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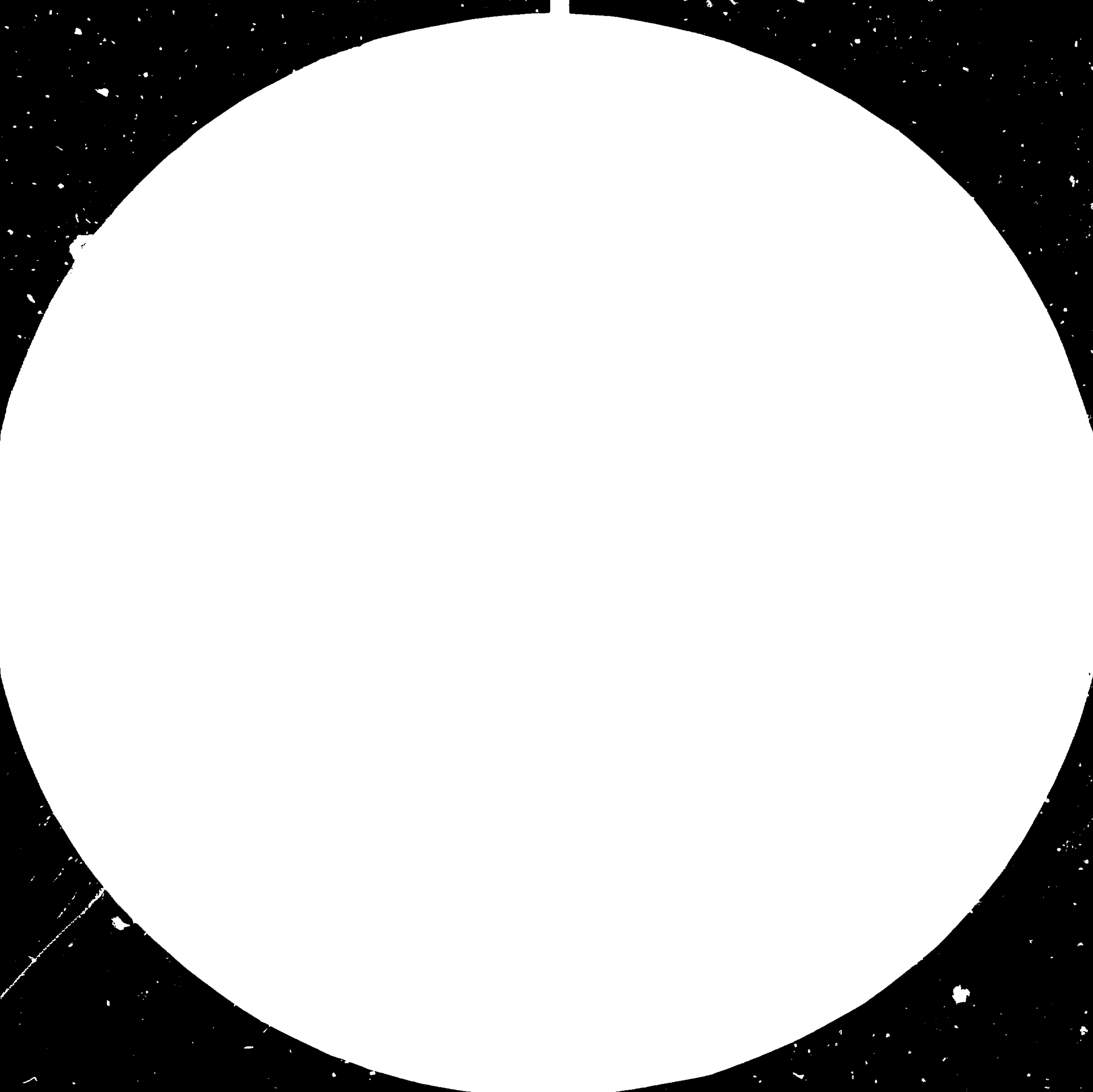
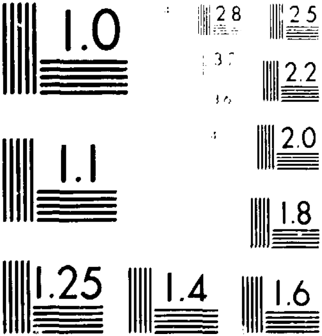
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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TRENDS REGARDING THE DEVELOPMENT OF ROTARY KILNS AND, IN PARTICULAR, OF ROTARY KILNS WITH HUMBOLDT PREHEATER APPLIED FOR PROCESSING RAW MATERIALS OF VARYING PROPERTIES*

by

Rudolf Kuhs**

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** Engineer, KHD Humboldt, WEDAG AG, Federal Republic of Germany

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Abstract

- The paper quotes some important kiln developments over a period of 60 years and logical advances made with regard to rotary kilns upon processing raw materials of satisfactory characteristics.

