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In-Plant Training Workshop on
the Production of Refractories

Pilsen, Czechoslovakia

11-28 June 1974

OPTIMATION OF PRODUCT MIXING IN VIEW OF KILN AND FIRING REQUIREMENTS 1/

by

H. Gatske and I. Elstner*

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* Keramische Industrie-Bedarfs-KG Paul Gatske, Berlin, Federal Republic of Germany

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SUMMARY

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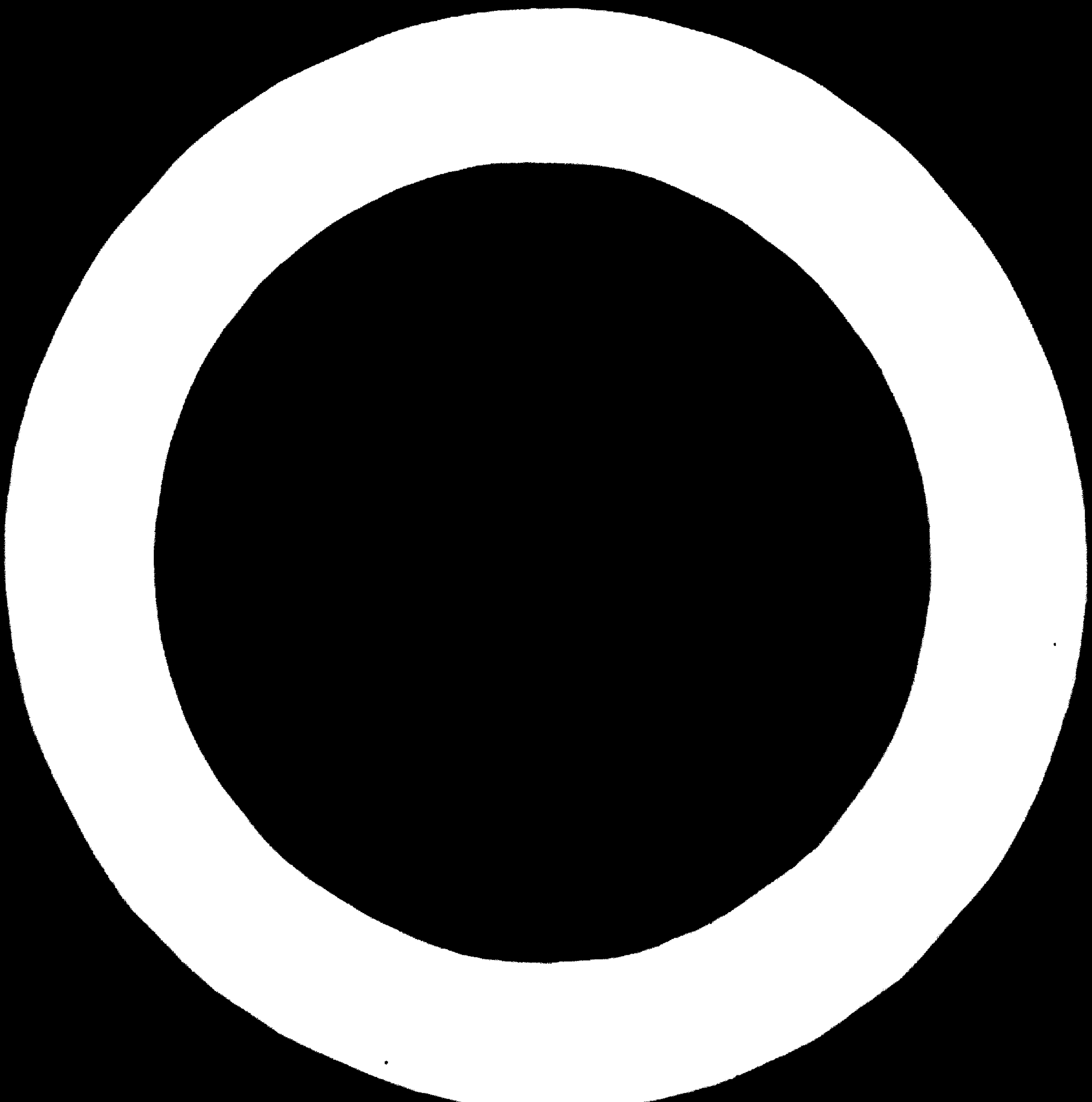

The ideal solution for a refractories factory would be to have a special kiln unit for each particular quality produced. However, to meet the demand of the market compromises in the form of product mixing is necessary.

Specific sections deal with the mix possibilities of the product groups fireclay bricks, silica bricks, high alumina bricks, highest quality and basic bricks and special refractories and illustrate the point that vast possibilities, especially within these groups, do exist if factors such as similarity in firing temperature and firing cycle, chemical properties, load bearing capacity of the bricks during firing, etc. are given due consideration. Practical examples of actual product combinations in tunnel kilns are given.

The setting technique and the drying of the bricks before firing is of the utmost importance for reaching a good firing result, and individual chapters are therefore devoted to those topics. In the chapter concerning setting technique special emphasis is placed upon the necessity to provide easy access of the firing gases to all parts of the firing goods and practical advice is given on how this may be achieved. The chapter also deals with ways of maximizing the output of a kiln and in this context the combination of various products plays an important role. The subsequent chapter on drying discusses general aspects of the technology and gives particular attention to the utilization of waste heat from the kiln.

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COMBINACIONES OPTIMAS DE PRODUCTOS PARA ATENDER LAS EXIGENCIAS EN CUANTO A HORNOS Y A CARACTERISTICAS DE COCCION 1/

por
H. Gatzke e I. Elstner *

RESUMEN

La solución ideal para una fábrica de productos refractarios sería contar con un horno especial para cada calidad producida. Ahora bien, la necesidad de atender la demanda del mercado obliga a arbitrar soluciones intermedias, es decir, a mezclar productos.

Distintas partes de la monografía tratan de las posibilidades de mezcla que se dan en los distintos grupos de productos -ladrillos de arcilla, de sílice, hiperaluminosos, ladrillos de gran calidad y básicos, y refractarios especiales- y dan idea de las vastas posibilidades de mezcla existentes, especialmente dentro de cada grupo, si se presta la debida atención a factores tales como la similitud de la temperatura y del ciclo de cocción, las propiedades químicas, la resistencia mecánica de los ladrillos durante la cocción, etc. Se dan ejemplos prácticos de combinaciones de productos realmente aplicadas en hornos tubulares.

Como la técnica de disposición en el horno y la operación de secado de los ladrillos antes de la cocción son importantísimas para que ésta salga bien, se les dedican sendos capítulos. En el referente a la técnica de disposición en el horno, se atiende en especial a la necesidad de que los gases tenga fácil acceso a todas las partes de los

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1/ Las opiniones que los autores expresan en este documento no reflejan necesariamente las de la Secretaría de la ONUDI. La presente versión española es traducción de un texto no revisado.

