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Technological Information Package

Energy Conservation and Management in Ceramics

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PREFACE

Ceramics and building materials industries are among major consumers of energy because of heat processes necessary to build up products.
Sc, in average 86 per cent of total energy consumption in the ceramics production is taken up by direct technological consumption on drying and firing while the left 14 per cent is spent on driving machinery and overheads.

In coincidence with soaring prices of fuels considerable research and managerial effort has been put to solving the problems of energy in ceramics. New technological processes, raw materials and production equipemnt have been introduced which have resulted into lowering the physical consumption of fuels per unit of output. At the same time new methods of energy management and audit have been applied which have brought futher energy conservation by reducing idle consumptions.

For example the introduction of methods of rapid single firing in the production of ceramic tiles, expsciallly floor tiles meant an important reduction of fuel consumption. However, this technology can be used only in case of a new plant or it requires a complete reconstruction. Important energy conservations can also be attained by using raw materials requiring lower firing temperatures, by modernizing firing equipment, by utilization of waste heat, inter alia, which are all measures that do not require a larger capital outlay.
All these measures to reduce energy consumptions of existing ceramic industries are subject to permanent concern of managers and technicians managing these industries in developing countries who also often apply to UNIDO for relevant inquiries. In order to respond to this concern this information package was compiled which brings a concise preliminary information on the subject. The package is based on four publications edited by the UNIDO-Czechoslovakia Joint Programme for International Co-operation in the Field of Ceramics, Building Materials and Non-metallic Minerals Based Industries in Pilsen, Czechoslovakia which were its response to the requirements from developing countries in the course of several past years.

It contains a brief description of principles of energy management in ceramics, a main part is devoted to the energy auditing in ceramics and equipemnt necessary to conduct successful energy diagnostics in the plants producing ceramics, glass and building materials.

The information contained in this package is by no means exhaustive nor should it be considered a replacement of technology profiles. Any contribution from our readers for updating of, or inclusion in the package would, of course, be welcome.

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I. ENERGY COSERVATION AND MANAGEMENT SYSTEM IN CERAMICS

(Reference 1)

Energy Management represents a wide, organization- and control-demanding complex of activities based on the detailed analyses of actual conditions, studies on technically feasible targets and determination of gradual steps for their realization.

Energy Management in the Ceramic industry is characterised by the following fields of activities:

1. Non-traditional technologies with lowered energy demand

The application of low fluxing raw materials or of fluxes as such lowers the firing temperature. The technology can be simplified, raw materials requirements can be reduced and progresive operations applied.

2. Thermal process optimization

To reach the optimum heat consumption during the firing process, two factors are to be analyzed:

a) Limiting firing conditions of the products, which depend on different structural cha nges of the blend during their heat treatment, such as loss of chemical water, decomposition of kaolinite, crystallographic changes of silica modification, changes of alumina structure, etc. Many of those changes must be respected during drying and firing to avoid any damage to the green products.

b) Kiln output It is obvious that the specific heat consumption grows if the kiln is only partly loaded with dry products. Each kiln's output shows an optimum of energy consumption since overloading of the kilns will waste the energy again.

3. Energy Diagnostics of heat processes

The objective data of the actual stay of the kiln or drier are necessary as the basis for the improvement of processing. To obtain these data, the diagnostic measurements are performed by a Mobile Diagnostic Unit, which is equipped with instruments, recorders and evaluating units enabling to perform the analyses of thermal processes as well as the heat balance of production units. The main contribution of diagnostic measurements in ceramics and refractories are

a) energy conservation,
b) output increase,
c) reduction of rejects,
d) quality improvement

4. Thermal equipment modernization means the step in which a capital input is already necessary. Therefore, the modernization is to be considered in two different levels:

a) Partial modernization which is usually realised according to a feasibility study. It covers, for example the change of burners, increasing the cooling capacity, installation of mixing fans to the preheating zone, etc. The increased efficiency of the kiln will cover the costs spent on the partial modernization.

b) Complex innovation of the unit which requires high investments and, therefore, this step is applied when the increased output is requested and it must be based on a feasibility study. The traditional lining is replaced by new insulating materials, the kiln can be extended, the automated regulation applied, etc.

5. Waste heat utilisation

Waste heat is the heat rejected from the thermal process at the temperature high enough above the ambient temperature to permit the extraction and utilisation of additional value from it. Usual sources of waste heat in the ceramic and refractory industries are combustion gases, the air from the cooling zones of kilns and driers outlet. Such heat is utilised either directly or indirectly, transferred in a heat exchanger.

6. Climate conditions which differ according to the geographical location and which, therefore, also influence the heat consumption of a plant. The temperature, pressure and relative moisture content of the air must be respected.

