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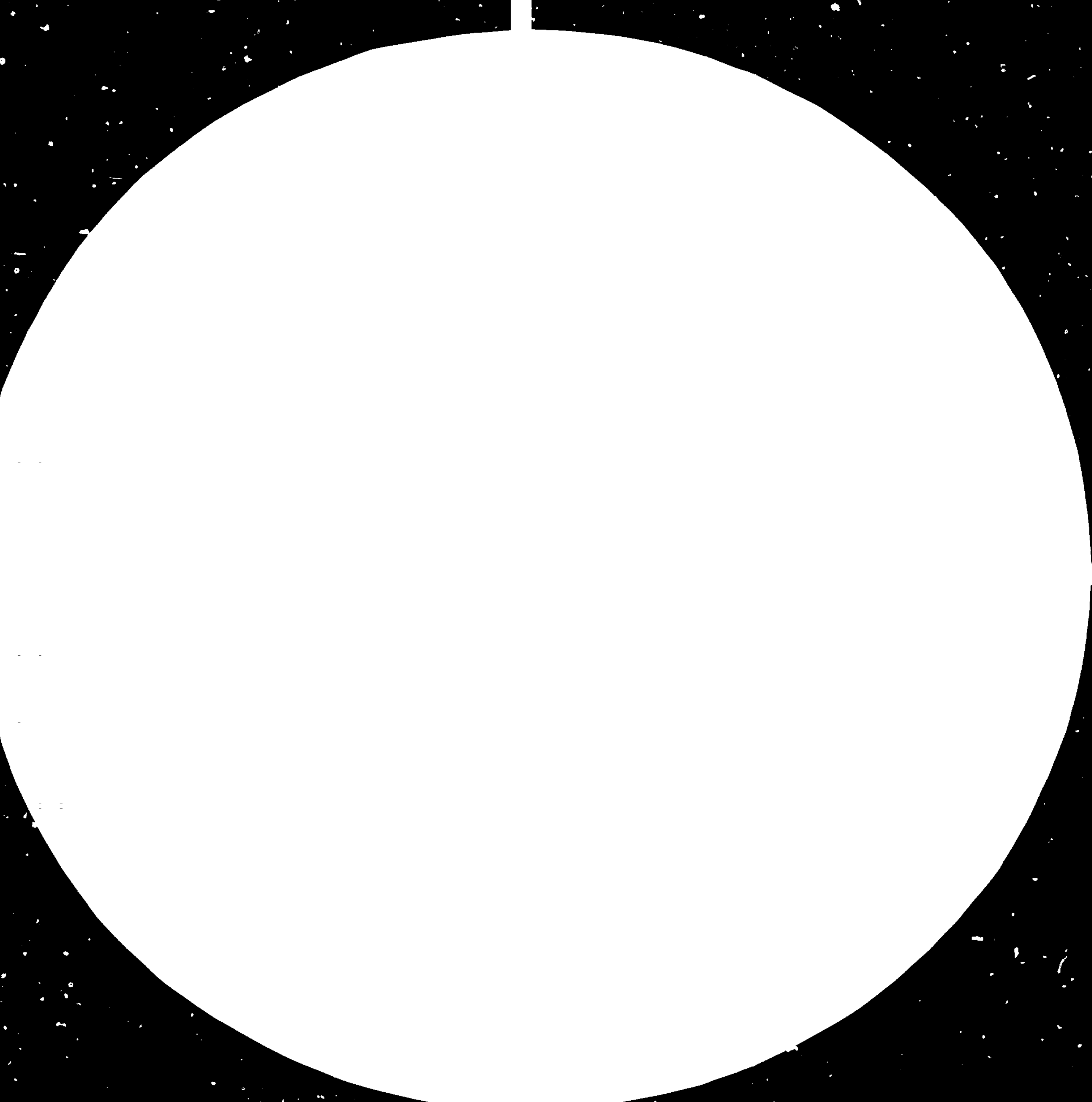

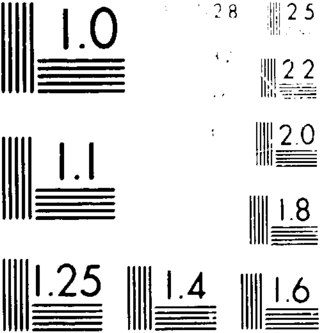
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UTILIZATION OF COAL IN CEMENT MANUFACTURE*

by

Villy Egesø**

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General

For many years coal was practically the only fuel available for utilization in an industrial scale, inclusive of the cement industry. In many heat requiring processes the necessary heat may be achieved by burning lump coal on a grate. In a rotary cement kiln such a procedure cannot be applied owing to the constructional principles of the kiln and because the clinkering process requires elevated and very well controlled temperatures. The success of the rotary kiln for cement burning was, therefore, from the beginning dependent on the domination of the coal grinding and coal dust firing technology. Since then, cement industry has been leading in the development within the field of coal dust firing.

Only fairly recently fuel oil and natural gas gained foothold in cement industry. In fact, not until the period following the Second World War did these fuels conquer any ground of importance, yet with the exception of a few geographical areas in which coal by tradition and by its abundance always was and always will be the main source of energy (Eastern Europe, Southern Africa, India etc.).

This trend in evolution was quite natural: The price of fuel oil and gas was in the fifties and sixties competitive to that of coal. Also these fuels are easy and neat to handle and use in the cement plant. In addition, in those years it became more and more difficult to attract labour to the hard and dirty work in the coal mines.

The situation changed suddenly in 1973-74 by the arrival of the oil crisis. Since then coal firing has had a tremendous revival, especially on cost of the fuel oil and often through legislation or public subsidy. During the fifties and sixties only a few coal firing installations were built and in these circumstances it is quite natural that coal firing technology suffered a certain degree of stagnation. When again new coal firing installations were required in a larger number, it was with a need for larger units and with more stringent demands to reliability, automation, safety and environmental protection. Consequently, we witness these days an important push-forward in the coal firing technology.

The question as to whether one should convert to coal firing has so far mainly been a matter of economy, but undoubtedly, in a not too distant future the shrinking oil resources will be reserved for other purposes than heat generation. As compared to fuel oil, the global coal reserves are far larger; - recent surveys show that even if taking into account a certain steady growth in consumption, the global coal reserves will last for another 300 years.

As a contrast to the fuel oil, the coal deposits are more evenly distributed throughout the world. Most countries possess coal deposits of a quality worth exploiting.

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Among the industrial fuels, the coals display the largest range of variation with regard to qualities. In the following the various examinations carried out on coal samples in the cement plant laboratories are briefly explained:

Moisture. It is important to stress that moisture percentages are always given in weight per cent. and are always related to the wet sample.

Generally, distinction is made between two types of moisture: - the surface moisture which evaporates by air-drying at ambient temperature, - and the inherent moisture which is more firmly bound to the coal and only evaporates completely when exposed to a temperature well above 100°C.

Actually, some coal types will even after exposure for hours at 105°C still hold some moisture which can only be expelled by distillation with an organic solvent.

Desiccation at high temperatures should be done in an atmosphere of nitrogen so as to avoid spontaneous ignition of the coal. For coal types with high contents of volatiles, the inherent moisture should preferably be determined by distillation with an organic solvent, since the coal during heating may lose some of its volatiles.

Surface moisture and total moisture is determined on a sample which is crushed to -5 mm. The examinations explained below are made on an air-dried sample ground to pass an 0.2 mm sieve.

Proximate analysis. Inherent moisture is determined by drying in an N_2-atmosphere at 105°C. Constant weight of the sample is usually achieved after 2-3 hours.

Volatiles (gas) is defined as the loss of weight after igniting the sample for 7 min. at 900°C and without the access of air (electric furnace, crucible with tight lid).

Content of ash is found by ignition in an open crucible (air) at 800°C until constant weight. The heating-up of the sample must follow a certain procedure and may take 2 hours.

For coal a content of mineral matter is sometimes indicated which is always superior to the ash content. During ignition not only the combustible material is burnt away, but also the residual weight of the sample is affected by decarbonation of any carbonates, oxidation of sulphur compounds and by expulsion of combined water.

Fixed carbon has by definition a value which makes the sum of volatiles, moisture and ash up to a 100%.

Ultimate analysis. In the ultimate analysis it is a matter of detecting the contents of the elements in the combustible part of the sample.

Carbon and hydrogen are found by combustion in a special furnace and a consecutive absorption of the CO_2 and H_2O formed in the combustion.

Sulphur is determined in the so-called Leco-furnace. The sulphur is oxidized to SO_2-gas which is afterwards absorbed and titrated by KJO_3.

In the nitrogen determination the Kjeldahl-method is used. The coal sample is digested in conc. H_2SO_4 (+ catalyst). Nitrogen compounds are converted to NH_3 which is evaporated, re-absorbed and titrated.

Oxygen may be found by analytical methods, but usually it is assumed to make up the sum of C, H, S, and N to a 100%.

Chlorides and alkalis are determined by Volhard titration and flame-photometry, respectively, - after a fusion of the sample with various agents.

Calorific value. The calorific value of a coal sample is found out by means of a calorimeter in which the sample is burnt in an oxygen atmosphere. The heat developed from the combustion results from the heat of combustion plus the heat of condensation of the steam formed from the combustion of the hydrogen-bearing compounds of the coal. The value measured is thus the gross calorific value (H_s).

In plant operation the steam escapes the process in the form of uncondensed water vapours and the heat of condensation is not available for the process. For this reason it is the net calorific value that is of interest. The net calorific value is arrived at by deducting from the gross value the contribution from the heat of condensation:

$$H_i = H_s - 5.85 \times (\text{\% water of combustion} + \text{\% inherent moisture})$$

$$\text{\% water of combustion: } 9 \times \text{\% H}$$

The difference between gross and net calorific value depends on hydrogen content of the fuel:

	% H	H_s-H_i (kcal/kg)
Graphite	0	0
Antracite	2	100
Bituminous coals	3	150
Fuel oil	12	600
Natural gas	22	1200

Course of desiccation. By the course of desiccation is understood the relationship between the temperatures to which the coal samples are exposed and the corresponding moisture retained in the sample.

The establishment of the course of desiccation is achieved by treating the sample, precrushed to -5 mm, in the following way:

24 h at 30°C
5 h - 50 -
5 h - 65 -
5 h - 85 -
2½ h - 105 -

The loss of weight is noted and based on these observations the desiccation curve is drawn.

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From an economical point of view the net calorific value of a fuel is interesting. The accuracy with which it is determined in the laboratory is fairly good, having a standard deviation better than 40 kcal/kg. Hence, it is often the way in which the sample is procured that is decisive when establishing the calorific value.

The calorific value depends on the volatiles, the moisture, and the ashes. The effect of an increasing ash content is obviously that it causes a proportional dilution of the combustible material.

An increasing moisture content causes in the same way a dilution of the combustibles, but in addition, the moisture will require some heat for its evaporation. Therefore, a certain increase in moisture content will result in a steeper drop in calorific value than is the case for an equivalent increase in ash content.

When the impact on the calorific value of the volatiles is studied, a more varied picture is found. One would expect to find the calorific value grow with the content of volatiles, since the heat of combustion of the hydrocarbons is higher than that of carbon, 11,000-13,000 against 8,000 kcal/kg approximately. This is, in fact, also found to be the case up to about 20% of volatiles, but when passing this value, the opposite trend is usually experienced. In the young coals, rich in volatiles, a significant proportion of the gas is made up of non-combustible compounds which do not contribute to the calorific value.

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The various coal types are usually classified according to their content of volatiles, and are subdivided according to other qualities. The coals span from young, gas-rich lignites, over ordinary bituminous coals, to old antracites, very low in gas. The ability of the coal to retain moisture (inherent) follows the same pattern, due to their structure getting more and more compact as they get older. Ash contents vary independently of the nature of the coal.

As compared to fuel oil and natural gas the hydrogen content of coal is moderate, resulting in relatively small differences between gross and net calorific values, and in a relatively low dew point of the combustion gases.

The sulphur content of coals varies widely according mainly to their geographical origin. European coals normally hold 0.5-1.5% S, whereas coals from certain locations in the U.S.A. contain as much as 4-5% S. Some British coals contain chlorides in an amount that makes them unsuited for preheater kilns, unless a by-pass is operated.

In the Seyler chart the properties of the coals are illustrated. It is seen that although the various coal qualities may vary widely, there is a certain regularity in their variation. The Seyler chart can be extended to cover most kinds of solid fuels.

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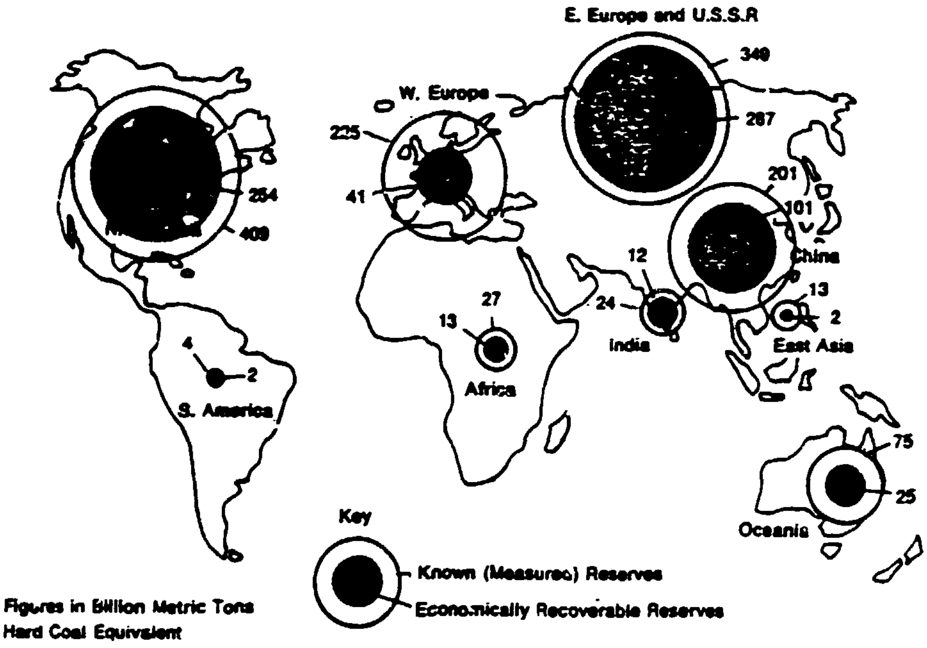
Coal Properties

Distribution of Coal Reserves



Figures in Billion Metric Tons
Hard Coal Equivalent

(Billion metric tons)

	Known (Measured) Reserves	*Economically Recoverable* Reserves*
U.S.A.	396	248
Canada	13	6
North America	409	254
W. Germany	100	16
United Kingdom	99	4
Rest of W. Europe	26	21
Western Europe	225	41
Japan	3	1
Rest of WOCA	140	53
WOCA	777	349
U.S.S.R. and E. Europe	349	287
China	201	101
Total World	1327	737

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* Note: The majority of these estimates were prepared prior to the oil price increases in 1973/74: in the new era of higher energy prices, economically recoverable tonnages are likely to be higher.

Coal Consumption.

$2{,}5 \times 10^9$ t/year (1974)

1 billion (amer.) $= 10^9$

Coal Properties

Laboratory testing

Moisture:	% total moisture % surface moisture
Proximate analysis:	% volatiles % inherent moisture % ash % fixed carbon
Ultimate analysis:	% C % H % S % N % O
Calorific value:	Gross (H_S) kcal/kg Net (H_i) kcal/kg % water of combustion
Desiccation curve:	% $H_2O = f(°C)$
Volatile impurities:	% K_2O, Na_2O, Cl
Ash analysis:	% SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, P_2O_5 ...... M_S, M_A Ash melting point, °C
Grindability:	kWh/t, Hardgrove index Abrasiveness (g/t)
Sieve tests:	Sieve residues of raw coal and coal dust

Coal Properties

Laboratory Testing

Moisture:

Surface moisture (air drying at ambient temp.)
+ Inherent moisture (105° C, N_2, or distillation)
Total moisture

Proximate analysis:

Inherent moisture: 105° C, N_2, 2-3 hrs. or distillation

Volatiles: 900° C, 7 min., absence of air

Ash: 800° C, 2 hrs., air

Fixed carbon: 100 - (inh. moist. + volatiles + ash)

Ultimate analysis:

C, H : Combustion + absorbtion of CO_2 and H_2O
S : Leco: $-S \rightarrow SO_2 \rightarrow SO_3^{--}$ + KJO_3
N : Kjeldahl: $-N \rightarrow NH_4^+ \rightarrow NH_3 \rightarrow NH_4^+$ (titration)
O : By difference
Cl : Fusion with MgO + Na_2CO_3 + Volhardt (Ag^+)
K_2O, Na_2O : Fusion with $CaCO_3$ + NH_4Cl + flame photometry

Calorific value:

Gross : Inclusive of heat of condensation (H_s)
Net : Exclusive " " " " (H_i)

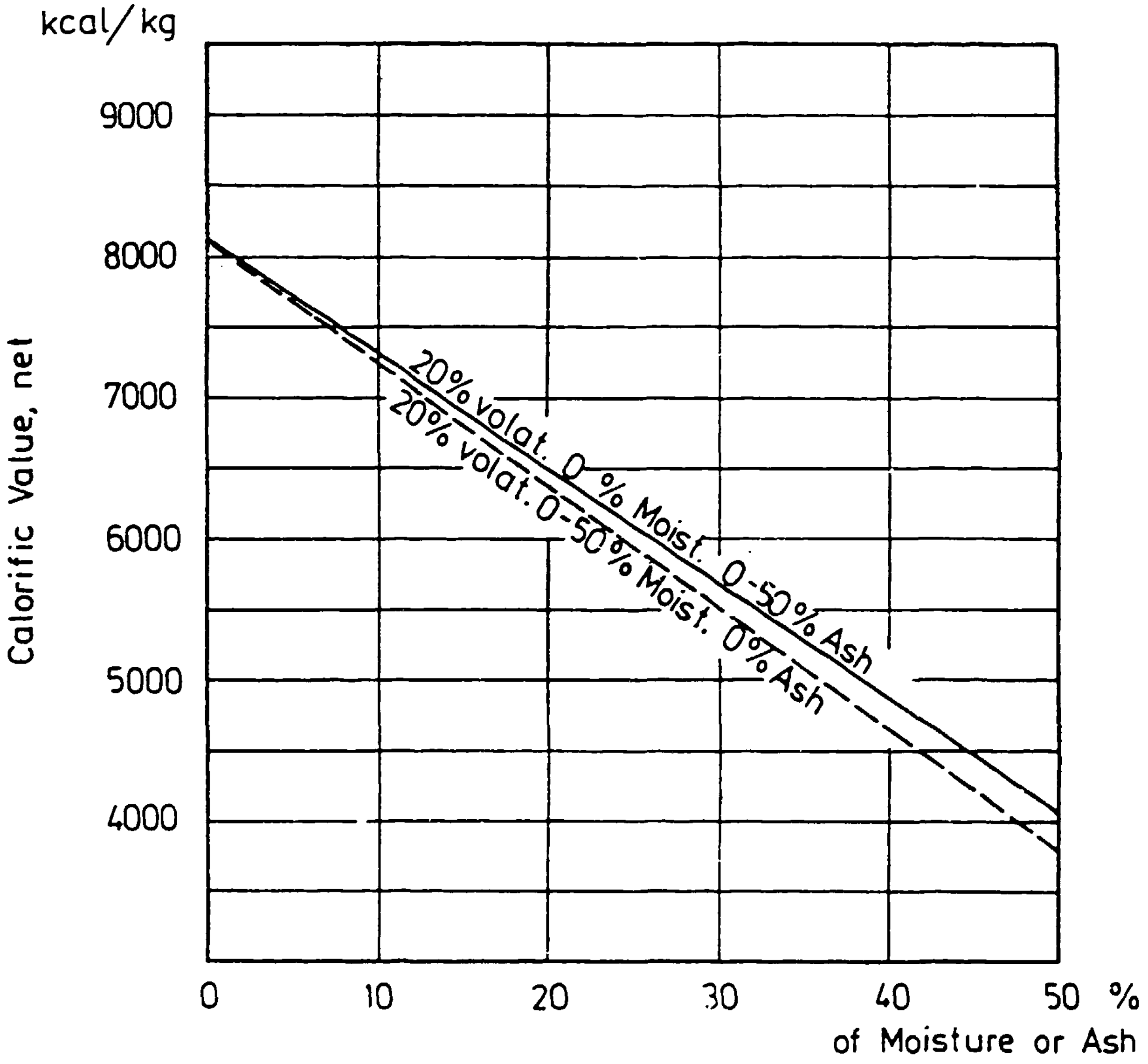
$H_i = H_s - 5.85$ (% water of combust. + % inherent moisture)
% water of combustion = 9 × % H

Desiccation curve:

24 h at 30° C
5 h at 50° C
5 h at 65° C
5 h at 85° C
2 1/2 h at 105° C

Coal Properties

Relation between Calorific Value and Contents of Moisture and Ash

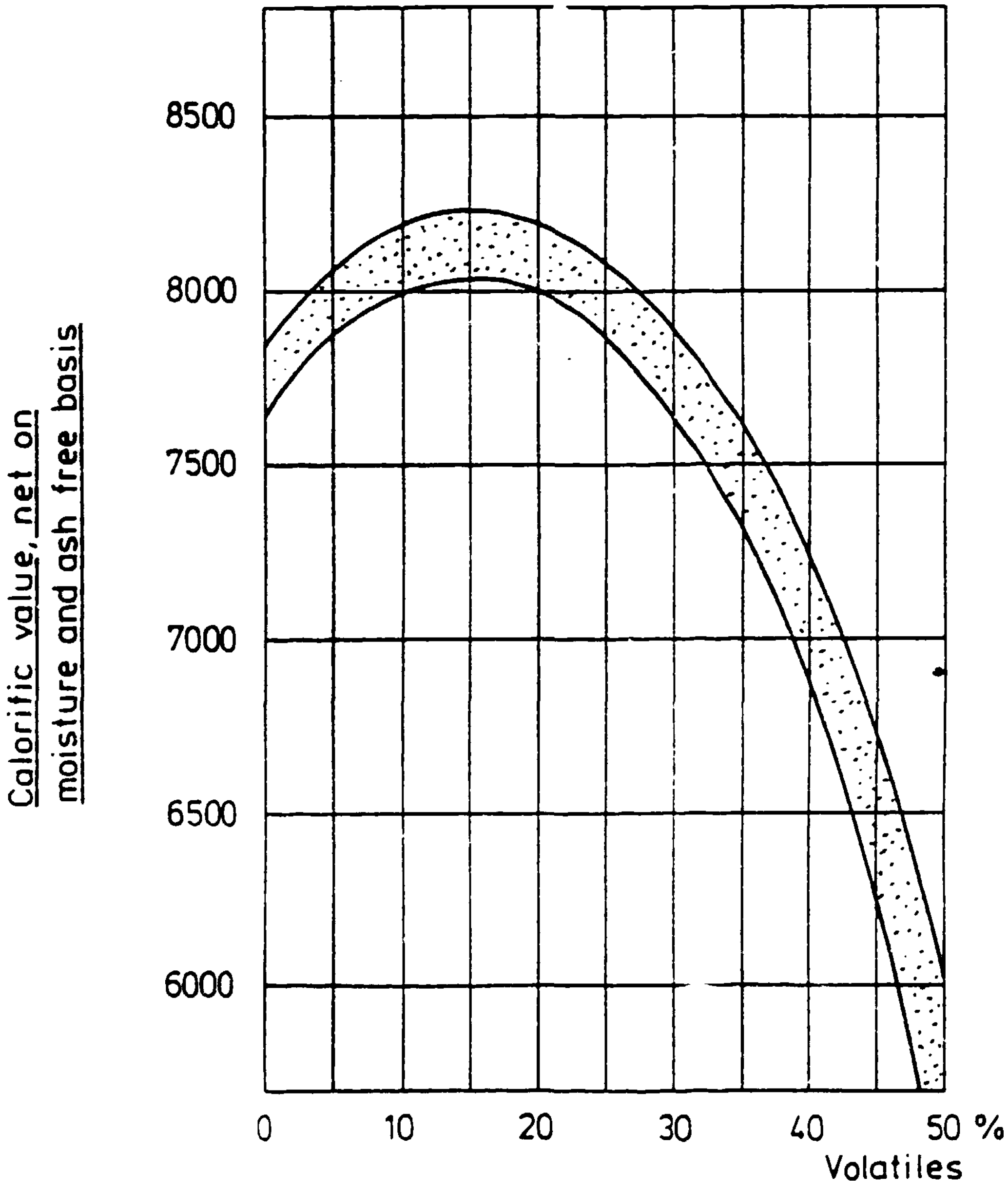


——————— $H_i = H_i^o \times \frac{100 - \%A}{100}$

- - - - - - - - $H_i = H_i^o \times \frac{100 - \%M}{100} - 585 \times \%M$

Coal Properties

Relation between Calorific Value and Content of Volatiles



$$H_i^o = (H_i^o + 5{,}85 \times \%M) \times \frac{100}{100 - \%M} \times \frac{100}{100 - \%A}$$

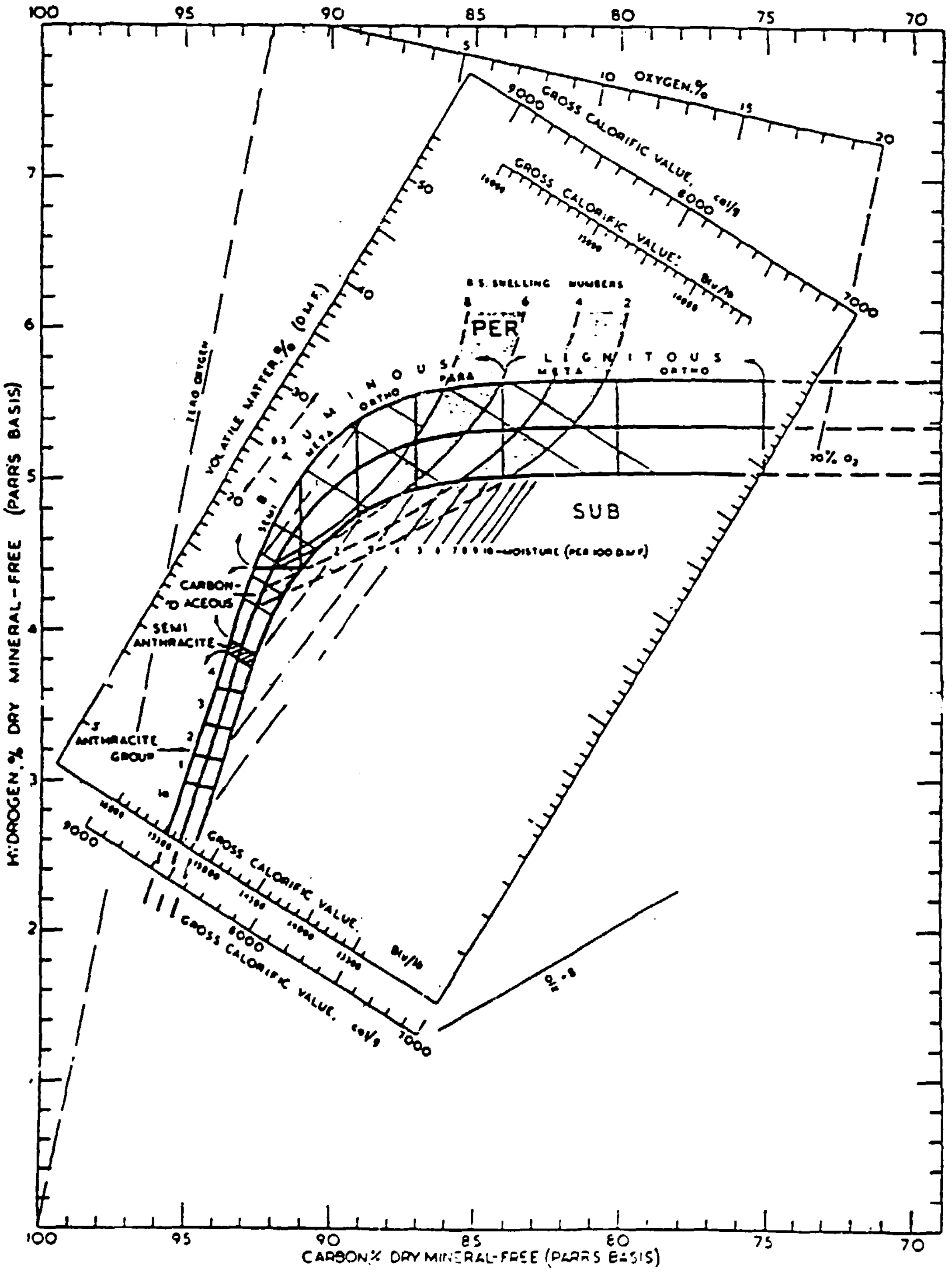
Coal Properties

Properties of Typical Coals

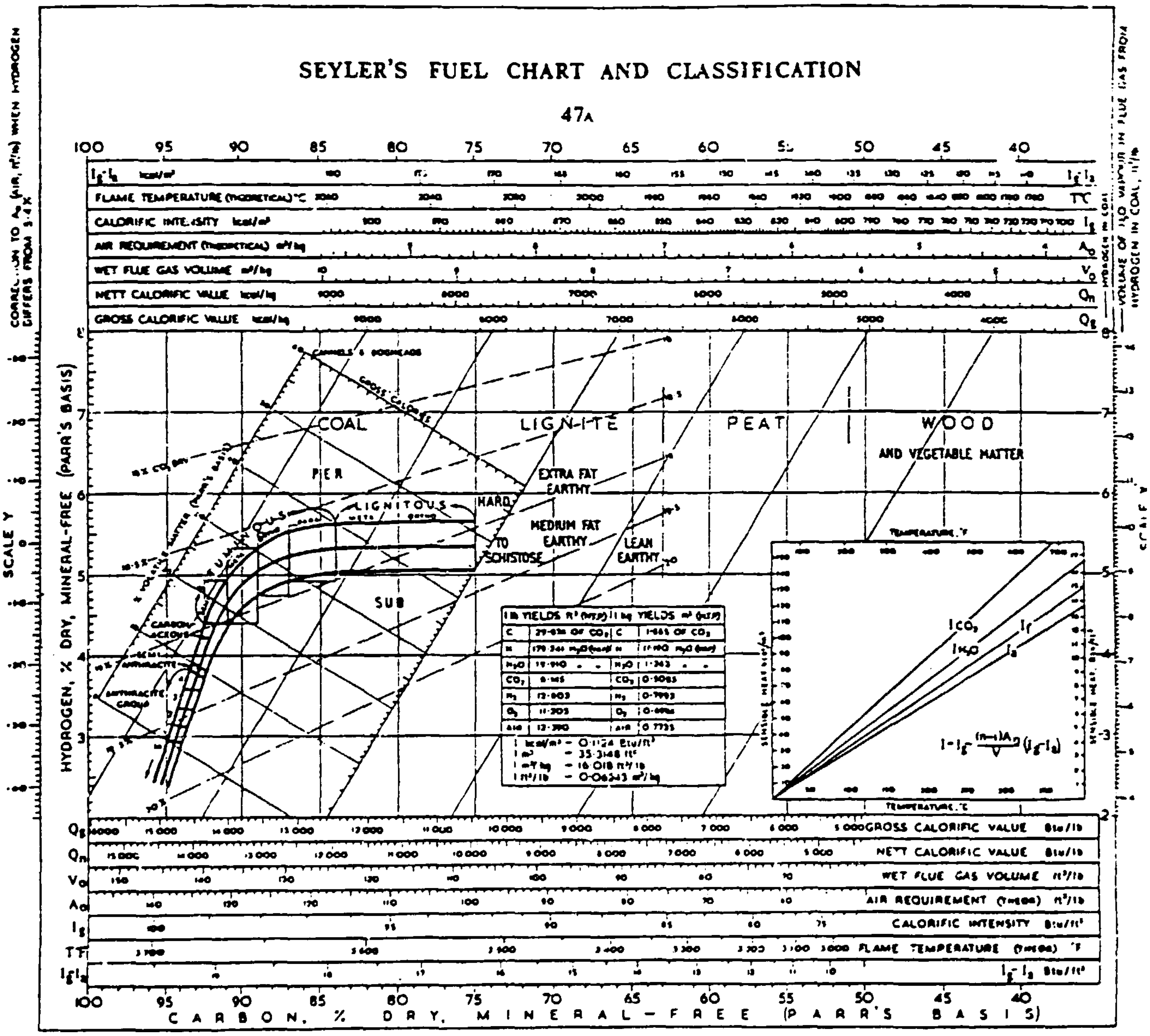
		Lignite	Bitum.Coal	Anthracite
Ranges				
Total moisture	%	40 - 50	5 - 10	0 - 3
Volatiles	%	40 - 50	10 - 40	5
Hygr. water	%	10 - 25	1 - 3	1
Ash	%	5 - 25	10 - 20	5 - 10
Examples (Commercial grade)				
Chemical Composition	%C	56	70	78
	%H	4	3	2
	%S	1	1	1
	%N+O	19	3	2
Calorific value	gross	5120	6625	7100
(kcal/kg)	net	4820	6310	6900
Combustion air	kg/kg	7,1	9,2	9,9
	Nm^3/kg	5,5	7,1	7,6
Combustion gases	Nm^3/kg	6,0	7,4	7,8
(wet, oxygen free)				
	vol% CO_2+SO_2	17,8	17,6	18,9
	vol% H_2O	10,0	6.5	4,5
	vol% N_2	72,2	75,9	76,6
	dew point °C	46	38	31

Coal Properties

SEYLER'S COAL CHART



Coal Properties



Drying and Grinding of Coal

Drying

Raw coal usually contains 6-12% of moisture. With a view to the grinding, transport and possible storing it is necessary to dry the coal, and such a drying is best carried out during the grinding.

Besides the surface moisture, which evaporates at ambient temperature, the coal contains inherent moisture, which is defined as water evaporating by heating from 30 to 105°C.

Typical desiccation curves appear from Fig. 1. Anthracite coal contains 1-2% inherent moisture, gas coal 3-6%, and lignite coal 15-25%.

The risk of fire and explosion can be limited considerably, if the coal meal is produced with a residual water content of 1-2% and 5-10% for lignite coal.

It appears from the desiccation curves that in order to obtain this content of residual moisture, the coal mill should be operated with an outlet temperature of 60-70°C, in certain cases up to approximately 80°C. To avoid condensation, especially in a possible filter, it is required that the temperature after a coal mill is approximately 15°C higher than the dew point. To reduce the amount of air for transport of the coal meal out of the mill it is desirable to operate the mill with a relatively high dew point. However, this may cause a higher temperature after the mill and a water content in the coal meal lower than desired, both giving an increased risk of fire and explosion.

These conditions appear from Fig. 2, showing the necessary quantity of air calculated as kg air/kg dry coal versus water content of the coal, calculated for various temperatures of drying air. The dotted curves indicate dew points for the mixture of drying air and water vapour. It appears that the dew point is solely depending on the temperature of the drying air, and is an increasing function of this temperature. At a dew point of 55°C and a water content of 10%, 1.0 kg drying air per kg coal will be needed, and at 15% water 1.6 kg.

If the dew point could be raised to 60°C, which should be possible, for instance by direct firing, it would be possible even at a water content of 15% to reduce the quantity of drying air to 1.2 kg per kg coal if the temperature of the drying air is raised to 450°C.

By using inert gas from a kiln preheater for drying of coal, larger quantities of drying air must be counted on, and correspondingly lower temperatures for keeping the same dew point since smoke gas contains more vapour.

Mills for Grinding of Coal

The Tirax Mill:

The Tirax mill is a ball mill arranged for drying and grinding. The material first passes through a drying compartment with lifters. The grinding mill used to be arranged with two grinding compartments, Fig. 3.

Grinding in larger mills and drying by means of inert gas of low temperature imply that the velocity of the air through the mill will be greater than in the smaller mills. In order to reduce the differential pressure over the mill, modern mills would be arranged with one grinding compartment and a classifying lining, Fig. 4.

The drying air passes through the drying compartment and the grinding compartment to the separator and performs thereby the transport of ground material from the mill to the separator.

The coarse return from the separator was formerly transported back through the outlet trunnion to the fine grinding compartment. At high air velocities this arrangement is considered to be inconvenient. Instead the coarse return will be sent to the inlet end of the mill by a screw conveyor.

The separator is of the stationary type. Regulation of the separation is performed by vertical displacement of an internal central tube and/or by change of the air velocity through the separator.

Vertical Mills:

Vertical mills for grinding of coal are manufactured by Raymond, Loesche, Pfeiffer, Polysius, B & W, and FLS.

Fig. 5 shows an FLS-Atox coal mill. The grinding of coal takes place between a rotating table and three grinding rollers in fixed position. The coal is fed to the centre of the table and from there it passes between the rollers and the table. After being crushed, it is flowing over the edge of the table, and there it is entering the racing current of the hot air coming through the air nozzle ring encircling the grinding table.

The ground coal is taken to the separator, integrated in the mill, and from there the coarse particles fall down into the mill again, and the fine particles are going with the air out of the mill.

The principal difference between Tirax mills and vertical mills is that the quantity of air sucked through the mill is around 2.5 kg per kg of coal against 1.2 kg per kg of coal in the Tirax mill. This implies that the drying capacity of the vertical mill is higher. In the vertical mill, 16 ot 18% of water can be dried from the coal. The larger quantities of air through the mill make it necessary that a return pipe is installed for air from the mill outlet to the mill inlet. In many cases also the installation of a separate filter for the mill air becomes necessary.

For grinding of coal the vertical mill uses about 9 kWh for the mill motor and 8 kWh per ton for the fan, i.e. in total 17 kWh/t. Under the same conditions the Tirax mill will use about 17 kWh/t per ton for the mill motor and 4 kWh per ton for the fan, in total 21 kWh. Thus, vertical mills use around 4 kWh per ton of coal less electrical energy than the Tirax mill. This corresponds to 0.5 kWh per ton of clinker. In return, the Tirax mill offers a very rough construction with a good run factor and small maintenance costs.

By comparison of Tirax mills with vertical mills the advantages and disadvantages of the latter could be summarized as follows:-

Advantages:

1. Cheap and simple installation
2. Lower energy consumption
3. Lower noise level

Disadvantages:

1. Larger quantity of air; approximately 2.5 kg/kg coal compared to approximately 1.2 kg for ball mills
2. Circulation of air not recommended, filter required
3. High wear
4. Sensitive to variations in feed
5. Higher maintenance costs

Cage Mills:

Coal used for firing in precalciners does not always have to be ground particularly fine. Such a relatively coarse grinding can be carried out without predrying in so-called cage mills or disintegrators (Fig. 6). The fineness of the ground material depends on the number of rod rings, the distance between the rods, and the speed.

The wear may often be very heavy, but since the mills are relatively cheap, it could be an acceptable solution to keep one mill as spare.

A cage mill may be considered for secondary firing in the riser pipe of a 4-stage kiln. It offers a way of fast convertion of an oil fired kiln to partial coal firing, until a proper coal installation has been commissioned.

Arrangement of Coal Grinding Plants

In arranging a coal grinding plant various factors have to be taken into consideration, for instance moisture content of coal, quality of coal, source of drying air, location of coal grinding plant relative to the kiln, and number of places to which the coal meal is to be distributed.

Direct firing implies a simple and cheap installation (Fig. 7). Regulation of firing in the kiln is made by varying the feed to the coal mill. The produced coal meal is precipitated in a cyclone and is, after passins an air sluice, blown into the kiln. Since direct firing implies only little risk of fire and explosion, this grinding mode is preferred when grinding coal with a high content of volatiles. Another advantage is that a high dew point is permitted, which makes it possible to operate with a relatively small quantity of air and a high temperature of the drying air. A drawback of the system is that a breakdown of the mill automatically causes a kiln stop.

Indirect firing (Fig. 8) differs from the direct firing installation only in the way of a silo for ground coal installed between the precipitating cyclone and the kiln. This silo can be equipped with one or more feeding apparatuses for coal meal.

Use of a silo for the ground coal implies that the kiln will be less dependent on the operation of the mill. The silo, however, is also a complication. It may involve an increased risk of fire and explosion. Compared to the direct firing a lower temperature at the mill outlet must be aimed at, causing a lower dew point.

Central coal grinding plant (Fig. 9). Equipped with a separate filter for dedusting the air from the mill the coal grinding installation will be independent of the operation of the kiln. Fine coal from the cyclone and dust from the filter are transported to the coal meal silo from where it can be extracted to a number of firing installations.

Inert coal grinding installation (Fig. 10) is characterized by a concentration of oxygen, less than 10% anywhere in the system, which prevents fire and explosions. Smoke gas from a 4-stage cyclone preheater is suitable as drying air in an inert coal mill installation.

For maintaining a concentration of oxygen less than 10%, efficient sealings at mill inlet and mill outlet are of importance and, further, return of air to the mill inlet should be avoided. With a vew to the regulation of the separation, air must be returned to the mill outlet.

For safety reasons the installation ought to be equipped with a reliable oxygen analyzer at the filter outlet; alarm limit at 10%; mill stop at 12%.

One problem by the inert coal grinding plant is that the heat content of the gas even from an economic 4-stage kiln is larger than required by the drying process in the mill, if the moisture of the coal feed drops below 10% approximately. Since it is not advisable to cool the gas by mixing with cold air, one may be forced to accept a mill outlet temperature which is somewhat higher than recommended from a safety point of view (Fig. 11). Or else the surplus heat must be destroyed by water injection in the mill or by means of a gas cooler installed in front of the mill.

This type of grinding plant cannot be ventilated to the kiln firing end, but must be operated in connection with a filter.

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Coal mill installations with vertical mills are principally arranged in the same way as installations with Tirax mills. Owing to the large quantities of air, direct firing will be avoided, and in most cases of indirect firing a filter for dedusting of part of the air from the mill must be installed.

The Drying in the Tirax Mill

As will appear from the displayed diagrams, the heat required for the drying in the mill can be drawn from the kiln system. From a grate cooler the hot air is drawn from a place half-way between the kiln hood and the excess air chimney. In this case there will be no increase in the heat consumption of the kiln. The hot air drawn to the coal mill would otherwise have gone through the excess air chimney. If, however, the kiln is equipped with planetary cooler, the air is extracted from the kiln hood, and in this case there may be a small increase in the heat consumption of the kiln.

The vapour coming from the coal mill enters the kiln together with the primary air and this will increase the heat consumption of the kiln, partly because this vapour has to be heated up to the exhaust gas temperature, leaving the kiln, and partly because this gas temperature will increase somewhat.