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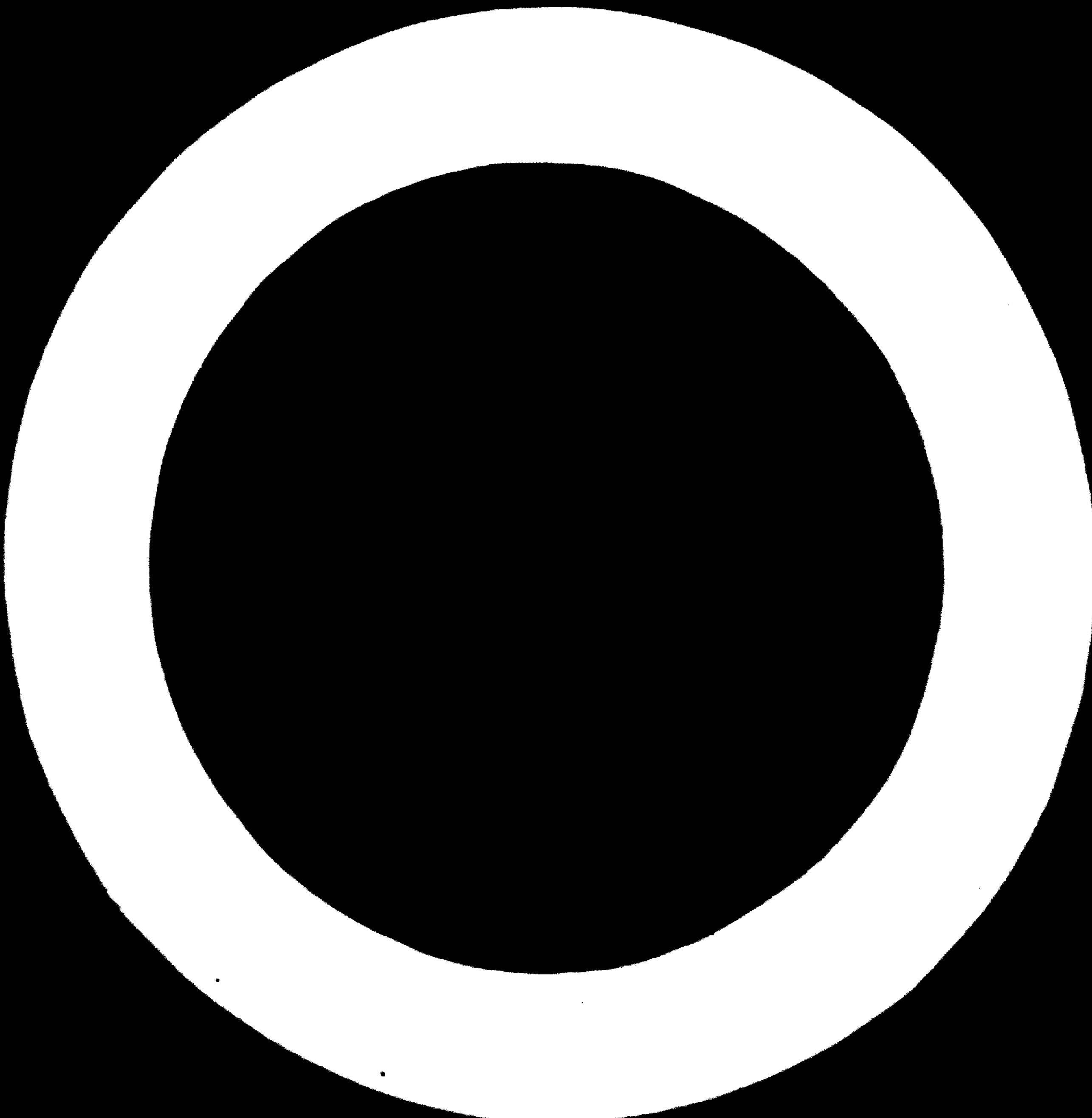
productos, y se dan consejos prácticos sobre la manera de lograrlo. El capítulo trata también de la manera de maximizar la producción de un horno, a los efectos de lo cual desempeña una función importante la combinación de los diversos productos. En el capítulo siguiente, que trata del secado, se examinan los aspectos generales de la tecnología y se presta especial atención al reaprovechamiento del calor del horno.



CONTENTS

INTRODUCTION

The theme of our talk is "optimation of product mixing in view of kiln and firing requirements, e.g. tunnel kiln". Decades of experience have taught us that there are no limits to the application of practice in the firing of ware types; a well conceived firing system can resolve any firing problem. A basic question, of course, is whether or not the quality of the resultant product justifies the cost of the equipment necessary for its production.

In the past a light ceramic plant was virtually a warehouse of mixed ceramic products. With the locally available raw materials one produced that ware which was in demand in the locality and that ware which could be relatively easily made in the firing equipment available. An old fashioned ceramic plant always had two preparation lines, one refractories and one for light ceramic products. In the refractory section setting furniture such as saggars or box type cranks, supports, balts and even thimbles and stilts were made together with any materials needed for the repair of existing kilns and the erection of new ones. In the second section the light ceramic body was produced and from it the sanitaryware, tableware or tiles.

As indicated previously all these products had to be fired together through or in whatever kiln equipment was available. The first picture shows how a typical production mix looked in those days:

Figure I: Combined setting on a non-modern earthenware plant which in earlier times would have all been in saggars. This could make available because of the thickness and volume of the saggars a considerable temperature difference, if such a difference were necessary, to fire the products to lower or higher temperatures.

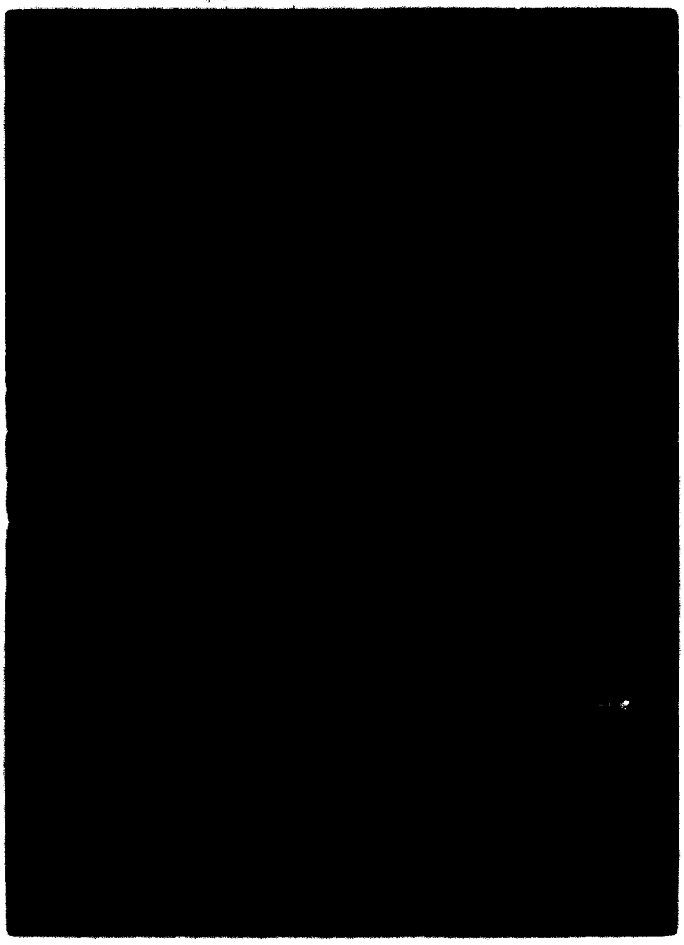


Figure 1

We wish now to examine the different combinations of product in a refractory production schedule.

A mixture of products is found on a refractories plant when the different types can be fired at the same or similar temperatures. Another reason to mix types is when a relatively high production capacity is catering for a relatively small market.

In the production of refractories we can differentiate between following groups:

1) Fireclay qualities
2) High Alumina qualities
3) Basic bricks
4) Acid refractories (acidic)
5) Special qualities.

Which types of kilns are available today for the economic production of these refractories?

1) Intermittent chamber kilns
2) Continuous chamber kilns (Hoffmann etc.)
3) Tunnel kilns.

In view of our extensive experience with the latter type of kiln we would like now to consider it.

Which firing conditions are needed by the major groups of refractory products, fireclay, high alumina, basic and acidic bricks? See the following table: (Figure 2)

Firing conditions for the main groups of refractory products:				
	Fire-clay	High Alumina	Basic	Acidic
1) Firing oC Temperature	1200-1500	1500-1750	1600-1850	1400-1500
2) Firing (hrs) cycle	35-80	70-120	80-140	140-240
3) Setting (mm) height	up to 1500	600-900	600-900	up to 1500
4) Setting type	pack	pack or blade	blade	pack or blade

Figure 2

Special quality refractories have their own requirements and we will later discuss the individual needs of the various types.