II. NON-TRADITIONAL TECHNOLOGIES WITH LOWERED ENERGY DEMAND

- use of non-traditional fluxes

to which albite ($Na_2.Al_2O_3.6\ SiO_2$), tuffs, tuffites, nephelines, phonolites, basalts, calcites ($CaCO_3$), marls, plagioclase feldspars, magnesium raw materials, glasses, light ashes and slags belong. The optimal use of each type of non-traditional fluxes must be determined by physico-chemical tests of the flux. The typical examples of applications of calcite and marls for the compositions of lime-siliceous non-vitrified earthenware bodies show that in comparison with traditional kaolinitic body the bisque firing temperature is reduced by 200 as far as 300°C, in addition, stable dimensions are reached so that further costs in calibration, material and energy are saved.

- simplification of production technology

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

- production and application of non-fired refractories

whose share in the total production of refractories amounts to 30 - 40% in the industrialised countries. About 60% of total energy consumption is saved by the application of non-fired refractories technologies.

- minimization of fired grog share

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

- use of proper insulations

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

III. LIMITING DRYING AND FIRING CONDITIONS (Reference 2)

While elaborating the energy balances, we are primarily concerned about the heat energy spent on drying and firing. Further sort of energy we are concerned about is that of the electric power spent on driving machines and equipment e. g. mills, presses, different sorts of fans, pumps, stirrers, blungers etc. It must be emphasized that first rate object of the interest of a technologist or a power engineer should be the heat energy since we have practically no influence upon power consumption of machines and equipment built-in in a production line.

There are numerous problems concerning the heat consumption when driers and kilns are projected in the ceramics. But in case of elaborating energy balances, a plainer theoretical apparatus will do. In solving this problem we only need to compare theoretical consumption of the heat, which can be determined at least by approximate calculation, with the practical consumption indicated on appropriate gauges.
In this way we can find loss of heat energy and by its analysis we can take corrective measures.

Heat Consumption for Drying

Drying process is nothing but the evaporation of water from ceramic body at a certain temperature. Theoretical consumption of heat will be the simple sum of the heat spent on bringing the body to a temperature of drying, the heat spent on evaporation of water from ceramic body at that drying temperature.

Heat consumption either theoretical or practical we always relate to one kilogram of evaporated water and call as <u>"Specific Heat Consumption of a Drier".</u>

Consequently, amount of the heat spent on evaporating one kilogram of water at a certain temperature consists of the heat needed for bringing water to a temperature at which evaporation begins and the evaporating heat of water at a considered temperature. The amount of evaporating heat depends on the temperature as shown in the following table where the heats spent on transforming one kilogram water with the initial temperature of 0°C into vapour at different temperatures of evaporation can be seen.

Temperature of evaporation °C	Evaporating heat kJ/kg
0	2,487.1
10	2,464.5
20	2,442.4
30	2,419.8
40	2,397.2
50	2,374.2
60	2,351.2
70	2,327.4
80	2,304.0
90	2,279.4
100	2,254.7

Theoretical heat consumption during drying is not <u>the really spent heat.</u> This really spent heat in a drier is only that heat which is spent on removal of mechanically bound water. The heat stored in dried ware could be regained and utilized (at least theoretically) for different ends but it is not done in practice since the temperature of the dried ware is usually not high enough. Strictly speaking even the heat accumulated in vapour can be utilised after its condensation. For this reason the really spent heat in the drier would be only a fiction and in fact it would be necessary to ascribe it to the account of the losses. However, with regard to the low temperature of vapour after drying and to its undesirable contamination, this heat is not utilised in industrial practice.

The amount of heat Q needed for bringing matter weighing m to a temperature T_2 from a temperature T_1 is derived from the formula $(1)^2$:

(1) $Q = mc\ (T_2 - T_1)$ where,
Q .... heat (kJ)
m .... weight (kg)
T_1, T_2 .... Temperatures (deg.°C)
c .... specific heat (J/kgdeg)

Specific heat c as known from physic, varies with the temperature. In case of the energy balance calculation we need not take into account these changes and we only consider its average in a given interval of temperatures. Specific heat of ceramic materials fluctuates approximately from 0.9 to 1.0 kJ/kgdeg.

The accurate amount of the specific heat and its dependance on temperatures must be assessed in concrete cases experimentally. However it is possible to say that influence of microstructure on the specific heat is negligible but influence of polymorphic transformations is greater.

Heat Consumption at Firing

The above mentioned formula (1) used for calculation of heat consumption in case of drying is valid for firing as well. The amount of the spent heat which is calculated according to this formula must be added to the amount of the heat spent on removal of chemically bound water and on possible decomposition of limestone or on other chemical reactions. Here is to say that for practical calculation only the heat spent on removal of chemically bound water and decomposition of limestone is taken into consideration. Since we lack accurate data for determining the amount of heat spent on other chemical reactions and since this amount of heat compared with that of the above-mentioned (i. e. on removal of chemically bound water and decomposition of limestone) is negligible, we do not consider it at calculation.

