8 Technological scheme of a tunnel kiln for firing of high-refractory ware

Fig.No 9 Technological scheme of a tunnel kiln for firing of sanitaryware

Fig.No 10 Technological scheme of a tunnel kiln for firing of ordinary fireclay ware

Fig.No 11 Tunnel kilns for direct and indirect firing

1 - preheating section
2 - firing section-burners
3 - air for burners inlet
4 - regulating valve
5 - burner
6 - regulating damper
7 - combustions exhaust
8 - kiln car
9 - ceramic muffle
10 - semi-muffle

Fig.No 12 Ways of indirect and direct firing in tunnel kilns

1 - Dressler muffle
2 - Swindell-Dressler muffle
3 - Allied muffle
4 - Sacmi-Poppi muffle
5 - Kerabedarf muffle
6 - Sacmi-Poppi semi-muffle
7 - Prerov semi-muffle
8 - Direct firing tunnel kiln

Fig.No 13 Tunnel kiln with SiC muffle of Carborundum Co.

Fig.No 14 Transport of the ware through the kiln

1 - kiln car
2 - rotating rollers
3 - sliding bats(sled)
4 - sliding bats(on balls)
5 - metal screen or wire belt
6 - air cushion
7 - stepping conveyor
8 - suspended chain conveyor

Fig.No 16 Top-hat kiln

1 - burner
2 - cooling nozzle
3 - smoke flue
4 - kiln car

Fig.No 15 Bottom-car(shuttle) kiln

For description see Fig.No 16

Fig. 1

THE KASSELER KILN (CROSS SECTION AND PLAN)

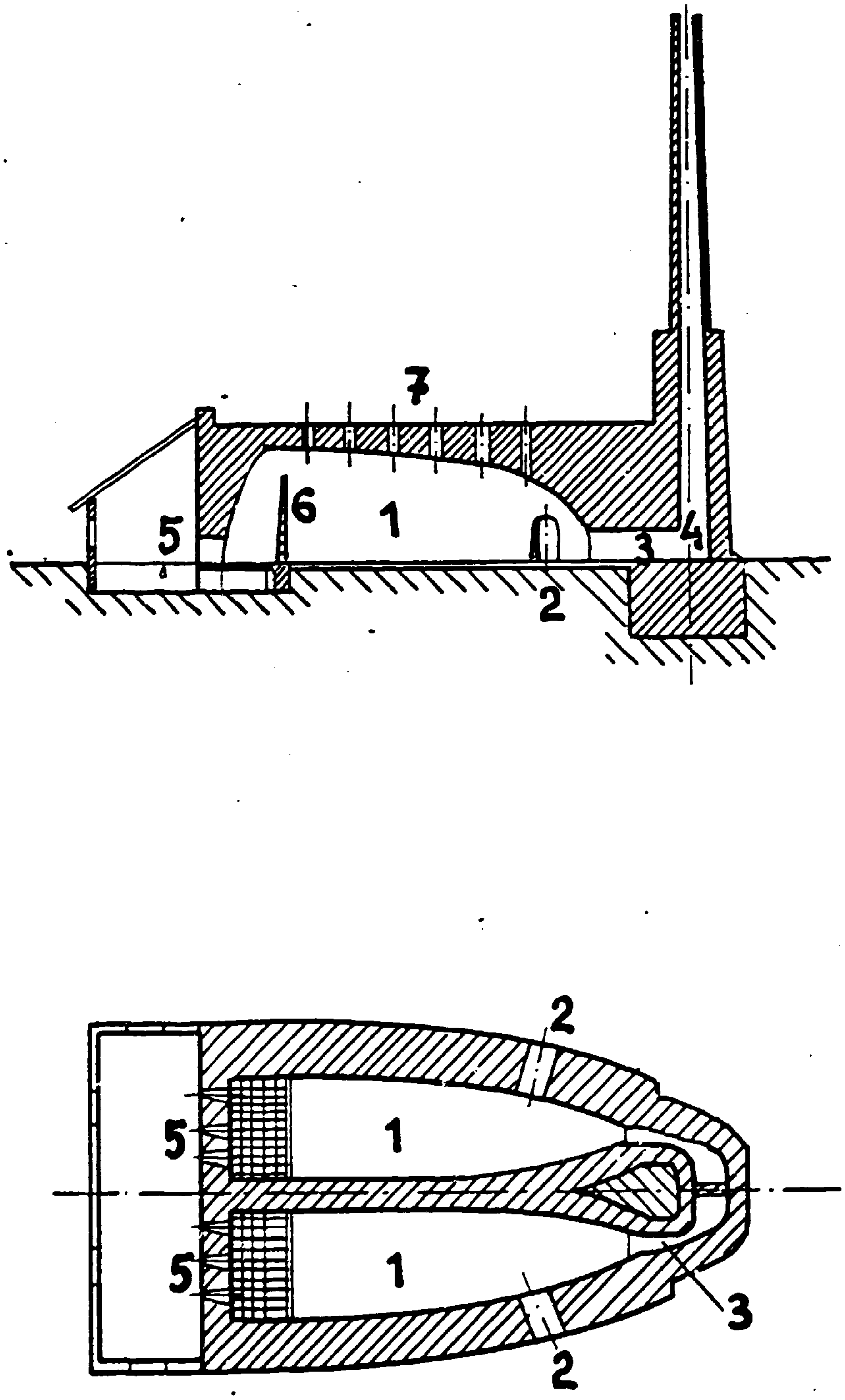


Fig. 2

DOUBLE DECKER ROUND KILN

(GROUND PLAN AND CROSS SECTION)