In Fig. 12 the relation is shown between the water content in the coal and the heat required for the drying in kilo calories per kilo clinker and the increase in heat consumption also in kcal per kg clinker.

By coal grinding it is normally necessary to use more primary air than when using fuel oil. This will increase the heat consumption of the kiln because less hot air from the cooler is used as secondary air. In Fig. 13 the relation is indicated between the amount of primary air and the additional heat consumption of the kiln.

Instrumentation and Automation of the Coal Grinding Plant

Fig. 14 indicates the measuring points and the automatic loops recommended for the coal mill plant. At the entrance of the mill there must be a small negative pressure, just sufficient to avoid that dust is leaking out, but not more than necessary, because a too high negative pressure will give rise to a too high volume of false air leaking into the system. The pressure is maintained at fixed values by regulating the damper after the fan, which is extracting the hot air from the kiln.

The pressure after the mill gives an indication of the mill operation. For instance, a too high negative pressure is an indication of blocked slots in the mill partitions. This can be provoked by pieces of grinding media or by too moist coal in the mill.

At the mill fan the quantity of air is measured. It is advisable to keep the air quantity constant, and that is obtained by an automatic regulation of the amount of return air to the separator.

It is of great importance to maintain a constant temperature after the mill, and this is done by automatic regulation of a cold-air valve which leads cold air into the hot-air duct coming from the kiln. In other words, it is a regulation of the inlet temperature to the mill.

If the inlet temperature to the mill rises above a certain pre-fixed value, there will be a risk of combustion in the mill itself. Therefore, if the temperature passes the pre-established alarm point, a cold-air valve at the mill inlet opens momentarily and the mill fan stops.

The mill can be equipped with a Folaphone, i.e. an electrical ear. This apparatus will measure the vibrations in the mill tube from the grinding media and the intensity of these vibrations is inversely proportional to the quantity of coal in the interior of the mill. A signal can therefore be used for automatic regulation of the feed to the mill.

Dedusting

If the coal grinding plant is not ventilated to a kiln, the dedusting may be done in either a bag filter or in an electrostatic precipitator. An example of an electrostatic precipitator is shown in Fig. 15. A series of safety measures must be taken to prevent explosions in the filter, but further the roof of the filter casing is equipped with a number of explosion doors which will relieve the pressure before damage occurs to the filter. For this reason the filter should always be installed in open air.

DEWATERING CURVES FOR COAL

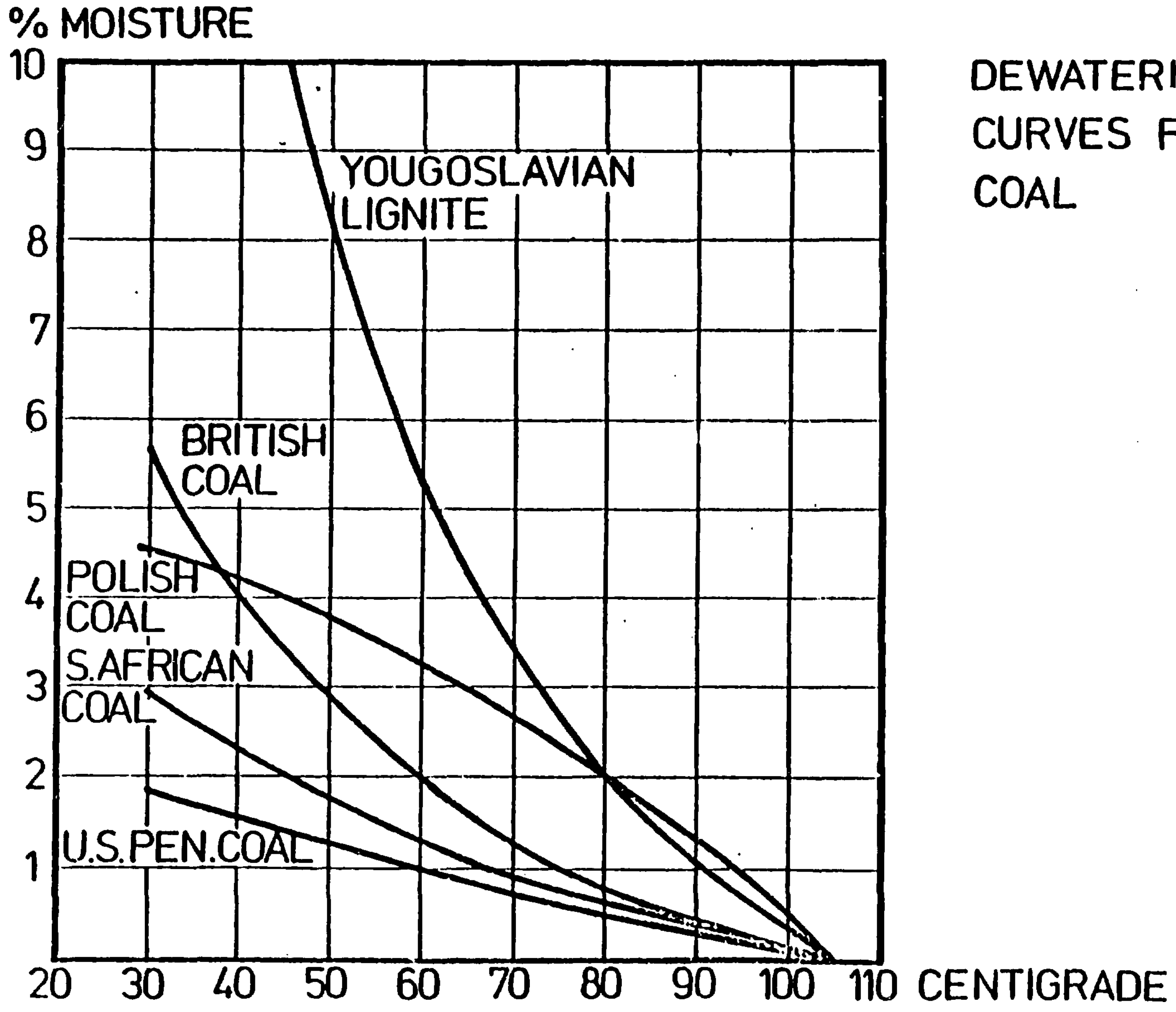
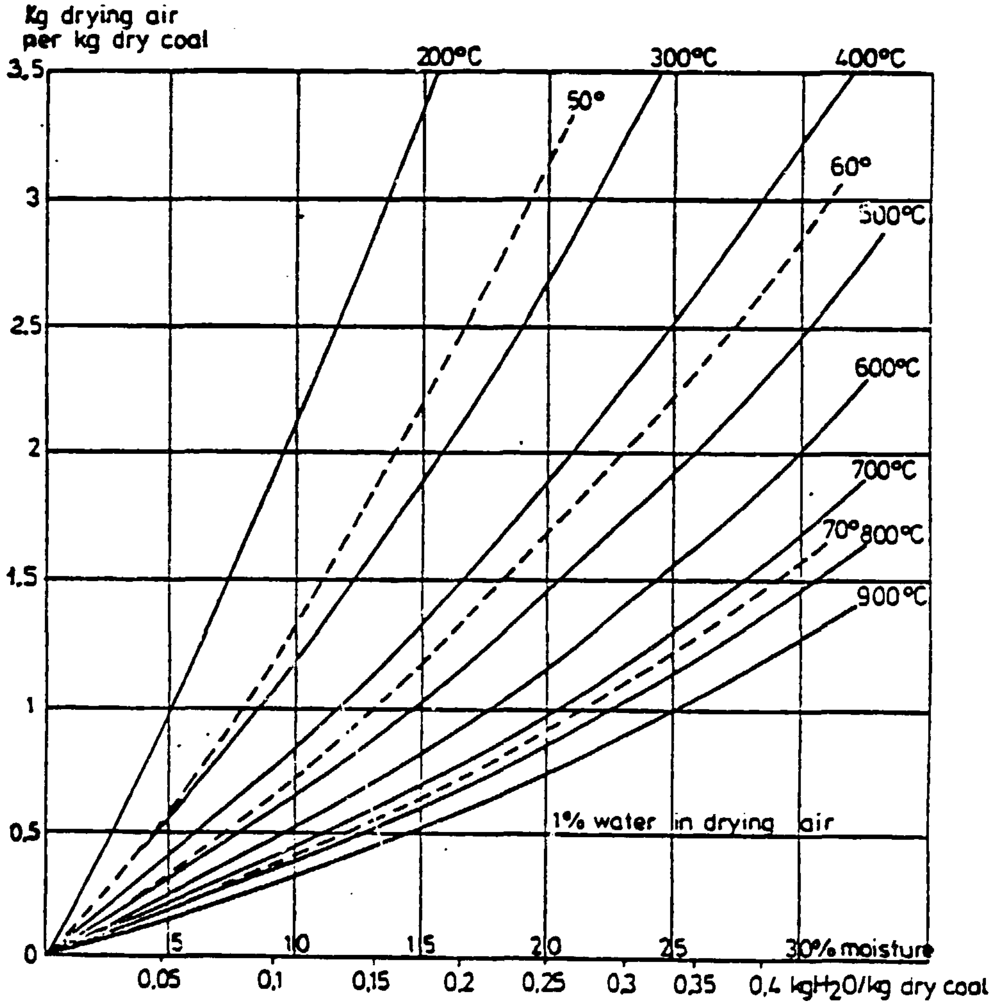


FIG. 1

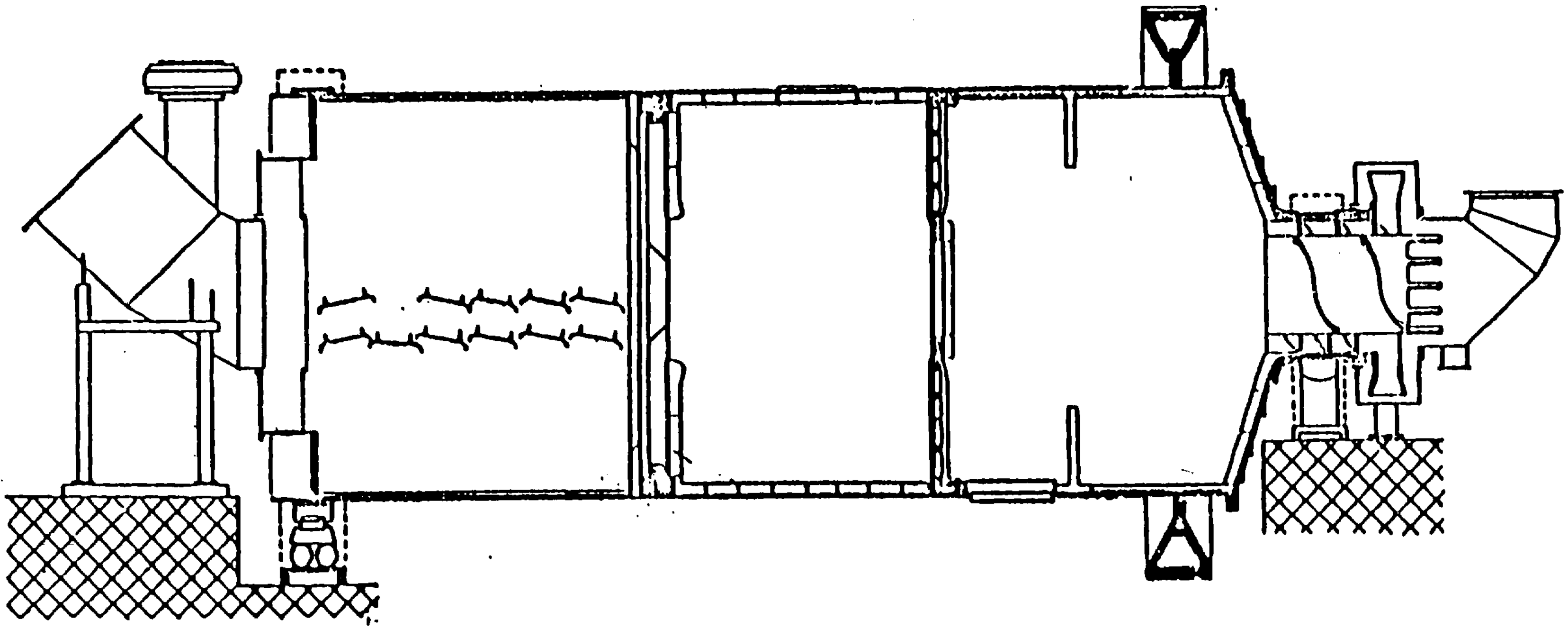
FIG. 2

Air Quantities for Coal Drying

Coal mill: 15 kWh/t Feed: 10° C Mill outlet: 70°C



Tirax mill for coal



CEMENT PRODUCTION SEMINAR

FIG. 3

CEMENT PRODUCTION SEMINAR

FIG. 4

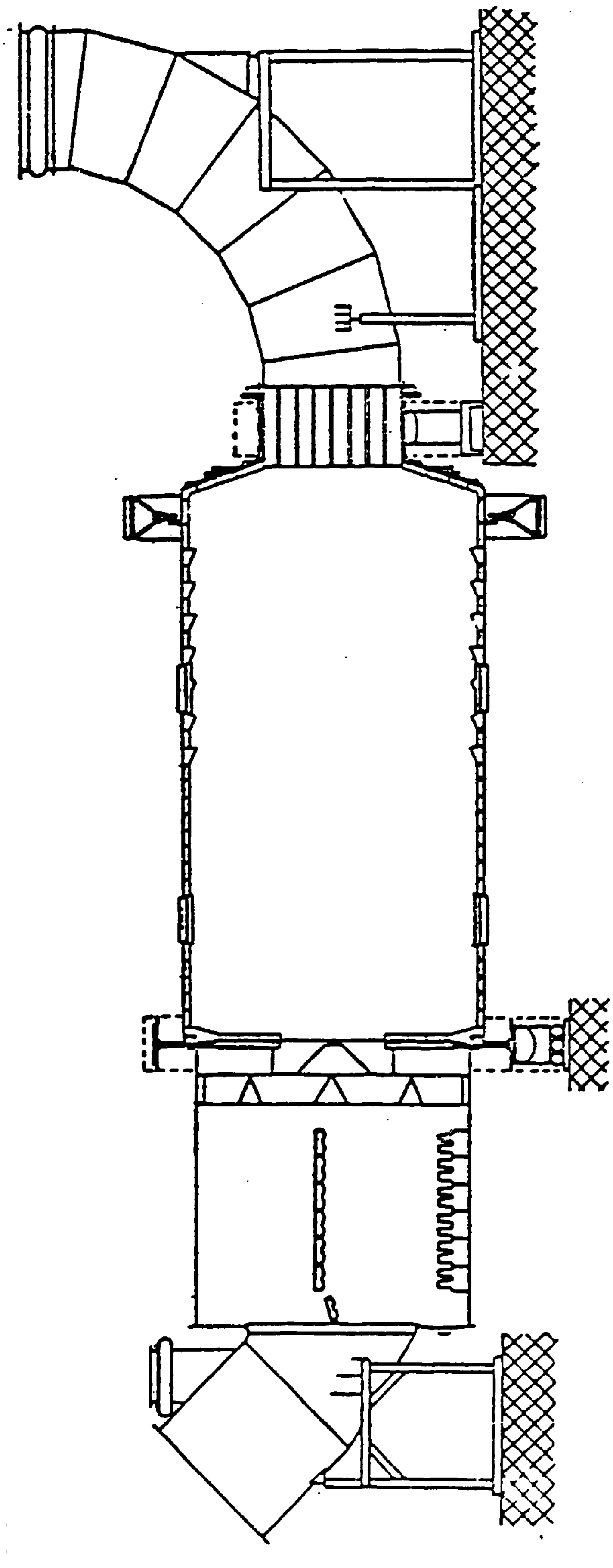


FIG. 5

ATOX MILL

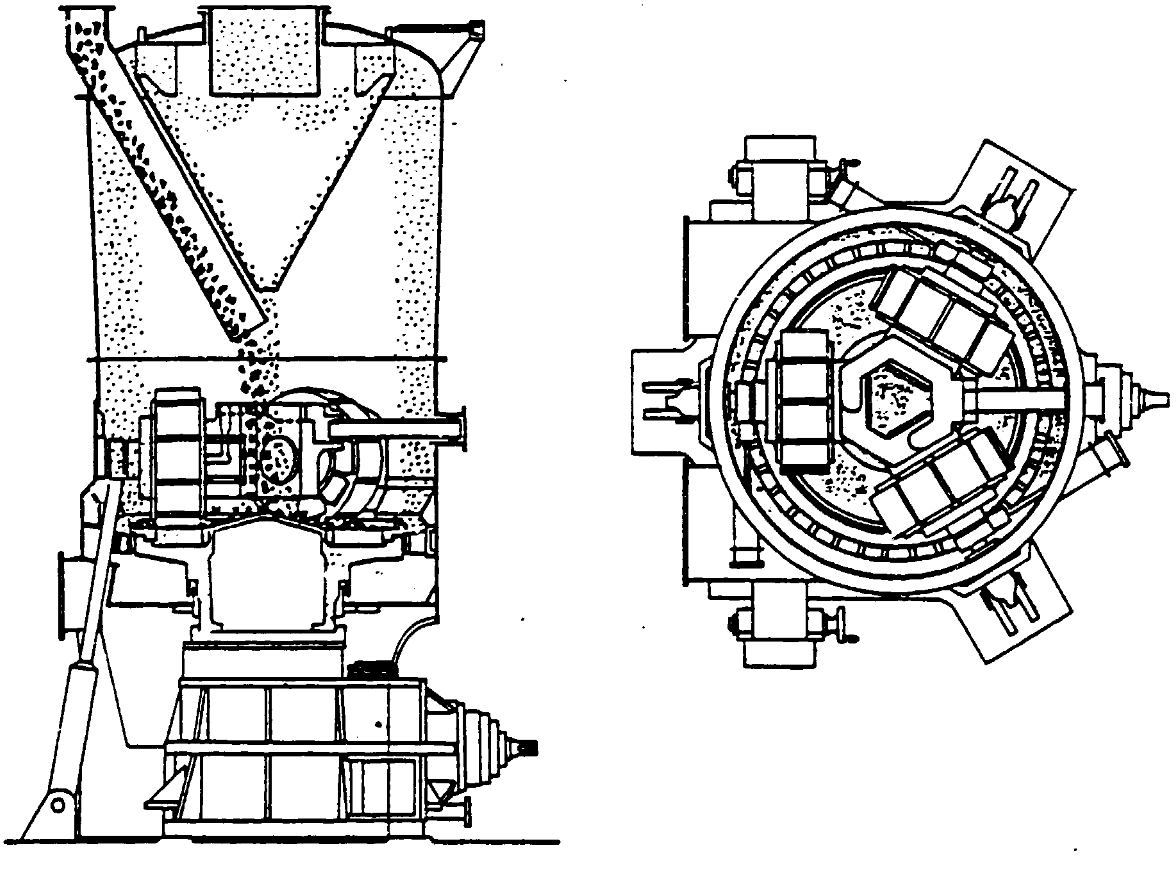
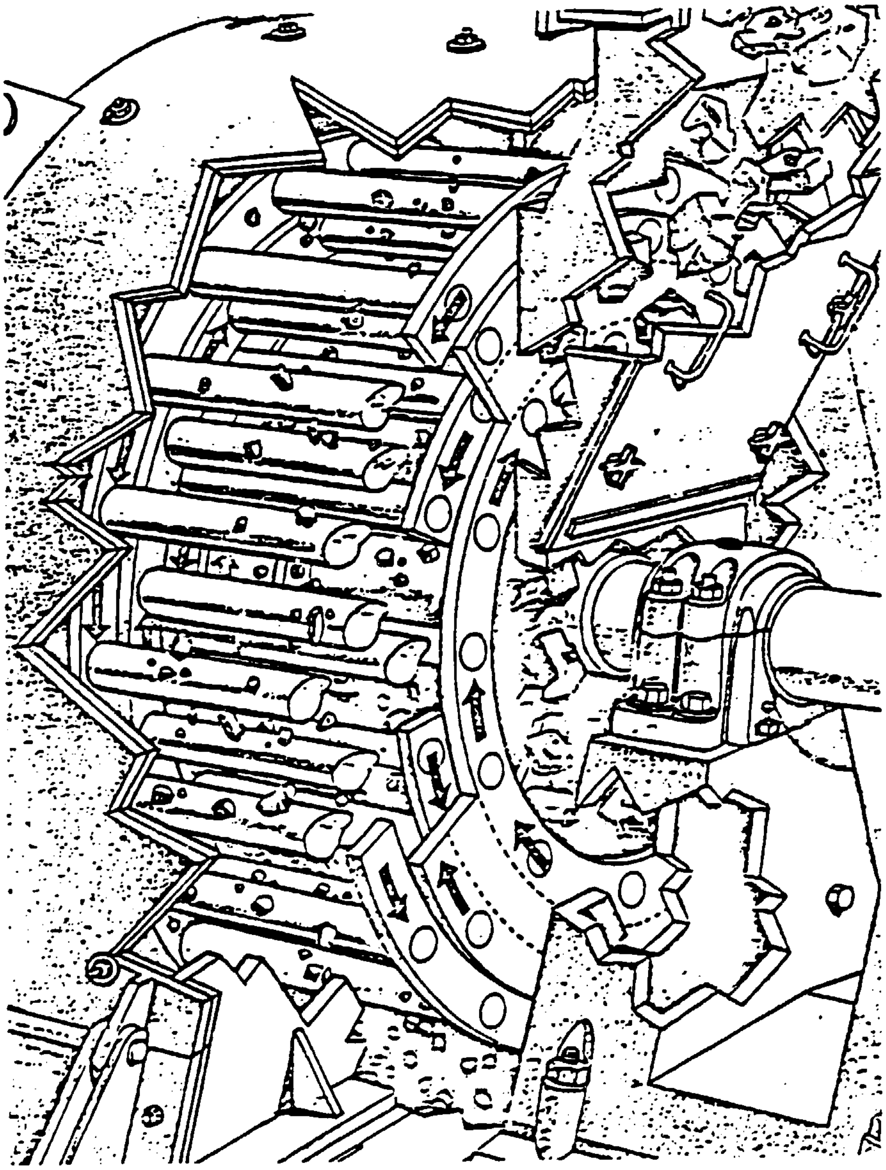