Generally speaking there is a rule in the refractory industry that a brick is more resistant to failure the smaller the chemical reaction rate to which it is exposed. This means that in the choice of products to be set together in a kiln we must observe, quite apart from any chemical reaction between the product and the kiln atmosphere, that different refractory qualities will react simply by contact with one another. Thus, in many cases, it is necessary to warn against the mixing of basic and acidic refractories in the same setting, contact must be avoided. This is a further factor controlling the degree to which products can be mixed together.

I. Production mix possibilities with similar refractory products

A. Fireclay qualities

In view of the previous comments one will therefore be able to fire all fireclay qualities together in a tunnel kiln with no special measures being necessary. To be more precise we refer to A O (+44 % Al_2O_3) to A III (32 % Al_2O_3) fireclay materials, acidic and semi-acid qualities for industrial furnaces and special bricks made from low iron fireclay material for the production of electric element supports etc. The firing temperature of these various products should not vary by more than 50 oC. Above the correct firing temperature fireclay products become brittle and start to bloat because of the excessive fused components in the body and the gas generated by the reaction taking place. Additionally the products may deform due to too low a viscosity in the liquid component of the mass. The nature of the raw material used and its composition is important in relation to the firing method used and the avoidance of excessive shrinkage. Bodies with high alumina content and kaolinitic clays show an earlier onset of firing shrinkage than siliceous and illitic clays. Quartzitic products, for example, can show little or no changes in shrinkage behaviour at temperature for a long time. With increased Quartz content, however, expansion effects appear which are conditional upon the β - α Quartz inversion at 575 oC and/or the / - β Cristoballite inversion as is made clear in Figure 3. Low shrinkage materials lend themselves to fast firing.

Both differing firing temperatures and differing shrinkage or expansion rates detract from a useful production mix. Acid or semi-acid bodies, often used as casting pit refractories etc., are fired at 1220 - 1295 oC whereas high alumina fireclay products are fired at between 1370 oC and 1450 oC. The highest quality, low flux, Flintclays are fired at up to 1500 oC.

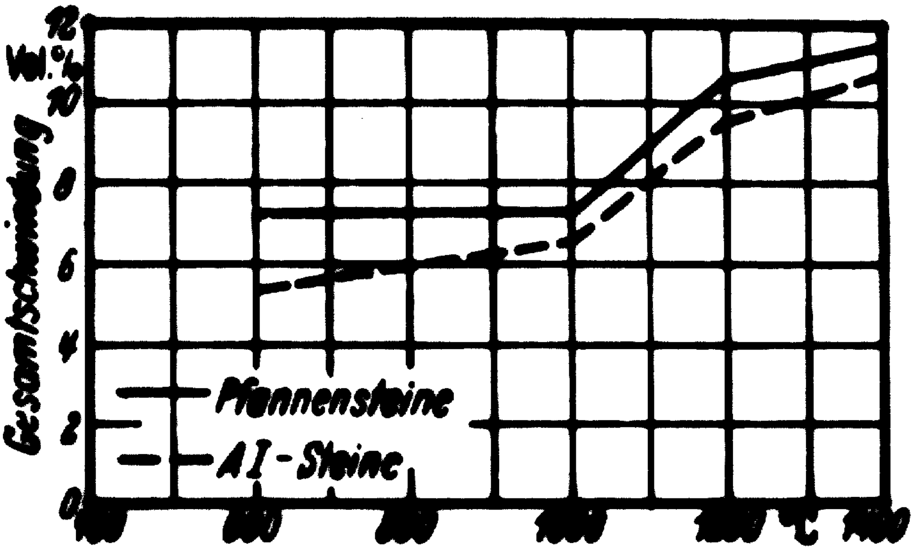

Vol.%
Gesamtschwindung
12
10
8
6
4
2
0
Pfannensteine
AI-Steine
°C

Figure 3

The use of periodic kilns means the existence of great temperature differences in firing. A successful solution can be found in the choice of a suitable production mix. In the hot spots (i.e. in front of a burner) one should place the high alumina materials and in the cooler spots the semi-acid bricks.

Differing refractory qualities can also be fired in the same tunnel kiln wihtout the need to alter its firing curve providing the pushing time is altered to give suitable periods, at the various temperatures, necessary for the respective products. The time-temperature relationship is, of course, very important in the firing of ceramic as well as refractory goods. Complete sintering can be achieved in such a way by maintaining necessarily high temperatures for longer periods to ensure the equality of those temperatures.

Conversely, with mixed settings and differing qualities, it is possible to induce faults by pushing the tunnel kiln too fast and hence remain at the temperatures necessary for too short a time. This can lead to shrinkage cracks and the incomplete burning out of any organic components present. If the times at temperatures are too short the product will not be clean burned and due to too severe a temperature gradient the organic components in the product will be reduced to carbon which will not be burned out because of the prematurely sealed pores of the outside layers of the material. Such bricks are rejected due to having brittle, friable black cores. Another fault which can appear due to frequent alteration of pushing times is the occurrence of spiders web cracks in the top bricks of the setting. In this case the temperature in the preheat zone falls to below dew point and water condenses on the top of the setting and the latter causes cracking upon being dried out again. This condensation can also dissolve salts in the body which later cause unpleasant discolouration and can even lead to patches of premature fusion.

What are tunnel kilns like which are suitable for firing different fireclay qualities? The firing temperatures must lie between 1200 oC and 1500 oC. The length of the kilns is between 100 and 120 m and the cycle between 60 and 80 hours. A rule of thumb method is to reckon production in tons per day equals length of kiln in metres. These relatively short kilns are possible due to the use of setting only 1.5 to 2.5 m wide and 1.4 to 1.7 m high with direct quick cooling immediately after the main zone. This rapid cooling can, however, only proceed to just above the crystal inversion temperature of the glass phase in the brick, about 700 oC to be safe. The subsequent cooling must proceed slowly enough to give a marked temperature difference across the car setting. This slow cooling must also last long enough to relieve all stresses induced by the previous rapid cooling.

The preheating gradient is about 30 oC to 40 oC/hour whereas the subsequent slow cooling gradient is only 20 oC to 30 oC/hour. Fuel consumptions of 500 to 600 kcal/kg can be achieved. Setting densities are around 800 kgs/m3 so that the kilns have an overall content of 130 to 230 tons and produce between 1100 and 2800 tons monthly.

Figure4: A combination of firing faults - black cores, crow's feet, flame impingement and slumping.

Figure 5: Fireclay qualities.

Figure 4

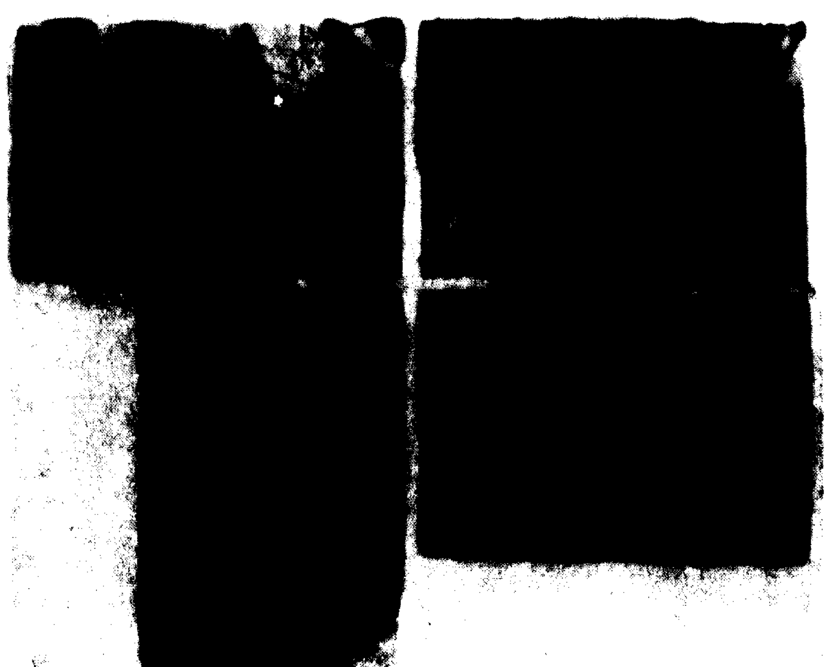


Figure 5

B. Acidic bricks

Fireclay tunnel kilns can also be used to fire Silica products which need a firing temperature of 1400 to 1450 oC. Due to the severe and rapid volume changes occuring with the inversion of Silica to its various forms, certain definite modifications must be made to the preheat and cooling curves or great production losses will result because of cracking.