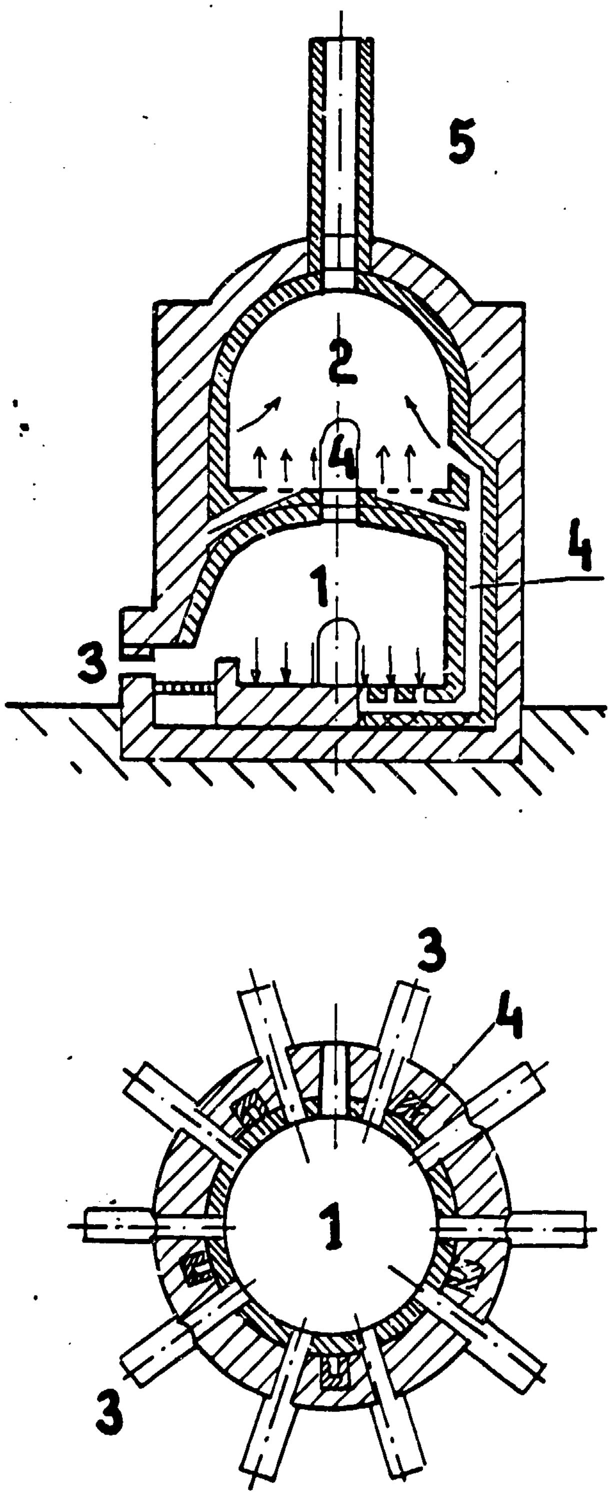


Fig. 3

THE FIRING OPERATION IN A ANNULAR HOFFMANN KILN

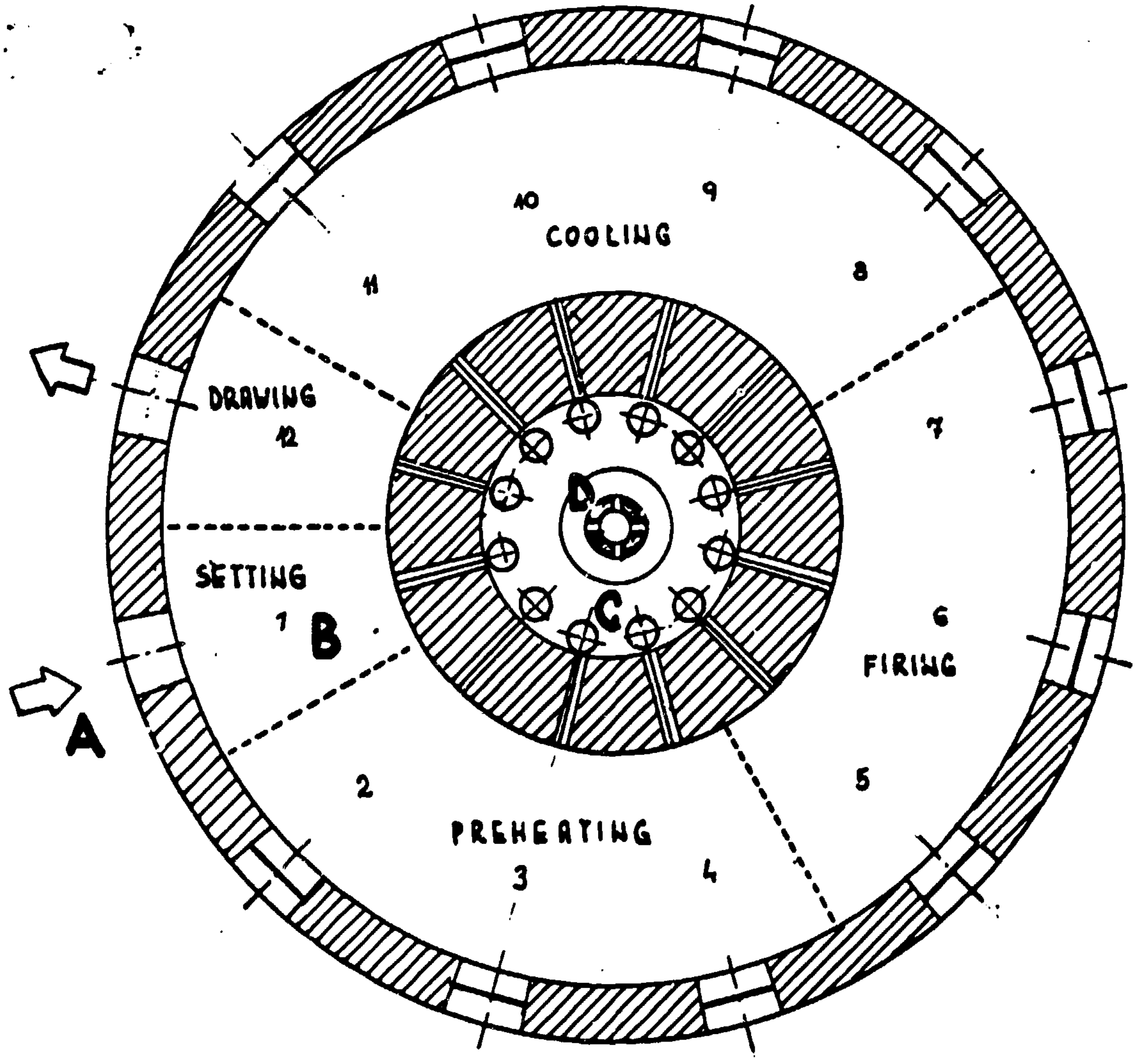
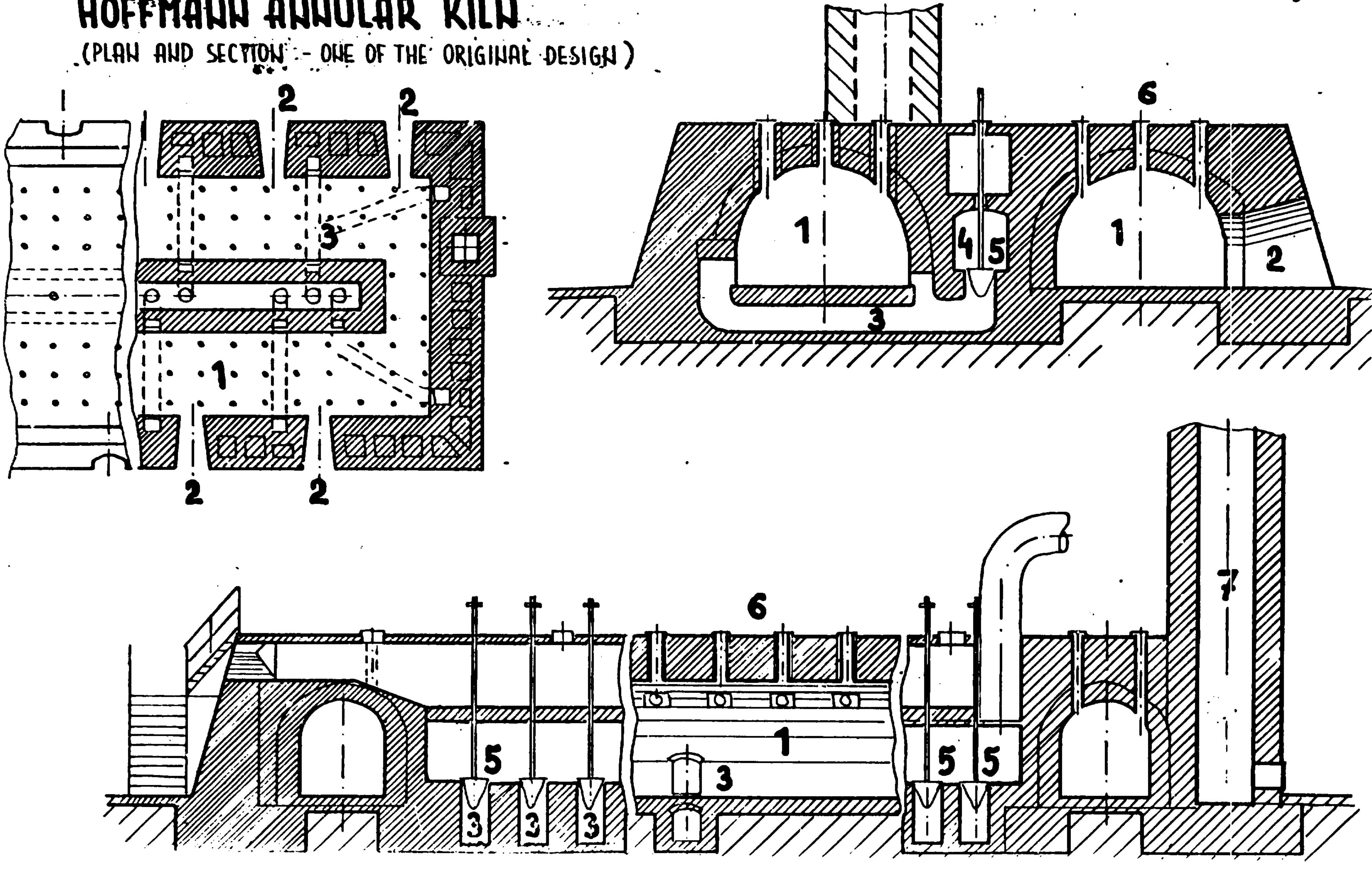