- The increased consumption of cement all over the world requires using raw materials for burning Portland cement clinker which were considered useless a few years ago.

- Humboldt Wedag have developed suitable technical concepts for meeting both requirements listed above.

It was in 1824 when the bricklayer Aspdin was granted the patent for producing Portland cement.

At that time, simple stationary kilns of low daily throughput were used. Some of the kilns installed did not operate continuously. The shaft kiln shown in

Illustration I

Development of the cement shaft kiln

was the burning equipment most appreciated at that time due its continuous operation and the quite satisfactory heat consumption, compared with other units.

The quality of the clinker burned and the daily output were improved and increased round the turn of the century by introduction of the rotary kiln. For more than 80 years, engineers have tried to increase the daily output of these kilns, accompanied by better clinker qualities, and to reduce the heat required for clinker burning.

Especially Dr. Nacken evidenced as early as during the twenties of this century that the rotary kiln is characterized by poor thermal economy over 2/3 of its length since it requires more than 40 m out of a total of 60 m length for drying the feed (raw meal), for heating it up to about 900°C and for decarbonating it. This situation is shown in

Illustration 2

Temperatures of the feed material inside a rotary kiln.

In 1932 O. Lellep dealt with better utilization of low-grade heat in rotary kilns. During these investigations he examined the time required for thoroughly heating raw-meal briquettes as a function of the diameter

Illustration 2b

and developed the grate preheater featuring at that time a heat consumption of about 1,000 kcal/kg of clinker.

Illustration 3

Grate preheater

This has been the trend-setting development for more than twenty years in the line of rotary kiln design until Franz Müller had a 4-stage cyclone preheater set up in front of the rotary kiln for preheating and partly decarbonating the dry and dust-fine raw meal. This very fine raw meal could not be used with the grate preheater of O. Lellep (illustration 2).
In the course of 30 years, this last-mentioned calcining system, i.e. the multi-stage preheater set up in front of the rotary kiln and followed by a cooling system has been generally accepted.

The grate preheater and - to a certain extent - also the cyclone preheater provided for partial decarbonation until in 1965 a burning system has for the first time been installed at the transition between rotary kiln and preheater. This burning system succeeded in increasing the degree of decarbonation of the raw meal in the preheater. This Pyroclon technology has been widely applied by KHD Humboldt Wedag AG. Details have been presented by me earlier on the occasion of the first symposium organized in Benghazi.

The logical consequence of the Pyroclon technology providing for up to 99 % decarbonation of the raw meal in the preheater has been that residual decarbonation will no longer have to take place within the rotary kiln so that the kiln tube can be shortened. The time that elapsed between first installing a burning system in the preheater and installation of a correspondingly shorter kiln has been about 15 years.
Physical laws according to which:

- linear heat transfer is particularly good with contact taking place over a large surface, i.e. raw meal included in the gas flow of the preheater, and
- heat transfer is excellent due to radiation within the sintering zone of a rotary kiln as per the formula established by Stephan Bolzmann: $C = Y \times CS\ (4.96) \times \left(\frac{T}{100}\right)^4$

are fully utilized when designing new rotary kilns.

Although Professor Nacken outlined the processes taking place inside a rotary kiln in the course of his investigations in the twenties of this century, we have by now successfully applied the physical laws of heat transfer in a rotary kiln reaching an output of 2,000 t/day.

Illustration 5

Pyrorapid kiln system with 5-stage preheater and tube cooler

The second firing system inside the preheater, which we call 'Pyroclon', enables an almost complete decarbonation of the lime while the raw meal is heated up to approx. 900°C at the same time.
The following considerations favour the use of a very short rotary kiln for clinker burning. Thermal decomposition of the calcium carbonate, of the clay minerals and other suspended raw-meal components results in the production of chemically active disintegration products. Their surfaces display greater chemical reactivity than materials heat-treated over long periods in long rotary kilns. Prior to the commencement of the most important clinker reaction within the sintering zone, i.e. the formation of alites (C_3S), heating above decarbonation temperature of 890°C is unavoidably accompanied by the reactions forming calcium aluminates (C_3A), calcium aluminate ferrite (C_4AF) and, in particular, belite (C_2S).