Normal Silica tunnel kilns are up to 200 m long, have a setting width of 2.00 to 2.50 m and a useful setting height of 1.50 to 1.75 m. Fuel consumption is about 1200 to 1300 kcal/kg and the setting density varies between 850 to 1000 kg/m^3 of the space available. Such kilns have a capacity of about 40 to 60 tons per day, coincident with a firing cycle of about 240 hours. A suitable temperature breakdown (curve) for the length of the whole kiln is shown in the following picture! (Figure 6)

Should a fireclay kiln sometimes be used for the firing of Silica then its brickwork must be suitably constructed in the sidewalls from good A I or A 0 quality firebricks whilst the arch must be made from Silica bricks. The burner ports would, preferably, be lined with Sillimanite or High Alumina bricks.

In view of the long firing cycle for Silica it is important, above all else, to adequately insulate the kiln cars and to provide them with a false setting deck, so that there will be little temperature difference over the whole setting.

It should not be forgotten that the output of a fireclay tunnel kiln will fall considerably when periodically firing Silica due to the fact that the pushing time is 3 to 4 times as long.

Naturally fireclay qualities can also be fired in silica kilns and providing they have suitable crushing strength they can be mixed in with a silica setting. This opens up the possibility of making optimum use of the tunnel kiln's capacity in spite of market fluctuations. Understandably the fireclay in this case would be fired at a rather wasteful fuel consumption level but this can be considered in relation to the overall economical use of the kiln. A silica tunnel kiln is shown in Figure 7, below.

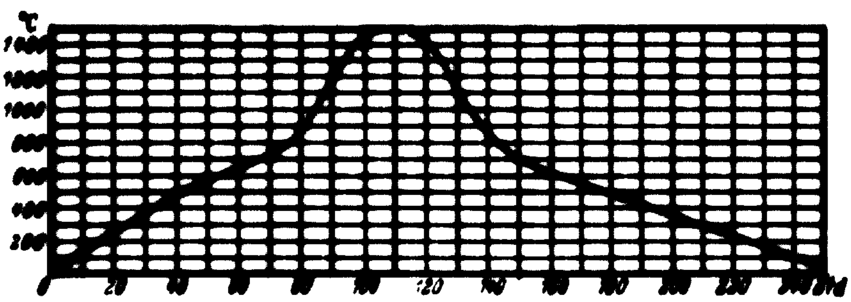


Figure 6

Figure 7

C. High Alumina bricks

Another possible firing combination one finds occasionally is that of various high alumina products which are firsd at about 1500 oC. To name a few we have Sillimanits, Mullite, Bauxite and Corrundum products which vary in alumina content from 70 to 80 %.

In planning a setting one must pay attention to the fact that the brick containing the greatest quantity (%) of alumina will be most prone to deformation under load.

Care is also necessary when firing Bauxite and Corrundum bricks if the Bauxite used is insufficiently calcined and therefore has a poor resistance to volumetric change.

One can reckon on reducing the large shrinkages occuring in Bauxite bricks by making small additions to the body of 0.5 to 2.0 % by weight of alkali sulphates, chlorides and fluorides, e.g. Sodium or Potassium Nitrate or Borate at about 1 %. As a consequence of these additions the kiln will have an alkaline atmosphere which can be meaningful as Corrundum will convert readily to Alumina at high temperatures in these conditions. Therefore an approximately 25 % volume expansion would occur which would render the Corrundum bricks in kiln lining useless due to excessive friability.

Kilns which are specially designed for the firing of high alumina products differ in construction and equipment hardly at all from fireclay kilns. Because of the higher firing temperatures the refractory construction would be made from higher qualities, the fireclay qualities being of no further application would be replaced by Sillimanite, Mullite or Silica bricks. Silica bricks can be used for such kilns, however, only when it can be guaranteed that no alkaline atmosphere will be present. For refractory plants the choice of a kiln with an high quality brickwork lining offers great possibilities in varieties of use. Todays kiln control equipment is developed to such an extent that a simple single adjustment to a temperature controller on the kiln control panel will automatically give the desired temperature change up or down. Fuel, drought and combustion air supply adjust themselves without any manual attention. Occasionally it is necessary in the firing of refractory products to alter the pushing time and even to push a car of scrap to bridge the change-over. The firing of high alumina materials is carried at on cycles of 80 to 120 hours with preheating gradients of 20 to oC/hour and cooling rates of 15 to 20 oC/hour. Production outputs of 60 tons/day would be achieved with setting densities of 900 to 1150 kg/m^3 and fuel consumptions of 650 to 750 kcal/kg fired.

The following slide shows a kiln which really does fire a variety of products.

Figure 8: Combinated kiln (main zone).

This kiln would be suitable for firing a varying programme of fireclay of 30 to 42 % Al_2O_3, Bauxite, Corrundum, Sillimanite and Zirconia refractories and would operate at a maximum temperature in the range 1400 oC to 1600 oC. Output is 50 tons/day of high alumina material of 57 tons/day of fireclay bricks. The kiln is 115 m long, has a setting width of 1.50 m and a useable setting height of 1.10 to 1.35 m. Pushing times vary from 100 minutes for high alumina materials to 60 minutes for firebricks so that the whole range of cycles from 63 to 103 hours is possible. The particular part of the kiln construction which lends itself to the firing of varying products is the firing zone with its 58 burners. When operating normally at temperatures of about 1400 oC only the 24 burners of the two lower rows would be in use, the 8 of the top row being off. If the kiln then has to operate at 1600 oC the upper and middle burner rows would be used. The reason for this

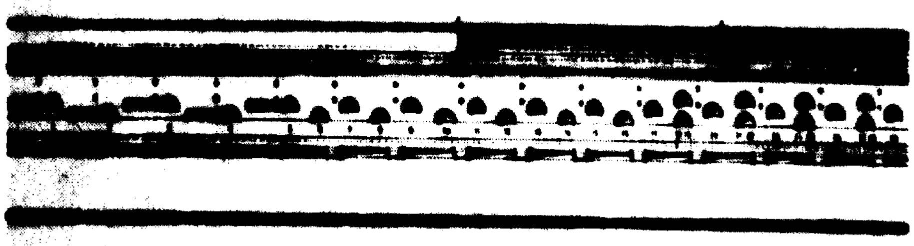


Figure 8

change can be explained as follows: in normal firing the setting should be so chosen and arranged as to provide access to the centre of the pack for the products of combustion via channels or flues. In the lower part of the setting cross-flues should be left which are at least 2 bricks high and a minimum of one longitudinal slot should also be left which is about 1/3 of the setting height. This arrangement provides relatively unrestricted entering to the setting for the hot gases. It is a fact that a flame will readily proceed upwards whereas it requires a great deal of kinetic energy to be forced downwards. With the sort of setting described above the physical nature of the process of combustion and hot air movement is used to give a good and even heating all over the setting.