Fig. 4

HOFFMANN ANNULAR KILN

(PLAN AND SECTION - ONE OF THE ORIGINAL DESIGN)



HOFFMANN ANNULAR KILN (DESIGN WITH CENTRALLY SITUATED CHIMNEY STACK AND UNDERGROUND COLLECTING CHANNEL)

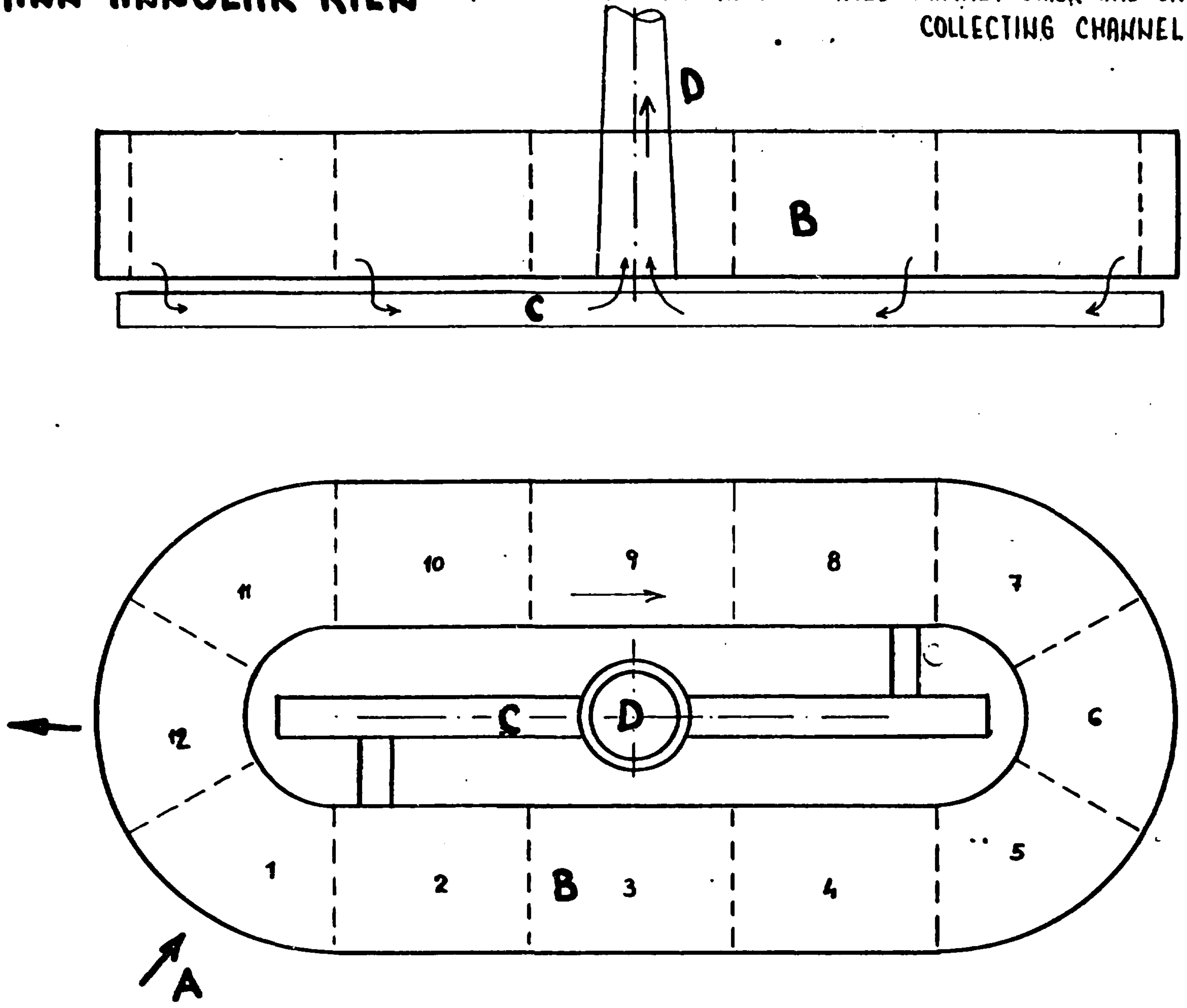


Fig. 5

Fig.6

MODERN TYPE OF HOFFMANN KILN (PLAN AND CROSS SECTION)