The longer the heating during alite stability, the more will the belite already formed and the remaining free lime have an opportunity of re-crystallization. This will hinder the delicate process of nucleus formation and complicate further growth of alite crystals.

Therefore, one of the aims of burning must be ensuring the active material state after calcining by rapid heating up to the temperature level of alite reaction and to utilize this period for a quick and extensive formation of alite nuclei. This will prevent re-crystallization processes and guarantee short diffusion distances for alite formation, this being identical to small alite crystals. Considering, moreover, that lime bonding is consistently decelerated with the duration of burning, rapid heating after quick calcining to the temperature required for alite formation, i.e. to sintering temperature, is equal to a multiplication of the lime-bonding velocity.

Seen from this point of view, the short rotary kiln is the equipment matched to the specific process requirements for achieving quick clinker burning.

Practical operation of the 2,000 t/day Pyrorapid rotary kiln system has revealed that very homogenous raw meal has to be fed into the preheater. If so, the residual CO_2 content of the kiln feed will range between 0.3 and 0.5 % being equal to 99 % decarbonation during normal operation. The hot-meal temperature will then vary between 890 and 920°C and the waste-gas temperature at the kiln inlet be near 1300°C at a total heat consumption of some 750 - 810 kcal/kg of clinker.

The fact that clinker mineralization is quicker in a Pyrorapid kiln than during conventional clinker burning, positively influences clinker and cement properties.

- high reactivity of the disintegration products originating from the raw-meal components reduces the necessity of pronounced sintering of the clinker granules which, in turn, means improved grindability.
- the alite crystals remain small. This has early compressive strength become less dependent on the Blaine value and has it improved compared with slowly burned clinker at identical lime standard.
- vice versa, it is analogously possible to lower the lime standard at quick burning while maintaing the strength development pattern.
- a positive or negative influence of secondary components - being dependent on kind and quantity - such as alkalies, sulfate, fluoride, heavy metal or transitory elements may be more pronounced for quick burning, as secondary components frequently affect, in particular, the formation of alite nuclei.

In addition, quick burning combined with preferably rapid cooling results in structural activation of the clinker phases. The crystal lattice may be characterized by disarrangement and by foreign elements being incorporated beyond equilibrium.

The opportunities offered by incorporating foreign elements have another aspect of the Pyrorapid kiln come to the fore, such as e.g. circuiting of trace elements in cement rotary kilns with cyclone preheater. We shall continue to ~~scrutinize~~ study these processes.

Clinker of good quality is produced in the new Pyrorapid kiln of a capacity of 2,000 t/day. It is suitable for the production of cement of any strength in accordance with the requirements of the corresponding German standard specification DIN 1164.

The specific plant we are speaking about here in this paper has to be operated at a free lime content of composition (see diagram 5):

C_3S	56 - 60 %
C_2S	22 - 27 %
C_3A	5 - 7 %
C_4AF	7 - 9 %.

This results in the following compressive strength figures after 2 and 28 days respectively for the different cement qualities:

cement	grinding fineness (cm^2/g)	compressive strength (N/mm^2) 2 days	28 days
PZ 35 F	abt. 2400	18	48
PZ 45 F	abt. 3400	28	55
PZ 55	abt. 5100	40	69

Good grindability values have been attained for the clinker which were evidenced by tests carried out with the "Zeisel" tester by open-circuit grinding.

grinding fineness (cm^2/g)	spec. work index (kWh/t)
2000	13.0
2500	19.0
3000	25.5
3500	33.0
4000	41.5
4500	52.5

We attribute these advantageous figures, in particular, to the high porosity of the clinker and to the clinker structure. The clinker appears extremely porous and features an average weight per unit volume of approx. 1,100 g/litre with the values quoted referring to the screened fraction of 4 - 8 mm size.

Microscopic examination of the clinker confirmed its extremely high porosity.

The alite crystals were of surprisingly small size and averaged 0.010 - 0.030 mm which is clearly below the normal values of industrially produced clinker.