This calculated heat, i. e. heat according to the formula (1) plus heat spent on removal of chemically bound water and on limestone decomposition, is called theoretical heat consumption at firing. At the end of firing all chemical reactions and removal of water are finished but the product contains the heat which was spent on bringing this product to the temperature of firing. This accumulated heat is not really spent since we can regain it by cooling the product to its initial temperature, e. g. by means of air. The really spent heat is only that heat spent on the removal of chemically and mechanically bound water and on the accomplishment of all the chemical reactions. A part of the heat accumulated in products and kiln furniture or kiln cars can be really used for drying, etc. Some 20% of heat brought to the kiln could be usually utilized in this way.

Heat Losses

There are heat losses in kilns, driers and other thermal equipments. They equals to the difference between the amount of the heat put in a thermal equipment and the amount of the really spent heat (both for chemical reactions and physical processes). Heat losses usually climb over 50%. Even if we made use of residual heat from kilns (e. g. in driers), the effect will be scarcely essentially better.

The principal kinds of heat losses in ceramics are as follows:

- the flue loss
- the heat contained in goods and kiln furniture
- the heat contained in linings of kiln cars
- the heat passing through walls and ceiling of the heat equipments.

Fuels

The source of heat energy in ceramic industry are different kinds of fuel, either gasseous, liquid or solid. A sort of fuel is chosen in the preparatory phase of an investment decision according to local conditions. Heat equipments and their parts (e. g. driers, kilns, burners etc.) correspond to that choice. For the computation of an energy balance, the matter of paramount importance is the calorific value of fuel. The values of both the calorific value and those of the combustion heat are given in Tables. The combustion heat is that heat which is yielded by burning up fuel to gasseous carbon dioxide, nitrogen, sulphur dioxide and liquid water respectively, on the other hand the calorific value is the heat released by burning up fuel to gasseous carbon dioxide, sulphur dioxide, nitrogen and water vapour. As liquid water has never been generated in industrial burning, we can consider only the calorific value when we calculate an energy balance. Both the calorific value and the combustion heat are given in KJ/kg or kJ/Nm^3 according to physical states of considered fuel - either liquid, solid or gasseous one. The calorific value depend on the content and composition of flammable parts and frequently is not fixed within the same kind of fuel, therefore, it must be periodically checked.

IV. EFERGY DIAGNOSTICS OF HEAT PROCESSES (Reference 3)

There are two types of diagnostic measurements, either focused on the technological process optimization or on the energy conservation. Nevertheless, the complex measurements, e. g. combination of the technological and energetical types of measurements, are the most advisable for the purpose of energy management.

Regardless of the type of measurements (energetical or technological) the activities performed during the measurements comprise three fundamental stages:

- statement of thermal unit operation conditions, performance of objective tests and functional measurements,
- evaluation of tests and measurements,
- working out proposals for technical, energetical and operational and organization arrangements or recommendations on heat balance or reconstruction purposes.

Technological Measurements

The technological type of measurement after its evaluation forms the essential basis for working out proposals of arrangements in the field of thermal technological process optimization. The essential information in this case is the course of thermal treatment of the ware and the temperature distribution in the cross-section of the unit. These data are expressed graphically by firing curves, measured in several points in the cross-section. The measuring points must be located so that the measured temperatures give the sufficient information about the temperature distribution in the cross-section of the unit. The measurement must inform about the temperature differences in the horizontal as well as in vertical directions and about the differences between the inner part and surface of the setting.

For the firing curve investigation in a tunnel kiln, a measuring kiln car is used. The kiln car lining is drilled through and thermocouples are pushed through the holes and fixed in the measuring positions. Cold junctions of the thermocouples are fixed under the steel boggie of the measuring kiln car. They are connected with a recorder or a data logger through the inspection tunnel of the kiln. While the measuring kiln car proceeds through the kiln, temperatures in the measuring points are measured and recorded. Thus the firing curve and temperature distribution in the cross-section of the kiln are obtained. Besides the firing curve, the pressure of the kiln atmosphere is measured and combustion gases analyses are done as well.

A drier being tested, the most important data are as follows:

- course of temperature
- course of the dew point
- drying medium flow velocity

A probe, measuring the drying medium dew point, is sent through the drier together with the dried material to investigate the drying conditions. This probe consists of a temperature resistance sensor and of a dew point sensor. The drying curve resultates from this measurement. The drying medium flow velocity is measured either by anemometers of by Pitot's tubes.

