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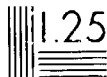For more information about UNIDO, please visit us at www.unido.org
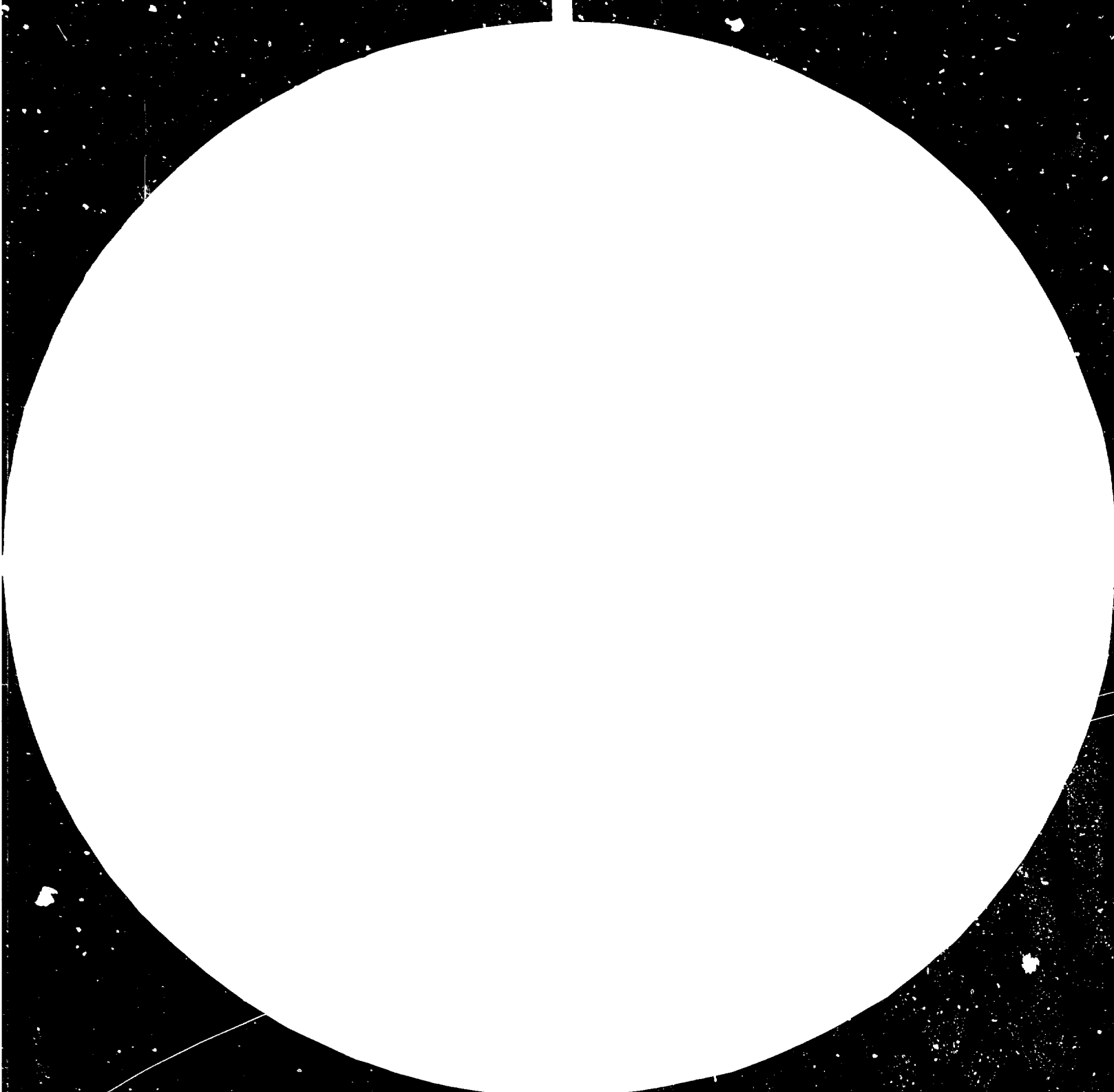
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Technical Workshop on Energy Conservation
in Silicate Industries
for the Least Developed Countries

Pilsen, Czechoslovakia
October 1981

CEMENT INDUSTRY - REDUCING THE ENERGY REQUIREMENTS

IN TECHNOLOGICAL PROCESSES AND HEAT CONSUMING UNITS

by: Jiří Lahovský

TECHNOLOGICAL PROCESSES OF PREPARATION OF THE RAW MIX FOR PORTLAND CLINKER BURNING

Rotary kilns are the most important equipment in each cement plant and therefore an exceptional care is being taken when a designer selects the kiln for his project. The output of the kiln determine: the capacity of the whole plant. The kiln consumes 80-100 % of all thermal energy and 5-20 % of electric power needed for the cement manufacture.

However, the selection of the thermal process can be affected by specific conditions of each individual plant. The crucial factor in this sense are physical and chemical properties of the raw mix components. From the point of view of the preparation of raw mix for its calcination in the cement kiln, we distinguish 4 basic technological processes which shall be described before the kilns are talked about.

a) wet process

b) semi-wet process

c) dry process

d) semi-dry process

Hereunder we give a brief description of different processes:

Wet process of the raw mix preparation

The raw materials are either washed or ground along with water. The slurry (which must have a good degree of fluidity) is then stored in silos, homogenized, and on basis of chemical analysis is corrected by the slurry from other silos until an adequate chemical composition is achieved. The slurry is then conveyed to a bin above the rotary kiln and with great accuracy fed into the kiln. Generally the slurry contains 33-40 % of water. Plastic raw materials occassionally require an increase in water content up to 50 % in order to reach necessary fluidity. On the other hand the non-plastic raw materials sometimes settle for only 28-33 % of water.

Semi-wet process of the raw mix preparation

The slurry prepared by wet process undergoes a filtration aimed at reducing the water content in the slurry; this results in the economy on heat which would have to be spent for evaporation of this unnecessary water.

For slurry filtration the vacuum filters or press filters are used. The filter cake is either fed into the rotary kiln, or for its

calcination on the grate it is sometimes necessary to thicken it by adding a certain amount of raw meal. This applies for the situation when the filter cake is not compact enough to provide granules formed in extrusion presses or other suitable presses, or on nodulizing discs. Moisture content of the raw mix particles that are fed into the kiln is 14-18 % of H20.

Dry process of the raw mix preparation

Crushed raw materials are either first dried in a drier and then ground, or drying and grinding are carried out simultaneously in a drying circuit mill. Individual components are fed into the mill by means of weigh feeders, or - in older plants - are batched by their volumes. Raw meal is then conveyed into the system of homogenizing and reserve silos where it is pneumatically or mechanically homogenized or possibly corrected and then it is routed and fed into the rotary kiln. Chemical control is of course more exacting than in the wet process of preparation. Moisture content of the raw mix is less than 1 % of H20.

Semi-dry process of the raw mix preparation

Dry and homogenized raw meal prepared by dry process (see above) is moistened in a screw, on a nodulizing disc or possibly in a noduli- zing drum. Moistened (or granulated) raw meal is in the form of irregular conglomerate pieces fed into the kiln, or (if granulated) onto a Lepol grate. Moisture content of the raw mix is 10-15 % of H20.

This process comprises also the preparation of the raw mix for the shaft kilns. However, since the raw materials for the shaft kilns have to contain pressed-in fuel (coke or anthracite) there are two alternatives:

a) Preparation of "white meal"

Raw meal prepared by dry process is weighed along with fuel that is ground down to a grain size of 1-8 mm. Such mix is thoroughly blended in a mixing screw, moistened to reach 11-14 % of water content, and granulated or compacted. Compressed pieces are fed into the shaft kiln.

b) Preparation of "black meal"

For preparation of black meal the fuel is ground along with other components in the raw mill, all components being very precisely batched into the mill. "Black meal" is blended in homogenizing

silos and prior to being fed into the kiln is moistened up to
11-14 % of H_2O and granulated or compacted.

Diagram of preparation of the slurry for the wet process of
cement manufacture

Limestone extraction
↓
Transport   Clay or marl
↓   ↓
Primary crushing   Extraction
↓   ↓
Secondary crushing   Washing
↓   ↓
Storage   Storage
↓
Feeding into the mill
↓
Water → Grinding ⟵————————————————— Feeding into the mill
↓
Storage of slurry and
blending
↓
Correction of chemical
composition
↓
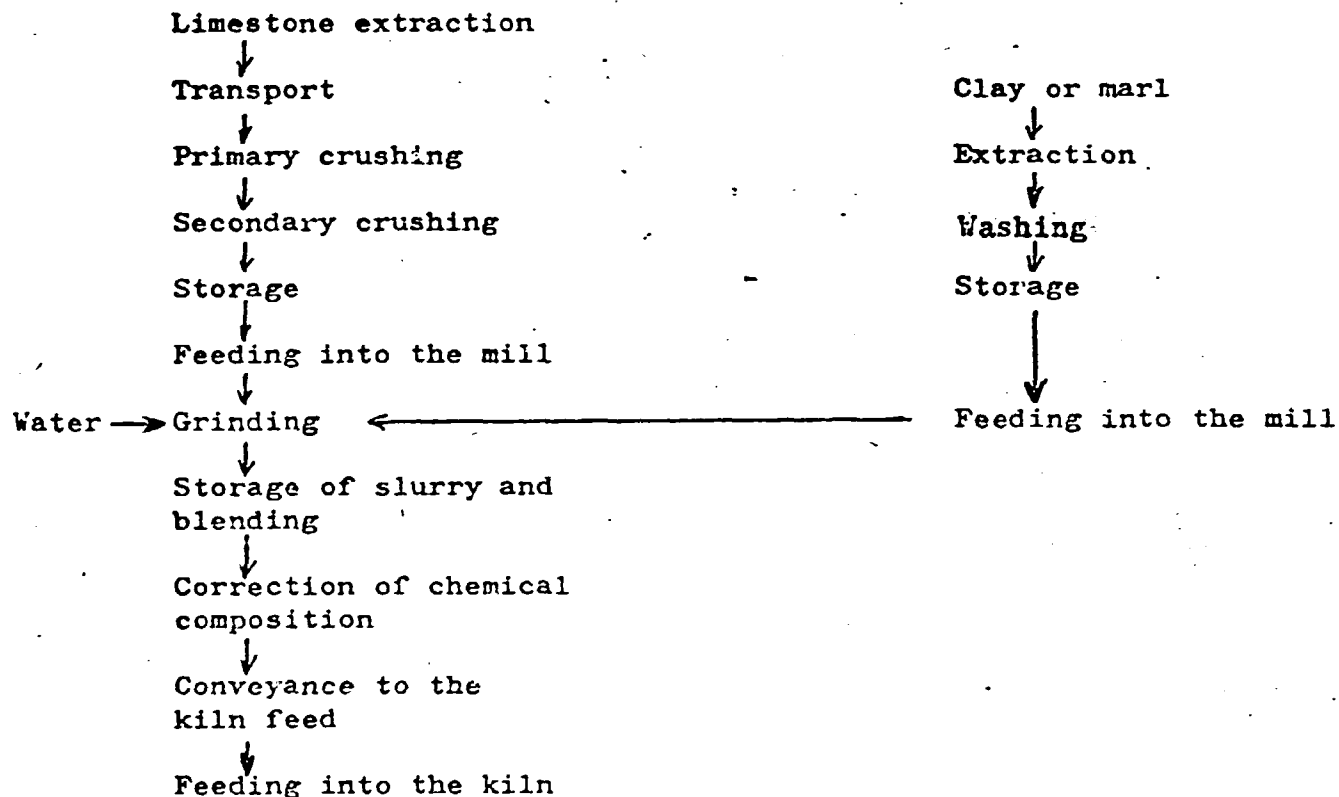Conveyance to the
kiln feed
↓
Feeding into the kiln

Diagram of preparation of the raw mix for the semi-wet process
of cement manufacture

Slurry prepared by wet process (bin)
↓
Press filtration
↓
Bin
↓
Granulation or compaction
↓
Feeding of granules onto the Lepol grate
or into the kiln
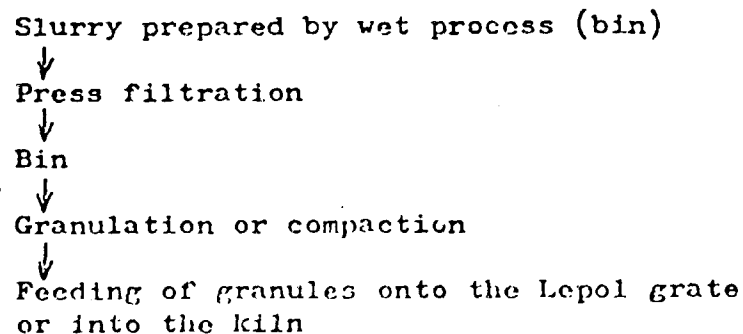
**Diagram of the preparation of the raw mix for the dry process
of cement manufacture**

Limestone   Slate or marl
↓   ↓

Extraction   Extraction
↓   ↓

Transport   Transport
↓   ↓

Primary crushing   Crushing
↓   ↓

Secondary crushing   Prehomogenization
↓   ↓

Prehomogenization   Drying   ^x)
↓   ↓

Conveyance   Storage
↓   ↓

Drying   ^x)   Feeding
↓   ↓

Feeding
↓
Grinding ←——————————————————————————————————————
↓
Raw meal conveyance
↓
Homogenization
↓
Conveyance and batching into the kiln
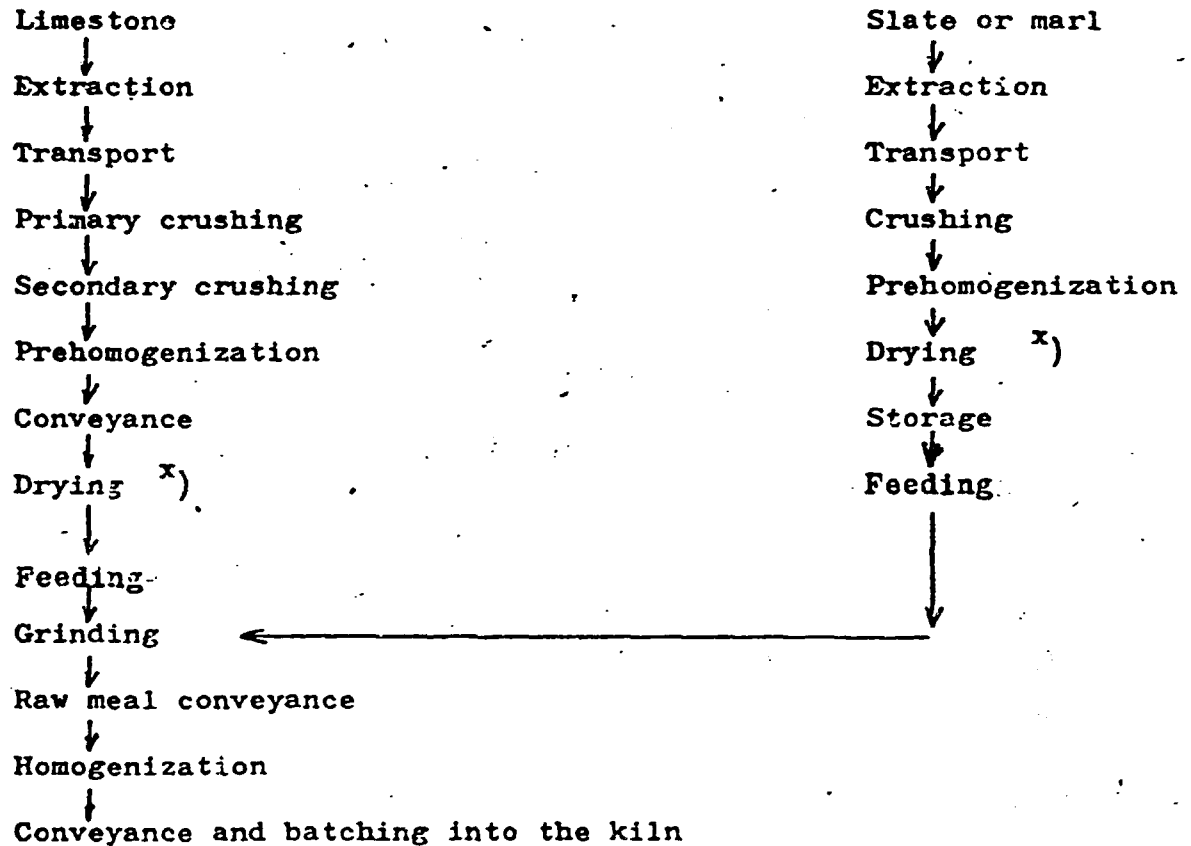
^x) Note: frequently the raw mix can be dried in the raw mill using
          hot combustion gases from the kiln.

Diagram of the preparation of the raw mix by semi-wet process
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Homogenized raw meal prepared by the dry process
↓
Granulation ←——————————————————————————— Water
↓
Feeding of granules onto the Lepol grate
or into the long rotary kiln
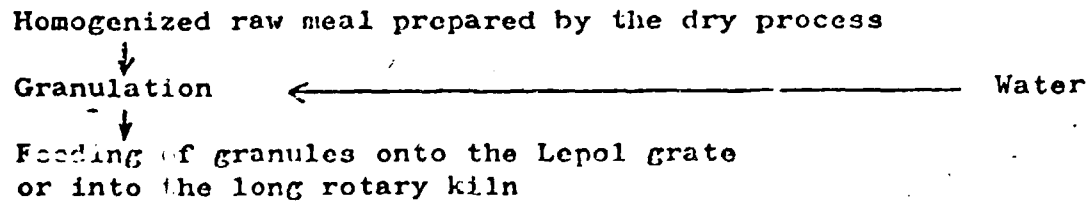
DEVELOPMENT OF SHAFT KILNS FOR CLINKER CALCINATION

Joseph Aspdin, mason from Leeds (Yorkshire), was the inventor of
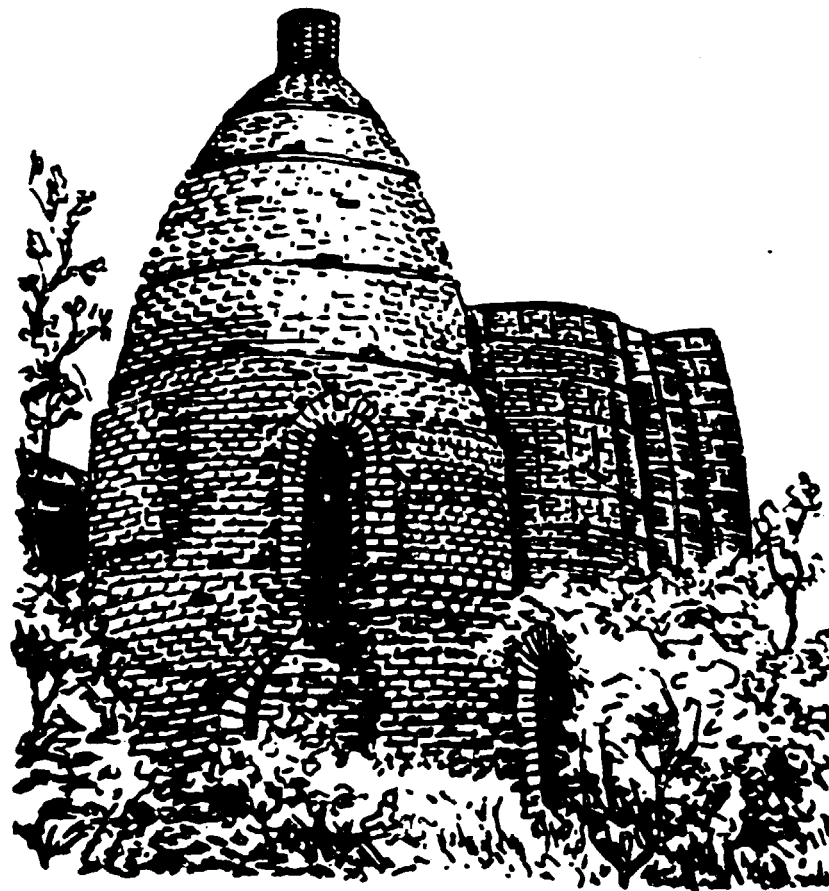Portland cement (Brit. Pat. Nr. 5022 of 18/7/1824). It is supposed

Fig. 1 - Remnants of the Aspdin kiln at Northfleet

that his product nowadays could not be designated as "Portland" cement since it would not meet strict requirement of our current standards. Lime kilns, used by Joseph Aspdin in his original works at Wakefield, did not provide the temperature needed for proper sintering of all the raw mix. According to nowadays criteria Apdin's product ground after the calcination should be more precisely called "Roman" cement or "hydraulic lime". Also in another works at Northfleet, the remnants of which can be seen in Fig. 1, the kilns called dome kilns or bottle kilns were constructed. These kilns used to operate periodically, i.e. once the fuel was burnt the kiln had to be left to cool down and discharged completely. No wonder that fuel consumption was very high and amounted to 30-50 % of the clinker weight.(see fig. 2)

The shaft kilns that were being developed in Europe in the second half of the last century used to be filled with bricks made from cement raw mix, with intermittent layers of solid fuel (coke or anthracite). Once the fuel in the shaft was burnt out, the contents of the kiln was cooled down by opening the ports in the lower part of the kiln; the kiln was then emptied. The mass was with great difficulties separated into clinker and underburned residue. Large pieces were desintegrated by iron bars or mattocks.

