OCCASION

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

DISCLAIMER

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

FAIR USE POLICY

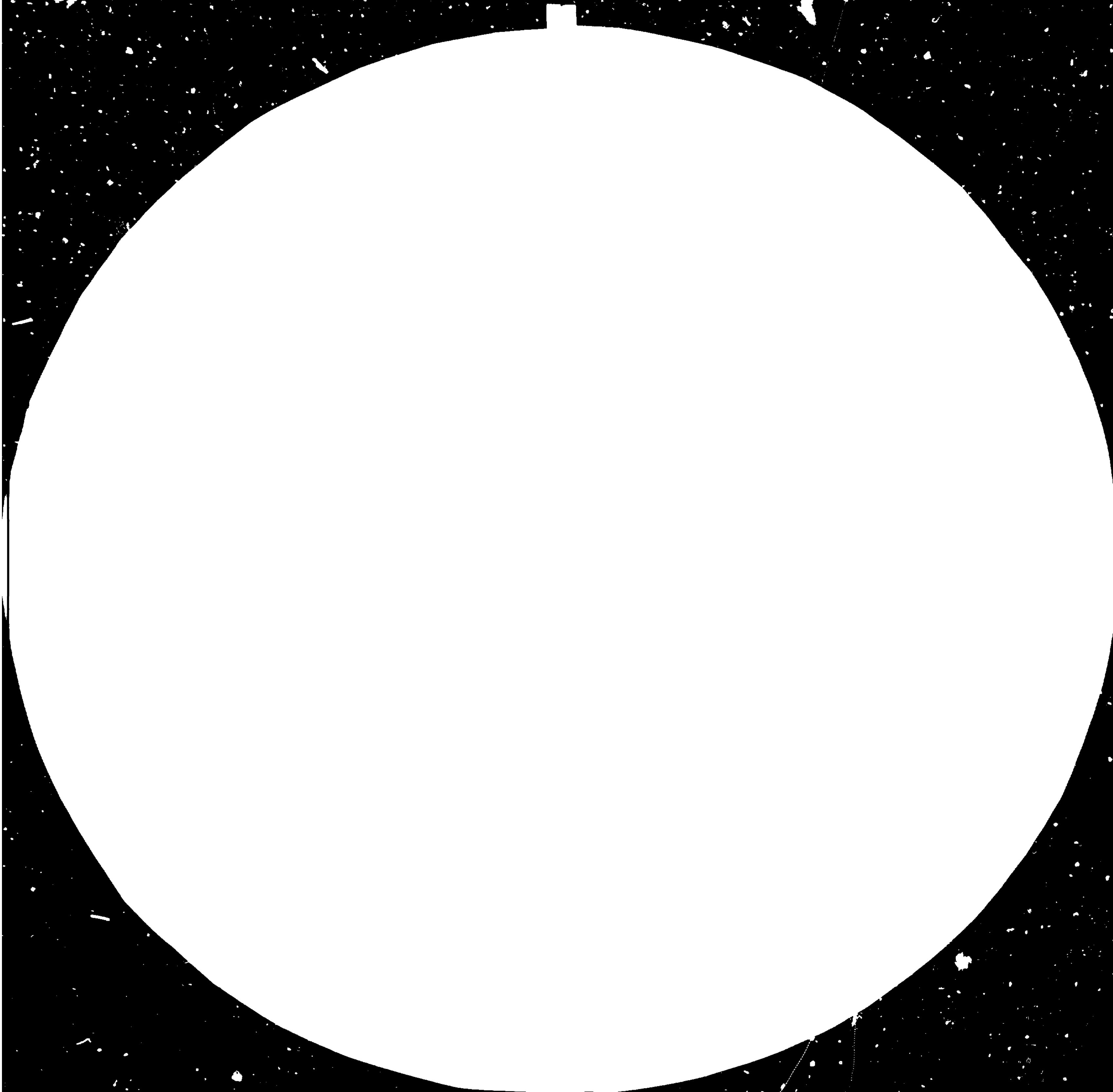
Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

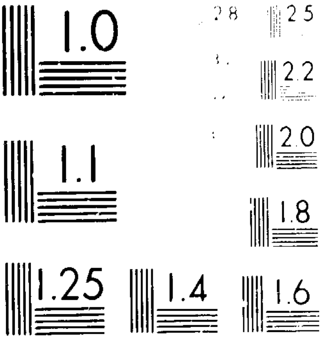
CONTACT

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

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

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




1.0
2.8
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

Mr. Biering:
not restricted

12450

Distr.
~~RESTRICTED~~

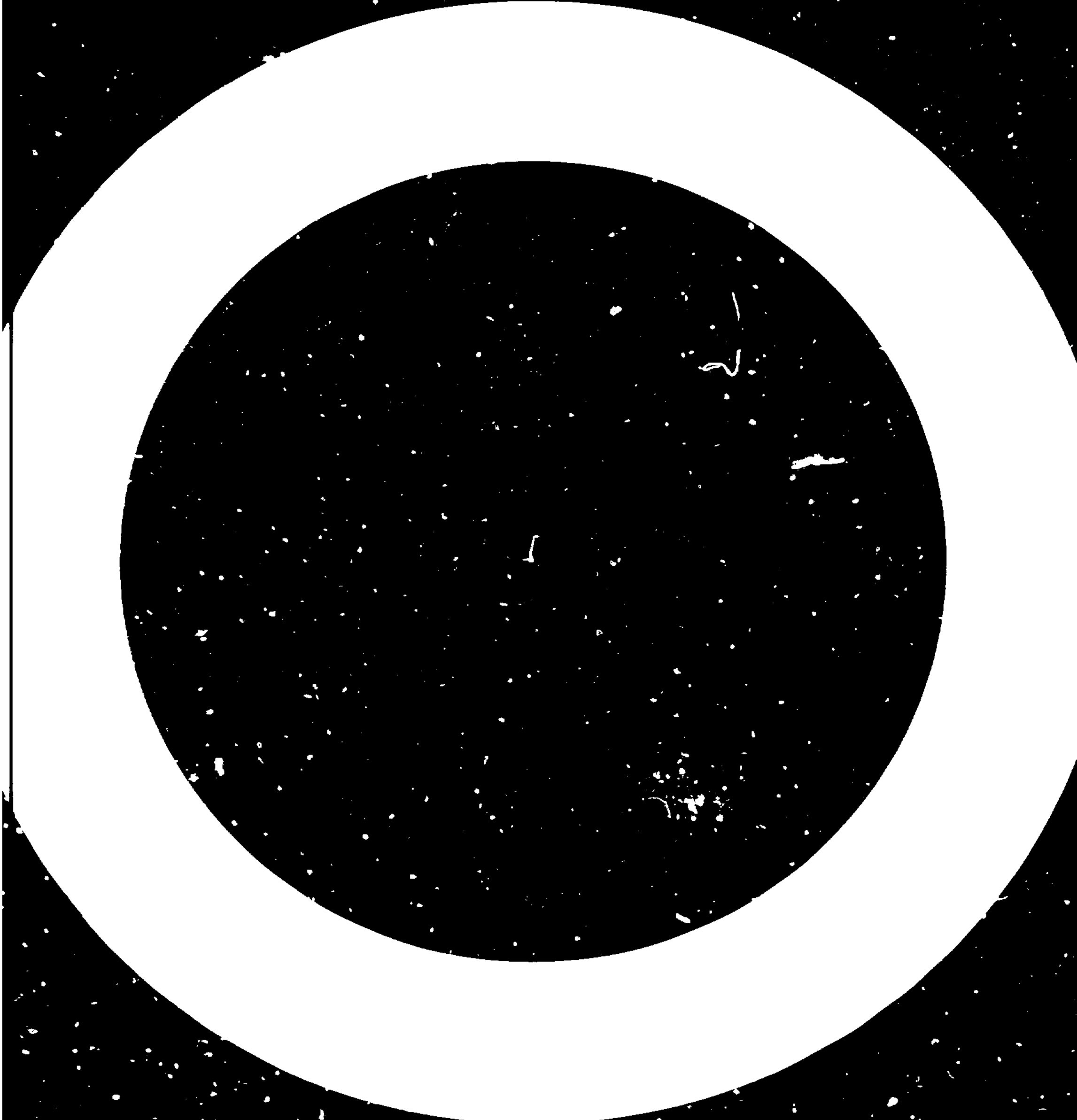
UNIDO/IO/R.88
9 December 1981

ENGLISH

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

ENERGY CONSERVATION IN
NON-METALLIC MINERALS
BASED INDUSTRIES

V.81-33301



INTRODUCTION

The importance of energy and energy-related technologies to the industrial development of developing countries was implicit in the Lima Declaration and Plan of Action on Industrial Development and Co-operation adopted by the Second General Conference of the United Nations Industrial Development Organization (UNIDO), held at Lima, Peru, 12-26 March 1975. The UNIDO Energy Task Force, created in 1977, prepared a comprehensive report which provided an overview of energy-related activities and programmes (UNIDO/EX. 108, 3 January 1980), and during the Third General Conference of UNIDO, held at New Delhi, India, 21 January-9 February 1980, the role and responsibilities of UNIDO in energy-related industrial development activities were defined. During its thirty-fifth session, the United Nations General Assembly endorsed the inclusion of these activities among the priorities of UNIDO (resolution 35/66).

The present action programme of UNIDO in this field comprises three main lines of activity which can be described concisely as "energy for industry", "industry for energy" and "industrial energy management". The present study has been prepared as a part of the third activity, which aims at securing the maximum self-reliance and efficiency of local industry with respect to energy production and use. It has been prepared in close collaboration with the UNIDO-Czechoslovakia Joint Programme for International Co-operation in the Field of Ceramics, Building Materials and Non-Metallic Minerals Based Industries, which in its own work programme attaches high priority to energy conservation efforts.

The study is intended as an in-depth presentation of the present possibilities of energy conservation in the non-metallic minerals based industries, with particular reference to the ceramic, cement and glass industries.

The above industries were selected for these reasons:

(a) Most developing countries possess deposits of raw materials for the selected non-metallic industries;

(b) The manufactured products of the selected non-metallic industries are building materials and other products indispensable for the development of housing and improved living standards in developing countries;

(c) These non-metallic products are strategic feedstocks as well, being prerequisites for the development of further industries;

(d) The benefits of the selected non-metallic industries are significant from the viewpoint of national economics;

(e) In most developing countries these industries have been established or are planned to be established; therefore local producers should be interested in the transfer of experience in energy conservation.

The body of the study consists of three parts related to industrial ceramics, glass and cement industries. The energy problems in all parts are dealt with in technological sequence. The extent of investigated products and technologies from the viewpoint of energy conservation required different approaches. The described measures for energy conservation are accompanied by achieved or supposed benefits. There are examples of improvements achieved by maintenance, change of technology or technical adaptations without investment costs and within a short period. There are other improvements that are feasible only by reconstruction or by new equipment with considerable investment cost. Every new project should be examined from the viewpoint of energy conservation as specified in this document.

This study was prepared by J. Dřeve,[1] Z.A. Engelthaler,[1] M. Grotte,[1] L. Kuna,[2] J. Lahovsky[3] and L. Meinhold.[1]

---

[1] UNIDO-Czechoslovakia Joint Programme for International Co-operation in the Field of Ceramics, Building Materials and Non-metallic Minerals Based Industries, Zborovská 1, Pilsen, Czechoslovakia.

[2] Research Institute for Ceramics, Refractories and Raw Materials, Horní Bříza, Czechoslovakia.

[3] Cement and Lime Works, Headquarters, Prague, Czechoslovakia.

CONTENTS

Chapter Page

Part one. Industrial ceramics

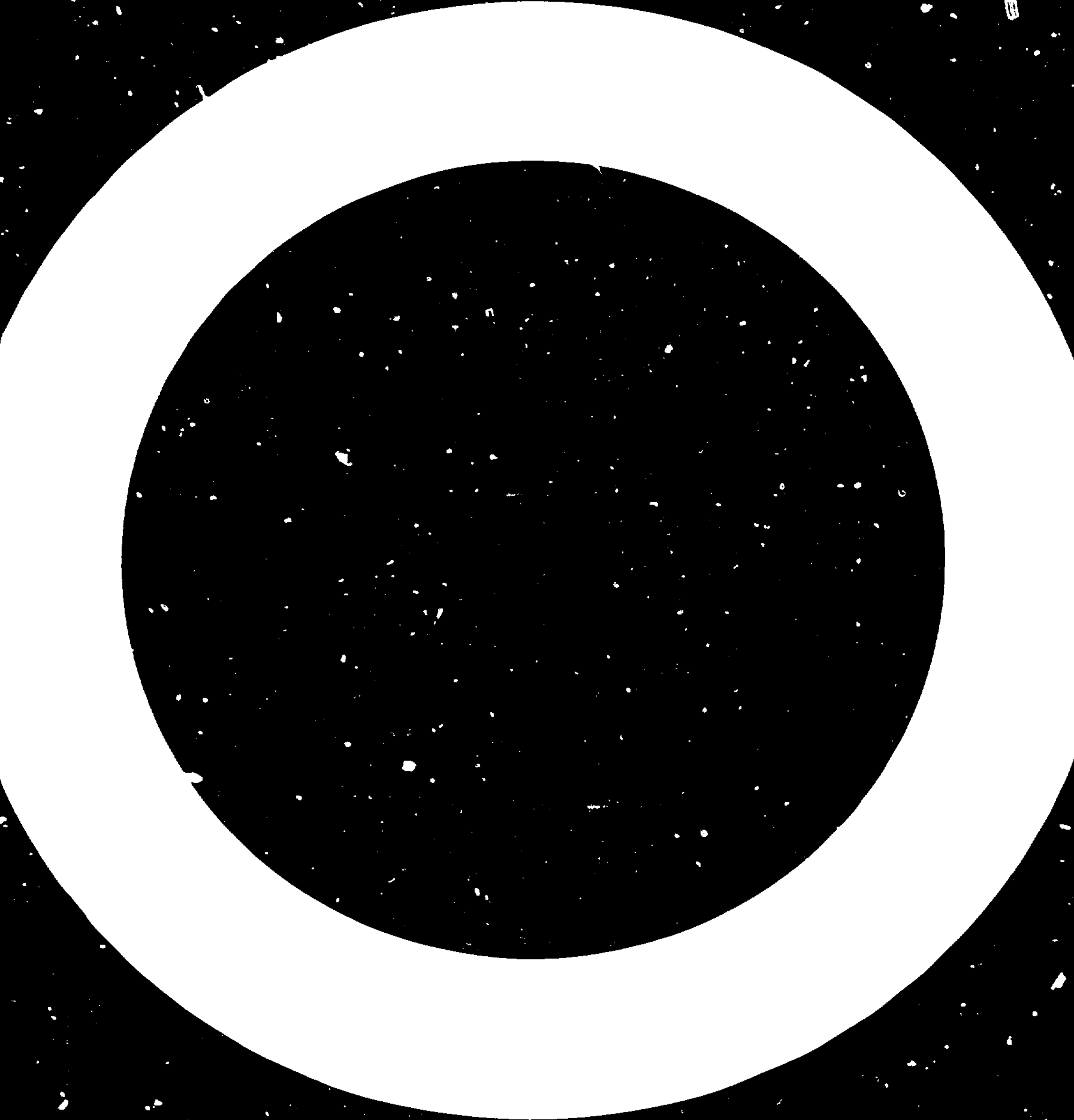
Page

Part Two. Glass industry

Part three. Cement industry

Tables

Figures



Part One. Industrial ceramics

INTRODUCTION

The ceramic industry has taken a significant position within the framework of national and world economies. It produces a broad assortment of ceramic facing materials for interior and exterior decoration of dwellings and public and industrial buildings and thus it contributes significantly to the realization of present demands of environmental conditions. The use of stoneware in the building industry has increased. Brickmaking is still important in many countries in spite of the extensive use of prefabrication and new materials in construction. Utility and artistic ceramics, as well as porcelain and stoneware, are a significant branch of the ceramic industry. Lining refractories and insulants are indispensable for metallurgy, the chemical and machine industries and electrical engineering. They are used for boiler lining, melting furnaces, heating and heat-treatment plants. Insulants of all kinds are used in the field of electrotechnics and electrical power distribution. Extracting and dressing of non-metallic raw materials for all kinds of silicate products are included.

The silicate industry has many extensive activities and is associated with a wide range of further industrial branches.

The world deposits of raw materials applicable to the ceramic industry, as well as the possibilities of their exploitation in new regions, are large. Present prices of raw materials and energy change according to the price changes in the world market.

The recent standards of plants have been widely different. New ceramic plants are equipped with highly mechanized and automated lines, but in others, older equipment is used with a different stage of modernization and therefore with a lower technology level and productivity. Simple plants without complicated mechanization and automatization are of better use in developing countries.

Energy insurance for production has become practically the most significant at present. It is possible to say that this problem is a crucial one also for the ceramic industry, which ranks as an energy intensive industry.

The heat processes - drying and firing - are the main technology stages which the ceramic products go through to obtain required properties and shape. The high energy consumption of those heat processes is caused not only by the large volume of processed materials and products but also mainly by the long firing, which is necessary for all structural changes in material and for obtaining the required properties.

The energy prices will probably increase and influence the economy, but later they could cause a reduction of some industrial branches. Cases have appeared in some countries where manufacturing was limited or suppressed because of energy insufficiency.

The position of the ceramic industry is not easy, since the ratio of cost on consumed energy to product value is considerably high. The producers who decrease the energy consumption at the technically admissible level will have a leading position in the ceramic industry.

I. CERAMIC TECHNOLOGY AND ENERGY CONSERVATION

Energy consumption in ceramics is concentrated in the following stages:

Dressing machines, mechanical equipment, shaping machines, handling and transport means

Driers and kilns

Overhead consumption (heating, lighting, conditioning and maintenance)

Energy consumption of the first phase is given by the technical and technological level, mechanization and automation of the plants and by the skills of labour and staff.

Quite similar conditions are applicable to driers and kilns.

Overhead energy consumption represents an inappreciable part of the total energy consumption, and it is dependent on the production capacity. Larger plants have lower overhead energy consumption and vice versa.

The time extent and maximum temperatures of drying and firing processes are determined by the used technology and raw materials. Energy conservation in this field can be achieved by changes in production technology that decrease the temperature and shorten the time cycles.

The above-mentioned changes depend on the following types of ceramic products:

Facing ceramic products
Stoneware
Refractory materials
Building bricks and tiles
Sanitary, utility and artistic ceramics
Porcelain

Facing ceramic products

Ceramic tiles

Facing ceramic products for interior and exterior decoration of dwelling, public and industrial buildings have acquired a great importance. Earthenware, tiles and mosaic are included in this branch. The energy consumption of the glazed and unglazed products is high and depends on the individual type of product.

Wall tiles

The traditional manufacturing process consists, with the exception of body preparation and pressing, of three cycles: drying, bisque firing and glost firing after glazing.

The manufacturing process has been based on the range of the ceramic plants of the kaolinitic-clay, semi-siliceous or feldspar body composition, requiring bisque firing temperature of 1,230°-1,280°C. Glazed bisque was fired at temperatures of 1,080°-1,120°C. Decrease in firing temperatures to 1,050°-1,080°C for bisque firing and to 960°-1,040°C for glazing can be reached by replacing those bodies with lime-siliceous, dolomite-siliceous and other ones.

Table 1 shows the basic types of earthenware tile body composition.

The reduction of firing temperatures resulted in energy conservation owing to the new raw material components. Significant energy conservation was achieved by using the new raw materials which allowed heat processing under lower temperatures.

Evaluation of energy savings shows that the manufacture of lime-silicate bodies can save up to 15,000 kJ per each square meter of produced wall tiles.

Simultaneously, firing periods were reduced from the original 60-120 hours for a body and 24-48 hours for a glaze to less than one-half. Consequent energy conservation represents 8%-12% of the total original consumption. A review of firing cycles is given in table 2.

Semigres glazed wall tiles

They are suitable for exterior wall lining and are closely related to the frost-proof tile materials. The body composition in the following table 3 may be taken as a typical one.

Semigres glazed floor tiles

They represent another type of ceramic product with possibilities of reducing firing temperatures by using non-metallic raw materials with the fluxing effect. Classical technology is based on using raw kaolin, washed kaolin and low-fusing clays. The firing temperatures of the standard body are within the range 1,200°-1,250°C but can be decreased to 1,100°C by using phonolite or other flux. This temperature drop saves 10%-15% of energy consumption. Table 4 compares the composition of the standard body and the body with phonolite.

Table 1. Body composition and properties of the basic types of wall tile

Component or property	Kaolinitic	Semi-siliceous	Feldspar	Siliceous A	Siliceous B	Siliceous C	Siliceous D	Siliceous E	Talc A	Talc B	Wollastonite A	Wollastonite B
Kaolinite (%)	80	60-85	55-40	55-40	50-40	36.84	40.66	13.15	40-30	20-25	45-50	30
Quartz (%)	15	27-30	35-50	38-45	40-45	38.44	37.87	43.45	15.20	-	25-30	10-15
Feldspar (%)	5	8-10	5-15	-	2.5	6.61	5.80	17.57	3	-	5-10	-
Limestone (dolomite) (%)	-	-	-	10-15	7.5	16.99	14.45	22.36	2	-	5-10	-
Talc (%)	-	-	-	-	-	-	-	-	40	75-80	-	-
Wollastonite (%)	-	-	-	-	-	-	-	-	-	-	18	55-60
Fe_2O_3 + TiO_2 (%)	1.0	1.0	1.5	1.5	1.5	1.12	1.22	3.47	1.5	1.5	1.5	1.5
Total grog (%)	60-65	60-65	55-60	55-60	55-60	64	60	87	60-70	75-80	55-60	70
Fired grog (%)	40-45	20-30	0-10	0-10	0-10	0-5	0-10	0-5	0-5	0-5	10-20	0-5
Firing temp. - bisque (°C)	1 280	1 230	1 230	1 050	1 150	1 060	1 080	1 060	1 200	1 180	1 130	1 060
- glaze (°C)	1 120	1 080-1 100	1 080	960	1 040	1 040 (960)	1 040 (960)	1 040 (960)	960 - 1 040	960 - 1 040	1 040	960 - 1 020
Calibration of bisque tiles	YES	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
CTE 10^{-7} a/	46.1	48.1	56.7	64.6	68.2	64.6	61.5	71.4	44.2	40.3	62.0	57.8

a/ CTE ..... coefficient of thermal expansion.

Table 2. Reduction of firing time for double fired wall tiles
(Hours)

Period	Bisque firing	Glaze firing
After the Second World War	60-120	24-48
At the beginning of the 1960s	24-48	3-24
At present	1-24	0.5-24
By the year 2000	0.5	lower than 0.5

Table 3. Body compositions of semigres glazed wall tiles

Component or property	Body A	Body B
Clay A[a]	60%	50%
Clay B[a]	-	35%
Fine milled phonolite	40%	-
Grog	-	15%
Firing temperature	1 060°C	1 250°C

[a] Clay A and clay B are not specific clays but merely typical examples.

Table 4. Composition of semigres glazed floor tiles

Composition or property	Standard body	Body with phonolite
Clay A[a]	35%	40%
Raw kaolin	10%	30%
Washed kaolin	25%	-
Phonolite	-	30%
Feldspar	30%	-
Firing temperature	1 250°C	1 100°C

[a] Clay A is not a specific clay, but merely a typical example.

Replacement of the double firing by the single firing process enables the technicians in the semigres glazed floor tiles manufacture to reduce the energy consumption by 50% of the total.

Ceramic glazes

Properties of ceramic glazes have to correspond to the ceramic body properties and to quality and appearance requirements. Table 5 shows the Seger formulas of opaque glazes dependent on their temperatures.

After the Second World War ceramic glazes passed through similar development as ceramic bodies. Opaque zircon glazes composed on the potash feldspar basis fired at temperatures of about 1,120°C were used for kaolinitic-clay bodies. The application of calcium-siliceous body in the manufacture allowed the development of new types of glazes with the sodium-lime feldspar and lead content, which were melted with firing temperature of 960°-1,040°C only.

Further development of glazes should enable single firing ceramic processes at temperatures as low as 900°C. Trends of further development will depend on successful adjustment of body composition, resulting consequently in decreased energy consumption.

Recommendations for ceramic tiles production

Replacement of the classical double firing technology in the ceramic tile manufacture by the single one can result in reduction of energy consumption by about 40%-50%. There are conditions for more significant decreasing of firing temperatures also in the field of semigres glazed wall tiles.

The use of fine milled fluxes with firing temperature reduced by about 150°C would decrease the energy consumption to 35%.

Table 5. Seger formulas for opaque glazes according to the firing temperatures

Firing temperatures	(Parts of a unit (e.g., grams))											
	Na_2O	K_2O	CaO	MgO	BaO	ZnO	PbO	Al_2O_3	SiO_2	B_2O_3	ZrO_2	SnO_2	TiO_2
960°C	0.045	0.049	0.1373	-	-	-	0.7687	0.3031	2.258	0.227	-	2.277	-
	0.012	0.026	0.291	-	-	-	0.671	0.2783	2.639	0.1973	-	0.279	-
	-	-	-	-	-	-	1.00	0.200	2.500	-	0.15	-	-
	0.60	-	0.24	-	0.08	0.08	-	0.360	5.500	1.092	0.454	-	-
1 000°C	-	-	0.25	-	-	-	0.75	0.28	2.05	-	0.15	-	-
	0.09	0.30	0.20	-	-	-	0.41	0.20	2.75	0.18	-	0.28	-
	0.046	0.103	0.544	-	-	-	0.307	0.563	3.385	0.784	-	0.391	-
	0.084	0.139	0.665	-	-	-	0.111	0.621	3.482	0.991	0.25	-	-
	0.386	-	0.614	-	-	-	-	0.681	4.509	1.320	0.42	-	-
	0.332	0.097	0.571	-	-	-	-	0.5813	4.386	1.16	0.425	-	-
1 060°C	0.347	0.100	0.456	0.097	-	-	-	0.435	3.750	0.670	0.317	-	-
	0.54	0.04	0.24	-	0.07	0.11	-	0.34	5.54	1.05	0.43	-	-
	0.381	-	0.619	-	-	-	-	0.591	4.472	1.108	-	0.177	-
	0.228	0.043	0.326	-	-	0.403	-	0.130	2.295	0.391	0.321	-	-
	0.239	0.045	0.2917	-	-	0.4243	-	0.1504	2.037	0.703	0.337	-	-
1 120°C	0.08	0.18	0.74	-	-	-	-	0.630	4.56	1.28	0.32	-	-
	0.07	0.15	0.68	-	-	0.10	-	0.430	4.05	0.5	0.30	-	-
1 250°C	0.13	0.06	0.50	0.07	-	0.24	-	0.36	2.60	-	0.36	-	-
1 250- 1 300°C	0.125	0.101	0.566	0.080	-	0.129	-	0.563	3.885	-	-	0.140	-
	0.089	0.075	0.438	0.277	-	0.121	-	0.452	3.613	-	0.176	-	-
	0.090	0.074	0.439	0.278	-	0.119	-	0.457	3.736	-	0.085	-	-
1 410°C	0.09	0.18	0.36	0.33	-	0.04	-	0.74	6.5	-	-	-	0.003
	-	0.2	0.7	0.1	-	-	-	0.90	7.0	-	0.42	-	-

Stoneware

Stoneware, generally called non-translucent and vitrified ceramic products, is classified into coarse- and fine-grained stoneware products.

Coarse-grained stoneware:

- Sewage pipes
- Stoneware for agricultural purposes
- Stoneware with salt or earthen glaze
- Electrotechnical stoneware (insulants)
- Unglazed floor tiles
- Chemical stoneware

Fine-grained stoneware:

- For sanitary purposes
- Utility and artistic ware
- Unglazed floor tiles

Kaolinitic clays of medium or low refractoriness are suitable raw materials for stoneware manufacture. Those clays vitrify at lower temperatures, as their content of alkali oxides amounts to 4% of the total. Their vitrifying temperatures, owing to the high content of fine clay particles, are about 50°-100°C lower than their softening points temperature. Depending on their plasticity, those clays are used directly or they are blended with grog, e.g., quartz sand, fired milled shale or crushed stoneware, in order to control their drying and firing shrinkage.

The following non-metallics, if fine-milled, can act in a ceramic body as a flux and result in lower firing temperatures and energy consumption decrease:

- Calcareous marl
- Phonolites
- Tuffs and tuffites
- Perlites
- Nepheline-syenite
- Dolomite, limestone and magnesite
- Glass (window, sheet, containers etc.)

The use of phonolite and marl for fancy tiles and gres facing tiles has shown the possibilities of decreasing firing temperature and energy conservation. The addition of phonolite in a tile body decreases firing temperatures from 1,180°C to 1,115°C and reduces energy consumption by 6%. Similarly a body of gres facing tiles with 33% marl requires the firing temperature of 1,140°C instead of the originally used 1,230°C. Energy consumption is about 8% lower.

It may be assumed that change in the composition of a stoneware body caused by fluxes will decrease the firing temperatures of stoneware by 150°-170°C.

Table 6 shows the body composition of the basic stoneware grades.

Table 6. Body compositions of basic stoneware grades
(Percentage)

Component	Coarse stoneware	Fine stoneware
Clay A[a/]	45	45
Clay B[a/]	25	-
Quartz sand	-	43
Feldspar	-	12
Grog	30	-

a/ Clay A and clay B are not specific clays, but merely typical examples.

There are of course certain differences between body compositions, used technologies and heat processes.

Sewage stoneware

Three different practical examples of the sewage pipes body composition are shown in table 7. It clearly indicates energy savings and temperature reduction if suitable fluxes are incorporated into the conventional sewage pipes body.

Table 7. Body compositions of sewage pipes

Composition	Conventional body	Body with marl	Body with phonolite
Clay A[a/]	47%	31%	32%
Clay B[a/]	47%	31%	31%
Marl	-	32%	-
Phonolite	-	-	31%
Fired reject	6%	6%	6%
Firing temperature	1 250°C	1 160°C	1 080°C

a/ Clay A and clay B are not specific clays, but merely typical examples.

Initial shaping moisture of stoneware amounts to 16%-20%. Pipes are dried down to the moisture content of 3% before being fired. The lower the initial moisture content, the lower is the energy consumption during drying. Improvement of driers and their efficiency allows further energy conservation. It is also possible to replace plastic body by stiff-mud body.

Many types of driers are used in the ceramic industry: units situated above the kiln, chamber and channel types using waste heat, heat from vapour heaters, chimney gases and hot blast from recuperators. The secondary sources, e.g., heat from the surrounding kilns, coupled kilns and driers and underpressure systems etc., are not fully used. The following indication may be taken as a typical heat consumption of drying in the stoneware manufacture: heat consumption related to 1 kg of green product amounts to 838-1,257 kJ and energy consumption to 0.01-0.07 kWh.

Sewage pipe firing is performed in chamber or tunnel kilns depending on their size. Tunnel kilns operate mostly in temperature ranges of 1,250°-1,280°C, and the firing cycle takes 40-65 hours, while the firing cycle in chamber kilns reaches up to 100-140 hours. Specific energy consumption differs significantly according to the type of kiln: heat consumption related to 1 kg of product in chamber and tunnel kilns is 3,770 kJ and 2,500 kJ respectively. The above mentioned heat consumptions depend on the technical conditions of the kilns.

Refractory materials

Refractory materials represent an extensive range of products, such as fire-clay refractories with an increasing content of alumina, corundum, silica, magnesite and chromemagnesite products, each of them requiring specific technology, raw materials and heat processing. In developing countries the most applied manufacture of refractories is the production of fire-clay products.

The main types of raw materials used in fire-clay body composition are refractory clays, kaolin and grog. Selection of raw materials for each quality class of fire-clay body depends on alumina and silica contents. Resulting properties have to correspond to a given standard in accordance with Equilibrium diagram of Al_2O_3-SiO_2 system (see figure I). Three basic quality classes of refractories - high duty, medium duty and low duty - are used for fire-clay body grading. They require different technological parameters and different firing temperatures. The manufacturing process is based on the two basic types of technologies such as plastic process and stiff-mud process. Basic fire-clay body compositions are shown in table 8.

Table 8. Fire-clay body compositions

Component	Plastic process	Stiff-mud process
Refractory clay A	50%	25%
Burnt grog	50%	75%
Moisture of processed body	14%-16%	7%-8%
Firing temperature	1 380°-1 400°C	1 400°-1 450°C

Drying of fire-clay bricks is carried out in different types of driers. Their firing is applied usually in chamber or tunnel kilns at temperatures of 1,380°-1,450°C. Specific drying and firing energy consumptions are 460-670 kJ and 2,700-5,000 kJ per kilogram of product respectively, depending on the type of fire-clay and kilns. Values for tunnel kilns are 2,700-3,300 kJ and for chambers 3,300-5,000 kJ.