All the technical data gathered by measurements together with the information about the location of regulating elements at the unit, conditions of the heating system, level of combustion processes, heat transfer in the unit and the amount and quality of production are evaluated using a computer.

The real firing (drying) curve obtained by measurements is then compared with the optimal one of the unit at this phase of work. The recommendations on the adjustment of regulating elements are worked out to minimise the difference between the real and optimal firing (drying) curves. Thus the optimal thermal treatment of fired (dried) material is reached. This interference with the adjustment usually causes the production intensification and quality improvement.

Energetical Measurement

The most important information for energy consumption minimisation is the heat balance of the tested equipment. It includes all items of heat energy entering and leaving the unit and shows the possibilities of energy conservation.

The most significant items of heat balance of a kiln are as follows:

Heat input

- is determined from the calorific value and amount of the fuel consumed

$$P = M \cdot H \ (kW)$$

M ... amount of fuel consumed $(kg.s^{-1})$
H ... calorific value of the fuel $(kJ.kg^{-1})$

To reach a better precision of the heat input determination and to check the results obtained by the direct method, the indirect method is used very frequently. The heat input is calculated from the combustion gases analyses and from the amount of combustion gases drawn from the unit by this method.

A small portion of the heat energy entering the unit is formed by specific heat of the fuel (usually 1 to 2%).

flue loss

- is determined from the volume, temperature and specific heat of combustion gases

$$P_1 = V . t . c \quad (kW)$$

V ...... volume of combustion gases $(m^3 s^{-1})$

t ...... temperature of combustion gases (K)

c ...... specific heat of combustion gases $(kJ\ m^{-3}\ K^{-1})$

The volume of combustion gases is calculated from the flow velocity and the cross-sectional area of the duct. The flue loss is the necessary phenomen of a firing process. It cannot be lowered under a certain limit ensuring proper pressure conditions in the kiln.

The flue loss of a tunnel kiln with open fire forms usually about 25% from the input.

loss by heat conduction of brickwork

- for continually operating kilns it can be derived from the kiln atmosphere temperature, heat conductivity of brickwork, surface area of lining and temperature of the ambient

$$P_2 = k . t . S \quad (kW)$$

k .... heat transfer coefficient $(kJ\ s^{-1}\ K^{-1}\ m^{-2})$

t .. temperature difference between inner and ambient temperature (K)

s .... lining area (m^2)

The loss by heat conductivity of lining forms usually about 15% from the input of a continually operating kilns with the classical type of lining (e. g. combination of fireclay and red bricks) and less than 10% from the input of a kiln insulated by up-to-date insulating materials (e. g. light-weight refractories and fibres).

loss by heat accumulated in kiln cars

- to ascertain this loss, the average temperature of the kiln car lining and average temperature of iron boggie must be determined from several measurements. The loss by accumulated heat is than calculated from the average temperature and specific heat of material.

$$P_3 = M \cdot t \cdot c \quad (kW)$$

M ... mass flow of material	($kg\ s^{-1}$)
t ... average temperature of material	(K)
c ... specific heat of material	($kJ\ kg^{-1} K^{-1}$)

The loss by heat accumulated in kiln cars forms about 3% from the input of a kiln with properly adjusted cooling zone.

loss by heat accumulated in ware

- the process is similar to that of kiln cars. This loss forms about 5% from the input.

loss by heat conduction of foundations

- this loss is very difficult to ascertain due to the complicated conditions of heat conduction. The item of heat conduction of foundations in the heat balance is usually lower than 5 - 10% from the thermal unit heat input. Therefore, this loss is usually comprehended in the so called undeterminable losses together with the loss by leakage and that through the inspection tunnel. All these losses form about 15% from the thermal unit heat input.

technological loss

- comprehends all losses for physical and chemical transformations in the material of ware. It alternates from 3 to about 25% from the thermal unit heat input according to the type and composition of the fired material. The amount of heat necessary for endothermic reactions can be determined by laboratory tests of a ceramic body.

loss by heated air draught from the cooling zone

- is calculated from the amount of heated air multiplicated by its temperature and specific heat

$$P_4 = V \cdot t \cdot c \quad (kW)$$

V .... amount of heated air	($m^3\ s^{-1}$)
t .... temperature of air	(K)
c .... specific heat of air	($kJ\ m^{-3}\ K^{-1}$)

To determine the amount of heated air, the average air flow velocity must be multiplicated by the cross-sectional area of the duct.

Despite of the use of heated air from the cooling zone in the technological process (e. g. for drying or preheating of the material), for the purpose of heat balance of a tunnel kiln amounts from 20 to 35%.

production of kiln

- the knowledge of this value is necessary for the purpose of the specific energy consumption determination. The energy consumed during the measuring period devided by the production volume durig this period form this important index enabling the comparison of various kilns mutually, from the operation economy point of view.