Because of low lime saturation, the portion of belite has been high. It frequently occurred as small, nest-like concentrations.

So far, we have frequently noticed aluminate and ferrite in the form of large crystals.

The low free-lime content could primarily be located in smaller, nest-like concentrations which may be due to coarse raw meal. The free-lime clusters were often completely surrounded by pores. This high porosity is detrimental since, in general, pores obstruct reactions.

It has not yet been entirely sorted out whether the advantageous clinker properties have to be attributed to the kiln length which resulted in a short retention time of the clinker in the kiln at high kiln speed. This would mean that the feed proceeded to clinkering more rapidly than in conventional kilns.

It may, however, also be that the extremely advantageous chemical and mineralogic composition of the raw materials either by itself or in combination with the kiln system, entailed these optimum conditions.

Clarifying this issue will be a main objective of further, intensive examinations.

Fuel splitting in the plant equals 38 - 42 % inside the kiln tube and 62 - 58 % in the Pyroclon, subject to normal operating conditions. This means that the kiln tube is subject to low thermal load. In spite of the diameter not exceeding 4.0 m, the cross-sectional load is not above 3.0 - 3.5 mill kcal/sq.m and hour, in accordance with the specific production rate. Therefore, so far no problems have turned up with regard to the kiln lining.

In summarizing the statements made it may be said that the diameter/Length ratio of 1 : 10 has been well matched for the Pyrorapid kiln. The material having been decarbonated up to 99 % in the Pyroclon is burned to portland cement clinker of top quality. The clinker is easy to grind and yields any desired cement quality. At a specific kiln space load of about 6 tonnes/day and cubic metre, utilization of the kiln volume is improved by about 50 % compared with kilns of standard length and pre-calcining system. A large number of planned investigations have not yet been carried out in this first rotary-kiln plant of that type. These criteria can be assessed only on the basis of long-term observations. We are convinced that there will be additional reports in this respect.

Secondly we would like to report below on a cement plant which has no other choice than using particularly poor raw materials for the production of cement clinker.

Components such as SO_3, K_2O, Na_2O and Cl- (Clorid) Influence the process run during burning. Moreover, they will be detrimental to the cement quality unless suitable precautionary measures are taken during the burning process already, i.e. by removing portions of these components from the clinker by way of appropriate process operations.

Illustration 6 is a summary of the raw materials available giving their analytical data.

Illustration 6

The portion of components harmful to the process is fairly high.
Raw-meal mixture calculations have been carried out with the clay originating from Wadi Fathwa and from Wadi Rahba; these are shown in

Illustrations 7 and 8.

Moreover, it has to be considered for the burning process that the sulfur content of the fuel oil may be up to 4.5 %. This sulfur will be found bonded in the clinker unless appropriate precautionary measures are taken.

In spite of the raw-material data specified above, not only standard Portland cement but also sulfate resistant clinker shall be produced. The following limit values, laid down in the pertinent Iraqi standard, have to be maintained:

	C_3A %	SO_3 %
sulfate-resistant cement	3.5 at a max.	2.5 at a max.
standard Portland cement	7.0 at a max.	2.5
standard Portland cement	above 7.0	3.0

In view of the statements made earlier according to which the high sulfur content of the oil may be carried on to the clinker, adequate precautionary measures have to be taken for the burning process to limit the sulfate content in the clinker to 1.5 % SO_3 at a maximum. This is necessary for maintaining an adequate margin required with respect to adding gypsum which latter is to regulate the setting time of the cement.

About 10 years ago hardly any machine supplier would have been prepared to set up a cement plant to be operated with the raw materials described above.

On the occasion of the first symposium held in Benghazi I explained to you circuit phenomena of Cl and sulfur between the sintering zone of the rotary kiln and the preheater. You will remember that I reported on the installation of a bypass at the kiln tube inlet which enabled an effective interruption of such circuits.
The examples quoted below shall give you an idea of the solutions implemented with respect to process engineering.
We have chosen no more than 3 arrangements for todays demonstration:

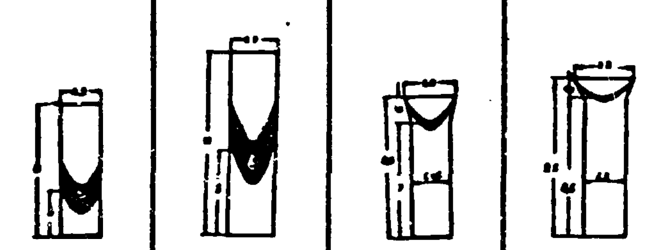
illustr. 9 - providing for 100 % withdrawal of waste gas
illustr.10 - providing for 25 - 60 % gas being withdrawn
illustr.11 - providing for 0 % gas being withdrawn.