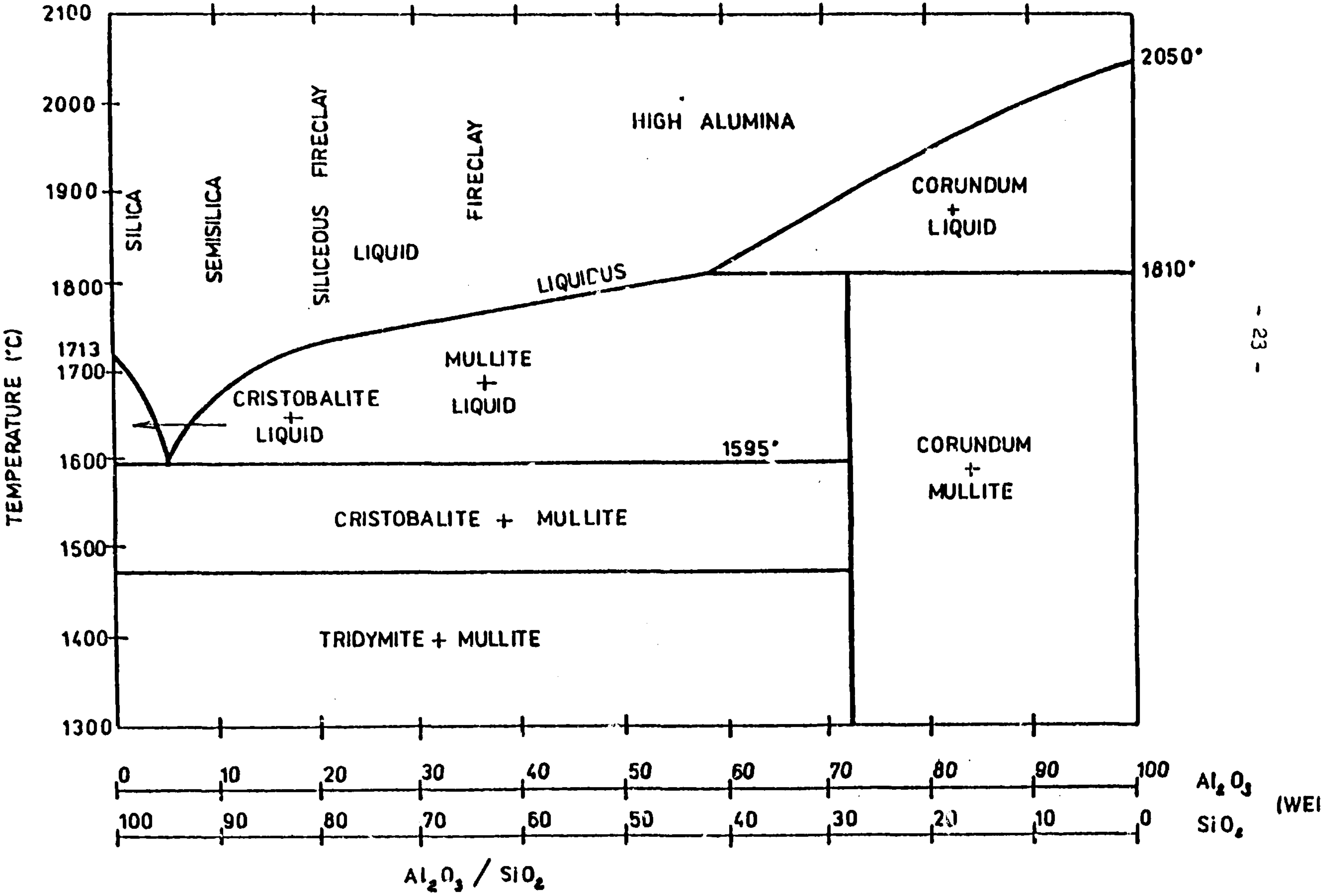


Figure I. Equilibrium diagram: Al_2O_3-SiO_2 system

Energy conservation possibilities of the fire-clay process are limited, from the technological point of view. Substitution of the plastic body process gives only limited energy conservation. Substitution of raw materials by other ones with the lower sintering point can decrease refractory properties and their temperature resistance with respect to softening. Also partial or total replacement of burnt grog by unburnt grog is of use. By replacement of 20% of burnt grog by a raw grog in the case of 200,000 tons fire-clay production, 35,000 tons of fuel per year can be saved.

The present stage of development offers replacement of burnt fire-clays by unshaped and unburnt materials, such as plastic ramming masses and refractory concretes. Both groups of masses substitute for and exceed in many specific cases the produced types of burnt clays. They are very suitable for developing countries with a capital insufficiency.

Plastic ramming masses with chemical or hydraulic bond are applicable up to 1,600°C. They enable the building of monolithic or prefabricated linings by direct ramming of masses into a formwork. Producers deliver them in the plastic stage for direct processing. Those masses are fired to the final shape during the initial run of a furnace. Refractory concretes that contain portland and alumina cements as a bonding agent possess similar structural characteristics. Dry refractory concrete mixtures are then processed with water additions directly before being rammed into a boarding. In industrially developed countries, refractory concretes are delivered in the shape of prefabricated elements, blocks, panels and bricks, and are fired during the start-up period of a furnace.

Both types of unfired refractory materials have proved successful, and their part in the total production of fired shaped materials reached 30% within a short time.

Production of the unshaped masses will continue to increase, because it results in a shorter time for furnace building and longer furnace life, and energy is preserved at the same time. Specific energy consumption represents 3,100-5,700 kJ/1 kg of the mass.

Building bricks and tiles

The manufacture of building bricks has been significantly influenced by developments in the building industry. The use of pre-cast units, concrete, glass, metal panels etc. has considerably decreased demand for building bricks. Nevertheless, bricks of all kinds and roof tiles remain the basic elements of residential buildings and will be the most applied construction elements in developing countries.

These products have a water absorption of 10%-20% and cold crushing strength of 10-15 MPa. The basic body composition is based on clays with 60%-80% SiO_2 and 5%-20% Al_2O_3. Brick clays contain 5%-8% of final dispersed iron-trioxide, which causes the red colour of building bricks after firing. Drying shrinkage depends on the used grog-sand, clinker, light ash, coal etc. Raw bricks are extruded with 16%-18% moisture content. The dry pressing technology requires the mass with 8%-12% moisture content.

The building bricks drying is done in channel and chamber driers using hot blast from steam heaters, other kilns and heat exchangers. Specific drying heat is 630-840 kJ/kg, air temperature 150°C and drying cycle 40 hours.

Building bricks firing developed from charcoal clamps over round kilns to tunnel kilns. The firing temperature is 900°-1,100°C. In some places solid fuel is still used, 70%-80% of which is blended with the mass, and the rest is fed by charging hopper to the heating zone.

The firing process energy conservation possibilities are implemented by grog additions into clay (it increases the coefficient of internal diffusion), or by coagulant $Ca/OH/_2$, which favourably influences the mass moisture transmissivity. More significant conservation can be achieved by applying the new concepts of heat transfer - heat convection in tunnel kilns - or by coupling driers and using waste heat for drying. Present values of specific firing heat are 1,700-3,000 kJ/kg of fired brick.

Sanitary, utility and artistic ceramics

It involves production of wash basins, toilet basins, bowls, tubes, utility crockery and pottery and artistic ceramics. These products are manufactured from earthenware, semivitrified and vitreous china bodies. Typical body composition of sanitary ware is shown in table 9.

Table 9. Body compositions of sanitary ware

Component	Earthenware double fired	Vitreous china single fired
Clay A[a]	20%	20%
Clay B[a]	15%	15%
Raw Kaolin	20%	15%
Feldspar	-	25%
Silica	-	19%
Fired rejects	-	6%
Fired grog	45%	-
Firing temperature	1 100°C	-
Glaze firing temperature	1 280°C	-
Single firing temperature °C	-	1 280°C

a/ Clay A and clay B are not specific clays, but merely typical examples.

During processing and slip casting, liquifiers such as water glass (0.1% of total) and soda (0.2% of total) are added. Drying takes place in the open air first to 17%-20% moisture, and later it continues for 36-48 hours in channel driers to the moisture of 1%-2%.

The firing process is carried out after glazing in tunnel kilns at 1,200°C for earthenware body and at 1,280°C for the sintered body. Products of larger dimensions are fired more slowly.

Volume of this type of ceramics is considerably lower in comparison with others and, therefore, it is produced in smaller ceramic plants. This fact influences the specific energy consumption unfavourably; it may exceed that of stoneware or porcelain firing.

Owing to simple machinery and ensuing low investment cost, vitreous-china type is suitable for developing countries in spite of its complicated technology.

Porcelain

The porcelain products with pure white, vitreous, compact translucent body include all types of utility ware and technical porcelain. With the exception of frit porcelain (Florentine and Sévres) these products are represented by feldspar porcelain. Kaolin, feldspar and silica are used as the basic raw materials in different proportions. The firing temperature depends on the type and content of feldspar. According to this temperature we recognize soft and hard grades of porcelain.

Soft porcelain

The original soft porcelain contained about 30% of feldspar and it was fired at 1,250°-1,300°C. New Sévres type raised feldspar content to 35% and with glazed body was fired at 1,280°-1,300°C. Meissen china type was very similar with firing temperature of 1,230°-1,280°C. Production of soft porcelain was established after the introduction of low vitrifying clays and kaolins with large interval of deformation. The composition:

Kaolin	25%
Clay	15%
Feldspar	28%
Quartz sand	32%

The firing temperature is 1,320°-1,380°C.

Hard porcelain

Hard porcelain is produced in a range of significant plants. It shows its firing temperature of 1,380°-1,460°C and the prevailing materials in the body composition:

Washed kaolin	55%
Feldspar	22%
Quartz sand	32%

Hard porcelain is more temperature resistant against scratching and breaking, and it has lower contents of glass phase in the body after firing.

Electrical porcelain

Chemical composition of electrical porcelain for low voltage products approaches that of the soft porcelain:

Washed kaolin	30%
Clay	10%
Feldspar	35%
Quartz sand	25%

The firing temperature fluctuates about 1,300°C.

Utility porcelain is produced by using drying, bisque firing and glaze firing processes. Drying of porcelain to 1%-2% of moisture is carried out in driers for hours, depending on the type and size of product.

Thin green porcelain utility ware is difficult to be glazed and, therefore, it is to pass preceeding bisque firing at 900°-1,000°C. After cooling the ware is glazed and fired. From the technological point of view, reduction atmosphere is necessary, especially at 900°-1,200°C when Fe_2O_3 is reduced to FeO, whereby the yellowing tint is removed. New developments are possible in the production of porcelain products in one-fire technology, i.e., without bisque firing.

Efforts to conserve energy during porcelain production are limited in comparison with other ceramic production. The limitation is given by the quality, demands, tradition, stabilized technology and used raw materials. However, there exist possibilities to change body composition aiming at decreasing bisque firing temperature or excluding this phase. Usual partial replacing of a clay by another one with higher content of alkali oxides does not offer a significant energy conservation. There is a more effective way to replace feldspar by nepheline-syenite with higher content of Al_2O_3 and more active fluxes. It decreases glaze firing temperature by about 60°C, firing is more intensive and 12%-15% of energy saving may be reached.

Soft porcelain production is more advantageous from the point of energy consumption. It saves 8% of energy consumption. More extensive energy conservation, amounting to 35%-45% of the total, is attainable in firing hard porcelain in the one-fire process. But the main sources of energy conservation are in efficiently working driers and kilns.

II. THERMAL PROCESS AND ENERGY

The maximum energy consumption in ceramics processing is at drying and firing. The drying process depends on the basic body structure, the firing process on the phase transformations during heating of individual components.

More details of both the processes are described in the following parts.

Drying process

The manufacturing process consists of:

Mixing raw materials with water of plasticity to the suitable workability, (water of plasticity content is 7%-30%)
Shaping by casting, extruding or pressing
Drying and hardening by a hot medium (air, waste gases)

The water of plasticity is continually removed out of the body surface during the drying process (outer diffusion). Different shrinkage on the surface and inside occurs during drying; tensile and pressure stresses arise which tend to crack and warp the shaped piece, making it useless. The shrinkage can be reduced by temperature control according to evaporation rate.

Theoretical specific heat evaporation is 2,680 kJ/kg of water including its heat-up. In respecting the limiting conditions, i.e., a certain time necessary for the given temperature gradient between the medium and the body, a higher amount of heat in kJ/kg will be needed for drying. The higher the inclination of a body to cracking, the more carefully and longer the body will have to be dried, which again will be reflected in higher energy consumption.

Energy consumption of 4,200-12,600 kJ is necessary to remove 1 kg of water from the product. More detailed energy consumptions are shown in table 10 for some basic types of products. It includes also the heat requirements for 1 kg of dry mass.

Drying heat amounts to only 10%-20% of the heat needed for firing, but in spite of it, there are different possibilities to conserve energy in this field.

Some principal tendencies for energy conservation in the drying process in the ceramic technology are:

- Using minimal amounts of technological water of plasticity
- Gradual substitution of dry pressing for plastic shaping
- Maximum utilization of waste heat from adjacent kilns
- Process control according to the critical evaporation rate
- Driers innovation using hot air and air blast control of ventilators or jets
- Coupling of driers and kilns and using waste heat for drying

Table 10. Specific drying heat consumptions in different ceramic technologies

Product	Energy consumption kJ per kilogram of water	kJ per kilogram of dry mass
Facing tiles	7 500-10 000	500-750
Floor tiles	8 400-12 600	550-920
Fire-clays	4 600-6 300	460-670
Stoneware	4 200-6 700	840-1 340
Building bricks	4 000-5 240	630-840

Firing process

Complicated physico-chemical processes occur during firing in a ceramic body which change its physical, chemical and mechanical properties. These changes influence one another in a broad temperature range. Depending on the heating and cooling rates, stresses arise in a body which are very difficult to be analyzed by means of the theory of elasticity and strength.

Detailed analysis of those effects in a ceramic body is rather complicated and involves a range of - till now - unknown factors.

Ceramic body production and glazing is of a good quality only within limited heating and cooling rates. These are given by limiting firing curves. Their knowledge is the first prerequisite for proper selection of firing technology and kiln type. The limiting firing curves cannot be derived theoretically but only empirically in laboratories. Therefore, it is necessary to define the limiting curves and, according to this curve, to determine firing process conditions and to design the corresponding type of kiln.

Long-termed firing does not improve the quality of ceramic body; it only compensates the previous imperfections of a firing unit and heat transfer.

The heat needed for the proper course of endothermic reactions in a ceramic mass is not high and makes 700-930 kJ/kg related to plastic ingredients. The main part of this reaction takes place in the ingredients. Heat consumption for a ceramic body heating-up to 1,000°-1,400°C, in order to reach required properties of a ceramic body, represents 1,000-1,400 kJ/kg. The rest of energy are losses during the thermal process.

Energy consumption for individual industrial firings of ceramic body are substantially higher and are given in table 11.

Table 11. Specific firing heat consumptions in different ceramic technologies

Product	Firing temperature (°C)	kJ/kg of product
Wall tiles		
Bisque	1 040-1 070	3 150-6 300
Glaze (tunnel kiln)	1 040-1 060	2 900-5 200
Glaze (tunnel el. resist. kiln)	1 040-1 060	1 250-1 700
Single firing	1 040-1 060	3 560-4 200
Floor tiles		
Semigres bisque	1 100	3 350-5 000
Glaze	1 050	2 500-3 300
Bisque	1 100-1 200	4 600-5 900
Semigres single-fired	1 100	3 350-5 000
Single-fired	1 100	3 300-4 600
Mosaic single-fired	1 180	7 100-8 000

Building bricks		
Bricks	960	1 700-2 900
Fireclay products		
Standard bricks	1 350-1 450	2 700-5 000
Stoneware		
Earthernware pipes	1 280	2 500-3 800
Floor tiles	1 090	3 800-5 000
Electrical porcelain		
Insulators (tunnel kiln)	1 300-1 400	10 500-17 000
Insulators (chamber kiln)	1 300-1 400	21 000-33 500
Sanitary ceramics	1 250	11 700-12 600

Several rules regarding the energy conservation in firing process are as follows:

The knowledge of the limiting heating and cooling rates of the body and their application in selecting the kiln type

Maximum utilization of waste heat from kilns

Intensive heat transfer by waste gases convection

Using more efficient fuels

Automation of heat processes in kilns

Single-fired glazes

Fuel type and total energy consumption

A number of ceramic plants were established originally on solid fuel consumption or generator gas bases. Progressive development of heating units, intensification of heat transfer and automation brought about the transition to pure gases with higher fuel efficiency (earthen and natural gases), to liquid fuels (fuel oils and petrol) and to the electric resistance heating as well.

With the present energy situation, it is necessary to select fuels according to national economic interests and available local energy sources. The selection process has to evaluate primary power sources, as is shown in the following example:

Kiln energy	Coal energy
1 kJ from electric energy	3.58 kJ from brown coal
1 kJ from coke-oven gas	1.61 kJ from brown coal

Primary efficiency of coke-oven gas is 2.2 times higher than that of electric energy.

World specific energy consumptions in the ceramic industry are shown in table 12. Total energy consumption consists of all parts, including the whole technological process, auxiliary plant and overhead consumption.

Table 12. World specific energy consumptions in the ceramic production related to general consumption and general output (kJ/kg of product)

Product	Fuel	Electric power	Total
Double-fired facing tiles			
Older plants	14 700	1 550	16 250
Average	12 600	1 800	14 400
New plants	10 500	2 100	12 600
Single-fired floor tiles			
Older plants	8 000	2 200	10 200
Average	7 500	1 900	9 400
New plants	7 000	1 700	8 700
Fire-clays			
Older plants	5 000	250	5 250
Average	4 200	350	4 550
New plants	3 350	460	3 810
Sewage pipes			
Older plants	8 600	500	9 100
Average	6 400	730	7 330
New plants	4 200	960	5 160

III. MEASUREMENTS ON THE HEATING UNITS

The world energy situation requires a solution to the present conditions of heating units and their energy consumption. The complex operational analysis of a unit can be a serious basis for such a solution. This analysis has to evaluate technical-service conditions and special energy efficiency measurement to compare possibilities of repairing, adaptation, complete overhaul, modernization, innovation or new plant building. The minimizing of the energy consumption is the resulting target which is considered, not only from the present energy-economical conditions but also with regard to future development in this field. Measurement on the heating units, evaluation of results and formulation of relevant conclusions is the most important basis for all studies in the field of energy conservation. Diagnostic measurements require the use of a set of measuring apparatus and a team of specialists in measurement and heat techniques. A mobile diagnostic unit which is equipped with required apparatus, including a data processing centre, represents the optimal solution for this demand. The unit can be located near the examined equipment, and sensors on the equipment can be connected directly to the apparatus in the mobile unit. Quick transfer and checking of measured values is thus allowed, and the possibility of damage to the apparatus is reduced.

A mobile diagnostic unit for the non-metallic industries, which is the property of the Research Institute for Ceramics, Refractories and Raw Materials in Czechoslovakia, can be used for such activities.1/ The unit was in operation in Czechoslovakia during recent years in the field of consultancy and diagnostic services for the Czechoslovak industry with a major activity in heat transfer. It was applied for consultancy services and for preparing serious recommendations on improvement of existing technologies, that resulted in considerable energy conservation and influenced decisions in the field of investment policy.

Both the basic spheres of measurement - thermal power and technological process measurements - needed a detailed analysis.

1/ See annex.

Heat balance

The heat balance measurement has to be carried out under stabilized operating conditions of a unit and trouble-free technologic flow of material.

Measured and calculated values:

Heat input per hour
Heat losses related to individual energy type and capacity of the unit
Specific heat consumptions related to 1 kg of a product

Heat input depends on the following topics:

Amount of the fuel delivered per hour
Fuel efficiency
Specific heat of fuel, air and material
Amount of air supplied

Heat losses depend on the following items:

Flue loss (temperature, quantity and analysis of waste gases)
Ambient loss (surface temperature of a unit and heat transfer)
Accumulation loss (temperature and mass of kiln car)
Emission loss
Loss through kiln door (air temperature and velocity)
Loss by material drawing-out (temperature and quantity)
Technologic loss (structural changes in material)
Other losses (non-measurable losses)

A part of the heat input is lost in waste gases, if they were not used for drying, recuperation or preheating.

The specific energy consumption (kJ/kg) related to the final product is the main measured value. This value enables the classification of the heating unit according to the energy consumption, but this comparison is possible only for identical technologic process and materials with similar raw composition.

The other significant values obtained by measurement are heating system conditions, especially those of burning process in burners. The waste gases analysis shows a characteristic of the burning process and accuracy of air-gas ratio setting. In accordance with this measurement the first corrections can be made, i.e., setting of burners. The final result is distribution of individual losses in relation to the total heat loss. From these values the final recommendations are derived for heat balance improvement. For example, excessive flue loss shows the possibility of utilizing the heat of waste gases for air preheating, for direct drying, etc. The excessive loss to ambient can be reduced by using better insultation materials in sufficient layers on inner or outer surface of the unit.

The accumulation loss in the kiln car can be lowered by using light-weight lining design with new types of insulants.

In summary, heat balance measurement consists of:

Classification of the heating unit
Information on the burning process and burners
Heat losses classification and evaluation
Conclusions and final recommendations for improvement

The energy conservation and partial use of thermal energy for other purposes is the main result of the above-meantioned steps.

However, the heat balance measurement cannot show the more detailed conditions of heat transfer to material, temperature distribution in individual sections of a kiln, waste gases flow etc.

Heat measurement of a technologic process

Detailed analysis of heat transfer from the kiln atmosphere into processed material, temperature variations related to time, temperature uniformity in the kiln car batch and waste gases flow in kiln space can be verified by measurements showing the following indications:

Time progress of temperature
Heating uniformity in individual sections
Suitability of the batch configuration for heat transfer
Waste gases flow in the kiln atmosphere
Cooling air flow in the cooling section
Uniformity of products quality in individual sections

Time progress of temperature distribution is recorded by so-called "check cars" where thermocouples are placed into standard batch and connected with cabling in the bottom part of the kiln car with a time-temperature recorder.

The waste gases flow in the kiln, or air flow in the cooling section is measured by using anemometers and Prandtl's tubes in kiln sections and exhaust hoods.

The complex diagnosis of the technologic process demands the limiting temperature curves determination. These curves define the limiting values for intensive heating and operation cycle shortening. These curves are derived from stage heating in laboratory conditions in accordance with chemical analysis, DTA and other material properties rated for different temperatures.

The conclusions, which are derived from this measuring, given the complex view of the heat transfer perfection level and possible regulations for its optimization.

From the comparison of real and limiting temperature curves, these indications are derived:

Optimal adjustment of individual burner outputs

Shortening of the heating cycle

Improvement of the batch uniformity from the standpoint of heat transfer and heating uniformity

Cooling section process optimization

The determination of pressure and waste gases flow conditions in the kiln significantly contributes to the heat transfer improvement and its optimization.

This measurement can be advantageously realized with the aid of a mobile measuring unit, too, and both types of measurement (technologic process and heat balance) can be connected.

Both types of measurements are necessary to be carried out for the complex heat unit analysis. All data necessary for selection of the most suitable kiln adaptations and achievement of relatively maximum energy conservation are thus obtained. The contributions for energy conservation are of non-investment character above all, and their implementation can be made step by step with minimum disturbance of manufacture.

The accomplishment of both measurements on heating units is technically difficult, but its price is negligible in comparison with the benefit achieved in energy conservation.

IV. HEAT LOSSES ANALYSIS AND POSSIBILITIES OF THEIR DECREASING

The basic possibilities of energy conservation in driers and kilns were mentioned in the previous chapter. The detailed description is necessary, as each modernization has to be in agreement with the trends in the field of thermal power equipment. In accordance with the results of diagnostic measurement we can, without any adaptation, improve the heating process and energy conservation by:

The accurate adjustment of the firing ratio
Improved setting of the burners output
Waste gases flow control by the kiln exhaust
More suitable composition of the car batch

Firing system

Drying equipment and firing equipment each have a different type of heating process. The dominant heat courses of the driers which are not connected to the secondary power sources are as follows:

Recuperators with steam heaters
Firing chambers placed out of the driers
Recuperators with electric resistance heating elements

The low pressure steam or hot water heaters were frequently used for former driers. Their successive replacement results from the necessity to increase efficiency of driers and recuperators. The heat transfer from boiler to heaters does not satisfy present conditions.

First of all, a hot blast air is suitable for drying from the energy point of view. A mixture of open and drying air is heated in exchanger chamber to operating temperature and distributed by pipes to the drier. The whole unit consists of the system driers-exchangers, and it is possible to change the total output of the drier by fans and jets. Driers with electric resistance heating elements have similar advantages, but they have high energy consumption related to primary energy sources. This adaptation is possible without high investment costs.

The using of secondary sources of energy, e.g., from the surrounding kilns, improves energy conservation substantially. The heating air recovered from the cooling zone of the kiln and used in the driers can decrease the original output of drier firing chamber by 15%-20%.

If the basic possibilities of the energy consumption improvement in driers are summed up, we find out that the optimal way consists of using heaters (recuperators) attached to the secondary energy sources, high velocity controlled circulation and automatic control of the whole unit.

In the firing kilns mostly of tunnel type, attention is given to the type of fuel and burner. The use of liquid fuels (oils) is suitable in cases when they can be easily obtained and are economical. But it is necessary to check fuel quality with respect to the quality of product (sulphur content etc.).

The industrial gases used in ceramic production are based on two types - low heating value (generator gas) and high heating value (town, coke-oven and natural gases). A great number of kilns in ceramic production operate with generator gas from their own generators. It is due to the traditions and local energy conditions. Using of generator gas is out of date now, and it is replaced by gases of higher heating value. Using generator gas has the following disadvantages:

Low efficiency of the generators
Large dimensions of supply and distribution pipes
Tar sedimentation in flow control elements
Automatic regulation is excluded
Soft, radiating flame without required kinetic energy
Limited possibilities of heat transfer intensification

The use of pure gases with higher fuel efficiency affords essentially different chances. It makes it possible to use partially or fully automated control of burners, temperature control and air-gas ratio adjustment during the heating process.

More important is the choice of burners according to the characteristic shape of flame and with regard to the waste gases outlet velocity. It makes it possible to intensify heat transfer and to replace simple heat radiation by the combination of radiation and convection. Development of burners proceeded from turbulent systems of different designs to injector torch, pulse, high-speed and iso-jet burners. The last three types are the most important in ceramic heating units They are similar in high outlet velocity of combustion gases and in ejection effect on combustion gases in burner surroundings.

By combining this effect with a suitable spacing of burners, determination of their outputs and adjusted setting of ware on kiln cars, so that the waste gases may flow through all gaps, an optimum heat transfer in the kiln is found.

It is useful to control an air-gas ratio at the burners in the kilns with continuous operation. On the other hand the kilns with intermittent operation (chamber, car-chamber and bell kilns) need fully automatic control of unit efficiency, including the control of individual burners for temperature homogeneity.

For efficient operation of heating systems for firing kilns, the following recommendations are given:

Introduction of pure gases with higher heating value instead of generator gas

Application of turbulent burners in muffle kilns or reconstruction of muffle kilns to open fire kilns

Use of pulse or high-speed burners in open fire kilns

Installation of full or partial automatic control

Application of high-speed burners on kilns with intermittent operation

Heat transfer through lining

Heat losses by heat penetration through the lining are fully influenced by the heat insulating properties of the lining and its thickness. At older kilns no attention was given to these losses, and emphasis was laid on the kiln stability and lifetime. Therefore predominantly dense, relatively conductive materials and insulating materials of lower quality were used. The opinion on the fire-clay and bricks lining has been changed, owing to the heat process intensification, temperature increase and the necessity to decrease heat losses through the lining. Therefore, medium temperature insulations have been applied to the lining, and development has been concentrated on the new light-weight insulations for higher temperatures. In accordance with the stage of development, some typical materials, such as diatomite bricks, foamed fire-clay bricks and masonry were used. None of these lining materials were sufficient for increasing demands. Their relatively high conductivity hindered the reduction of wall thickness and lining weight.

Increasing trends to reduce the energy consumption resulted in new types of linings. Insulating refractory materials for 1,500°C with specific weight of 1 kg/dm^3, for 1,300°C with specific weight of 0.5-0.8 kg/dm^3 or light insulations for 900°C, with specific weight of about 0.3 kg/dm^3 and fibre-based insulations for 750°C, were developed.

The following dependence of temperature-lining thickness shows the difference between classic and up-to-date linings for the same firing temperature of 1,100°C and the same heat losses.

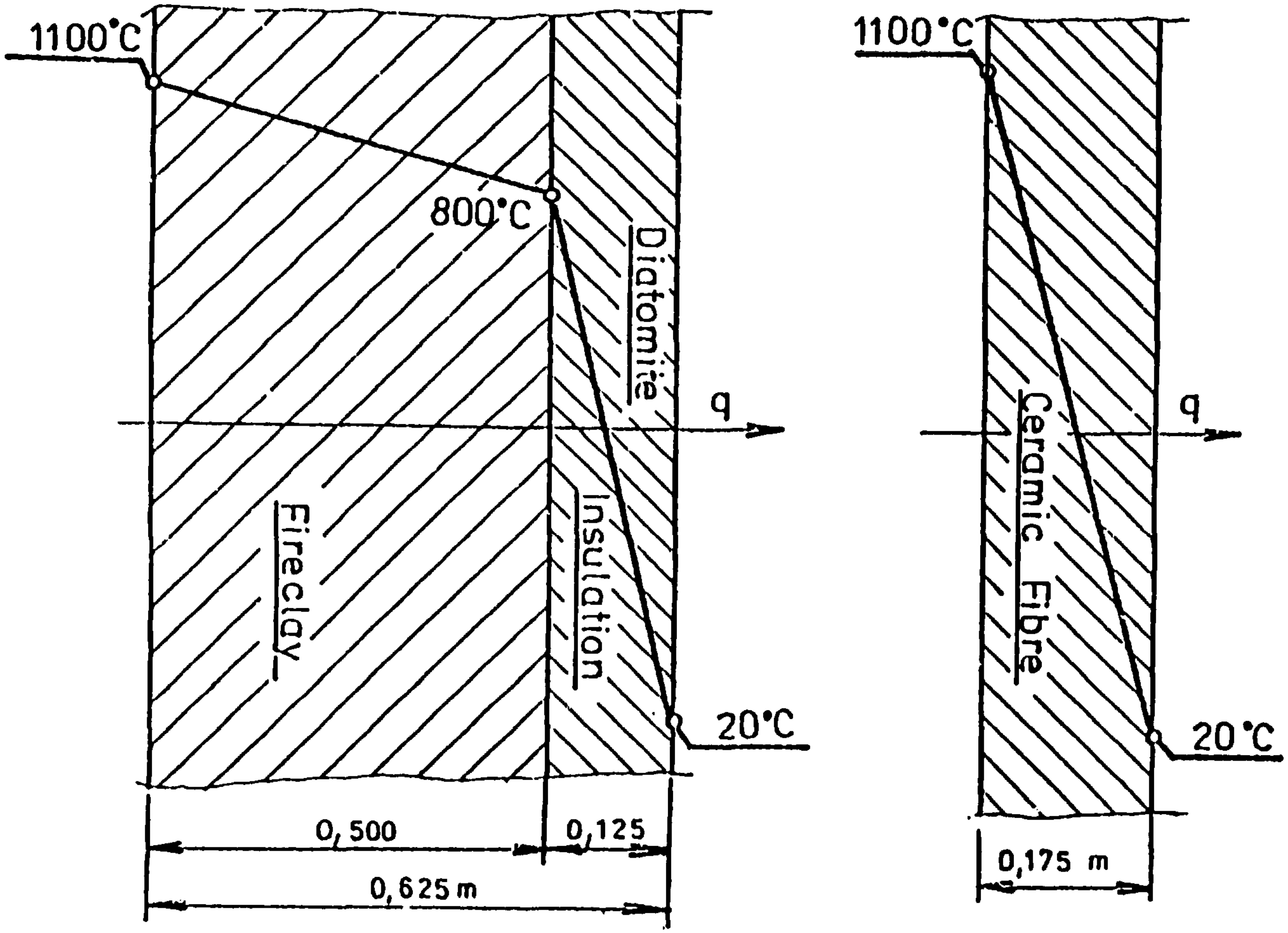
The insulating capacity of fibre lining with 17.5 cm thickness is equal to 62.5 cm of classic lining. The original weight of 1,100 kg/m^3 was reduced to 17.5 kg/m^3 (see figure II).

The last development in the field of fibre ceramics has led to materials on Al_2O_3-SiO_2 Basis, which are used to 1,260°C, and Al_2O_3 based materials up to 1,600°C.

New possibilities were thus prepared for lining structure. The former red and diatomite masonry linings were replaced by multilayer and sandwich structure with minimum weight and thickness. The new type of linings reduces the loss by heat penetration through the walls to surroundings.

Relatively high losses of energy which are caused by the passage of heat through the large surfaces (walls and crown) of a ceramic kiln require the use of the new refractory insulations.

A broad selection of bricks and fibre materials is available for these external insulations. To determine their thickness, special calculations which take temperature gradient and mechanical stability into account are carried out. These calculations are essential, because additional external insulation may result in too much heat being confined to the interior of the kiln, thus causing the failure of the original lining. Therefore the performance of the additional outer lining under graduated conditions of increased temperatures must be carefully calculated. If the amount of heat which is saved can be measured, then the additional amount of heat inside the kiln can be determined, and possible negative effects to the interior lining can be guarded against.



Classical filn and furnace

Up-to-date kiln and furnace

Figure II. Comparison of classical and up-to-date kiln and furnace

Accumulation losses

The heat losses by accumulation are significant for kilns with intermittent operation. Shorter heat cycles have higher heat losses. The lining accumulates a lot of heat during the heating period, and it is wasted during cooling. The total accumulated heat value depends on the wall mass, especially inner layers.

The chamber and car-chamber kilns with dense lining react slowly on temperature changes; heating and cooling take place gradually. The kilns with dense lining are built for difficult firings only with regard to the heat losses in the lining.

Modern refractory insulations enable minimizing heat losses at kilns with intermittent operation and make this type of kiln advantageous.

Ceramic fibres and insulations of high quality allow a reduction of the energy consumption to 60%-65% and a shortening of the operation cycles. The kiln operation is more flexible.

At first sight it seems that older kiln types with dense linings cannot be adapted to reduce heat losses by accumulation. However, it is possible to improve the kilns with intermittent operation by additional insulating layer on the internal lining surface in the same way as in the case of continuous kilns, and also with additional external insulation. For these purposes the ceramic fibres are used with thickness of 30-60 mm attached to lining by anchors or cement. This layer creates considerable temperature gradient, and original dense lining has lower temperatures. This adaptation results in 20%-40% energy conservation. A similar problem is a kiln car lining. For its improvement it is necessary to replace older types of linings by new ones with maximum use of light-weight materials.

Chimney draught

Heat loss by chimney draught is the incidental phenomenon of the firing process which cannot be removed, but only lowered to such conditions which would still guarantee the necessary chimney draught.

Chimney-draught loss is given by the kiln and exhaust design, and it can be reduced by incorporating economizers for air or water preheating. Careful burners adjustment, stabilization of waste gases circulation and reliable adjustment of dampers rank among the basic regulations tending to minimize this loss. Excessive heat of waste gases can be used in recuperators for air preheating.

A built-in tubular economizer can be used for heating of technologic or sanitary water. It is suitable at kilns with waste gases temperature of about 400°C.

Other losses

The other heat losses are of smaller significance and hardly measurable. There are included heat losses by flowing and emission through holes, entry and exit doors, leakage in the space under cars, leakage in the lining, peep hole etc. These losses can be suppressed by increasing the care of the equipment, e.g., using covers, improving channel packing, roller shutters etc.

Technologic losses are also included. These are connected with phase endothermic reactions of ceramic body during firing. The heat amount necessary for these reactions can be determined by laboratory tests of a ceramic body.

Kiln type and structure

Differences in energy consumption exist among new and old kilns during the same technologic process, as well as among conformable kilns of different producers. In spite of the latter being not so important, they depend on the type of structure, equipment and technologic parameters of the kiln and on the producer's responsibility. Results of the heat power measurements serve for comparing similar kilns and kiln structure optimization.