The other tests, performed during the energetical measurement:

<u>combustion gases analyses</u>

The samples of the kiln atmosphere for the purpose of the combustion gases analyses are taken through the sight holes of the kiln. The economy of combustion is determined by these analyses. The air excess coefficient is calculated from the portion of CO_2 in the combustion products and expresses the excess of burning air above the theoretical volume. The fuel consumption of a kiln can be calculated from the portion of CO_2 in the combustion products, from the amount of these products and from the theoretical portion of CO_2 in the combustion products.

<u>Stack draught</u>

A sufficient value of the stack draught enables the operation of a kiln in optimal pressure conditions.

<u>The drier</u> being the object of testing, following values must be determined:

- heat input
- heat losses - by efficiency of heat exchanger
  - flue loss
  - by exhausted drying medium from drier

  - by heat conduction of brickwork
  - by heat accumulated in dried material
  - by heat accumulated in residual water
- production of drier
- combustion gases analyses
- relative moisture content of exhausted drying medium
- relative moisture content of entering material
- relative moisture content of dried material

The advantageous arrangement of measuring instruments and of an evaluation centre in a mobile diagnostic unit brings about an effective and operational utilization of the equipment in different production plants. The partial evaluation of measurements on the spot minimizes undesirable production conditions. The contributions reached by the realisation of proposed recommendations are direct and indirect ones:

Direct contributions

Energy conservation

realized by

- adjustment of burning con ditions (adjustment of optimal air excess, adjustment of the outlet temperature of burners, etc.)
- adjustment of pressure conditions (reduction of too high pressure in the firing zone brings about reduced penetration of kiln atmospher to inspection tunnel)
- adjustment of firing curve (if the temperature in some part of the kiln is higher then necessary, its reduction brings about lower losses by conduction of brickwork)
- adjustment of entrance and exit air locks, etc.

Quality improvement and rejects decreasing

accomplished usually by
- firing curve optimization
- temperature equalization in the cross-section (by the use of mixing fans, by pressure curve adjustment, by setting optimization, etc.)

Output increase

can be realized by:

- optimalization of setting (with optimal heat transfer to and from the fired material)
- temperature equalization in the cross-section of the unit, firing curve optimalisation (it enables in some cases to shorten the firing cycle and thus increase the output)

Substitution for fuel used

Detailed knowledge of material thermal treatment gained by the diagnostic measurement enables a successful substitution for the fuel used, together with the second measurement, serving for optimal adjustment of the unit, firing the new fuel.

Indirect contributions

Besides the direct contributions, an indirect profit can also be gained. A detailed technical information about the heat consuming unit serves as the basis for

- constructional improvements
- decision about the stage of modernization
- recommendations on waste heat utilization (utilization of the heat escaping from the cooling zone, by combustion products, etc.,)

V. MODERNIZATION OF HEAT UNITS (Reference 4)

Ceramic Kilns

The types of kilns originally implemented in the production cycle were constructed prevailingly for low quality fuels, mainly coal, producer gas and the spaces aloft the kilns of higher temperature were used for drying. The characteristic feature of these kilns either annular or chamber or tunnel ones was their robust structure and the building material used for them were mostly compact refractory bricks and red-brick masonry. Considerable weight of these kilns of a low effective utilisation of the supplied energy were and sometimes still are the cause of high consumption of heat energy, time- consuming thermal cycles and they are rather long while the relative productivity of such kilns are too low.

The development of new types of kilns in ceramics was stimulated primarily by an accent given to increase capacities, , higher quality of products and to make a quick change in assortment feasible. Hand in hand with this trend a requirement for better quality of energy (power, natural gas and gas supplied by long-distance pipelines) has become more distinct. Thereby it also becomes indispensable to cut the present specific energy consumption which, under the contemporary critical energy situation in the world, has grown into a need of first priority.

New designs and types of kilns vary considerably from the conventional ones chiefly in the field of ceramic building material firing processes. The tunnel kilns used so far make place step by step to line single-story kilns, multiple-story kilns, roller kilns, rotary-hearth kilns or fakir furnaces, double firing process of bisque firing and glaze firing in two cycles is being replaced by one-firing cycle. Traditional drying processes give way to dust spray driers in the preproduction stages where the bodies are prepared and to roller drier lines in case of products, etc. The present position of development has ensued from a detail research of heat transfer method proper and it goes without saying that it will keep its pace henceforward.