Back in 1845 Isaac Charles Johnson proved positive effects of the raw mix calcination with transition into sintering and pointed out the importance of a precise maintairing of each component's share in the raw mix. His discoveries however were made practical use of much later. First an improvement in the shaft kilns was needed. It was not until 1872 that a kiln designed by Johnson was set up in England. It was already using hot gases for raw bricks drying. (See fig. 3)
Great progress in clinker calcination was brought about by Dietsch kilns, so-called "desk kilns". (Fig. 4). These kilns had a pre-heating vertical shaft, sintering zone in the horizontal part, and a cooling shaft. Raw bricks were inserted into the upper part of the vertical shaft, and proceeded down the shaft to an almost horizontal desk. Sometimes it was necessary to push the bricks down with iron bars or rakes. The sintering process took place in the horizontal part called "desk" or "bridge". From this place the bricks were routed into the cooling shaft which broadened downwards. This proved to be advantageous since the flame for sintering was concentrated in the tapered upper part while broader space towards the bottom prevented burning-on. Clinker was being gradually withdrawn out of the shaft which resulted in an almost continuous flow of the mass through the kiln.

Firing in the Dietsch kiln required great skill an experience since it was necessary to fill the calcining shaft in such a way that the
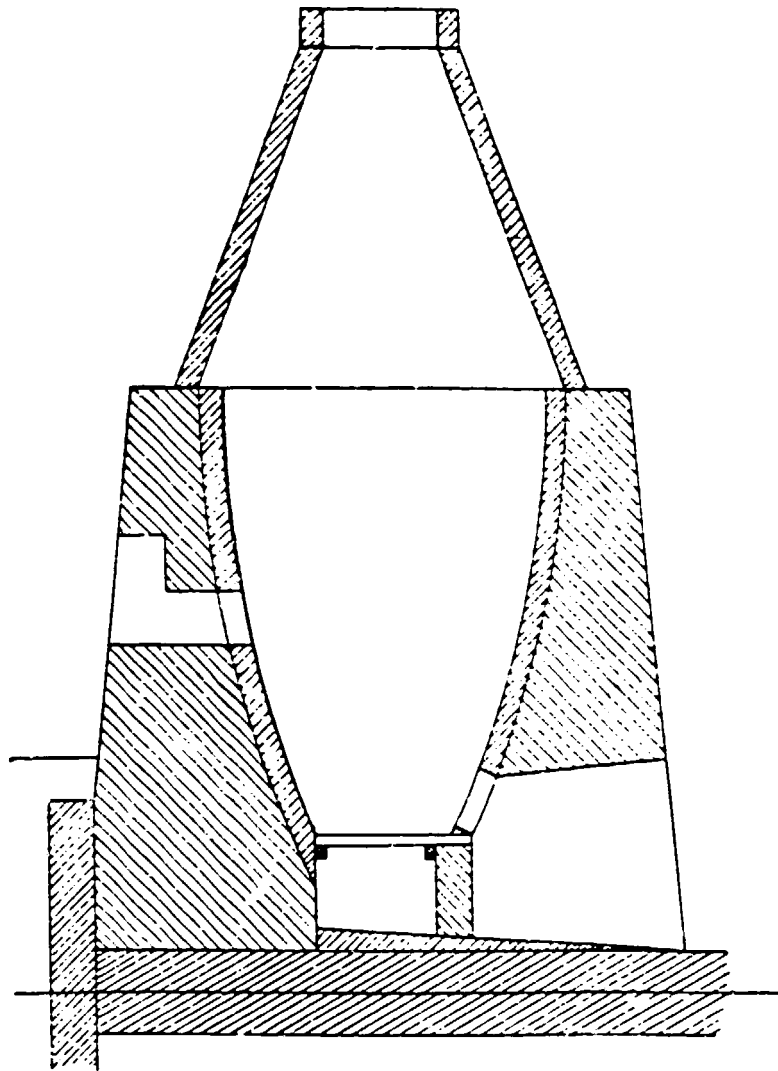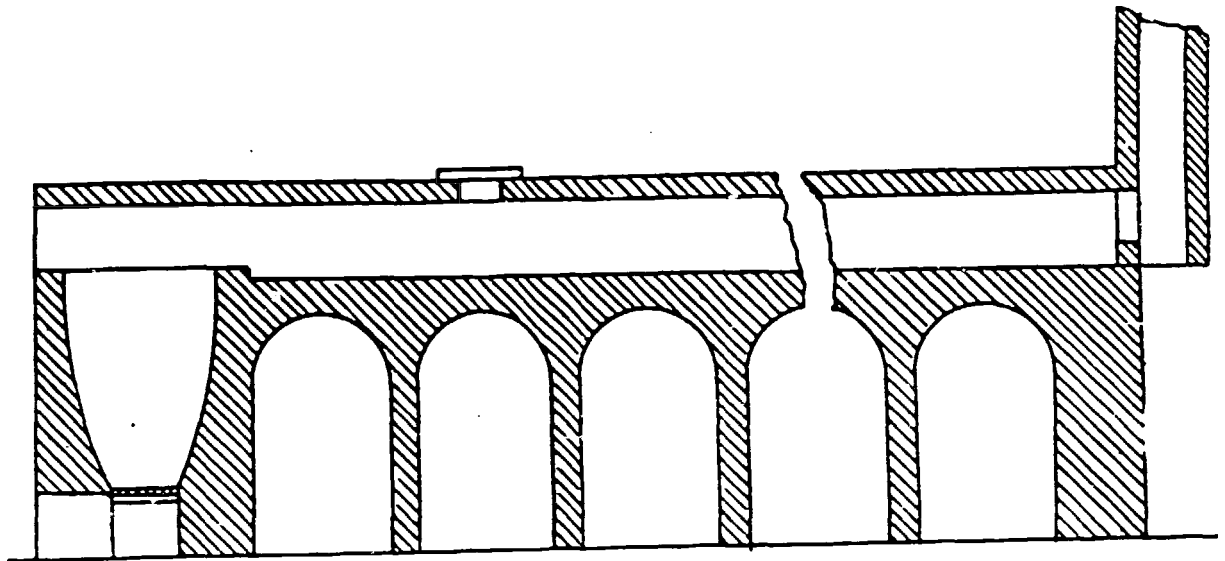
Dome kiln.

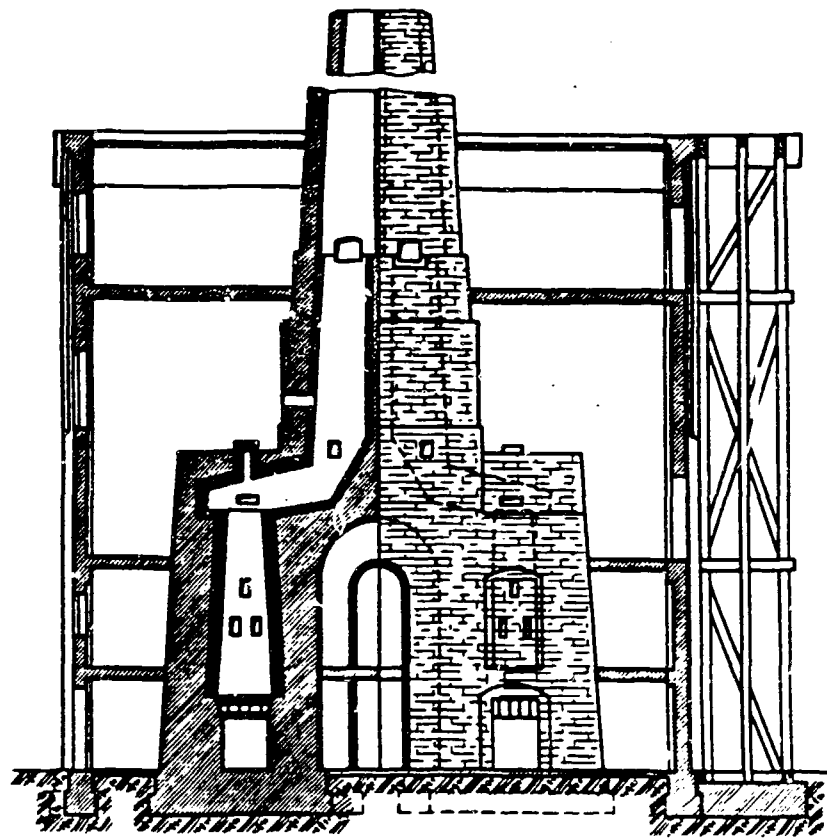Fig. 2 - Dome kiln

Fig. 3 - Johnson kiln

Fig. 4 - Dietsch kiln

air could flow freely through the gaps between the bricks, and care had to be taken that the cooling zone allow a steady passage of air. To counterweigh this, however, the kiln produced an excellent quality clinker since the raw mix remained in the calcining shaft for a sufficiently long time (2-3 hours) and the sintering process temperature was adequately high. Moreover the cooling was comparatively fast (in particular when a fan was used to blow the cooling air) which improves the quality of clinker.

Another advantage of the Dietsch kiln was a lower fuel consumption (19-25 % of coke and anthracite of the clinker weight), as well as a higher output (12-20 tpd). After implementation of the blown-in air, the output of twin kilns reached 30-40 tpd for which only 17 % of the mix coke + anthracite was consumed (related to the weight of clinker).

Another two kilns were competing with the Dietsch kiln; the Hauenschild kiln (designed 1869) and similar Schneider kiln (fig. Nr. 5 and 6). These types featured a simpler service and maintenance in view of a lesser burning-on of clinker on the walls. The consumption of coke was approx. 17 %. The output was still quite low - 15-20 tpd.

Schneider kiln gained such a popularity in Europe that e.g. in 1919 half of all clinker kilns in operation in Germany were of this design.

The shell of the Schneider kiln consisted of two sheets and the space between them served for air cooling. Schneider used to place one layer of raw bricks onto the fireclay refractory lining and thus separated the refractory bricks from the hot clinker. Prior to each filling of the kiln with the layer of bricks, a bank of bricks was placed on the perimeter and thus the protective cuff was becoming longer and longer.

The Dietsch kilns and other kilns of european design, particularly the Danish one (called also Aalborg or Schöfer kiln) (fig. 7) were constructed in the U.S. and Latin America as well.

Automatic shaft kilns

The greatest progress in the design of shaft kilns was enabled by the invention of Hauenschild Jr. (1912), so-called "automatic shaft kilns". This denomination is not precise, since the kiln was not automatic in today's sense of the word; a continuous withdrawal of clinker was implemented and a gyratory grate was installed at the
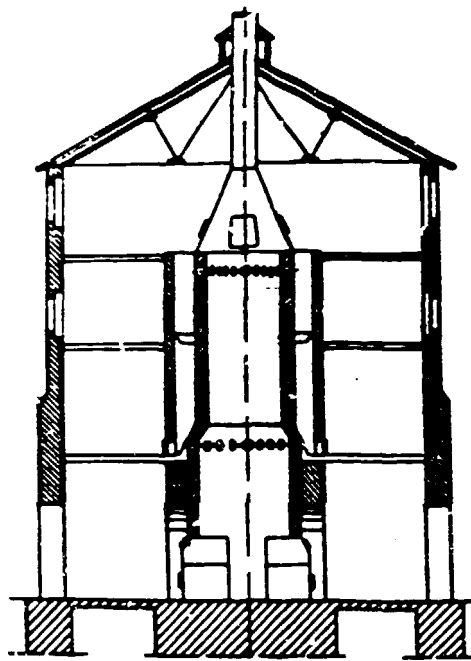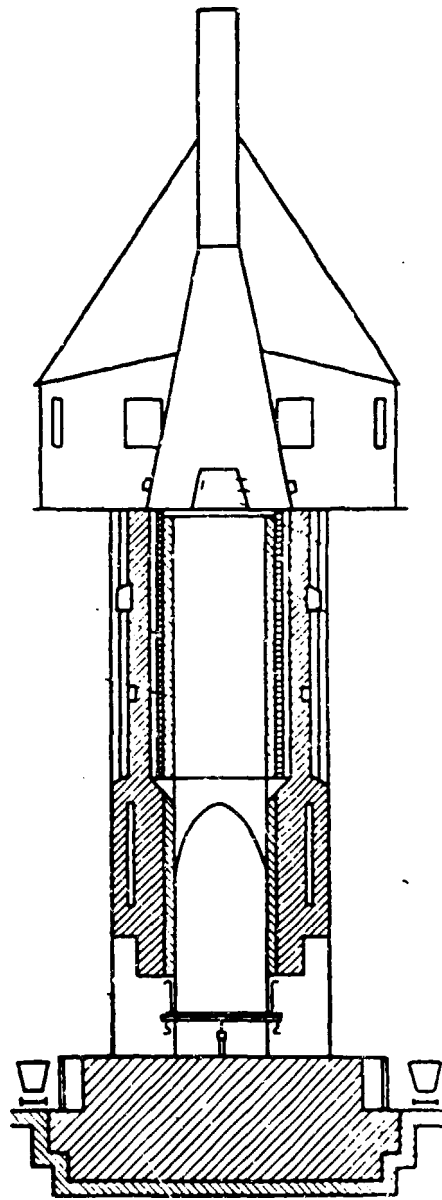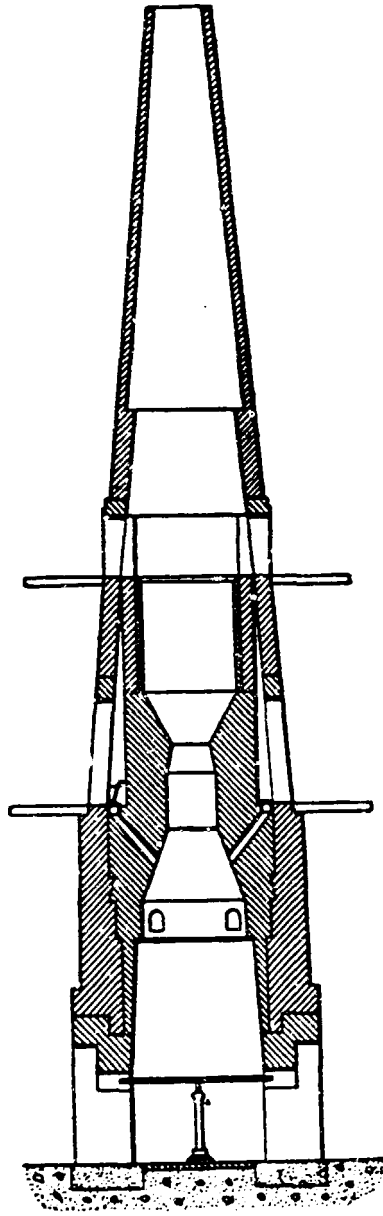
Fig. 5 - Hauenschild kiln

Fig. 6 - Schneider kiln

Schoefer kiln.

Fig. 7 - Schoefer kiln (called Aalborg kiln)

bottom of the shaft. In view of the fact that the grate which served for clinker crushing was almost continuously withdrawing clinker in the overall cross-section of the kiln, clinker was sinking in the kiln evenly.

This procedure was tested for the first time in 1912 in Beočin (today's Yugoslavia) and later at Ladce (today's Czechoslovakia). The production of horizontal gyratory grate was started in the German company Curt von Grueber in Berlin and as early as in 1917 the first kiln denominated as "automatic" went onstream at Blauenberg in Germany. New design of the kiln enabled an easy control, no more difficult manual rake-out was necessary, the quality of clinker improved and it was possible to maintain the sintering zone in the upper part of the kiln. With all these advantages the consumption of fuel was considerably lower in comparison with then existing rotary kilns. The output of the "automatic" shaft kiln was only 30-40 tpd but after the improvements were implemented it reached 70 tpd or even more.

The Hauenschild's patented design was in its era an unprecedented success.

The "automatic" shaft kilns with gyratory grate became rapidly widespread which can be evidenced by these figures:

Year	Number of kilns installed
1917	1
1919	48
1927	500

As can be seen from Fig. Nr. 8, the shaft kiln of Curt von Grueber Co. consisted of a vertical shaft which was a steel shell provided with refractory lining. The shaft was in the upper part closed with a steel sheet cover in the form of truncated cone with a loophole. The cover was connected to the chimney. Compacted raw pellets with coke grit (or anthracite), moistened to approx. 8-14% of H_2O, were evenly distributed by means of a gyratory distributing disc. Lower part of the shaft contained the horizontal gyratory grate provided with numerous lugs by means of which the clinker was crushed and through the openings in the grate fell down; from under the grate it was discharged by three-chamber closures (Grueber System) onto a conveyor. The air necessary for burning of fuel was blown into the space under the grate. The air was distributed through the holes in the grate along the overall cross-section of the shaft and rose upwards intensely cooling clinker and protecting grate from being damaged. Passing through the mass, the air became preheated; entering the sintering zone the air was burning fuel since penetrated (through pores) even into the raw bricks. Hot gases in
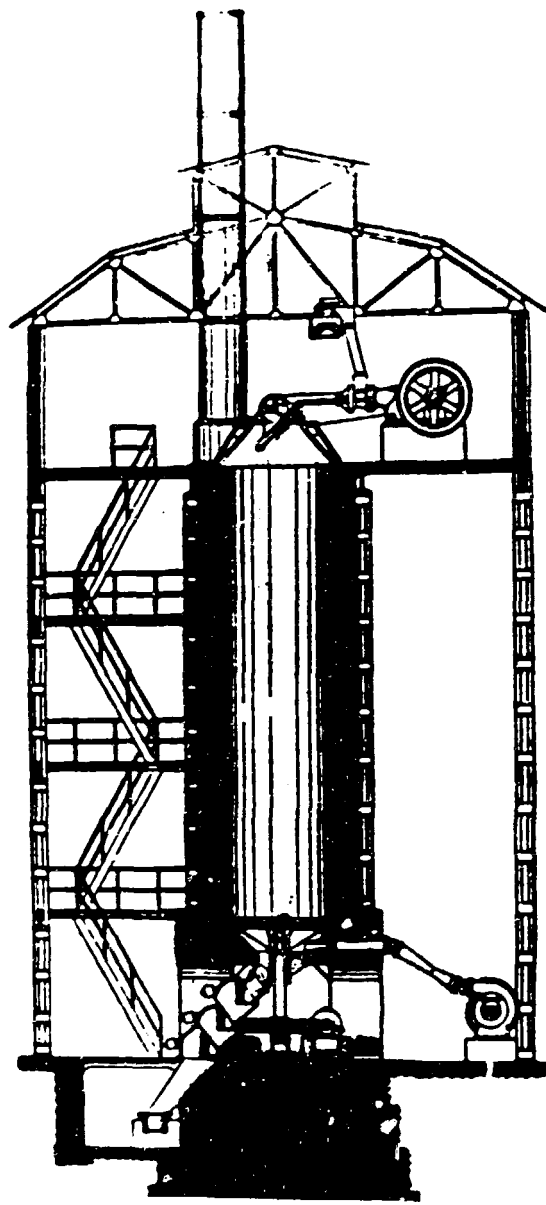
Fig. 8 - Automatic kiln of Curt von Grueber Co.

the upper layer served for raw bricks drying and were cooled
down to approx. 120 °C.