FIG. 6

Cage Mill



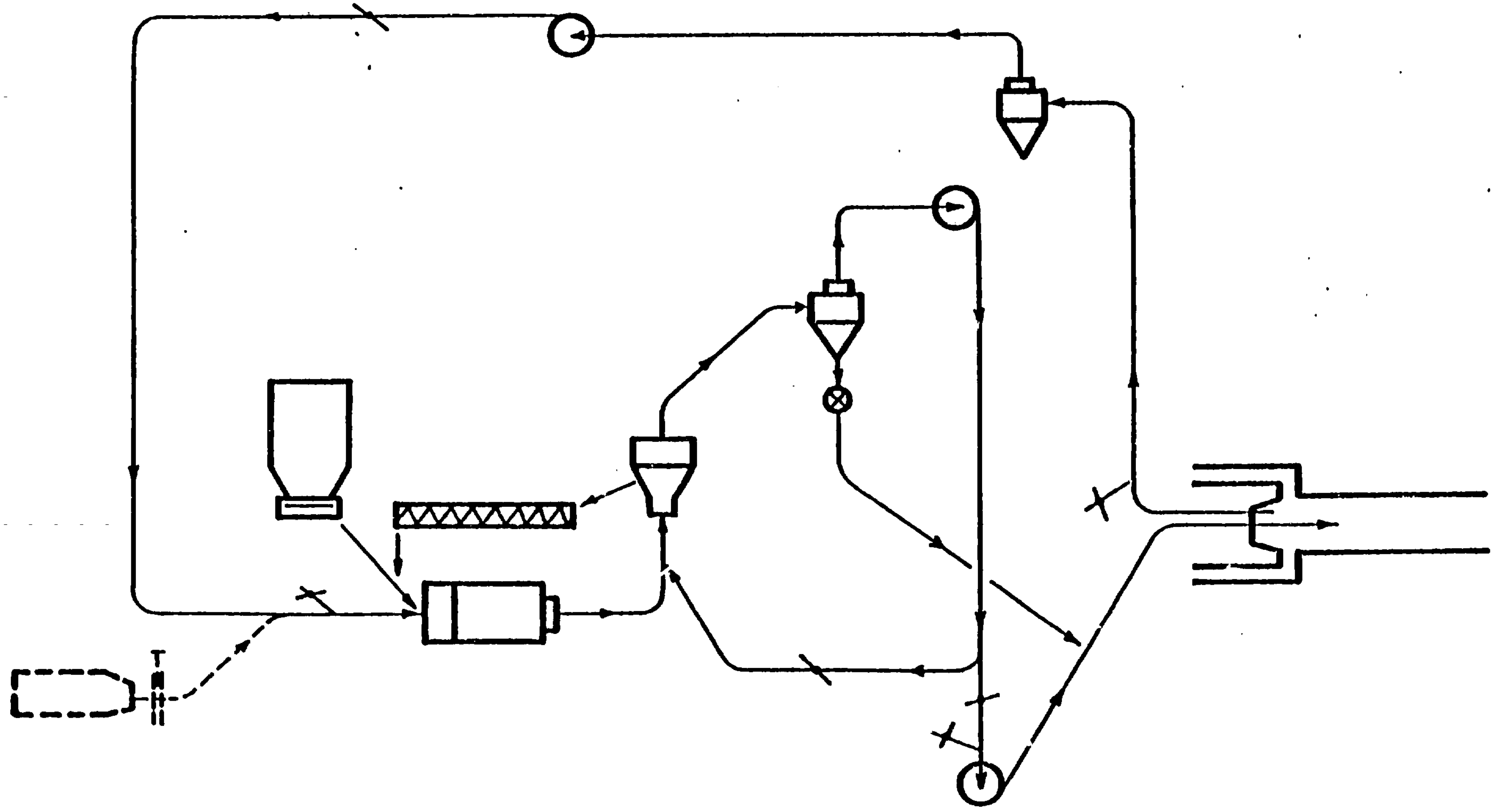
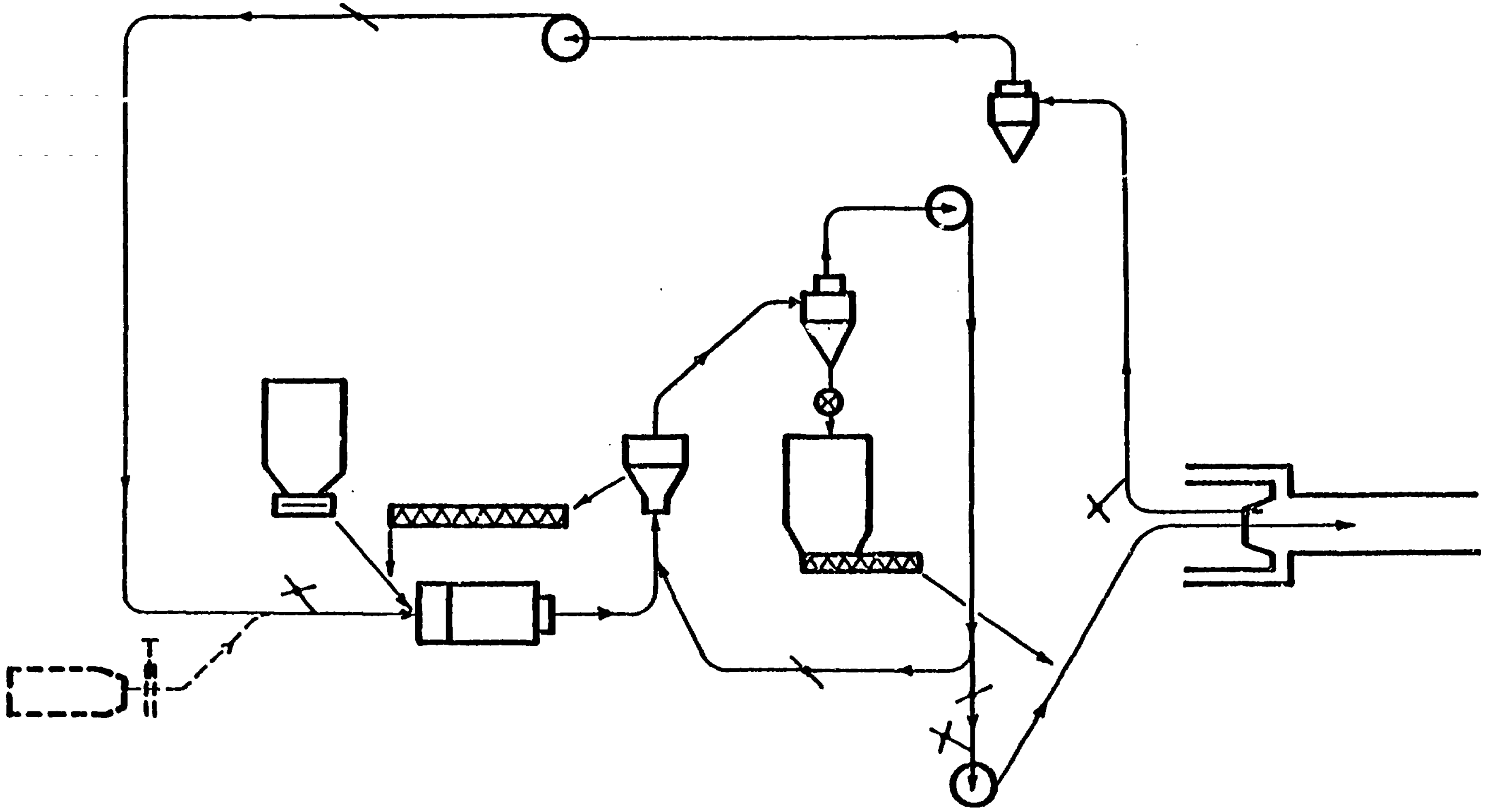