When firing at 1600 oC on the one hand the product is so heavy that the use of a smaller setting height is necessary to hinder deformation of the material and on the other a great deal of extra insulation of the kiln car top is required. On the higher temperature campaign better insulation of the car top and the longer firing cycle both assist to achieving of the higher temperature. It is common practice here to assist the process by setting a 25 cms course of high quality fired standard squares right across the car top. It is now obvious why the bottom row of burners can no longer be used.

A change-over from a 1400 oC to a 1600 oC campaign is very easily conducted. On the control instruments the required temperatures and pressures are set and the kiln adjusts itself to the new set of conditions more or less automatically. Because the change from one type of firing to another does not occur daily, it is usual for the lighting or turning off of burners to be carried out manually. An automatic arrangement for the alteration of burner settings is possible but seldom found in practice.

D. <u>Highest quality and basic bricks</u>

If a refractory plant decides to produce special products from the highest quality refractory bodies, the use of an "High Fire Tunnel Kiln" becomes necessary. In such a kiln materials can be fired at up to 1850 oC (actual product temperature). Temperatures of 1700 oC and above are necessary for the firing of the highest quality Corrundum bricks, which employ alumina as a binder, direct bonded Magnesite and Chrome-Magnesite bricks. Such kilns can also be used to fire Spinels, Mullite, Forsterite and Chromeore products.

How do these High-fire tunnel kilns differ from other tunnel kilns? The weakest point in a kiln's design is its arch. One should preferably strive for the narrowest arch possible, but this means a strictly limited output from the kiln. Therefore our company decided to design and build kilns of such widths and setting heights that the materials, operating at the aforesaid temperatures, would just be capable of undertaking the duty and lasting successfully. These kilns have been developed with a cross section of 1.00 m x 3.00 m.

The major problem when firing at high temperatures is naturally the correct choice of the inner lining materials of the kiln brickwork. Such materials should give the largest possible life when working at 1800 to 1900 oC so as to reduce the chance of interruptions in production and give the kiln equipment, with its very expensive constituent parts, an output sufficiently great to ensure the achievement of the planned amortisation (write off period). In accordance with the prevailing technical and economic situation in the refractory industry, the use of special magnesite products and fusion cast alumina bricks can now be considered for kiln construction.

The use of a wide arch naturally means the load on the buttress blocks will be great and in design discussions the merits of sprung buttress blocks were considered against the more normal solid brickwork; eventually it was decided in favour of the latter.

The materials used for arch, sidewall,bench and even springer blocks must all be of the highest temperature resistant quality and these materials have the unfortunate disadvantage of being good conductors of heat. This condition makes necessary the taking of measures to inhibit the egress of heat from the kiln brickwork into the supporting steelwork. This can be achieved by the use of an "autothermic" cooling system which cools the arch, springer blocks and kiln bench.

Another problem is that of the actual burner equipment. The demands of an high temperature kiln are such that the burners should impart their heat energy to the innermost part of the kiln car setting. Here the use of oil firing with its flame temperature of about 2.200 oC is most obviously suitable. Naturally gas firing can also be used but only with the simultaneous use of preheated combustion air and this gives rise to more complicated pipework systems than are needed for oil firing and this in turn gives rise to different problems in kiln control. In both these cases of oil firing and gas firing the burner itself must be protected from the intense back radiation from the product at a firing temperature of 1800 to 1850 oC. Through the use of the latest insulation techniques the kiln wall thicknesses of these high temperature kilns have been reduced to about 90 cms, and therefore it has been possible to successfully cool the burner components which protrude into the kiln and protect the same from overheating and damage.

Naturally the kiln car brickwork must also be up to the demands of high temperature work. Care must be taken to design the car brickwork to be as well insulated and yet as light as possible and at the same time it should be strong enough to maintain a smooth and even setting deck which will not induce deformation in the product and hence losses.

Every kiln must operate under certain specific pressure conditions so as to maintain the temperature and heat balance in the kiln and this means that the design of the sand seal must be suitable. Also here it has been possible to develop a new techniqus giving rise to the so called "aerodynamic sand seal". This system maintains air flows such that there is no pressure difference across the sand seal itself.

As far as fuel consumption and firing cycle at 1850 oC are concerned it can be stated that a kg of material can be fired with 1200 to 1350 kcal in an overall cycle of 80 to 140 hours.

Kiln car dimensions for these special kilns are dependent upon the size of the setting packs which in turn are dependent upon the standard brick sizes of the individual manufacturer. We have found that an overall pack size of 220x70x70 cms is the most useful.

The following pictures give an idea of the many types of high temperature refractories available and it is also advisable here to find setting combinations which,under certain special conditions, lend themselves to the convenient firing of those various qualities and shapes. This leads to the many types of setting as, for example, the uniform pack for equally dimensioned bricks, the setting with widely varying shapes and even the setting suitable for hollow shapes.

Figures 9, 10 and 11.

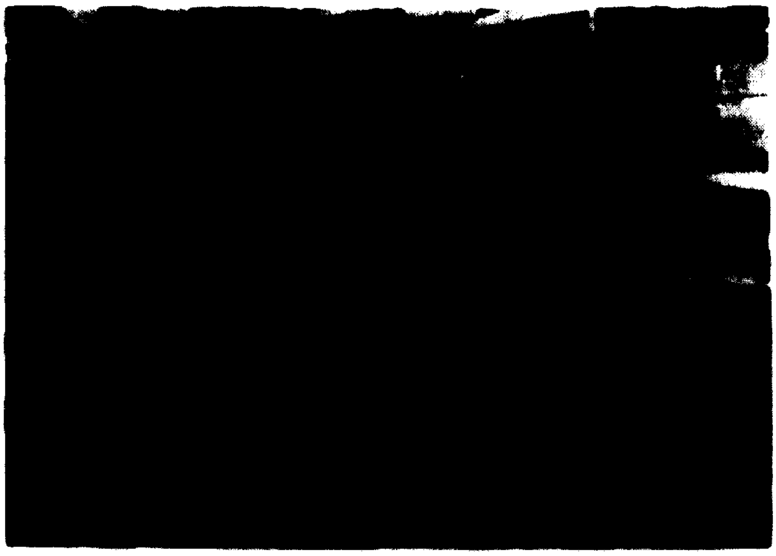


Figure 9

Figure 10

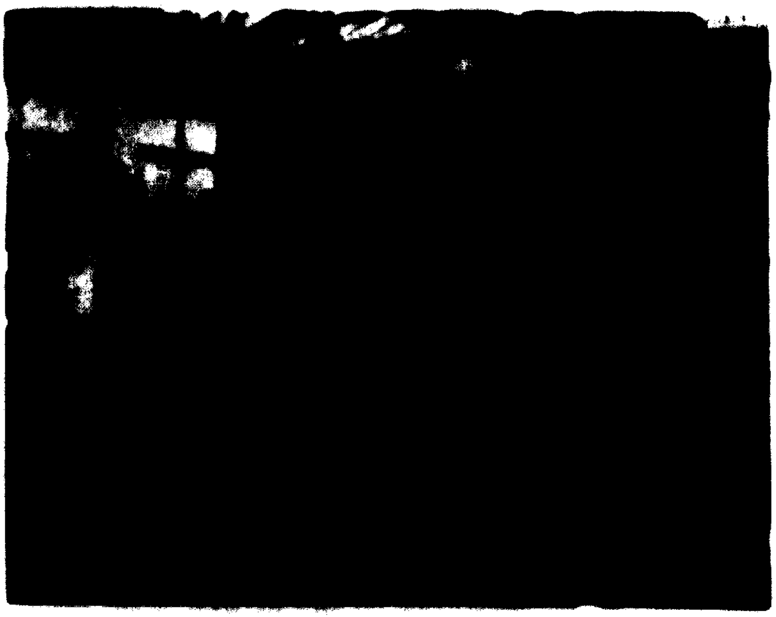


Figure 11

E. Special Qualities

These special qualities require a different heat treatment from that described above. In this context we have to consider porous and lightweight insulation refractory bricks. In respect of actual firing temperature they are suitable to be fired along with appropriate quality solid refractories but their gross setting density does, in many cases, necessitate the use of a different firing curve. Because of the additives used to high fired porosity these qualities differ in usually requiring a very oxidising atmosphere. In part these pore generating additives have the inconvenient property of gasifying. This leads, under certain conditions, to the ignition of the gases produced and increases in temperature in areas of the kiln where such increases could damage the ware. Here the mixed production of solid and insulation bricks has developed a useful setting. the heavy solid refractories absorb any extraneous heat given out by the premature "burn out" of the insulation products and at the same itme tend to help in diluting any reducing atmosphere so generated.