The development of the shaft kilns illustrates a progressive
tendency towards smaller raw pellets. Instead of original bricks
with dimensions upto 290 mm of length used in the old shaft kilns,
the automatic shaft kilns processed smaller and smaller pellets and
the latest granules do not exceed 30 mm. This trend is shown in
Table Nr. 1.

Link between hourly outputs of the shaft kilns and the raw
particle size

Table Nr. 1.

Brick (particle) dia. mm	Output of the kiln t/h	Depth of fire m	Velocity of the passage of the mass m/h	Sintering time h	Period
120	4,15	3,0	0,60	5,00	1920-30
70	5,40	2,0	0,78	2,56	1930-40
35	6,25	1,3	0,91	1,43	1940-50
25	7,30	1,0	1,09	0,91	1950-60
17	8,45	0,8	1,23	0,65	1960-80
10	10,70	0,6	1,56	0,39	

Figures shown in Table Nr. 1. evidence that it was necessary to
amend even the mechanical equipment in view of the particle size.
The machines producing bricks disappeared and were superseded by
various briquetting presses and extrusion presses. After the
World War II. the nodulizers became widespread, in particular
nodulizing discs for forming of granules.

Nodulizing discs were also being progressively improved. The best
discs to produce granules for the shaft kilns proved to be the
shallow discs (or three-stage discs) of the Loesche Company.
These discs produce granules that are sufficiently porous and can

better withstand the thermal shock ,i.e. do not explode at
a rapid temperature rise.

Fast calcination and a narrow sintering zone enabled to erect
kilns with lower shaft. Optimum height to inner dia. ratio is
generally 3-4 : 1 .

The drag of the kiln rose during the 60 years of development from
500 mm of water column (4.900 Pa) to 1.600 mm of water column
(15.690 Pa). This went hand in hand with a decrease in raw particle
weight. This results in a greater likelihood that the air channels,
so-called chimneys, could appear; these channels allow a substantial
part of air to leak. Therefore it is necessary to check during the
calcination how the sintering zone behaves and to pack possible
leaks, otherwise the percentage of the imperfectly calcined residue
would be undesirably high.

Regarding the grates, the most widely used was the gyratory grate
(Curt von Grueber Co., Krupp - F.R.G.), however also the cylinder
grates emerged (Mannstaedt or Stchmann Systems - Humboldt F.R.G.)
and sliding grate Thiele (Pfeiffer Co. - F.R.G.).

Modern shaft kiln can be seen in Fig. Nr. 9.

Your attention can be drawn to the shape of the upper part of the
shaft that broadens into a sort of a funnel. This concept improves
the packing of kiln edges by the raw material. The sintering zone
should ideally be placed within the funnel as it is shown in the
figure.

The shape as well as the size of the openings in the grate must
be dimensioned according to the size of small granules, to prevent
self-discharge of the kiln through the grate's openings. For this
purpose the Spohn's conical grate is most suitable (Fig. Nr. 10).

In order to improve the quality of clinker, Dr. Spohn pioneered
in 1958 at Blauebern the technology of "black meal". Fuel is
ground along with the raw materials, while in the "white meal"
process the grains of solid fuel are only added prior to nodulizing.

In the "black meal" process, the particles of ash are extremely
fine and thus react perfectly with the raw mix.

To complete the subject it is necessary to mention also some
efforts to intensify the burning process, e.g. by applying the
oxygen-enriched air (O2) amounting to approx. 40 % of O2 (of the
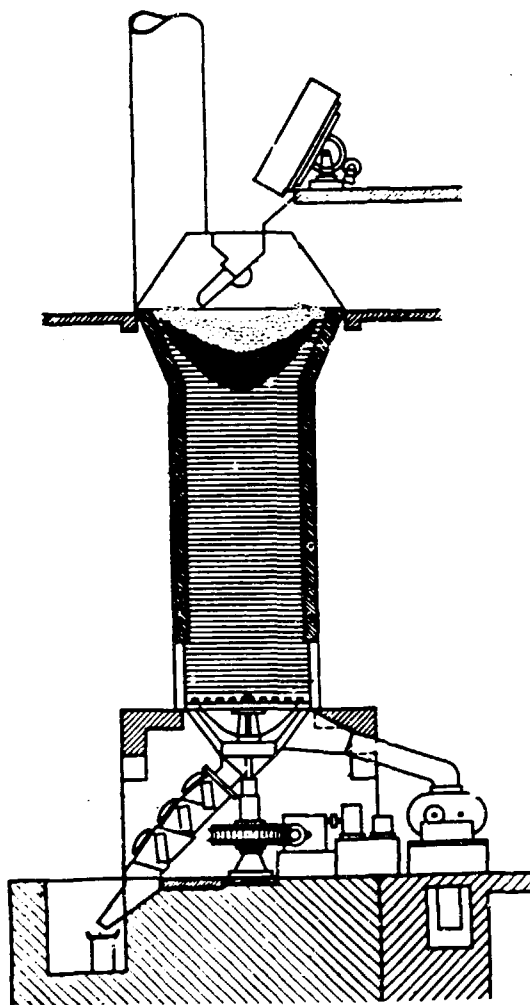total amount of air). This is the so-called A-K process (Anselm-
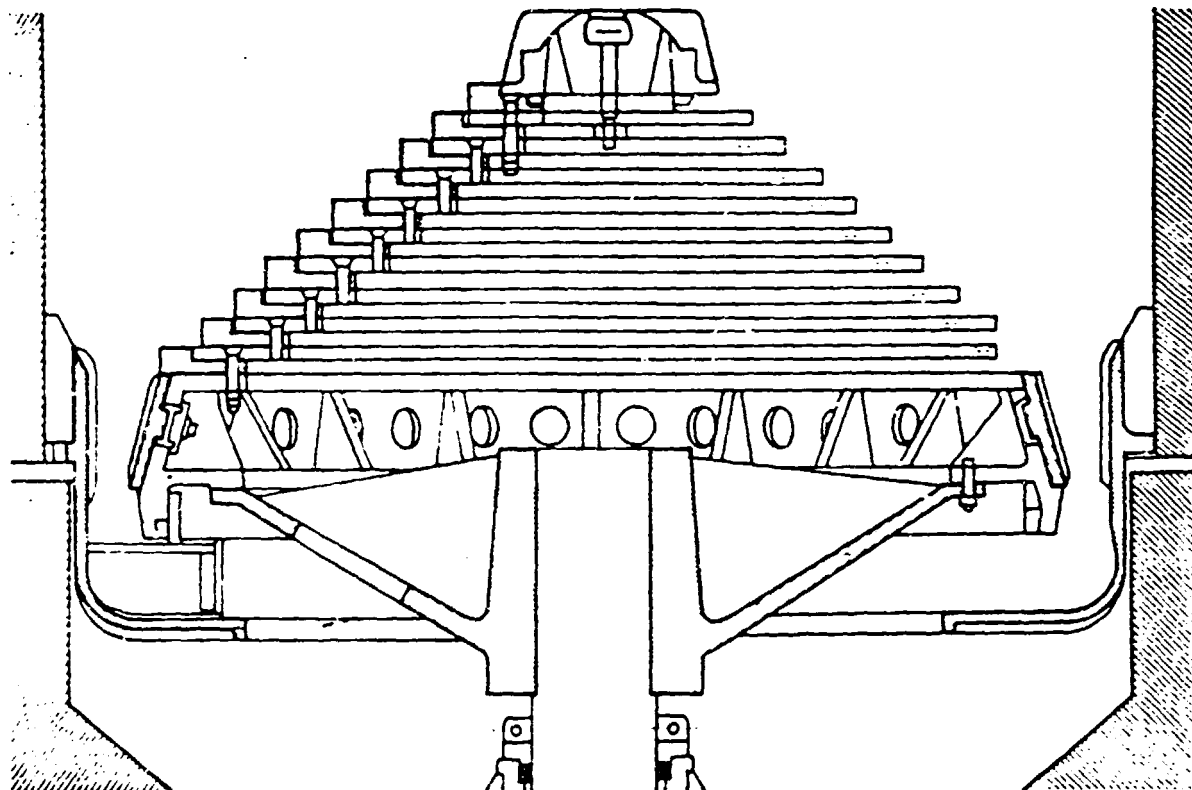
Fig. 9 - Modern shaft kiln

Fig. 10 - Spohn conical grate

-Koch). On a similar principle E.I. Chodorov designed a high-
-capacity automatic shaft kiln (Fig. Nr. 11). A rise of 50 % in the
output was obtained with a drop of 16 % in heat consumption, but the
high price of oxygen prevents this process from spreading.

In addition to well-known producers who have already been mentioned
here, the shaft kilns were manufactured also by other companies,
such as von Roll (Switzerland), Loesche (F.R.G.) or Přerov Machinery
(Czechoslovakia).

Raw materials for clinker calcination in shaft kilns

Only those raw meals that are easily burnable and reactive are
suitable for calcination in the shaft kilns.

Requirements for raw meal chemical composition:

- silica ratio $SR = \dfrac{Si\ O2}{A12\ O3 + Fe2\ O3} = 2,4$ (maximum)

- lime saturation factor of clinker varies generally between 89-91 %.

- quantity of silica grains above 60 microns has to be limited
  to 1,5 % of the raw meal weight as a maximum.

The calcination has to provide a sufficient percentage of fused
phase in the clinker. Therefore alumina ratio

$$AR = \frac{A12\ O3}{Fe2\ O3}$$

is to vary between 1,5 - 2,0.

It is possible to add certain amount of fusing agents or mineralizers to
the raw mix, e.g. fluorite (approx. 0,5 %), or waste fluorosilicates
(0,5 - 1,0 %), which however makes the production more expensive;
moreover these additives are not available everywhere and in
sufficient quantities.

Raw meal has to be ground to max. 18 % of a sieve residue (sieve
4.900 mesh/cm^2 - 170 BSS). Optimum fineness is 6% /4.900. Raw meal
has to be well homogenized and mixed in precise ratios with computed
amounts of fuel.

Raw meal must have also a suitable mineralogical composition to create
granules resistant to temperature rise; on leaving the nodulizing
diso the granules must be compact enough to prevent deformation
during the conveyance and fall into the shaft kiln and they must not
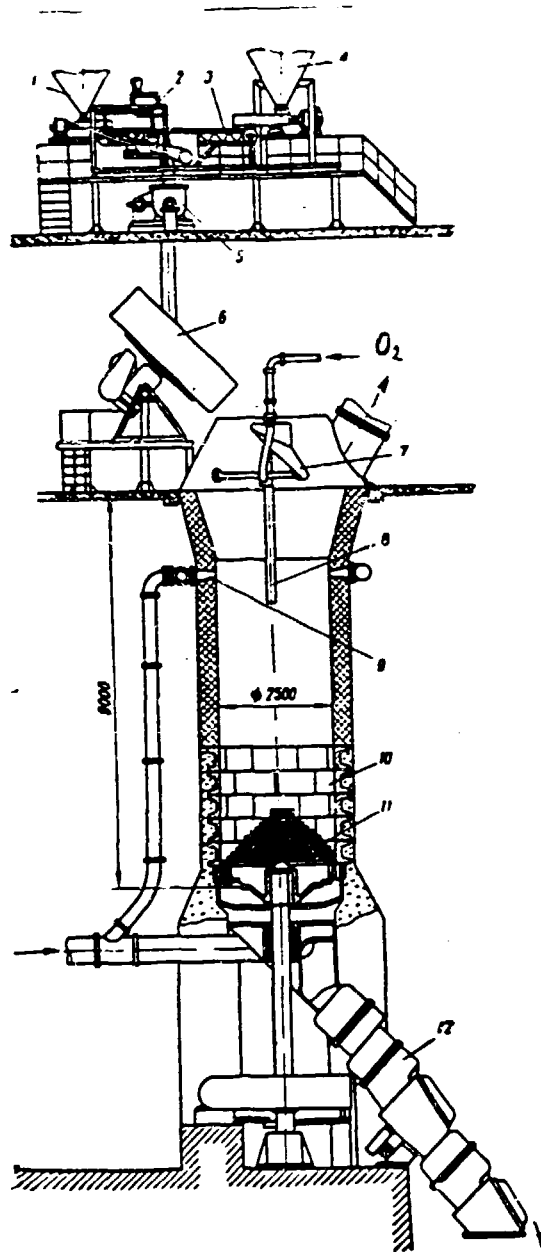form an impenetrable layer.

Fig. 11 - Shaft kiln (E.I. Chodorov's design) with intake of oxygen into the sintering zone

The occurrence of the mineral montmorillonit in the raw meal is recommendable, while certain minerals of the illite group should be avoided.

Fuel for the automatic shaft kilns

For the automatic shaft kilns the homogenized raw meal is mixed with fine-grained fuel (1-8 mm) of a low volatile matter (max. 7 %), i.e. coke, anthracite or kerosene coke; such mix is afterwards moistened and nodulized.

Advantages and shortcomings of the shaft kilns

In comparison with rotary kilns, the capital investment for the shaft kilns was 60 % lower, their design was comparatively simpler and did not require much space.

Heat consumption was low and moreover the shaft kilns were using overwhelmingly coke of 1-8 mm which used to be a difficult waste for many years. The grindability of clinker was better which resulted in an economy on electric power needed for cement grinding.

On the other hand even the largest shaft kilns were small units and to build a medium-sized plant it was necessary to gather them in batteries. The control and monitoring of the process of calcination was more difficult.

The burner operator's work required great physical effort since clinker used to become burnt on the refractory lining. The burnt-on pieces had to be torn down by means of steel bars. Quality of clinker was generally lesser than quality of clinker produced in rotary kilns.

Shaft kilns remain in operation even in the most advanced countries, however their share in the total cement production is on a decline. They are considered as an obsolete technology and shall be progressively superseded by dry rotary kilns with preheaters.

SHAFT KILNS FOR PORTLAND CLINKER CALCINATION

	Unit	Oldest periodical kilns	Dietsch duplex kiln	Periodical shaft kilns	Schneider kiln	Automatic shaft kilns with horizontal grate		with cone grate
Specific heat consump.	kcal/kg	2300--3500	1200--1650	1700	1200	960	950	860
	kJ/kg	9630--14600	5024--6908	7118	5024	4019	3977	3600
Raw particles shape size	- mm	dried bricks	dried bricks	dried bricks 290x140x80	briquets	compacts	granules	granules of black meal
Moisture content of r.m.	%	5	5	2	2	12	12	12
Height of the shaft (less chimney)	m	5,5	12	7	8-12	11,4	8,6	8,0
Inner diameter of the shaft (less chimney) upper part lower part	m m	1,5 4,0	- -	1,8 2,5	2,5-3,5 2,5-3,5	2,4 2,4	2,8 2,4	2,8 2,4
Fuel		coal	coal anthracite or mix	coke	coke	coke	anthracite	70 % anthracite 30% coke
Electric power requirement of the whole kiln group per 1 t clinker	kWh/t	0	0	0	0	12	12-14	20
Year of commissioning	-	1840-60	1890-1910	1870-10	1910-20	1950-60	1967	1968
Output	tpd	2	17-20	8	15-20	140	180	185
Weight pf fuel to weight of clinker ratio	%	35-55	17-25 ∅ 24	26	17	13	13	12

DEVELOPMENT OF ROTARY KILNS

English engineer Frederic Ransome was seeking to design a rotary
kiln since as early as 1873. In 1885 he was awarded the British
Patent Nr. 5442 (Fig. Nr. 12) on the rotary kiln. His first kiln
for gas firing was set up in 1887 in a small plant at Oregon but
this plant was soon liquidated. Approximately at the same time
his kiln in East Kingston (N.Y.) belonging to Atlas P.C. Corporatic
was being tested. After certain initial difficulties had been
overcome the kiln operated satisfactorily. Ransome's original desi
was for a gas-fired kiln, but then he switched to oil firing. He
also amended the technology of cement manufacture for the rotary
kilns. Based on operational experience, he got the raw meal ground
more finely and moistened it.

Another improvement of the rotary kiln was implemented by American
engineers Harry and Seaman and Atlas Cement Corp. and their amended
kiln of 1895 is considered to have been the first economically
operating unit in the world. The size of the kilns poised on
$\emptyset$ 6 x 60 ($\emptyset$ 1,83 m x 18,3 m). The output reached 34,1 tpd (dry
process) and 23,8 tpd (slurry with 35 % of H20).

After 1890 the rotary kiln appeared in Europe too. For example
in 1896 a rotary kiln $\emptyset$ 1,8 x 12 m was erected at Lollar bei Giesse
this kiln was producing 30 tpd and in 1899 was followed by another
kiln at Hemmoor.

Also the Danish company F.L. Smidth began to construct rotary kilns
with pulverized coal firing, their output reaching 30-60 tpd.

Even T.A. Edison was invited to cooperate on an improved design
of rotary kiln, in particular regarding economy of operation.
(cuts in specific fuel consumption). Edison was clever in realizin
that the kiln dimensions, in particular kiln length, would have to
be enlarged. In 1903 his kiln $\emptyset$ 2,5 x 45,7 m at Stewartsville
was successfully commissioned. The output was 150 tpd in dry
process (heat consumption 2000 kcal/kg of clinker = 8.374 kJ/kg)
and 135 tpd (2530 kcal/kg of clinker = 10.366 kJ/kg) in wet process.

Rotary kiln started gaining predominance over the shaft kilns and
its dimensions were increasingly growing; serious efforts were bein,
made to cut the fuel consumption, in particular by making a better
use of the heat contained in exit gases. This heat was recuperated
either by built-in installations in the kiln, or by heat exchangers
located behind the kiln.

View of the longitudinal section

Cross-section
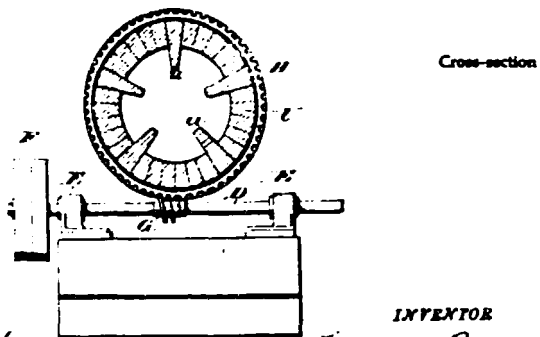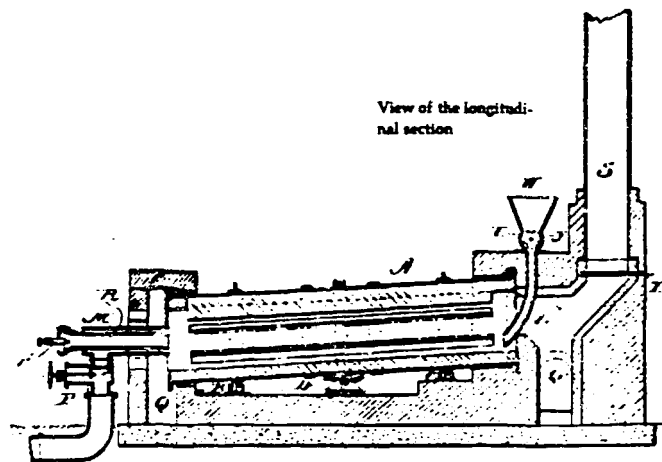
WITNESSES
J. L. Durand
H. A. Smith

INVENTOR
Frederick Ransome
By T. J. W. Robertson
Attorney

Fig. 12 - First rotary kiln for portland clinker
burning (sketch from Ransome's patent)

Raw materials were either ground along with water - consequently
a well fluid slurry was obtained - or were dried, ground in a dry
condition and fed into the kiln in the form of raw meal. In the
former case we speak of the wet process of production, in the latter
of the dry one. In the initial stages of cement manufacture the
wet process was more advantageous since the slurry was perfectly
homogenized which was not possible to achieve with the dry raw meal.
The wet plants produced less dust, were simpler and the quality
of cement was generally better. Particularly good results were
obtained with chalks which were by their high natural water content
and an easy washability, (with no grinding needed) predestined for
the wet process. Easy service and lower consumption of the expensive
electric power were equally advantageous.