V. TRENDS IN FURTHER DEVELOPMENT OF THE DRIERS AND KILNS IN INDUSTRIAL CERAMICS

The world energy situation has influenced the views on heating unit development, not only for ceramics but also for other industrial branches.

This was natural, since all the kilns and driers were built primarily for single technologic process, and for long service life at the stage of industry development when the energy consumption did not influence the world energy sources, and when energy consumption was not crucial to the whole financial balance. The heat losses were of a smaller importance, and the regular method of manufacture was crucial. Similar views of the kiln functions prevailed in countries with relatively cheap energy sources not long ago.

Sudden complications with energy supply caused change in the concept of kilns and driers design which was characterized by the two following principles:

Maximum automation of heat process
Minimizing the heat losses regardless of production costs

This "technical philosophy" is correct and in compliance with the prognosis according to which the prices of energy will rise and the cost of investment depreciation will rise at a lower rate. Correctness of this prognosis may be confirmed by the following consideration: In case the world energy crisis reaches a point that it will be necessary to reduce industrial activity, the ceramic industry will most assuredly be affected. Then the units with minimum energy consumption will go on producing.

Heating units equipped by automated heat process control are fully suitable for an energy-saving technologic process. Besides, the detailed knowledge of used raw materials and blended bodies, including their changes during heating and cooling, is necessary. This results in requirements for development of blended bodies using new raw materials which make it possible to decrease the firing temperatures and cycles without decreasing the quality.

To this purpose, measuring, calculating and verifying techniques of phase transformations, limiting temperature gradients and limiting heating and cooling curves have to be developed.

In the future, the ceramic heating units will use largely pure industrial gases of higher calorific value. Electric ceramic kilns will be used only for special applications and for kilns firing flat ware in one layer only, where the radiation of heating elements will be effectively used.

The heating units will be incorporated in the production lines in such a way as to utilize waste heat effectively. The energy conservation in such a line will be designed as a complex system aimed at a rational energy consumption.

VI. CONCLUSION

The ceramic industry is one of the leading consumers of thermal energy. Its consumption consists of 86% productional consumption (22% - drying, 64% - firing) and 14% overhead. This fact demonstrates existent dependence of the ceramic industry on energy sources as well as on the constantly changing trends of the world energy supply. From this comes the necessity to utilize all changes which may positively influence the energy consumption and improve the chances of the ceramic industry in the future.

With respect to the most important part of these problems, the organization of all activities has to be directed from control centres, and it is necessary to establish the head committee assembled from specialists in the field of individual branches of heat power technics. The role of this committee should cover three areas:

Establishment of consistent inspection of energy consumption, including all individual pieces of equipment

Determination of principles tending to energy conservation

Preparation of trends in the field of power engineering for the next 10-20 years on the basis of a complex analysis

The complex analysis of the heat system in the ceramic industry makes it possible to determine the following arrangements:

Non-investment arrangements - improvements of heating units made on the basis of measurements

Investment arrangements - decisions for new heating equipment construction have to be based on a complex analysis; new equipment has to satisfy the future trends

Research and development - to verify new technologic possibilities in the field of raw materials and components, new drying and firing processes, fluid drying and firing, new types of kilns for single layer firing etc.

Energy diagnostic routine of heating units, which evaluates the existing stage and proposes minor arrangements, will have an important influence on the tasks of energy conservation. Its significance is limited by time, but it is possible to start immediately on a wider range and in all countries.

Czechoslovakia has taken part in diagnostic measurements and in "Energy Project UNIDO" in the field of silicate industry through the UNIDO-Czechoslovakia

Joint Programme for International Co-operation in the Field of Ceramics, Building Materials and Non-metallic Minerals Based Industries placed at Plzeň. The mobile diagnostic unit, which is the property of the Research Institute for Ceramics, Refractories and Raw Materials, could be used with the team of specialists in developing countries for immediate recommendations for improvement in the industrial use of energy.

In the above-mentioned considerations about the connection between ceramics and power engineering, it was not possible to account for the whole range of problems. Concentration was given to energy problems as the limiting factor of further development in all industrial activities.

Part two. Glass industry

INTRODUCTION

The history of glass-making is marked by revolutionary changes with impact on labour productivity and energy consumption. In ancient times glass manufacture was very laborious and expensive. Such techniques as casting glass objects, fusing small pieces and carving were used. Glass-blowing was also known in the distant past, but it was not until the first century A.D. that it was developed by the Romans as an industry capable of considerable outputs. This change required also new batch compositions, higher melting temperatures and larger pots, and even small tank furnaces were invented. The labour productivity increased and the extent of the glass manufacture was not so large as to exhaust the reserves of burnable wood.

An energy crisis broke out in London in the early years of the seventeenth century. It was caused by spreading manufactories, especially by glass manufactories, with the effect that an area of a radius of 80 miles around London was deforested, and James I had to ban the burning of wood in glass furnaces. This crisis initiated the transition to coal firing, and in a few years coal-fired furnaces were developed.

In 1867 the Siemens brothers invented the gas-fired regenerative tank furnace. This invention caused a tremendous increase in the volume of glass manufacture in comparison with pot furnaces and a wider introduction of gas fuel. Consequently the labour productivity increased and prerequisites were formed for the introduction of machines, especially in the phase of glass forming.

The introduction of the continuous furnaces proper reduced the production costs by reducing dramatically the cost of labour; however, the specific output of glass per energy unit was decreasing. It was not until the end of the nineteenth century that the introduction of forming machines enabled full utilization of continuous furnaces, which entailed increasing specific output of glass per energy unit. The most important inventions of that period were the cylinder glass machine and semi-automatic bottle machine, followed closely by the sheet glass machine and automatic bottle machine.

The few examples of historical revolutionary changes in glass-making show that while it took centuries to change the technology of glass manufacture, the development in the period 1890-1910 was characterized by such crucial innovations as the introduction of continuous melting and mechanization, which brought about the mass production of glass. Glass became a commodity of mass consumption, and the rapidly expanding glass industry participated in the exploitation of world's deposits of fuels.

The glass industry development in the twentieth century has been characterized by electrification of machine drives, diversification of produced glass commodities and automatic production control applied in the last years. As a fuel-intensive industry it is sensitive to the present energy crisis and is seeking measures to solve its energy problems.

The present estimates of the participation of the main glass industries in the world's glass production may be summarized as follows:

Containers	75%
Plate and rolled glass	10%
Sheet glass	8%
Technical glass	7%
	100%

The objective of this paper is to review the possibilities of energy conservation in the glass industry with special regard to developing countries. In most cases, container manufacture has been the first glass industry established in these countries, and its percentage therein is evidently higher than the above average. Therefore the potential energy savings are demonstrated predominantly in container manufacture. Most of them are applicable to the other glass industries as well.

I. RAW MATERIALS AND ADDITIVES

The raw materials for glass-making have always been one of the determinant factors in glass quality. Their range has increased and changed with progressing technology and investigation of the nature of technological processes.

The raw materials and additives enter the melting process and play different roles in glass creation. The molten glass can be visualized as a conglomerate of oxygen ions held loosely together by the tiny silicon ions, each of these forming bonds with the four nearest oxygen ions and the calcium and sodium ions scattered at random throughout, having lost their original share of oxygen ions to the general conglomerate.

Because of this picture, the silicon ion and others like it are often called network formers, and the scattered ions are called network modifiers. The raw materials introducing these elements into the glass are designed accordingly.

An example of a soda lime batch and glass composition is in table 13.

Raw materials

Glass sand

Although sand and sand stores are widely distributed, few sources are suitable for high-grade glass with only elementary washing and sieving. Grains possessing yellow surfaces with iron or titanium oxide must be beneficiated by scouring, abrading the surface of each other. The grains with dark iron specks may be removed by electro-magnetic separation. The sand and clay are separated by elutriation (flotation). The most proper grain size for glass manufacture is 0.5 mm.

This raw material contains 97.5%-99.85% of silica, small percentages of Al_2O_3, CaO, MgO, Fe_2O_3, Na_2O, K_2O, TiO_2 and Cr_2O_3. The Fe_2O_3 content should be under 0.025% for clear glasses. Silica as the network former is the main constituent of glass (50%-80%). Its melting temperature is about 1,810°C.

Soda ash

This natrium carbonate is the main source of natrium oxide for the glass. As a network modifier it acts as a fluxing agent and decreases the melting temperature of glass, which would be otherwise substantially higher (see silica). The fluxes belong to the network modifier group, being all alkali metal oxides.

Table 13. Example of the calculation of glass composition from batch composition

Batch composition					Glass composition		
		Oxide contribution					
Raw material	Relative weight	Oxide	Weight fraction in raw material	Relative weight in batch	Relative weight	Oxide	Proportion of total (%)
Sand	1 000	SiO_2	0.997	997			
		Al_2O_3	0.003	3			
		Fe_2O_3	0.00025	0.25	SiO_2	1 099	72.5
Soda ash	335	Na_2O	0.580	194	Na_2O	221	14.6
Salt cake	5	Na_2O	0.430	2.2	B_2O_3	11	0.7
Borax	30	Na_2O	0.163	4.9	Al_2O_3	30	2.0
		B_2O_3	0.365	11.0	CaO	90	5.9
Feldspar	150	SiO_3	0.680	102			
		Al_2O_3	0.180	27	MgO	64	4.2
		Na_2O	0.130	20			
		Fe_2O_3	0.001	0.2	Fe_2O_3	0.6	0.04
Dolomite	160	CaO	0.560	90			
		MgO	0.400	64			
		Fe_2O_3	0.001	0.2			
Total	1 680			1 516	1 516	100	

Source: UNIDO, Glass and Glassmaking (ID/136), p.42.

Note: The theoretical glass-to-batch ratio 1516/1680 = 0.902 takes into account only the loss of gas and water from the raw materials. In practice the weight fractions determined by chemical analysis (fourth column) are adjusted for each furnace to correct for volatilization losses and for losses by dust carried over by the flames into the flues. These additional losses usually amount to 5%-10% in the aggregate and the practical glass-to-batch ratio (melted-weight factor) may lie between 0.80 and 0.85.

Dense granular soda ash is produced nowadays and delivered to glass factories.

Salt cake

The sodium sulphate is another important source of natrium oxide. Earlier it was used as flux; now it is added as a refining agent to help in the dispersion of residual scum in glass melting.

Caustic soda

Sodium hydroxide is not contained in table 13, but it will be discussed in the chapter on batch preparation.

Borax

A small addition of borax evolving B_2O_3 is added to soda lime glasses to increase both the rate of melting and refining.

Feldspar ($(K_2O, Na_2O).Al_2O_3.6H_2O$)

This mineral is used for the introduction of a certain quantity of alumina into the melt where this inhibits glass devitrification. The form of feldspar is used as being cheaper than pure alumina; its melting point lies between 1,100°-1,200°C, and the silicium potassium and natrium oxides are applicable in glass composition.

Dolomite ($CaO.MgO.2CO_2$)

This mineral contributes to glass composition with calcium and magnesium oxides. Calcium oxide is the most important stabilizing network modifier in high tonnage glass production and makes the glass insoluble in water and other liquids. Limestone is its most important source. Limestones including dolomite are the third largest constituent of glass batches after sand and soda ash. The ratio 6:4 between CaO and MgO inherent to dolomite inhibits glass devitrification.

Additives

Fining agents

Besides borax, mentioned above, arsenic and antimony oxides are refining agents used at present. The effect is to enrich the bubbles in oxygen so they they dissolve more readily in the glass.

Colouring and discolouring agents

This theme may be omitted, as it is doubtful to what extent various application of these agents could influence energy conservation. Their applications require various melting atmospheres. Some of them, however, may be added after melting in the forehearth, which enables colourless glass to be continually melted and eliminates the production drop during the change of batches of different colours.

The above raw materials and additives refer to the batch and glass composition in table 13. There are, however, further raw materials applied in other glasses. It is not the point to describe them all. Important is the role of some types of them in further processes.

II. BATCH PREPARATION

Some measures for energy conservation are taken already in the phase of batch preparation. Two examples, the benefits of which appear in the phase of melting, are given below.

The use of cullet

It is well known that the use of cullet in the batch composition of container glass has a favourable effect on glass melting. In Switzerland considerable work has been done on the increasing use of cullet, and it has been implemented in container production. They estimate that for every 1% of cullet increase starting at 10%, the energy saving is 0.25%. The main reasons for this fuel economy are: less humidity in the batch, lower melting temperature, less heat absorbed by CO_2 and a lower volume of exhaust gases. In addition, there are savings made as a result of lower consumption of soda ash. The relative saving is calculated to be 0.29% per 1% of cullet increase in relation to the basic fuel consumption of the furnace. A glass container manufacturer in the United States of America claims that by using 60% cullet it can save as much as 4 million of litres of oil each year in the manufacture of 200,000 tons of glass containers. Increasing use of cullet also reduces the need for pollution control equipment since it reduces particular emmissions, and it is claimed that at 60% cullet usage level electrostatic precipitators would not be required.

Batch agglomeration and preheating

While agglomeration of batch components has been running on an industrial scale in Japan since 1965, the agglomeration combined with preheating and prereaction has been subjected to research in the last decade and stands now on the threshold of practical application.

The agglomeration proper of glass-making materials involves increasing the size of a fine mass of particulate matter by agitation, rolling or pressure, or by chemical or heat treatment of fines. The final product of agglomeration processes is either in the shape of a pellet, a briquette, a granule, bead, flake, extrudate or clinker. The two most frequently tested and applied agglomeration methods have been pelletizing and briquetting. Pre heating and prereaction of glass batch refer to the application of temperatures above

540°C to agglomerated batch prior to furnace feeding, in order to increase rate of melting, reduce furnace fuel consumption, and utilize a bed of pellets or briquettes through which furnace exit gas can be circulated, depositing condensated pollutants on the pellets. Hence, the bed of pellets acts concurrently as a collector for condensates, dissociated and carry over products of furnace emmissions, thus combining in a single stage preheating, primary emmission control, and material recovery.

A review of agglomeration methods may be established as follows:

By method - pelletizing (granulation, balling) in discs, drums or cones, briquetting in high pressure roll presses, extrusion in auger extruders or pellet mills

By process - binderless (water or pressure only), binder additives (starch, gums, lignins clays), modified glassmaking additives (lime, caustic soda, silicates) with or without size reduction of sand

By post-treatment of agglomerates - no post-treatment, low temperature drying 95°-260°C, sintering, calcining, preheating above 540°C, prereaction

By types of driers and calciners - conveyor drier, rotary drier or kiln, fluid bed drier, travelling grate, shaft furnace, circular grate, vertical oscillating grate

A typical agglomeration system would be an extension of a standard batch plant. Instead of mixed and wetted loose batch being conveyed to the feed hopper, an intermediate surge hopper receives and stores the mix, which is gravemetrically fed by a weight belt to either a palletizer or a double roll briquetter. Moist or green pellets or briquettes are fed to a drier which hardens the agglomerates and removes all or most of the free moisture added during agglomeration. If the process does include a prereaction step, the predried agglomerates are transferred to a calciner or preheater for temperatures above 540°C. It has been tested, and a possibility is considered to combine drying and preheating in a single stage unit, such as a continuous travelling, straight or circular grate, a vertical shaft furnace or a modular vertical kiln. Practical research results for recent years in the Federal Republic of Germany, Japan, Sweden and the United States show that the advantages of the agglomerated-batch process over the loose-batch process are:

Reduction of melting time	24% to 28%
Increased melting output	32% to 38%
Reduction of melting temperature by	100° to 200°C

Reduction of energy consumption	6%
Reduction of time for volatiles dissociation	50%

Another benefit is that during the pelletizing process caustic soda can be added for partial replacement of soda ash in the batch.

Advantages of preheated agglomerated batch consist of further reduction of melting time and the other ensuing parameters. Concurrently the problems of stringent emmission control regulation are solved.

III. GLASS MELTING

Batch and glass transformations

The batch consisting of raw materials and additives properly prepared and mixed is proportioned into the glass melting tank, where it is subjected to the melting process. The batch components are of different melting temperatures, the highest one being that of silica (1,810°C). The glass melting temperature of about 1,500°C is achieved because of the activity of fluxing agents. The melting temperature in the tank is not uniform, the melt being heated from above and cooled by tank sidewalls and bottom. This entails, if demonstrated on a continuous tank furnace, vertical temperature gradients with the highest temperature in the middle of the melt surface causing circulating flows. These flows combine with the main flow of glass moving from the charging space of the melting chamber to the working end, with the effect that the point of the highest temperature is shifted nearer to the bridgewall and acts as a thermal barrier. Consequently all the glass passes through this temperature maximum, which enables a perfect refining and homogenization.

The refined glass in the continuous tank furnace flows to the working chamber, where it is cooled to a working temperature of about 1,100°C to be ready for further treatment. This temperature must be high enough above the devitrification point of a particular temperature at which glass would crystallize.

Glass melting furnaces

Before approaching the possibilities of energy conservation in the phase of glass melting, it is essential to say a few words about the glass melting furnaces and the furnace operation.

The glass melting furnaces may be subdivided as follows:

Periodical pan furnaces
Day tanks
Continuous tank furnaces

The continuous tank furnaces are capable of high outputs and are suitable for mass production of flat, container and technical glass. They are fired by gaseous or liquid fuels, or heated by electric current passing through the melt.

Gas-fired regenerative furnaces

As gas has been the most frequently applied fuel, a gas-fired regenerative tank furnace is briefly described. It consists of a superstructure and understructure.

Superstructure

Supporting steel grid and tank pertaining to the melting chamber and working chamber. The two chambers are separated by a bridgewall through the opening of which, a throat, the melted glass passes to the working end. At the melting end a narrow extension, called doghouse, is attached for batch feeding

Cooling system of tank walls and throat including tubing and fans

Burners and burner shafts including dampers

Walls and crown of melting and working chamber

Understructure

Burner shafts (from dampers downwards)

Equipment for heat recovery from waste gases (air and gas regenerators if need be)

Collecting flues of regenerator chambers, flues for air and gas feeding including reversal and closing equipment

Exhaust flues from the reversal equipment up to the stack footing

Stack

The melting chamber is as a rule of rectangular shape, the width to length ratio being between 3:5 and 1:2.

The bottom of the tank lies on a supporting grid consisting of steel I profiles and a grate of flat hoop iron. The layer of refractories is formed by aluminous fire-clay blocks 300 mm thick and reinforced by plates 100 mm thick of a high alumina material for higher temperatures.

The walls of the tank are 200-300 mm thick. Rammed or cast blocks are applied with regard to required temperatures. There is a wide choice of aluminous fire-clays, mullite, corundum or zirconium corundum materials.

The walls and crown of the melting and working chambers are separated from the tank walls by a gap of 30-80 mm. These upper walls are fastened to the steel skeleton of the superstructure. They must be heat resistant, as they are facing the space of the firing zone over the glass being melted in the tank. The most frequently applied materials for them are silica and silimanite. These refractories are also applied for the crown. Lately mullite is applied.

The burner chambers and burner stones are constructed of high refractory materials, while for shafts a better grade of fire-clay bricks is sufficient, as well as for regenerative chambers and checkers.

Gas-fired regenerative furnace operation

The air, preheated in the regenerator to more than 900°C, mixed with gas in the mixing chamber is blown through openings in walls close to the glass surface and clear of the crown refractories. The combustion originating in the mixing chamber develops fully in this space. Waste gases are exhausted through opposite or otherwise placed burners that are not being used for firing during that reversal period, and ducted to the other regenerator to accumulate here their heat for further preheating. In this way, two regenerators accumulate the heat and preheat the air alternatively. If poor gases are applied (under 10.47 MJ = 2,500 kcal/[illegible]) gas is also preheated. The efficiency of regenerators is about 90%.

The heat distribution in the melting chamber is affected by the positioning of burners and exhaust openings. Accordingly, cross firing may be applied with more burners, longitudinal and U turn firing. The proper system depends on the type of furnace and applied fuels.

The temperature setting varies according to glass composition. The glass is refined as volatiles are expelled. The refining is accelerated by refining agents, bubblers and boosting. The refined glass passes through the cooled throat of the bridgewall to the working chamber.

Gas-fired recuperative furnaces

These furnaces are provided with a recuperative system. The hot waste gases and the air to be preheated pass through parallel channels in a refractory or metal recuperator (heat exchanger). The air is preheated to 700°C, the efficiency being about 75%. The life time of a ceramic recuperator is relatively short. The metallic ones made of heat resistant steel have a longer service time.

Liquid fuel-fired furnaces

These furnaces are in principle arranged like gas-fired furnaces. Only the air is preheated, fuel oil injection burners are placed in underport or throughport positions.

Potentials of energy conservation in the phase of glass melting process

The energy consumption amounts to 70% of the total in-plant requirements in this phase. The bulk of fuels is consumed by continuous regenerative or recuperative furnaces. Their development in this century has been characterized, from the point of view of energy conservation, by gradual reduction of specific heat consumption per kilogram of products entailed by innovations, and measures such as construction of larger furnaces of higher daily outputs, transition from fuel gases of low calorific value to fuels possessing high heating value, application of increased melting temperatures, mechanized uniform batch feeding, design of more efficient regenerators, introduction of fuel oil and electric boosting, control of melting process by measuring and control equipment etc.

Particular cases of potential energy savings are described in further paragraphs. An example of a regenerative furnace heat balance demonstrates the efficiency and distribution of losses in the phase of glass melting (figure III).

Development trends in continuous glass melting before the outbreak of the energy crisis

As mentioned above, there were trends to substitute high calorific fuels for low calorific ones. Natural gas, town gas, coke-battery gas and propane-butane as well as fuel oil were introduced. These measures were aimed at higher flame temperatures and better heat transfer from the flame into the surface of the glass melt, at a higher furnace efficiency. Such measures are nowadays hindered by scarcity and high prices of most of these fuels.

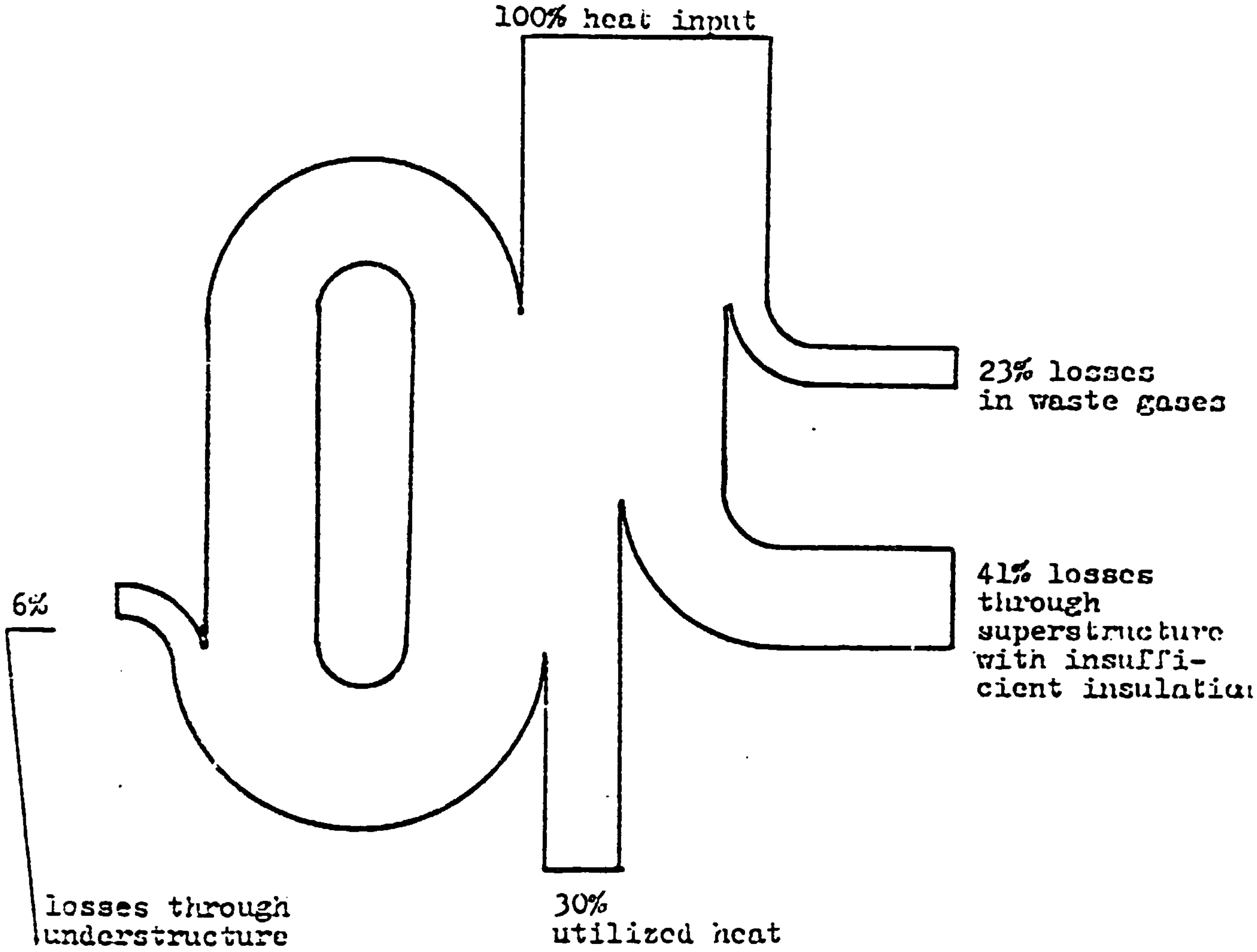


Figure III. Example of heat balance in gas-fired regenerative furnace

Electric boosting was being introduced in gas- or oil-fired furnaces to increase their thermal efficiency and specific output. This method has been successfully continued till now.

The application of refractories of higher quality and higher heat resistance for heavy duty parts of furnaces is still being attempted. Satisfactory materials have not yet been developed to prevent tank sidewalls from excessive erosion. Therefore the parts exposed to erosion must be cooled from outside, and considerable heat losses arise. Improved technology of batch feeding is implemented by feeding the batch by means of mechanical feeders. The operation is controlled by level indicators of glass surface.

Control of furnace operation

The regenerative furnaces are said to have been run reliably in the last 50 years without any control equipment. However, measuring equipment has been introduced in the last decades and designs of high capacity furnaces cannot dispense with automatic control. The operation control is expected to make further contributions to coping with the present energy crisis.

Construction of high regenerative chambers

The design of sectional vertical chambers, with crowns on the same level as the crown of the furnace melting chamber, shortened to a minimum the shafts of burners. The effect lies in lower heat losses through superstructure and higher furnace efficiency.

Application of magnesite and chrome-magnesite shapes for checkers

These materials of higher thermal conductivity and higher specific heat accelerated the heat exchange; corrosion and dusting lessened. Higher thermal efficiency of regenerator chambers and furnaces was achieved.

Measures to retard reverse flow of glass in the tank and to increase temperature in lower spaces of the tank

These measures were implemented by lowered throats and crowns, bubblers, and electric boosting. A better melt quality and furnace efficiency was achieved.

Many of the preceding trends show that much has been done for improved efficiency of furnaces and consequently for lower specific heat consumption.

Further examples should show the present endeavour to face the problems of energy conservation in conditions of the energy crisis.

Insulation of regenerative furnaces

The heat losses through the walls of superstructure and understructure of regenerative furnaces still amount to 30%-40% of the furnace heat input. As long as fuels were cheap the furnace design was focused more on improving refractory linings enabling higher corrosion and erosion resistance, higher outputs and longer service lives. The originally applied fire-clay blocks for internal lining of tank bottoms and tank side walls were replaced by, or combined with, mullite, corundum or zirconiumcorundum materials. The crowns of tank furnaces made earlier of silica bricks are constructed of silimanite or mullite materials, providing a better expansion stability and a higher refractoriness. Also the walls and crowns of regenerators are provided with aluminous fire-clay bricks now, while basic bricks were substituted for fire-clay bricks of the checkers.

The reason that the insulation of furnaces lagged behind the development of refractory lining was not only the low price of fuel. Also a higher investment cost of insulated furnaces was taken into account, as well as an easy access to refractory blocks and bricks for inspection and repairs, and the necessity of cooling some critical parts of refractory blocks from the back side. Nowadays, the insulation is progressively being applied, and a few practical examples are given below.

The crown of the furnace is the most suitable and accessible part and can be insulated in many cases by factory masons. The first example is from a factory where the crowns of four furnaces were insulated with two courses of high temperature insulating brick, and a one-inch blanket of mineral fiber was laid to reinforce the insulating brick. To protect the mineral fiber from impurities and from being damaged, a heavy aluminium foil was placed over the entire area. The regenerator walls were insulated with ceramic fiber and block insulation.

In another case the crown made of silica bricks was laid by two layers of insulating heat-resistant bricks and one layer of light insulating bricks. Silica mortar was applied. The crown surface temperature was reduced from 350° to 100°C. The insulation of the other parts is more difficult to be carried out and is usually connected with a reconstruction.

The tests show that the total of losses through superstructure, excluding stack losses, amount approximately to 40% of heat input. The crown, the walls and the tank bottom participate in this total loss by about 10% each, leaving the remaining 10% for losses through burners, shafts etc. Practical results show that additional insulation can reduce particular losses by 50%-75%.

Practical example of setting insulation on the crown of a tank furnace and on burner shafts

The insulation of a silica crown is demonstrated in figure IV. It consists of two stretcher courses and of bond layers between them and on the surface.

In figure V another system of setting insulating shapes is shown consisting of one header course and one stretcher course.

In installing the insulation the following rules should be observed:

Only a crown in good condition should be insulated

The arch should be properly cleaned

For the heat-up up to 700°C a provisional insulation of glass wool should be applied

The new insulation should be installed at the temperature not exceeding 700°C

A successive removal of the temporary insulation of glass wool, recleaning and plastering of the upper surface of the crown (a layer of 3 mm) should follow

Dry setting of the first insulation course without the top row

Filling the top row after 24 hours, the plastering of the first course

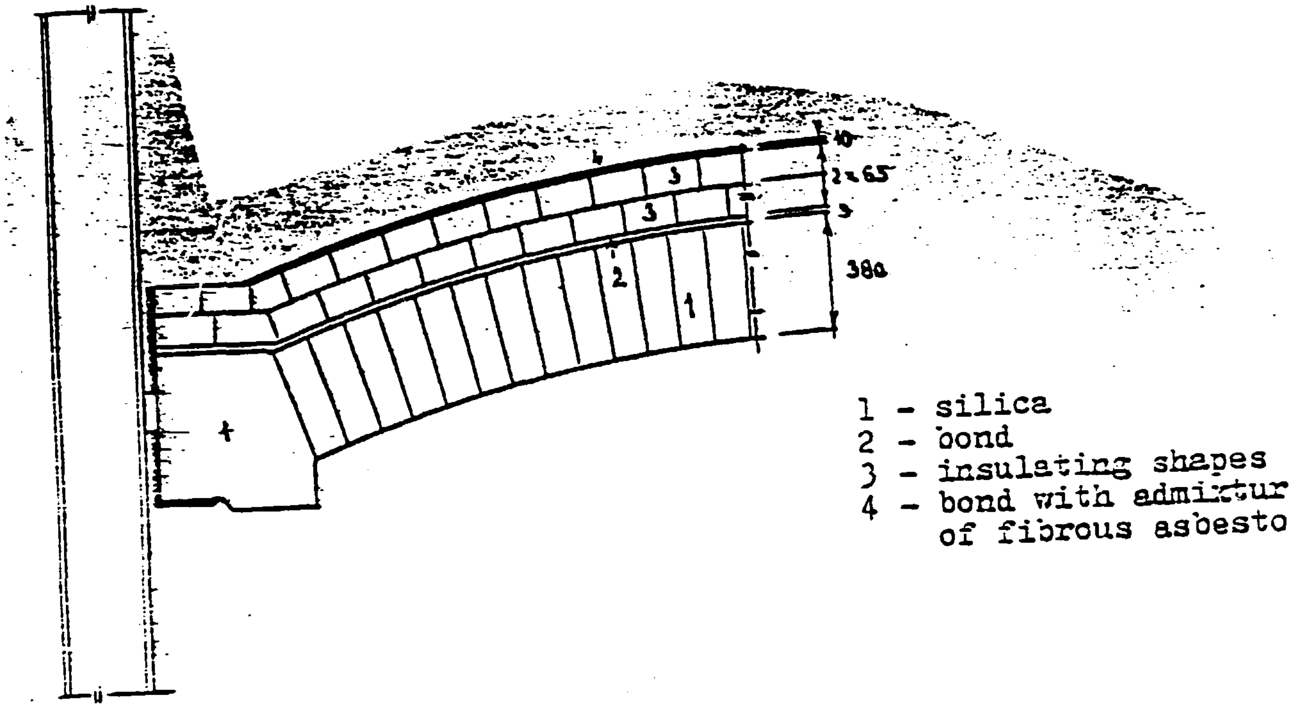
Setting the second course by the same method but with overset joints

The upper insulating course should be provided with a plaster 10 mm thick with admixture of asbestos fibres

Expansion joints and opening for sensors should not be insulated

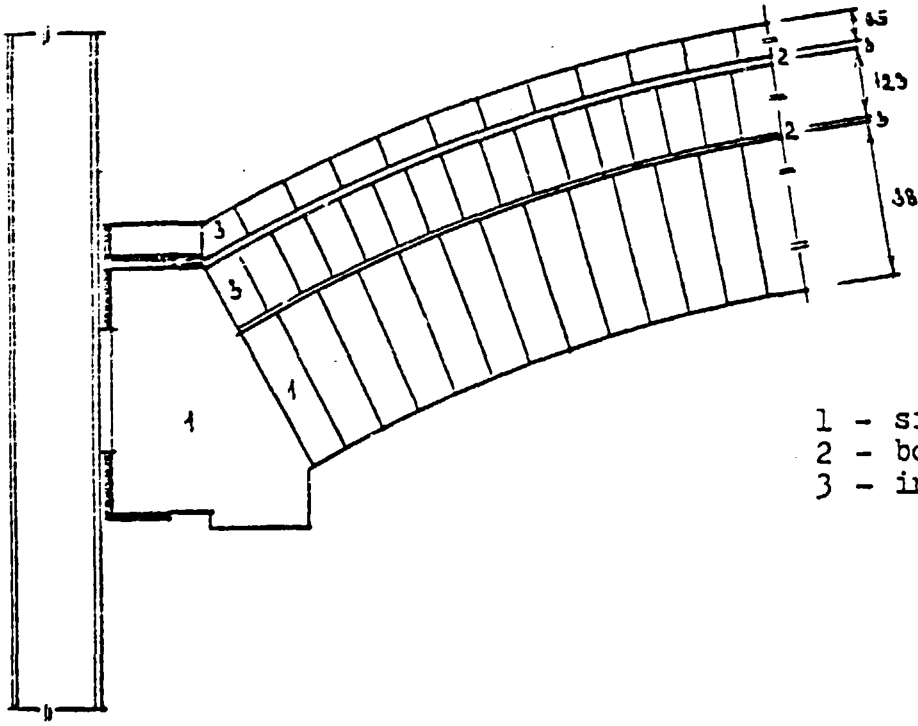
Insulation of burner shafts is simple. Vertical parts should be insulated with high weight standard bricks during the first phase of the heat-up. The

Figure IV. Insulation of a silica crown by two stretcher courses



1 - silica
2 - bond
3 - insulating shapes
4 - bond with admixture
of fibrous asbestos

Figure V. Insulation of a silica crown consisting of one header course and one stretcher course



1 - silica
2 - bond
3 - insulating shapes

brickwork is cleaned and plastered, then the bricks are dry set, either as stretcher in 2 courses or as headers in one course. Insulation is fastened by hoop steel; the outer plaster is not necessary.