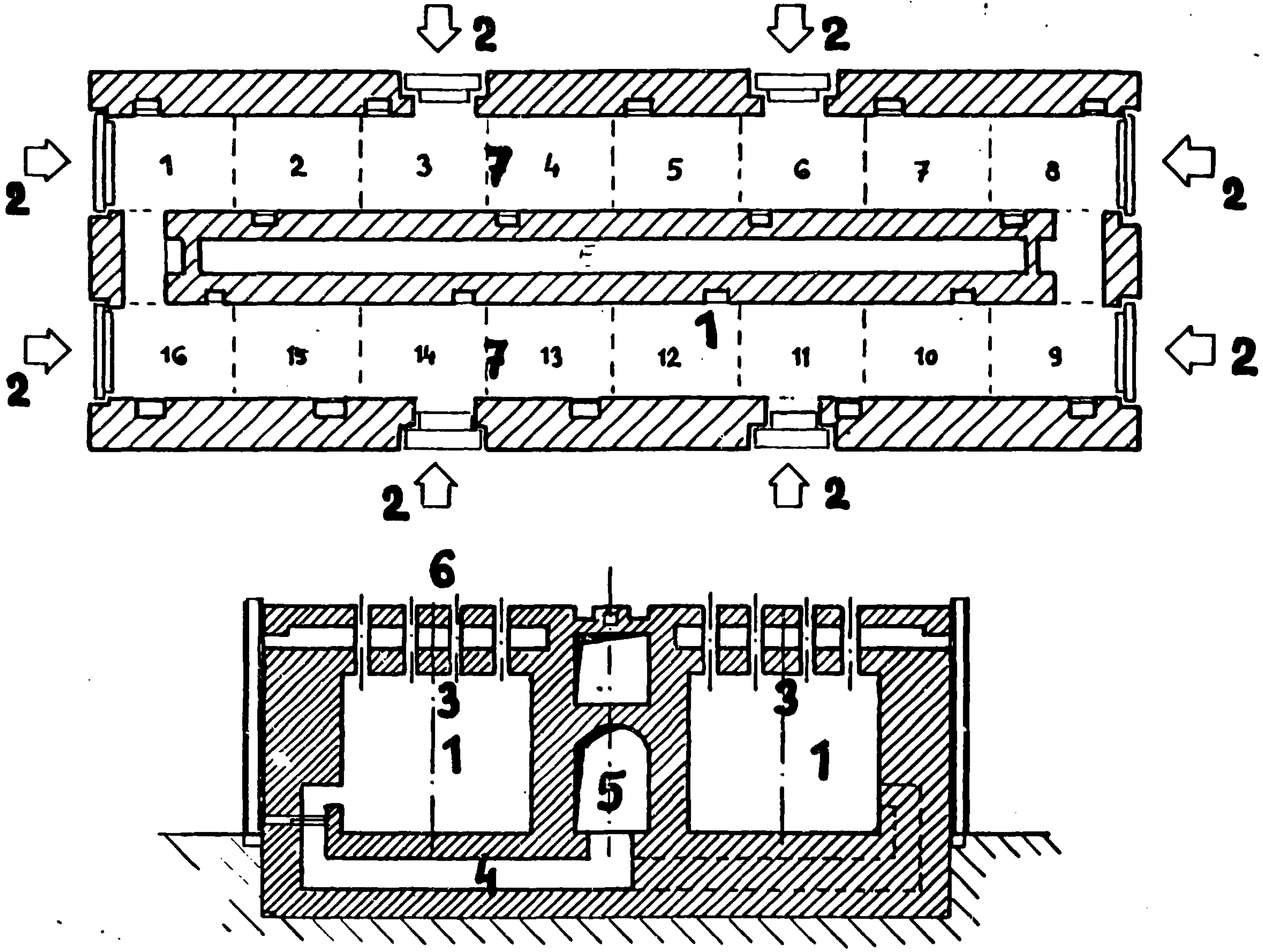


Fig. 7

CONTINUOUS CHAMBER KILN MENDHEIM

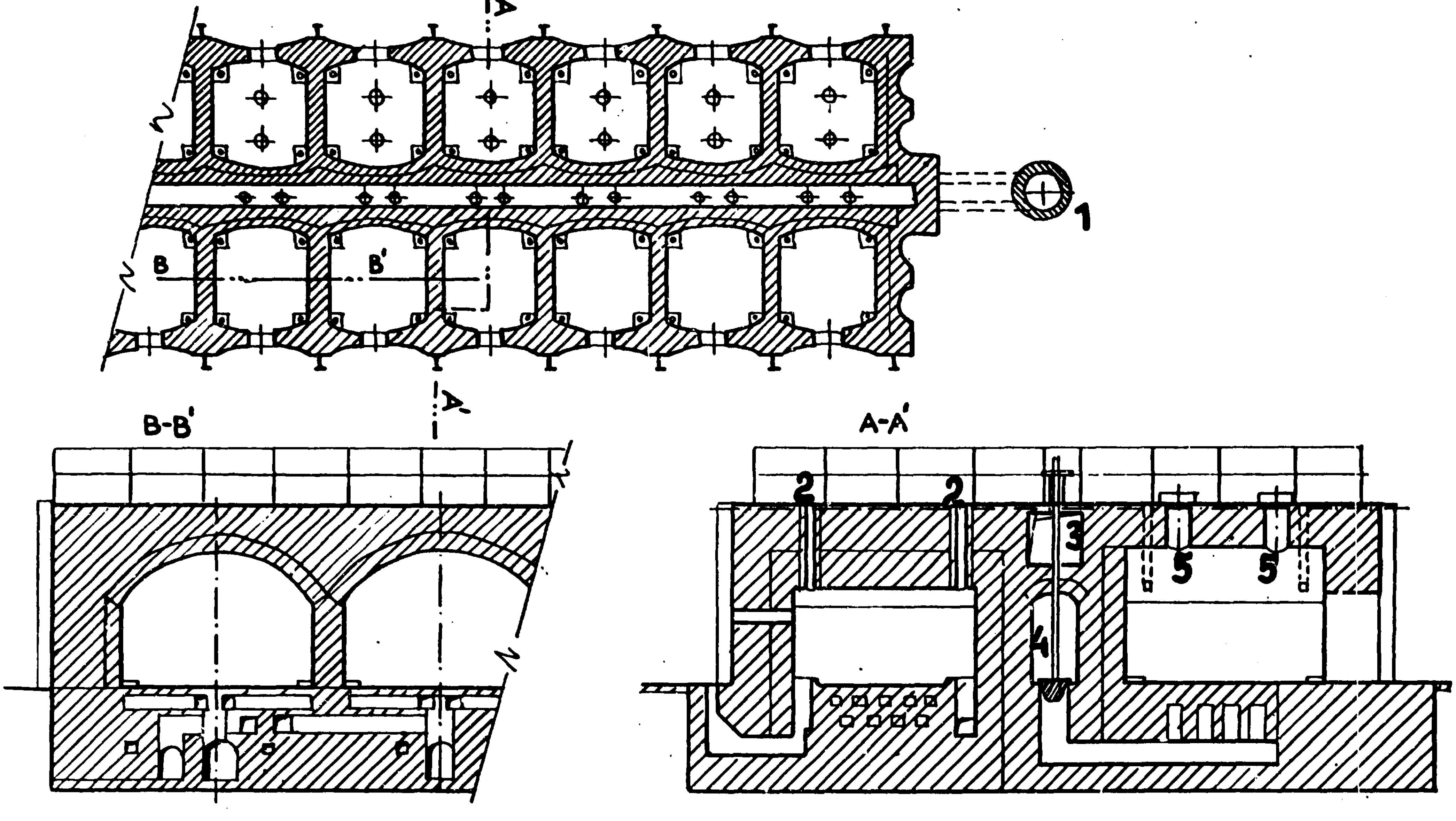


Fig. 8

TECHNOLOGICAL SCHEME OF A TUNNEL KILN FOR HIGH-REFRACTORY WARE

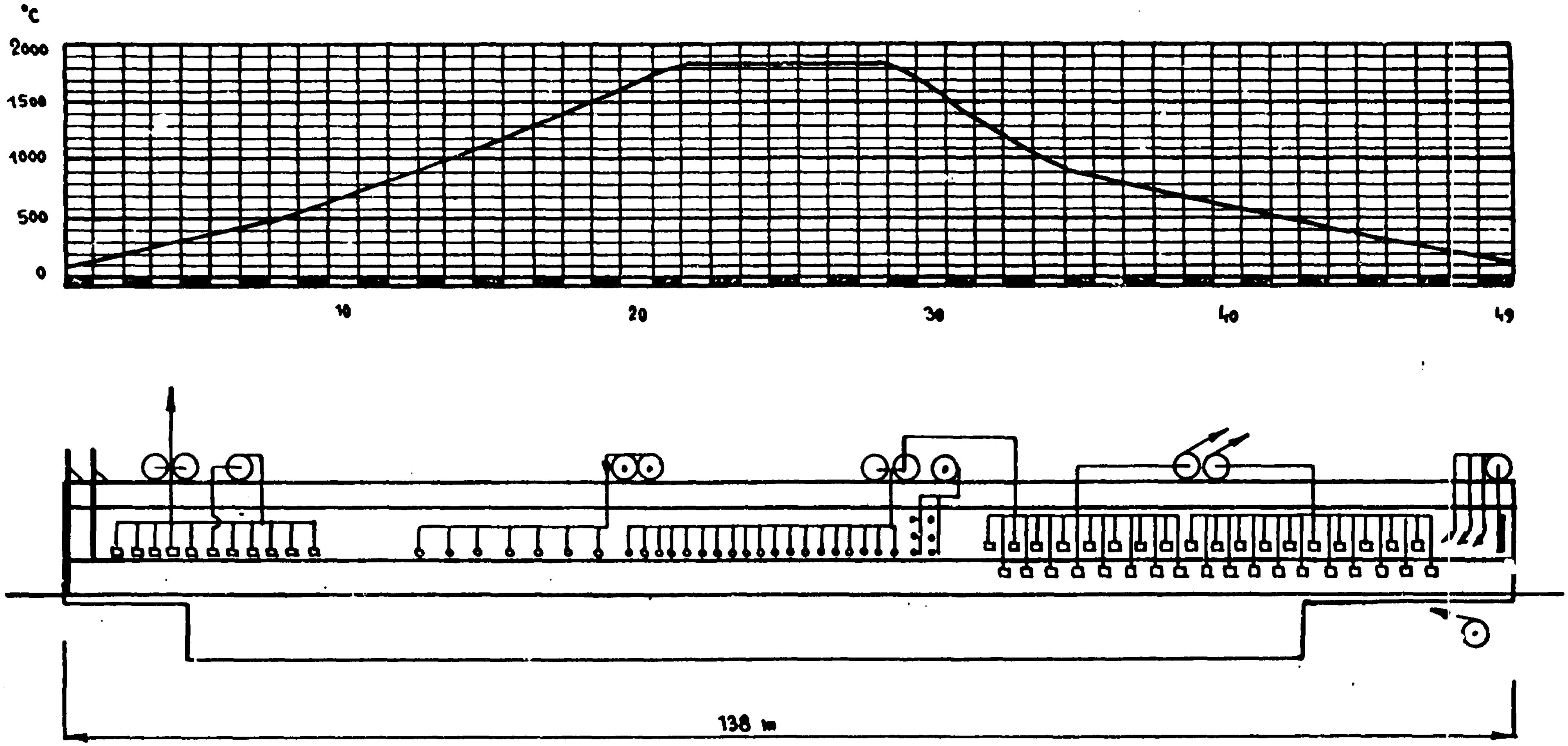


Fig. 9