Development of long wet rotary kilns

Wet rotary kilns calcined the slurry whose water content enabled the
sufficient fluidity for conveyance, homogenizing and feeding into
the kiln. Water content was mostly 33-38 %, in some cases (when
plastic raw materials were used) exceeded 40 % of H_2O, rarely even
50 %. Non-plastic raw materials and those ground along with
fluxing agents sometimes require only 28-33 % of H_2O.

Thermal balances) shows that the bulk of heat in the wet kilns
is consumed for evaporation of water from the slurry. In the short
wet kilns however the greatest losses of heat were registered in the
hot combustion gases (more than 45 %). Therefore the designers first
sought to increase the length of the kiln. While first rotary kilns
had the dia. : length ratio 1 : 12, currently this ratio for the
wet kiln is 1 : 33 up to 1 : 40. In order to reduce the temperature
of exit gases, i.e. to make use of their heat, the enlarged kilns
had built-in internal heat exchangers that enabled the heat transfer,
sometimes serving also for other purposes (diminishing dust content,
breakage of mud rings, helping the passage of mass through the kiln
and formation of granules).

Among internal heat exchangers in use in rotary kilns we can mention
at least the most widespread ones.

a) Slurry preheaters located at the entrance to the kiln
   Slurry preheaters with heat exchange compartments (Fig. Nr. 12 and
   13). As the figures show, those preheaters are of two basic
   designs of the F.L. Smidth Company - preheaters with transversal
   and longitudinal arrangement of grates.

   Generally in the cement plants the preheaters with transversal
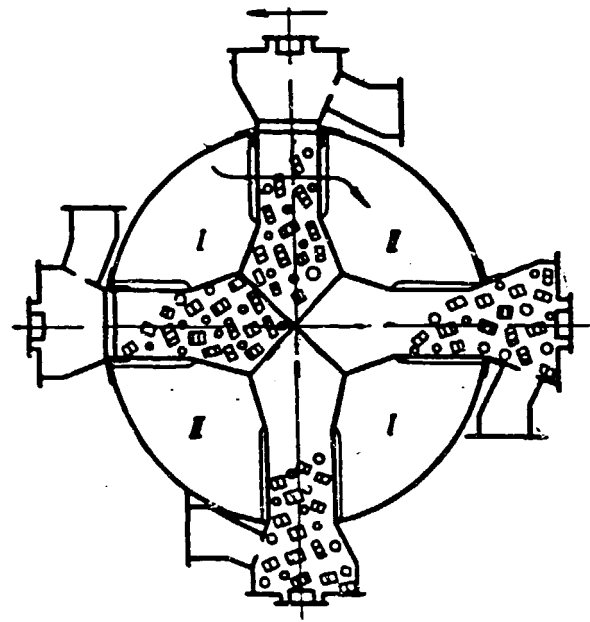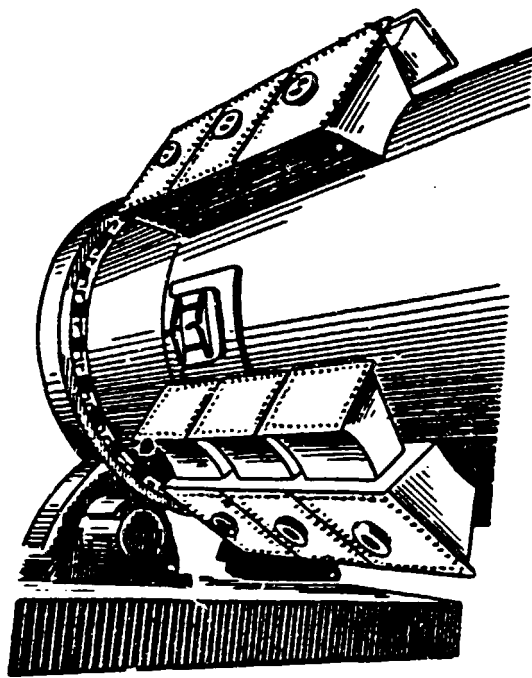   arrangement of grate are in use. They are located 3-5 m from

Fig. 13 - Slurry preheater with heat exchange com-
partments-longitudinal arrangement of the
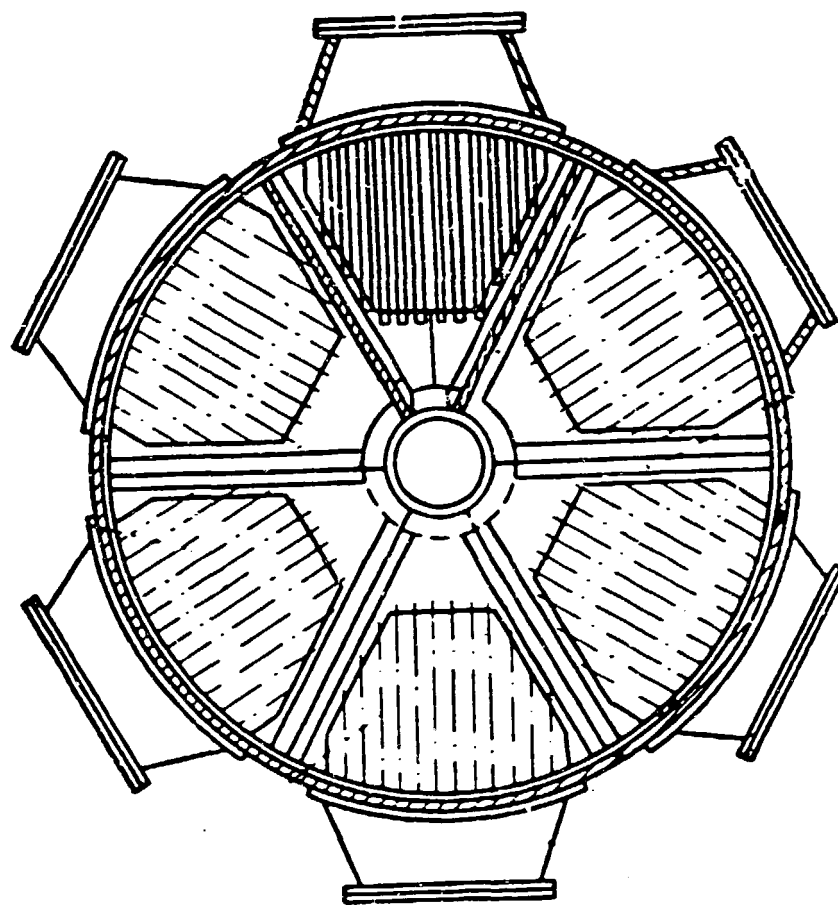grate of F.L. Smidth

Fig. 14 - Slurry preheater with heat exchange com-
        partments-transversal arragement of the
        grate

the end of the kiln and consist of two circular grates built-in tranversally in the kiln. The spacing between the grates is 600 mm as a minimum. The space between the grates is divided into 6 radial sections. The kiln shell above these sections is provided with openings covered from outside by metal pockets. The sections are filled (approx. up to 50 %) with steel rings of approx. 100 mm of length.

Slurry passes through the openings in the diaphragm grate bar and gets in touch with the rings heated by the exit gases that flow in the opposite direction. Moreover, the rotation of the kiln brings the slurry into the flow of gases. Slurry temperature rises by 20-30 % and water evaporates. In addition, nearly half of the dust carried by the exit gases is being intercepted.

Preheaters necessarily increase the aerodynamical resistance by 25-50 mm of water column (i.e. 245-490 Pa). Moreover an inexpert service of the kiln can cause the grates of the preheater to get clogged by the dried slurry which results in a backward flow of slurry into the dust chamber. Therefore sometimes these preheaters are being removed at the expense of the thermal balance of the kiln.

Sometimes chains are being suspended instead of the preheaters with heat exchange compartments.

b) Preheater in the drying zone of the kiln
The most widely used preheater and heat exchanger in this zone are chains, suspended either loosely (chain curtain) or in chain garland. Long wet rotary kilns can have a chain zone that reaches 15-20 % of the kiln total length.

Properly designed chain zone is to help the passage of slurry (later granules) through the kiln, is to transfer maximum possible amount of heat from the gases to the slurry and thus reduce the temperature of gases at the end of the kiln, using the heat for evaporation of water from the slurry. It also has to prevent formation of mud rings in the central part of the kiln, in which the mass is in the form of plastic paste. Last but not least it has to help dedust the exit gases. Granules leaving the chain zone are to have 6-10 % of water content.

c) To accelerate the final drying and preheating of the granules, specia built-in metal fixtures are used, made of abrasion-resistant materials that can also withstand high temperature of exit gases (approx. 800 °C). They are shown in Fig. Nr. 14 and 15). These units are made of high resistant Cr-Ni Steel (25 % Cr and 6 % Ni), are expensive and heavy and can be destroyed if an unskillful operator allows an excessive temperature rise.
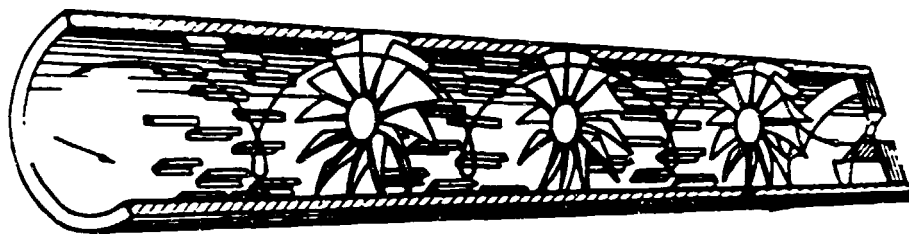
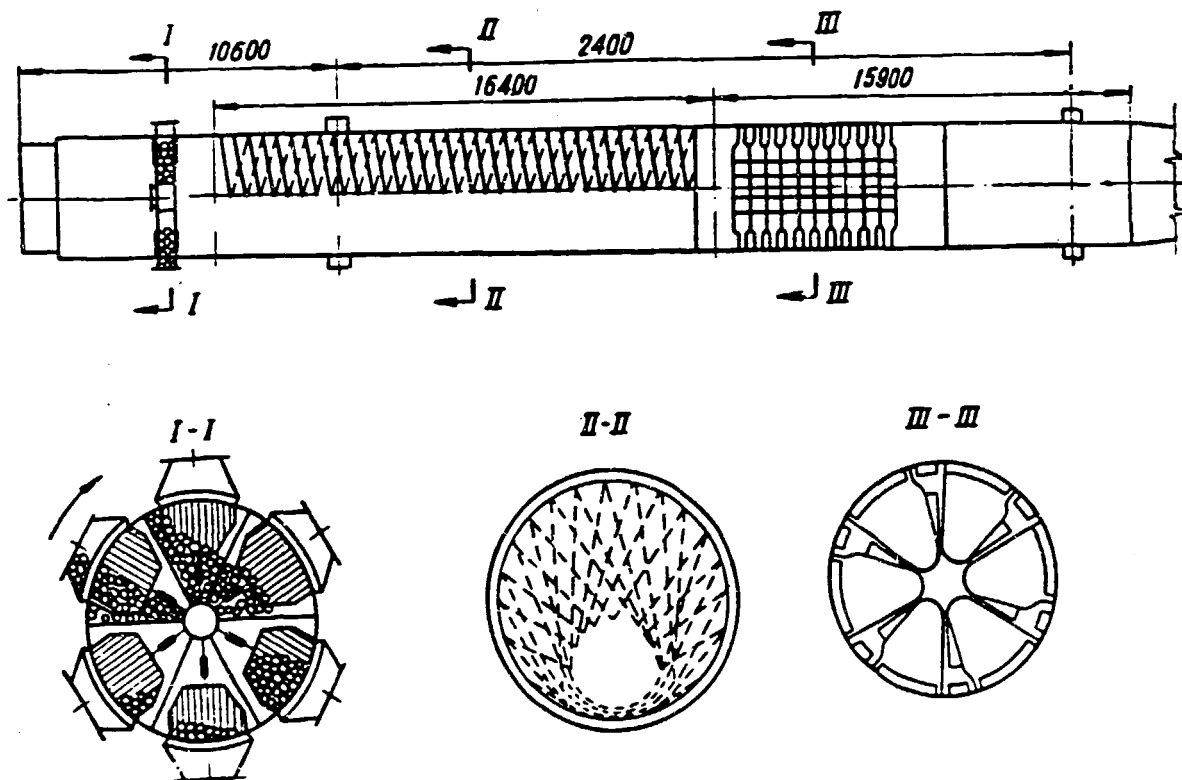Fig. 15 - Preheater Gygi - Holderbank

Fig. 16 - Internal heat exchangers in the long wet

rotary kiln

I - I   slurry preheater with heat ex-
change compartments

II - II   chain zone (garlands)

III - III   cross-shaped built-in instal-
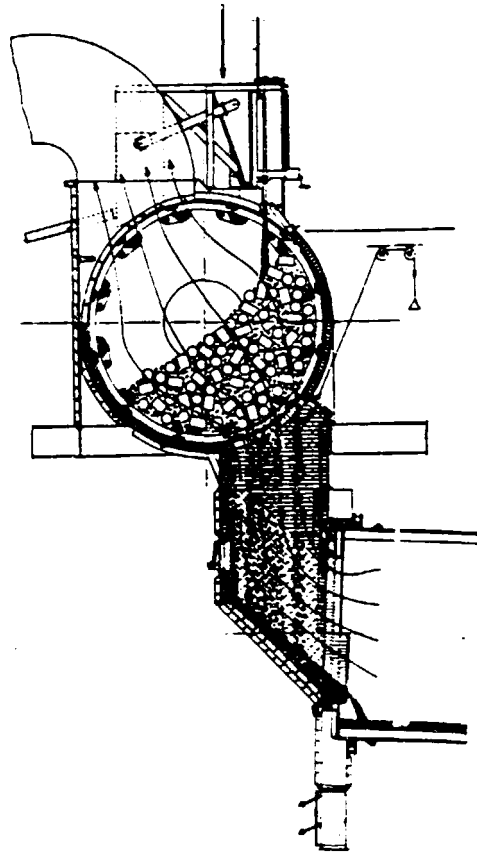lation of the Giprocement design

Fig. 17 - Cross-section of the "slurry calciner"
of Miag Co.

Deeper in the kiln at the end of the preheating zone the ceramic heat exchangers can be installed. These however are more frequently in the rotary lime kilns, while in the cement industry they are scarcer.

External heat exchangers for wet process rotary kilns

Concentrators (calciners) of slurry

In an effort to reduce specific consumption of heat in the short wet kilns in the 1930's, the so-called "concentrators" (Krupp) or "calciners" (Miag.) were in use.

As can be seen from Fig. 16, the equipment consists of a horizontal drum the shell of which is formed by grate bars with gaps of 70 mm. The drum is filled with cast iron ring-shaped pieces. Hot exit gases leave the kiln at a temperature of approx. 600 $^{\circ}$C. The drum rotates slowly (1-2,5 rpm). The slurry is fed into the drum from above and is evenly distributed. In the drum most of the water from the slurry evaporates and simultaneously the gases are cooled down to only 150 $^{\circ}$C.

First concentrators were set up in cement plants in England and Germany and soon spreaded all over the world. The wet kilns from the 1930's that had originally the specific heat consumption of 2.100-2.200 kcal/kg of clinker (8.792-9.211 kJ/kg), once the calciner were installed this figure dropped to 1.500-1.600 kcal/kg of clinker (6.280-6.700 kJ/kg). The output rose by 10-25 %.

In addition to such reconstructions, new more modern units were being installed; their specific consumption was considerably lower - approx. 1.350 kcal/kg of clinker (5.652 kJ/kg), or even less (exceptionally 1.230 kcal/kg of clinker - 5.150 kJ/kg).

Among the deficiencies of the equipment we can mention high emissions of dust, although current electrostatic precipitators enable a perfect dedusting of exit gases. As a matter of fact however, the long wet kilns with a system of internal build-ins provide a simpler operation in comparison with wet kilns with concentrators, they have lesser maintenance requirements, do not consume so much electric power, and there is no danger of the influence of the false air which in the concentrators plays an important part.

Polysius vertical chain drier

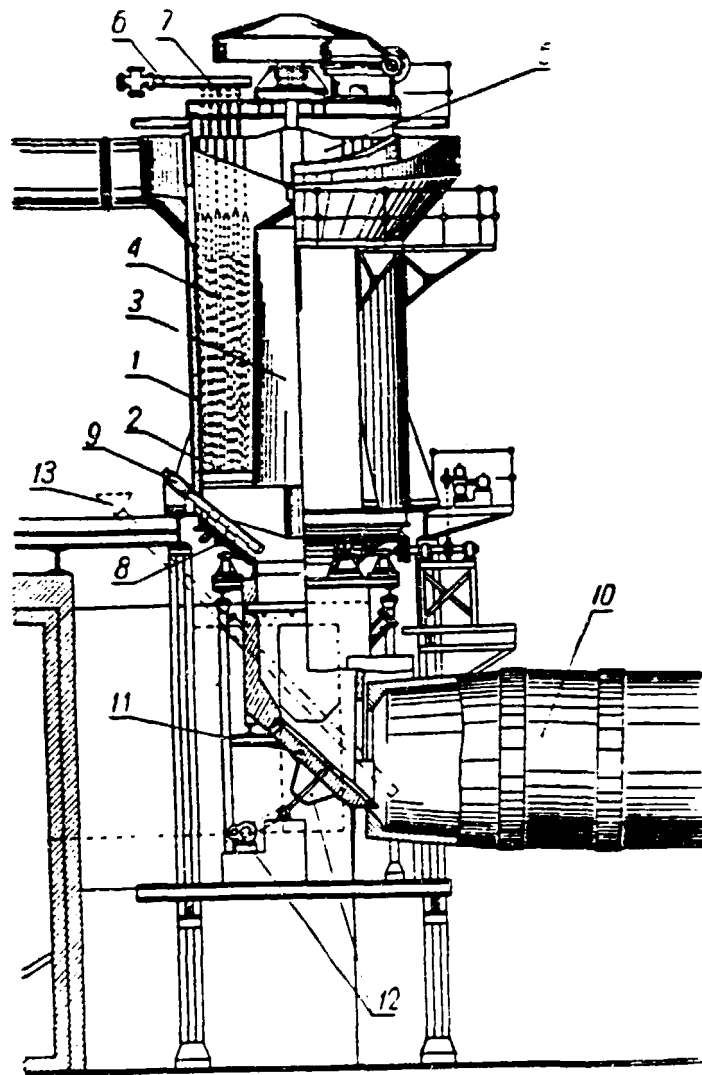The Polysius drier used to be coupled to the wet rotary kilns

Fig. 18 - Polysius vertical chain drier

whose inner dia. : length ratio was approx. 1 : 20. Heat of the
hot combustion gases was used for preheating of the slurry (Fig.
Nr. 17).

The drier consisted of two vertical concentric steel-sheet
cylinders; the outer one was thermally insulated and had at the
bottom a discharge hopper that emptied into the rotary kiln.
In between the cylinder shells, the chains were suspended from
a steel structure that was rotating slowly. The slurry was fed and
distributed evenly onto the chains. During the rotation of the
structure the chains were hitting each other thus being cleaned up
and the material fell onto a gyratory pan; from the pan it travelled
to a movable chute and into the kiln.

With the Polysius drier the output rose by 25 % and the consumption
of fuel dropped by the equal percentage. Exit gases entering the
drier had a temperature of 650-760 °C and were cooled down to
140-200 °C; water content of the slurry was reduced from 35-40 %
down to 10 % of H2O. The equipment required much maintenance.

Drying of slurry in the atomizing drier

In some cases the kiln was combined with atomizing driers that were
drying the slurry in the compartments in which the slurry was
being atomized into the flow of hot exit gases. The output was
raised by 30 % and specific heat consumption was 12 % lower. These
results were obtained e.g. by the Danish company Niro-Atomizer in
cooperation with F.L. Smidth Company. (See fig. 19)

Clinker calcination in long wet rotary kiln

In the wet process of production the kiln is fed with slurry with
water content of 29-55 %, most often 35-40 % of H2O. From the
technological point of view the wet process is the most versatile one.
Although in recent years the wet process is giving way to the
thermally more economical dry process with rotary kilns with
dispersion heat exchangers, yet 40 % of the world production of
clinker comes from the wet process.