Carbon refractories, another special product, on the other hand require a completely different treatment in firing. These products are set upon conventional kiln cars in saggars and are packed around with coke dust or fines which enables them to be completely surrounded with a continuous reducing atmosphere. An example of this kind is shown in Figure No. 12.

Initially carbon products were fired in this way on saggar cars which were pushed through the tunnel kiln along with normal refractory bricks and neither was affected by the other.

The last example of a special product will be given in a few words concerning the use of silicon carbide containing materials for tunnel kiln construction and for kiln car furniture in the

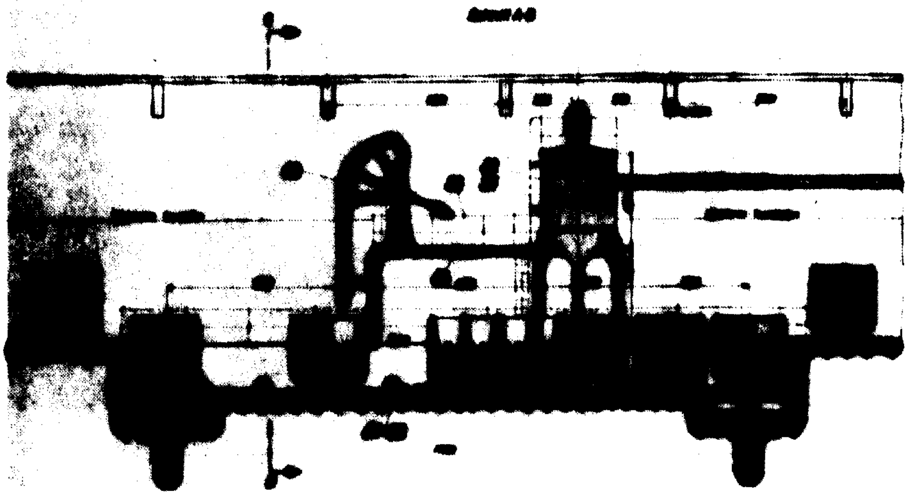


Figure 12

Figure 13

light ceramic industries. SiC materials have proved, by experience, to be suitable for firing along with certain other refractory qualities which need the same temperature and kilning conditions. In order to guarantee success here it is merely necessary to ensure that consecutive kiln cars are loaded to equal weights so producing a regular rhythm in the kiln and avoiding unnecessary temperature rises and falls which would otherwise be caused by uneven loading. It therefore follows that in a works producing only SiC materials ideal conditions would exist for ensuring this evenness of loading.

(See figure 13)

Cordierite and other quality setting furniture products behave in a similar manner to the previously described SiC materials and it is only necessary to remark upon the need for different firing temperature requirements.

This last really good example of product mixing in the refractories industry concerns glass tank blocks. In the first case we consider a special kiln solely for the production of differing quality glass tank blocks. Here the firing conditions must be adjusted to the needs of the largest block. In the second case where conventional smaller refractories are made alongside glass tank blocks the kiln car setting must so be arranged that once more a uniform kiln car loading is guaranteed. Naturally the progress of the car through the kiln will be governed by the sensitivity of the glass tank block and due thought must be given to this in planning.

(See figures 14, 15).

Figure 14

Figure 15

F. General considerations to be given to product mixing

In conclusion it can be said that the following points apply to the mixing together of refractory products for firing:

Before the actual planning of a tunnel kiln the future market trends should be analysed in order to obtain an idea of likely variation in quantity of the products to be made. To arrive at suitable product quantities, it can be more economical to plan a tunnel kiln programme so that additional products not really lending themselves to tunnel kiln setting are fired in intermittent kilns of the lifting hood or car operated type. It is true that intermittent kilns generally consume twice the amount of fuel as do tunnel kilns but the latter type rapidly loses its economic advantages when small series products are fired and so interrupt continuous and stable conditions; quite apart from the fact that single items are seldom fired to the desired conditions. It must also be decided whether or not additional investment can be justified for the firing of these small quantities in view of the fact that these very different shapes already require additional investment in equipment right through from body preparation to pressing and additionally the investment needed for an intermittent kiln can easily approach the cost of a small tunnel kiln.

In arriving at product mixes on a tunnel kiln one should strive for long runs and change as seldom as possible the shapes set. In arriving at such conditions one can either produce simultaneously a great many different shapes and qualities or one can use a storage area as a buffer.

When changing over from one firing curve to another the preheating and cooling gradient change as do the zonal temperatures and the times at these temperatures. One can often ease the situation here by the use of buffer cars laden with materials having a very wide and accommodating range of temperature requirements. The most useful situation of all is when the buffer cars allow gradual alteration of both the preheating and cooling zones.

II. SETTING TECHNIQUE

A good and thorough firing in a tunnel kiln depends mostly - along with the firing technique and gas circulation - on the setting technique. An old saying goes "Well set is half fired". This is true not only for the tunnel kilns, but earlier also, this was the rule for periodic kilns. An inadequate setting would lead to a number of firing defects in spite of having the best firing technique and fire circulation.

In case of refractory products we first have to differentiate between two different firing systems viz. continuous and periodic push. The systems differentiate themselves not only through the pushing art of the kiln cars but specially also through the burner arrangement, so that the firing can be carried out in one way continuously on the settings or under it, or in another way, in the so called firing slits.

In general, the most suitable process is considered to be the one in which the green material is continuously pushed forward so that they are continuously preheated, fired and cooled. For a thorough soaking, it is recommended to have horizontal and vertical slits in the setting. For continuous pushing of the kiln cars, the setting is carried out mostly in layers with a few big horizontal slits and according to the furnace cross section in direction of the kiln axis, two or more slits are put on near a middle slit. The horizontal slits, which run from a side of the kiln car to the other, have the task to allow the firing gases during a continuous movement to circulate right to the core and then flow through the slits in direction of the kiln axis to the kiln entrance.

Quite often, this method cannot be used. This is mostly the case with a long firing time, i.e. when the kiln cars are moved forward very slowly. Here the danger exists that by a continuous process the outer bricks of the settings would be overfired because the

flame

lingers over each brick a longer time. In such cases we must go back to the periodic movement. To give the firing gases enough chances to carry and transfer the heat, wide slits are kept in fixed distances between the setting blocks in which from both sides the fire is directed. Setting slits along the axis give further possibilities for the gases to come in contact with the material. To avoid overheating in the middle of the cross slits, the burners are so fixed or regulated that the right and the left burners exchange short or long flames.

For firing refractory products, occasionally an undersetting is used. Hence there are enough big channels, through which the firing in general is easier than other practised methods, where the firing material is directly placed on the kiln car platform. While firing with undersetting, kiln furniture or setting hoops are required whose use is limited. The undersetting should be light so that the load can be quickly heated up and cooled. Therefore a good heat-flow is required of the kiln furniture. On the other hand they must possess enough resistance under load to fire to eliminate deformation during firing. That means the setting height depends on the refractoriness of the undersettings.