The measuring of surface temperatures and respective calculations indicate that crowns (380 mm silica) at the surface temperature of 240°-290°C lose without insulation 4,400-5,800 W/m^2, and burner shafts (300 mm silca) at the surface temperature of 240°-260°C lose 5,100-5,800 W/m^2. By insulation these losses are reduced by 30%-40%, and the incurred costs are repaid in a few months.

Before starting the insulation a thorough calculation must be prepared. Detailed information must be procured regarding the state and condition of the existing refractories and an insulation designed with respect to its thermal conductivity and required surface temperature of the crown. Some important data necessary to this purpose are indicated in figure VI and in tables 14 and 15.

Savings through melting process control

A very obvious cost improvement is available from tighter control of melting energy. It is logical to suppose that one would rather use a little more fuel to be sure that a satisfactory melt is obtained than to try to save a small part of the fuel and risk losing production. If the furnace is operated at the minimum temperature needed to melt the required amount of glass, the slightest upset in the operation may cause unmelted material to pass through the furnace. Therefore, it is common to run a little on the hot side.

If controls are installed making upsets less likely, or warning of an upset and thus enabling the operator to take preventive measures, then operating temperatures can be reduced. It may be estimated that on a furnace using upwards of 4 MJ per kg of glass a 5% saving may be realized.

Automatic temperature control on a regenerative furnace can result in further savings. There is a rapid surface temperature loss during each reversal, which can be recovered with a slight fuel increase at the beginning of the subsequent cycle. During the rest of the cycle, a much lower input will maintain the required temperature. The problem lies in

Figure VI. Thermal conductivities of refractories

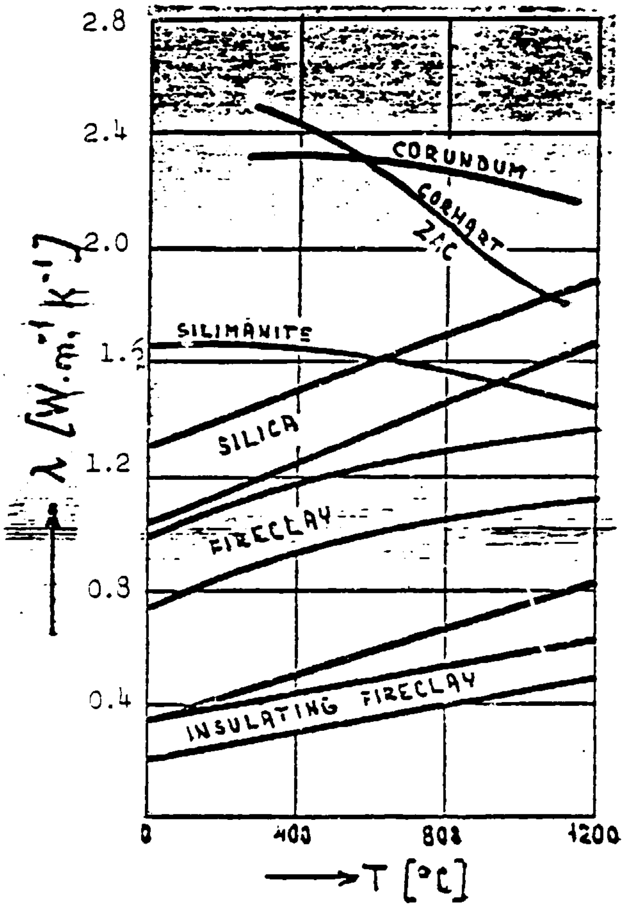


Table 14. Empirical formulas for the calculation of thermal conductivities of some refractory and building materials

Material	Bulk density ρ_v [kg m^{-3}]	Thermal conductivity [W m^{-1} K^{-1} a/]
Dense fibre-clay	1 800-2 200	$0.7 + 0.64 \times 10^{-3}t$
Dense silica	1 700-2 000	$0.84 + 0.76 \times 10^{-3}t$
Fire-clay high in Al_2O_3	3 000	$1.69 - 0.23 \times 10^{-3}t$
Mullite	2 160-2 900	$2.29 + 1.7 \times 10^{-3}t$
Zircon		$1.3 + 0.64 \times 10^{-3}t$
Magnesite	2 600-2 700	$7.17 - 2.68 \times 10^{-3}t$
Chrome magnesite	2 900-3 000	2.1 to 4.1
Silicon carbide	2 100-2 500	$9.3 + 1.75 \times 10^{-3}t$
Red brick	1 750-2 100	$0.47 + 0.51 \times 10^{-3}t$
Concrete	2 400	0.92
Light-weight fire-clay	810-1 340	0.175 to 0.33
Light-weight silica	690-1 000	0.256 to 0.48
Asbestos board	900-1 200	$0.157 + 0.14 \times 10^{-3}t$
Crushed asbestos	800	$0.106 + 0.18 \times 10^{-3}t$

a/ In the formulas, t is the temperature in °C.

where to measure the temperature for such a control. It has been found that the best temperature control point for short-term effects, where reversal cycles can be sensed, seems to be at the crown, about 80% of the distance towards the throat.

For longer-range efforts it is useful to have a bottom thermocouple, either in the glass or just below the top paving course. In relatively deep furnaces and at very high rates of pull, a furnace operator will find that this is a very critical point. He will learn that there is a minimum bottom temperature that must be maintained just ahead of the throat.

High output furnaces and those with good fuel efficiency tend to have the surface almost entirely covered with unmelted material. Superstructure surface temperatures tend to become meaningless. In this case the bottom temperature is the best guide. The rule is to maintain it, keep the fuel

Table 15. Losses through refractories in various conditions

Refractory material	Thickness (mm)	Insulation[a/]	Internal furnace temperature (°C)	Losses through 1 m^2 per hour	
				(kWh) 1 m^2	(kcal)
Monofrax M	300	None	1 450	15.0	12 900
Corhart ZAC	300	None	1 450	13.0	11 200
Corhart Standard	300	None	1 450	10.0	8 600
Corhart Standard (floor)	150	300 mm fire-clay	1 400	4.4	3 800
Corhart ZAC (floor)	150	200 mm fire-clay	1 400	6.7	5 750
Corhart Standard (floor)	150	180 mm fire-clay+120 mm B	1 200	1.75	1 500
Fire-clay	300	None	1 400	5.3	4 600
Fire-clay	300	None	1 300	4.9	4 200
Fire-clay	300	None	1 200	4.3	3 700
Fire-clay	300	None	1 100	4.1	3 500
Fire-clay	300	120 mm B	1 250	1.6	1 380
Fire-clay	300	60 ins.B + 60 ins.C	1 100	1.0	860
Silica (crown)	300	None	1 450	6.0	5 200
Silica (crown)	300	None	1 400	5.8	5 000
Silica (crown)	300	60 ins.A + 60 ins. B	1 400	2.0	1 720
Silica (crown)	300	60 A + 60 B + 60 C	1 400	1.1	940
Silica (crown)	300	120 A + 60 B + 60 C	1 400	0.95	830
Silica (crown)	300	60 A + 120 B + 60 C	1 300	0.88	760
Silica (crown)	300	120 B + 120 C	1 200	0.7	585

a/ Insulation material	Conductivity	λ[W $m^{-1}K^{-1}$]	Applicable up to
A	0.40	0.40	1 500°C
B	0.26		1 000°C
C	0.12	0.12	800°C

steady and watch the checker temperatures for any upset which may be caused by the fuel, air or pressure control or by a burner problem. The lag from the bottom thermocouples is probably too long to use them for short-term temperature control to make up for reversal losses. In general, good furnace temperature control can save between 5%-10% of the fuel consumption.

Glass furnace rapid heat-up

After repairs the furnace should be brought to working temperature as soon as possible. The traditional heat-up method used temporary natural gas pipe burners placed on the tuckstones and protruding into the furnace. The burners produced small. soft, luminous flames, and temperature was increased by gas and air addition. At 760°C or higher the port burners were lit and combustion maintained. Short furnace reversals were frequently employed to elevate the temperature of relatively cold checkers to operating temperatures. The heat-up lasted 20-30 days, depending on furnace volume.

The hotwork method utilizes high velocity hot air to effect rapid convection heat transfer to the furnace refractories. Special high velocity burners are applied with stable flame retention characteristics. A portable one-burner heat-up unit comprises burner, air blower, electronic controller console, temperature programmer, air and fuel hosing, ultra violet flame sensor and safety fuel shut-off valve. The system is capable of heating-up a glass melting furnace in a temperature range from approximately 90°C to beyond 1,370°C.

The heat-up programme for the furnace is established in advance, and the temperature curve is automatically followed. The programme includes also the setting of refractories expansion regulating elements.

The rapid heat-up method reduces the heat-up time to 5-8 days and leads to economic benefits in which energy savings also participate. Besides, damages to refractories such as cracks, breaks and spalls due to thermal shocks are eliminated.

Utilization of waste heat

The combustion waste heat proper is the portion of heat contained in combustion gases after exiting from the regenerators or recuperators. It can still be partly utilized, and the chimney losses amounting up to 30% of furnace heat input may be reduced. The percentage of savings achieved in this way fluctuates between 8%-15% of the total fuel consumption of a furnace. It corresponds to the reduction of 30%-50% of the value of chimney losses. Practical examples are given below.

Waste heat boiler

For melting 37.2 t of container glass per day natural gas was applied. The consumption amounted to 365.1 Ncu.m per hour, and the chimney loss according to thermal balance made 30%. Under these conditions the ratio of the inlet natural gas and the humid combustion gases exiting from the recuperator was 1 Ncu.m/14.555 Ncu.m. These combustion gases include carbon dioxide, water steam, nitrogen and excess combustion air. The inlet temperature of combustion gases at the entrance of waste heat boiler was 530°C, the outlet temperature of exiting gases made 400°C.

Calculation of the quantity of utilizable heat of combustion gases based on their medium specific heats:

$$\begin{aligned} 365.1 \times 14.555 \times 0.344 \times 530 &= 968{,}854 \text{ kcal/h} \\ 365.1 \times 14.555 \times 0.332 \times 250 &= \underline{441{,}064 \text{ kcal/h}} \\ \text{Difference} &= 527{,}790 \text{ kcal/h} \end{aligned}$$

If 8% of losses by radiation and conduction of the waste heat boiler are taken into account, the heat quantity for steam generation is obtained:

$$527{,}790 \times 0.92 = 485{,}567 \text{ kcal/h}$$

If the generation of saturated steam of gauge pressure of 4 atm corresponding to the temperature of 151°C and heat content 656 kcal/kg is taken into consideration, while the temperature of the feed water is supposed to be 70°C, then the required heat for steam generation is 586 kcal/kg. Under these conditions the following quantity of steam is produced:

$$485{,}567/586 = 829 \text{ kg/h or } 19.9 \text{ t/24 h}$$

It has been proved that the use of combustion products waste heat for steam production is very advantageous. The steam won in this way may be applied for various purposes, e.g., for technological process, steam heating, heating feed water, air saturation for gas producers, spraying fuel oil and boosting heating oil systems. An interesting application is the use of steam to generate electricity for boosting. It is a way to heat for later use in the melting chamber for glass melting. This method has been applied successfully with kilns working without regeneration or recuperation.

Heat economizers

For smaller furnaces and for lower temperatures of combustion gases, as well as for periodic furnaces, it is more advantageous to use waste heat for heating water which may be applied for social conveniences and central heating.

For such cases a heat economizer has been developed recently. It utilizes exhaust gases of a minimum temperature of 400°C and delivers them with remaining 200°C to stack. The recovered heat is used for heating water from the inlet temperature of 15°-95°C. The equipment is furnished with a fan (300-350 revolutions per minute) provided with a specially adjusted rotor. It may be used for the heating of buildings.

Renaissance of gas producers

It is well known that gas produced on a coal basis has been abandoned by advanced glass industry and replaced by fuels of high heating value. Apart from the technological advantages of rich fuels in glass manufacture, it was also the fluctuation of the producer gas composition and the ensuing impossibility of establishing stabilized heat conditions in furnace operation which contributed to this substitution.

Now, in countries possessing sufficient coal reserves, efforts are under way to develop an efficient coal gasification technology on a higher technical level without the drawbacks of the out-dated gas producers. Below is a description of such a gasifier developed in Europe.

The gasification process is a combination of the pyrolysis of coal plus the gasification of carbon by reaction with steam and carbon dioxide. Both of the above steps require energy input at high temperature, which is supplied by partial combustion of fuel with air.

The design represents a two-stage fixed bed gasifier. The upper stage is the distillation zone, and the lower the gasification zone. Coal enters the top of the vessel and passes into the distillation zone. A portion of the gas produced in the gasification zone is routed up through the distillation zone and provides the heat for the distilling operation. When the coal has reached the bottom of the distillation zone, it has been reduced to coke. At the base of the gasifier, ash is removed through a water seal, and steam and air are introduced through a grate in the base of the coal bed.

After being preheated through the bed of hot ash, the steam-air mix enters the fire zone (a narrow band 100-260 mm deep operating at over 980°C) where a partial oxidation reaction takes place. This step produces carbon monoxide, some carbon dioxide and hydrogen, and generates the heat for the balance of the gasification reaction to take place above the fire zone.

The gas leaving the distillation zone at above 120°C is known as "top gas". The gas leaving the gasification zone at above 650°C is called "bottom gas". The sensible heat in the bottom gas entering the distillation zone provides the heat for driving the volatiles off the coal. This step is accomplished slowly and gently without cracking, repolymerizing or otherwise forming undesirable by-products such as tar and pitch.

When coal is slowly heated, only water vapour and a small amount of carbon dioxide are driven off until the temperature reaches approximately 400°C. Above 400°C the coal becomes more plastic and the main gases evolved are methane, ethane and propane, followed by oils and tars. If the temperature were to be raised rapidly, as in a single stage gasifier, the oils and tars would crack and polymerize to heavy viscous tar. The two-stage operation of the gasifier is designed to heat the coal gradually, and thus the oils and tars formed are sufficiently fluid to be handled easily.

Above 480°C the plastic components resolidify and decompose, yielding a dry coke and gas rich in hydrogen. Some of the hydrogen reacts with carbon at these temperatures to form a small additional amount of methane. The top gas containes almost all of the oil and tar and the devolatilized methane, as well as all the residual water entering with the coal.

The coke is reduced to ash in the fire zone. Ash moves down onto the grate and out of the gasifier via the water seal. The bed of ash between the fire zone and the grate is used in the gasification zone to cool the shell and generate the steam required for the gasification reaction at the same time.

The purpose of adding steam to the process is twofold: the steam reacts with carbon to form carbon monoxide and hydrogen and also acts to cool the fire zone, so that ash will not agglomerate, fuse and form large clinkers that would block its flow out of the units.

The operation of the gasifier enables three alternative processes with three end products as shown below.

Gas type	Temperature of product gas (°C)	Heat values removed from the gas
Hot raw gas	400	Base case
Hot detarred gas	400	Some tar
Cold clean gas	38	Tar, oils, sensible heat
Cold clean desulphurized gas[a/]	38	Tar, oils, sensible heat, sulphur

---

[a/] The variant for coal of very high sulphur content.

The comparison of the processes shows their thermal efficiencies and approximate heating values:

Gas type	Process thermal efficiency (%)	Approximate heating values (MJ/m^3
Hot raw gas	85-93	6.78-7.51
Hot detarred gas	77-87	6.35-7.07
Cold clean gas	69-76	5.78-6.35

Electric melting

Electric melting, as an innovation in the glass melting process, deserves to be dealt with separately. If there was a great reluctance some years ago to introduce electric melting, the boom in fuel oil prices and the increasing scarcity of natural gas in the last years have accelerated the introduction of this process. There is sufficient theoretical literature on the electric melting process, but there has not been enough practical experience, and some failures have occurred in furnace operation. Therefore, it is believed that an extract of practical guidelines of an experienced furnace designer is a useful contribution to energy conservation.

Furnaces using electric power for melting may be classified as follows:

(a) Furnaces with electric boosting are gas- or oil-fired furnaces with additional electrodes postioned in the space of the batch serving for boosting and maintaining uniform melting

(b) "Hot top" furnaces are electric furnaces with gas boosting and are useful for extremely difficult melting glasses;

(c) "Cold top" furnaces are all-electric furnaces.

Batch blanket

The thickness of the batch blanket in the cold top furnace is important for maintaining heat in the glass to use less kilowatt input, and for keeping the volatiles in the glass. Usually a 8-15 cm thick blanket is maintained. Bridging may occur if the blanket gets too thick. The underside of the blanket forms a semi-melted crust which extends to the sidewalls and will actually trap volatiles in a large bubble. A too thick blanket puts more cold batch deeper and reduces the molten surface temperature, thereby increasing resistance and producing excess stones and cords. But the thick blanket insulates better and retains more of the radiant heat deeper in the blanket. Frequently there is enough heat to soften the batch, but not enough heat to melt the materials completely, so that a semi-hard crust is formed. The crust formed may actually bridge all the way to the sidewalls, allowing the molten glass level to decrease and form a pocket of trapped gases. The level will continue to decrease until the crust is broken. Sometimes the forehearth has been drained before this condition has been noted.

To eliminate bridging, the batch blanket should not cover the complete surface area of the melter. The charger is adjusted so that no batch is deposited within 8-15 cm off the sidewall all around. This area will remain red and hot, so that batch does not form a thick blanket or become attached to the sidewalls.

Current density

Electrode size, placement and current density are extremely important factors but are often overlooked or misapplied. Electrodes have been made from molybdenum rods and plates, iron and graphite bars, solid tin oxide blocks and liquid tin. Molybdenum rods are usually preferred, as they are easy to handle, install or push in when required.

Current density is normally considered as the amount of current which flows from, or is applied on, each unit of surface area of an electrode. It is believed that molybdenum can apply current to glass at a maximum rate of 3 A/cm^2. Above this, the surface temperature will start increasing towards its melting temperature. Glass convection currents near the electrode surface will become hotter and move more rapidly, causing excess erosion of the softer electrode surface. Excess current density will greatly decrease the life of electrodes and often cause them to needle-point, bend down or break-off, depending upon the placement and applied current. Therefore, 3 A/cm^2 is in reality too large a design factor for a continuous operation. A more reasonable design factor of 1.5 A/cm^2 should be considered. This factor will allow for some normal erosion of the electrode during an operation and allow for the excessively high current sometimes required during an upset.

Positioning of electrodes - the following alternatives are used:

(a) Parallel electrode rods protruding from the tank sidewalls. The position allows a straight path for currentl flow. One half of the surface of each electrode faces the other one. The applied current is dispersed evenly through the entire length. Electrodes in this placement will cause very little erosion;

(b) Electrode rods, each protruding from the opposite sidewalls of the tank. This position is unfavourable, as the electrodes face each other only with their tips. The current flow is concentrated at the tips, which causes themolybdenum rod to be exessively hot, almost to its melting point (2,600°C). The excessive erosion by abnormal convection currents of the glass causes the electrode to wear down to a needle point. In many cases electrode life has been shortened by 50%-80%;

(c) The opposite positions of the electrodes are feasible if rods are replaced by plates fastened to opposite walls. In this case the electric current is dispersed through the whole surface of the plate.

The main problem in these installations has been the physical connection to the plate itself. In case of failure, draining of the furnace is necessary before all the glass freezes. In such a case the rod electrode, if broken or eroded, has the advantage of being easily pushed more forward into the glass. Most rods can be ordered with threaded studs and holes for easy addition of extensions;

(d) One electrode rod protruding from a sidewall, the other one projecting from the end wall. This placement is fairly common but also increases the erosion of both the electrodes;

(e) One electrode protruding from the tank sidewall, the other one protruding diagonally from the end wall. This placement is preferable to the preceeding one, as more surface area of each electrode is exposed to the other one;

(f) Bottom parallel electrode rods projecting vertically from the bottom. This placement gives a very good lifetime, but the electrodes are difficult to push in and create more danger of bottom leaks, if the electrode breaks and causes excessive heating of the bottom block.

Electrode holder

The main purpose of the electrode holder is to freeze the glass around the electrode, so that it will not be pushed out by pressure, and to keep the surface temperature below the oxidation temperature of the molybdenum. Some holders are flush with the inside wall, some go to a step from the inside face, and some are flush with the outside wall with only the electrode through the refractory. Some holders have water flowing directly on the electrode, and other holders are complete water jackets which extend through the sidewall or bottom to cool 250-380 mm of the electrodes. A completely water-jacket-encased electrode, for 300-400 mm from the glass interface, with the addition of Argon and Nitrogen to the air space, appears to be the best answer for extended life if the electrode is not often pushed in.

Refractories

Erosion of the refractory sidewalls of an electric furnace is quite different than normally found in a conventionally gas/oil-fired furnace. In the electric furnace, erosion of the blocks below the metal line is quite severe. The blocks tend to dish out in the centre while not greatly affecting the joints. This is caused by the hot glass below the surface in the electric tanks as against the hot glass on the surface of a conventional furnace. The erosion on the metal line is almost nonexistent in the electric furnace. The hot glass deep in the electric furnace tends to penetrate into the softer large-grained crystals of the refractory blocks. The outside surface of all blocks is essentially the same when cast and annealed, but after the hot glass has attacked the surface of the large sidewall blocks, the softer core is exposed to attack. The joints, being together, are more resistant to attack, as well as the fine-grained more dense section of the block.

To combat the fast erosion of the sidewall blocks, the wall should be constructed with only 30 cm wide blocks or a maximum of 40 cm where necessary. This type of construction will give a heavier and a denser sidewall than possible with 50, 60 or 75 cm wide blocks. A comparison of block weight as against theoretical weight indicates that the small blocks are more dense. Although small blocks for a sidewall are against standard practice in the glass industry, the change did contribute to a 30% increased length of an operation.

The economics of sidewall insulation must be weighed against fuel cost or savings with regard to the length of the campaign. A new furnace with 30 cm wide blocks was completely insulated covering all joints. Six months later there was a very definite and deep cut at each joint extending almost 15 cm through the joint. The glass contact face of the blocks was just starting to show some erosion or dishing out. Therefore, all insulation was removed, and 25 mm open steel deck grating was placed across the entire sidewalls. Wind cooling lines were also placed to direct very light airflow on the centre of each block. At the end of the operation the centre of each block was dished out so that 25 cm remained. The joints were not damaged so deeply.

Blocks for the electric furnaces should be deep cast with the scar place downward during construction. Some of the casting voids extend 13-18 cm down into the block, and if the void is on the top, the erosion of the block just below the metal line finally allows glass to get into the void and cause pieces of the block to wash into the glass. Since most furnaces have paving, the bottom 8 cm of the blocks are protected, and a downward placed casting void would extend only 8-10 cm above the paving. Since the bottom sidewalls of an electric furnace erode only slightly, there is no chance for the glass to get into the void area and/or cause stones.

The furnace crown of "cold top" furnace with superstructure should be constructed with a mullite or mullite-type refractory approaching 60% Al_2O_3 instead of the normal silica brick. These bricks cost 3 to 5 times more, but their use will eliminate spalling, refractory stones and the labour of adjusting tie rods.

Normally silica bricks are good during the initial heat-up with gas burners, but after the glass becomes molten and electric current flows, the burners are turned off. With the addition of batch to bring the level up, the crown temperature will decrease from about 1,300°C to 200°-300°C in 4 to 10 hours. The cold batch will absorb much of the furnace radiant heat and rapidly decrease the temperature. The rapid decrease of temperature greatly affects the expansion of the silica brick, often causing cracking and breaking off of the silica brick hot face. The rods should also be adjusted for the decrease of expansion.

A similar situation may also occur during the campaign in case of a failure. Therefore, for any case, the mullite crown is preferable.

Process control

A combination of autotransformer with an automatic voltage regulator or silicon control rectifier will give almost fully automatic control; namely the kilowatt setting, current control, tap changes and constant monitoring are eliminated or minimized to just an occasional check or recording every hour or two. An automatic voltage regulator or SCR will increase or decrease the voltage to keep a constant current between a pair of electrodes.

Electric melting - conclusion

Electric furnaces utilize 65%-80% of direct heating energy, as against 15%-30% efficiency of gas or oil-fired furnaces. However, if also the low efficiency of power generation is taken into account (30%), the total efficiency (power generation plus glass melting) based on primary source makes only 20%-24%. The specific heat consumption is 0.8 kWh (2.88 MJ) per kg of melted glass. Electric furnace construction is less expensive, because there is no need for regenerator chambers, checkers, flues and reversal equipment, blowers and fans. Besides the expensive air pollution control equipment is not necessary.

The electric furnaces seem to be prospective with regard to future trends. Electricity is the medium of transfer for nuclear and hydroenergy. If coal is to be utilized economically and with respect to air pollution control, it will have to be converted in central power plants into electric energy as well.

IV. ANNEALING

During the moulding process glass has been abruptly cooled down from its working temperature. Within this short peroid it has passed safely the point of devitrification - a temperature of about 1000°C - at which a crystalline phase may form if glass is held there for any time. On the other hand great stresses arose by the rapid cooling which would cause later breakage due to the stress. To avoid this, the glass must be annealed. This process is performed in lehrs or annealers.

After the annealing had been properly investigated, an efficient type of the annealing curve was introduced. To follow this curve, recirculating lehrs were developed. The lehr consisted of a tunnel through ware was moved on a conveyor. In every section a prescribed temperature was controlled. The tunnel comprised the heating, annealing and cooling zone. Such annealers are in operation all over the world and guarantee good quality of ware. However, their fuel and power consumption are considerable. A series of measures has been taken to curtail their energy consumption. The heating section where the glass is reheated to a uniform temperature slightly over the annealing point (540°-560°C for soda-lime glasses) has not been subjected to any changes.

There have been significant changes designed and tested in the annealing zone, where glass products are cooled very slowly from the annealing point to their strain point (approximately 480°C for soda-lime glass).

For example, in a lehr with five annealing sections, three recirculating sections were replaced with plain sections, i.e., controls, burners and gas consumption in these sections were eliminated. A considerable reduction in power and gas consumption was achieved.

Another example is a new design of a lehr achieving the required cooling through a system of muffles incorporated in particular sections. This design is characterized by the individual recirculation section placed as the last annealing section for stabilizing temperature at critical strain point of the passing glass ware. Besides, an air curtain produced in this section provides an effective barrier to forward draught, particularly along the sidewalls where the passing air is detrimental to the quality of ware. In this design, recirculating fans were eliminated in all but the last section of the annealing zone as well as burners and controls. The energy consumption was substantially reduced. Side benefits are simplified construction, decreased operating and maintenance requirement and lower initial cost.

A further energy-saving design is featured by the application of new high velocity burners for air recirculation instead of fans. The burners are placed in a staggered opposition pattern under the lehr belt in the heating and five annealing sections. The high velocity combustion products entrain tunnel air to create sufficient turbulances for positive temperature control. Also in this case power consumption for fans is eliminated. A more effective cooling in the lehr is achieved by cooling ware from above, using room air for recirculation instead of extracting heat from base surfaces of the ware.

Quite a different concept of lehr design embraces the following principles: It conserves the air recirculation with fans and temperature control in all sections. The insulation of bulk rock wool sandwiched between the inner housing of particular sections is introduced. It reduces the environmental heat losses and aids in maintaining an even temperature within the section. Heat losses are reduced to 40% of conventional lehrs.

The lehr belt returning inside the lehr is accepted by all designs. It performs the recuperative function. Up to 25% of the belt heat load can be saved.

V. MAINTENANCE

A scheduled system of maintenance is one of the prerequisites for energy conservation. Check lists should be established for machinery and furnaces with frequencies of checking particular points. Reviews of daily production reports showing defects of technological equipment should be evaluated and consequences drawn for direction of maintenance. It may be found surprising that, e.g., measured losses through pressure air leakage constituted in some cases, 5% of a plant's power consumption. Regular analyses of all kinds of energy consumption are recommended.

VI. CONCLUSION

The presented series of practical examples of energy savings should show the approach to energy conservation. Some of the measures are feasible during operation, others between operations; some are applicable in a reconstruction or in the construction of a new plant. Also in this context, the question for developing countries with introduced or planned glass industry arises as to which fuel base they should turn in the present energy crisis. The approach will be evidently different in each country.

The entrepreneurs in the few countries with still sufficient reserves of oil and natural gas will doubtless go on using these fuels.

Glass industry in countries with coal reserves and opened mines should convert to coal as a primary source of energy. In the least developed countries, this change might proceed by means of coal gasifiers dimensioned for the needs of particular plants only. The oil would be applied for power generation in a glass factory where electricity is not available. In countries with developed infrastructure and high fuel consumption, large coal gasifiers and a gas distribution network could be constructed in industrial areas, or gasifiers-power plants with power distribution for larger areas could be established. In countries with hydroenergy converted into electric power the only solution would be a fully electrified glass plant. The same applies to the few developing countries now constructing nuclear power plants because of lack of other energy sources.

Countries with no energy sources whatsoever for industrial purposes have no other choice but to resort to the cheapest available energy source abroad. It should be emphasized that in all cases the choice of energy is a matter of economic calculation, taking into account both the production and investment cost of the glass plant.

Part three. Cement Industry

INTRODUCTION

The history of industrial cement manufacture is characterized by the endeavour to achieve larger outputs, lower energy consumption and lower operation costs per ton of product. The development of manufacturing and firing methods and equipment responded to the demands of the building industry in various stages. Although the up-to-date prevailing technology is the dry or semi-dry process, also some earlier techniques, e.g., the wet process with rotary kilns and the semi-dry process with shaft kilns, have not fully lost their position, as they meet some special conditions or correspond to certain stages of development of some countries. Also the present energy crisis introduced new criteria of assessment. For these reasons, this study presents the review of the cement industry in its development, thus offering a wide choice of technologies and equipment suitable for various steps of industrial progress in relation to the energy conservation possibilities.

I. CEMENT-BUILDING MATERIAL

Cement is one of the fundamental building materials manufactured for innumerable applications in almost every country.

Fortunately enough, almost every country has more or less suitable raw material deposits available to cater to its building industry requirements. Fundamentally, all sorts of cement are hydraulic compositions made as a result of joint milling of suitable raw materials, such as limestone, lime marls, lime clays, chalks, pyrite cinders, bauxite, silica sands, shales etc., which are weighed into a mill in an accurate ratio. The raw material mixture so obtained is homogenized and fired up to a sintering state - clinker. After cooling the clinker is milled along with approximately 3% of gypsum into a fine powder called Portland cement. Portland cements may further be classified according to their specific properties. For instance, current specifications of the American Society for Testing Materials (ASTM) recognize five major types of Portland cement:

Type I - Standard (general-use cement) for use in general concrete construction

Type II - moderate heat-of-hardening cement - for use in general concrete construction exposed to moderate sulphate action or where moderate heat of hydration is required

Type III- High early-strength cement - for use [illegible] high early strength is required

Type IV - Low heat cement - for use when a low heat of hydration is required

Type V - Sulphate resisting cement - for use when high sulphate resistance is required

The above-mentioned types of Portland cement can be manufactured in almost all cement factories, as far as the composition of the raw material mixture has been suitably adjusted whereby the fired clinker composition is adjusted, too. Furthermore, the firing process in the cement kiln, as well as the cement milling process, is to be adjusted to this raw material to achieve the required fineness.

Chemical compositions of this, as well as other types of Portland cements, are shown in table 16. Apart from the above-mentioned five types of cement, the table also includes cements of extreme compositions,

Table 16. Chemical compositions of Portland cement
(Percentage)

	Type I - Standard		Type II - Moderate heat of hardening cement		Type III - high early-strength cement		Type IV - low heat cement		Type V - sulphate resisting cement		Ore cement	Ferrari cement	Kühl cement	White Portland cement	
Component	Limits	Typical composition	Limits	Typical composition	Limits	Typical composition	Limits	Typical composition	Limits	Typical composition	Example	Example	Example	Limits	Average
SiO_2	19-23	21.3	20-24	22.39	18-22.5	20.0	20-26	24	24-26.5	24.4	21.92	22.92	17.00	20.62-26.68	23.25
Al_2O_3	5-8	6.0	3.9-6.0	4.60	3.6-9	5.2	3-6	5	3.5-1.9	3.1	1.99	3.92	8.20	0.77-9.19	4.75
Fe_2O_3	2-4	2.7	2.1-6.0	4.25	2-4	2.5	2-6	4.5	3.3-1.3	3.3	8.46	5.66	6.00	0.16-1.05	0.40
CaO	62-66	63.2	62-65	62.85	63-67	65.6	58-65	60.5	64-54.5	64.3	64.11	64.19	64.60	60.90-71.19	66.00
MgO	1-4	2.9	1.4-4	2.50	0.6-4	1.4	1-4	3	0.7-2.5	1.7	1.02	1.50	1.60	0.05-2.76	0.58
Ignition loss	0.6-2	1.3	0.3-1.0	0.60	0.8-2	1.0	1-2	1.0	0.9-1.3	0.9	0.40	0.30	0.30	0.85-9.06	2.89
Res. Ins.	0.08-0.2	0.2	0.03-0.2	0.10	0.07-0.01	0.05	0.01-0.03	0.02	0.02-0.2	0.05	0.09	0.10	0.10	0.07-1.01	0.31
K_2O	0.3-1.0	0.5	0.3-1.5	0.55	-	0.44	-	0.3	0.15-0.3	0.22	0.30	0.15	0.50	0.04-0.79	0.09
Na_2O	0.2-0.5	0.3	0.05-0.5	0.25	-	0.21	-	0.2	0.08-0.15	0.08	0.20	0.10	0.25	-	0.76
SO_3	1.0-2.5	1.8	1.0-2.0	1.64	2-3	2.3	1-2	1.7	1.4-2.0	1.4	1.53	1.80	1.50	0.10-2.94	1.78
Total	-	100.2	-	99.72	-	99.15	-	100.32	-	99.45	100.02	100.64	100.05	-	100.31
$3CaO.SiO_2$	33-65	45	29-50	44	52-81	60	10-33	20	35-50	41	56.39	47.09	64.60	18-85	46.70
$2CaO.SiO_2$	10-36	27	22-46	31	3-20	13	41-61	52	27-49	39	20.30	26.34	-	8-62	27.62
$3CaO.Al_2O_3$	8-14	11	1.8-8	5	7-15	10	3-8	6	3-5	4	G2R-9.08	0.82	11.59	1-24	11.91
$4CaO.Al_2O_3$ Fe_2O_3	6-15	8	6-18	13	6-11	8	6-18	14	4-16	10	9.47	17.20	18.24	0.5-2.7	1.21
$CaSO_4$	2.2-3.3	3.1	1.9-3.3	2.8	3.4-5.1	3.91	1.7-3.4	2.89	2.7-3.1	2.38	2.60	3.06	2.55	0.17-4.99	3.02
MgO	1-4	2.8	1.4-4.0	2.5	0.6-4.0	1.3	1-4	2.9	0.7-2.5	1.7	1.02	1.50	1.60	0.05-2.65	0.58
Free CaO	0.2-2.0	0.4	0.1-1.8	0.4	0.1-1.2	1.8	0.1-0.9	0.4	0.1-1.8	0.5	0.20	0.10	1.37	0.35-7.0	1.38

particularly as far as the Al_2O_3 and Fe_2O_3 contents are concerned.