Long rotary kiln is a steel cylinder provided with refractory
lining. It rotates generally at a speed of 1,1-1,2 rpm. Raw
slurry is batched at one end of the kiln, while at the other end
(in the kiln hood) the fuel is brought. The slurry proceeds
slowly through the kiln towards the kiln hood which is enabled
by a slight inclination of the kiln (4 %). The slurry is dried
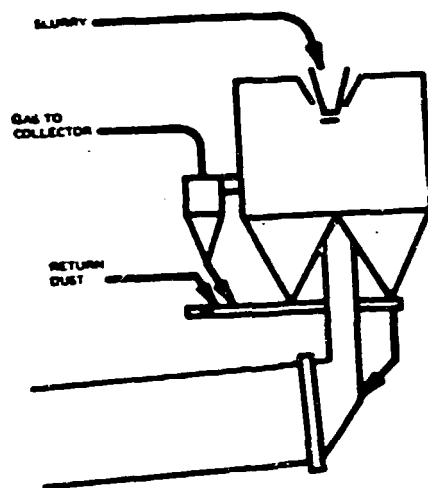in the drying zone equipped with steel chains. The chains absorb

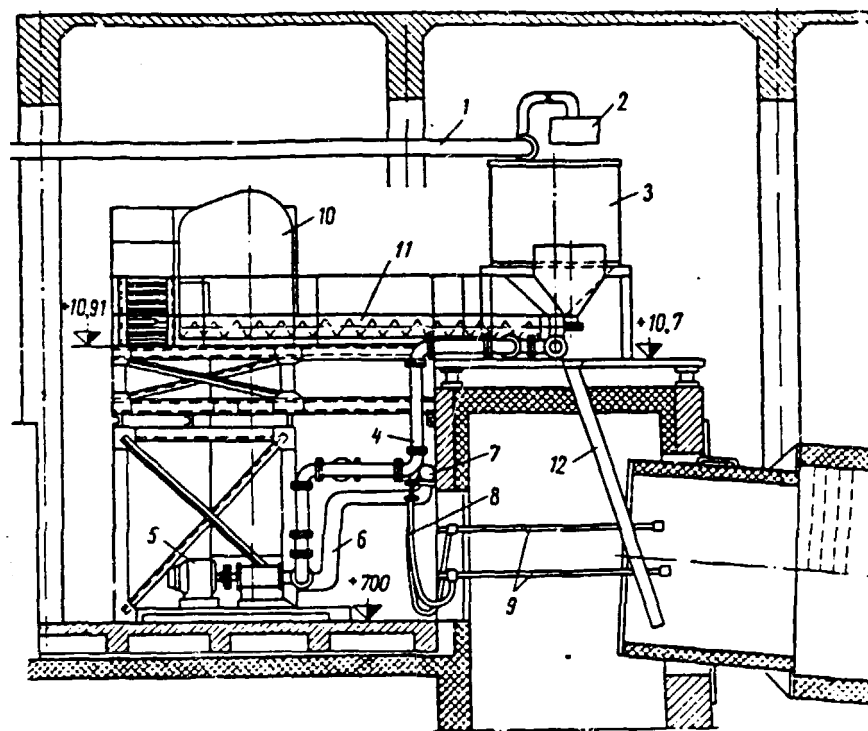Fig. 19 - Operational scheme of spray drying

Niro-Atomizer Co.

Fig. 20 - Slurry force feed atomization into the chain
zone Rigby. (This system was in use in many
countries between 1911 - 1950's. Due to va-
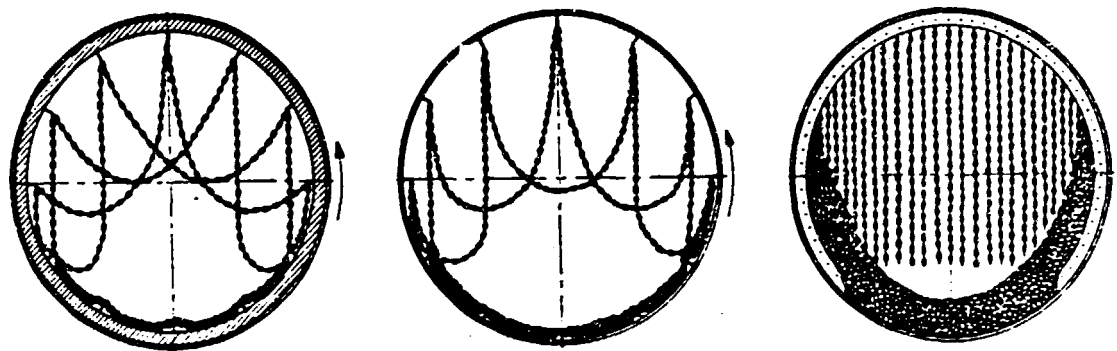rious operational difficulties the system
was abandoned)

Fig. 21 - Cross-section of the chain zone of long
rotary kilns; chain garlands and chain
curtain

the heat from the exit gases and transfer this heat to the slurry. Simultaneously the gases in the chain zone cool down to leave the kiln at 120-300 °C. The chain zone also serves for partial dedusting of the exit gases. On leaving the chain zone, the mass is already in the form of granules with residual moisture 6-10 % of H2O. The granules dry up very fast and proceed further into the calcining zone where (at 900 °C) the calcium carbonate decomposes. In the sintering zone at a maximum temperature of 1450 °C a number of chemical reactions take place, giving rise to tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminosilicate, magnesium oxide and approx. 0,5 % of free lime. At the temperatures that occur in the sintering zone approx. 23-28 % of the mass is in the form of melt and the mass sinters. The product of sintering called Portland clinker is quenched in a planetary, grate or drum cooler and leaves the cooler at 80-150 °C. As a coolant we use the air which is simultaneously heated to a high temperature (500-800 °C) and serves as secondary air. Primary air enters the kiln along with the fuel and represents (when natural gas or fuel oil is used) only 5-15 % of the total amount of air needed for firing; if a coal-fired kiln is concerned, this percentage is approx. 25 %.

Long wet kilns can be built up to the output 4.000 tpd.

Temperatures and individual zones of the wet process rotary kiln can be seen from the following table.

Kiln zone	Temperature of burnt mass in °C		Gas temper. in °C		Estimated length of the zone (in % from total effective kiln length)
	zone entry	zone end	zone entry	zone end	
drying	40	100	200	700	20
preheating	100	550	700	1250	21
calcining	550	1100	1250	1500	33
exotermic	1100	1450	1500	1750	13
sintering	1450	1300	1750	950	8
cooling	1300	1100	950	800	5

Advantages of the wet process of production

1) Preparation of perfectly homogenized raw materials is easier

and therefore the requirements on the extraction, storage, and
joint batching of the raw material components are lesser.
Additional correction of the composition and homogenization is
very simple.

2) Mechanical equipment is not that sophisticated which means
   an easy maintenance and service.

3) If easily washable raw materials are used (soft marls, chalks
   and clays), the wet process enables to remove very easily
   the undesirable admixtures of the rocks, such as quartz sand,
   pebbles, flints, pieces of unweathered primary rocks, gypsum
   crystals etc.

4) Wet grinding is easier than the dry one. Particular economy
   on grinding is noticeable with washable chalks and soft marls,
   where no grinding at all is needed.

5) Porous, soft raw materials with high water content at extraction
   do not need any drying which would even in the dry process
   require the installation of driers with certain heat consumption
   for drying.

6) Very fine chalks that in the dry process cause an excessive
   amount of flue dust from the heat exchanger, are on the contrary
   suitable for the wet process; they form compact granules and this
   not only makes the firing easier but reduces the dust content
   so that no electrostatic precipitators are needed.

7) Wet process of raw mix preparation does not require dedusting.

8) In the wet process cement plant in the departments of raw mix
   preparation and laboratory the numbers of servicemen and
   maintenance staff are substantially lower.

9) Wet process requires less capital investment both for mechanical
   equipment and civil works.

10) Hygienic conditions of work in the wet plant are generally better
    which reflects in a lower accident rate etc.

11) Lower consumption of electric power is a considerable advantage
    of the wet process.

12) Wet rotary kilns produce a better quality clinker. Even if the
    raw meal could be homogenized as perfectly as the slurry, the
    content of alkalies in clinker from dry kilns is 60 % higher

than that from the wet ones, since the absorption of alkalies
in the raw meal in the dispersion heat exchanger is practically
complete.

13) Wet process can make use even of those raw materials for
which the dry process is absolutely inadequate. They are
e.g. sea oysters and other "salted" raw materials with
elevated levels of chlorides, further certain raw materials
that are extremely fine already at extraction, raw materials
with exceptionally high water content (often extracted from
below water level), etc.

14) Refractory lining of the same quality in the sintering zone
of the wet kiln has a longer life (almost a double). Therefore
the wet kilns benefit from shorter downtimes than dry kilns
with dispersion heat exchangers, with logical effects on the
economy of operation.

15) An easy homogenization and correction of raw materials enable
to process raw mixes of four and more components, with great
fluctuations of chemical composition of individual components.

Drawbacks of the wet process

1) In comparison with the dry process with dispersion heat exchange
the wet process always consumes more heat for the burning
proper. The difference is so high that the increased cost of
fuel counterweighs all other advantages of the wet process.
The world energy crisis with sharp rise in fuel prices has
dealt a lethal blow to the wet process. It is believed that
the long wet kilns are going to be used only under very special
circumstances.

2) The wet process is not suitable for highly plastic raw materials
that require exceptionally large amounts of water in order to
reach normal fluidity of the slurry (often above 50 %); thus
the heat consumption (in contrast to the lower output) rises
in view of the necessity to evaporate excessive water from
the slurry.

3) Raw materials containing higher levels of bentonite are less
suitable for the wet process since they can create in the kiln
the so-called mud rings the removal of which is not easy.
Also thixotropic slurries can mean some problems during
conveyance and storage in the silos. On the contrary, the
slurries absolutely non-plastic (e.g. from limestone and slag)
tend to liquation and sedimentation.

All these physical and chemical properties of the slurry can be anticipated and defined by laboratory procedures in analyzing the final raw material samples.

4) Also the consumption of non-return process water is rated among the important disadvantages of the wet process. This kind of water is in some areas of the world very scarce and can be used only for agriculture. In some cases even (in certain regions of Mexico or Iraq or others) the official institutions do not authorize construction of wet process plants.

Semi-dry and semi-wet process of production

Lepol process

For the semi-dry process the raw meal is moistened to 8-15 % of H2O and nodulized. Similarly the semi-wet process uses raw particles obtained by filtration of the raw slurry with granulation or compaction of filter cake with water content of 15-18 %. For the calcination of the raw meal prepared by semi-dry or semi-wet process it is possible to use either long rotary kilns with internal preheaters or short rotary kilns with grate calciners (Lepol System) which are the most economical as far as thermal consumption is concerned.

Rotary kilns with grate calciners (Lepol kilns)

It was in 1927 in Germany when Dr. Lellep was awarded the Patent Nr. 446298 which remarkably influenced the development of kiln systems. Dr. Lellep made use of his vast experience regarding sintering of ores and applied his knowledge to calcination of cement clinker. Essentially he suggested to calcine the nodulized raw mix on the grate by hot exit gases leaving the short rotary kiln. Partially calcined granules enter the rotary kiln in which they sinter. The patent was made use of by the Polysius Company which called the kiln as "Lepol kiln". In 1929-31 the first kiln was installed by Polysius in Germany and shortly afterwards another one in Switzerland. Low heat consumption and high output of the Lepol kiln promoted its rapid spreading in the period between the two World Wars. As many as 53 kilns in 18 countries were operating in 1937, and 2 years later (in 1939) this figure rose to 120.

After the World War II the design department at Neubeckum
implemented various constructional improvements. The so-called
duplex conduction of exit gases through the calcining grate was
developed thus making a better use of their heat; moreover it
improved the calcining process on the grate and dedusting of gases
in the cold chamber (Fig. Nr.22 and 23). While the kilns with
the single conduction of gases featured thermal consumption of
1.050-1.300 kcal/kg of clinker (4.400-5.440 kJ/kg), this data for
the kilns with duplex conduction of gases was below 900 kcal/kg
of clinker (3.770 kJ/kg), and the the large units operated at even
740-780 kcal/kg of clinker (3.098-3.266 kJ/kg), which places this
kiln still among the most economical in this field. .

The largest Lepol kilns produce 3.000 tpd of clinker. In the
post-war period the leading manufacturers of the Lepol kilns
became Polysius and Miag in F.R.G., Zementanlagebau in G.D.R.
and Allis-Chalmers in the U.S.

Good results in reducing the thermal consumption were obtained
also thanks to a series of other technical improvements such as
replacement of drum coolers with the grate ones, etc.

In 1960 as many as 290 Lepol kilns were in operation. In the 1970's
there was a slowdown in their construction due to the competition
with the kilns with dispersion heat exchangers, which apart from
lesser maintenance requirements make use of the hot exit gases
of 360 °C that serve for drying of raw meal in the mill or in
a drier.

Clinker calcination in the Lepol kiln

Raw materials are conveyed to the Lepol kiln either in the form
of homogenized raw meal with residual moisture of approx. 0,5 %
of H2O (A), or as a filter cake with 15-17 % of H2O (B).

In case of (A) the raw meal is routed onto a nodulizing disc where
it is moistened and where the meal forms granules of Ø 10-15 mm
with moisture content of 12-14 % of H2O. These granules are
directed onto the calcining grate. We speak of a semi-dry
preparation.

In case of (B) it is also necessary to convert the filter cake
into grains with appropriate moisture content, geometrical shape
and compactness. For solid cakes, obtained by pressure filtration,
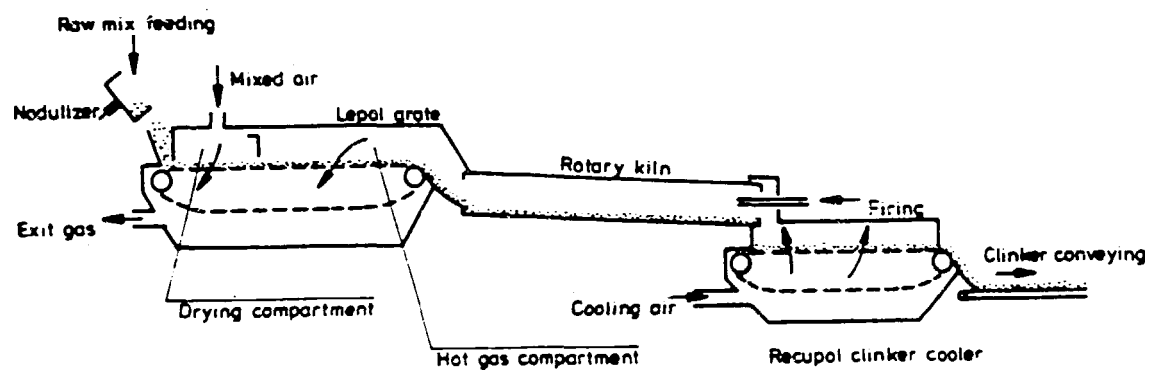the extrusion presses generally suffice. If the cakes are too soft,

Raw mix feeding
Mixed air
Nodulizer
Lepol grate
Rotary kiln
Firing
Exit gas
Clinker conveying
Drying compartment
Cooling air
Hot gas compartment
Recupol clinker cooler

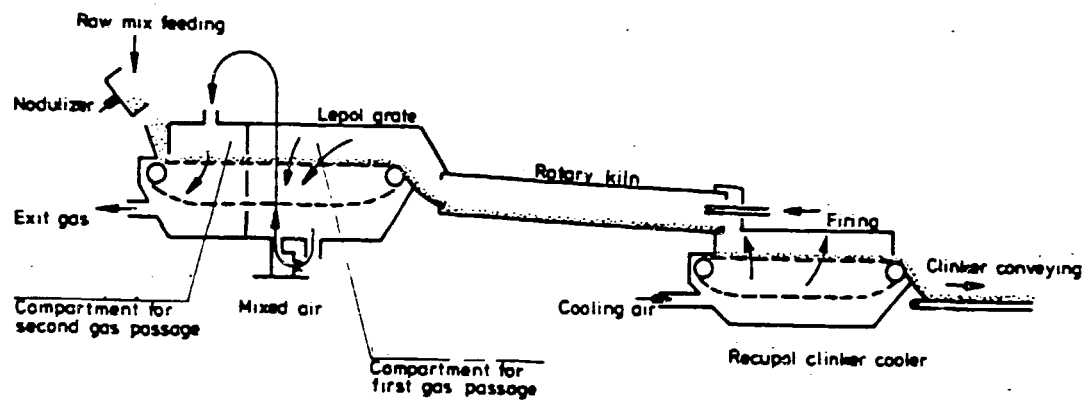Fig. 22 - Lepol kiln with single gas circuit

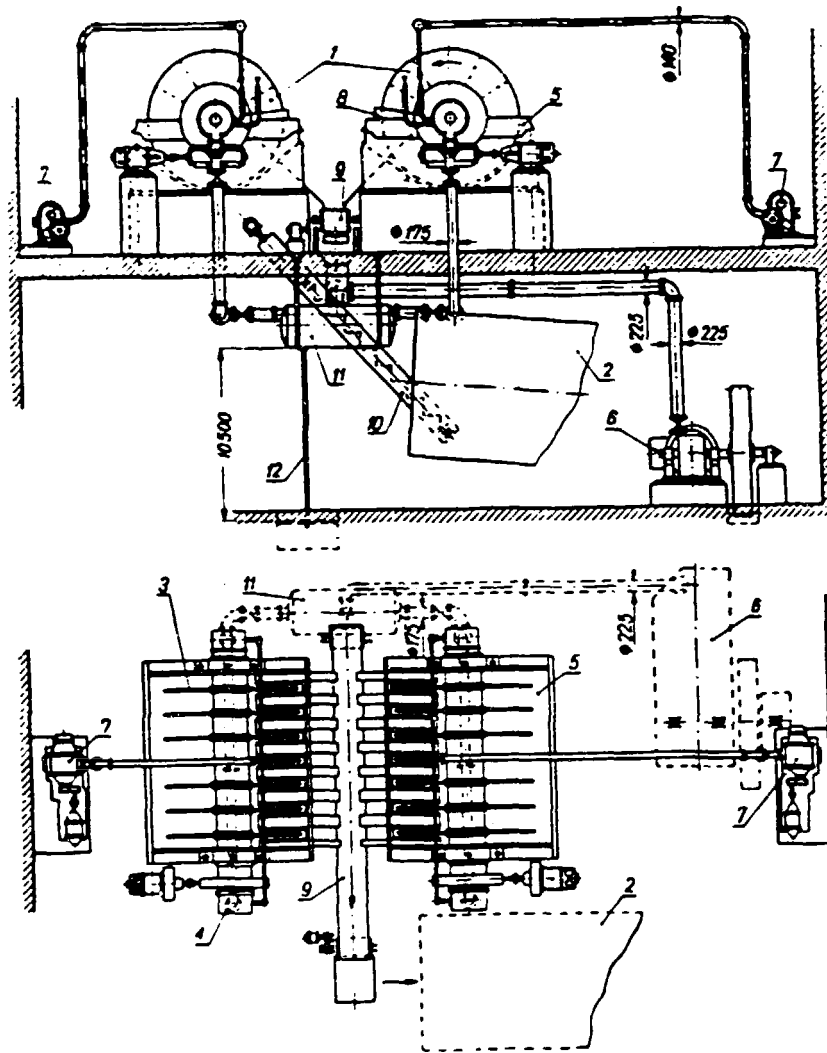**Fig. 23 - Lepol kiln with double gas circuit**

Fig. 24 - Vacuum disc filters for slurry filtration
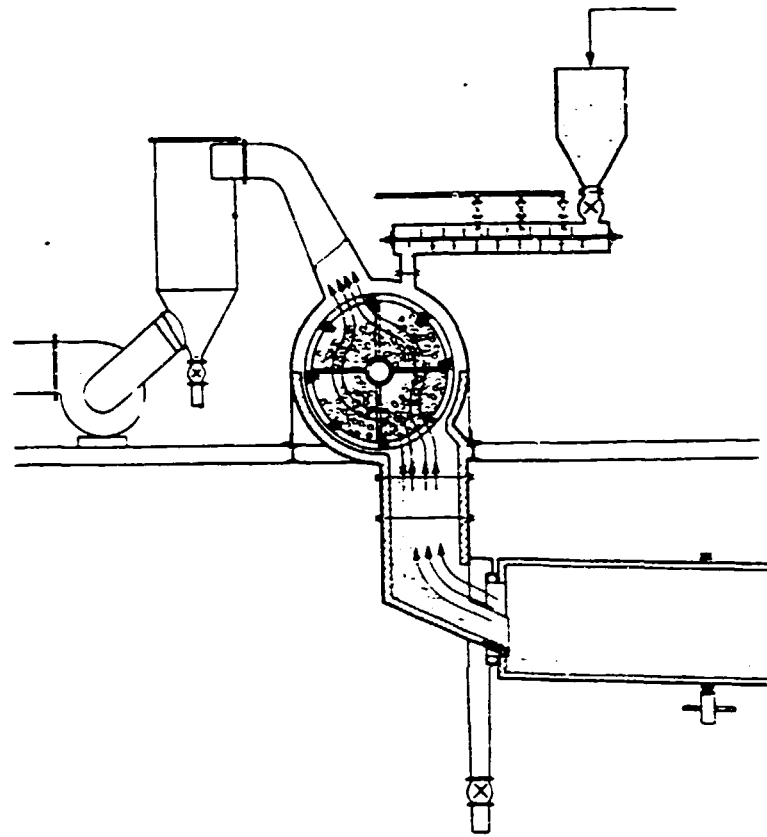and filter cake feeding into the rotary
kiln

Fig. 25 - "Concentrator" of the Miag Co. for
moistened raw meal

it is sometimes necessary to add dry raw meal or precipitated dust, granulation following afterwards. These processes are particularly advantageous if the wet kilns under reconstruction use soft raw materials with high moisture content, e.g. chalks. In this case we speak of a semi-wet process of production. This process can be also resorted to if soft raw materials with elevated chloride content are to be used. A substantial part of chlorides is removed during filtration and the rest can be eliminated by means of the so-called by-pass which enables a derouting of a part of exit gases from the hot chamber of the calcining grate.