Any percentage between the values quoted will be possible.
At this juncture I would like to remind you of the table shown in

Illustration 12

which outlines the opportunities for setting the bypass withdrawal portion as a function of the analytical data ascertained for Cl and SO_3 for the hot meal at the last cyclone in front of the rotary kiln. This possibility of adjusting the percentage of waste gas to be withdrawn enables troublefree plant operation and the production of clinker of optimum quality.

The statements made will have given you an idea of the approaches that can be made by machine suppliers to arrive at the required clinker and cement qualities in spite of unfavourable raw material conditions.

	1915	1925	1950	Entwicklung
				
Durchsatz tato (Capacity)	35-55	70-90	155-190	220
kcal/kg Klinker (fuel consumption)	1600-1400	1300-1200	1100-1000	900
Verbrennungsluft m³/min (Air requirements)	50-65	80-100	140-150	165
Druck mm WS (Working pressure.)	100-300	500-700	1400-1500	1600
Abgastemperatur (Exhaust gas temperature.)	500	400	300	275
Klinkertemperatur ° C (Clinker temperature.)	450	400	275	250

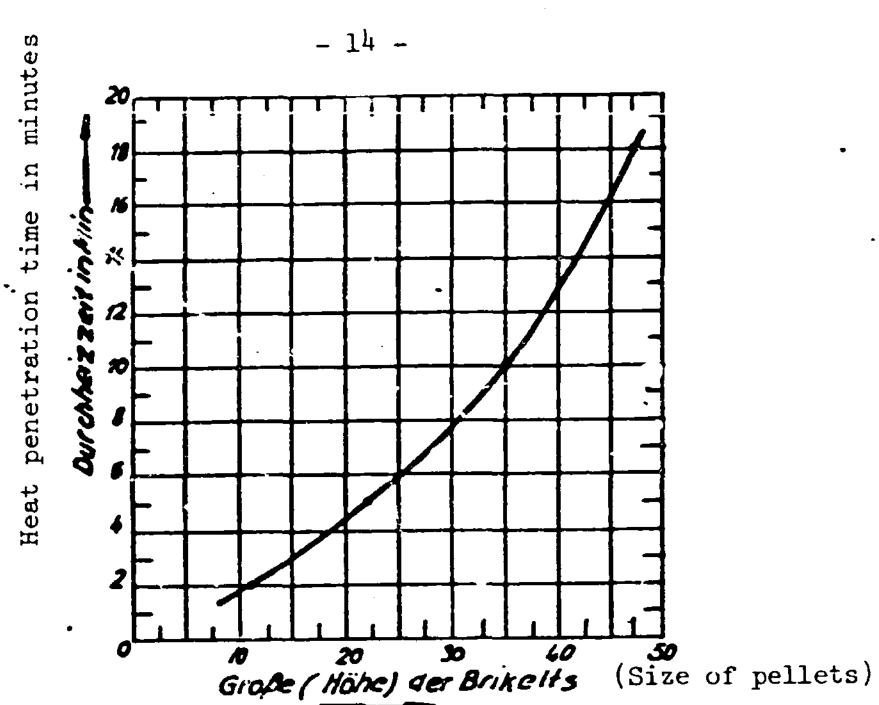
Jahr	Klinkerqualität (Clinker quality.)	Höhe - m (Kiln height)	li Durchmesser in m (Kiln diameter)	Mittlerer Durchsatz tato (average capacity)	Wärmeverbrauch kcal/kg Klinker (Heat consumption)	Gebläse Zug (Draft control)
1880	schlecht	8- 9	2 -2,2	20	1200-1100-1000	(natürl.)
1910	mittel	8- 9	2,5-2,6	35- 55	1600-1500-1400	TG
1925	-	10-14	2,7-2,9	60-100	1400-1300-1200	TG
1935	gut	9-12	2,6-2,8	100-150	1300-1200-1100	DG
1950	sehr gut	8- 9	2,4-2,5	150-180	1100-1050-1000	DG
1952	-	9-10	< 2,3	180-220	1000 - 900	DG

Bezeichnungen:

TG = Turbogebläse, Centrifugal blower

DG = Drehkolbengebläse Rootes compressor

Nach W. Anselm: Der Schachtofen. Zement-Kalk-Gips, Sonderausgabe Nr. 1, 1952, Seite 4 und 5.