The white Portland cement is particularly interesting and required in the market. It is an ordinary Portland cement, containing only a low proportion of iron oxide, manganese oxide, titanium oxide and magnesium oxide. Either non-ferrous or highly abrasion-resistant grinding media are used in the production of white cement, and the firing process in the kiln is so arranged that the whitest possible clinker is obtained. As a rule a reduction or inert atmosphere is used in the sintering and cooling zones and even in the cooler, as the case may be. In some cases the clinker is cooled by water.

Cements contining higher percentages of Fe_2O_3 are all resistant to sea water and sulphate waters effects. Their production is very limited.

There are three examples shown in the table: Kühl Cement (called after its inventor - Prof. Hans Kühl) is a Portland cement of low silica and high alumina and iron oxide contents, the strength of which corresponds to rapid-hardening cement. Iron ore cement (Erz Zement) was a type of Portland cement once manufactured in the Federal Republic of Germany. It originally had a high iron oxide content and was of light chocolate-brown colour. It has been replaced by Ferrari cement now.

Another significant group of Portland cements is formed by mixed cements. The most important mixed Portland cements are: (a) Portland blast-furnace slag cement manufactured by joint fine milling of dried blast furnace granulated slag, clinker and gypsum; and (b) pozzolanic Portland cements manufactured by joint milling of pozzolana, Portland clinker and gypsum.

The pozzolana word is usually broadly explained, and in this group there are usually incorporated mainly natural materials containing active silicic acid in vitreous state, as it is in case of volcanic ashes which, according to their origin, are called Pozzolana, Santorin Earth, Tosca, Trass etc. This group covers also artificially made products, i.e., industrial wastes, such as fly ash, Si-Stuff etc.

Besides, a use is made of activated kaolinitic clays or shales and diatomites fired at about 700°C temperature.

Portland blast-furance slag cements and pozzolanic Portland cements are manufactured and used in water structures. Examples of chemical composition of Portland blast-furnace slag cements and of pozzolanic Portland cements are shown in table 17. The percentage ratio of mixing clinker with slag or pozzolana are specified in the respective national standards.

Besides the Portland and mixed cemets, several tens of types of cement have been developed which are of limited use for specific purposes. Though the production volume is insignificant when compared with the total production of cements, they are important for a number of branches and deserve to be mentioned, e.g.:

Expanding or non-shrinking cements
Air-entraining cements
Oil-well cements
Masonry cements etc.

Just for the sake of completeness, it is necessary to mention cements not manufactured on the basis of Portland clinker. There are, e.g., slag cement, manufactured by joint milling of blast-furnace granulated slag and hydrated lime, or super-sulphated cement, composed of slag, gypsum and a small addition of lime. The significance of the two cements is more or less historical only.

In conclusion, an aluminous or high alumina cement should be mentioned here which is manufactured by melting, or electric melting, of bauxite and limestone or lime. It has a remarkable initial strength and resistance against sulphate water. It is used also for refractory concretes.

Table 17. Composition of various types of cement

(Percentage)

Component	Portland blast furnace slag cement	Supersulphated cement	Lime-slag cement	Pozzolana cement
Loss on Ignition	-	-	0.5	4.8
SiO_2	22.8	25.2	29.0	26.0
Al_2O_3	8.1	13.1	15.5	6.9
Fe_2O_3	0.5	1.0	1.5	3.6
CaO	59.0	45.0	48.0	52.3
MgO	3.5	3.5	2.5	4.2
SO_3	1.7	7.0	2.0	1.8
S	0.5	1.0	-	-
FeO	0.5	0.9	-	-

II. RAW MATERIALS

There are rather rarely occurring rocks whose chemical composition corresponds exactly to that required for the raw material mixture intended for the manufacture of Portland clinker. Most often it is necessary to use two or three, and exceptionally four, or even five raw material components.

From the calcium carbonate content point of view, the raw materials may be classified into high-percentage (exceeding 78% of $CaCO_3$) and low-percentage (having less than 78% of $CaCO_3$).

The so-called "high-percentage" raw materials are considered to be fundamental ones. The so-called "low-percentage" ones are used for correcting the high-percentage component. Besides that there are corrective components used for the adjustment of one of the components of the raw material mixture, e.g., the SiO_s content can be increased by adding diatomite, silica sand, the Al_2O_3 by adding bauxite, Fe_2O_3 by calcined pyrites, iron ore, ore dust etc.

Apart from the natural raw materials, industrial wastes are also used. The most usual is the blast furnace slag.

For example of raw materials see tables 18, 19 and 20.

Table 18. $CaCO_3$ content of cement raw materials
(Percentage)

Material	$CaCO_3$ content
High grade limestone	96-100
Marlaceous limestone	90-96
Marlstone or calcareous marl	75-90
Marl	40-75
Clayey marl	10-40
Marlaceous clay	4-10
Clay	0-4

Table 19. Chemical composition of calcereous raw materials used for the manufacture of Portland clinker
(Percentage)

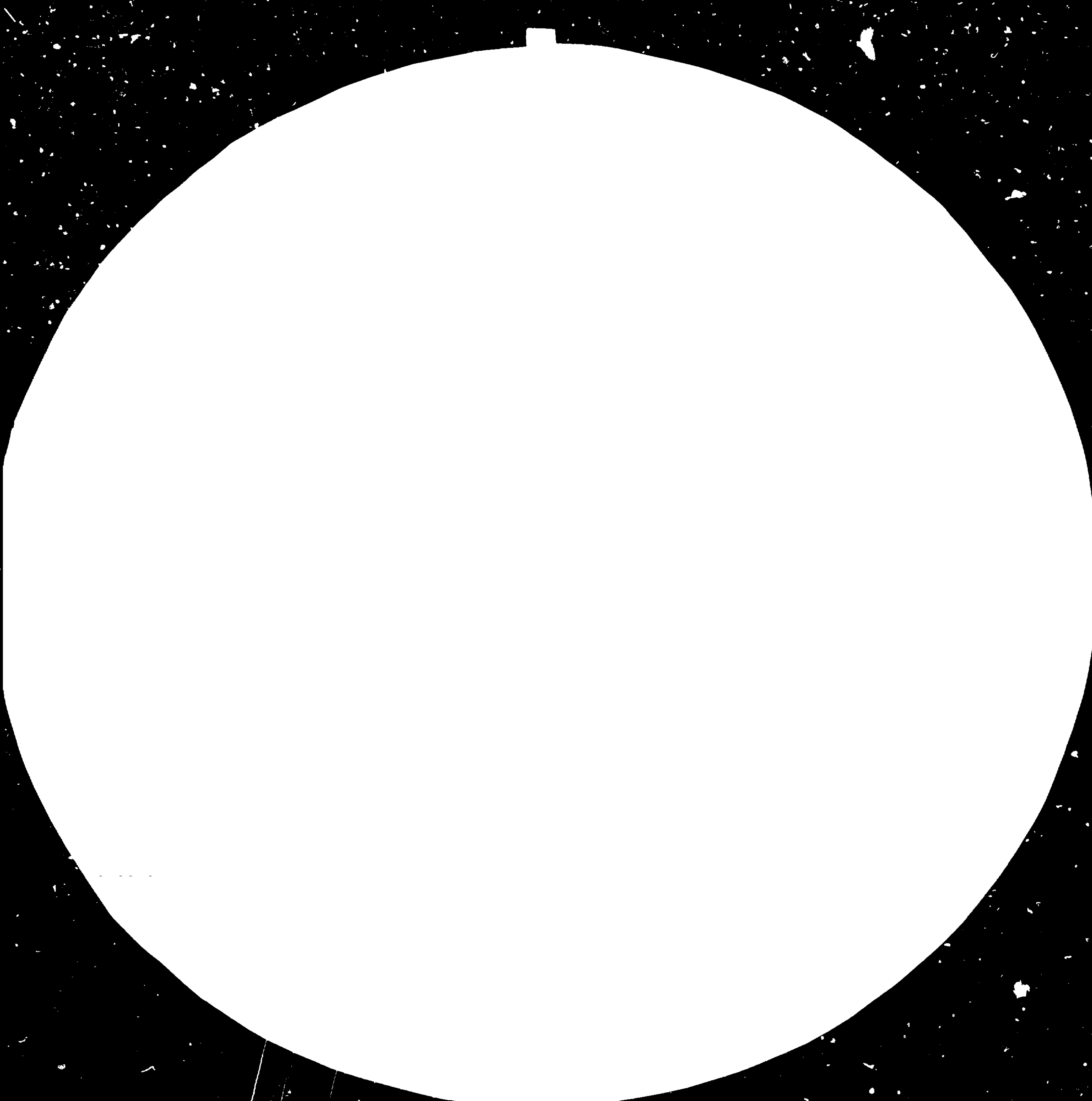
Material	Source	Loss on ignition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	MnO	K_2O	Na_2O	SO_3	Cl
Pure limestone	Vitošov, Czechoslovakia	43.12	0.17	0.10	0.07	55.58	0.50	0.01	Trace	0.09	0.04	0.00	-
Siliceous limestone	Castelo, Brazil	34.66	15.57	1.60	1.10	45.24	1.67	-	-	-	-	-	-
Lime rich coastal dune	Jumeira, Dubai	42.28	3.53	0.45	0.22	51.36	1.08	-	-	0.10	0.41	0.35	0.01
Pure chalk	Benghazi, Libyan Arab Jamahiriya	43.17	0.77	0.48	0.17	53.60	1.36	0.01	0.03	0.12	0.09	0.22	0.02
Coral sand	Mauritius	45.02	0.13	0.17	0.06	51.70	2.62	-	-	0.01	0.37	-	0.20
Oyster shell	São Luiz, Brazil	43.34	1.39	0.76	0.09	53.11	Trace	0.04	Trace	0.06	0.76	Trace	0.18
Limestone	Mokrá, Czechoslovakia	39.20	4.30	1.75	0.41	51.51	1.32	0.12	Trace	0.19	0.08	0.04	0.02
Cement rock	Chimborazo, Ecuador	36.69	13.39	3.10	0.74	44.45	0.86	0.04	-	0.16	0.14	-	-
Calcareous sand	Big Lake, Edmonton, Canada	40.91	9.92	1.26	0.66	42.76	1.22	0.05	0.11	0.24	0.30	2.24	-
Calcareous marl	Mossoró, Brazil	37.70	10.34	3.64	1.42	44.72	0.72	0.23	-	0.75	0.08	Trace	0.03
Marl	Adana, Turkey	31.87	29.37	9.46	5.03	35.83	2.72	-	-	-	-	-	-

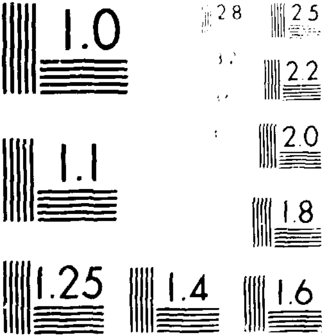
Table 20. Chemical compositions of corrective ingredients (Percentage)

Ingredient	Source	Loss on ignition	SiO	Al O	Fe O	CaO	MgO	SO	K O	Na O	TiO	P O	Cl	MnO
Lateritic clay	Tulukkpatti, India	10.74	55.32	12.58	6.31	8.87	2.66	0.03	1.87	-	1.62	-	-	-
Loes	Herat, Afghanistan	14.24	51.55	8.41	4.04	15.09	2.35	0.13	1.70	1.50	0.82	0.18	0.004	-
Silica sand sandstone	Leeds, Alabama United States	-	92.48	2.69	1.69	1.50	0.83	-	-	-	-	-	-	-
Diatomite	Auxillac, France	4.01	91.61	1.53	2.22	0.18	0.29	-	Trace	Trace	0.10	-	-	-
Iron ore	India	4.78	3.30	3.40	86.80	1.03	0.12	0.22	0.13	0.08	-	-	-	-
Low grade iron ore	San Luis, Argentina	5.00	28.30	3.10	62.97	0.55	-	-	-	-	-	-	-	-
Bauxite	Santo Agostinho, Brazil	31.16	2.94	64.10	1.29	0.02	Trace	-	-	-	0.60	-	-	-
Blant-furnace slag	Vítkovice, Czechoslovakia	-	37.99	9.13	4.00	42.14	4.43	0.19	0.48	0.28	0.29	-	-	1.50
Pyrite cindres	Přerov, Czechoslovakia	-	17.28	4.60	63.35	4.17	1.10	2.35	0.47	0.30	0.55	-	-	4.44

83.12.08

AD.85.03




1.0
2.8
2.5
2.2
2.0
1.8
1.1
1.25
1.4
1.6

III. BASIC PRODUCTION PROCESSES

The cement production may be basically divided into two types depending upon the technical and economic conditions. From the technological point of view, wet, semi-wet, semi-dry or dry processes are applied.

Wet process method of preparation

The raw material is blunged or milled together with water. The well liquid slurry so obtained is put into silos, homogenized and corrected, on the basis of chemical analysis, by slurry from other silos to achieve the required chemical composition. The slurry so prepared is transported to the storage tank above the rotary kiln and dosed accurately into the kiln. The slurry contains usually 33%-40% of water. In the case of plastic raw materials, it is sometimes necessary to prepare the slurry with as much as 50% of water content to achieve the required fluidity of the slurry. In the case of non-plastic raw materials, however, sometimes a mere 28%-33% of water content is sufficient.

Semi-wet process method of preparation

Slurry prepared by wet process is subjected to filtration with the aim of reducing the water content in the slurry; this results in less water to be evaporated from the slurry, whereby the amount of heat consumption necessary for evaporation is reduced.

Vacuum or pressure filters are used for the filtration of the slurry. The cake so obtained is either supplied directly to the kiln, or, before being fired on the grate, it is to be strengthened sometimes by raw material powder, unless the filter cake alone is pressed sufficiently by the extrusion presses, or by some other suitable presses or granulating discs. The moisture of the raw material bodies supplied to the kiln amounts to approximately 14%-18% of water.

Dry process method of preparation

The crushed raw material is first dried in a drier and milled in dry state, or it can be dried in a drying circulating ball tube mill. The raw material components are weighed into the mill or dosed by volume in some old factories.

The raw material powder is transported into a system of homogenizing and storage bins where it is homogenized pneumatically or mechanically and corrected if necessary. Then it is transported and dosed into the kiln. It is evident, of course, that the chemical composition testing is more demanding than at the wet process. The raw material moisture content is below 1% of water.

Semi-dry process method of preparation

Dry, homogenized powder is wetted in a worm or on a granulating disc or in a granulating drum, and the wetted powder is then either granulated or in wet state, in the form of irregular conglomerate lumps, supplied into the rotary kiln, or, in case of granulated form, to the Lepol grate. The raw material moisture amounts to 10%-15% of water content.

Under this group belongs also the preparation of raw material for shaft kilns. Because the raw material for the shaft kiln must include fuel pressed in (coke or anthracite), there are two variants:

(a) Preparation of "white powder". The raw material powder prepared by the above described method is weighed, along with a currently weighed crushed fuel of 1-8 mm grain size. This mixture is thoroughly mixed in a mixing worm, wetted to 11%-14% moisture content and granulated or pressed. The pressings are supplied into the shaft kiln;

(b) Preparation of "black powder". When black powder is to be prepared, the fuel is milled together with the other components in a raw material mill. All the components must be weighed accurately for the mill. The black powder is homogenized in homogenizing bins, wetted to 11%-14% and granulated or pressed before being supplied to the kiln.

IV. WET PROCESS

The wet process is the most universal one from the technological point of view. Though the wet process is being quickly replaced by the dry process in recent years, about 40% of the world production of clinker still comes from the wet process plants.

There are certain advantages to this process and, therefore, it may seem more suitable under certain conditions.

First of all, it is the preparation of perfectly homogenous raw material blend. It is simple, and less labour is required in all the preparatory stages starting from the winning in a quarry to the supply of slurry into the kiln for firing. Power consumption is slightly smaller than at the dry process, but the heat consumption is considerably higher.

The wet process in the cement production is better applied where soft, porous raw materials are available having high moisture content when mined from the quary. The high moisture content is decisive, since drying in such a case would result in higher capital investments and higher fuel consumption.

Because of easier homogenizing in wet process, raw materials with fluctuating chemical composition, or those containing a high percentage of alkalis, can be processed this way into cement. The wet process in the production of cement is classified into three stages (see the flow sheet figure VII).

All the raw materials are to be properly dressed before processing. It depends on their chemical composition and hardness of components. If a higher amount of hard components is in the raw material, more crushing and milling operations are required, resulting in higher consumption of energy and water. Therefore, the availability and choice of suitable raw materials is the first prerequisite for determining if the valuable power, fuels and water will be wasted or preserved as early as in the preparatory stages. It goes without saying that the distance between the quarry and the cement plant plays an important role, too.

Figure VII. Typical technology flow sheet of wet-process cement manufacture

	Process		Equipment
I. Preparation of raw materials	Limestone and correction raw materials winning	Blasting, excavating, loading, transport	Clay pit, excavators, trucks
	Crushing and prehomogenizing of raw material components		Jaw crusher, hammer crusher
	Grinding of raw materials	Washing storing	Wash mill, ball mill
	Homogenizing		Slurry silos, bins and basins
	Preparation of fuel		Oil tanks
II. Production of clinker	Firing of raw materials		Rotary kilns
	Cooling of clinker		Clinker cooler
	Maturing and storing of clinker		Clinker silos and bins
III. Production of cement	Milling of clinker and admixtures		Cement mill
	Storage of cement		Cement silos
	Packing and dispatch		Packing machine

Washing is another step in the raw material preparation. Soft, clayey and marly materials which cannot be crushed are supplied to wash mills in which they are mixed with water into a slurry.

Slurry is then supplied to mills mostly by means of centrifugal pumps, or by screw conveyer and bucket elevators via storage tanks.

Grinding is an important operation during which the raw material of up to 25 mm grain size is ground continuously, and 80% of ground material below 70 micron particle size is obtained. The finer are the particles, the quicker can be the firing process in the production of clinker that again results in saving fuels. When this process is kept within optimal limits, particularly in case of high capacity equipment, the economy becomes more significant.

Stability of the chemical composition of the raw material supplied to the kilns for the production of clinker is vital for the smooth kiln operation, life of its lining and quality of clinker. For this purpose the slurry must be corrected and well homogenized and, to reduce the water content, deflocculants may be added.

The slurry having been so prepared contains about 33%-38% of water.

The slurry, having been accurately and regularly dosed by a dosing machine, a so-called Ferris wheel, is supplied through an inlet pipe into the inlet portion of a rotary kiln.

The firing operation in a wet-process rotary kiln

A wet-process rotary kiln is a steel tube lined with refractory bricks. Most often it rotates at 1.1 rpm speed. Slurry is supplied at one end and fuel from the other (at the kiln head). The slurry moves slowly inside the kiln towards the kiln head. The movement is supported by a slight incline (4%) of the kiln. The slurry is dried up in the drying zone in which there are steel chains. The chains get heated by the flue gases and they pass this heat to the slurry. In the chain zone also the flue gases get partially rid of dust, and slurry rings formation is prevented. The raw material comes from the chain zone in the form of nodules with remaining 6%-10% moisture content. The nodules get quickly dried up and proceed to the calcination zone, where the calcium carbonate disintegration takes place at 900°C temperature. This reaction is strongly endothermic and consumes most of the heat in the clinker formation. In the sintering zone, where the material is 1,350°-1,420°C hot, a series of reactions takes place, and tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, magnesium oxide and about 0.5% of free lime are formed.

About 23%-28% of this mixture forms a melt in the sintering zone, and the material gets sintered. The product of sintering called Portland clinker is quickly cooled in a satellite grate, grate or drum cooler from where it comes out being only 80°-150°C hot. The cooling medium is air, which gets heated up to a high temperature (as much as 850°C) and is used as secondary combustion air for the conbustion of fuel. Primary air is supplied into the kiln together with the fuel and represents merely 5%-15% combustion air in the combustion of natural gas and oil, and about 25% in the combustion of coal.

The temperatures and individual zones in the wet-process rotary kiln are shown in table 21.

Development of long wet-process rotary kilns for reducing the heat consumption and raising the output

It is obvious from the heat balances that the majority of heat in the wet-process kilns is consumed for the evaporating of water from the slurry. In case of short wet-process kilns, however, the maximum heat losses occurred in the hot flue gases (more than 40%). Therefore, the endeavour of designers was first focused on elongating the kilns. While the first rotary kilns', ratio of their diameter to their length was 1:12, the present optimal ratio of their diameter to their length is about 1.40. Inside heat exchanges were built in the kilns to reduce the temperature of the outgoing flue gases and to utilize more heat. The heat exchangers have not only enabled the exchange of heat, but they have also been useful in reducing the dust occurrence in the kilns by breaking the formed slurry rings, helping the material movement through the kiln, and assisting mechanically in the formation of nodules.

Table 21. Temperatures of particular stages of the wet-process rotary kiln

Zone	Temperature of the material being fired (°C)		Temperature of gases (°C)		Approximate length of zone relative to the total kiln length (%)
	Beginning of zone	end of zone	Beginning of zone	End of zone	
Drying	40	100	200	700	20
Preheating	100	550	700	1 250	21
Calcination	550	1 100	1 250	1 500	33
Firing					
Exothermic	1 100	1 450	1 500	1 750	13
Sintering	1 450	1 300	1 750	950	8
Cooling	1 300	1 100	950	800	5

Of the well-known inside heat exchangers in the rotary kiln, let us mention those which are most frequently used:

(a) Chain system - formed by chain curtains or chain garlands suspended freely in 15%-20% of the total length of the kiln;

(b) Cross-shaped internal heat exchanger - or, less often, trifoil ceramic heat exchanger, for quick heating of nodules from about 90°C-300°C, while the flue gases entering the inner structure have still 700°-800°C temperature. (The most common steel inner structure is the cross-shaped one, although others have been developed, such as the shovel lifter);

(c) Slurry preheaters with heat exchange compartments were especially developed. They used to be situated only several metres from the kiln inlet. Therefore the slurry preheaters were also effective dust-removing equipment. They were increasing the resistance of the kiln and, sometimes during an unskilled handling with the kiln, they caused sticking of the material, whereby the slurry flew back to the flue-gas uptake. That is why they were removed from some factories because of the heat schedule of the kiln.

External heat exchangers for wet-process rotary kilns

Concentrators (or calcinators) of slurry

In the efforts to reduce the specific heat consumption at the short wet-process rotary kilns in the 1930s concentrators, called also calcinators, were installed behind the kilns.

The equipment consists of a horizontal drum, the jacket of which is formed of grate bars with 70 mm gaps. The drum is filled with ring-shaped small cast iron pieces. Hot flue gases leave the kiln at about 600°C temperature. The drum rotates slowly (1-2 rpm).

Slurry is supplied into the drum from the top. A substantial part of water evaporates from the slurry in the drum, and the flue gases are cooled down to a mere 150°C at the same time. The first concentrators were installed in the cement factories in England and in the Federal Republic of Germany, and they soon spread to the whole world. In case of wet-process kilns the specific heat consumption, which amounted to 2,100-2,200 kcal/kg of clinker (8,792-9,121 kJ.kg^{-1}) before reconstruction, dropped down to 1,500-1,600 kcal/kg of clinker(6,280-6,700 kJ.kg^{-1}) after the calcinators were installed. The output was increased by about 10%-25%, too.

Besides the reconstructions, new, modern units with the concentrators were built. Their specific heat consumption was distinctly lower - about 1,350 kcal/kg of clinker (5,652 kJ kg^{-1}) and even less. (The peak ones consumed even 1,230 kcal/kg of clinker (5,150 kJ.kg^{-1}).)

High dust content was the disadvantage of the equipment, though under the present level of electrostatic dust separators the flue gases can be freed from the dust perfectly. Nevertheless, it is a fact that long wet-process kilns with a system of built-in structures are simpler from the operational point of view; they require less personnel and less electric power, and they do not suffer from the harmful influence of false air, which always plays a significant role at the additional heat exchangers.

Advantages of the wet process

1. Preparation of perfectly homogenized raw material is simpler, and therefore the winning, storage and joint dosage of raw material components are less demanding. The additional correction of composition and homogenization is very simple.

2. The machinery is simpler so that it does not need so many skilled personnel for operation and maintenance.

3. In case of blungeable raw materials - soft clays, chalks and earth in wet state - very simple dressing methods may be applied to remove undesirable rock contaminations such as silica sand, pebbles, flints, remainders of weathered primary rocks, gypsum crystals etc.

4. Wet grinding is much easier than dry grinding. A particularly high saving of grinding work is the case with raw materials which can be blunged, where in some special cases the grinding process can be omitted altogether (when fine, completely blungeable chalk and marls are used).

5. In case of porous, soft raw materials of high moisture content in winning state, it would be necessary to build expensive driers in dry-process plants with additional hearth, because the waste heat from the dry-process kilns would be insufficient for the drying.

6. Very fine chalks which cause an excessive fly-off from the heat exchanger in case of the dry process are, to the contrary, very

advantageous for the wet process because they form solid nodules, so that not only is firing easier, but also dust content in the kilns is substantially reduced.

7. Wet-process preparation of the raw material does not require dust separators.

8. Wet-process cement factories employ substantially less labour in the raw material preparation plant, laboratories, plant operation and in the maintenance.

9. In the case of the wet process there are lower investment costs of both technological equipment and buildings (but not for the kiln proper).

10. There are more favourable hygienic conditions of work in the wet process that substantially decrease the accident rate etc.

11. The wet process is substantially advantageous due to the lower consumption of electric power.

12. Wet-process rotary kilns enable the production of clinker of higher quality. Even though the powder could be homogenized as well as the slurry, there remains the fact that clinker from the dry-process kilns contains 60% more alkalis than the clinker from the wet-process kilns, because powder absorbs the alkalis in the dispersion heat exchanger almost completely.

13. By the wet-process even such raw materials can be processed which cannot be processed by the dry-process (with a dispersion heat exchanger) at all. Here, e.g., sea shells, which contain more chlorides as well as other "salty" raw materials belong; furthermore, very fine-grained raw materials in natural state, raw materials of high moisture, the winning of which often takes place under water level etc.

14. The life of a lining of identical quality in the sintering zone is almost double. That is why the wet-process kilns show a higher degree of time utilization than the dry-process kilns with dispersion heat exchangers. Thereby the economy is substantially influenced.

15. Raw materials containing more alkalis and chlorides can also be fired in the wet-process kilns.

16. Easy homogenization and correction of raw materials enable the processing of raw materials consisting of four or more components with high fluctuating chemical composition of the individual components.

Disadvantages of the wet process

1. The wet process always consumes more heat for the firing proper than the dry process with a dispersion heat exchanger. The difference is so great that the increased costs outbalance all the other advantages of the wet process. The world energy crisis, along with the spiralling costs of fuels, has condemned the wet process to extinction. It may be supposed that only in particularly reasonable cases will the long wet-process kilns be used.

2. Difficulties in the wet-process firing occur when highly plastic raw materials are used which consume too much water (often more than 50% of water) to achieve a normal fluidity of the slurry, and thereby an increased calorific consumption, while the output is decreased due to the evaporation of superfluous water from the slurry.

3. Less suitable raw materials are those containing an increased proportion of bentonites, because they tend to the formation of rear, so-called mud rings in the kiln, which are difficult to be removed. Thixotropic slurries may also cause troubles during the transportation and storage in the bins. To the contrary, however, completely non-plastic slurries (such as slurries from limestone and slag) tend to separation and sedimentation. All these physical and chemical properties of the slurry can be foreseen and determined by laboratory testing of binding raw material samples.

4. Consumption of non-returnable technological water is another substantial disadvantage of the wet process. Industrial water is very scarce in some parts of the world and is allowed to be consumed for agricultural purposes only, e.g., in some areas of Mexico, Iraq etc. The governments of these countries do not permit construction of wet process cement factories.

V. SEMI-DRY AND SEMI-WET PROCESSES

The semi-dry production process is used for the firing of a wetted and granulated raw material powder of 8%-15% moisture content. Similarly, the semi-wet process is used for the firing of raw material pieces obtained by the filtration of raw material slurry, and by granulating or pressing the filter cake containing 15%-18% moisture.

The raw material prepared by the semi-dry or semi-wet processes may be fired either in long rotary kilns with inside structures, or in short rotary kilns with grate calcinators (Lepol system), which are the most economical in view of the heat consumption.

Rotary kilns with grate calcinators (Lepol kilns)

Dr. Lellep in the Federal Republic of Germany was granted a patent in 1927, the realization of which significantly influenced the development of kiln systems. Dr. Lellep proposed to calcine granulated cement raw material on a grate by means of hot waste flue gases coming out from the short rotary kiln. Partially calcined nodules enter the rotary kiln, where they become sintered. The patent was adopted, and the kiln was called a Lepol kiln. The first kiln was built in the Federal Republic of Germany in 1929-1931 and another one in Switzerland soon afterwards. Low heat consumption and high performance of the Lepol kiln helped it to spread quickly in the period between the two World Wars. About 53 kilns in 18 countries went into operation as early as by 1937, and another 120 were commissioned within the next two years (by 1939).

The design of this kiln was improved after the Second World War. The so-called double flue duct was developed and led through the calcinating grate whereby the heat of the flue gases was utilized more efficiently, and, moreover, the calcination on the grate and dust separating of the gases in the cold chamber were improved. While kilns with a single flue duct were achieving the heat consumption of 1,050-1,300 kcal per kg of clinker (4,400-5,440 kJ.kg^{-1}), the kilns with the double flue duct of gases dropped below 900 kcal/kg of clinker (3,770 kJ.kg^{-1}), and at large units even to 740-780 kcal/kg of clinker

(3,090-3,266 kJ.kg^{-1}), whereby they still rank among the most perfect kilns for the firing of clinker.

The largest Lepol kilns capacity is 3,000 t of clinker a day.

The favourable results in reducing the heat consumption have been enhanced by a number of further technical improvements, e.g., drum granulators have been replaced by granulating discs, and grate coolers have been substituted for drum coolers etc.

There were as many as 290 Lepol kilns in operation in 1964. The construction of these kilns slowed down in the 1970s; this was quite a natural consequence of the competing kilns with dispersion heat exchangers, because apart from lower maintenance, they still have hot flue gases of 360°C at disposal, which can be utilized for the drying of raw materials either in the mill or in the drier.

Firing of clinker in the Lepol kiln

Raw material is transported to the Lepol kiln either as a homogenized powder of 0.5% remaining moisture (A), or as a filtered slurry cake of 15%-17% moisture (B).

In the (A) case the powder is fed to the granulating disc, where it is wetted and nodules of 10-15 mm and 12%-14% moisture are formed. These nodules are supplied to the calcinating grate. It is a semi-dry method of preparation.

In the (B) case small pieces or pellets are also to be made of the slurry cake, and they should have suitable size, geometric shape and rigidity. In case of solid cakes obtained from the pressure filter the use of extrusion presses is usually sufficient. In case the cakes are too soft, they are to be sometimes mixed with dry powder or with fly-offs, and then only the granulation may follow.

These processes are of a particular suitability when wet-process kilns in cement factories are reconstructed and where moist and soft raw materials are processed, e.g., chalks. In such a case it is a semi-wet method of production. This process can also be applied in the processing of soft raw materials with higher content of chlorides. A substantial part of chlorides is removed during filtration, and another part can be removed by using so-called by-passes for leading a portion of flue gases out of the hot chamber of the calcinating grate.

Pieces of raw material are fed to the calcinating grate. The space of the grate is provided with a masonry wall, and thereby it is divided into a cold (drying) chamber and a hot chamber. A layer of nodules (140-200 mm thick) is carried by the grate first to the drying chamber where it comes into contact with the flue gases of 300°C temperature; when they pass through the layer of the wet nodules the flue gases get cooled down to 90°-120°C. Flue gases, having passed the layer of the nodules, flow then through the gaps between the grate bars (9 mm wide gaps). Dried up and preheated nodules are then carried to the hot chamber, where they are calcinated by hot gases from the kiln (as much as 1,100°C hot).

The firing process of the clinker comes to its end in a short rotary kiln where the nodules are sintered. The optimal ratio of length of the Lepol kiln to its inside diameter is 14:1. Due to the thermal preparation of the raw material on the grate, the final phase of the firing in the rotary kiln is very intensive, which is proved by the specific output of the Lepol kilns, achieving in peak operation as much as 2.2 t/m^3 of inside space a day.

The grate moves at 25-50 m per hour. The material passage through the kiln takes 80-100 minutes. The disintegrated nodules fall through the grate of the calcinator and are, too, transported by a bulk conveyor and elevator into the kiln. The fired clinker centers cooler - most often a grate cooler.