Where are then the advantages of a load with undersettings? As has been said before, it is a fact that it is easier for a flame to fire from bottom to top than when the flame is forced due to a higher kinetic energy to fire from top to bottom. Due to this the undersetting has the same function as of the roastplate of a garden griller. If the thermal energy is allowed to flow in its natural way, from bottom to top, then by continuous pushing a thorough firing is attained. The ideal form of heat transfer from bottom to top and a continuous pushing are the best conditions for a good firing and allow high firing speed. Precondition is naturally that the raw material and the formgiving allow a quick firing.

During setting, we first have to consider the setting height, which according to firing producte may vary a lot. Of course, the raw material, the compoeition, the formgiving and the firing temperature play an important role. Therefore it must first be cleared what material is to be fired in the kiln in question, the maximum firing temperature and the behaviour of the raw material and the composition.

Let ue think for example of the two opposite products, wet pressed fire bricke to be fired say at 1400 oC and a high pressed magnesite brick of special compoeition to be fired at 1850 oC. In both cases it is advisable not to have too high a eetting height. The wet preseed fire bricks deform due to their high shrinkage, the magnesite bricke due to the excessive temperature which brings the material to the limit of their softening point.

An oderly kiln car setting is always chosen, when the firing material can be eafely stacked with enough distance between the blocke. Such settings can be pushed through the driers very well and after the necessary intensive drying, such settings can be eaeily heated up in the preheating zone leading to a problemless firing and cooling.

There ie no question that every company strives to attain the maximum capacity from their kilne. As much as poeeible material with a high eetting density (kg/m^3 firing space) with a quick pushing time are to be pushed through the kiln. Theee wishes naturally have their limits:

1) due to the possible speed of heat transfer from the firing gases to the goods to be fired
2) due to the fuel type and
3) due to the method of formgiving to the products.

A good heat transfer possibility from the firing gases to the firing goods is given when the gaces can linger on the material. This can be achieved through a corresponding loose kiln car setting. This means a lower setting density than is generally practised. Only so, after a thorough study, a higher firing speed may be realised, which results in a higher kiln capacity than that which is possible with a densely loaded and difficult to heat up setting.

In many cases it is not possible for refractory products, due to the raw-material composition, to have a high firing speed as well as a dense setting. This is especially the case when the raw materials contain organic substances as impurity, which during preheating must fully burn out. If any rest of organic substances come to the sintering zone of the kiln along with the product to be fired, then a black core is the result.

Anyone from the refractory industry knows that such bricks with a black core are not only ugly but may also lead to reclamation. If under circumstances refractory material containing bitumen come under the influence of changing kiln atmosphere, it can lead to a full sintering of the whole car setting.

Here only the setting technique helps, where one chooses a light and loose setting where the gases can flow. The setting must be so loose that all the organic material may fully burn out during preheating. That means corresponding oxygen concentration must be able to be brought, without any difficulty, to the product to be fired, and the firing must allow the necessary period of uniform preheating.

A very good and practical help for loose setting has been given us - the fingerwidth. It guarantees in case of manual setting the necessary distance that is to be kept between two bricks, without bringing them together. In most cases this distance is enough to lead the firing gases to the products to be fired for an intensive heat transfer (chemically bound water and sulphur products are given to the flue gas).

Apart from the setting technique, the kiln construction is of immense importance for an adequate burn out of the organic components. Good control of the preheating and firing zone is just as responsible for the uniform firing as a clean loose setting.

Strewing sand is a further help for a good burn out in our refractory products. However, this is disadvantageous for the setting, as during heating up and cooling the well known phase change occurs, through which tearing and distroyance of the car cover settings take place. In most cases it is not possible to dispense of this help. A packed setting on top of one another is avoided. During manufacture, the refractory bricks vary slightly in their dimension, so while setting them one top of another in a number of layers, under circumstances, a few centimetres difference is found. Only through strewing sand is this balanced.

For refractory products, certain differences are to be kept regarding the setting technique. We differentiate between stiff plastic, dry pressed and slip cast formgiving processes. Apart from these manufacturing processes, the shape of the firing product is to be considered too. Thinking about the problem of burning out the organic substances, they are naturally acute in the products manufactured by the wet process, as in the dry pressed process a high percentage of grog is present which is prefired. Not only the setting is done according to the products manufactured, also the atmospheric conditione during preheating and firing are fixed by it.

One should be careful that in case of big sized products, they should be fired in a number of kiln cars, one after another. Firstly due to their size, the firing process is slower, requiring a longer soaking period and secondly quick setting changes bring a turbulance in every tunnel kiln which may easily cause considerable temperature difference over the cross section of the kiln.

Very often there are the running-in difficulties for new factories because of not having a person with enough experience on setting or because of the absence of routine of a number of years or the failure of overseeing capacities of the full product range to be fired. There is no end to the richness of ideas that constructors and engineers possess and similarly there is no end to the demand of the different shaped refractory bricks. It has often been tried to standardise this variety of shapes. Even through higher prices for special shapes it has not been possible to limit the assortment of forms of refractory works. Due to this, very often the setting supervisor faces unsolvable problems, because he is responsible for uniform loading of all the kiln cars. In spite of a number of different forms, he has to keep a constant loading weight in each car, keeping the slit configuation the same.

Only in old experienced factories this problem has somewhat stabilised, so that it is possible to programme an exact setting plan over a long period. This gives the guarantee to eliminate as far as possible the temperature difference caused by different settings of kiln car to kiln car and ensures a harmonic firing progress in the preheating and firing zone.

Big changes in the setting weight have different influences on the heat consumption. But the heat input from kiln car to kiln car must not be changed at will, because it will require too big a load on particular burners. This could easily lead to higher heat input by particular burners which might cause overfiring for the setting in the following kiln car, which is perhaps lightly set. The firing in a tunnel kiln is done in combination system, in which each zone is influenced by the one following it, because mainly it is fed from there.

From what has been explained, it is clear that at least the last third of the setting should consist of simple forms, whereas the specials are then set on top of them. However, if the largest part of a production consists of stoppers and channels then one is forced to use them at the lower setting. Three channels, totalling about 1.0 m,are set on top of one another, which are then covered by pre-fired setting plates. But even here the rule is to keep air between the bricks and to keep the corresponding slits. It is clear from this how carefully the setting should be carried out to guarantee a good firing and to avoid crashes in the kiln.

Practically all different forms and qualities can be so set provided they possess the same firing characteristics. Even insulation bricks, with or without burn out material,can be set at the top of the setting without any problem.This is done because these delicate bricks are under no load at the top. Precondition is that the firing curve must be suitable for these special products.

Products with the same firing characteristics can naturally only then be set together when their chemistry allows it, otherwise they must be set in different kiln cars.

If a refractory works manages to become the supplier of a large concern,which is satisfied with a less assortment of formbricks, then perhaps a fully automatic loading and unloading machine can be sensibly used. There has been no lack of ideas or projects in this line but regretably till today such equipment has not found its way to the refractory sector. These loading and unloading machines can be successfully combined with more or less rapid firing kilns. The term rapid firing is naturally relative here. The possible running through time in a tunnel kiln depends upon the material rpoperties and sizes. So e.g. in case of silica bricks, a firing time of 60 hours would be a rapid firing. Rapid firing kilns are characterised through their low setting height and their considerable width and are therefore ideally suited for the operation of fully automatic loading and unloading equipment. The automatic setting, composed with hand setting, has the advantage of constantly maintaining the uniformity of air and firing slits in a very short time. It may be concluded here that also in the refractory industry the fullyautomatic rapid firing is not a risk anymore and the preconditions for a quick and, in spite of that, a thorough firing are given.