TECHNOLOGICAL SCHEME OF A TUNNEL KILN FOR SANITARY WARE

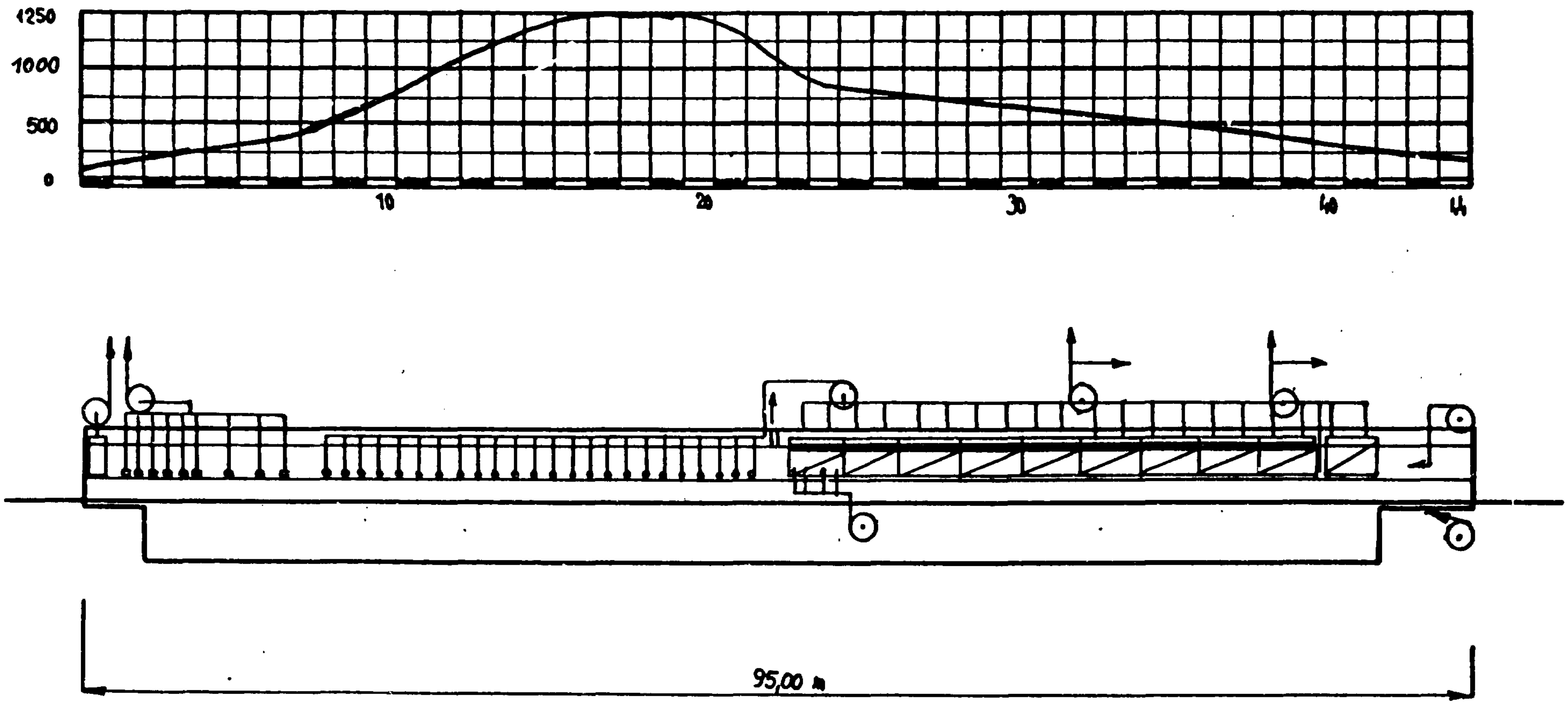


Fig.10

TECHNOLOGICAL SCHEME OF A TUNNEL KILN FOR ORDINARY FIRACLAY WARE

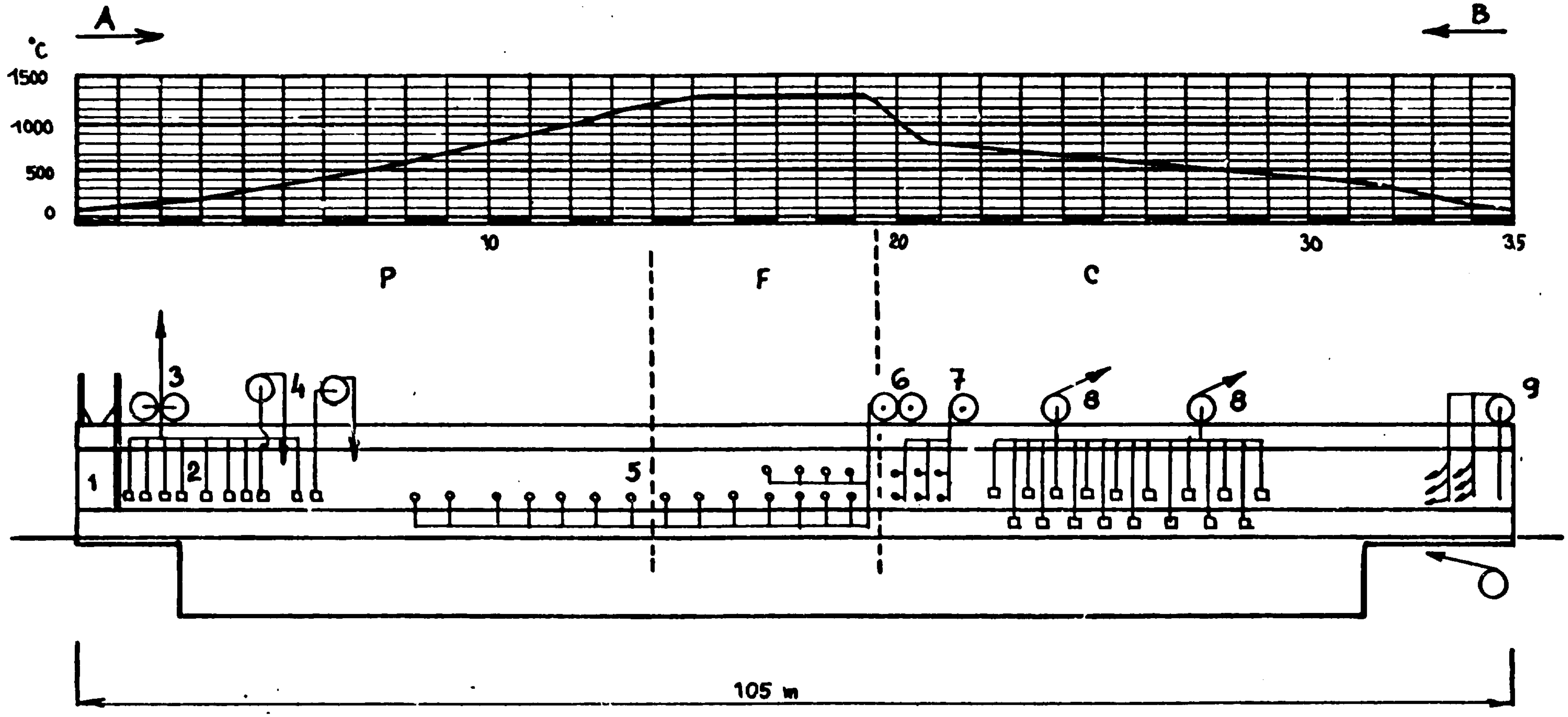
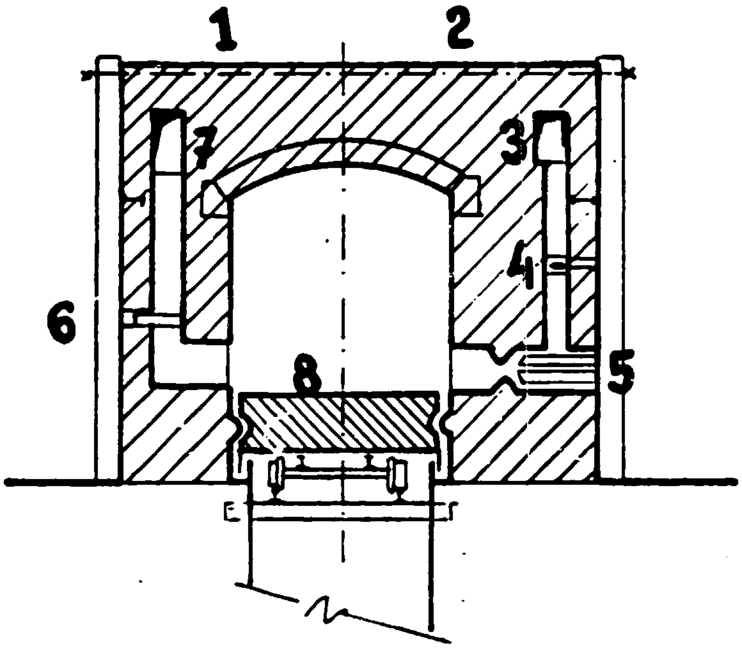