Raw materials suitable to be fired in the Lepol calcinating grate

It is essential to choose a suitable process to form the raw material pieces to be fired in the Lepol grate. The pieces should have sufficient strength and resistance to thermal shock and abrasion at the same time. For this purpose, more suitable are plastic raw materials containing clayey material montmorillonite. Hence, an extraordinary care is to be given to the choice of raw material components, particularly to the sialitic one, usually to clay. The nodules should be solid enough not to get deformed during the transportation from the granulator to the grate, so that due passability of flue gases through the nodules layer should be secured. It is an essential condition for normal run, not only of the grate but of the kiln as well. Too solid nodules of point strength exceeding 1,500 g at 15 mm diameter are of low porosity, and are less resistant against thermal shock by hot gases, which results in their disintegrating or explosion. To the contrary, nodules of a strength lower than 600 g get deformed. The method of forming is very important, too. Raw materials of low plasticity are less resistant to abrasion. Undersizes falling through the grate in the quantity up to 5% may still be considered acceptable from the operational point of view. Out of the facts mentioned above, a conclusion may be drawn that an extraordinary attention should be given to the choice of raw materials and their testing which can only be done in close co-operation with the supplier of the technological equipment.

"Automatic" shaft kilns for the firing of Portland clinker

So-called "automatic shaft kilns" invented by Mr. Hauenschild, Jr. (1912) may be considered to represent the greatest progress in the design of shaft kilns. The name is not comprehensible enough. There was namely no automation, but a continous removal of clinker by using a rotary grate at the shaft bottom. Since the grate crushed and removed clinker almost uniformly over the entire cross section of the kiln, the material descended uniformly, too, in the kiln.

The flat rotary grate manufacture was started in Berlin, and the first kiln was commissioned as early as in 1917, in Blaubeuern in Imperial Germany in what is now the Federal Republic of Germany. The kiln was easy to be operated and put an end to the hard manual removal, improved the quality of clinker, and the firing zone was successfully kept in the upper part of the shaft. In addition, the fuel consumption was substantially lower than in the contemporary rotary kilns. The output of the "automatic shaft kilns" amounted to a mere 30 or 40 t/day, but after their improvement it was soon raised to 70 t/day and even more.

How much favour was paid to the "automatic" shaft kilns with rotary grate can be shown by the following figures:

Year	Number of kilns constructed
1917	1
1919	48
1927	500

The Grueber shaft kiln consisted of a vertical shaft formed by steel jacket lined inside with a refractory lining.

The shaft was closed on the top with a steel sheet cover of the shape of truncated cone provided with a peep hole. The cover was connected to the chimney. Pressings of the raw materials powder with coke (or anthracite) rice wetted to 8%-14% moisture were uniformly distributed by means of a rotary distribution disc.

The flat rotary grate was situated in the bottom part of the shaft, and it was provided with numerous lugs by which the sintered clinker was crushed and fell down through the grate openings below the grate, from where it was discharged by triple-chamber closures into a conveyor. Air was forced in the space beneath the grate to support the conbustion of fuel.

Quick firing process and a narrow sintering zone enabled the construction of kilns with a lower shaft. Optimal ratio of the shaft height to its inside deameter is H:iD = (3 to 4):1.

The kiln resistance has increased from 500 mm of water column (4,900 Pa) to 1,600 mm of water column (15,690 Pa) during the past 60 years of development.

In the range of grates design, the most widely used has become the rotary grate, but even cylindrical grates were used (Mannstaedt or Stehmann system) and Thiele traveling grate system.

The upper part of the modern shaft kilns is made broader into the shape of a funnel.

The shape of the grate is to be adjusted, too, for fine nodules to prevent spontaneous emptying of the kiln through the grate holes. The Spohn conical grate is very suitable.

Spohn implemented the technology of "black powder" in 1958 to improve the quality of clinker. Under this method the fuel is ground together with the raw material, while in the method of "white powder" the fuel grains are mixed in before granulating only.

Table 22. Dependence of output per hour of shaft kilns on the size of the raw material lumps

Diameter of a lump (mm)	Kiln output (t/h)	Depth of fire (m)	Speed of material movement (m/h)	Time of dwell in the firing zone (h)	Peroid
120	4.15	3.0	0.60	5.00	1920-1930
70	5.40	2.0	0.78	2.56	1930-1940
35	6.25	1.3	0.91	1.43	1940-1950
25	7.30	1.0	1.09	0.91	1950-1960
17	8.45	0.8	1.23	0.65	1960-1980
10	10.70	0.6	1.56	0.39	

In the case of "black powder" method the grains of ash are very fine and can react perfectly with the raw material.

The present output of the cement shaft kilns is 150-280 t/day, while the specific heat consumption is 880-1,050 kcal/kg.

Raw materials for the firing of clinker in shaft kilns

Only reactive, easily burnable raw material powders are suitable for the firing in the shaft kilns.

Required chemical composition of the raw material powder

$$\text{Silicate modulus } Ms = \frac{\overset{SiO_2}{Se}}{Al_2O_3Fe_2O_3} = 2.4 \text{ max.}$$

Saturation with lime degree in clinker is usually kept within the value of 89%-91%

Silica grains exceeding 60 microns may be present in the raw material in the maximum quantity of 1.5%

The fluid phase should be long enough to allow sufficient fixing of clinker. Therefore, the aluminate modulus $\frac{Al_2O_3}{Fe_2O_3}$ should be within 1.5-2.0.

It is possible to add fluxes and mineralizers into the raw material, such as fluor-spar (about 0.5%) or waste fluorosilicates (0.5%-1.0%), which, however, make the production costs higher, and such admixtures are not available everywhere in the required quantity.

The raw material powder should be ground to max. 18% residue on 4,900 mesh sieve (170 ISS). The optimal fineness is 6%/4,900. The powder should be well homogonized and mixed in an accurate ratio with the calculed quantity of fuel.

The raw material should have also a mineralogical composition suitable to form nodules resistant against thermal shock, and solid enough so that while coming from the granulating disc they should neither get deformed nor form an impermeable layer during transportation. Presence of clay mineral of montmorillonite is suitable for the purpose. Some of the illite minerals are undesirable.

Addition of fuel into the automatic shaft kilns

The homogenized raw material powder for the shaft kilns is mixed with fine grained fuel (1-8 mm) of low volatile combustibility (up to 7%), i.e., with coke, anthracite or oil coke, wetted and granulated.

Advantages and disadvantages of shaft kilns

When compared with the rotary kilns, the shaft kilns investment costs are lower by as much as 2/3, their design is comparatively simple and they require less construction area.

The heat consumption is low and, moreover, mostly coke of 1-8 mm grain size is burnt in them. Such coke used to be an inconvenient waste. The grindability of the fired clinker is better. It results in electric power savings in the cement milling process.

On the other hand, even the largest shaft kilns have been rather small units, and in the construction of medium-sized factories they had to be built in parallel batteries. In such a case it is more difficult to watch and control the firing process.

The work of the kiln operator is physically hard because the molten clinker sticks to the lining, and it should be pushed off by means of steel bars. The clinker quality is usually worse than that from the rotary kilns.

The firing in shaft kilns is still being done even in the industrially developed countries, but its share in the total production keeps decreasing. It is an obsolete technology which will be gradually replaced by dry-process rotary kilns with heat exchangers.

VI. DRY PROCESS

Dry-process production method with dispersion heat exchangers

The first cyclone heat exchanger KHD was commissioned in the Federal Republic of Germany in 1951. Nowadays, hundreds of kilns all over the world are equipped with dispersion, either cyclone or countercurrent, heat exchangers. Low heat consumption and high specific output, as well as the possibility of utilization of waste heat from the flue gases for the drying of raw material, are advantages lacking in other firing systems.

Firing of clinker in kilns with dispersion heat exchangers

Homogenized powder is weighed continuously into the shaft dispersion heat exchanger (or into a four-step dispersion cyclone heat exchanger). Hot gases of 1,050°C from the rotary kiln enter the heat exchanger and heat up and partially pre-calcinate the raw material powder. The raw material powder is 40°C warm while entering the heat exchanger, and its temperature reaches 800°C at the outlet. The hot gases transfer their heat to the raw meterial powder and leave the heat exchanger at 340°C. These gases are cooled in a conditioner, and dust is removed from them in an electrostatic dust separator.

The preheated powder from the heat exchanger enters the short rotary kiln (L:iD ratio is 17:1) where the calcination process is completed. Clinker is formed then in the sintering zone, and it is cooled down on a grate cooler. It is possible, of course, to use other types of coolers such as satellite, drum or shaft coolers.

The preparation of raw material powder for the dry process is rather more complicated, but the fuel consumption is so low that this method is a prospective one.

Kilns for the dry-process production with the dispersion heat exchangers are constructed for 300-5,000 t/day outputs, while the calorific consumption is 960 kcal/kg of clinker, i.e., 3,132 kJ.kg^{-1} to 720 kcal/kg of clinker, i.e., 3,015 kJ.kg^{-1}. The larger the kiln, the more economically it operates.

The dispersion heat exchangers are either cyclone-type ones, or shaft countercurrent-type ones, or they are a combination of cyclones and turbulant shafts, while the gases are divided into two branches.

A technical description of all the systems of the dispersion heat exchangers would be beyond the framework of this study. However, suffice it to say that heat exchangers for kilns of 3,000 t/day output can be easily built; some heat exchangers with an output of more than 4,000 t/day have already been built, and in one case a heat exchanger of more than 5,000 t/day has been built. As far as the specific heat consumption is concerned, all the heat exchanger systems are capable of achieving specific consumption of 800 kcal/kg of clinker (3,349 $kJ.kg^{-1}$ and even less. It also depends on the kiln capacity. A lower heat consumption may be achieved at larger units for the cyclone heat exchanger.

Table 23. Dependence of specific heat consumption on kiln capacities (kilns with cyclone heat exchangers)

	Specific heat consumption	
Kiln capacity (t/d)	(kcal/kg)	(kJ/kg)
300	860	3 600
400	850	3 559
500	845	3 538
600	835	3 496
800	810	3 391
1 000	800	3 349
1 200	785	3 287
1 400	770	3 224
1 800	765	3 182
1 800	765	3 203
2 000	760	3 182
2 500	750	3 140
3 000	745	3 119
3 500	740	3 098
4 000	730	3 056

Some more details about the most well-known heat exchanger systems

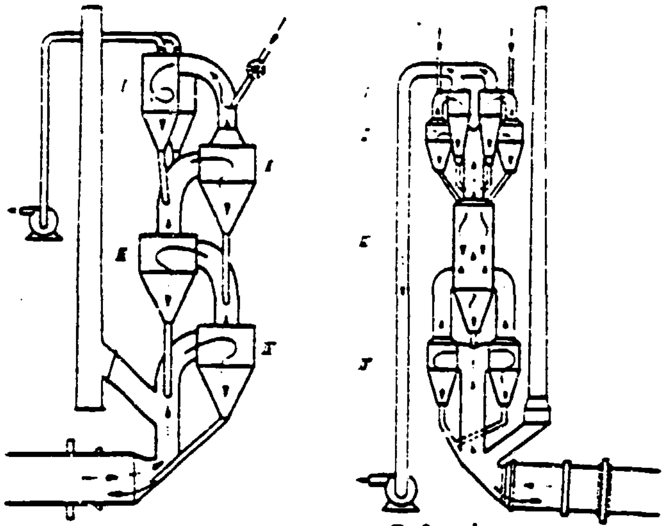
Humboldt heat exchanger (sometimes indicated by KHD).

The four-stage cyclone dispersion heat exchanger was first commissioned in 1951 in a cement factory at Bremen-Oslebshausen in the Federal Republic of Germany.

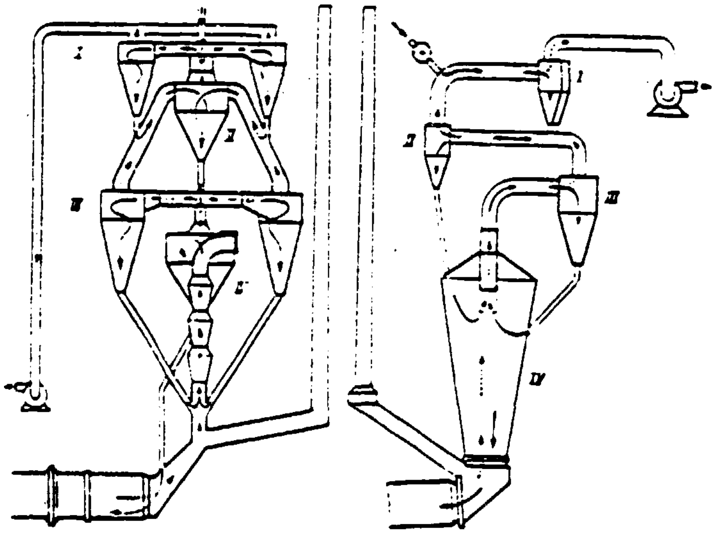
The Humboldt heat exchanger is the most well-known and oldest dispersion heat exchanger.

As it may be seen in figure VIIIa, the cyclones are installed above each other. They are interconnected with a piping of square section. The heat exchanger is made of steel sheets with a refractory lining, and the whole assembly is built in a supporting structure made of reinforced concrete.

The raw material mix is fed into an elbow of the piping leading upwards from the top of the IInd cyclone into the pair of parallel cyclones being the first stage (see the figure). The velocity of flue gases at the point of entrance of the mix into the piping is sufficient to entrain the raw material mix into the pair of cyclones in the first stage. A portion of the flue gases heat is transferred to the raw material mix at the same time, whereby the mix is preheated. The preheating process of the mix goes on in the head of the pair of cyclones in the first stage. The mix gets separated from the flue gases in these cyclones and descends through the conical portion of the cyclones and a pipe into the elbow of the piping connecting the IIIrd and IInd cyclone stages. The process here is repeated. The mix is entrained into the IInd cyclone and preheated. The mix separated from the flue gases in the IInd cyclone descends from it into the piping between the IVth and IIIrd cyclone etc. Out from the IVth cyclone, then, the mix is led through a refractory piping into the kiln. The passage of the raw material mix through the exchanger takes merely 20 to 30 seconds, while the passage of the material through the kiln takes at least 40 minutes.



a Humboldt b Polysius



c Wedag d Miag

Figure VIII. Dispersion heat exchangers

The temperatures of flue gases and of the mix in the individual stages of the Humboldt heat exchanger are as follows:

Stage		Mix	Gases
First	Inlet	40	530
	Outlet	315	340
Second	Inlet	315	650
	Outlet	510	530
Third	Inlet	510	840
	Outlet	650	650
Fourth	Inlet	650	1,100
	Outlet	780	840

The raw material mix at the inlet to the heat exchanger has been partly precalcined. Therefore, to complete the calcination and sintering processes, a rather short kiln is sufficient, its specific output reaching 1.4-1.8 t/m^3 of its inside volume per day (max. 2.3 t/m^3 in peaks only).

In case of kilns the capacity of which exceeds 1,800 t of clinker per day, there are two parallel heat exchanger towers situated behind the kiln.

Hot gases from the heat exchanger are utilized for the drying of raw material, either in the raw mill or in the drum drier.

A kiln with the KHD exchanger operates with an excellent heat efficiency, particularly in the case of large kiln units. The specific heat consumption ranges between 720 and 840 kcal/kg of clinker (3,015-3,517 kJ.kg^{-1}).

Except for flaps there are no movable parts in the heat enchanger. Nevertheless, the heat exchanger must be inspected during the general overhauls, and its packings must be repaired to prevent excess false air intake that may result in an increased heat consumption, and even in a reduced output.

The KHD heat exchangers have considerable losses in draught - about 600 mm of water column - and to make their lining is rather complicated. The heat exchanger does not have a self-supporting structure.

Dopol heat exchanger

The Dopol system is the second most widely used heat exchanger. As it may be seen in figure VIIIb, the raw material mix is divided into two branches of cyclone exchangers in which the mix is preheated in the first and second stages. The two streams are joined in the third stage into a counter-current turbulent shaft. The mix falls from the turbulent shaft into the uptake piping of flue gases from the kiln, where it is entrained into the pair of cyclones which are the last, fourth preheating stage.

Dividing the raw material mix into two branches of cyclones enables using cyclones of smaller diameters and enhancing their efficiency. Besides, a single heat exchanger is sufficient for kilns of up to 3,000 t/day rated production of clinker. Kilns of 4,000 t/day capacity are in operation. Kilns with Dopol heat exchangers operate with an excellent heat efficiency up to the limit of 720 kcal/kg of clinker (3,015 $kJ.kg^{-1}$).

Wedag raw mix suspension preheater

The Wedag suspension preheater, (illustrated in figure VIIIc) operates in four stages. The first and third stages are formed by pairs of parallel cyclones. A vortex chamber is situated between the pair of cyclones in which a counter-current heat exchange takes place. The raw mix enters the vortex chamber, out of which it passes tangentially into the pair of cyclones of the first stage. The raw mix is separated from the flue gases in the cyclone and led into the connecting piping of the main cyclone, which is the second stage of the heat exchanger. The connecting piping is comparatively long, thus enabling a prolonged contact of the raw mix with the hot flue gases.

The raw mix is led from the main cyclone into the vortex chamber in the third stage of the heat exchanger. Out of these cyclones it enters the rising duct of the fourth stage and the rotary kiln.

In addition to the type of the heat exchanger described here, two other modified versions of the heat exchanger are made which are applied to suit the size of the kiln.

A Wedag heat exchanger was built in Japan; its daily output reaches 5,400 tons, which makes it the largest conventional (without precalcination) dispersion heat exchanger in the world.

The heat consumption is commensurable with the other described units.

Miag heat exchanger

This heat exchanger is illustrated in figure VIIId. Its first stage is formed by a pair of cyclones, while a single cyclone is in its second stage.

Raw material separated from the flue gases in the second stage is led into the upper part of the tapered countercurrent shaft (14 degree angle). A portion of the raw material descends into the lower part of the shaft in the countercurrent of the flue gases, which entrain the remaining portion of the raw material and take it into the third stage. The so-called cyclic stage. The separation efficiency of the third stage is high (it is said to be 95%). From there the raw material is led into the upper third of the shaft where it stays (dwells) for a certain time, gets preheated and "rains" slowly down to the inlet part and into the kiln.

The cyclic quantity of raw material and, hence, its preheating and decarbonizing, can be changed within certain limits by the adjustment or closing of inlet pipes of the upper part of the shaft, practically from a double quantity of the raw material being fed up to as much as eight times more.

Depending upon the required sizes, these heat exchangers may be supplied in modified versions. One of the well-known versions is the one consisting of three pairs of cyclones situated above each other, thus forming three heat exchanger stages; the fourth stage is formed by the shaft described already in the former case.

Miag heat exchangers are built in Japan.

The heat consumption in these heat exchangers reaches as low as about 750-800 kcal/kg of clinker (3,140-3,349 kJ.kg^{-1}).

Dispersion shaft conuntercurrent heat exchanger (PM)

This heat exchanger has a completely welded self-supporting structure with a refractory lining. For its schematic illustration see figure IX.

The raw material is fed into the narrowed part of the shaft, usually through an air filter. The raw material is entrained into a pair or quadruple of thickening cyclones where it is preheated and, after separation, it descends to the distributing taper, which spreads it over the inner circumference of the shaft. The raw material descends in a spiral motion, while being preheated by the flue gases entering tangentially the bottom part of the shaft just above the taper. The raw material mix, having been preheated in the heat exchanger, concentrates in the bottom part of the shaft, from which it falls down a pipe, made of special refractory steel, into the rotary kiln.

The PM heat exchanger structure and operation are very simple, with a very low draught loss. Lining is simple.

Kilns of 2,000 t capacity and more are provided with two heat exchangers.

The largest kiln with two heat exchangers has 3,000 t capacity, its heat consumption being 740 kcal/kg of clinker (3,098 kJ.kg^{-1}).

The raw material mix enters the heat exchanger at 40°C temperature, and when it leaves the heat exchanger it is preheated to 780°C temperature and has reached 45% of calcination. The inlet flue gases are of 1,050°-1,100°C temperature, whereas they leave it having 340°C temperature only.

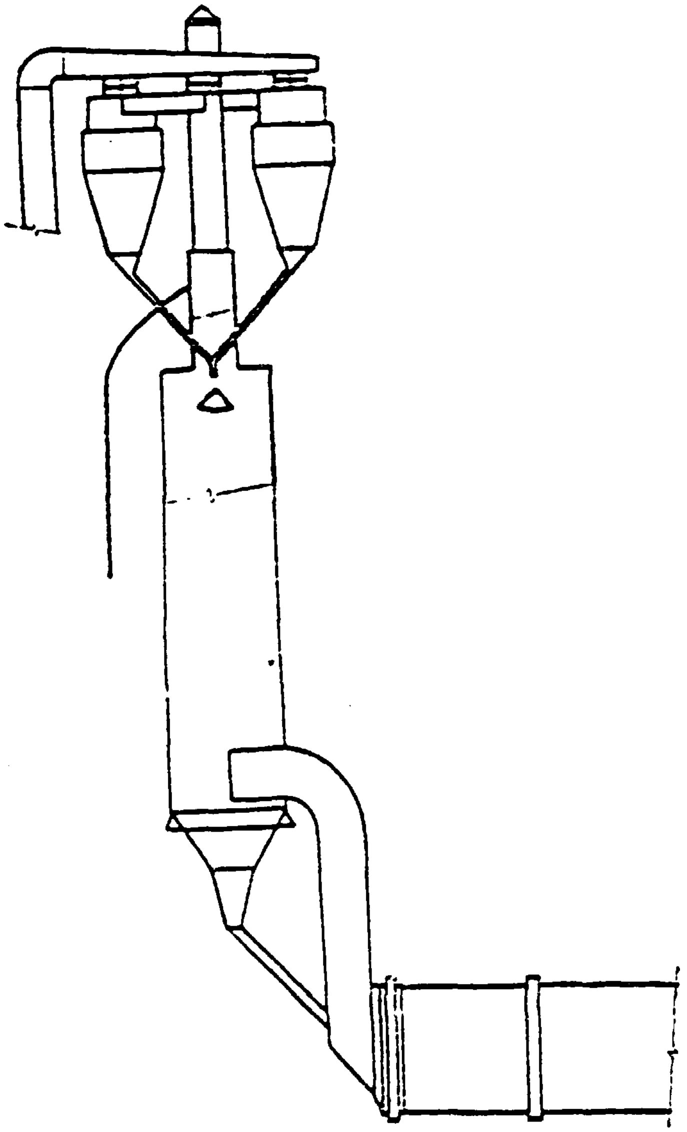


Figure IX. Dispersion shaft counter-current heat exchanger (PM)

Countercurrent heat exchanger

The design and operation of this heat exchanger (Figure X) are different from those of the PM shaft heat exchanger. Raw material mix is conveyed into two cyclones situated in the upper part. It falls from the cyclones into the upper pre-heater compartment, in which it descends and then whirls in the bottom narrow part, through the flue gases supplied there, countercurrentwise. The raw material mix descends from the fourth compartment into the kiln. The flue gases are supplied by the same route.

Flue gas temperatures measured:

In the cyclones	340° to 360°C
In the first compartment	450° to 470°C
In the second compartment	525° to 550°C
In the third compartment	600° to 650°C
In the fourth compartment	700° to 750°C
At the outlet from the kiln	1,000°C

Heat consumption amounts to about 800 kcal/kg of clinker (3,350 $kJ.kg^{-1}$).

Kilns with dispersion heat exchanger and precalcination process

The suspension flash (SF) process has been developed in Japan.

In Japan a kiln of 3.9 m in diameter and 51 m long with Lepol grate was reconstructed in 1971. Its original output of 700 t was increased to 2,000 t/day after the reconstruction.

The chart of the SF process is in figure XI. The chart shows a combustion chamber situated between the kiln and the heat exchanger. Owing to the additional heating into the heat exchanger, the calcination degree of the raw material mix was raised to as much as 85%-90%, and the kiln specific output from 1,522 t/m^3 of inside volume a day to 3,384 t/m^3 a day. Hot air of 600°-650°C temperature for combustion is led from the grate cooler to the combustion chamber.

This system has spread not only in Japan but all over the world. About 45 kilns (16 of them in Japan) were in operation in 1979. The largest kiln reaches the output of 7,700 t/day.

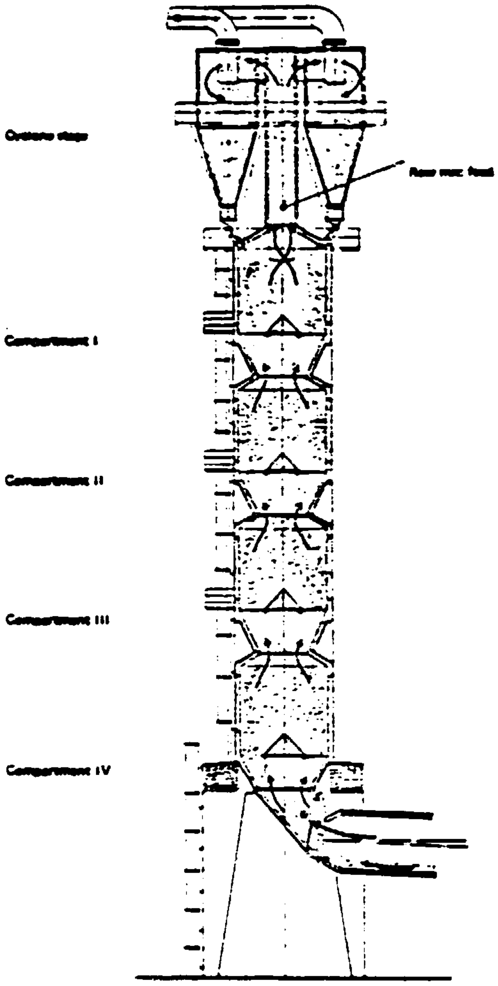


Figure X. Cross-sectional view of counter-current heat exchanger

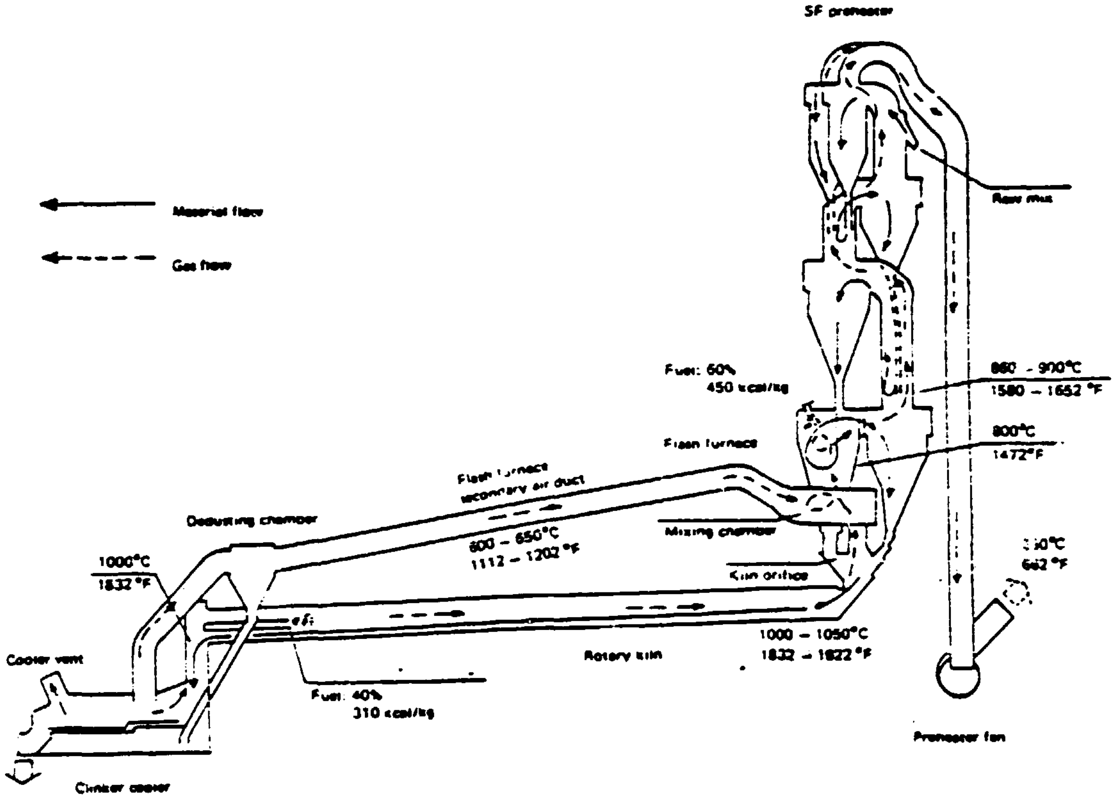


Figure XI. Sketch of the SF heat exchanger

Favourable features of the system are:

(a) Low consumption of heat - 740-830 kcal per kg of clinker (3,098-3,475 $kJ.kg^{-1}$);

(b) High degree of calcination - 85%-90%;

(c) Low content of NO_x in flue gases - about 100 ppm only at 10% of O_2;

(d) High specific output of the kiln - 3.6-4.1 t/m^3 a day;

(e) As much as 30% savings in linings;

(f) It enables building individual kilns of up to 10,000 t/day output.

FLS dispersion heat exchanger (see figure XII)

This system differs from the others in principle by supplying two separate streams of hot gaseous medium from two different sources (two-stream arrangement) into the two heat exchanger branches:

(a) The first gaseous medium being hot gases generated in the calcination combustion chamber in which hot air from the grate cooler was used for the combustion;

(b) The second gaseous medium being the flue gases from the rotary kiln.

The cyclones of the heat exchanger branches operate on a similar principle as described at the Humboldt heat exchanger, with the only difference being that the raw material mix is led into the calciner at the bottom part of the heat exchanger, i.e., from the fourth cyclone of the kiln branch and from the third cyclone of the calciner branch. After having been separated in the fourth cyclone of the calciner branch, the raw material mix is fed into the rotary kiln.

Since the two branches have different pre-heating capabilities, 68% of the raw material is to be dosed into the calcirer branch and 32% into the kiln branch. Both branches are controllable independently, and their output can be changed within a considerable range. The specific heat consumption of the kiln with the FLS heat exchanger amounts to 750 kcal/kg (3,140 $kJ.kg^{-1}$).

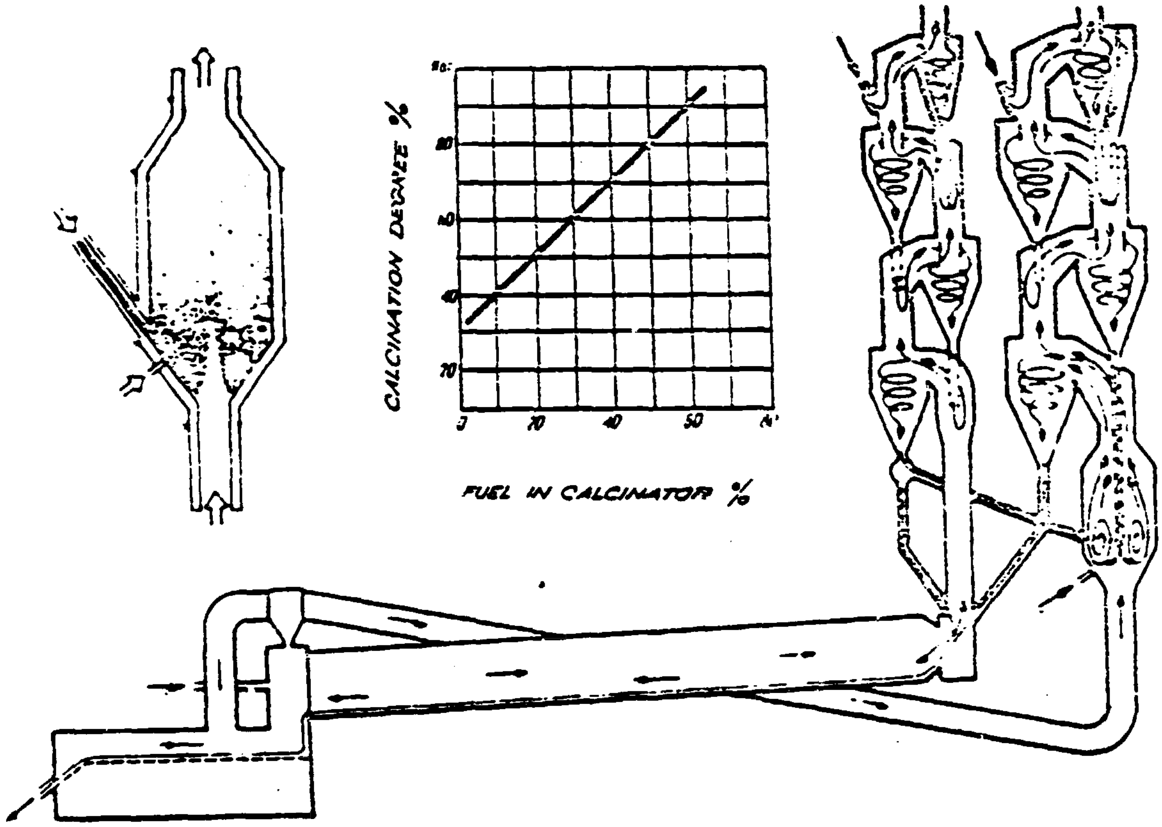


Figure XII. Flash-calciner system

MFC suspension pre-heater

The system most often consists of a conventional heat exchanger in combination with a fluid bed reactor. (Figure XIII shows this system in combination with the Humboldt heat exchanger.)

Either a portion of the raw material may be fed into the reactor, resulting in partial increase of output only (particularly suitable for reconstructions), or all the raw material may be led through the fluid bed reactor.

Even coal can be used for the firing. The dwelling time of the raw material mix in the reactor is 5 minutes on the average. The largest kiln unit output is 7,200 t/day. The combustion air for the fluid bed reactor is led from the hot chamber of the grate cooler by means of a fan. The system makes it possible to achieve a high specific output of the rotary kiln - as much as 3.9 $t/m^3/day$.

KSV and NKSV systems

The calcining fire box consists of a vertical cyclindrical vortex chamber, into which the hot combustion air from the cooler is led by an independent branch, fuel by means of several burners, and the preheated raw material is fed from the heat exchanger.

The situation of the KSV fire box is shown in figure XIV. The system has made it possible to achieve 8,500 t/day kiln output, which is the highest output of a kiln unit in the world at present.

In figure XIV also the change in the shape of the NKSV chamber and burners situation can be seen. Since 1979 the NKSV chamber has been used in two plants already. The new concept of arrangement stemmed from the effort to cut out the pressure loss and to reduce the formation of mud rings above the inlet chamber, where the velocity of flue gases has been slowed from the original 80 m/sec to 35 m/sec.

The design of the reinforced suspension pre-heater (RSP) fire box is successful, too.