In case of rapid firing a certain problem crops up in view of the necessary kiln furnitures and the refractory materials of the kiln cars, as they have to be resistant towards the quick and often changing temperature. In the refractory industry, apart from the undersettings, inbetween plates are required as setting helps in order to set insulating bricks on standards or channels or to get a plane surface for different firing goods on top of the relatively shaky undersetting so that they may be fired accurately without any deformations. Further, spacer or conical setting pallets are taken as setting helps.

III. DRYING

After the body has been given a form, the moisture content, which can be up to 18 weight % H_2O in case of refractory bricks, must be extracted before firing. In refractory raw materials the moisture between the particles is relative easily removable. It is harder with the moisture surrounding the particles.

One has also to face the possibility of the presence of layer moisture in case of clay minerals capable of expanding. If now the formed material is brought into an atmosphere whose partial vapour pressure is smaller than that of the moisture in the formed material, then the formed material gives its moisture to the atmosphere, i.e. the drying process begins. This proceeds in the following way:

In a body all the particles may be surrounded in moisture. By giving up this moisture, the particles come nearer, a volume change takes place, it is the drying shrinkage. Lastly the particles come together, touching each other, reaching an end condition. The shrinkage has ended. In most cases the moisture content now is <10 weight % so that dry pressed bodies, which contain a maximum of 8 % moisture, show no more drying shrinkage. The further giving up of water from inbetween spaces leads only to the formation of pores. Further forcing of the drying procedure leads to the giving up of the absorbed and the inbetween layer moisture.

At the beginning of the drying process the moisture is uniformly distributed throughout the material, andthis is the case at the end with the rest moisture. But inbetween there are differences and one has to take special care when the maximum difference in moisture content occurs. As the moisture evaporates from the surface first, the first shrinkage occurs also there. The surface is also under tension, which can lead to cracks. The moist core is at the same time under compression. Later the rest moisture of the core would be forced out under capillar force. At this time the core would be under tension and the outside under compression. It is known that inhomogeneous masses easily tend to crack along the existing texture. Therefore the drying should not be carried out very fast which leads to cracks. Only when the moisture content has come down so far that all in all the end stage of the shrinkage procedure has been reached, can the drying be strongly accelerated.

But in factories one is interested in quick drying. It can be carried out so fast that due to the occuring tension no cracks take place. It is therefore important that during drying a big difference in moisture content should not come up in the material. A drying process may be accelerated by raising the temperature, thus lowering the viscosity and surface tension of the water and rising the vapour pressure and the acceleration of diffusion of the vapour.

The drying at high temperatures is made difficult by thermodiffusion. The moisture should travel from the cold inside to the hot surface. However, in the water filled capillaries the tendency of travel is from the hot to cold side. This so-called thermodiffusion is the opposite procedure to drying, thus choking it. One can remove this problem by heating the material up to 70 to 80 oC before drying. To avoid a high evaporation rate right at the beginning of the drying procedure, the humidity of the atmosphere must be kept high, which means that during heating up the air moisture content must be very high. On reaching the required drying temperature, the humidity should be sunk. When the shrinkage has been completed, the temperature is raised and the humidity strongly lowered.

In practice this takes place in a chamber dryer (pre-dryer) and tunnel dryers. Chamber dryers consist of a row of chambers next to one another, which can be entered from one or both sides and may be locked by doors. The forms are set on wooden setting stripe and are brought in by transporters or fork lifters and set in corresponding heights. The chamber width is normally 1.20 to 1.50 m. The chambers are heated from bottom with hot air coming through covered channels. The hot air is either sucked in or pushed through by fans into the chambers, goes over the material to be dried, thereby collecting water vapour, and leaves the chambers through channels existing on top. The hot dry air is continuously circulated till it is saturated with moisture and the drying material is hot. Then the moisture content of the air is lessened by blowing in dry air in doses and thus starting the real drying process.

If the material is not sensitive towards drying then this conditioned drying is not required. In such cases a simple air circulation by means of a fan is enough. The instruments are to be so manipulated that the temperature increases constantly and the relative humidity goes down while the pressure in the chambers goes up slightly from about 0.2 to 1.5 mm.

The semi-dried and dry-pressed products are mostly dried in tunnel driers, because these products are already so hard before drying that they can be directly set on the kiln cars at the height required for the kiln firing. They do not require to be re-set after drying.

The tunnel drier comprises a single or a number of single track channels, separated by walls from each, so that they may be operated separately. The other walls and the flat roof of the drier are set with insulating layers.

The tunnel drier works on the counter current principle, i.e. the fresh formed materials first meet the cold and moist air then go forward through different zones of constantly rising hotter and dryer air, so that their moisture is uniformly extracted.

An air heater may produce the necessary hot air. Apart from it, the waste heat of the kiln can also be used. The hot air enters the drier spread out in different positions in the roof arch and from there enters the drying space through rectangular openings situated at the lower part of the dryer walls. The rising hot air is intercepted by fans situated at the top of the channels and thus is circulated throughout the cross section of the drier. The final exit of the moist hot air takes place through a chimney at the entrance end of the drier. Because of these placings, it is possible to keep the humidity at the entrance of the drier relatively high.

The cold and moist formed material comes also first in contact with moist and slightly hot air, then with further transport forward the material is heated up according to its optimum drying conditions and continuously looses its moisture up to its exit from the drier in flow of the rising hot and dry air.

A. Possibilities of utilising the waste heat in case of refractories:

Due to heat economy one strives today to dry the material with the help of the waste heat from the tunnel kiln, i.e. to extract the water required for formgiving.

Here there are cases where a cent per cent heat requirement is obtainable, not considering the drying of the raw material.

By the manufacture of dry pressed or complicated hand pressed refractory shapes, one may consider the possibility that the total heat requirement for drying as well as for the preheating of the forms may be obtainable from the kiln waste heat. After formgiving, these products are either directly set on the kiln car or they are stored for a time at room temperature for a uniform distribution of the moisture content, and then go through the tunnel driers on these kiln cars, which serves both as dryer and preheater.

It is different with plastic products. These must be predried in a different drier to obtain at least a setting hardness before they can be set on kiln cars.

With the operation of two driers, predrier and tunnel drier, a heat gap may come up if the predrying is not carried out, where-ever it is possible, in a big hall or perhaps in open air.

This gap can be closed very simply by inserting an additional energy source (firing place) in the hot air system. It can be a simple, under circumstances, a directly heating firing chamber, depending upon the fuel, regulated from the drier.

In case of mixed products such an arrangement is strictly re-commended so that the heat requirement for drying is guaranteed. This is so because while firing because of its size, a certain product has to be fired slowly, thus giving relatively little waste heat, but during drying this material may requirs a much larger amount of hot air.

The combination predrier - tunnel drier - tunnel kiln sets naturally a precondition, which is that the complete manufacturing unit should be as compact as possible so that no heat loss is encountered, as hot air of 80 to 120 oC temperature should not be transported over a long distance. The extra power requirement and the unavoid-able heat loss would topple the advantages of a combination system and would perhaps even put the tunnel kiln on additional strain.

It is also recommended not to overload the cooling zone of the kiln, meaning one should not take out more heat from the kiln than it can put at disposal. The tunnel kiln should not become a hot air producer.

IV. SUMMARY

Conclusively it may be said:

1) It is ideal for a refractory factory, if for each special material a special kiln unit is available. Then there will be the best ratio between investment costs of the kiln unit and the proceeds of the fired goods.

2) In practice, however, a factory has to produce according to the needs and requirements of the market. In this regard compromises are necessary in order to meet the demands of the market. Financially these compromises will not have any effects or only minor effects, as the market, due to this situation of constraint, has to balance the additional costs required by the company through the price.

3) All efforts of preparation and shaping may be frustrated by bad operation of drying and the firing technology, as well as of the smooth setting technique in connection with this operational process, causing rejects.

If the setting, drying and firing technology are taken carefully into consideration, it should not cause any difficulties to create the most extensive variety of product combinations with a view especially to excellent qualities and favourable prices.

[redacted]