Fig 11

TUNNEL KILN WITH DIRECT HEATING



TUNNEL KILN WITH INDIRECT FIRING

FULLY MUFLE SEMI-MUFFLE

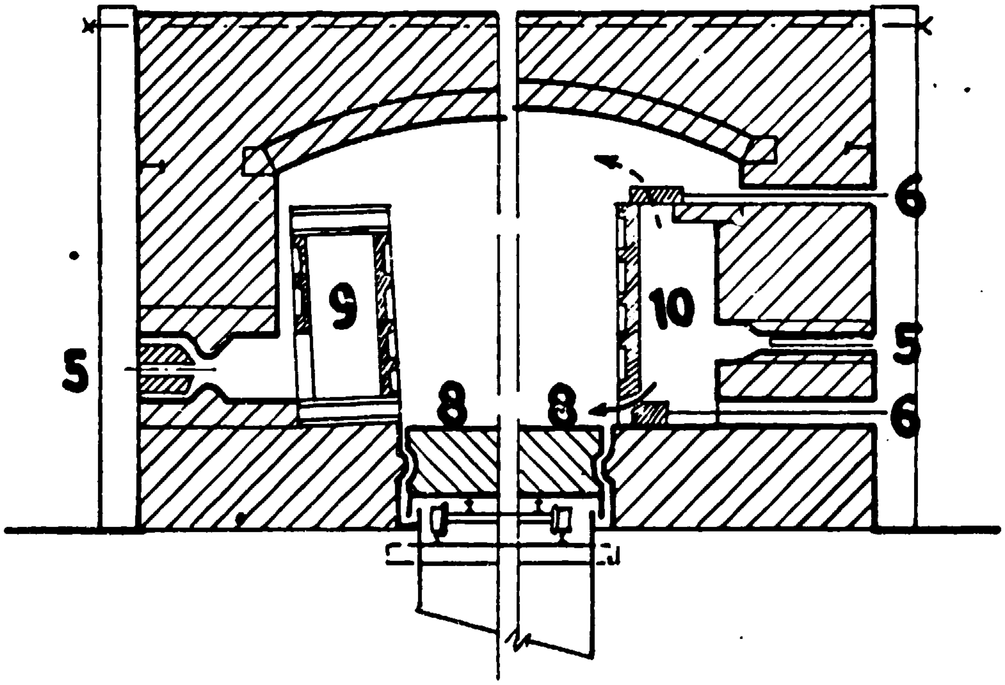


Fig. 12

WAYS OF INDIRECT AND DIRECT HEATING THE TUNNEL KILNS

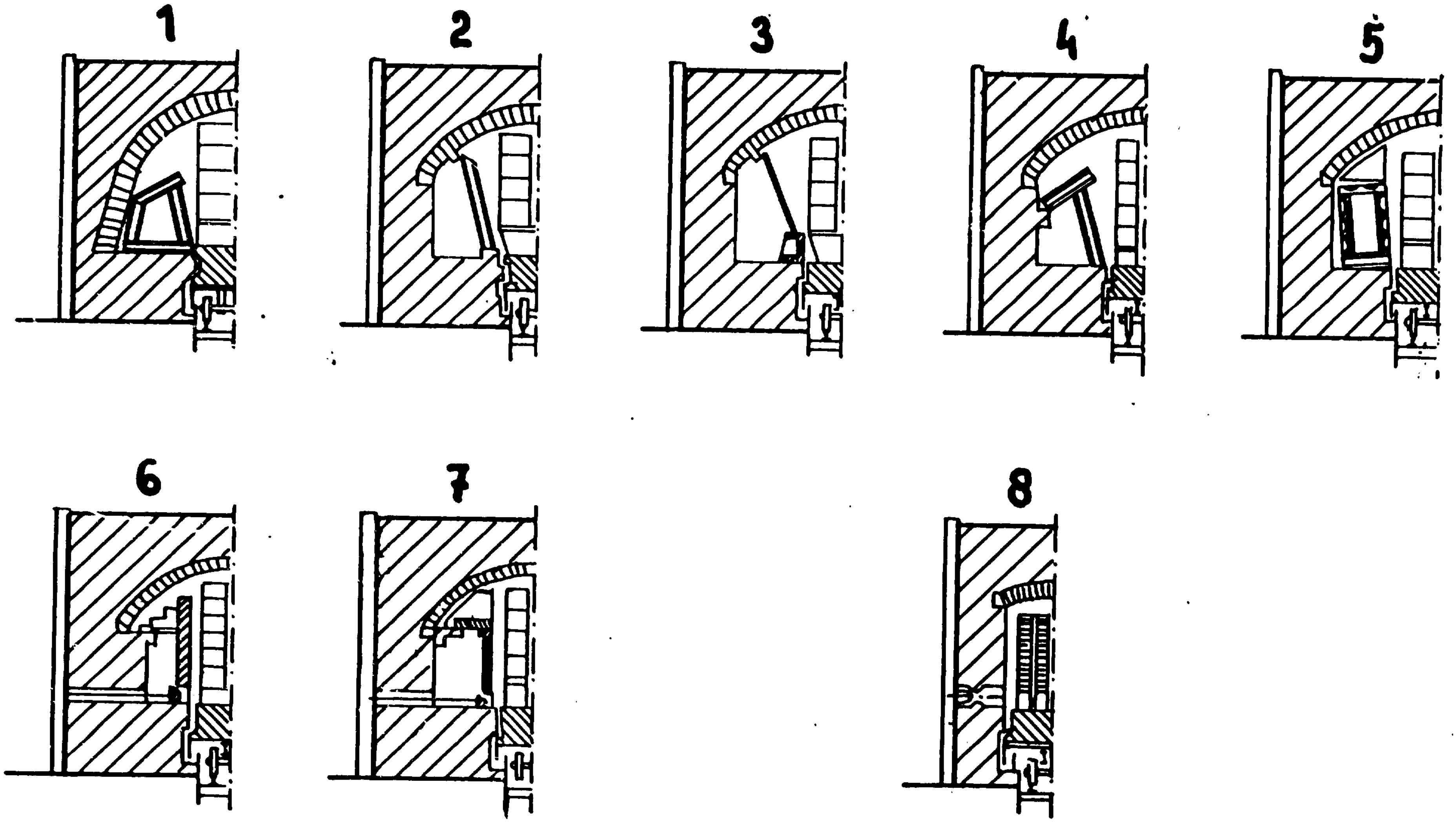


Fig. 13

SECTION OF TUNNEL KILN WITH SiC MUFFLE OF CARBORUNDUM Co (ENGLAND)