Lately, efforts aimed at reducing the content of some harmful volatiles in flue gases have been met with more frequently. An example is given by the dual combustion and denitration calciner (DD) precalcining system (figure XV.) The combustion method in the precalcining chamber enables reducing the content of nitrogen oxides NO_x

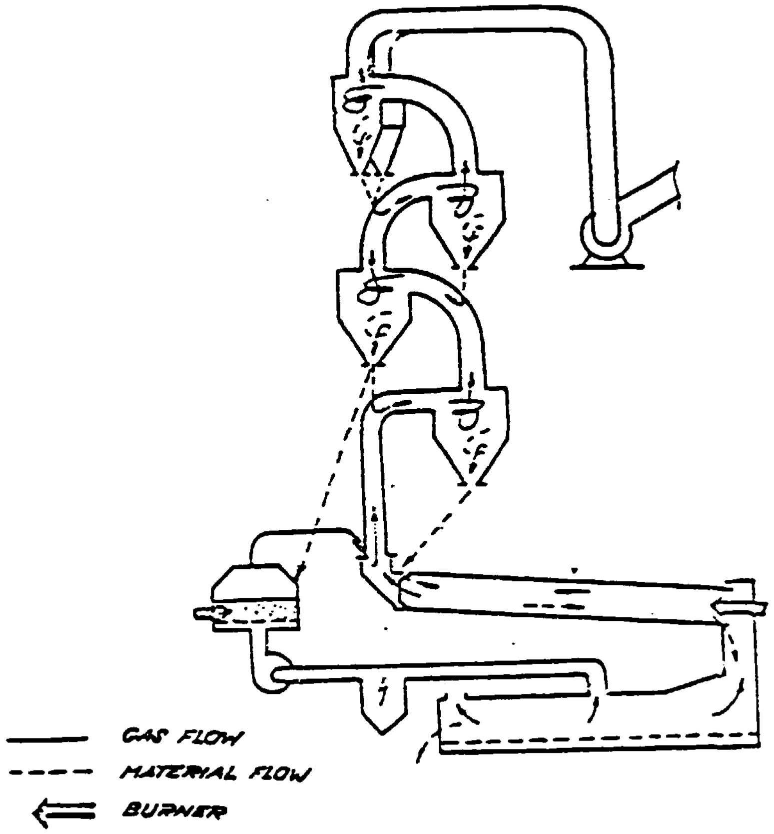


Figure XIII. Fluidized calciner sketch (MFC)

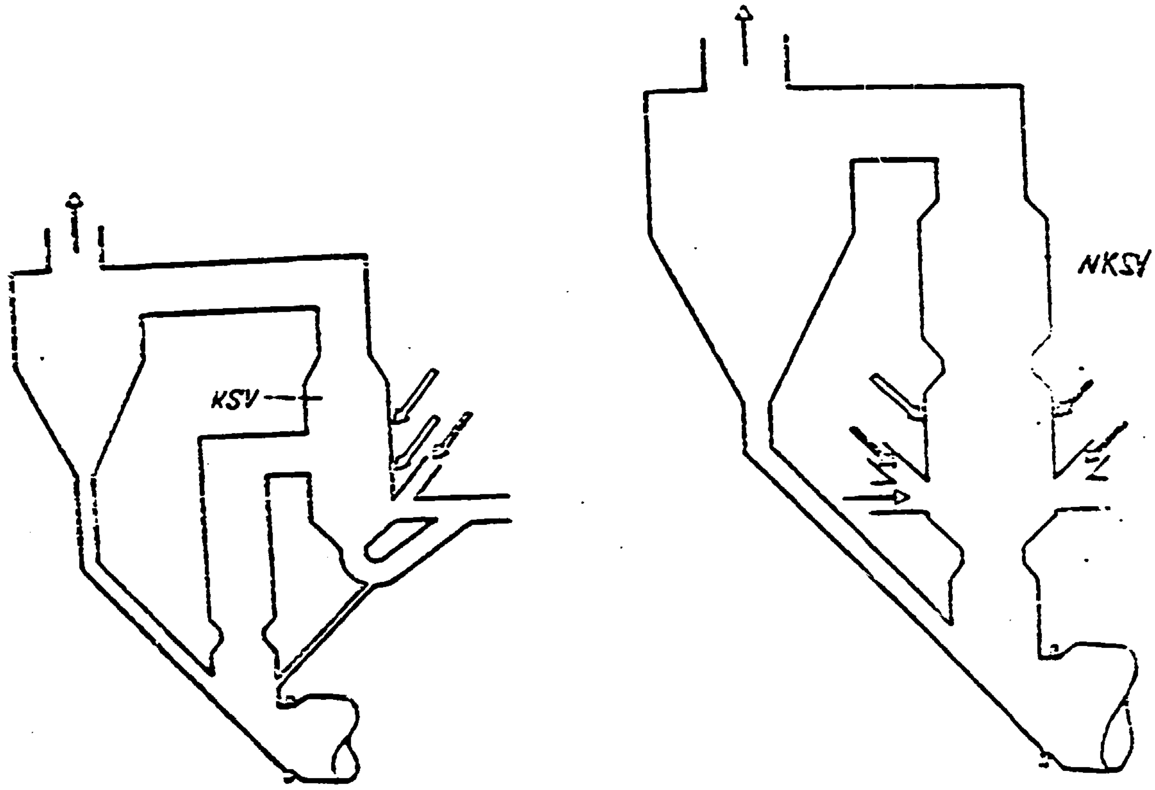


Figure XIV. Fire box of the flash-calciner system KSV and NKSV

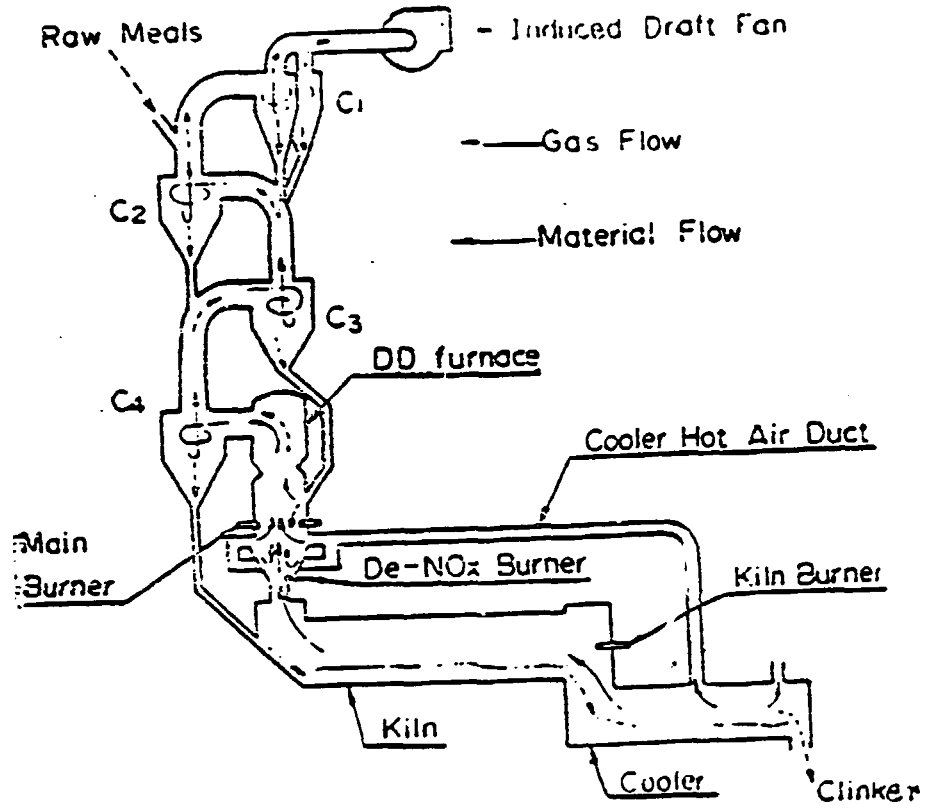


Figure XV. DD flash-calciner system (dual combustion and denitration calciner) in the fourth stage of the heat exchanger to a mere 50-150 ppm. This is achieved by adding an auxiliary burner as well as correctly situated main burners in the bottom part of the calcining chamber.

The system is in operation in two cement factories in Japan of 500 t/day and 3,600 t/day capacities. The degree of calcination from the heat exchanger reaches 85%.

Some more data and comparisons of the main precalcining systems are shown in tables 24, 25 and 26.

Simple precalcinations

In some cases it is more advantageous to increase the kiln outputs less, e.g., by 10%-15%, only, because the capacity of the other equipment would not allow any larger increase, or, in such a case, it may not be useful to make extensive reconstructions including clinker coolers, conveyance of cliner, heat exchanger etc. In such a case the combustion air requried for the firing in the precalcining chamber can be additionally heated at a suitable point directly in the heat exchanger, or at some point of the flue duct between the kiln and the heat exchanger.

Raw materials suitable for the dry-process production in kilns with dispersion heat exchangers

During the preparation of technology for the dry-process production, an increased attention is to be paid to the overall contents of alkalis, sulphides, sulphates and chlorides, both in the raw material and in the fuel.

There is a standing requirement that the content of alkalis (R_2O) in the raw material should not exceed 1.5%. The content of chlorides (in terms of Cl) should be 0.04% maximum and sulphur content from the raw material as well as from the fuel calculated to SO_3 should be 1% maximum.

Dispersion heat exchangers are unsuitable for raw materials with an increased content of alkalis. Alkalis cause sticking of material both in flues and in the heat exchangers, particularly when combined with sulphates and chlorides. Therefore serious breakdowns and even stoppages of kilns happen quite often.

Table 24. Comparison of dry rotary kilns with dispersion heat exchangers and flash-calciner system

Characteristic	MFC	SF	RSP	KSV	FLS
Specific heat consumption (kcal/kg)	750	750	750	750	760
(kJ/kg)	3 140	3 140	3 140	3 140	3 180
Output of the kiln (t/d)	7 200	7 700	3 100	8 500	4 150
Specific daily output of the kiln (t/m^3)	3.9	3.8	5.2	3.2	3.7
Temperature of gases after kiln (°C)	1 150	1 030	1 050	1 100	1 100
after exchanger (°C)	390	340	260	340	380
Temperature of raw meal into the kiln (°C)	850	830	830	860	870
Temperature of gases after calcining chamber (°C)	860	880	830	860	870
Percentage of apparent dissociation (%)	90	93	88	91	90
Temperature of secondary air (°C)	800	800	680	950	800
Amount of fuel into the calciner (%)	59	62	60	55	57
Number of calciners	2	2	1	2	1
Calciner diameter (m)	8.0	7.4	3.6	6.8	7.1
Type of heat exchanger	four-stage cyclone type				
Speed of the kiln (rev/min)	3.0	3.0	2.7	2.0	2.3
Inclination of the kiln (degrees)	4.0	4.0	4.0	4.5	4.5
Kiln dimensions diameter x length (m)	5.4 x 95	5.5 x 100	3.45/3.75 x 75	6.2 x 105	4.75 x 75
Ratio of length to inner diameter	19.4	20.4	23.4	18.4	17.6

Note: RSP = Reinforced Suspension Preheater
MFC = Mitsubishi Fluidized Calciner
KSV = Kawasaki Spouted Bed and Vortex Chamber
FLS = Dispersion Heat Exchanger
SF = Suspension Flash Process

Table 25. Summary of maximum output achieved by preheating and precalcinating systems

Type of system	Maximum output achieved (also kilns under construction) (t/d)
SF	7 700
NSC	7 200
Mitsubishi Fluidized Calciner Prepol C	
RSP Reinforced Suspension Preheater	5 200
KSV Kawasaki Spouted Bed and Vortex Chamber	2 500
NKSV New KSV	4 500
DD Dual Combustion and Denitration Calciner	4 000
FLS	4 300
GG	4 400
S	4 500
H	
U	
Pyroclon	3 200
Prepol B	4 200
Prepol AT	
Prepol AS	700

Table 26. Comparison of the two precalcination systems

Characteristic	Single precalcination	Complete precalcination
Calcination chamber	Burners are installed in the adjusted flue duct or in the bottom part of the heat exchanger	Separate chamber with burners with combustion air intake
Combustion tarciary air	led directly through the rotary kiln (so called superfluous air)	Led through a separate piping from the clinker cooler (from another source only exceptionally)
Fuel proportion in the precalcination (%)	30 to 50	45 to 65
Degree of decarbonization of raw material, (%)	60 to 75	70 to 90
Usability up to the output of: t/day	5 000	10 000
Technical feasibility	Simple	Complicated
Usability of coolers	All types	Except satellite ones

It is also necessary to be careful when raw materials from arid areas are used. They usually contain a considerably higher proportion of soluble alkalic salts (chlorides, carbonates, sulphates). This applies particularly to Middle East and Near East countries - Egypt, Iran, Kuwait, Saudi Arabia and to Argentina.

Reaction of alkaline salts with reactive aggregate in concrete

It would be certainly incorrect to think of the effects of alkalis only from the point of view of the problem of mud-ring formation in kilns. It is also necessary to notice the influence of alkali salts on the quality of cement, particularly of concrete. This interest, however, is directly related to the rotary kilns and their dust-separating system. More sophisticated firing systems provided with perfectly working electrostatic dust separators, from which the dust is returned into the kilns, produce clinker with double content of alkalis when compared with the former "wet" kilns, which were not equipped with a proper dust-separating system, and thus enabled the alkaline salts to escape into the open air.

The harmful effects of alkaline salts in concrete with the presence of reactive aggregate was noted, and later on even studied, in the concrete of the Buck Dam body built on the New River in Virginia. The investigations made in 1922, i.e., 10 years after the dam had been completed, showed that the concrete affected by alkali-aggrogate expansion developed typical random pattern-cracking at the surface.

Professor R.J. Holden concluded this case in 1935 by a petrographic study and proved that the reaction of cement components with the aggregate had been the cause of the cracks.

At about the same time cracks in concrete were found on other significant structures in the United States. For instance, the bridge on the river Santa Clara (construction in 1914-1915), the bridge in King City (California) (construction in 1919-1920) and others.

Only the serious cracks that occurred in the concrete dams of significant works, such as the Parker Dam, Gene Wash Dam, and Copper Basin Dam in Colorado, necessitated a detailed investigation.

T. E. Stanton published two essential works on this subject in 1940. They evoked extraordinary attention all over the world, but particularly in the United States. Suitable methods were elaborated to determine alkaline content in active aggregates, and extensive research was made first in the United States and subsequently in other coutnries. (See the ASTM Standards: C 289 - 64 test for potential reactivity of aggregates (chemical method) and C 227 - 64 test for potential alkali reactivity of cement aggregate combination (Mortar bar method).

Alkali reactivity of aggregates can cause deterioration of concrete containing high alkali cement through production of alkalic silica gels, which subsequently absorb water osmotically from the cement paste, developing hydrostatic pressures in excess of the tensile strength of the concrete.

The minerals opal, chalcedony, tridymite, cristobalite and heulandite, zeolites rocks such as glassy or crypto-crystaliine rhyolites, dacites and andesites (and their tuffs), opaline and chalcedonic cherts are deleteriously reactive with cement alkalis.

It became apparent that alkaline-active aggregates occur in at least 14 states of the United States. Similarly active rocks were found in Australia, Brazil (construction of Jupia Dam), Denmark, India, the Netherlands, New Zealand, Scandinavia and in many other countries. The only exception was the United Kingdom.

The studies also proved that the alkali content, i.e., the total of $K_2O\%$ and $Na_2O\%$ in Portland cement converted on the basis of $Na_2O\%$ (i.e., $\% Na_2O + \% K_2O \times 0.659$), would not cause any harmful expansion in the concrete due to the reaction with the reactive aggregate, as long as it would not exceed 0.4%. According to the Bureau of Reclamation, the limit of 0.6% content of Na_2O is still acceptable. These cements are called low-alkali cements, and they can be used in the construction of dams in the United States. Admixtures of some pozzolanas or fly ashes from the electrostatic dust separators used in the cement may also have a stabilizing effect. It is quite understandable that the United States and some other countries hesitated to start with the construction of rotary kilns for the dry production process with dispersion heat exchanger. Clinker produced in these kilns contains more $K_2O + Na_2O$ than that produced in the formerly used wet-process rotary kilns without returnable dust particles from the separators. Besides, there are fears of possible formation of mud rings and build-ups which might hamper the firing process.

Circulation of alkalis in a rotary kiln

Alkalis, chlorides and sulphates are contained in the raw material mix, in fuels and partly even in the dust particles from the separators (as far as the latter are returned into the kiln). They volatilize at the temperature above 800°C, and particularly in the sintering zone, and proceed along with the flue gases towards the end of the kiln, where they come into contact with the raw material mix. The temperature of the raw material mix is lower by 250°C than that of the flue gases. Besides, there are also the effects of the flue gases particularly due to the contents of SO_2 and SO_3, resulting in the formation of alkaline sulphates and calcium sulphate.

Smelted salts cause the particles of the raw material mix to stick together and partly share in making mud rings in the flue ducts and in cyclones of the heat exchangers; the greater part of them proceed with the raw material mix into the sintering zone, where they volatilize again and return into the bottom part of the heat exchanger.

The concentration of alkaline salts in the kiln may be balanced to some extent by discharging them along with the clinker. As soon as, however, the alkali content in the raw material exceeds certain limits, it results in so heavy a concentration of alkalis in the cycle that it may cause serious problems in the production, and often even choking of the flue ducts, or of some parts of the heat exchanger with sticking raw material.

By-pass system

To prevent the problems caused by the formation of excessive mud rings, and to reduce the alkali content in clinker, additional devices have been designed - these may be described as alkali "valves". Basically, it is a by-passing of a portion of the flue gases from the kiln, cooling them down by an additional intake of cold air and injection of water, whereby the gases are cooled down below 300°C temperature. The gases are subsequently dedusted. Thereby the alkali content is kept low in the kiln inner-operation cycle. Gases freed from alkaline dust are then led either to the upper part of the heat exchanger or let out into the open air.

The three most well-known design versions of this by-pass system are shown in figures 16, 17 and 18.

The quantity of gases led away through the by-pass amounts to 3%-10% of all the flue gases. It may reach, however, 25% maximum.

The by-pass system increases the heat consumption in the firing of clinker by 4 to 5 kcal per kg of clinker (17-21 $kJ.kg^{-1}$) per each 1% of flue gases volume. It also increases the electric power consumption by about 2 kWh per ton of clinker (regardless of the quantity of the flue gases). Also the investment costs are distinctly higher.

When the alkalis and chlorides volatility factor is known, such a by-pass can be designed to suit the particular heat exchanger and the raw material of a known composition to produce clinker of the required and acceptable content of alkalis.

Dispersion heat exchangers with precalcination

The advantages of dispersion heat exchangers with precalcination are:

(a) The proportion of fuel burnt in the calcining chamber amounts to as much as 60%, whereby the calcination degree is about 85%;

(b) Short start-up of the kiln and its putting into full operation (5-20 hours);

(c) Extended life of linings by 25%-30% due to the lower thermal load in the firing zone of the kiln and due to the relatively smaller kiln diameter;

(d) Easier transportation and erection of the rotary kilns for large units because the kilns can be substantially smaller than in case of classical kilns with heat exchangers;

(e) Even coal or other waste and low-grade fuels can be used for the additional heating in the heat exchanger, whereby high-grade fuels can be preserved;

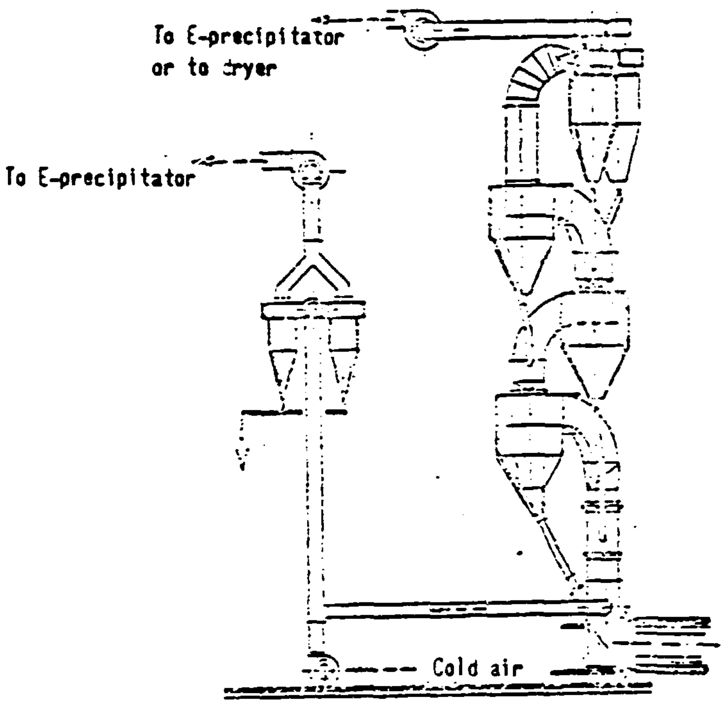


Figure 16. Pre-heater by-pass-system with cyclones for preliminary dust collection and separate E-precipitator for the by-pass gas

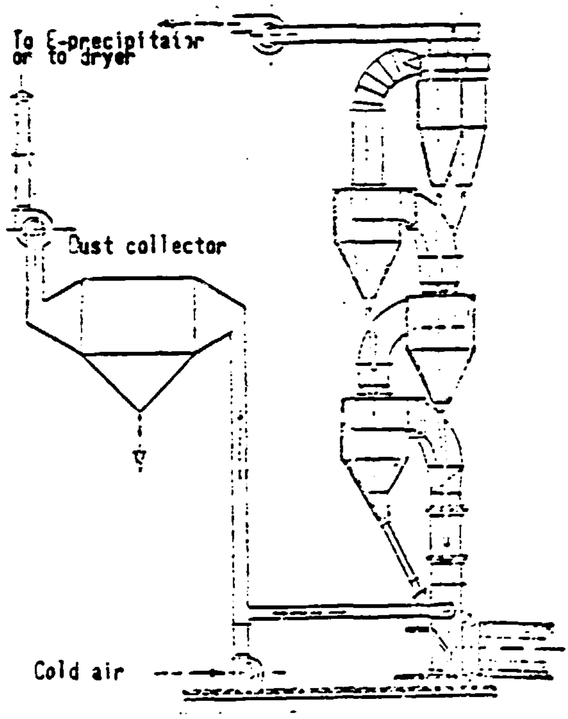


Figure 17. Pre-heater by-pass-system where the dust of the bypass gas is directly precipitated in a separate dust collector

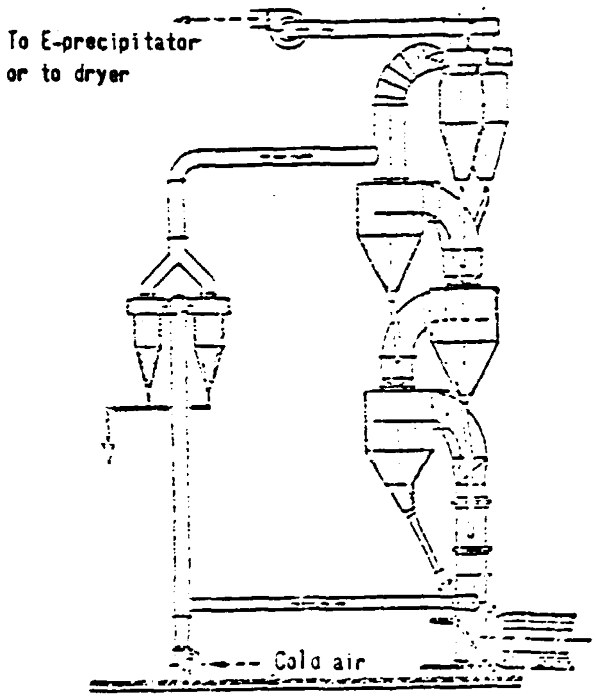


Figure 18. Pre-heater by-pass-system with diverting of the alkali dust and with feed-back line for the diverted gas into the main exit gas duct

(f) The construction area is by 25% smaller;

(g) Lower content of NO_x in flue gases, particularly at special combustion chambers (DD, GG) - a mere 150-300 ppm at 10% of O_2 is considered;

(h) The clinker grain size is usually finer;

(i) The heat consumption of the high-capacity lines above 3,000 t/day is about 730-790 kcal/kg of clinker, i.e., 3,056-3,308 $kJ.kg^{-1}$;

Disadvantages are:

(a) In case of some older types the heat consumption was slightly higher (by 0%-5%), while the consumption in the latest units is commensurable with the classical design without precalcination;

(b) Slightly higher consumption of electric power. It may be assessed by 1.5 KWh/t of clinker in average;

(c) Despite the fact that a rotary kiln is of smaller diameter for identical output, the system is more complicated and the economization can be seen at the kiln of more then 3,000 t/day output, and more distinctly with outputs exceeding 4,500 t/day.

Long dry-process rotary kilns

The long dry-process rotary kilns are those whose ratio of their inside diameter to their length is 1:30 or more. This ratio at modern kilns is 1:33 up to 1:38. These kilns were developed mainly in the United States because they were reliable, required few operators and minimum maintenance, and the electric power consumption for the kiln drive was 6-8 KWh/t of clinker, which was the lowest one of all the kiln units. Slightly higher heat consumption, when compared with the European kilns, was negligible until the outbreak of the energy crisis.

There were 314 of these kilns in operation in the United States in 1962/63, and they still produce 1/3 of clinker in the United States. These kilns in Europe and in other parts of the world can be found only rarely.

The long dry-process kilns were originally constructed without any inside or outside heat exchangers. Flue gases at the end of the kiln were 700°C and hotter, and they had to be cooled effectively, most often by water spraying, so they could be exhausted by an exhauster or dust-separated.

In the 1950s, however, we can generally deal with the systems of the inside heat exchangers. First there were systems of chains made of heat-resistant steel. Later there were tried ceramic cross-shaped internal heat exchangers in the calcinating zone, then even steel cross-shaped inner structures. The temperatures at the end of the kilns dropped to 430°-530°C, and the heat consumption in the kiln was reduced to 950-1,170 kcal/kg of clinker (3,977-4,900 $kJ.kg^{-1}$) according to the technical level of the design. When hot flue gases are used as a drying medium in the drum drier, as much as 13% of the moisture from the crushed raw material can be dried up.

A distinct progress has been made in the development of the long dry-process kilns by adding cyclone heat exchangers. Thereby not only partial dust removal from the flue gases was achieved, but the temperature of the flue gases was reduced, and the heat consumption was cut to as much as 850 kcal/kg of clinker (3,559 $kJ.kg^{-1}$).

The following combinations are used most often:

1. Long dry-process kiln with two cyclone heat exchangers installed parallel (i.e., single-stage heat exchange).
2. Long dry-process kiln with one heat exchanger in the first stage, and with two other smaller heat exchangers in the second stage.
3. Two-stage heat exchanger, consisting of an outside brick-lined cyclone heat exchanger and one inside cyclone heat exchanger.

All of these arrangements are attractive in view of the reconstruction of the long wet-process rotary kilns into long dry-process kilns.

The long dry-process kilns have been constructed for a maximum output of 3,000 t/day. Since the heat exchange in the long kiln is very ineffective, the specific output is low, too, and the dimensions of these kilns are gigantic. From the designing point of view the long dry-process kilns may be of as much as 5,000 t/day capacity. The dimensions of the jacket of such a kiln have been calculated as follows: length 260 m, diameter 7.5 m. Therefore, its investment cost is 45% higher than that of a short kiln with the dispersion countercurrent heat exchanger.

As far as the production reliability is concerned, the long dry-process kilns are less sensitive to sticking of material due to alkalic salts, and they have low resistance that results in lower electric power consumption of the kiln fan.

In some cases it is more advantageous to increase the kiln output a little less, e.g., by 10%-15%, because the capacity of the other equipment does not permit any larger increase. It may not be advantageous in the particular case to make large scale reconstructions, including clinker coolers, clinker transportation, heat exchanger etc, evoked by a large increase in the kiln output. In such a case the combustion air can be led through the kiln and make additional heating at a suitable spot in a heat exchanger directly, or in another suitable spot of the flue duct.

VII. ENERGY CONSUMPTION AND CONSERVATION

About 85-135 kWh of electrical energy and 800-2,000 kcal of thermal energy are consumed for the production of 1 ton of cement. The energy consumption depends not only on specific conditions prevailing in each factory, but also on the choice of a suitable technological equipment and proper technology, on the technical condition of the equipment, and on its professional maintenance and its correct operation.

Fuel savings

Possible fuel savings may be classified into three groups:

(a) Savings in the existing equipment by its correct operating and maintenance;

(b) Savings in the equipment by its suitable reconstruction;

(c) Savings achieved by the construction of an entirely new, up-to-date plant and closing of the obsolete and uneconomical cement factories.

It is quite obvious that steps mentioned under (b) and particularly under (c) would require considerably high investment costs. Realization of the intended investments is a time-consuming matter because it depends on too many circumstances.

Thermal energy saving in a rotary kiln

From the fuel consumption point of view, it is suitable to divide the technological method into dry process wet process methods of production. Characteristic indices of rotary kilns applied for different production methods are indicated in Tables 27, 28 and 29.

When an analysis is made of a large number of plants operating with dry process and wet process production, the following average internal division of fuel consumption will be obtained:

Table 27. Comparison of wet-process rotary kilns

Characteristic		Unit	Shorty rotary kiln	Long rotary kilns with a chain zone			Rigby System Injection of slurry into the chain zone		Kiln with a concentrator (preheater)
Specific heat consumption		kcal/kg	3 100	1 375	1 228	1 180	1 220-1 600	1 236	1 220-1 730
		kJ/kg	12 980	5 760	5 141	4 940	5 108-6 700	5 175	5 108-7 243
Kiln output		t/d	24	737	1 560	568	100-800	700	125-1 000
Specific daily kiln output per unit of inner volume (t/m³)			0.72	0.74	0.58	0.48	0.63-1.00	0.99	0.63-0.89
Moisture content of raw material		%	35	40	30	37.5	34-40	32	34-40
fed into the kiln		%	35	40	30	37.5	34-40	32	8-12
Gas temperature	behind the kiln	°C	800	212	290	130	500-765	233	500-750
	behind the heat exchanger	°C	-	-	-	-	100-185	-	100-185
Temperature of raw material entering the kiln		°C	40	40	40	40	90	40	90
Ratio of length to inside diameter			12	41	43	40	25	24	18 to 25
Electrical energy required per unit of output		(kWh/t)		11	8	11	14	14	18-10
Fuel		-	oil	coal	residual oil	coal	solid, liquid, gaseous	coal	solid, liquid, gaseous
Cooler		-	without cooler	Fuller	satellite one	Folax	various designs	drum one	various designs
Kiln dimensions, diameter x length (m)			1.82 x 18.2	3.8/3.2/ 3.8 x 132.5	4.65/4.15/ 4.6 5x 175	4.0/3.6 x 135	-	3.75 x [illegible]	-
Year		-	1896	1968	1957	1957	-	1957	-

Table 28. Characteristic indices of dry-process rotary kilns

			Dry-process kiln			
				Long with inside structure		With a boiler for waste heat
	Units	Short	Short		With a cyclone	
Specific heat consumption	kcal/kg kJ.kg^{-1}	2 200 9 211	2 000 8 374	950 3 977	850 3 559	1 500-1 850[a] 6 280-7 746
Kiln output in tons of clinker per day	t/d	35	150	630	1 000	80-3 300
Specific kiln output in metric tons of clinker production a day in 1 m^3 of inside space	t/m^3/day	1.02	0.868	0.6	0.7	0.80-1.32
Moisture content of supplied raw material	%	0.5	0.5	0.5	0.5	0.5
Raw material to the kiln	%	0.5	0.5	0.5	0.5	0.5
Gas temperature: behind the kiln	°C	950	650	450	400	700-1 000
Behind the heat exchanger	°C	-	-	-	-	180
Raw material temperature when entering the kiln	°C	40	40	40	40	40
Degree of apparent dissociation of raw material entering the kiln	%	-	-	-	-	-
Ratio of length to inside diameter of the kiln L : iD	m/m	12 : 1	21 : 1	44 : 1	38 : 1	17 : 1 to 25 : 1
Electric power consumption in the entire thermal unit in the production of 1 t of clinker	kWh/t		10	8	7	12-15
Kiln dimensions D x L (diam. x length)	m x m	18.2x1.82	2.5x45.7	3.75/3.45/ /3.75x144	-	various
Year	-	1887	1903	1963	1973	1930-1980

a/ Of this 500 to 700 kcal/kg will be utilized for generating electric power.

Table 29. Characteristic indices of semi-dry and semi-wet rotary kilns and sintering grate

	Units	Long rotary kiln for nodules with inside structure	Lepol kiln leading of gases			Kilns with calcinators for wett powder	Krupp-Lurgi sintering grate
			simple	double	3 chambers		
Specific heat consumption	kcal/kg kJ.kg^{-1}	1 180 4 940	1 050 4 400	850 3 560	760 3 180	1 100-1 200 4 605-5 024	1 240 5 192
Kiln output	t/d	338	250	400	1 920	100-1 000	340
Specific kiln output in metric tons of clinker production a day in 1 m^3 of inside space	t/m^3/day	0.58	1.62	2.09	1.41	0.8-1.1	15 t/m^2 of grate/d
Moisture content in the supplied raw material	%	13	14	14	13	12-15	14
Gas temperature – behind the kiln	°C	250	900-950	1 000-1 100	1 120	700	240
Gas temperature – behind the heat exchanger	°C	-	120	90	120	240-400	-
Raw material temperature when entering the rotary kiln	°C	(nodules) 20	760	800	850	250	20
Degree of apparent dissociation of raw material	%	-	40	45	45	-	-
Ratio of length to the inside diameter of the kiln l : iD	m/m	28 : 1	15 : 1	14 : 1	17 : 1	20 : 1	-
Electric power consumption of the entire thermal unit for the clinker production	kWh/t	9	9	13	17	18-19	25-30
Fuel	-	coal	oil	oil	heavy oil	various	coke
Type of cooler	-	satellite	drum	grate	grate	various designs	-
Kiln dimensions D x L	m x m	3.4 x 85	2.8/2.6/x 36	3 x 36	4.7 x 75	-	26 m^2
Dimensions of the calcination grate w:l	m x m	-	2.42 x 12.5	3 x 12.5	4.76 x 37.5	-	-
Year and country	-	1958 Yugoslavia	1954 Jordan	1963 Jordan	1966 Japan	- FRG	1952 FRG
Manufacturer		Miag, FRG	Polysius, FRG	Polysius, FRG	Kawasaki Japan	Miag, Krupp FRG	Krupp, Lurgi FRG

	Production method	
	Dry process	Wet process
Heat consumption in the rotary kiln operation (including accessory equipment)	83%	96%
Raw material drying	14%	-
Drying of coal (if it has been used as technological fuel)	3%	4%
	100%	100%

It ensues from the above-mentioned figures that the first possible saving of thermal energy in the dry process method can be achieved by using the waste heat for the drying of raw materials without the use of an auxiliary combustion chamber. This possibility appears particularly at kilns with dispersion heat exchangers where hot gases of 350°C are available. Hence, at least 120 kcal/kg (502 $kJ.kg^{-1}$) can be utilized for the drying of raw material, as far as the drying mill or drier are in operation at the same time. Otherwise, these flue gases would have to be let out into the open air without utilizing their heat. A similar situation is at the long dry process rotary kilns. When the correct drying scheme has been implemented, raw material can be dried by flue gases.