FIG. 7

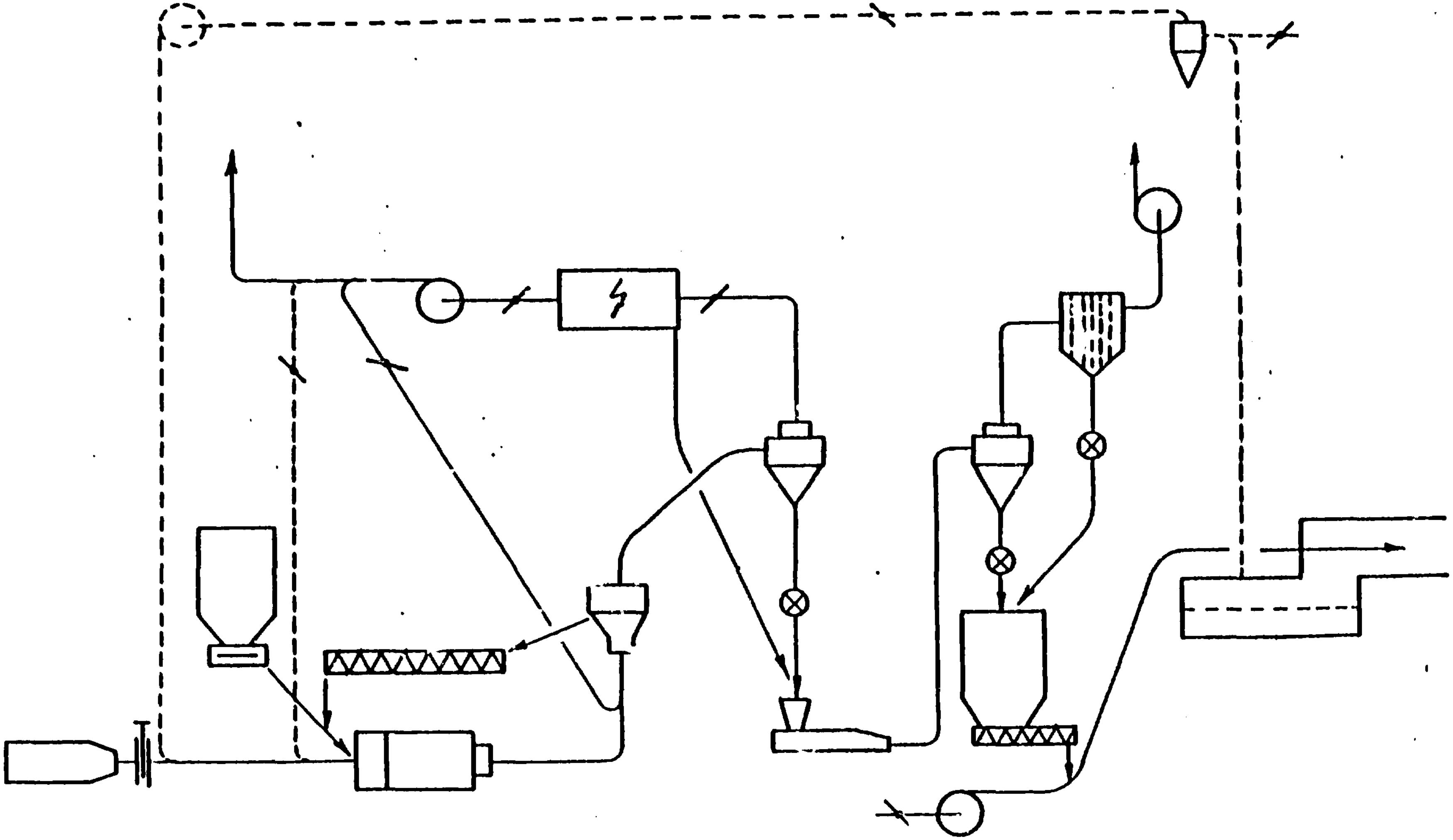
FLS TIRAX COAL MILL FOR DIRECT FIRING



FLS TIRAX COAL MILL FOR FIRING VIA COAL MEAL BIN

CEMENT PRODUCTION SEMINAR

FIG. 8

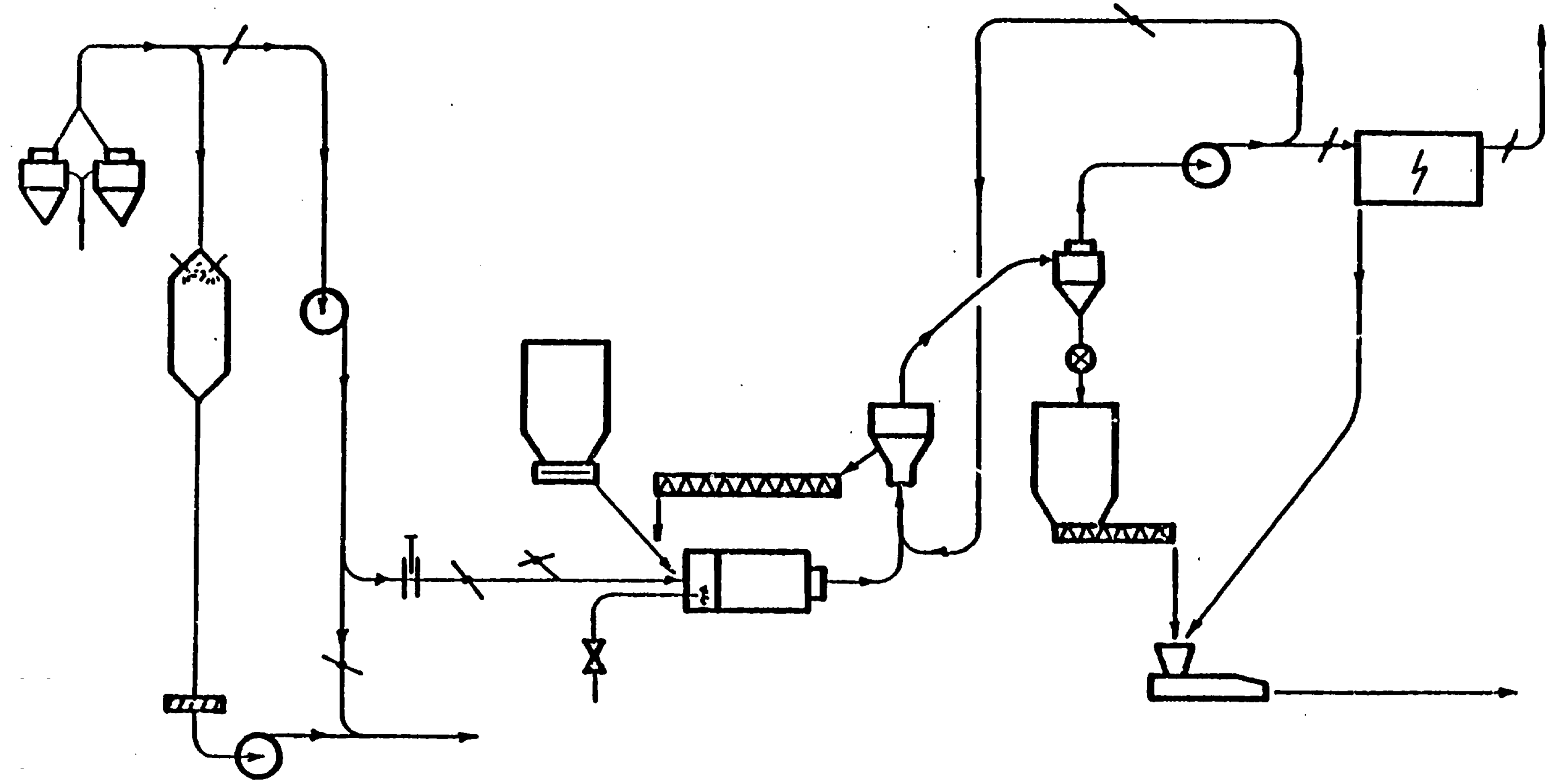


Central Coal Grinding Plant

CEMENT PRODUCTION SEMINAR

FIG. 9

CEMENT PRODUCTION SEMINAR

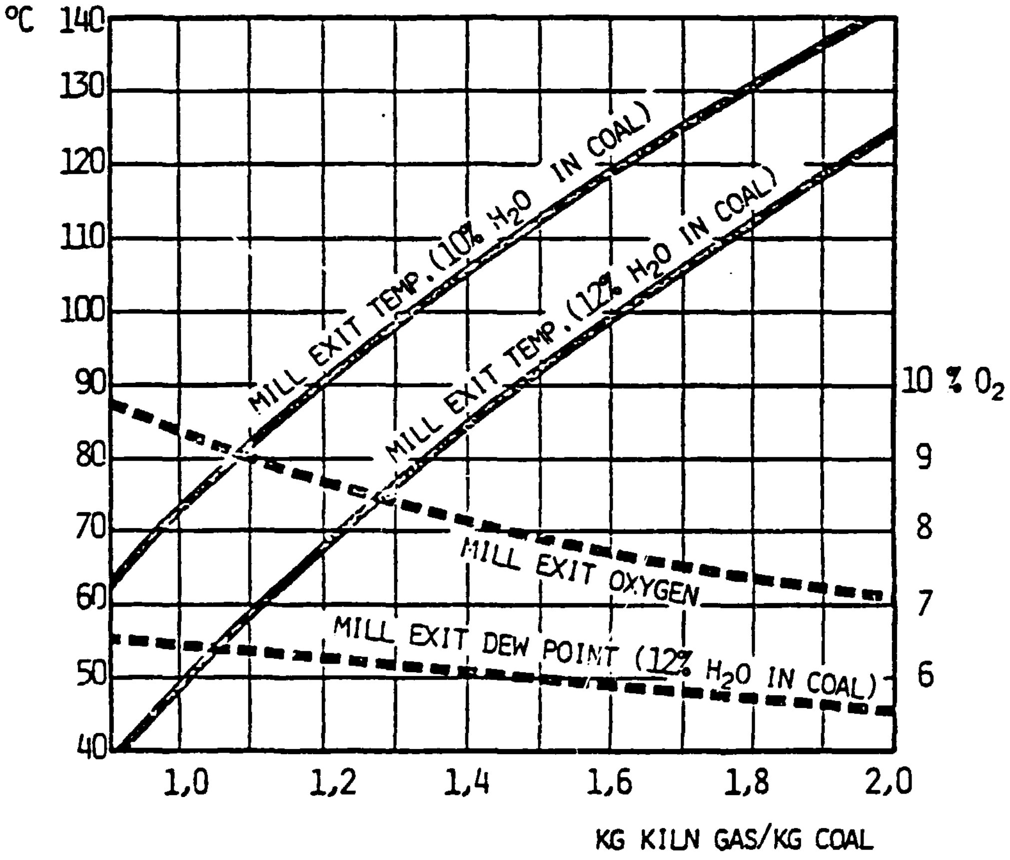


FLS TIRAX COAL MILL FOR INERT OPERATION

FIG. 10

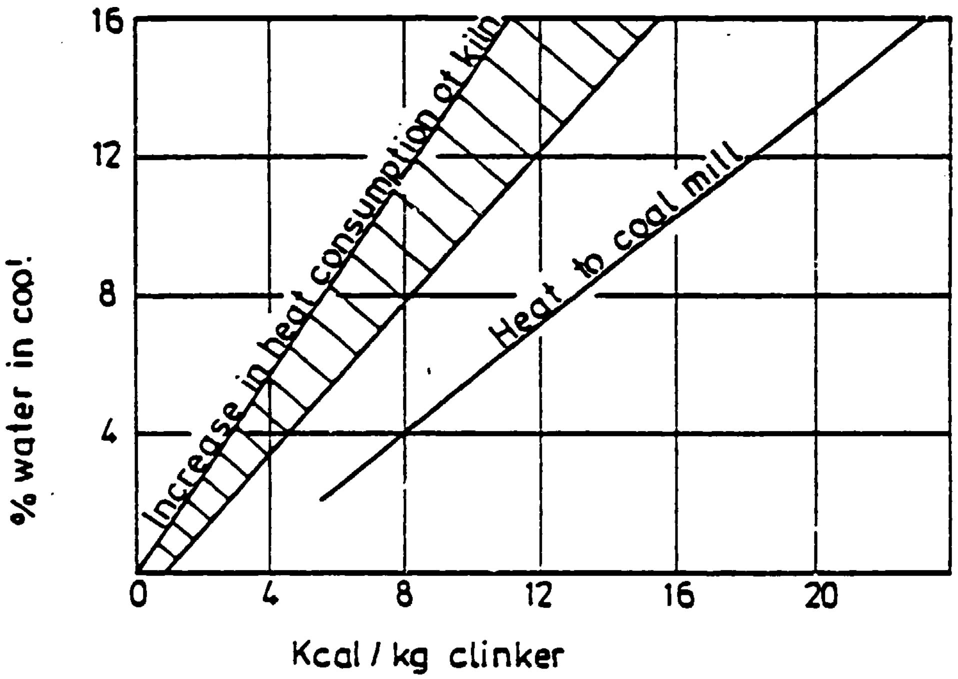
FUELS AND FIRING SYSTEMS

INERT COAL MILLING PLANT



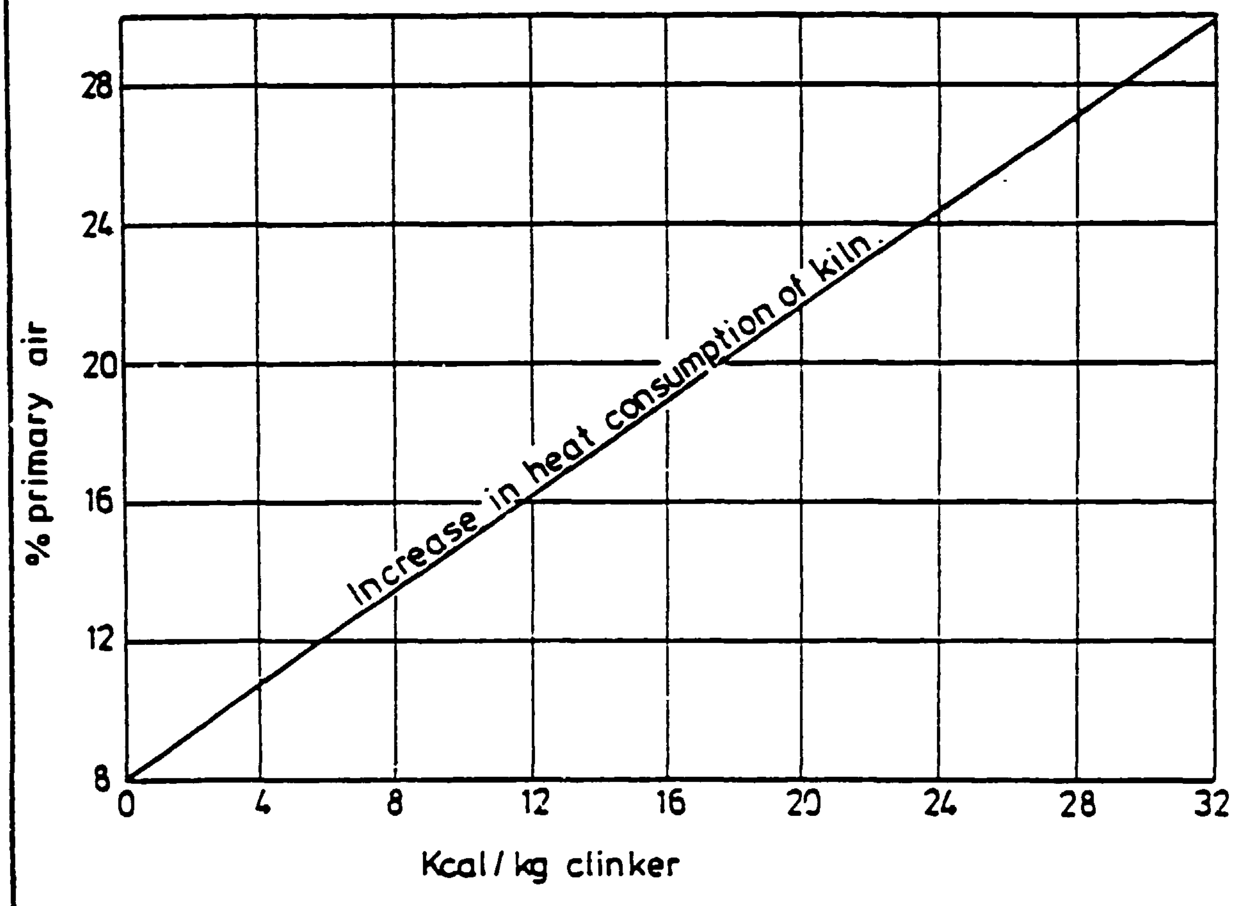
BASIS: KILN GAS 325 C, 4% O_2
COAL DUST 2% H_2O
FALSE AIR IN MILL 0,4 KG/KG COAL

Tirax Coal Mill.

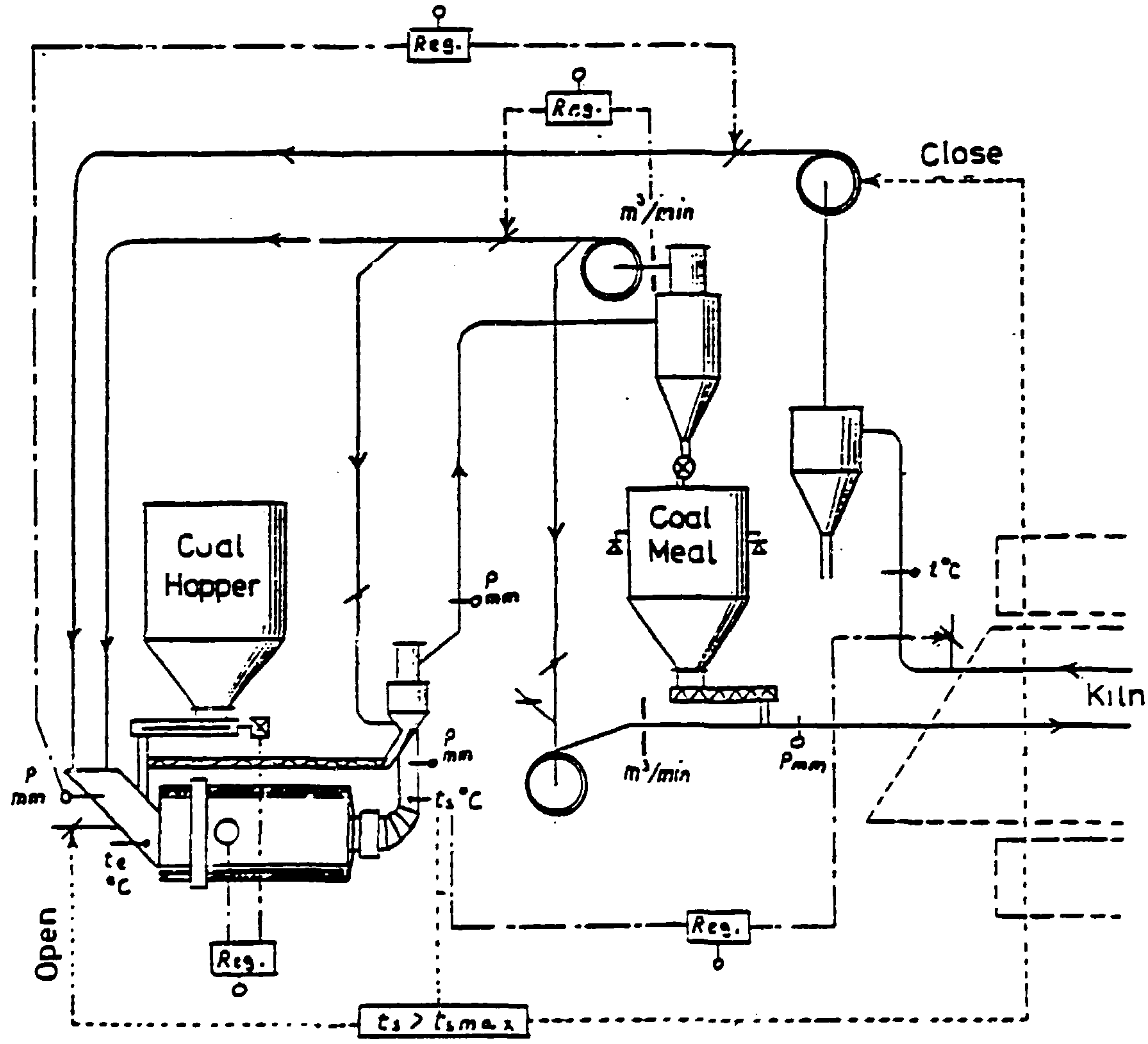


Tirax Coal Mill.

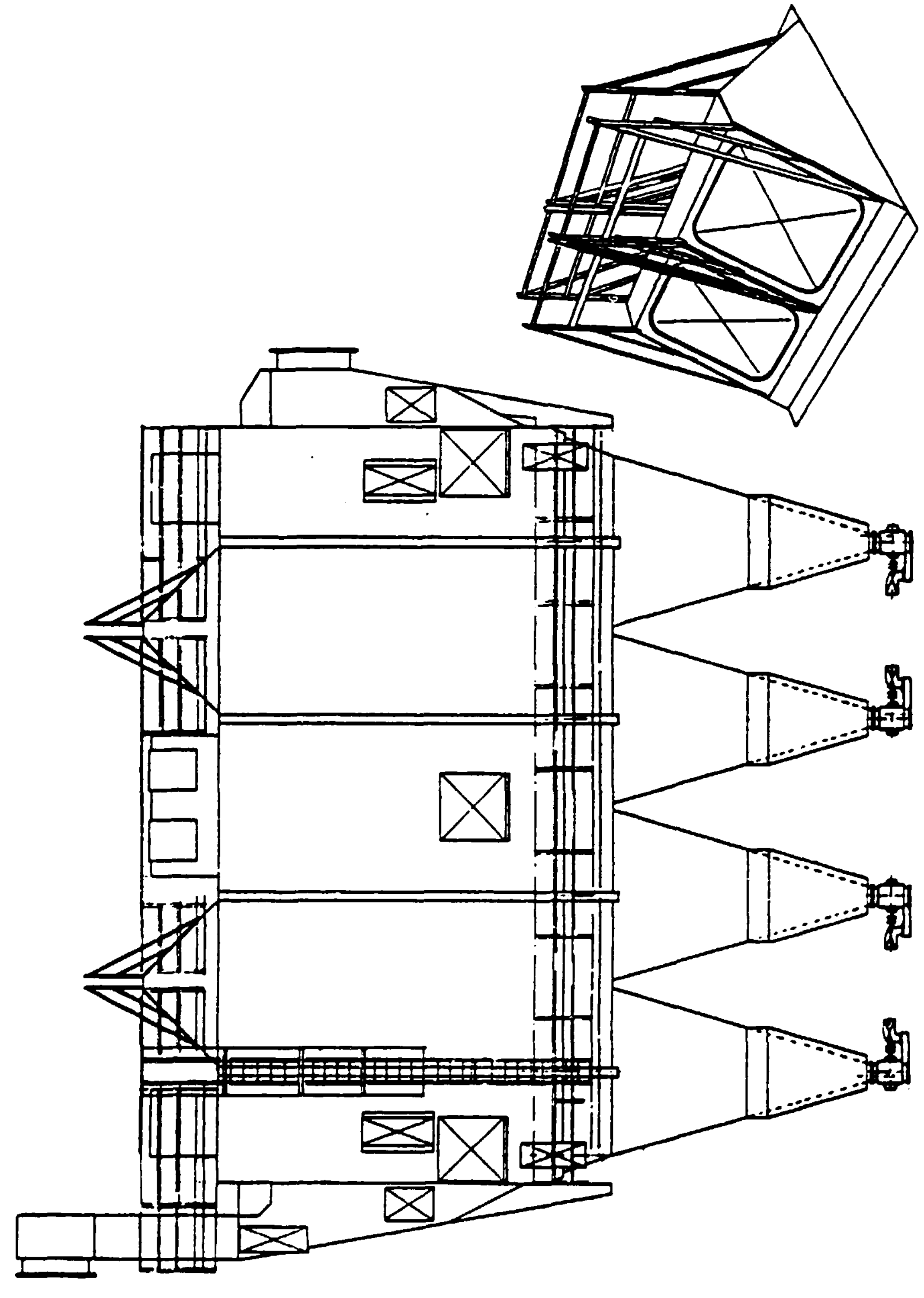
Relation between primary air and heat consumption.



Instrumentation in the Coal Mill Section.



ELECTROSTATIC PRECIPITATOR
TYPE »FE 300«



Coal Dust Firing

General on Combustion

The purpose of firing in a cement kiln is, of course, to convert the latent heat in the fuel to free heat and to transfer this heat to the material in the kiln. However, it is not sufficient to set free the necessary quantity of heat, it is also a requirement that at least a certain part of the heat is supplied at a temperature which is sufficiently high to ensure an adequate velocity of the clinkering processes.

It is a simple matter to calculate a theoretical flame temperature; it is the temperature which the flame would achieve if the combustion were completed within a small volume without any loss of heat to the surroundings.

The theoretical flame temperature depends on the calorific value and the chemical composition of the fuel - especially the hydrogen and ash content. Further, the temperature of the combustion air is important as well as the amount of excess air taking part in the combustion.

For coals of good quality theoretical flame temperatures of just above 2000°C are calculated. The actual flame temperature achievable in practice is more complex to define and to measure, as we are here dealing rather with a certain temperature distribution. As a result of an unavoidable loss of heat from the flame, the actual flame temperature in a cement kiln is 15-20% lower than the theoretical temperature.

There are three factors which can be utilized when a high flame temperature is desired.

Firstly, it is essential to ensure an efficient heat recovery in the clinker cooler so as to get a high temperature of the secondary air.

Secondly, it is important to operate the kiln at an optimum of excess air, which does not necessarily mean at the theoretical minimum. Practice shows that a moderate percentage of excess air offers the best condition with regard to fast and complete combustion.

Finally, the rate of mixing of fuel and combustion air is decisive for the intensity of combustion and for the flame temperature.

The type of combustion which is applied in a rotary kiln, the so-called diffusion flame, is characterized by the fuel and the combustion air being introduced separately into the combustion chamber. The proper mixing of the two components is a result of the kinetic energy with which they leave the burner, being converted into a turbulent flow. By coal firing it is mainly the primary air that carries the kinetic energy. The kinetic energy of the primary air results from its quantity and velocity. Often the so-called flame torque (M) is calculated, which is proportional to the kinetic energy of the primary air:

$$M = \% \text{ primary air} \times \text{velocity of injection}^2$$

If the air velocity is measured in m/sec., the flame torque for a normal coal flame turns out in the order of 70,000-80,000.

According to the formula, a desired flame torque may be obtained at varying air velocities as long as the percentage of air is balanced accordingly. In practice, adequate conditions are achieved in the range 50-100 m/sec. The different coal types require more or less the same flame torque, but procured in different ways.

	% primary air	Velocity of injection
Anthracite	low	high
Bituminous coals	medium	medium
Lignite	high	low

The kinetic energy of the primary air could be assisted by swirling the primary air in the burner nozzle. Some reduction in the primary air percentage could then be gained.

Usually, it is not a problem to obtain a high flame temperature, but the regard to the refractory kiln lining sets a limitation to how far one should go: A short and hot flame often destroys the coating and the lifetime of the basic lining will suffer.

The heat transmission from the flame and the combustion gases is in the burning zone almost exclusively a matter of radiation. Radiation follows the well-known Stefan's Law:

$$R = \varepsilon \times \sigma \times T^4$$

R: Energy transmitted by radiation
T: Flame temperature
ε: Coefficient of emission ($0<\varepsilon<1$)
σ: Constant, dependent on units

It would appear that if ϵ drops faster by increasing temperature than T^4 increases, then a raise in temperature will result in a poorer heat transmission. Therefore, it might not in all circumstances be of advantage to aim at maximum flame temperature.

A misunderstanding often met is the belief in the importance to the heat transmission of having a bright, luminous flame. That this is not so, is understood when energy emission along the spectrum is studied. By far the major part of the radiation is in the invisible infrared range, and only about 1% is emitted as visible light.

Coal Dust Dosification

By a direct-firing coal mill the rate of firing in the kiln is controlled by the raw coal feeder for the mill. It is, therefore, important to have an accurate feeder of the weighing type.

By indirect firing the coal dust is fed from an intermediate hopper. The simplest feeding equipment consists in a variable-speed screw fitted under the hopper. Generally, 2 or 3 screws would be installed in parallel. It is important to have a screw with a small clearance between the screw and the casing; the screw should be sufficiently long to offer a good sealing against the overpressure in the primary air duct. It is also important that the speed of the screw over the whole range of regulation is relatively slow as else the screw will not feed the coal dust in a well-defined manner.

If the coal dust hopper is always kept full to a constant level and if there is no difficulty in extracting the coal dust, the simple volumetric coal screw gives a dosification which is acceptable.

By inserting a weighing unit after the coal screw, for instance of the impact type, and letting the weighing signal control the screw speed, a dosification by weight is obtained. This arrangement provides a compensation for a varying bulk density of the coal dust and also to a certain extent counteracts a partial failure in extraction.

Today a variety of accurate, but rather complex coal dust feeders is available on the market (Simplex, Carbodos etc.)

If the coal plant is ventilated to the kiln, one should be aware that some coal dust goes directly with the primary air and by-passes the feeder. This is normally not a problem as the quantity is very constant, but it should be compensated for when starting and stopping the mill.

What is actually aimed at when feeding the coal dust to the kiln is a well-controlled dosification of calories. Not even the most accurate coal dust feeder is in a position to compensate for variations in ash or moisture content. It has been tried to let the oxygen analyzer control the rate of oal feed, but often the gas analyser is not sufficiently reliable.

By supporting the coal dust hopper on load cells two advantages are obtained: The coal dust feeder is now easily calibrated even when the kiln is operating, and the stock of coal dust can be made to control the coal mill output in an automatic way so as to ensure continuous operation of the mill.

By the indirect firing the coal dust is introduced into the primary air on the delivery side of the primary air fan. The high pressure - often up to 1000 mm Wg - against which the coal dust is introduced, may present a problem, and sometimes it is found necessary to install one or even two rotary air sluices at this point. It would be simpler to feed the coal dust on the suction side of the fan, but by doing so it would result in an excessive wear on the fan impeller.

If more kilns are supplied with coal from a centralised grinding plant, the coal dust may be conveyed pneumatically - by Fuller pumps, for instance - directly to the individual burners in the kilns or precalciners. By appropriate dimensioning of such installations, coal dust may be conveyed over distances up to 200 m without pulsations.

In coal dust bearing pipelines it is important to maintain velocities of about 25 m/sec. to avoid settling of the coal dust in the pipes - otherwise, at lower velocities, the coal dust will arrive at the burner in surges. Frequent and large oscillations in the oxygen of a coal fired kiln are often the result of such surges.

The coal burner is often a simple, smooth steel pipe with external insulation. The top of the burner pipe is usually made of refractory steel and it has a diameter which at the desired percentage of primary air gives an adequate velocity of injection. For this type of burner 15-30% of primary air is needed, depending on the coal quality.

From a fuel economy point of view it would in modern dry kilns be desirable to reduce the percentage of primary air as much as possible. Some newer coal dust burners are designed to operate with as little as 7-8% of primary air (Cohen, Pillard, FLS ....).

The coal dust is ignited in the kiln at a certain distance from the burner. The length of the "stalk" of not yet ignited coal depends on the quality of the coal and on its fineness, - further on the conditions of injection and on the radiation from the kiln and the hot clinker. The ignition will happen when the temperature of the coal/air-mixture reaches the temperature of ignition of the coal.

To achieve the best conditions for ignition and combustion it is important to grind the coal to the correct fineness. One might think that conditions would improve, the finer the coal is ground. This is also true to a certain extent for low-volatile coals. Coals of higher volatile contents must be ground coarser as a means of controlling the rate of expulsion of the gas. If the volatiles are driven off too fast, the mixing of coal particles, volatiles and hot secondary air will become more difficult. Each coal type has an optimum fineness to which it should be ground. The optimum fineness depends mainly on the content of volatiles.

Lighting of a coal-fired kiln

The lighting of the kiln is simple if an installation for fuel oil is available. The kiln is started on fuel oil and once it is hot, the oil is gradually replaced by coal.

If fuel oil is not available, the classical method may be used, lighting a heap of firewood placed in the kiln in front of the burner pipe. Such a procedure is troublesome and is rarely seen today.

A more modern method is to acquire an ignition burner for Diesel- og gas oil. This burner is inserted in the coal burner pipe through a protection pipe located in the center line of the coal pipe. For heavier types of oil the ignition can be effected with the aid of a small gas burner supplied with propane from a couple of bottles of domestic economy size.

Combined Firing

Coal can be combined with either fuel oil or natural gas or both. The most common combination is coal/fuel oil-firing. In this case the oil burner is inserted concentrically in the coal burner. This combination is over a wide range very flexible with regard to the ratio between the two fuels, and also the oil burner makes the start of the kiln very easy.

Effect of Coal Ash

The coal ash will in the kiln be absorbed by the kiln charge and combine with it. The chemical composition of the ash is always quite different from that of the clinker, for which reason the ash absorption must be taken into account when making the raw meal. By burning coal of good quality with about 15% ash, there is in wet kilns found a drop in lime saturation from kiln feed to clinker of about 8-10, whereas in an economic dry kiln the LSF-reduction generally amounts to 4-5.

What is of great importance to the clinker quality is the way in which the ash is absorbed by the kiln material. Preferably the ash should be absorbed before the final clinker formation takes place. If the ash is absorbed by a granular material, the ash will be contained mainly in the surface layers of the granules. The result would then be clinker with a shell of low-LSF material and a core with high free lime. This can be a problem in kilns which are fed with nodulised raw meal, or in small wet kilns in which the material leaves the chain system as plastic nodules.

A problem which is sometimes met in coal fired kilns is related to the kiln start. In the hours following the start the kiln is not yet in heat balance and more heat must be supplied than required by the process in order to heat properly the installation itself. In other words, the kiln is over-fired. In this situation it might happen that the ash quantity supplied with the coal becomes excessive, resulting in a fusion of the clinker charge and damage to the burning zone lining.