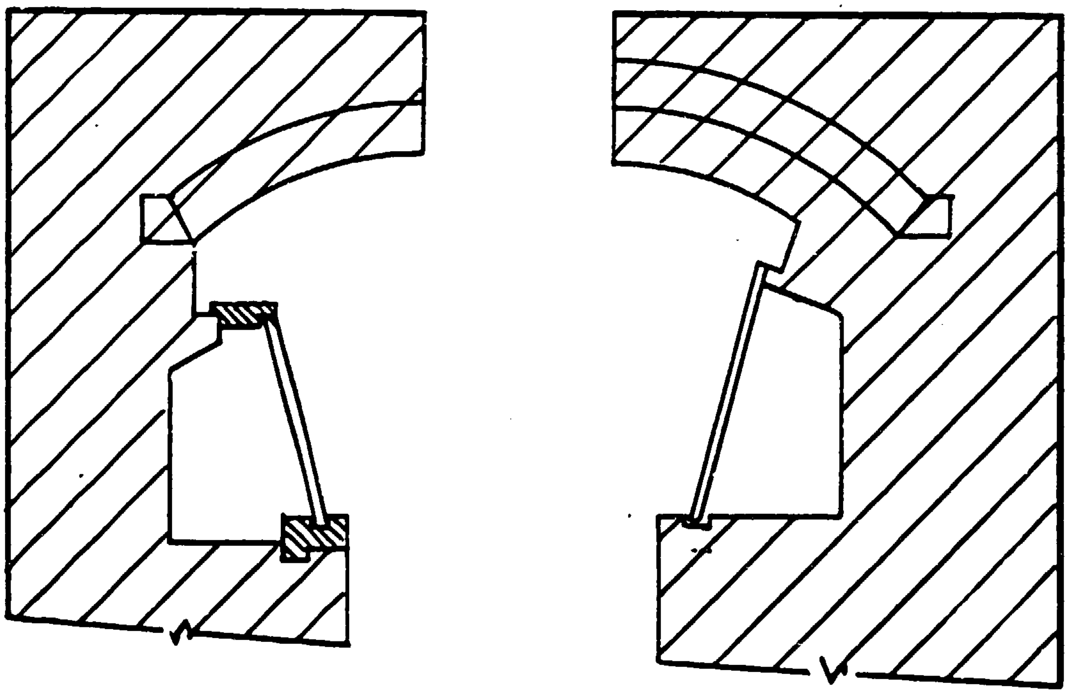


Fig. 14

TRANSPORT OF THE WARE THROUGH THE KILN

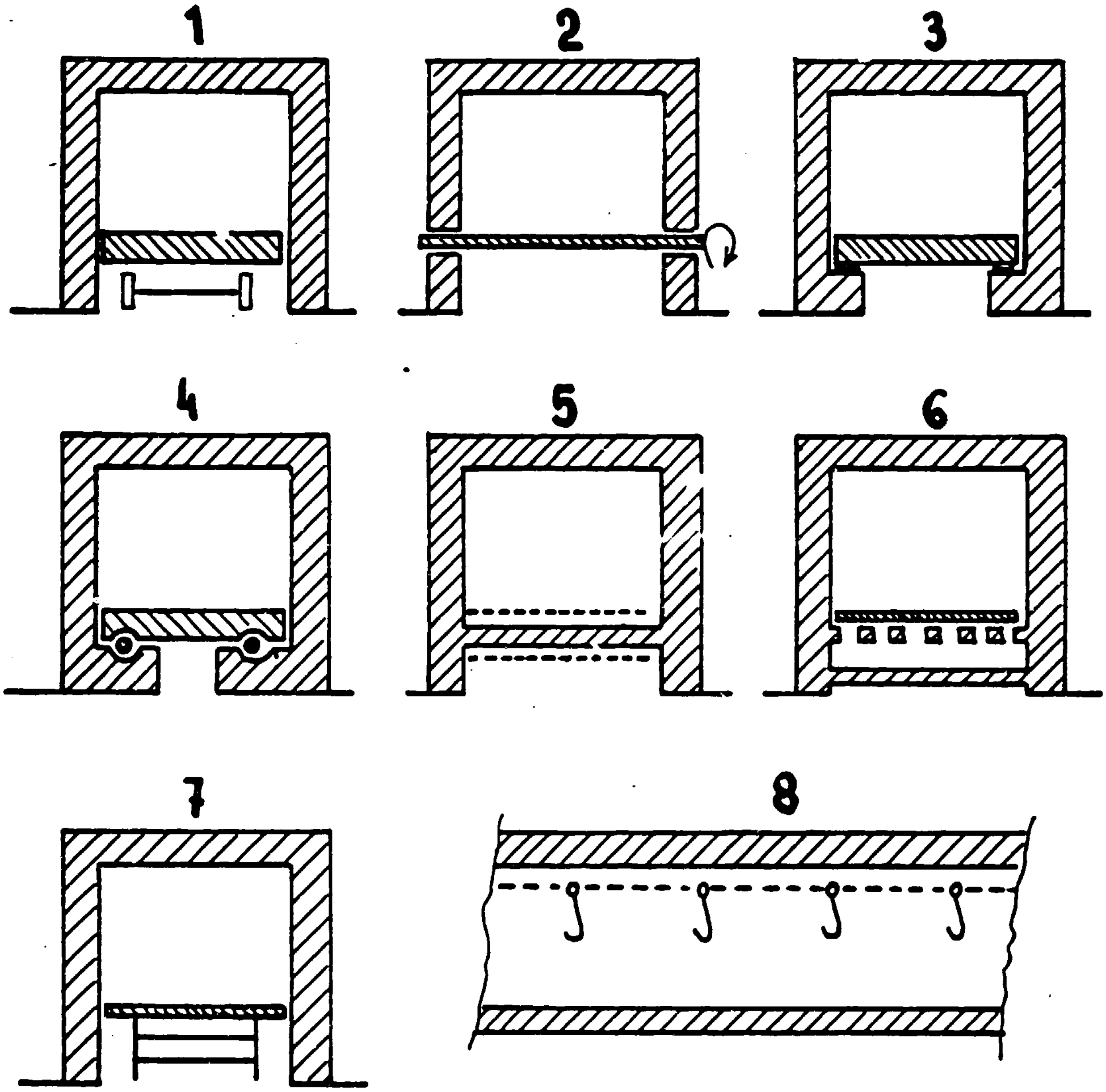


Fig. 15