Durchheizzeiten der Rohmehlbriketts von verschiedener Größe [nach O. Lellep]

Heat penetration time for pellets of different Size.

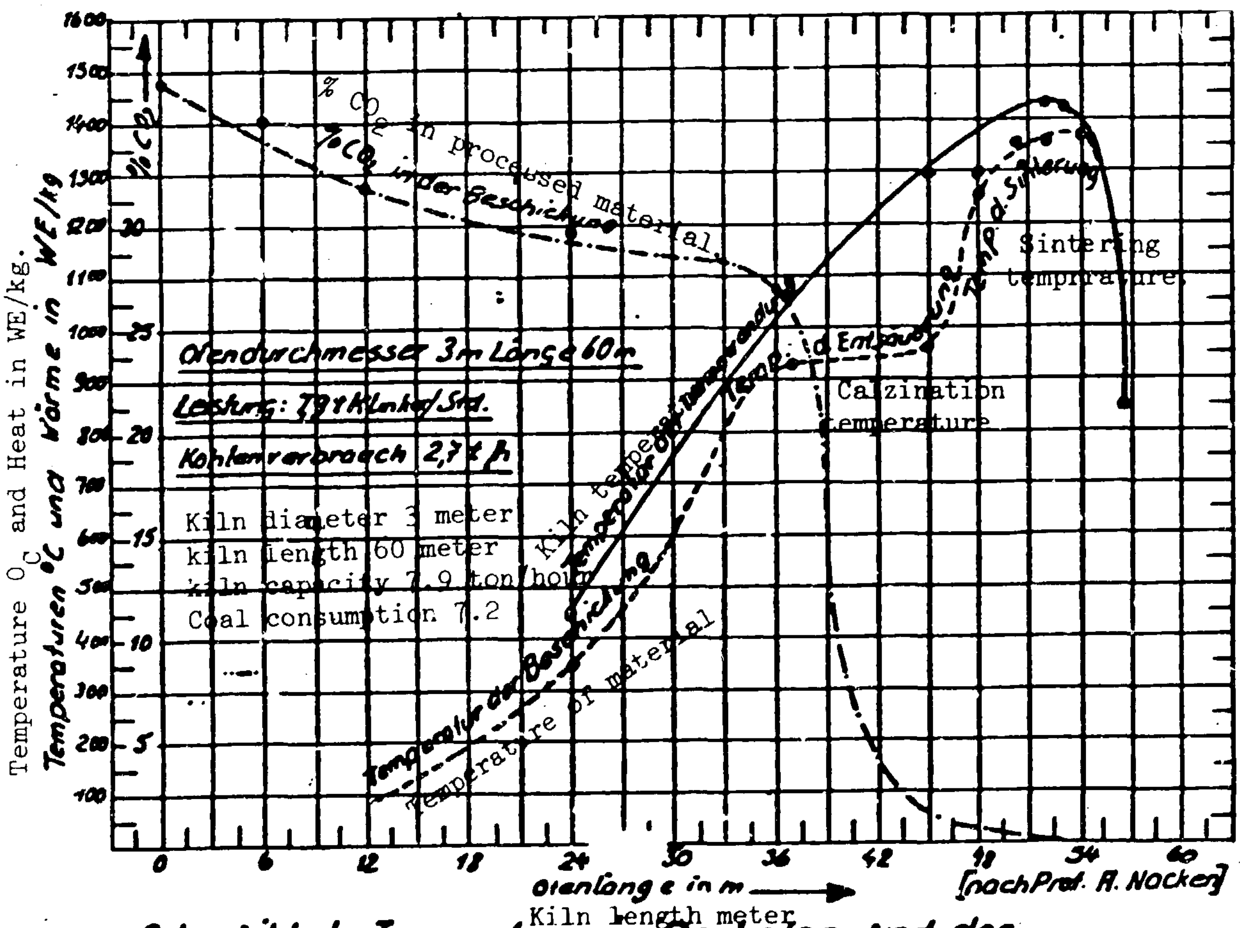
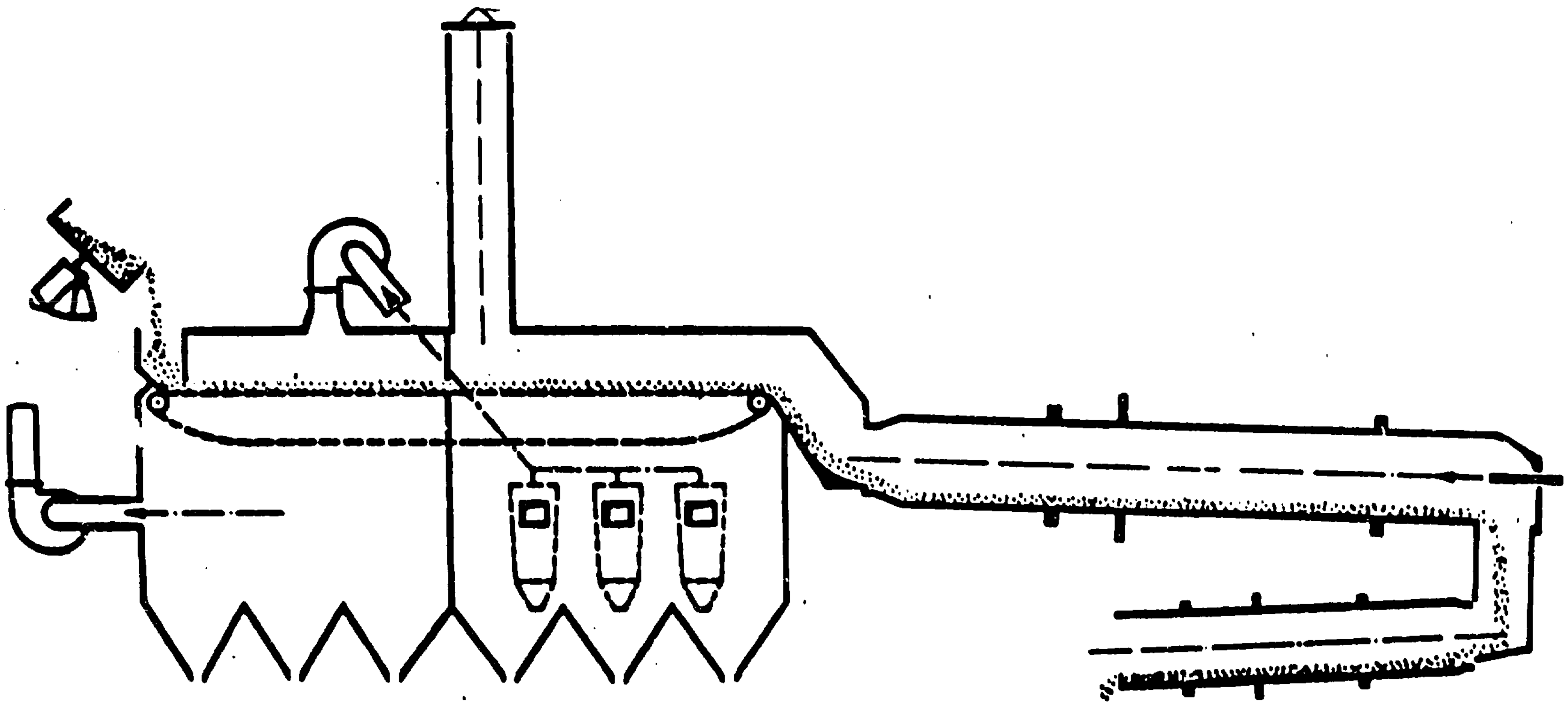
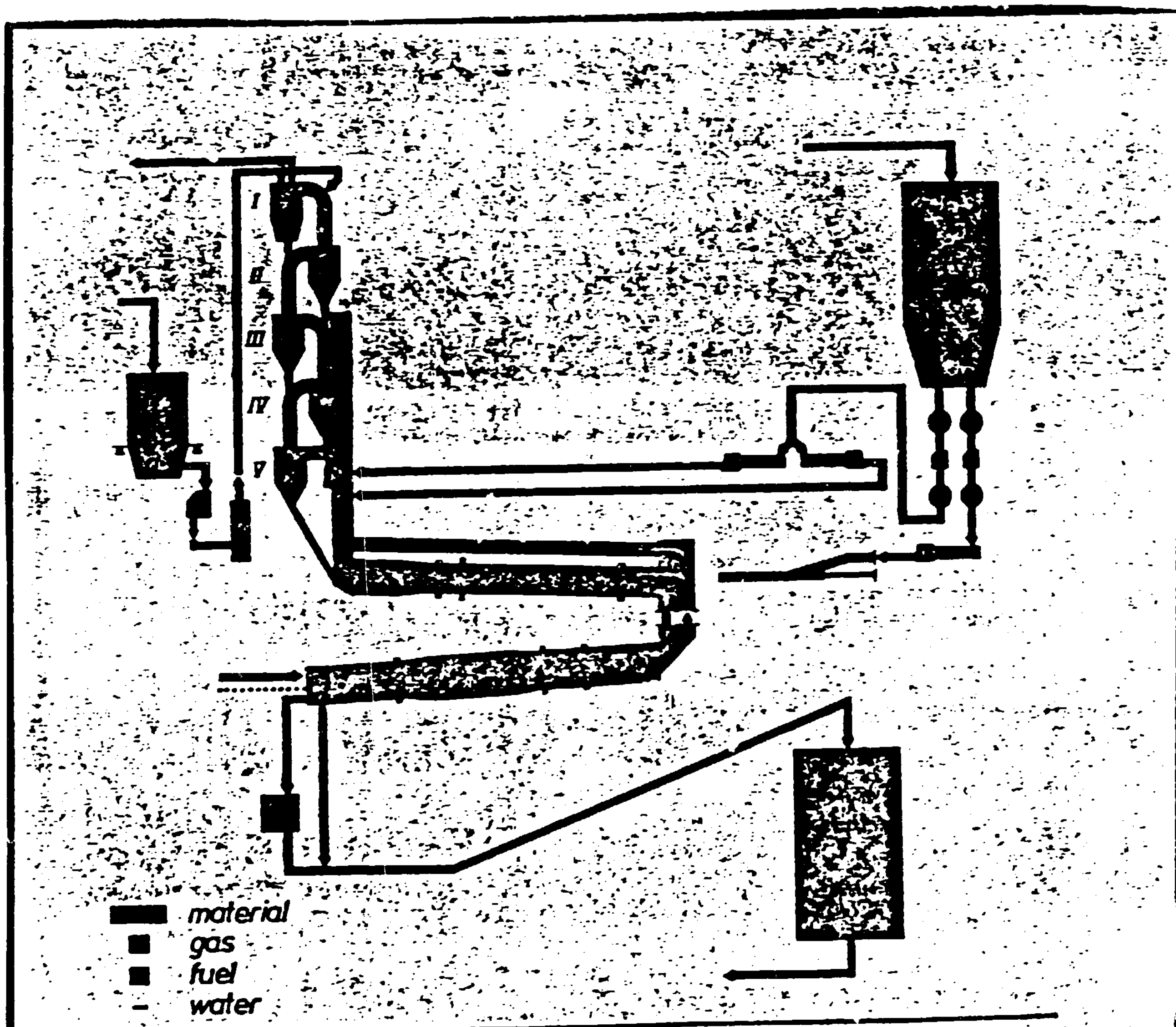


Schaubild der Temperaturen im Drehofen und des CO_2-Gehaltes des Brenngutes

Profile of temperature and CO_2 of the raw mix as moving through the kiln.



Drehrohrofen mit Rostvorwärmer
(etwa 1950)
rotary kiln with grate preheater
(abt. 1950) DP 413-004 D/E



PYRORAPID kiln system
with tube cooler

DP 841 - 071

C_3S		56-60%	
C_2S		22-27%	
C_3A		5- 7%	
C_4AF		7- 9%	
cement	cm^2/g	N/mm^2 2 days	N/mm^2 28 days
PZ 35 F	abt. 2400	18	48
PZ 45 F	abt. 3400	28	55
PZ 55	abt. 5100	40	69

cm^2/g	kwh/t
2000	13,0
2500	19,0
3000	25,5
3500	33,0
4000	41,5
4500	52,5

	characteristic value of cement	5

HB 267 a/1