Basically, the ceramic products properties are predetermined first by a choice of initial raw materials and admixtures and, secondly significantly enough by a suitable thermal process-firing during which thermo-chemical reactions take place whereby the mass structure changes into the final state possessing the required properties. The thermal process must meet the technological requirements as far as the time and thermal course in the structural and phase changes in masses are concerned. It has to follow necesarilly the basic laboratory research work. It is solely the laboratory testing of the thermal process for the firing of a ceramic body which can determine, in its sequential alternatives, so called "limiting curves of heating and cooling" at the final research phase.

The curves show the conditions under which the respective changes in the basic body will take place so that the product reaches its final properties. The quickest heating and cooling processes are found out at the some time at which a minimum thermal energy consumption per cycle may be expected from the duration point of view. The firing process proper in the kilns cannot be determined according to the limiting curves. The limit thermal process may be too risky since it could cause too many rejects in the production but the process in the kiln should only come to the vicinity of this curve and a certain safety factor must be adhered to.

Neither a way of heating proper nor a type of kiln can be determined by mere laboratory determination of firing conditions.

Another step in the research work takes its turn by simulating the thermal processes in the kilns, it is simulating the heat transfer from the heat sources into the ceramic products under certain conditions.

While the space in which the products are situated is known the simulating method of research should examine and verify the optimal dimensions of the space, the way how the products are placed therein, size and shape of the kiln furniture under which the determined thermal schedule can be reached by means of verified both thermal input and flow of combustion products.

The exigency of the simulating method of research of the thermal processes in the kiln has been evoked by efforts to minimize the energy consumption as well as by requirements for the firing process to be uniformly spread over the entire cross section of the kilns at all the charged products giving them thus an equal quality. The uniform firing process in the kiln could have been achieved solely by changing the character of heat transfer used so far by a flame i. e. by radiation and by heat conduction for firing utilizing thus convestion of hot combustion products for maximum heat conduction in the kiln space. The simulating method of research for a given space results then in the way how the ceramic products are placed, direction of combustion products flow, size and arrangement of burners, etc.

Out of the simulating research method the noweday's designs and types of kilns and furnaces have been derived. Their main parts are new types of burners, at gas-fired kilns or suitably situated heating resistor elements at the electric resistance kilns.

Based upon the above mentioned trends of development new types of kilns have been invented the specific heat consumption in which has been cut down to considerably lower values than those at the classic ones. Such types of kilns used for ceramic tiles are e. g. improved types of tunnel kilns for the firing of bisque proper, electric resistance channel kilns, roller-type konveyor kilns, electric resistance kilns with wire carriers, rotary hearth kilns and kilns with carrying pins at which the bisque firing is partially combined with firing of glaze.

Apart from intenzification of heat transfer at these kilns first of all the weights and sizes of these kilns have been minimized owing to the use of new highly insulating refractories, the considerable weight of kiln furniture has been cut down. The kiln furniture is essential for a systematic placement of products into the firing space. A reduced demand for energy was the common denominator of all these changes.

The intensive modernization of kilns and furnaces systematically aimed at a reduction of energy consumption in the ceramic industry in industrially developed countries has resulted in reducing the total energy consumption per 1 sq. m. of ceramic tiling materials by 30 to 35 per cent in the recent 10 years.

It is a matter of course that the energy savings are influenced by the overall extent to which the plants have been modernized and what sort of energy is required. When electricity is applied the heat consumption can be reduced as much as by 75 per cent but another question arises i. e. the price difference between electricity and fuel. In ČSSR e. g. by modernizing the original ceramic works about 30 per cent of energy savings have been achieved at floor tiles production while the present consumption per 1 sq. m. amounts to 100.10^3 kJ and at the wall tile production 29 per cent of energy consumption in the present production of $83.4x10^3$ kJ. The plants newly reconstructed have cut down the consumption of implementing new types of kilns and new technological processes as down as to $22,75.10^3$ kJ/sq. m.

Smaller modifications have been applied also for kilns in which refractories and insulating products are fired, the contemporary tunnel kilns which are rather satisfactory chiefly due to their capacity have their process rather accelerated both in the stage of heating by convection of combustion products from the high-speed burners and by quick circulating cooling. Besides, car-hearth chamber kilns and hood-type kilns begin to be used in case of special, demanding heavy-duty refractory materials.

The present trend in the manufacture of ever more perfect kilns and driers will go on necessitated by the energy crisis.

In case of double-fired tiling materials the original value of bisque firing temperature is shown in the following table:

Average firing temperature of double-fired wall tiles

	bisque firing temperature °C	glaze firing temperature °C
after the World War II	1280 - 1300	1180
beginning of 60's	1120 - 1200	1080 - 1120
at present	1040 - 1060	960 - 1020
prospects by the year 2000	lower than 1000	900 - 960

Under this trend of development in the C.S.S.R there have already been verified new types of bodies and glazes for wall tiles at which the two present thermal cycles - bisque firing and glaze firing can be substituted by a single fire at lower temperatures and during a very short time interval. Top level results are achieved in the glazed floor tiles manufacture realized by a single firing technology with the firing temperature of 1050°C and with the kiln cycle of 60 minutes. These results of research have enabled erection of new types of kilns of considerably smaller sizes than before and have led to a significantly reduced energy consumption because the firing without bisque represents about 55 per cent of total energy consumption in the double firing wall tiles production.