BOTTOM-CAR (SHUTTLE) KILN

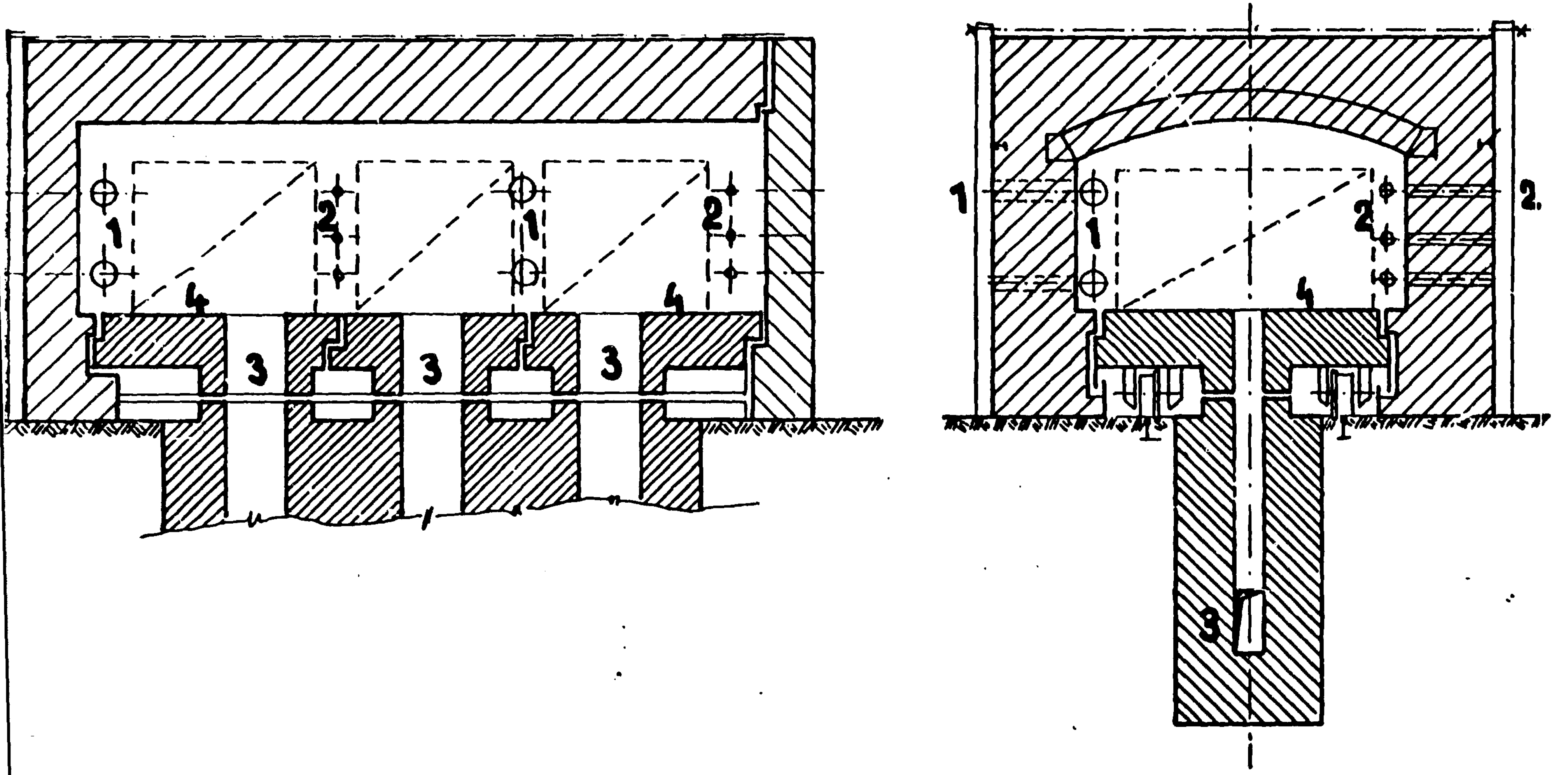
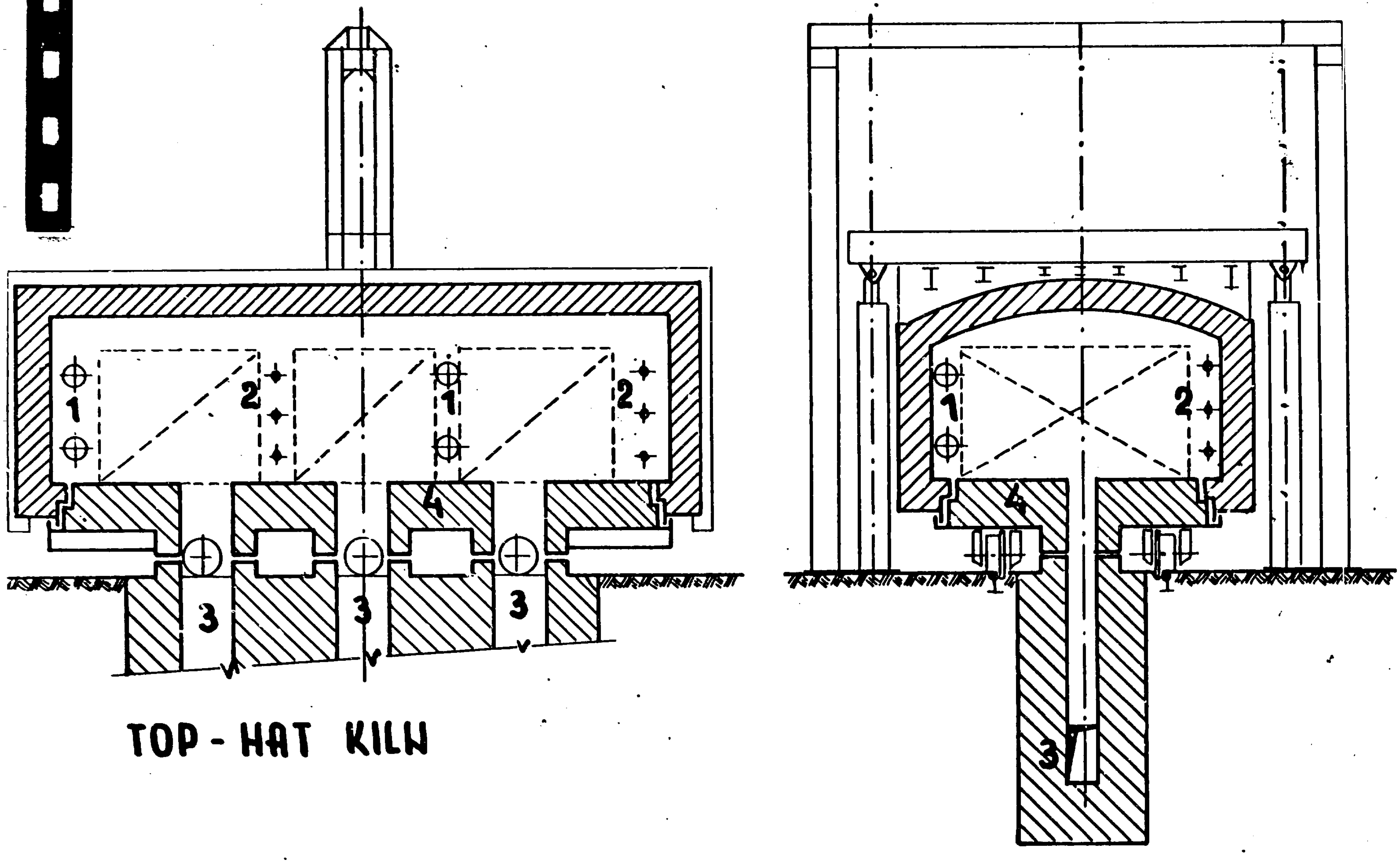


Fig. 16



TOP - HAT KILN