Raw meal grains are fed onto the calcining grate. The space around the grate is lined and divided into a cold (drying) chamber and a hot chamber. The layer of granules (140-200 mm thick) is carried by the grate first into the drying chamber where it meets the combustion gases (300 °C); on passing through the layer of moist granules the gases cool down to 90-120 °C. Gases that passed through the layer of granules travel then through the gaps in the grate bars (of 8 mm of width). Dried and preheated granules then enter the hot chamber where they are calcined by hot gases from the kiln (1.100 °C).

The clinker calcination process ends up in the short rotary kiln where the granules sinter. The Lepol kiln has the optimum length to inner dia. ratio of 14 : 1. Owing to the thermal preparation of the raw materials on the grate, the final phase of burning in the rotary kiln is very intense which is testified by the specific output of the Lepol kiln which - at peak performance - reaches 2,2 t/m3 per day. The grate shifts at a speed of 25-50 m/hour, while the passage of material through the kiln takes 80-100 minutes. Disintegrated granules that fall through the grate are conveyed by means of a chain conveyor and elevator into a cooler, generally the grate cooler.

Raw materials suitable for calcination on the Lepol calcining grate

The crucial point here is the necessity to obtain the raw particles that are perfectly compact, can withstand temperature upsurge, and must be abrasion-resistant. More suitable for these purposes are the plastic raw materials containing the clay mineral montmorillonite. Therefore a maximum possible attention is to be paid to the selection of the raw material components, in particular regarding the sialit[ic] component (generally clay). The granules are to be compact enough to avoid their deformation during conveyance from the nodulizer to the grate, enabling an adequate permeability of the layer of granules for the hot gases, which is a precondition for a normal operation of not only the grate but of the kiln as a

whole. If the granules are too hard, with strength exceeding
1.500 g (at granule dia. of 15 mm), they are less porous and
generally less resistant to the thermal shock of hot gases which
results in their disintegration or explosion. On the other hand
granules with strength below 600 g get plastically deformed.
Also the way of formation is of great importance. Moreover the
less plastic raw materials feature a low resistance to abrasion.
If a maximum of 5 % of grains fall through the grate it is
considered as operationally tolerable.

In order to summarize the topic we can say that an extraordinary
care has to be taken to select the raw materials and that their
analysis deserve a special attention, all this being possible
only in a close cooperation with the manufacturer of mechanical
equipment.

Dry process of production

In cement plants that operate on the dry process of production,
the old short kilns without the heat exchangers are today practically
non-existent. Most of the kilns currently in use have dispersion
heat exchangers, or they are long kilns with internal preheaters,
or possibly with one- or two-stage exchangers; still there are
plants using dry process kilns with waste heat boilers which were
left over from older systems.

Short rotary kiln with waste heat boiler

The waste heat boilers were being incorporated to rotary kilns in
order to recuperate the heat of hot exit gases whose temperature
reached 700-1.000 °C (Fig. Nr.26). Of the total thermal
consumption of 1.550-1.850 kcal/kg of clinker (6.490-7.746 kJ/kg),
approx. 550 kcal/kg (2.302 kJ/kg) were used for production of
electric power. This technology was used mainly in 1940's.

Currently it is more economical to construct kilns with heat
exchangers of a lower thermal consumption, and to procure electric
power in the power plants where its production uses a lower-grade
fuel and is much more efficient.

Dry long rotary kilns

Among the dry long rotary kilns we generally reckon those whose
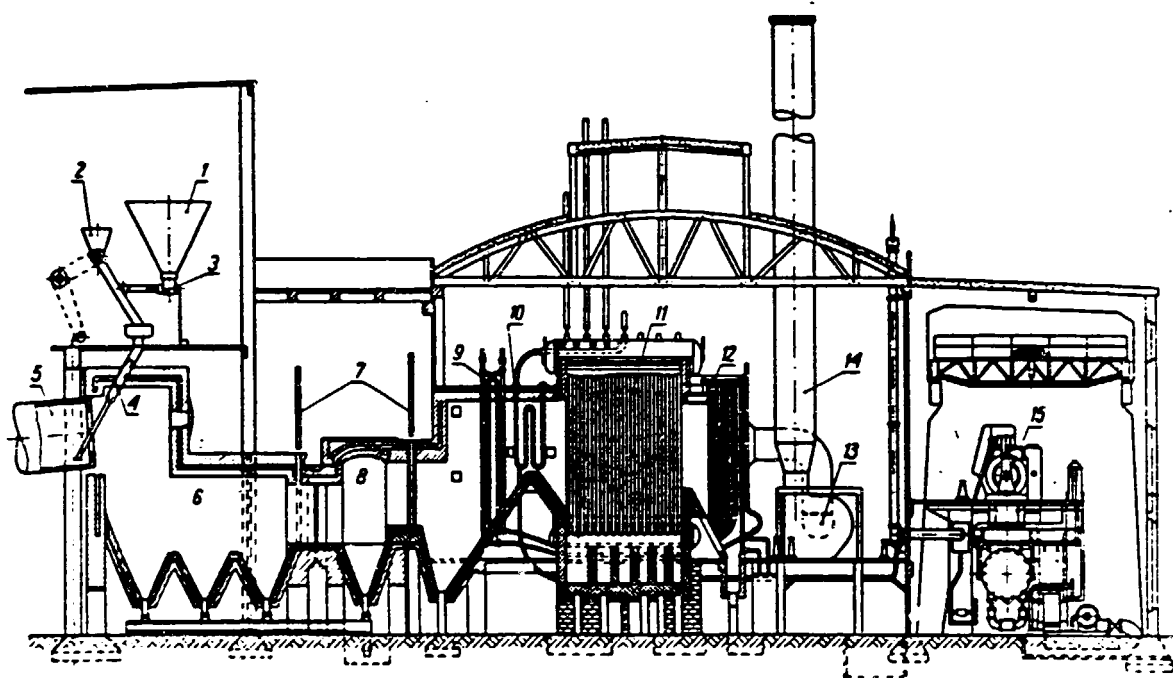inner dia. : length ratio is 1 : 30 or more. Modern kilns have this

Fig. 26 – Boiler using waste heat from the rotary kiln

SEMI-DRY AND SEMI-WET ROTARY KILNS AND SINTERING GRATE

	Unit	Long rot. kiln on granules and preh.	Lepol Kiln conduction of gases			Kilns with calciners on moiste- ned raw m.	Sinte- ring gra- te Krupp- -Lurgi
			single	duplex	3 chambers		
Specific heat consumption	kca/kg kJ/kg	1.180 4.940	1.050 4.400	850 3.560	760 3.180	1100-1200 4605-5024	1240 5192
Output of the kiln	tpd	338	250	400	1.920	100-1000	340
Specific output of the kiln in metric tons/day for 1 m3	t/m3/d	0,58	1,62	2,09	1,41	0,8-1,1	15 t/m2 of grate/d
Moisture content of raw mix	%	13	14	14	13	12-15	14
Temperature of gases after kiln after exchan.	°C	250	900-950 120	1000-1100 90	1120 120	700 , 240-400	240 -
Temperature of raw mix into kiln	°C	(granules) 20	760	800	850	250	20
Percentage of apparent dissoci- ation of raw meal entering kiln	%	-	40	45	45	-	-
Length : inner dia. ratio	m/m	28:1	15:1	14:1	17:1	20:1	-
Electric power requirements for clinker production (total kiln group)	kWh/t	9	9	13	17	18-19	25-30
Fuel	-	coal	oil	oil	heavy oil	various	coke
Cooler type	-	planetary	drum	grate	grate	various	-
Kiln dimensions Ø x length	m x m	3,4x85	2,8/2,6x36	3x36	4,7x75	-	26 m2
Calcining grate size widthxlength	mxm	-	2,42x12,5	3x12,5	4,76x37,5	-	-
Country/year	-	Yugoslav. 1958	Jordan 1954	Jordan 1963	Japan 1966	FRG -	FRG 1952
Manufacturer	-	MIAG FRG	Polysius FRG	Polysius FRG	Kawasaki Japan	Miag,Krupp FRG	Krupp, Lurgi FRG

ratio 1:33 - 1:38. These kilns were developed in the U.S. since
they were operationally reliable, required minimum service and
maintenance and the consumption of electric power for the kiln
drive (6-8 kWh/t of clinker) was absolutely the lowest of all
kilns. Somewhat higher heat consumption in comparison with
European kilns was (until the breakout of energy crisis) of
secondary importance.

In 1962-63 as many as 314 these kilns were operating in the U.S.,
and today they still provide 30 % of the North America's production
of clinker. In Europe and in other parts of the world however
these kilns are very scarce, e.g. in F.R.G. they account only for
2 % of the clinker production.

Dry long kilns were originally constructed with no internal or
external heat exchangers. Exit gases at the end of the kiln used
to have a temperature of 700 °C or more and had to be efficiently
cooled down - most frequently by injections of water - in order to
be exhausted by a fan or dedusted.

In the 1950's the internal heat exchange system were becoming more
widely used. First the systems of heat-resistant steel chains were
implemented. Later the cross-shaped internal ceramic heat exchangers
were tested in the calcining zone, later also the cross-shaped steel
exchangers. Temperatures at the end of the kiln dropped to 430-
-530 °C and the heat consumption lessened to 950-1.170 kcal/kg of
clinker (3.977-4.900 kJ/kg), according to the quality of design and
workmanship of the exchangers. If the hot exit gases are used
as a drying media in a drum drier, it is possible to remove as much
as 13 % of the moisture from the raw mix.

The incorporation of cyclone preheaters meant a significant progress
in the development of dry rotary kilns. This helped not only dedust
partially the exit gases, but resulted in diminishing their
temperature and reducing the specific heat consumption down to
850 kcal/kg of clinker (3.559 kJ/kg).

As a rule the following combinations are in use:

1) Dry long kiln with two cyclone preheaters in parallel arrangement
   (i.e. one-stage heat exchange).

2) Dry long kiln with one preheater in the first stage and two
   preheaters (smaller ones) in the second stage.

3) Two-stage preheater of the F.L. Smidth Company consisting of
   an outer cyclone preheater with lining and an inner cyclone
   preheater (Fig. Nr. 27).

All these arrangements are interesting also from the point of view of conversion of the long wet rotary kilns to the long dry kilns.

Long dry kilns were constructed for outputs of up to 3.000 tpd. In view of the fact that the heat exchange in the long kiln is far from being efficient, the specific output of these kilns is low and their dimensions are extreme. A kiln of even 5.000 tpd of clinker was designed; the shell of this giant kiln was computed to be $\emptyset$ 7,5 x 260 m.

In comparison with the short kiln with dispersion counter-current heat exchanger, the long dry rotary kiln requires 45 % more of capital investment.

As regards the operational reliability, the long dry kilns are less sensitive to clogging caused by alkali salts, and their drag is low which reflects in the power requirement of the kiln exhaustor.

The Grudex System

This heat exchanger, constructed by Kennedy van Saun Co. in the cement plant at Coplay (Coplay Cement Corp., Pa ` loses the meal to the pneumatic Fuller-Kynion pump which for es t. .eal through a spiral tube made of heat-resistant Cr-Ni steel. The spiral is located in a vertical tower provided with lining, through which the hot gases from the dry rotary kiln pass (Fig. Nr. 28). Raw meal is preheated to 700-760 °C. The Grudex heat exchanger contributed to an increase in output by 36 %, and to a drop in heat consumption by 44 % (specific heat consumption for clinker burning after reconstruction amounts to 1.090 kcal/kg of clinker (4.564 kJ/kg).

Dry process of production with dispersion heat exchangers

Homogenized raw meal is continuously dosed into the shaft dispersion heat exchanger or into the four-stage cyclone preheater. Hot gases from the rotary kiln entering the exchanger have a temperature of 1.050 °C and they pre-heat and partially calcine the raw meal. Raw meal enters the heat exchanger at 40 °C and leaves at 800 °C. Exit gases enter the exchanger at 1.050 °C, transfer their heat to the raw meal and leave the exchanger at 340 °C. These gases are cooled and moisten in the conditioning tower and dusted off in the electrostatic precipitator. Preheated raw meal from the heat exchanger enters the short rotary kiln where the burning process
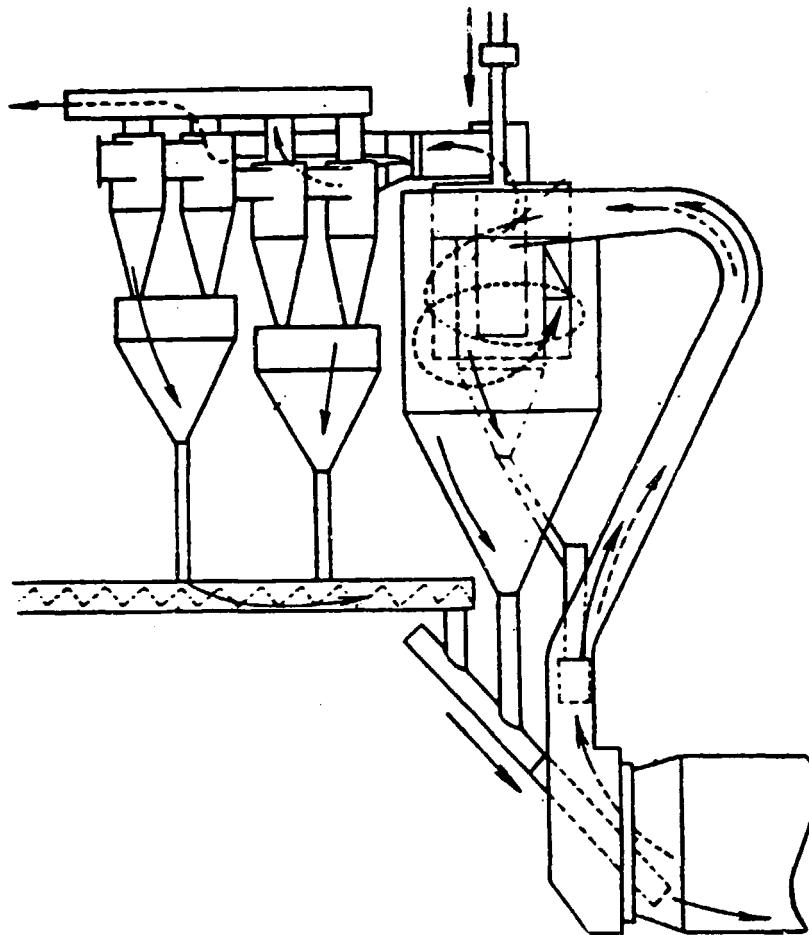
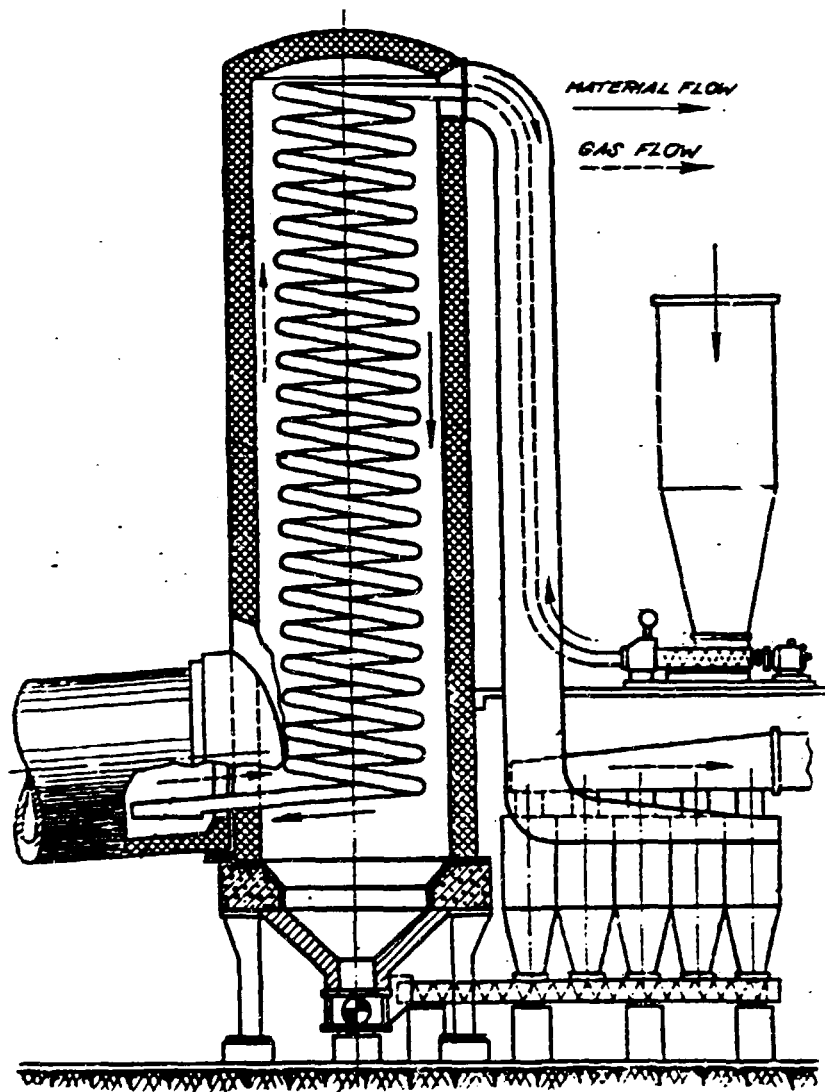Fig. 27 - Two-stage cyclone heat exchanger of

F.L. Smidth Co.