Average reducing of firing cycle at double fired wall tiles

	bisque firing hrs.	glaze firing hrs.
after the World War II	60 - 120	24 - 48
at the beginning of 60's	24 - 48	3 - 24
at present	1 - 24	0,5 - 24
prospects by the year 2000	0,5	lower than 0,5

Along with this trend a research of new types of bodies and glazes for building ceramics will go forward which, due to their new properties, will facilitate further reduction in thermal processing demands and, thereby, further energy savings.

Refractories and insulating materials

The general opinion on the quality of linings which require a maximum durability and insulating capacity has been gradually uprooted from the conception of heavy refractory blocks and red-masonry owing to the evolution and has passed through two development stages.

The first stage has affected insulating layers proper in the other one the evolution has brought light-weight refractories up to 1000°C and other types of perlite, vermiculite and refractory concrete materials. Due to this development the linings have been gradually reduced in thickness and weight-while heat losses due to heat passage to ambient atmosphere have been reduced simultaneously.

Even these linings, however, did not meet fully the new requirements because their weight and the necessary heat accumulation did not facilitate the thermal flexibility of kilns, i. e. fast temperature changes during heating as well as during cooling as required by the new technological processes in the kilns.

The indispensability of further improvement of the insulating properties has affected even the first insulating layers made of heavy materials for temperatures up to 1500°C while their volume weight has been up to 1 kg/cu. dm., light weight refractories at volume weight 0,5 kg/cu. dm. for temperatures up to 1300°C and highly insulating fibre mats and boards for the insulating layers. A wide variety of these products has been recently supplemented with fibre products for the temperatures of 1100 to 1600°C.

The present kiln and furnace linings therefore are completely different from the original ones their total thickness are cut down to a quarter and their weights as much as to 1/5 of the weights of the original classical linings. It results in an effective considerable saving of energy.

The difference in opinion on the really classical and up-to-date kiln lining under similar conditions, i. e. similar inner and ambient temperatures and similar heat losses to ambient atmosphere is demonstrated by the reduction of linings. A classical lining of 0,625 m total thickness made of a 0,5 m fireclay layer and 0,125 m diatomite layer is thermally equal to an up-to-date lining made of ceramic fibre mats of 0,175 m total thickness layer.

Apart from a distinct difference in total thicknesses i. e. 0,625 m and 0,125 m a similarly distinct is the difference between weights which e. g. for 1 sq. m. of classical lining is 1080 kg and 23 kg per sq. m. of the up-to-date one. Hence, the difference totals 1057 kg. The weight is being cut down as low as to 1/50 of the original weight.

Further trend will tend towards an optimal utilization of refractory insulating materials in linings first of all to their technological cum erection and repairs should minimize the kiln fall-outs.

Plastic green ramming masses, gunning masses and refractory concretes represent an entirely special group of refractories which all contribute to energy saving by their use in the linings since they do not require energy for firing at the producer while the time required at the consumer for their application is reduced considerably and the life of such linings is 2 to 3 times longer in average.

These masses intended prevailingly for furnace linings in a metallurgical industry for temperatures up to 1600°C in further development will be supplemented with new types at which, too, efforts to cut their weight and to improve their insulating properties will be seen, first of all by using lightweight types of refractory fillers for high temperatures.

The significance of refractory ramming masses grows ever more and in the world production rate of refractories these masses represent about 30 per cent nowadays.

It may be envisaged that the production of these types of refractory masses will go on growing and will exceed 50 per cent by the year 2000.

VI. EQUIPMENT OF ENERGY DIAGNOSTICS (Reference 3)

A Temperature Measurements

Apparatus - sensor	range
Resistance Pt thermocouples	up to 600°C
Mercury thermocouples	up to 450°C
Ni-NiCr thermocouples in protective ceramic tubes	up to 1200°C
Ni-NiCr flexible jacketted thermocouples	up to 1200°C
Pt-PtRh thermocouples	up to 1400°C permanently, peaks up to 1600°C
PtRh6-PtRh30 thermocouples	up to 1600°C permanently peaks up to 1800°C
Digital thermometer Ni-NiCr for both atmospheric and surface temperature contact measurements	up to 1200°C
Radiometer Thermopoint for surface temperature measurements	-30 - 1100°C
Total radiating pyrometers	150 - 2000°C