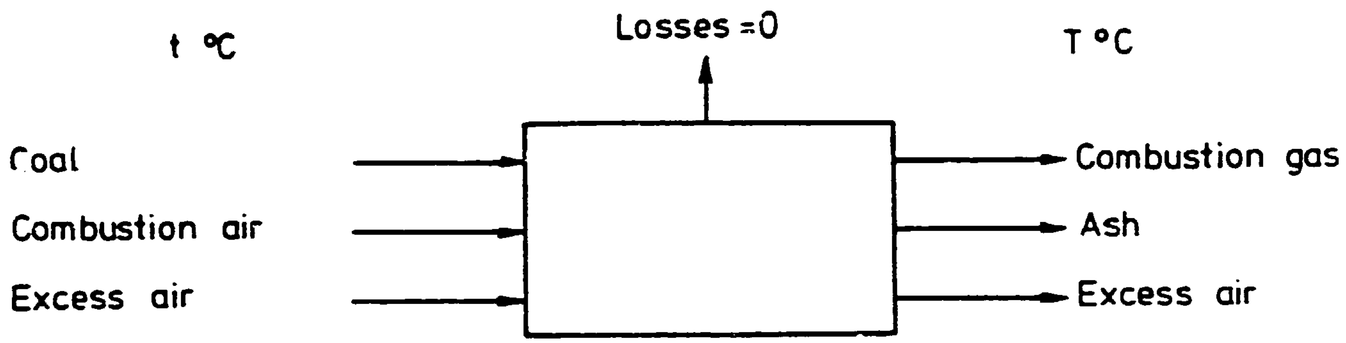
Low-Grade Coal

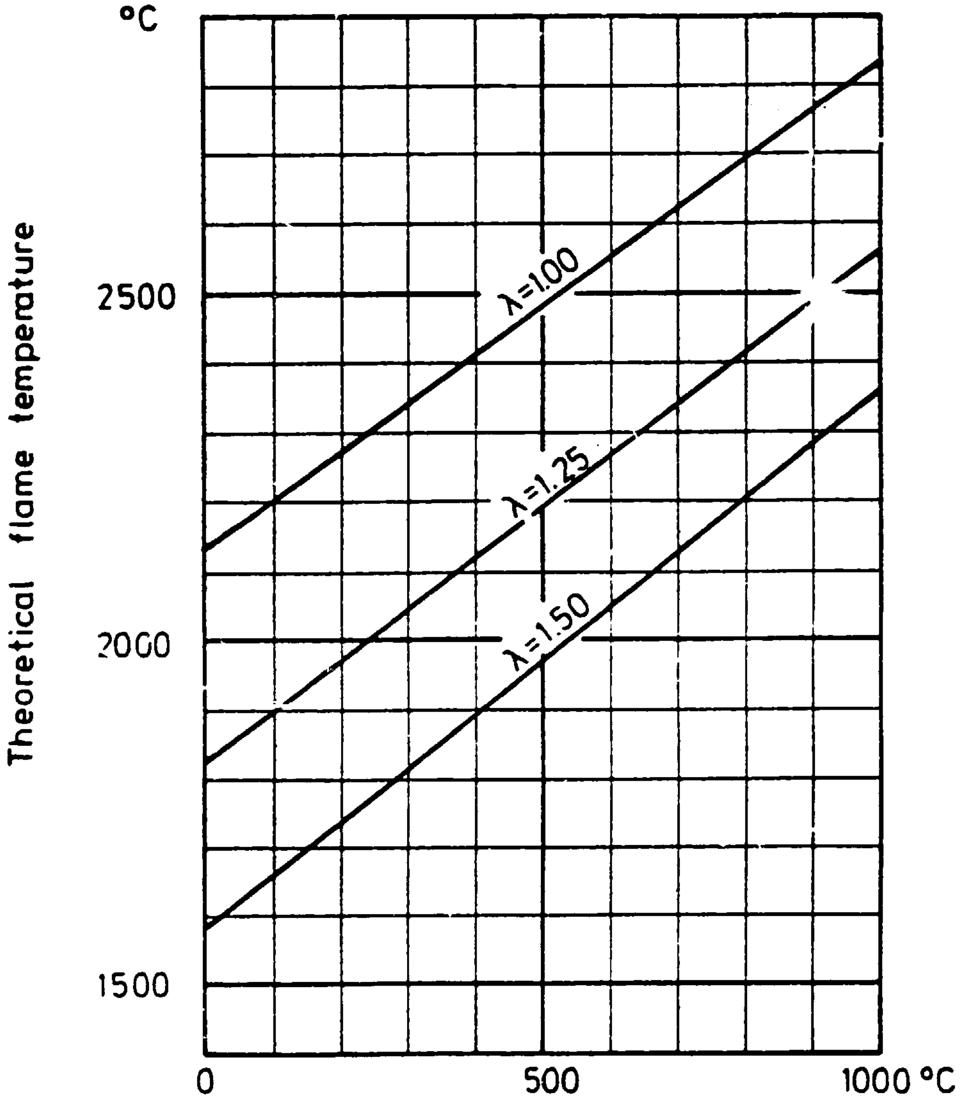
There is a limit to how poor a coal quality that can be used for firing in the kiln. Demand to flame temperature and clinker quality sets a limit at 4-4,500 kcal/kg. If a good coal quality is available, then normally some low-grade coal, like coal shale, can be mixed with the good quality - how much depends on the ash contents of the two types.

In recent years it has become increasingly common at 4-stage kilns to fire up till 25% of the fuel into the riser pipe, which connects the kiln and the preheater. A number of advantages may be gained this way. In such a case, and in the case of true precalciner kilns, the secondary combustion at the back-end is a low temperature combustion and there is no demand for a high flame temperature. The only limitation to how much low grade fuel may be used here is a matter of making a raw mix which has the ability to absorb the ash. The extreme case would be to feed the preheater with pure limestone meal.

Coal Combustion

Theoretical Flame Temperature





Coal : 12% Ash
6300 kcal / kg (Hi)

Coal Combustion

M = % primary air × velocity of injection^2

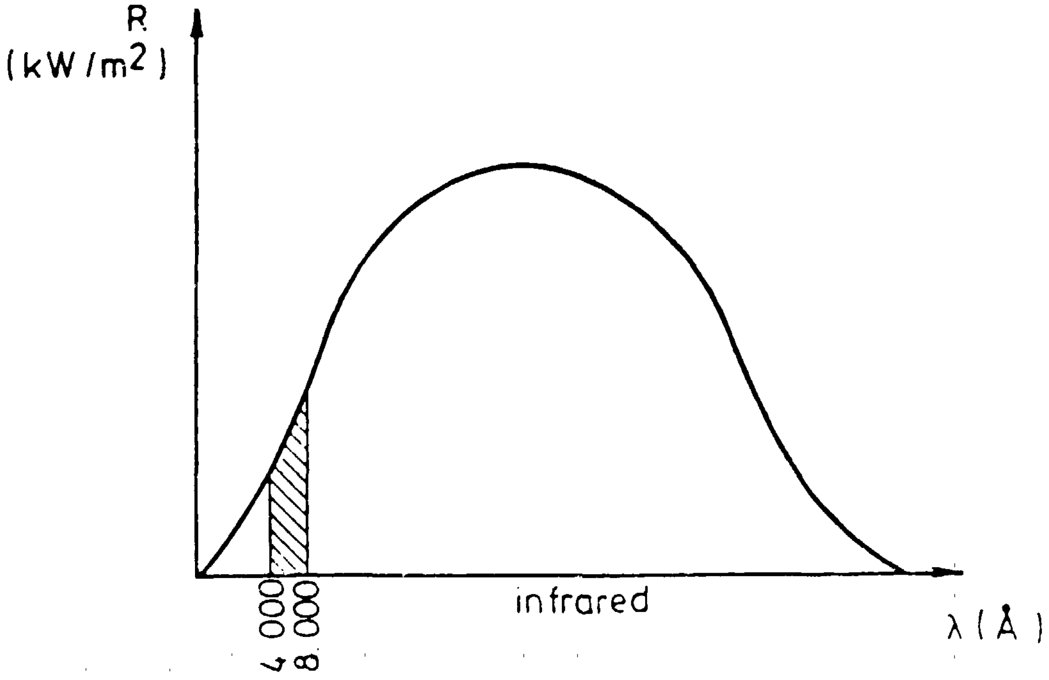
Coal: $M \sim 75.000$
Fuel-oil: $M \sim 100.000$

	% primary air	velocity
Antracite	low	high
Bitum. coal	medium	medium
Lignite	high	low

Stefan's law:

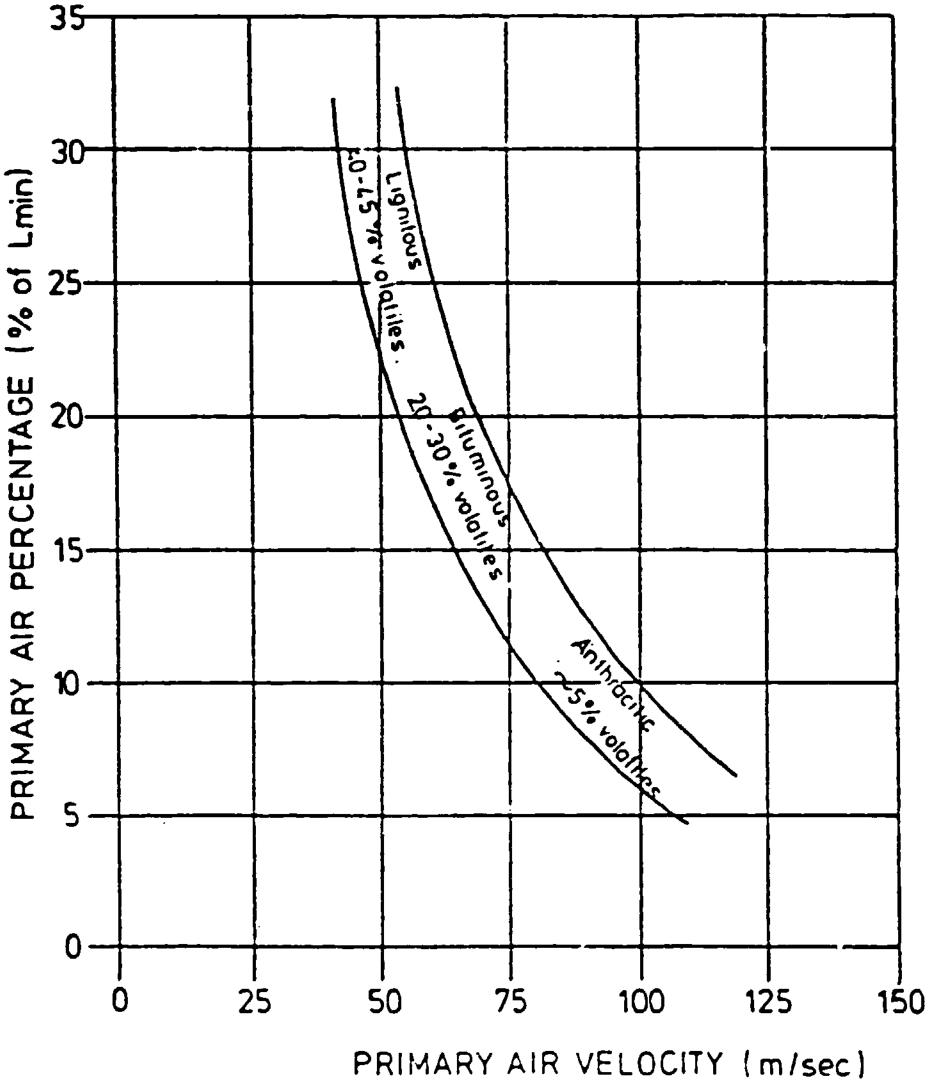
$$R = \varepsilon \times \sigma \times T^4$$

R: kW/m^2
T: °K
ε: $0 < \varepsilon < 1$

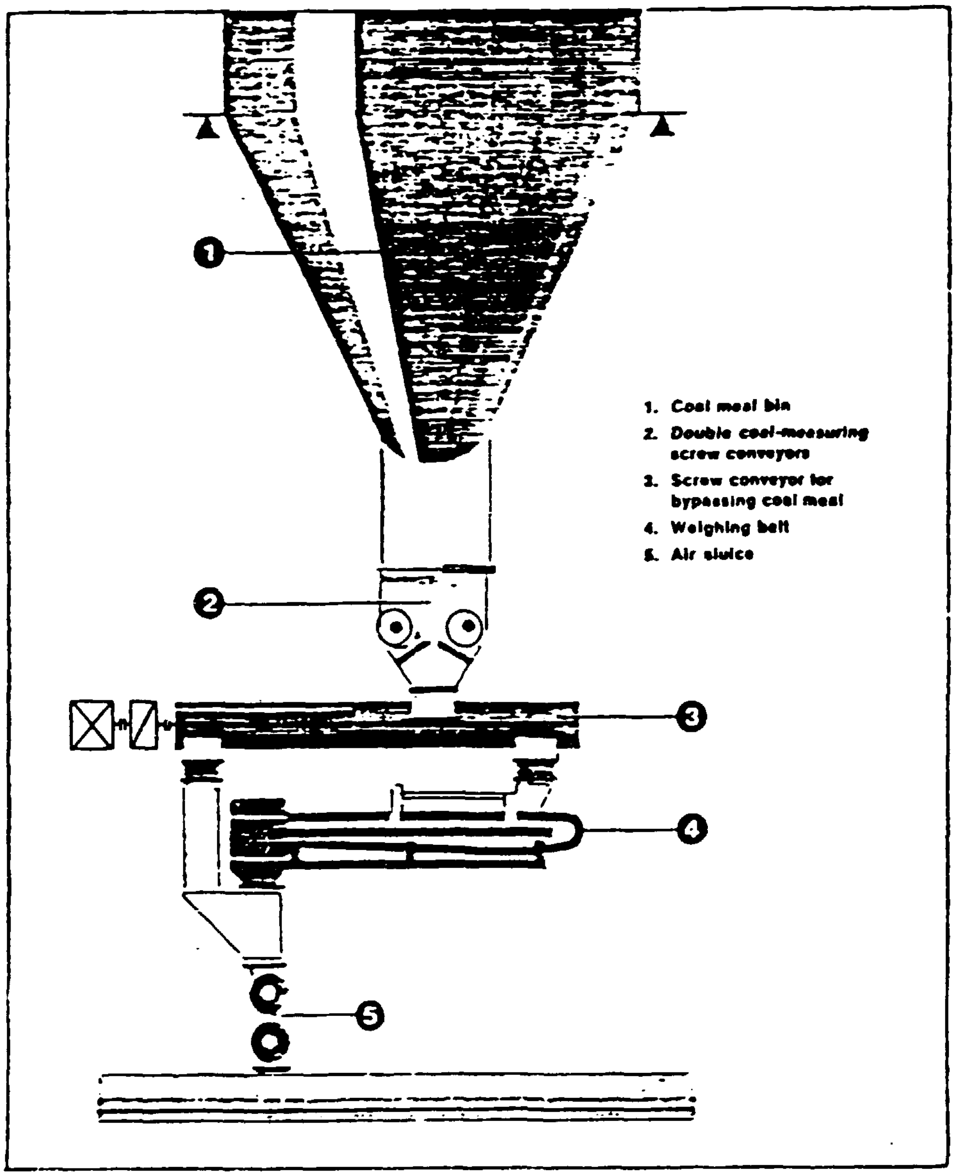


COAL FIRING

PRIMARY AIR
VELOCITY / PERCENTAGE - RELATION

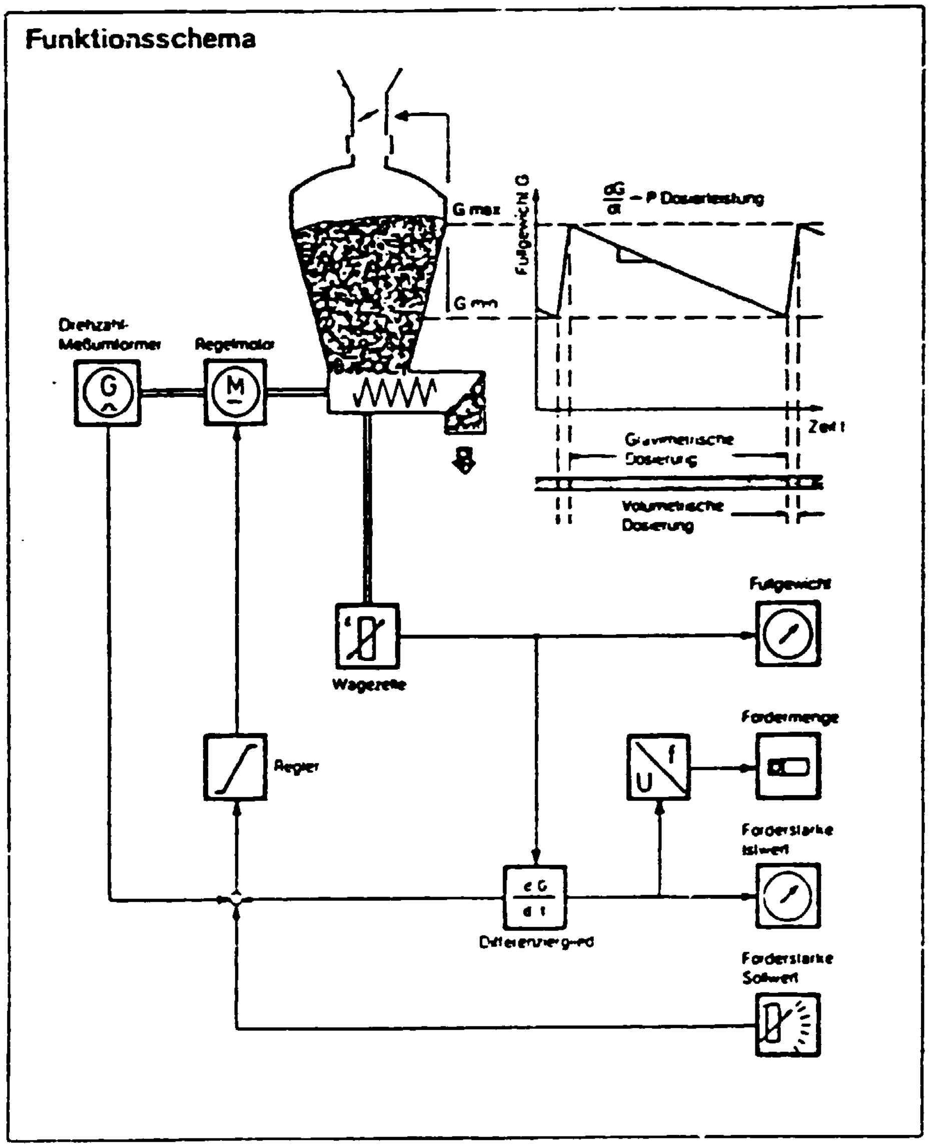


Coal Feeding (FLS-Schenck)