MATERIAL FLOW →

GAS FLOW - - →

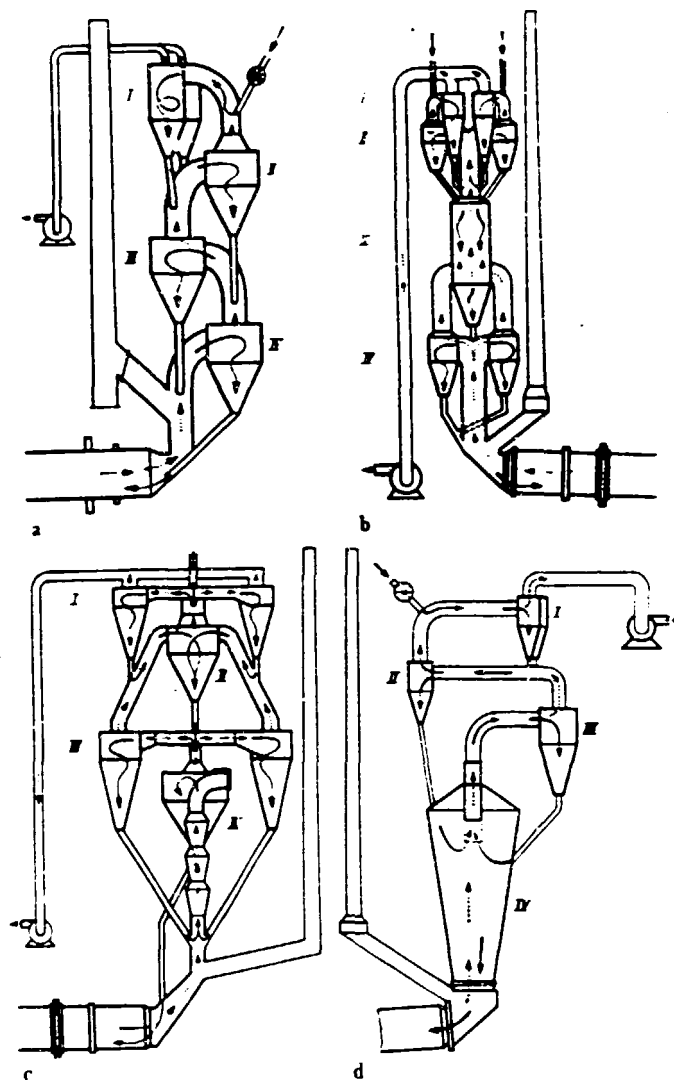Fig. 28 - Grudex heat exchanger (Kennedy van Saun Co.)

Fig. 29 - Dispersion heat exchangers

      a) Humboldt

      b) Polysius
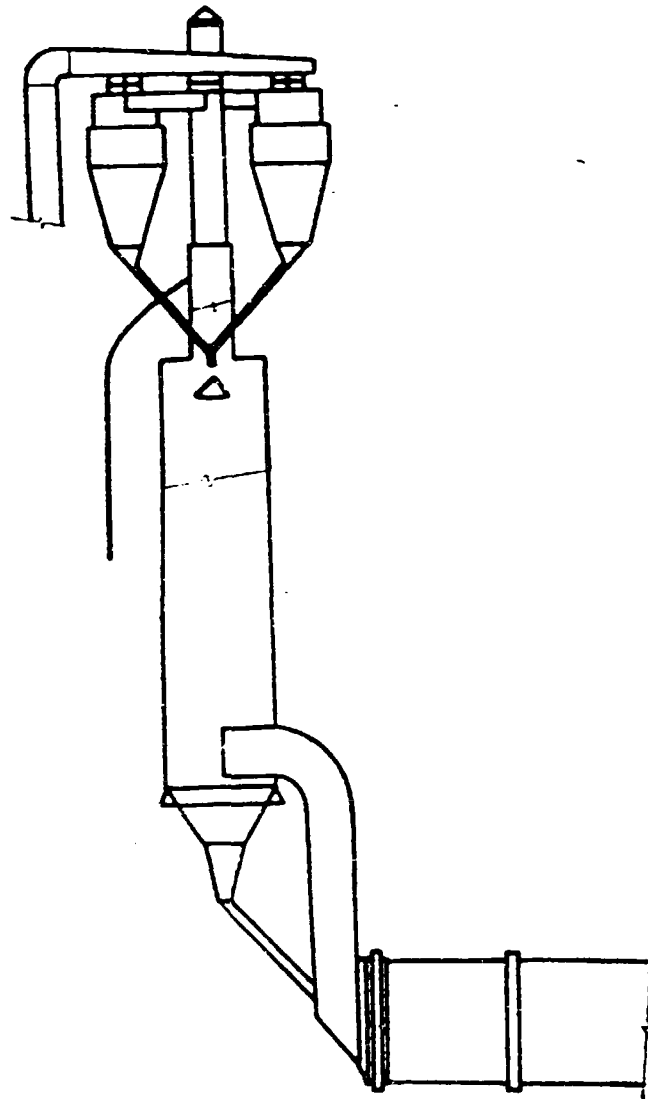
      c) Wedag

      d) Miag

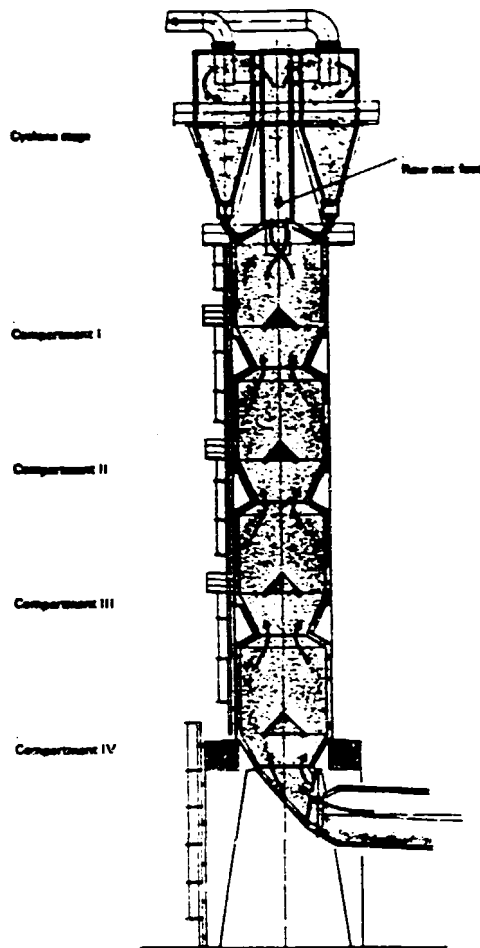Fig. 30 – Dispersion shaft counter-current heat
exchanger of Prerov Machinery

Fig. 31 – Cross-sectional view of the Krupp counter-
current heat exchanger

terminates. Clinker produced in the sintering zone is cooled in the grate cooler.

The preparation of the raw meal for the dry process of cement manufacture is considerably more complex, but the heat consumption in this case is low and therefore this process shall in the future prevail.

Dry process kilns with dispersion heat exchangers can produce 300-5.000 tpd at calorific consumption of 960 kcal/kg of clinker (3.182 kJ/kg) - 720 kcal/kg of clinker (3.017 kJ/kg). The larger the kiln, the more economical operation.

Dispersion heat exchangers are either cyclone heat exchangers of Humboldt, F.L. Smidth Co., Ishikawajima-Harima Co., or shaft counter-current heat exchangers - Prerov Machinery, Krupp, Zement-anlagebau Dessau, or they combine cyclones with turbulence shafts where the gases are routed into two channels - Polysius, Wedag, Kawasaki, UBE, Miag, Allis-Chalmers.

Some of the mentioned manufacturing companies were themselves the inventors of the systems, some of them build the systems with a license. Technical description of all systems of dispersion heat exchangers would go beyond the framework of this study. However it is possible to say that generally all these companies are able to construct exchangers for the kiln of 3.000 tpd, some of them erected heat exchangers for over 4.000 tpd. In one project there is even a heat exchanger of over 5.000 tpd of clinker. As regards the specific heat consumption, all heat exchanger systems are capable of reaching the specific heat consumption of 800 kcal/kg of clinker (3.349 kJ/kg) or even lower. It depends also on the output of the kiln. Larger units have a lower thermal consumption as was found by G.A. Schroth for cyclone heat exchangers in 1973:

kiln output	Specific heat consumption	
tpd	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
1.600	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

DRY ROTARY KILN WITH DISPERSION HEAT EXCHANGERS

		Short rotary kiln with dispersion heat exchanger	
		KHD four-stage cyclone exchanger	Shaft counter-current exchanger Prerov Machinery, grate c.
Specific heat consumption	kcal/kg kJ/kg	724 3.031	740 3.098
Output of the kiln	tpd	1.530	3.000
Specific output of the kiln in tons of clinker/day per 1 m3 of inner space of the kiln	t/m3/d	1,79	1,63
Moisture content of raw meal	%	0,5	0,5
Temperature of gases after kiln after exch.	°C	1.050 340	1.050 350
Temperature of raw meal into the kiln	°C	800	800
Percentage of apparent dissociation of the raw meal	%	45	45
Length to inner dia. ratio	m/m	17,4 : 1	17,6 : 1
Electric power requirements for the whole kiln group	kWh/t	17	-
Fuel	-	oil	heavy fuel oil
Kiln dimensions	-	4,4 x 68	5,6 x 90
Manufacturer		KHD - F.R.G.	Prerov Machinery Czechoslovakia

**Raw materials suitable for the dry process of production
with kilns with dispersion heat exchangers**

In preparing the technology for the dry process of production,
special attention has to be paid to the total content of alkalies,
sulphides, sulphates and chlorides both in the raw mix and in
the fuel.

General condition is that the alkali content in the raw mix must
not exceed 1,5 %. Chloride content (expressed as Cl´) is not to
exceed 0,04 % and sulphur content of raw meal plus fuel, calculated
in SO3, may not exceed 1 %.

Dispersion heat exchangers are not very suitable for the raw
materials with elevated content of alkalies. Alkalies clog the
gas ducts and exchangers, in particular when they are combined
with sulphates and chlorides. Difficult problems in operation
are frequent and sometimes even the kiln has to be shut down.

Maximum caution has to be taken when raw materials from desert
areas are used, since they generally contain dangerous levels of
soluble alcalic salts (chlorides, carbonates, sulphates). This
is true in particular for the Middle East countries, namely
Egypt, Saudi Arabia, Iran, Kuvait, further certain regions in
South America e.g. northern parts of Argentina etc.

Kilns with dispersion preheaters and flash-calcining system

The Ishikawajima-Harima Heavy Industries Co. (I.H.I.) developed
a system of the so-called flash chamber which is coupled to the
lower part of the heat exchanger. By means of conduction of
larger amounts of heat into the exchanger the rate of calcination
of the raw meal entering the kiln rose to 90 %. Part of the hot
air from the grate cooler (temperature 600-650 °C) was used as
the firing air. This system has been put into operation in the
cement plant in Chichibu Cement Co. on the kiln $\emptyset$ 3,9 x 51 m
with a KHD heat exchanger. Specific output rose from 1,522 t/m3/
/day to 3,384 t/m3/day. This system enabled to build the cement
producing unit of 7.700 tpd.

Additional firing into the heat exchanger is a basis for a couple
of recent systems. Due to the lesser amounts of fuel burnt in
the rotary kiln, the life of refractory lining is longer, which
was decisive particularly in large units. The transfer of
calcining process into the heat exchanger made the burning process

DRY ROTARY KILNS

	Unit	Dry rotary kiln				
		Short	Short	Long kiln with pre heater	and cyclone	with waste heat boiler
Specific heat consumption	kcal/kg	2200	2000	950	850	1500-1850 x)
	kJ/kg	9211	8374	3977	3559	6280-7746
Output of the kiln of cl.	tpd	35	150	630	1000	80-3300
Specific output of the kiln in metric tons of clinker/day per 1 m3 of inner space	t/m3/d	1,02	0,868	0,6	0,7	0,8-1,32
Moisture content fed raw m.	%	0,5	0,5	0,5	0,5	0,5
raw m. into the kiln	%	0,5	0,5	0,5	0,5	0,5
Temperature of after kiln gases	°C	950	650	450	400	700-1000
after exch	°C	-	-	-	-	180
Temperature of raw. mix into the rotary kiln	°C	40	40	40	40	40
Percentage of apparent dissociation of the raw m. entering the kiln	%	-	-	-	-	-
Length to inner dia. ratio	m/m	12 : 1	21 : 1	44 : 1	38 :1	17-25 : 1
Electric power requirement of the whole kiln group	kWh/t	-	10	8	7	12-15
Kiln dimensions ⌀ x length	mxm	1,6 x 18,2	2,5x 45,7	3,75/3,45 /3,75 x144	-	various
Year	-	1887	1903	1963	1973	1930-80

x) Out of this quantity 500-700 kcal are used for production of electric power
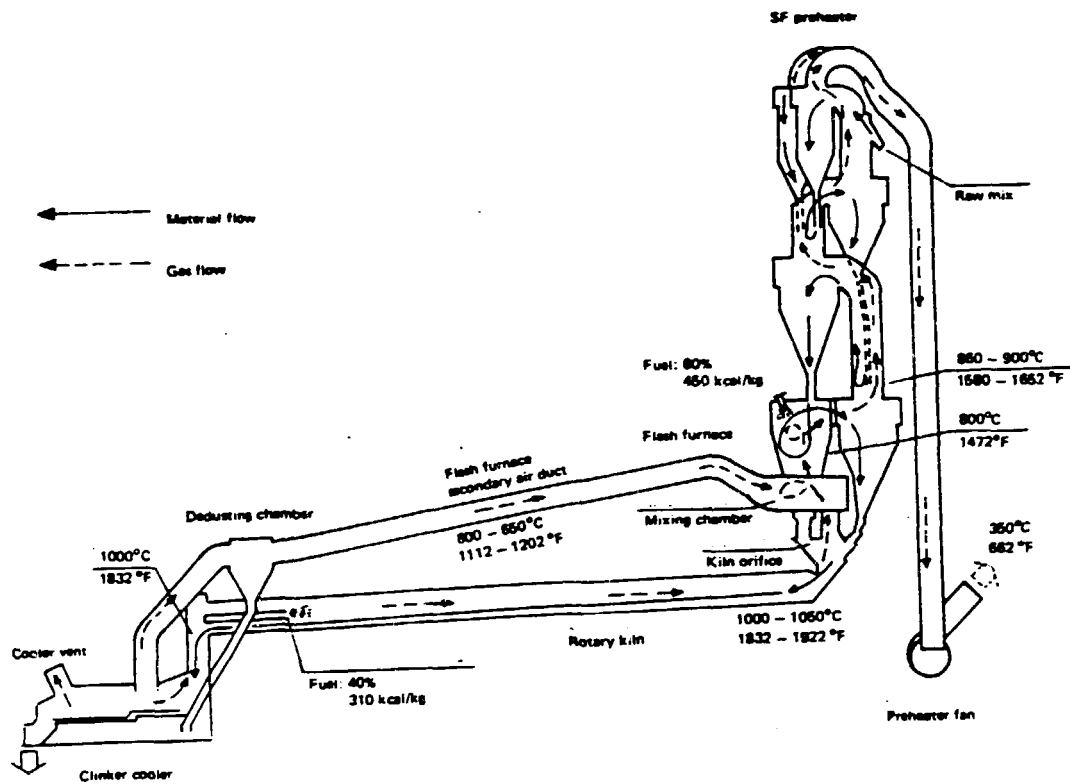
Fig. 32 – Sketch of the SF heat exchanger of the
Ishikawajima-Harima Heavy Industries Co. Ltd
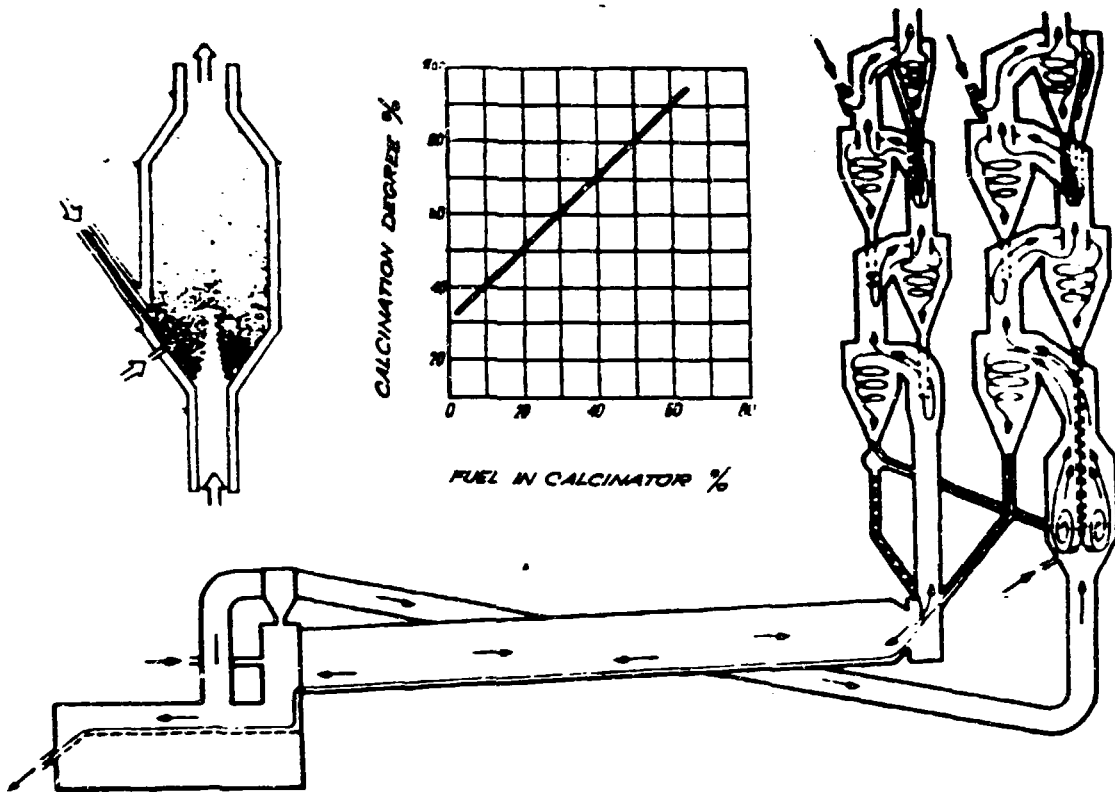
Fig. 33 - Flash-calciner system of the F. L. Smidth Co.
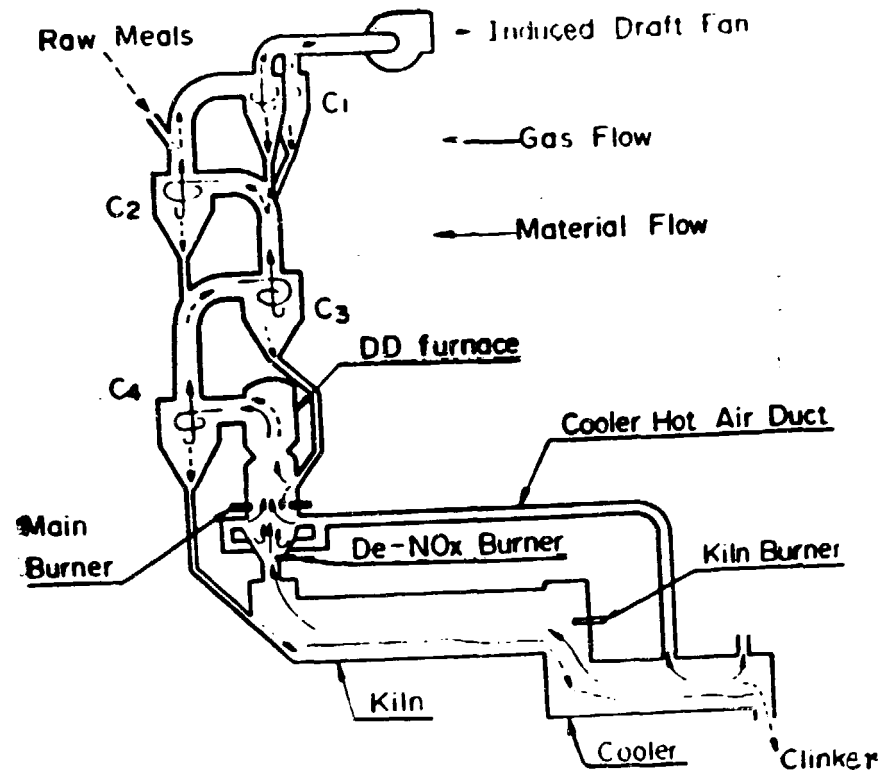
Fig. 34 - DD Flash-calciner system (Dual Combustion
and Denitration Calciner) of the Nihon
Cement Co. Ltd
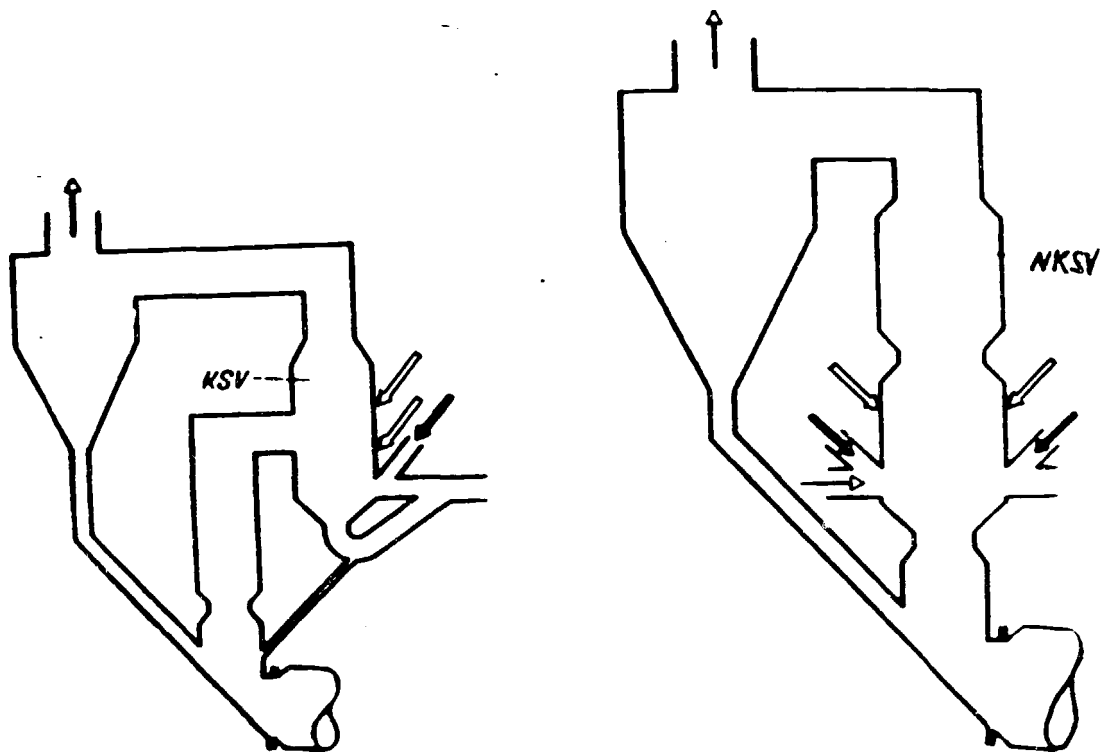
Fig. 35 – Fire box of the flash-calciner system