In some cement factories producing mixed cements, even slag can be dried by flue gases. The heat of the waste gases from the grate cooler can be properly utilized for the drying. Use of the waste gases depends on the specific conditions of a factory. They can be used for technological purposes (drying of raw material, slag, coal, partly as preheated primary air etc), or in countries with cold climates these dust-separated gases from the grate coolers are led to the heat exchanger for hot water, which is then used for heating in buildings. About 40-50 kcal/kg of clinker (167-209 $kJ.kg^{-1}$) are available for these purposes.

Selection of suitable fuels

Rotary kilns, being the principal part of a cement factory, can be fired either with gaseous, liquid or solid fuels. Gaseous and liquid fuels do not usually need special preparation. When coal is used, however, it must be properly stored, mixed, dried, ground and dosed accurately to ensure a high degree of burning stability. Oil must be duly preheated (to 2° Engler viscosity) so that the oil can be perfectly atomized and, hence, perfectly burnt. Fuels used in rotary kilns must develop a temperature as high as 1,350-1,450°C of the baked material in the firing zone to enable the formation of clinker. The clinkering process is completed when lime has been converted into silicates, aluminates and aluminoferrates. The clinker then proceeds to the cooling zone of the kiln and down to the cooler. The heated air from the cooler is led back to the kiln as secondary air to support complete burning of fuel. The more carefully the erection of a rotary kiln is made, the less power is required for its drive. The rotary kiln shell must be perfectly round and fitted to increase the kiln lining life and kiln stability, and to minimize losses in power drive due to an inappropriate resistance. When due care is paid to the erection, less refractory material can be consumed for repairs, which results in less idle time of the kiln and prevents wasting of energy in kiln stoppage and start-up.

By analysing the remarkable world-wide development, a considerable growth in capacity can be noted. The size of kilns and heat exchangers is limited by the fact that the life of the kiln lining rapidly decreases as the diameter of kilns is increased. Some manufacturers solve this problem by pre-calcination, and it may be said that the way into the most intensive process in cement technology has thus been paved. A temperature of 900°C required for it can be achieved by using even low-grade fuels. It also enables utilizing the waste heat from the cooler.

In principle, good kilns have been built with a specific heat requirement ranging from 3,180 kJ to 3,260 kJ per kg of clinker at the daily production capacities from 2,000 to 8,000 metric tons. In terms of specific fuel consumption it may be expressed in 142.6 kg per ton of cement. When optimum conditions are created to achieve about 60% thermal efficiency, the value of specific heat consumption may be reduced to 2,930 kJ per kg of clinker.

Comparisons of heat consumption in using different fuels are shown in tables 30 and 31.

Great attention should be paid to the coal quality and composition, as well as to its preparation. Coal used for the firing of clinker should be of uniform quality. Its calorific value should exceed 6,000 kcal/kg of dried coal (25,000 $kJ.kg^{-1}$). The lower limit of the calorific value should be 5,000 kcal/kg of coal (21,000 $kJ.kg^{-1}$). As the coal calorific value decreases the kiln output also drops quickly, and the specific heat consumption increases, and the clinker quality gets deteriorated due to the excess quantity of ash. Even ash rings may occur.

The content of volatile matter should usually be determined daily, as soon as the coal has been supplied. Optimal content of the volatile matter is 18%-25%. It pays to ensure this content by blending two or even three sorts of coal.

Coal containing too much volatile matter has too high a flame but gives less heat. Such coal also starts burning very near to the burners. However, coal containing little volatile matter burns with a very short, concentrated flame, burning too far from the burners. Such a discrepancy can be improved to some extent by finer milling of coal.

Coal should not be dried excessively because it is difficult to light it. In the case of black coal, it is always suitable to leave about 1%-1.5% of moisture in it.

Fineness of coal: It is recommended to mill coal to the grain size of 12%-16% rest on 0.085 mm (85 microns) sieve. To assess it approximately the following formula may be useful: % of residue on 0.085 mm sieve = 0.6 times % of volatile matter.

Table 30. Additional heat consumption for clinker burning in preheater kilns using fuel oil versus coal

Rotary kiln capacity (t/)	Heat consumption when using coal (kJ/kg)	Heat consumption when using fuel oil (kJ/kg)
180	4.187	4.396
250	3.559	3.894
380	3.768	3.978
1 500	3.496	3.559[a]

[a] Mixed firing of fuel oil and coal.

Table 31. Additional heat consumption for clinker burning in preheater kilns when using natural gas versus fuel oil

Rotary kiln capacity (t/d)	Heat consumption when using fuel oil (kJ/kg)	Heat consumption when using natural gas (kJ/kg)
400	3.475	3.768
810	3.768	3.936
1 600	3.433	3.559
1 600	3.140	3.496[a]
3 500	3.098	3.266

[a] In this case, when switching to natural gas the kiln capacity dropped from 1,600 to 1,500 t/d.

A perfect combustion is one of the important requirements for an optimal technological process. When combustion is imperfect carbon monoxide is developed, and about 30%-35% of calorific value only is utilized. Excess air during the combustion process should range from about 3.7% to 17%, i.e., in terms of oxygen from 0.77% to 3.56% of O_2 in the flue gases. However, at a well-adjusted kiln the value should be moved around 1.5% of O_2.

The majority of new kilns are provided with an electrostatic dust separator. To prevent explosions the carbon monoxide content must be checked. When the CO content exceeds 0.4% a danger warning is signalled, and the filter should be switched off. Therefore, it is desirable to increase the O_2 content in the gases behind the kiln by 1%, and the CO content is to be kept at 0.0%-0.1% value.

It is also important to avoid all leakages which may cause penetration of excess air into the kiln, because this results in imperfect combustion and mal-functioning of the cooler as a heat recuperator, which indirectly increases fuel consumption. When the penetration of excess air is reduced by 1% only, about 42,134 kJ per ton of clinker in wet process and 34,269 kJ per ton of clinker in dry process can be saved.

Following the foregoing analysis, different approaches towards a significant reduction in fuel consumption are as follows:

(a) Reducing the heat losses due to radiation - these losses may amount to as much as 10%-25% of the total heat consumption. Such a reduction can be achieved by suing an insulation course of fire-bricks of high alumina content. One inexpensive way to reduce radiation is to keep a constant layer of clinker on the kiln lining in the firing zone. Lately, it has been possible to use an insulation layer of 2-3 mm thick paper made of high purity alumina and silica fibres between the kiln shell and the refractory lining;

(b) Reducing the kiln cooling fan temperature by installing inner heat exchanging equipment, such as filters and chains. Particular attention is to be paid to the chain zone. The trying of the best chain zone takes several years. The chain zone supports not only water evaporation from the slurry but also the transportation of raw material and removal of slurry rings. It decreases the dustiness and reduces the temperature of the flue gases, whereby it enhances the output and decreases the specific heat consumption. Therefore, it is necessary to determine the optimal length of the chain zone for every kiln, density of the chains in the individual sections, weight of the chains and method of their suspension. In case there is no sufficiently experienced expert available in the factory, it is advisable to request an engineering company or an expert to do this engineering job;

(c) Reducing the slurry moisture in case of the wet process from 35% down to 30%. This way about 336,948 kJ per ton of clinker can be saved. This saving can be achieved only in compliance with the adjustments of the other inside structures in the kiln, particularly chains, otherwise a portion of the preserved heat would be lost by the flue gases of an increased temperature. The moisture can be reduced by substituting flue ash for clay, or by using deflocculants (ligninsulphonates, tripolyphosphates, silicates, carbonates etc.) or mechanical devices.

It is to be noted that whatever steps are made towards the optimal use of a technological process, under the present condition of technical progress no radical reduction in fuel consumption can be achieved. Nevertheless, such steps as a whole may contribute considerably to the reduction.

Other measures in heat energy conservation

It is obvious that the firing affects most significantly the specific energy consumption value. Therefore, the energy rationalization in this section is being implemented in a broader context with the aim to reduce the specific energy consumption, not only by an absolute reduction in fuels consumption, but also by an increase in the efficiency of the calorific value of fuels.

The following steps are recommended for the cement industry to meet the present requirements of heat conservation:

(a) New construction of dry process or semi-dry process kilns only;

(b) Automatic process control;

(c) If possible, the cement factory should choose the most reactive raw materials. Reduction in silica modulus and alumina modulus, as well as in the lime saturation factor, always results in a decreased fuel consumption. Nevertheless, the lime saturation factor cannot be reduced due to the quality reasons, and the other moduli must be kept within certain narrow limits, too.

(d) Copper slag - when 2%-3% of copper slag is added as a mineralizing agent, the heat saving may amount to as much as 3,945 kJ against the former 4,209 kJ per kg of clinker.

(e) Reducing moisture content in the raw material (deflocculants);

(f) Improving the coefficient of heat exchange at the wet-process kiln inlet;

(g) Utilization of hot flue gases either by improving the inside structures (particularly the chain zone and heat exchangers) or by installing outside heat exchangers;

(h) Reducing hot gases in the cooler (recuperation of a part of the outlet air for raw material drying, utilization of heat from the cooler for heating [illegible] the primary air or fuel or for municipal heating, industrial or agricultural use);

(i) Modification of linings to improve the kiln insulation;

(j) Utilization of solid fuel (coal);

(k) Prevention to kiln stoppages due to breakdowns on mechanical and electric equipment or for technological reasons;

(l) Optimal use of the firing process.

Reconstructions connected with change of the production method

Examples of plant reconstructions aiming at the reduction in heat consumption and an increase in output at the same time:

Reconstruction of wet-process cement factories

	Before reconstruction	After reconstruction
Example I		
Country	Switzerland	
Production method	wet process	semi-wet process
Kiln DxL (m)	2.8 times 124	2.8 times 124 + cyclone, two-stage heat exchanger
Heat consumption		
kJ.kg^{-1}	6,175	4,100 to 4,200
kcal/kg	1,475	980 to 1,000
Output t/d	300	550
Moisture content in raw material %	32 to 44	15 to 22
Measures taken		filtration + two-stage heat exchanger

	Before reconstruction	After reconstruction
Example II		
Country	Japan	
Production method	wet process	dry process
Kiln DxL (m)	3.3 times 150	3.3 time 150 + Polysius heat exchanger
Output t/d	1,400	2,025
Specific heat Consumption		
kJ.kg^{-1}	5,443	4,379
kcal/kg	1,300	1,046
Measure taken		additional installation of the heat exchanger and reconstruction of raw material preparation plant into dry-process one

Example III	Before reconstruction	After reconstruction
Country	Japan	
Production method	wet process	dry process
Kiln D (m)	5.2/4.9/5.3	5.2/4.9
L (m)	187.5	94.5 + Polysius heat exchanger
Output t/d	1,800	2,800
Specific heat consumption $kJ.kg^{-1}$	5,443	3,224
kcal/kg	1,300	770
Measures taken		shortening of the kiln, addition of heat exchanger, reconstruction of raw material preparation plant into dry-process one

Example IV		
Country	Japan	
Production method	wet process	semi-wet process
Kiln D x L (m)	3 x 4 x 60	3 x 4 x 50 + Lepol grate
Output t/d	312	540
Specific heat consumption $kJ.kg^{-1}$	7,955	3,978
kcal/kg	1,900	950
Measures taken		shortening of kilns, installation of Lepol grate, satellite cooler have been reconstructed into grate coolers, vacuum filtration added, filtered cake mixed with raw material powder inl:1 ratio supplied from a new plant and granulation

Example V	Before reconstruction	After reconstruction
Country	Greece	
Production method	wet process	dry process
Kiln output t/d	2 kilns: 750 each	1 kiln 1,500 + KHD heat exchanger Wedag
Specific heat consumption		
kJ.kg^{-1}	5,850	3,260
kcal/kg	1,400	780
Measures taken		removal of 2 wet-process kilns and construction of a new one for dry-process production, reconstruction of the raw material portion to dry-process method

The above examples show clearly enough that there is no uniform recommendation on how to reconstruct the wet-process plants with the aim of reducing the heat consumption. The choice of an optimal alternative of the reconstruction must come from the specific conditions prevailing in a particular plant.

Other examples of reconstructions

Before reconstruction		Measures taken	After reconstruction	
Rotary kiln	Specific heat consumption		Specific heat consumption	% of increased output
Wet process	kJ.kg^{-1} 6,700 kcal/kg	Additional construction of a concentrator	kJ.kg^{-1} 5,234 kcal/kg 1,250	25
Wet process	kJ.kg^{-1} 5,862 kcal/kg 1,400	Additional construction of dust spray drier	kJ.kg^{-1} 5,158 kcal/kg 1,230	30

Dry process with a boiler for waste heat	kJ.kg^{-1} 7,536 kcal/kg 1,800 in the kiln proper	Additional construction of a heat exchanger and removal of the waste heat boiler	kJ.kg^{-1} 4,019 kcal/kg 960	60

Energy conservation in the field of electric power consumption

The electric energy represents less than 20% of the total energy required in the cement production, but it is mostly more expensive than the fossil energy. It is necessary to realize that it is generated from thermal energy in thermal power stations (except hydro power stations and nuclear power stations), and there are considerable losses in its generation.

Thermal energy required for the firing of clinker stands first in energy consumption, while the electric power required, being slightly less, is in second place, and its maximum consumption lies in crushing and grinding of raw materials, coal and clinker into cement.

Basic factors in electric power savings are as follows:

(a) Smooth and uniform operation;

(b) Reducing stoppages and idle runs;

(c) Keeping to the prescribed technology and operation rules;

(d) Correct compensation of power factors and optimal gearing;

(e) Correct calculation of drive;

(f) Skilled maintenance;

(g) Choice of optimal technology;

(h) Elaboration of standards of consumption and evaluation of results.

The most demanding process is the grinding of raw material and clinker. These processes represent about 60-75% of total electric power consumption in a cement factory.

Electric power consumption in grinding process

Ball mill designs at present have almost exhausted all their possibilities, and it is the roller mill which now offers an interesting alternative to grinding raw materials and consuming half of the electric power when compared with the ball mill. The roller mill allows quicker withdrawal of raw material from its milling path, whereby excessive milling can be avoided to some extent. The roller mill can be fed with a larger batch than the ball mill so that no power is consumed in terciary grinding. Only fans require a little more power.

Power saving at the roller mill, as against the ball mill, amounts to 6 kWh per ton of clinker. In case of coal milling the roller mill power consumption is 5.5-8.2 kWh, whereas the ball mill power consumption amount to 15.5-20.8 kWh.

The following table 32 shows the comparison of power consumption in the milling of raw material (12% residue on the 90 mm mesh sieve).

The above-mentioned advantages, however, apply only to soft and medium-hard limestones and marls. When hard and very hard limestones are ground the results are quite opposite, because the output of the

Table 32. Comparison of energy consumption - raw material grinding (Raw material grinding - 12% sieve residue on 90 mm mesh sieve) (in kWh)

	Initial crushing	Grinding	Fans and auxiliary equipment	Total
	kWh	kWh	kWh	kWh
Ball mill with pneumatic withdrawal	0.4	15.9	4.4	20.7
Ball mill double rotating	0.4	12.8	5.3	18.5
Single chamber mill with bucket elevator	0.4	12.8	5.0	18.2
Roller mill		7.6	7.0	14.6

mill drops particularly in case of fine grinding. It is, therefore, necessary to subject the raw materials to grinding ability tests before the final decision on what type of grinding equipment is to be used.

Energy conservation in the process of grinding clinker

1. Experiments have proved that more porous clinker is easier to be ground. It is, therefore, necessary to determine the litre weight of the clinker and to prevent the clinker from an excessive firing. While the litre weight of the clinker is being determined, due attention is also to be paid to the content of free lime in it and its compressive strength. Optimization of the litre weight of the clinker always results not only in the saving of electric power in the grinding process but in fuel savings, too.

2. Dependence of grindability on the mineralogical composition of clinker; brittleness of grains in clinker depends on the ratio of C_3S (alite), C_2S (balite) and C_4AF in clinker. If an optimal ratio, stable kiln operation and optimal cooling process are achieved, it may result in 10% energy saving in clinker grinding. This finding, however, is of academic significance only, because when the proportions of minerals in the clinker are changed the cement properties are changed, too. It is possible, however, to pay due care to these findings within certain narrow limits.

Grindability can be increased by a higher content of free lime, whereas when MgO content is higher than 2% the grindability is decreased. This finding, however, may be applied only partially in a cement factory. The content of free lime in a clinker manufactured by wet process should not exceed 0.5%, and in case of dry process 1%.

Grindability can be improved by increased content of C_3S while C_2S is decreased.

When hot clinker is supplied for grinding it does not reduce grindability, but the grinding process output is decreased by electrostatic charge.

Sometimes, due to commercial reasons, cements of excessive fineness are produced. For instance, when cement fineness is increased from 3,100 to 5,000, according to Blaine, it results in increased energy consumption by 200%, while the ISO mortar strength after 28 days is increased by a mere 130%, strength of concrete by 110% within the same period, when cement 3,100 g/cm^2 is taken as a basis of 100%, according to Blaine. Very fine cements are required for special purposes only when high initial strength is required (1 to 3 days).

3. The largest power saving in the grinding process can be achieved when the grinding machinery is correctly operated. It is quite currently known that an experienced specialist may save as much as 15% of electric power on the grinding machine which has been amended after years of unskilled handling. It is necessary to notice the following factors which can increase the output of the grinding machine and reduce the specific energy consumption:

(a) Grain size of the material to be ground - coarsely ground material, most often due to broken grate bars in the crusher, reduces the grinding machine output, particularly the operation of the first chamber.

It is advisable to grind clinker after it is well seasoned; that itself may increase the grindability by as much as 10%;

(b) The length of the grinding machine cannot be changed in a cement factory, but the number and length of chambers can be changed by shifting the partition walls. Such a modification may be made only after a prolonged watching of the grinding machine operation, on the basis of grinding curves prepared according to sieve analyses of samples taken from the inside of the grinding machine;

(c) The quantity of grinding balls in the individual chambers (degree of filling) and their mutual proportion influence the fineness of the grinding as well as the output. The test results, including grindability tests, grinding machine output, fineness and granulometry of the entering material, must be carefully registered;

(d) The moisture content in the material to be ground is important. Slight wetting up to 2% of moisture content usually supports the grinding process, whereas a higher moisture content, to the contrary, reduces substantially the output of the grinding machine, or it may even cause its choking;

(e) The shape of the plates is very significant. Raising plates should be installed in the first chamber, while sorting plates are to be in the last one. They sort the big balls towards the inlet;

(f) The degree of filling with material to be ground is important and may be checked either by an electric sensor or by the operator himself (by listening to the grinding machine run);

(g) The slots of the partition walls must be kept clean and they should allow enough space;

(h) Grinding intensificators are successfully applied in many cement factories. They must be dosed accurately and uniformly into the grinding mill. They are suitable both for wet grinding of raw material and for grinding of cement. Their high cost prevents their general use. About 3%-12% of electric power can be saved. These matters must neither affect the cement quality adversely nor must they be poisonous;

(i) Correct ventilation of the grinding mill is one of the fundamental requirements of good grinding process and should be checked;

(j) The required fineness of the grinding (to achieve good quality cement or good firing of raw meterial) must be adhered to, but excessive grinding process always entails superfluous energy losses.

VIII. MAINTENANCE AND MEASUREMENTS

It is a well-proven experience in all factories that a sound maintenance programme always results in reduced energy consumption, increased production, extended life of equipment - particularly kilns - and sometimes in better quality of products.

Anyone can build a good kiln and use good insulating materials corresponding to the latest knowledge. But the energy conservation programme becomes more effective when a proper kiln and other equipment maintenance programmes are implemented.

Measuring excess oxygen or excess fuel in flue gases is the best method of determining air/fuel ratio in the combustion process. It really pays to use at least a portable oxygen analyser to monitor the kiln firing process. Such a measuring unit does not need any maintenance and can be used even under difficult working conditions.

If, however, a complete set of instruments for measurements, registration and evaluation of combustion processes can be used, for instance in a mobile unit, which is the latest trend in the world, and if this unit can be engaged in measurements and diagnostics for many plants successively, such a system may operatively detect many discrepancies in the firing process. Based upon such findings, remedial steps towards more economical and fuel-saving processes can be made.

Following proper diagnostics performed on the important production units, e.g., the firing process, efficiency can be increased by:

(a) Reducing the combustion heat down to a quasi-stoichiometric combustion;

(b) Increasing the combustion heat by preheating the combustion air.

IX. NOTE ON LIME

All types of lime-firing kilns can be met with nowadays in developing countries. In the vast rural areas situated far from any industrial centres, lime is fired in very primitive field and shaft kilns, which operate periodically and consume a rather high amount of heat. These kilns are built by the owners themselves. They fire lime without consuming any electric power, utilizing local fuel sources (wood, charcoal etc) which, provided that the forests are re-cultivated, would be restored again. These kilns are of low output, but there are a lot of them in operation. They exploit both large and small limestone deposits and supply local markets with minimum transportation costs. These kilns cannot be replaced in the foreseeable future. The latest shaft kilns or rotary kilns need relatively high investment costs, larger marketing possibilities and fuel transportation over long distances, in addition to a specially trained labour force and pure limestone deposits which are many times larger.

However, in the industrial centres of the developing countries a modern foundry and chemical industry can be found which consume a lot of lime of first-class standard quality. Therefore, modern kilns for the lime production may also be found there.

Shaft kilns for all sorts of fossil fuels, as well as rotary kilns, are built in highly industrially developed countries.

The enclosed tables, 33 and 34 show clearly the differences in kiln outputs as well as in the specific consumption of fuels.

The parallel flow regenerative shaft kilns are most economical from the specific heat consumption point of view. Lime is burnt soft, being thus particularly suitable for the building industry.

Lime burnt in long rotary kilns is also of a very good quality. The heat consumption of these kilns, however, is 2-2.5 times higher. Therefore, the rotary kilns, particularly in Europe, are provided with shaft heat exchangers (or grates) in which the heat of hot flue gases is used. The rotary kilns are particularly advantageous for burning even very small fractions of limestone which cannot be burnt in the shaft kilns. Hence, when the combination of shaft and rotary kilns is used, the limestone supplied from the quarry can be better utilized.

Limes intended to be used in foamed concrete are better to be burnt in shaft kilns of the Beckenbach system, in which coke or anthracite are fired, and the lime obtained is hard and overburnt to some extent.

There are also kilns with outside hearths for long-flame coal or producer gas firing.

When compared with the firing of Portland cement clinker, much lower-grade fuels may be used for lime burning, because limestone gets decomposed into lime and carbon dioxide as early as at 894°C temperature, and the burning temperature of white lime practically amounts to 1,050-1,200°C.

It may be stated in conclusion that out of the latest kilns lime is better to be burnt in the regenerative shaft kilns, where the specific heat consumption is as low as 3,560 $kJ.kg^{-1}$. That is why these kilns should be preferred whenever a new lime factory is to be constructed.

Some technological reasons may change the choice of kilns. Apart from some of the already mentioned reasons, a rotary kiln may be chosen due to the disintegrating property of chalks and of some coarsely crystalline limestones at an elevated temperature. Such materials would get disintegrated completely during the burning process into small crystals or dust, choke the shaft and make the burning process impossible. That cannot happen in the rotary kiln.

Table 33. Comparison of modern shaft kilns for lime production

Characteristic	Regular	Cross flow	Annular	Parallel flow, regenerative
Shaft shape	round	rectangular	round	round
Cross section area (m^2)	40-30	3.9	9.2-17.6	2.3-16
Capacity (tons)	45-450	180	90-270	100-600
Feed size (mm)	60-200	20-75	20-125	90-600
Fuel	coke oil gas	oil gas	oil gas	oil gas
Fuel rate kcal/kg of lime	940-1 250	1 100-1 220	1 050-1 160	850
kJ/kg	3 930-5 230	4 650-5 110	4 396-4 860	3 560
kWh/t	2.7-3.8	22-33	9-33	22-27

Table 34. Modern lime rotrary kilns

Characteristic		Long kilns without preheater				Kilns with preheater		
Kiln size Diameter metres Length metres		3.2 91.4	3.2 135.6	3.5 123.7	4.1 121.9	3.9 20.1	4.4 89.9	5.2 61.0
Internals Type m		Trefoil 27.4	Lifters 19.2	Lifters 52.4	Trefoil 12.2 Metal-vane 19.5	-	-	4 DAMS
Cooler type		Contact	Satellite	Grate	Contact	Contact	Grate	Shaft Polygon
Capacity T		455	420	430	1 000	390	1 000	900
Fuel type		coal gas	oil	coal	coal	oil	gas	coal
Specific heat consumption	kcal/kg	1 990	1 910	1 556	1 767	1 472	1 489	1 306
	kJ.kg-1	8 330	8 000	6 515	7 398	6 163	4 181	5 468
Feed size mm		20-45	6-50	10-65	25-60	20-50	13-45	10-50
Power kWh/t		25	15	23	33	25		39
Preheater type		-	-	-	-	Shaft	Grate	Contact

X. CONCLUSION

There cannot be any universal recipe prescribed for all the cement and lime factories on how to achieve an optimal manufacturing process. Which solution to choose so as to prevent losses and to achieve an optimal process depends chiefly on local conditions. To sum up, the following hints may be recommended:

(a) The supply of constant and uniform composition of raw materials must be ensured, and the grinding process must be intensified;

(b) Utilization of the kiln operation time should be increased, and stoppages should be reduced;

(c) A maximum reduction in heat consumption in the firing process can be attained by removing all deficiencies, and by a perfect control of the firing process;

(d) The technological process should be strictly adhered to, and fluctuations should be reacted to quickly and carefully;

(e) A sound maintenance programme of the plant machinery, and of the kilns in particular, should be implemented;

(f) Automatic controls to eliminate the human factor in the production process should be implemented;

(g) Plant employees should be provided with more know-how and experience, and be acquainted with the latest developments in this field.

As the progress at the engineering and machinery producers goes on hand in hand with the research in the field of non-metallic minerals, there are promising views to better and more effective technologies and machinery - particularly kilns.

As the machinery and equipment become more sophisticated - and in the technologies of cement and lime production any profound changes and betterments cannot be expected in the foreseeable future - new methods (ways) of energy conservation should be sought in the existing plants.

FINAL NOTE

The presented review of potential energy conservation in selected non-metallic industries is concerned directly with the manufacturing processes. The measures aimed at evident cost savings are incentively effected by the entrepreneurs. If, however, energy conservation provisions require considerable investment costs the industrialists are reluctant to invest. Such situations have arisen in many countries, and the intervention of the Government is necessary, as the energy crisis is too serious a problem, influencing national economics directly, to be left without attention. The Governments' intervention will vary according to local conditions and will comprise, e.g., a tax holiday for producers investing for turning to another recommended source of energy, regulations protecting the residential users by giving them the highest priority (e.g., in gas delivery), regulations of imports of fuels, planning of development of local energy resources, subsidized research programmes for increasing the efficiency of electric power generation etc.

The table 35[a] gives a review of the potential world production of energies. It has been published to be discussed at the 11th World Energy Conference convened at Munich (FRG) in September 1980.

According to this forecast the peak in oil production should be reached in 1985, and in natural gas in 2000. A great development is expected in mining solid fuels and power generating in nuclear as well as in hydro-electric power plants.

The present shortage of fuels should be bridged over by increased coal production before the extent of nuclear, water and renewable energy resources becomes effective. However, the increase of coal production in many industrialized countries does not fulfil the expectations, because favourably situated coal deposits have been extracted, and the geological and mining conditions grow worse, which is reflected in growing mining and investment costs. In this context it should be emphasized that at present some 50 developing

[a] Weltenergie Konferenz 1980 in München, Glückauf, 115, 1979, Nu. 6.

Table 35. World production of energy
(Exajoules)[a]

Primary energy resources	1972	1985	2000	2020
Coal	66	115	170	259
Oil	115	216	195	106
Natural gas	46	77	143	125
Electricity from nuclear energy	2	23	88	314
Electricity from hydroenergy	14	24	34	56
Unconventional oil and gas	0	0	4	40
Renewable, solar, geothermal and	26	33	56	100
Total	269	488	690	1 000

---

[a] 1 exajoule (EJ) = 10^{18} J.

countries are known to have coal resources, and only 30 are currently exploiting them.

In view of the present circumstances, the developing countries without oil and gas deposits should focus on exploitation and utilization of coal, water and renewable (especially solar) resources. This should be taken into account in their long-term planning regarding the development of energy resources and silicate industries.

Bibliography

Industrial ceramics

Budnikov, P.B. Technology of ceramics and refractory ware. Moscow, Union of Soviet Socialist Republics, 1960.

Campbell, I.E. and E.M. Sherwood High temperature materials and technology. New York, John Wiley, 1967.

Engelthaler, Z.A. Rationalisation of production and application of lining materials. ČSVTS, Symposium High Tatras, Czechoslavakia, 1977.

Engelthaler, Z.A. and J. Krejsa. Non-metallic raw materials - Source of energy conservation, UNIDO, 1980.

Harders, F. and S. Kienow Feuerfest Annual. Berlin, Springer Verlag, 1960.

Kilns and driers in the silicate industry. *By* D.B. Ginsburg *and others*. Moscow, USSR, 1949.

Kuna, L. Insulations of heat and cold in industry. Bratislava, SNTL, 1965.

__________ Linings for industrial furnaces. Bratislava, SNTL, 1969.

Kuna, L. and M. Grotte. The past, present, future trends of energy savings in the non-metallic minerals based industries, UNIDO, 1980.

Prabhu, E. Development of kilns. In-plant training workshop, UNIDO-Czechoslovakia, Plzeň, ČSSR, 1974.

UNIDO: Report and Proposed Action Programme, UNIDO Energy Task Force, 1980.

Glass industry

Burger, K.R. and H.A. Nelson Glass furnace heat-up. *The glass industry*, March 1976.

Brocker, R. On-site coal gasification. *The Glass Industry*, February 1978.

Dreyfus, R.G. Process control in glass container manufacture. *The Glass Industry*, September 1977.

Edgington, J.H. Energy saving in the container production process. *Glass International*, March 1979.

Engelleitner, W.H. Agglomeration in the glass industry. *The Glass Industry*, August 1978.

__________ Lehr design for energy conservation. ACS ceramic bulletin, No. 3, 1975.

__________ Lehr design to reduce power and fuel costs. The glass industry, May 1975.

Hibscher, C.W. and W.R. Steitz Challenge to U.S. glass manufacturers in these energy critical times. ACS ceramic bulletin, No. 6, 1975.

Glenshaw. Furnace maintenance results in saving glass co. Ceramic industry, July 1979.

Loesl, R.E. Practical data for electric melting. The glass industry, February 1975.

Mainer, V. Sklářské pece. SNTL Prague, 1967.

Martin, D.N. Revolutions in glassmaking. The Glass Industry, June 1976.

Northwestern Glass. Design criteria and operation, 165 ton/day, all-electric furnace, ACS ceramic bulletin, No. 8, 1978.

Penberthy, L. Electric melting's place in the energy picture. The glass industry, March 1977.

Pont, R.S. Oil firing systems for glass furnaces. The Glass Industry, June 1977.

Roos, P.W. Lehr priority: design concepts to save energy. The Glass Industry, April 1975.

Stanek, J. Electric melting of glass, New York, Elsevier, 1977.

Tavenískla. By J. Hlaváč and others. SNTL Prague, 1970.

Volf, M.B. Chemie skla, SNTL Prague, 1978.

West-Oram, F.G. Raw materials for glassmaking. Glass technology, December 1979.

Cement industry

Ahrends, J. and W. Gieslinski Technologia cementu. Warszawa, 1955.

Anselm, W. Der Schachtofen. Heidelberg, 1952.

__________ Die Zementherstellung. Wiesbaden, 1941.

Bárta, R. Chemie a technologie cementu. Praha, ČSAV, 1961.

de Beus, A.J. Mind your chain dollar. Minerals processing, October 1967.

Blanks, R.F. and H.L. Kennedy The technology of cement and concrete. New York, John Wiley, 1955. vol.I.

Bogue, R.H. The chemistry of Portland cement. New York, Reinhold, 1965.

Boynton, R.S. Chemistry and technology of lime and limestone. New York, Interscience Publishers, 1966.

Desko. Naladka i teplotechničeskije ispitanija vrasčajnščichsja pečej na cementych zavodach. Moscow.

Duda, W. Cement data-book. Wiesbaden, Bauverlag, 1976.

Jirka, Emil. Pálenie slínku na šachtových peciach. Horné Srnie.

Klaczak, A. Möglichkeiten zur Verringerung des Brennstoffverbrauchs bei der Zementherstellung im Nassverfahren. Zement-Kalk-Gips (Wiesbaden) No. 8, 1979.

Kühl, H. Der Baustoff Zement. Berlin, VEB Verlag für Bauwesen, 1963.

Lahovský, J. Bílý cement. Praha, Disertace, 1970.

Lea, F.M. The chemistry of cement and concrete. London, Eward Arnold, 1956.

Lurje, J.S. Portland Cement. Moscow, 1959.

Pastala, A.L. The application of precalciner technology for the cement industry of developing countries. World cement technology, No. 7, 1977.

Plassmann, E. Beitrag zur Wärmewirtschaft von Nassarehöfen. Zement-Kalk-Gips, No. 2, 1957.

Vorobjev, Ch.S. and D.J. Mazurov Teplotechničeskije rasčoty cementnych pečej i apparator, Gosudarstvennoje izdatelstvo. Moscow, 1962.

Vranka, L. and J. Horwáth Výrobní stroje a zariadenie silikátového priemyslu. Bratislava, 1963.

Weber, P. Heat transfer in rotary kilns. Wiesbaden, Bauverlag, 1963.

Witt, J.C. Portland cement technology 2.ed. New York, Chemical Publishing, 1966.