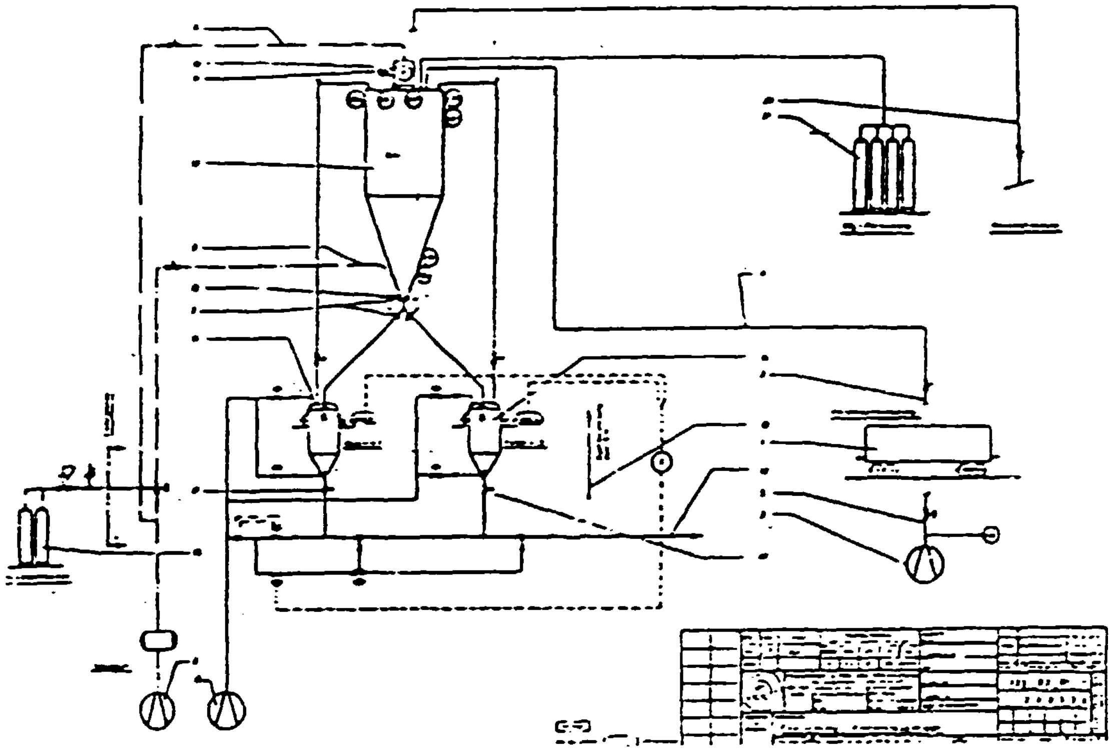


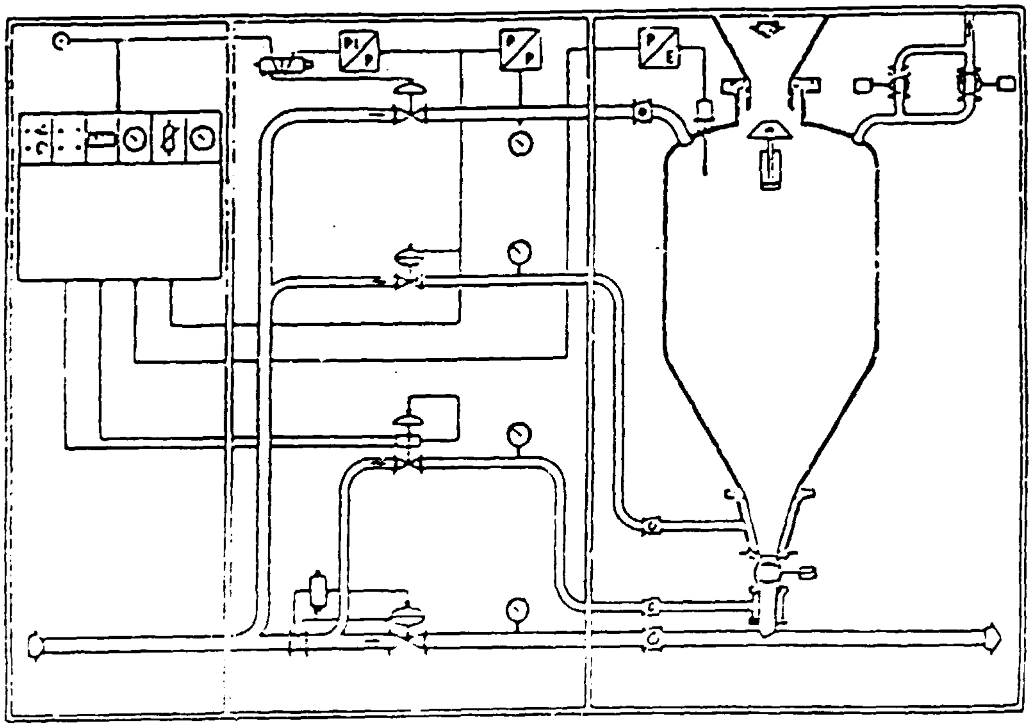
Gravimetric feeding of coal meal

Coal Feeding (Schenck-"Simplex")

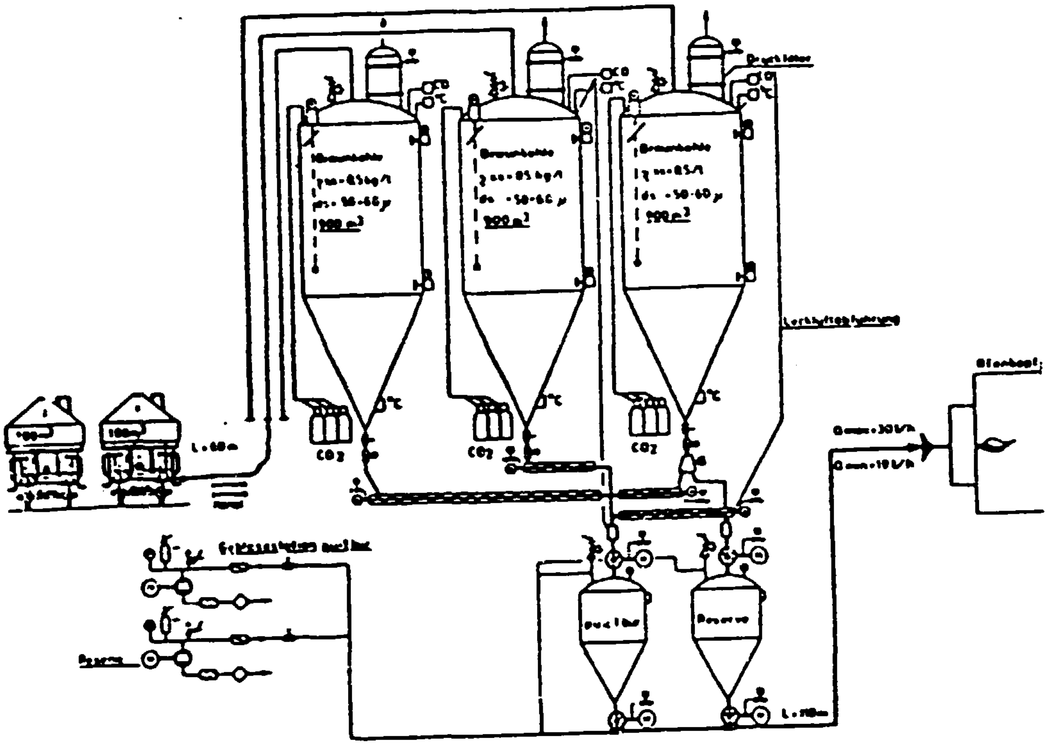


Coal Feeding (Polysius "Carbodos")





Coal Feeding (Waeschle)



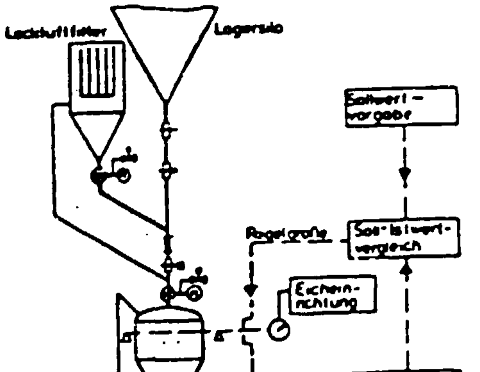
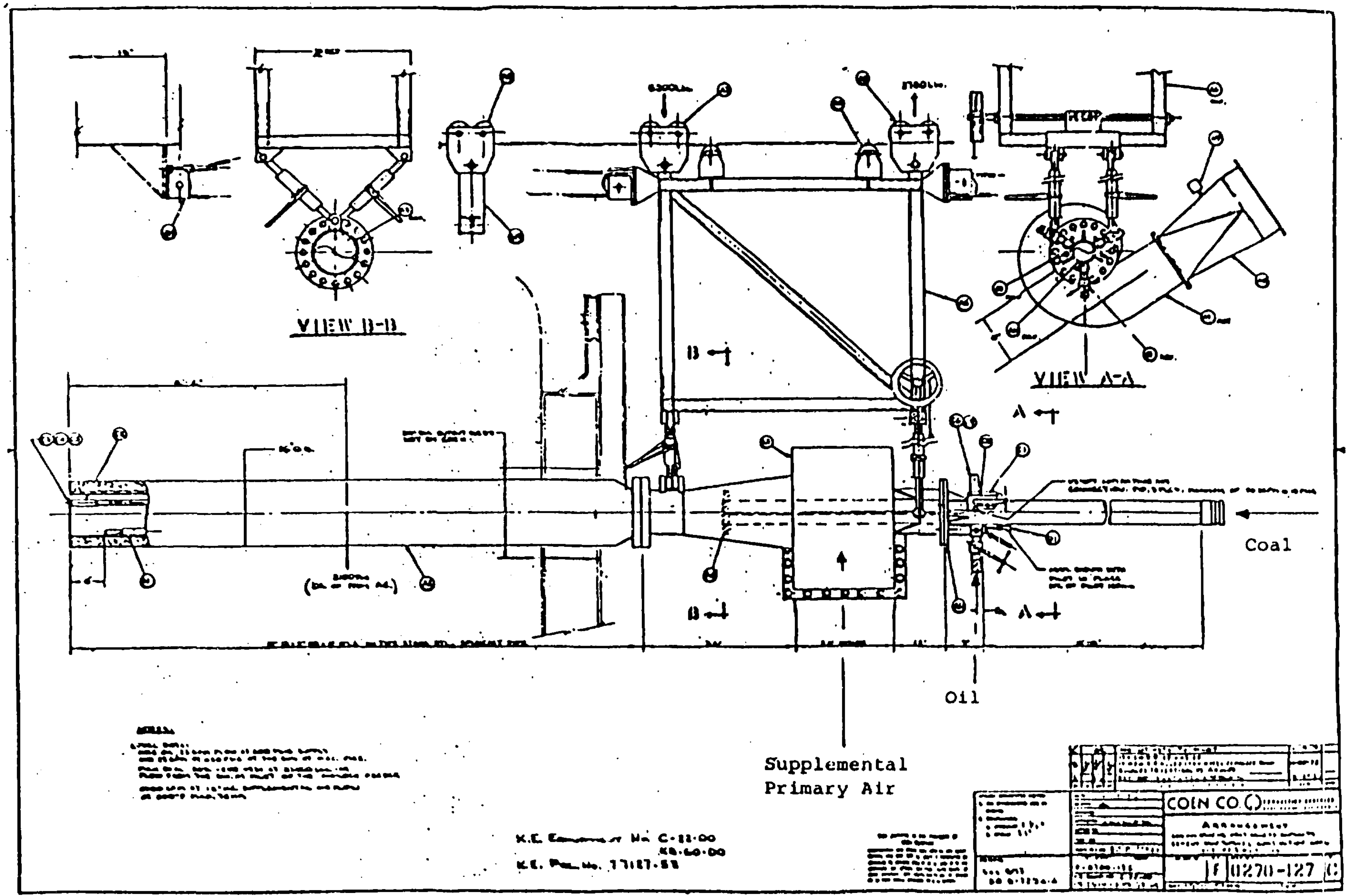
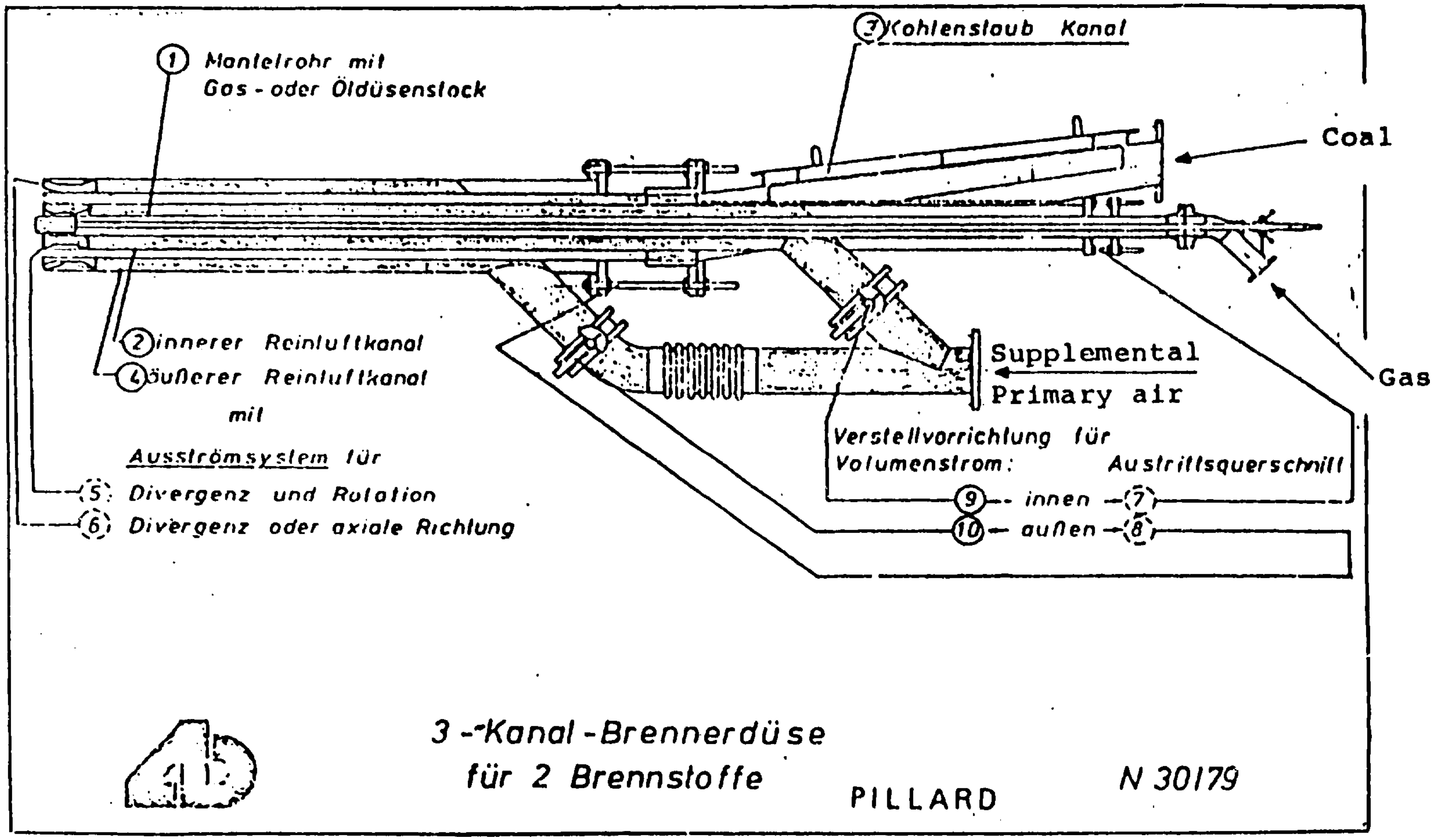


Bild 2: Druckdifferenzsteuerung
Differential pressure control

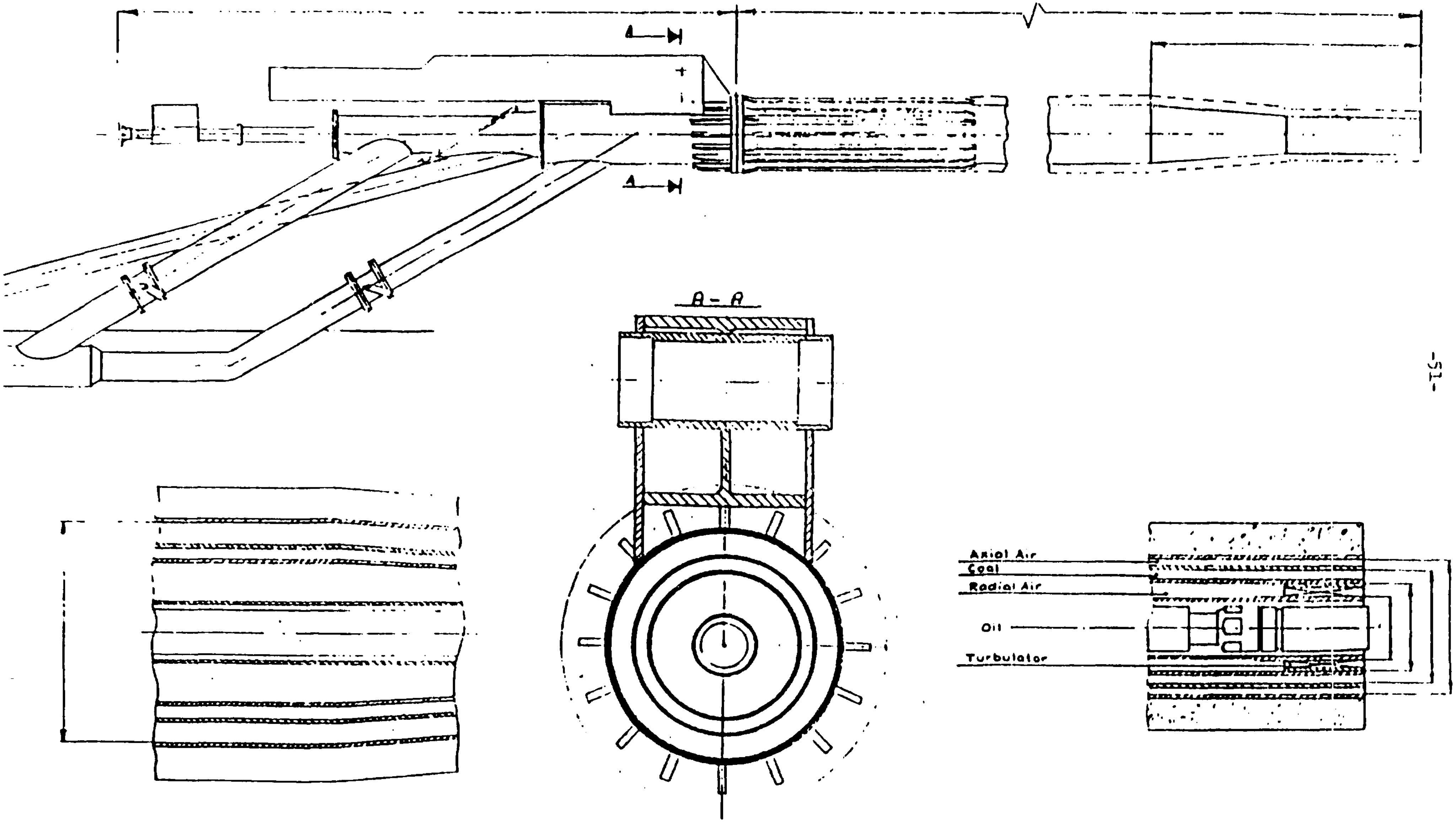
Combined Coal-Oil Burner (COEN.)

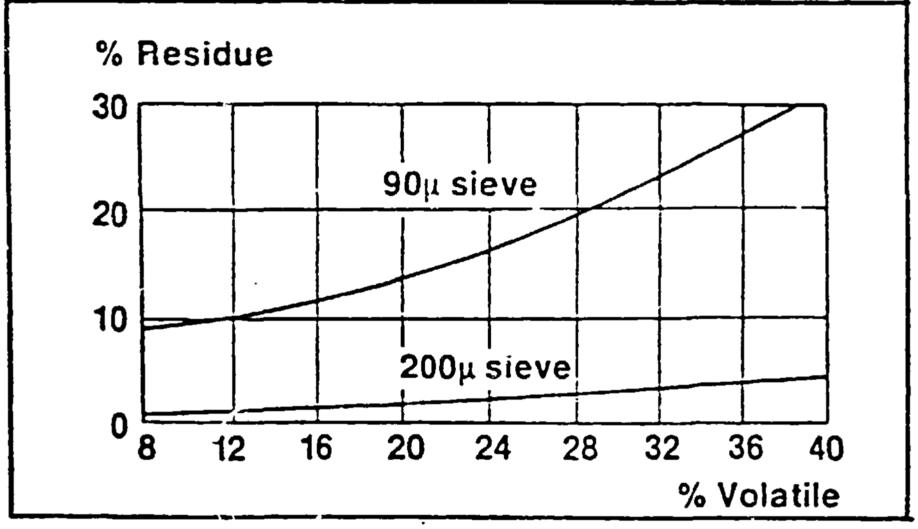


Combined Coal-Gas Burner (Pillard)

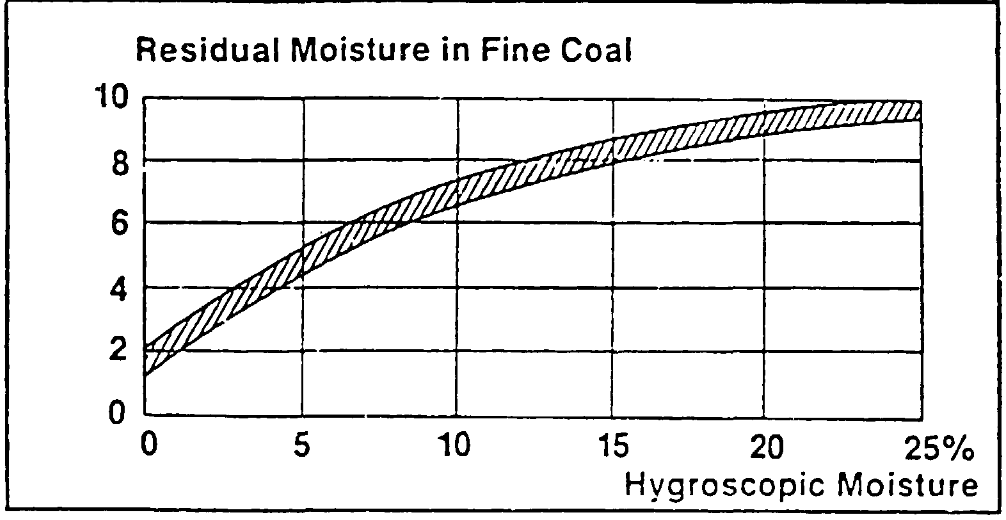


Combined Coal-Oil Burner (FLS)