KSV and NKSV of the Kawasaki Co.
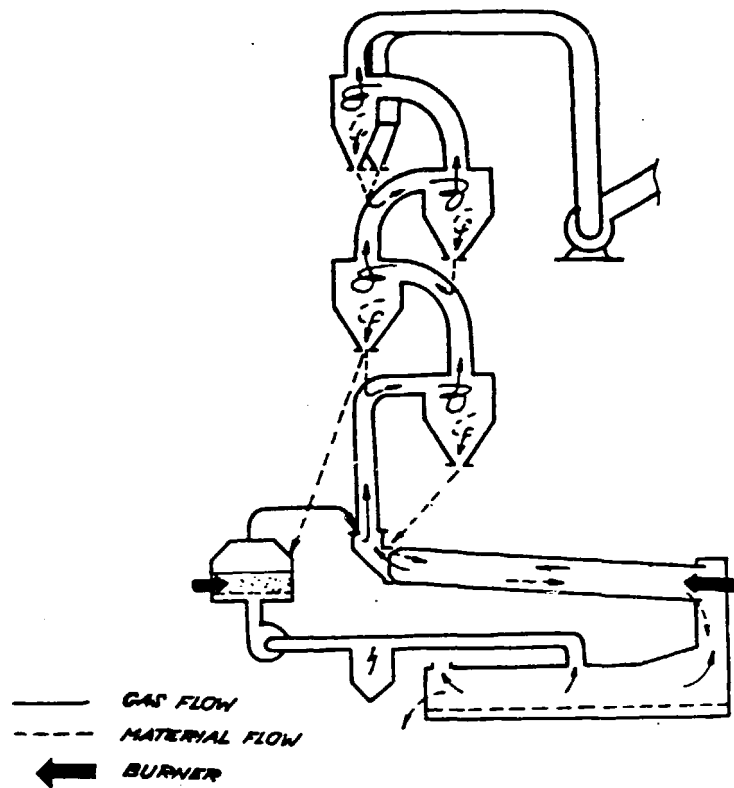
Fig. 36 - Mitsubishi Fluidized Calciner sketch (FMC)

easier and enabled to design kilns of up to 10.000 tpd.

Large number of the flash-calciner systems that have been developed
so far does not allow their description individually in this work.
Therefore we give at least a review of the main systems in the
following table.

System denomination	Inventor	Manufacturer	Max. output (actual or planned)	Licensee
SF	Chichibu Cement Co. Ltd. Ishikawajima Harima Heavy In. Co. Ltd.	Ishikawajima Harima Heavy Industries Co. Ltd.	7.700 tpd	Full Co.
MFC	Mitsubishi Mining and Cement Co. Ltd.	Mitsubishi Heavy Indust. Co. Ltd. Mitsubishi Polysius	7.200 tpd	
RSP	Onoda Cement Co. Ltd.	Kawasaki Heavy Industries Co.	5.200 tpd	Allis-Chalmers Creusot-Loire V/O Lice: sintorg (USSR)
KSV Kawasaki Spouted Bed and Vortex Chamber	Kawasaki Heavy Industries Co.	Kawasaki Heavy Industries Co.	2.500 tpd	
NKSV (New KSV)	– " –	– " –	4.500 tpd	

System denomination	Inventor	Manufacturer	Max. output (actual or planned)	Licensee
DD Dual Combustion and De-nitration Calciner	Nihon Cement Co. Ltd.	Kobe Steel Ltd.	4.000 tpd	
FLS	F.L. Smidth Co. Ltd.	F.L. Smidth Co. Ltd.	4.300 tpd	
GG	Mitsubishi Heavy Industries Ltd.	Mitsubishi Heavy Industries Ltd.	4.400 tpd	
S	Sumitomo Cement co. Ltd.	Sumitomo Cement Co. Ltd.	4.500 tpd	
H	Hitachi Zosen	Hitachi Zosen		
U	UBE Industries Ltd.			
Pyroclon	Klöckner-Humboldt-Deutz	Klöckner-Humboldt-Deutz	3.200 tpd	
Prepol B	Polysius	Polysius	4.200 tpd	
Prepol AT	Polysius	Polysius		
Prepol AS	Polysius	Polysius	7.000 tpd	

Partial pre-calcining

In some cases it is more advantageous to embark on a more modest
increase in the kiln output, e.g. by 10-15 % since the capacities of

cther equipment do not allow a major rise, or in a given situation
it may not be considered as reasonable to undertake a large-scale
reconstruction incl. clinker coolers, conveyors, heat exchanger etc.
In this case it is possible to withdraw the firing air needed for
burning of fuel in the pre-calcining kiln and use it for an additio-
nal firing in a pre-elected place in the exchanger, or possibly
in an adequate part of the gas duct between the kiln and the heat
exchanger.

Comparison of both pre-calcining systems

	Partial pre-calcining	Complete pre-calcinin
Calcining chamber	The burners are placed in the amended gas duct or in the lower part of the exchanger	Self-contained cham-ber with burners with the combustion air intake
Combustion terciary air	Conducted directly through the rotary kiln (so-called excessive air)	Conducted through an independent duct from the clinker cooler (rarely from another source)
Fuel share in the pre-calcining	30-50 %	45-65 %
Decarbonation grade in %	60-75	70-90
Usability up to	5.000 tpd	10.000 tpd
Design	simpler	more sophisticated
Usability of coolers	all kinds	except for the planetary coolers

DRY ROTARY KILNS WITH DISPERSION HEAT EXCHANGERS AND FLASH-CALCINER SYSTEM

	Unit	MFC Ishikawa-Jima Hari-ma H.Ind.	SF Mitsubi-shi Mi-ning C.	RSP Onoda + Kawasaki	KSV Kawasaki Heavy Industries	FLS F.L. Smidth
Specific heat consumption	kcal/kg kJ/kg	750 3140	750 3140	750 3140	750 3140	760 3180
Output of the kiln	tpd	7200	7700	3100	8500	4150
Specific output of the kiln	t/m3/d	3,9	3,8	5,2	3,2	3,7
Temperature of gases after kiln after exchang.	°C	1150 390	1030 340	1050 260	1100 340	1100 380
Temper. of raw meal into the kiln	°C	850	830	830	860	870
Temper. of gases after calcin.chamber	°C	860	880	830	860	870
Percentage of apparent dissociation	%	90	93	88	91	90
Temperature of second. 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	–	f o u r	– s t a	g e c y	c l o n e	t y p e
Speed of the kiln	rpm	3,0	3,0	2,7	2,0	2,3
Inclination of the kiln	o	4,0	4,0	4,0	4,5	4,5
Kiln dimensions ∅ x length	mxm	5,4 x 95	5,5x100	3,45/3,75 x 75	6,2 x105	4,75x75
Length to inner dia. ratio	m/m	19,4 : 1	20,4 : 1	23,4 : 1	18,4 : 1	17,6 : 1
Year of commissioning	–	1975	1973	1978	1975	1977

Advàntages of the dispersion heat exchangers with flash-
-calciner system
_____

1) Out of the total quantity of fuel, 60 % is burnt in the
   calcining chamber which enables to achieve the calcination
   rate of approx. 85 %.

2) The start-up time of the kiln is relatively short and the full
   operation begins between 5-20 hours.

3) Longer life of refractory lining (25-30 %) due to a lower
   thermal load of the sintering zone, and due to a relatively
   smaller diameter of the kiln.

4) Easier transport and erection of the rotary kiln in large units,
   since the kilns can have considerably smaller dimensions in
   comparison with conventional kilns with heat exchangers.

5) For the additional firing in the heat exchanger it is possible
   to use also coal or waste low-grade fuels, which helps save
   quality fuels with high calorific values.

6) Area needed for civil works is 25 % lesser.

7) Lower content of NO_x in the exit gases, in particular in special
   calcining chambers (DD, SG) - it has been proved only 150-300
   ppm at 10 % of O2.

8) Clinker grain size is generally finer.

8) Large units (above 3.000 tpd) reach the heat consumption of
   730-790 kcal/kg clinker (3.056-3.308 kJ/kg).

Deficiencies
_____

1) Older plants featured somewhat increased heat consumption
   (by 0-5 %), in the most recent units the consumption is comparable
   to the conventional design without the flash-calciner system.

2) Slightly increased consumption of electric power. It is estimated
   at an average of 1,5 kWh/t of clinker.

3) In spite of the fact that the rotary kiln for the same output
   has a smaller diameter, the system is more complex and economical
   effects can be seen starting from the output of 3.000 tpd,
   more evidently from 4.500 tpd.

Fuels used for the production of portland clinker in rotary kilns

In order to reach the sintering temperature in the burning zone
of the rotary kiln it is necessary to heat the clinker up to
1.390-1.480 °C. The temperature of the flame is approx. 1.800 °C
and can be obtained by combustion of a high-quality fuel and
preheated air. In this respect the cement kilns differ from the
lime ones.

Gas.

For a gas-fired kiln it is necessary to use gas which has a calorific
value of at least 5.500 kcal/Nm3 (theoretically the lowest possible
calorific value for gas firing is 4.350 kcal/Nm3 - 18.213 kJ/kg).
Average value for natural gases used in cement plants is 8.300 kcal/
/Nm3 i.e. 34.750 kJ/kg). Implementation of gas firing in the
cement plants is simple and does not require much capital investment.
Needed is only a duct for connection to the main gas line, relatively
cheap reducing and measuring station, automatic de-pressurizing and
a special burner. Once the burner is correctly tuned-up, the service
demands little effort. Gas mixes easily with the primary air and
the control is not very difficult either. In comparison with coal
or oil firing it is necessary to tolerate a slight drop in output
and an increase in specific heat consumption.

Oil

Cement plants generally use the cheapest kind of oils, i.e. heavy
duty fuel oil. These oils are transported to the plants in the
tank trucks and are preheated. In contrast to gas firing, the oils
require that storage tanks be built, and prior to burning they must
be heated to a higher temperature in order to reach a perfect
atomisation of oil leaving the burner. It is necessary to reach
the viscosity of 1,2 - 2° of Engler, which corresponds to the
temperature of these oils approx. 125-145 °C.

Heavy fuel oils have   calorific values of 9.400-9.800 kcal/kg of
oil (39.356 - 41.031 kJ/kg).

Coal

The quality and composition of coal deserves great attention, as
well as its preparation. Coal used for clinker burning should be
of uniform quality, of a calorific value above 6.000 kcal/kg of
dry coal (25.121 kJ/kg). The minimum calorific value of dried coal
should be of 5.000 kcal/kg of coal (20.934 kJ/kg). With decreasing
calorific value of coal the output of the kiln rapidly drops, the
specific heat consumption rises and the quality of clinker deterio-
rates due to the excessive amounts of ash. Also the ash ring can

emerge.

Coal is not to be over-dried since then does not catch fire easily.
Black coal should have 1-1,5 % of moisture content.

The content of volatile matter is to be daily checked, already on
delivery of coal to the plant. Optimum content of volatile matter
is 18-25 % and it pays off to maintain this content even by mixing
two or three kinds of coal.

Coals with high content of volatile matter provide the flame which
is too broad and less hot. The coal also ignites at a small distance
from the burner. On the contrary the coal with low content of
volatile matter burns with a concentrated short flame, but far
from the burner. The situation can be to a certain extent improved
by grinding the coal more finely.

The fineness of coal is recommended to be of 12-16 % of sieve
residue (sieve 0,085 mm - 85 micr.)For estimation purposes the
following formula can be used:

% of the sieve residue 0,085 = 0,6 x volatile matter %

Possibilities for burning of low-grade fuels in the cement
rotary kilns

As it has already been explained, the sintering in the sintering
zone requires a high-quality fuel. This conclusion however does
not exclude a possibility if using fuels of low calorific values,
provided they are suitably applied.

In the dry process of production, the least suitable method is
the mixing of fuel with the raw materials. Practical tests have
proved that this process does not bring expected results, but
on the contrary causes major problems.

The more reasonable way is to bring the fuel by means of another
burner (auxiliary one) in an adequate quantity (up to 20 %). Thus
for example garbage is burned in a cement plant in England, low-grade
coals in Netherlands, Brazil and other countries.

The dry process enables to burn low-grade solid, gaseous and liquid
fuels in between the rotary kiln and the heat exchanger, in an
independent combustion chamber, the hot gases being conducted into
the heat exchanger. It is possible however to burn a smaller
amount of fuel either directly in the exchanger or in the gas duct
which connects the kiln to the exchanger. This is already in use
in a couple of kilns in the world. The combustion air is either

conducted by an independent duct from the cooler, or it is exhausted trough the kiln. This process is called the dry process with pre-calcining.

The pre-calcining means that the raw meal is thermally better prepared in the heat exchanger; thus in the kiln it is not necessary to burn so much fuel. It results in an increase in the kiln outputs and longer life of refractories.

To conclude this chapter we have to point out that using of another fuel with its transport, storage and handling represents a more complex operation in the plant and it is necessary to consider a simpler and more efficient burning of fuel in other thermal units.

This consideration of course requires a more detailed study with regard to specific conditions of individual plants.

Bypass - system

This system is in use in some case in the kiln groups with dispersion heat exchanger. It reduced the content of alkalies and chlorides in the clinker and the circuit of circulating salts inside the kiln by means of exhausting a part of the gasses (3-10%) out of the kiln.

These gases are then colled and the alkali-rich dust is removed.

Lessening of the content of alkalies in the exit gases prevent the excessive formation of alkalic coating in the lower part of the heat exchanger and the gas ducts.

Inplementation of the bypass-system results in an increase in heat consumption by 4 - 5 kcal/kg of clinker (17 - 21 $kJ.kg^{-1}$) per each 1% of the by-passed exit gases. Moreover a grater capital investiments is needed as well as the consumption of the electric power rises (by total of 2 kWh per 1 t of clinker).

The most usual arrangement of the bypass-system can be seen from Fig. 37, 38 and 39.
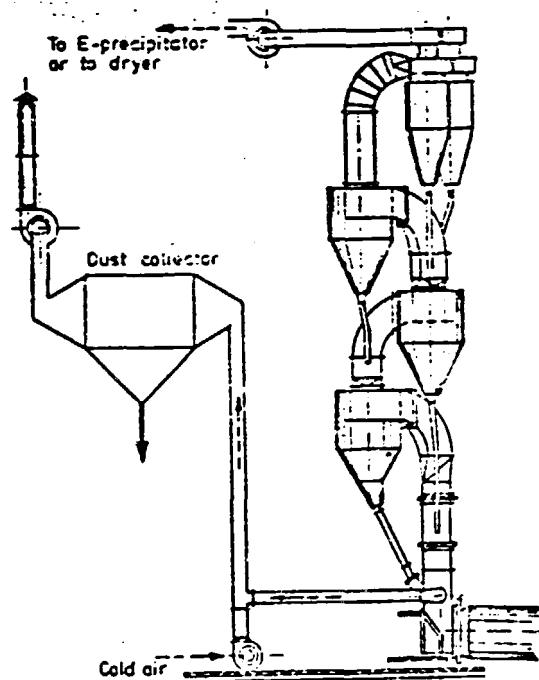
Fig. 38 - Preheater bypass-system where the dust
of the bypass gas is directly precipi-
tated in a separate dust collector

To E-precipitator
or to dryer
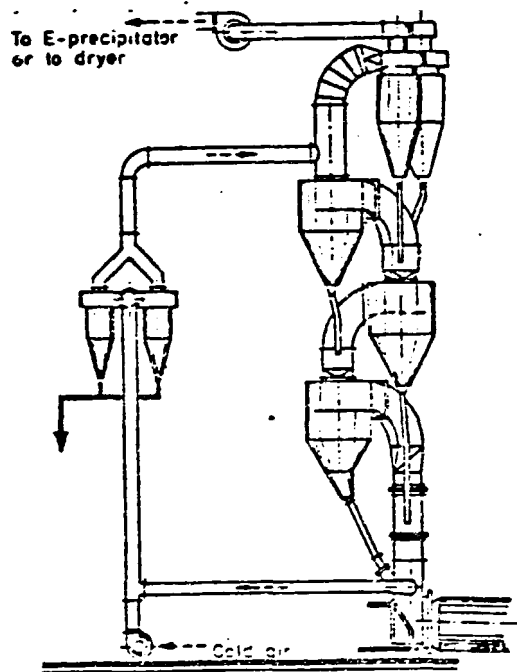
Fig. 39 - Preheater bypass-system with diverting
of the alkali dust and with feed-back
line for the diverted gas into the main
exit gas duct

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Fig. 1 - Remnants of the Aspdin kiln at Northfleet

Fig. 2 - Dome kiln

Fig. 3 - Johnson kiln

Fig. 4 - Dietsch kiln

Fig. 5 - Hauenschild kiln

Fig. 6 - Schneider kiln

Fig. 7 - Schoefer kiln (called Aalborg kiln)

Fig. 8 - Automatic kiln of Curt von Grueber Co.

Fig. 9 - Modern shaft kiln

Fig. 10 - Spohn conical grate

Fig. 11 - Shaft kiln (E.I. Chodorcv's design) with intake
of _ygen into the sintering zone

Fig. 12 - First rotary kiln for portland clinker burning
(sketch from Ransome's patent)

Fig. 13 - Slurry preheater with heat exchange compartments-
- longitudinal arrangement of the grate of F.L.
Smidth

Fig. 14 - Slurry preheater with heat exchange compartments-
- transversal arragement of the grate

Fig. 15 - Preheater Gygi - Holderbank

Fig. 16 - Internal heat exchangers in the long wet rotary
kiln - I - I   slurry preheater with heat ex-
change compartments

II - II chain zone (garlands)

III - III cross-shaped built-in installa-
tion of the Giprocement design

Fig. 17 - Cross-section of the "slurry calciner" of Miag Co.

Fig. 18 - Polysius vertical chain drier

Fig. 19 - Operational of spray drying Niro-Atomizer Co.

- 44 -

CONTENTS

C-173

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