B Gas Flow Measurements

Apparatus	range	piece
Mechanical anemometer	0 - 15 m. s.$^{-1}$	2
Mechanical-electrical anemometer	0 - 15 m.s^{-1}	2
Mechanical-electrical anemometer with two ranges	0 - 5 m.s^{-1} 0 - 30 m.s^{-1}	2
Set of Pitot´s tubes with direct indication of gas flow velocity	length from 0,5 to 2 m	4

C Pressure Measurements

Apparatus	range	piece
Digital micromanometer with additional direct indication of gas flow velocity with 3 ranges	0-120 Pa 0-14 m.s^{-1} 0-500 Pa 0-28 m.s^{-1} 0-2500 Pa	1
Micromanometer with changeable sensitivity	maximum 0-2450 Pa	2
Set of precise manometers	-100 kPa - 0,5 MPa	5
Annular balance with recorder and changeable sensitivity	maximum - 200 - 200 Pa	1

D Dew Point Measurements

Apparatus	range	piece
Digital relative humidity measuring instrument with temperature indication	5-98% rel. hum. 0 - 70°C	1
Dew point measuring set "Feutron" consisting of three probes and one plotting recorder, each probe measures the temperature of dry thermometer and the temperature of wet thermometer	0-100% rel. hum. 0 - 150°C	2

E Combustion Gases Analyses

Apparatus	range	piece
Transportable analyzer "Infralyt" with two ranges		
for CO_2 content	0 - 10% 0 - 20%	2
for Co content	0 - 2,5% 0 - 5%	1
for SO_2 content	0 - 0,5% 0 - 1,0%	1
Analyzer "Permolyt" for O_2 content	0 - 10% 0 - 25%	1

F Gas Quality Measurements

Apparatus	range	piece
Wobbe´s number meter with built-in recorder	Wobbe´s number of generator gas, town gas, natural gas and propan	1

G Recording and Evaluation

Apparatus	range	piece
Digital data logger with built-in printer and automatic timing	6 inputs for Ni-NiCr thermocouples 6 inputs for Pt-PtRh thermocouples 6 mV inputs	1
Compensation recorder, writing width 250 mm	12 inputs for Ni-NiCr thermocouples or Pt-PtRh thermocouples or mV changeable by range modules	3
Small computer with built-in thermal printer for 21 digits and 16 digits display, stored programme system with 1024 steps in main routine and two levels of subroutines of the capacity 1024 steps each, External storage of the programme on magnetic cards.		

H Accesories

Filters for gas cleaning

Calibrating gas for analyzers and Wobbe´s number meter

Cables

Compensating lead wires

PVC pipes

Set of tools

Protective aids

Communication set-three pieces of short-wave transceivers

VII. SELECTED WORLD SUPPLIERS OF ENERGY DIAGNOSTICS EQUIPMENT

AMR Holzkirchen FRG	temperature measurements, relative humidity measurements, losses through the brickwork, gas flow velocity, recorders, data loggers
AIRFLOW Rheinbach, FRG	gas flow velocity, pressure measurements, relative humidity measurements, temperature measurements,
AGA Infrared Systems, Danderyd, Sweden	temperature measurements, thermovision systems
Ari Industries, Farnborough, Great Britain	thermocouples, resistance thermometers
BBC Brown Boveri, FRG	electric multimeters, recorders
Comark Electronics Ltd. Rustington, Great Britain	temperature data loggers,
Hewlett Packard, Palo Alto, USA	data loggers, computers
Honeywell Inc. Phoenix, Arizona, USA	recorders, multichannel recorders, flow measurements
Keithley Instruments, Inc. Cleveland, Ohio, USA	digital thermometers
Neotronics Ltd., Takeley, Great Britain	electronic digital micromanometers, combustion gases analyzers

Philips Eindhoven, the Netherlands	temperature measurements, humidity measurements, gas analyzers, recorders
Servomex Ltd., Crowborough Sussex, Great Britain	O_2 analyzers
Testoterm KG, Lenzkirch, FRG	temperature measurements, gas flow velocity, humidity measurements, pressure measurements, flue gasses analyzers
Takeda Riken Co., Ltd. Tokyo 176, Japan	data loggers, recorders, computing data loggers
Taylor Ltd., Great Britain	analyzers
Ultrakust, Ruhmannsfelden, FRG	temperature measurements, gas flow velocity, recorders and data loggers, relative humidity measurements
VDO Mess- und Regeltechnik GmbH, Hannover, FRG	recorders
VEB Junkalor Dessau, GDR	gas analyzers, pressure measurements, Wobbe s number
VEB Thermometerwerk, Geraberg, GDR	thermocouples
Wilhelm Lambrecht, GmbH, Göttingen FRG	gas flow velocity

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