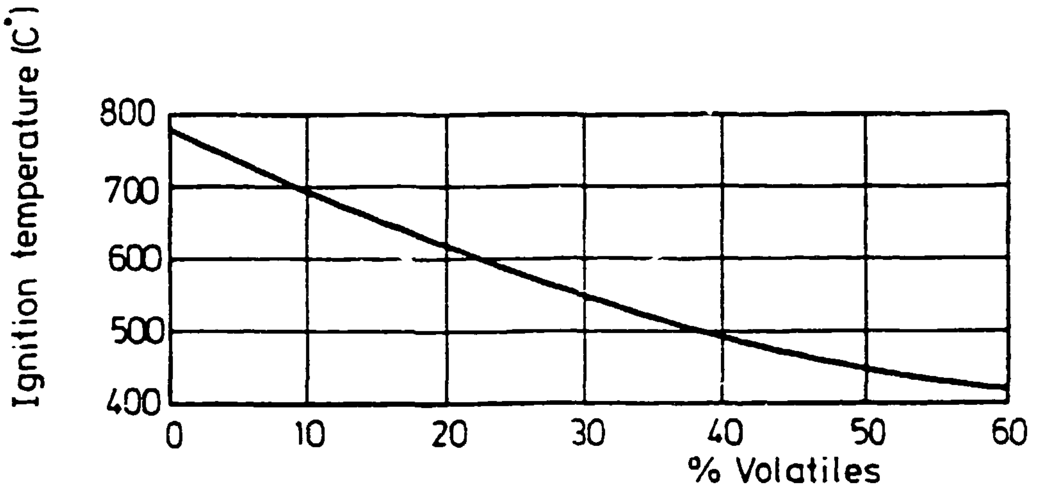


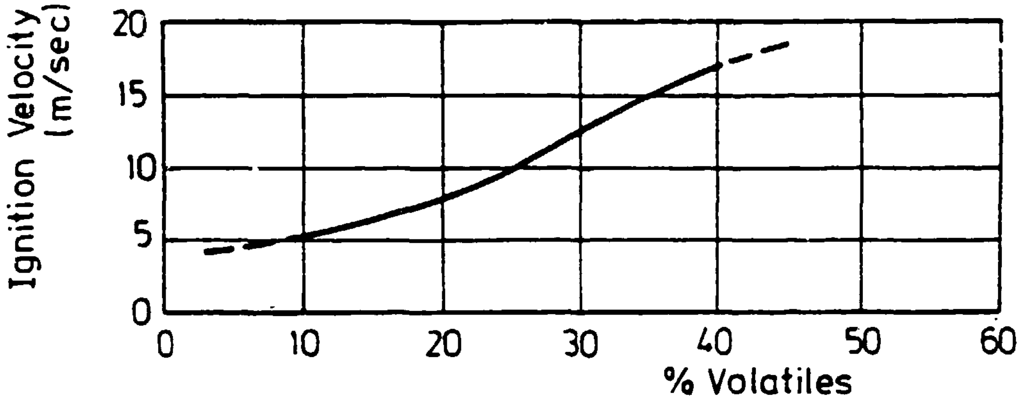
Recommended Fineness of Coal Dust

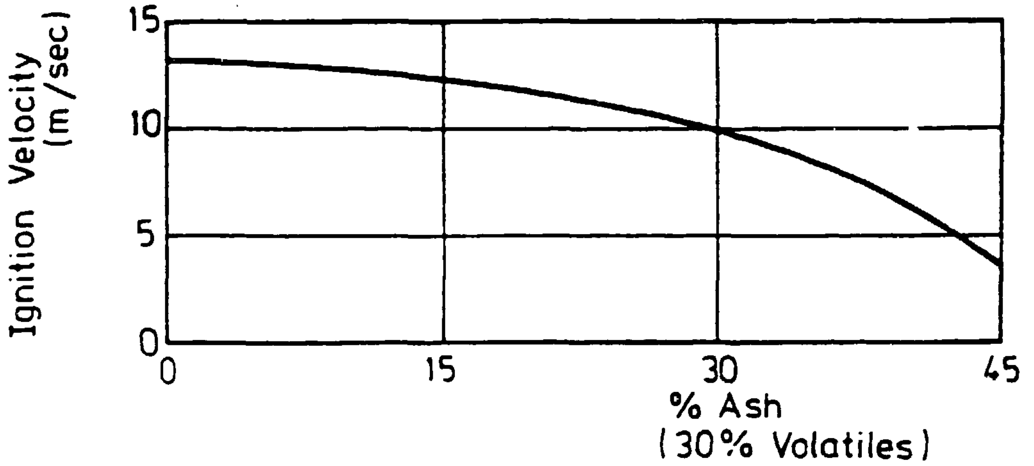


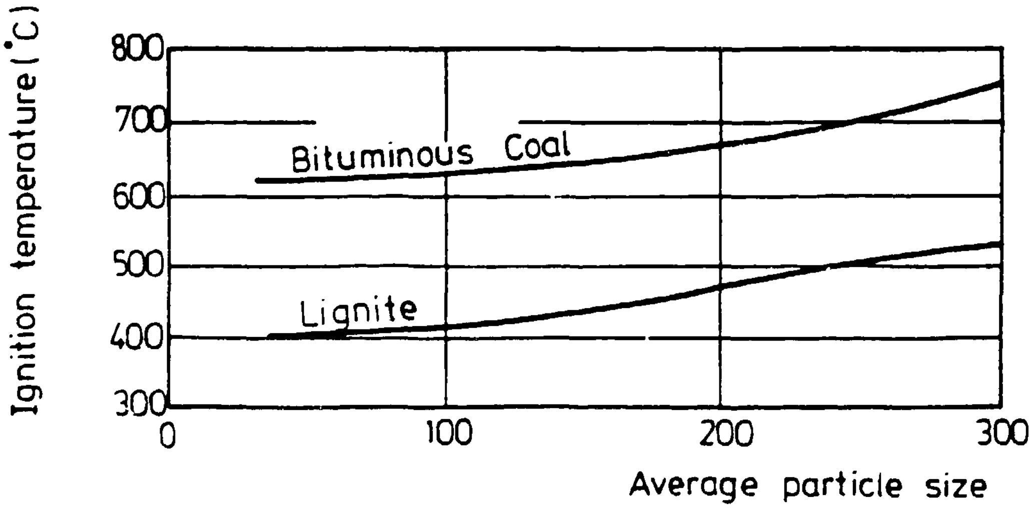
Recommended Moisture of Coal Dust

Coal Combustion

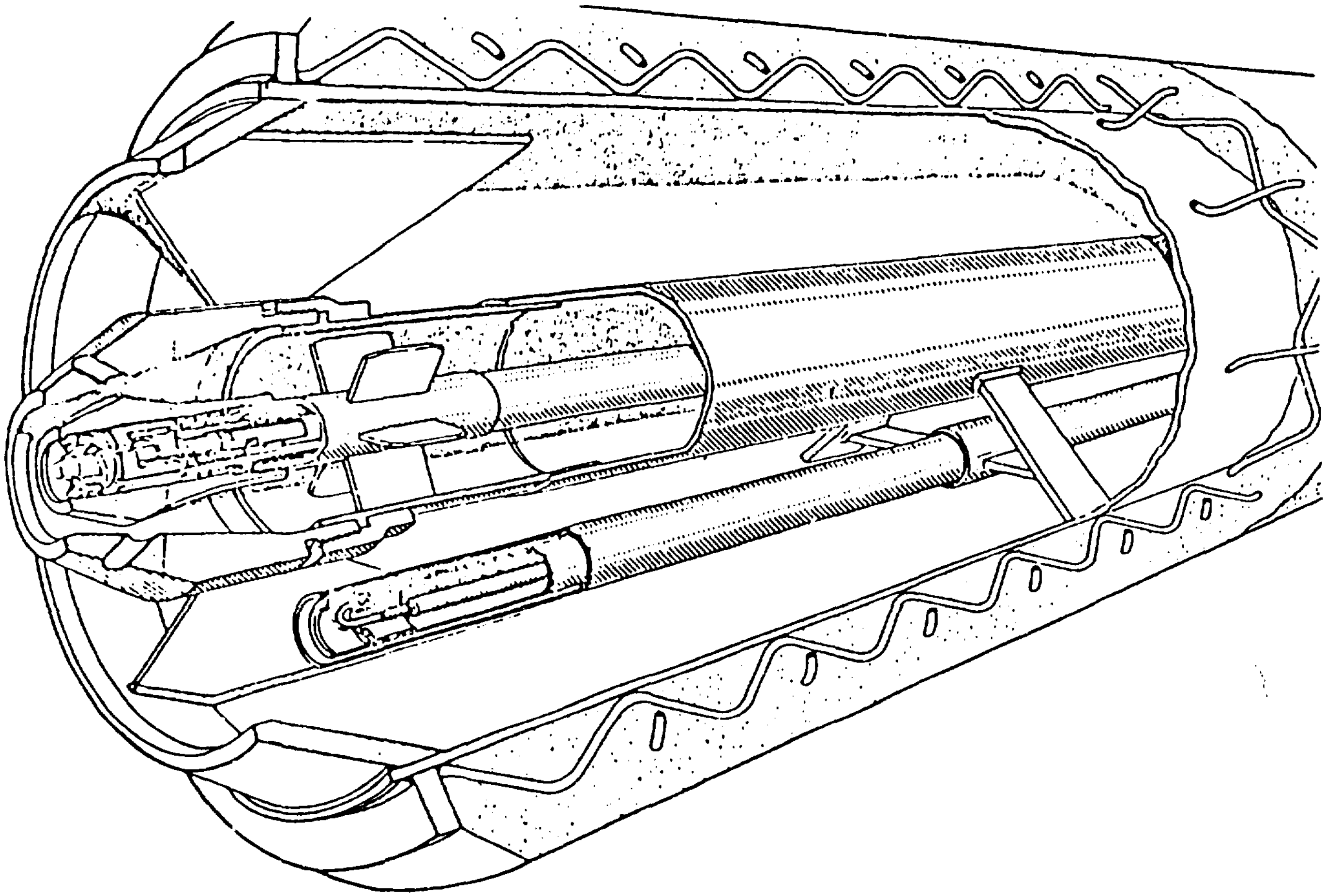








FLS Combined Oil / Gas Burner



Coal Combustion

Ash absorption (typical example)

	98 %x)	+	2 %	=	100 %
	Raw mix	+	**Ash**	=	**Clinker**
SiO_2	13		50		20.75
Al_2O_3	3		20		4.96
Fe_2O_3	2		10		3.24
CaO	41		0		62.28
Ms	2.60		1.70		2.53
MA	1.50		2.00		1.53
LSF	99.4		0		94.3

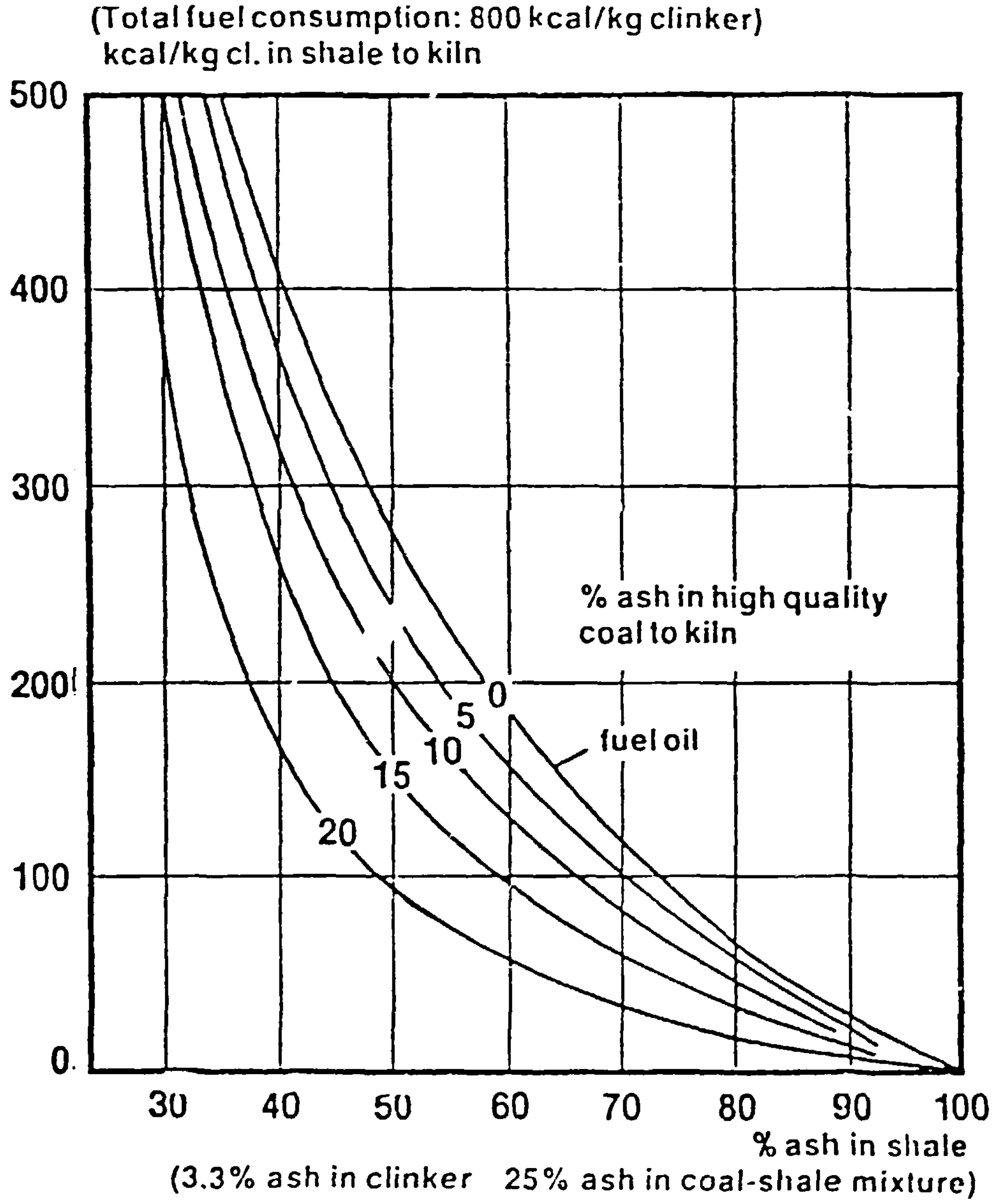
ΔMs ▷———— ~ -0.1 ————→

ΔMA ▷———— ~ 0 ————→

ΔLSF ▷———— ~ -5 ————→

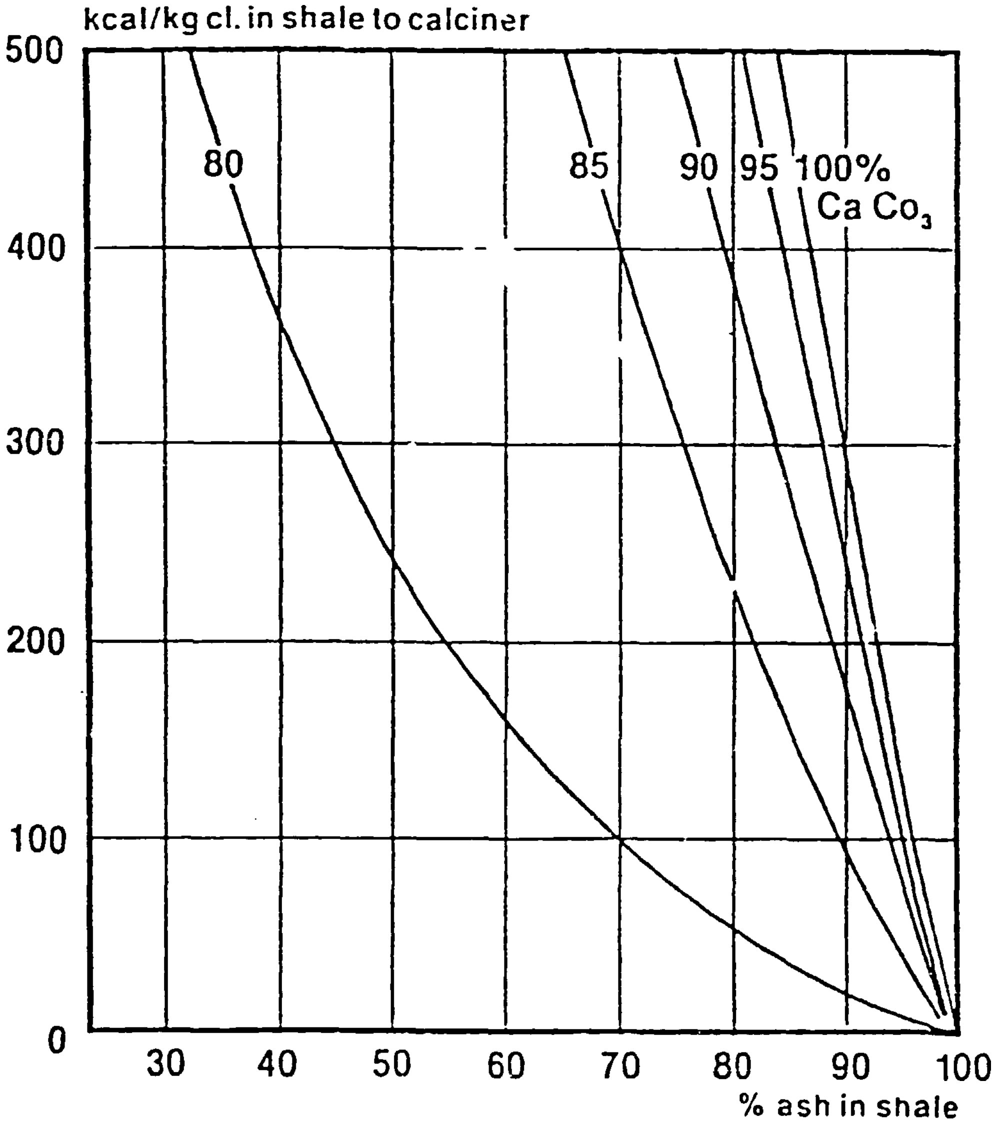
x) On ignited basis

Conventional 4 – Stage Preheater Kiln



Precalciner Kiln

(Total fuel consumption: 800 kcal/kg cl.)
Kiln fired with oil



Pulverized Coal Installations
Safety Regulations

The operation of coal grinding and firing installations involves certain risks of spontaneous fires and explosions. For this reason safety regulations have been enforced in some countries by either public or insurance authorities with the purpose of limiting damages to personnel and property.

To our knowledge such regulations are existent in West Germany, USA, UK, Norway, Sweden, and Poland. Other countries, having no regulations of their own, often refer to the regulations of West Germany.

West Germany

The safety regulations for pulverized coal installations amount to nine pages only in the general mining regulations. They are not very specific and are by now due for the first revision since 1958. In the meantime it has been deemed necessary to back up the 1958-regulations by a recent article (1978) in "Steine und Erden" and by two "VDI-Richtlinien". It is stated quite clearly that it is not enough for the manufacturer and the buyer of the equipment to comply with the regulations. A project must be evaluated and approved by the authorities (Steinbruchs-Berufsgenossenschaft and Gewerbeaufsichtsamt) already at the planning stage.

Based on the written regulations and on details collected during the recent Lägerdorf and Märker projects it can be established that three different types of coal grinding plants may be considered by the authorities for their approval:

1. Plants operating with inert gas, i.e. with reduced O_2 content throughout the installation (10% O_2: alarm, 12% O_2: shut-down).
2. Plants designed to withstand the full explosion pressure (7-8 bar abs.) without deformations (druckfest). Explosion ventings are not allowed.

3. Plants of which each element is designed to withstand a certain pressure (1.2 - 4 bar abs.). Deformations - but no fissures - are allowed (druckstossfest). All machine elements must be equipped with explosion vents of approved size and type according to the mechanical strength of each piece of equipment.

The regulations stipulate a number of details on plant lay-out, design of buildings and equipment, and on plant operation. As an example can be taken the requirements to a fine coal hopper:

This hopper must be designed in such a way that mass flow (plug flow) is achieved so as to avoid dead stock. Unless the silo is permanently inertised with CO_2 or N_2, it must be made to withstand a certain pressure (druckstossfest) and be furnished accordingly with explosion vents. Instruments for continuous monitoring of temperatures and of CO content in the silo must be provided. An adequate source of inert gas must be available for immediate inertisation of the silo in case of excessive CO or high temperatures. The silo should rest on load cells which automatically must cut the supply to the silo of coal dust in case of overfilling.

USA

The National Fire Protection Association (NFPA) has compiled quite comprehensive safety regulations concerning coal dust installations. However, so far they are not of federal validity. Locally these fire codes may be adapted by the authorities and then become compulsory.

As a whole, the NFPA codes are similar to the W. German regulations, but divert from these mainly in two details:

1. The W. German solution of combining a certain limited mechanical strength of the equipment with adequate pressure relief is not acceptable.

2. To comply with the requirement of the coal plant being fully explosion proof, the design criterion is only 50 psig (= 3.5 bar abs.).

The FLS attitude in the actual circumstances is the following:

1. To revise and modify the type of coal grinding plant that until recently was the standard FLS design so as to comply with the W. German regulations for plants relying on pressure relief.

2. To develop an inert coal grinding installation that complies with the W. German regulations (including the necessary dust collector).

3. For the time being not to consider the fully explosion proof grinding plant.

Safety Regulations for Pulverised Fuel Installations

West Germany

1. Steinbruchs-Berufsgenossenschaft
   Unfallverhütungs-Vorschriften
   16.1. Kohlenstaubanlagen (VGB 3)
   1. januar 1958.

2. Der Umgang mit Kohlenstaub in der Zementindustrie.
   Dipl. Ing. Heinz Wibbelhoff
   Steine und Erden 2/1978.

3. VDI3673 Druckentlastung von Staubexplosionen.

4. VDI2263 Verhütung von Staubbränden und Staubexplosionen.

5. VDE 0100 + 0165 for electrical installations.

U.S.A.

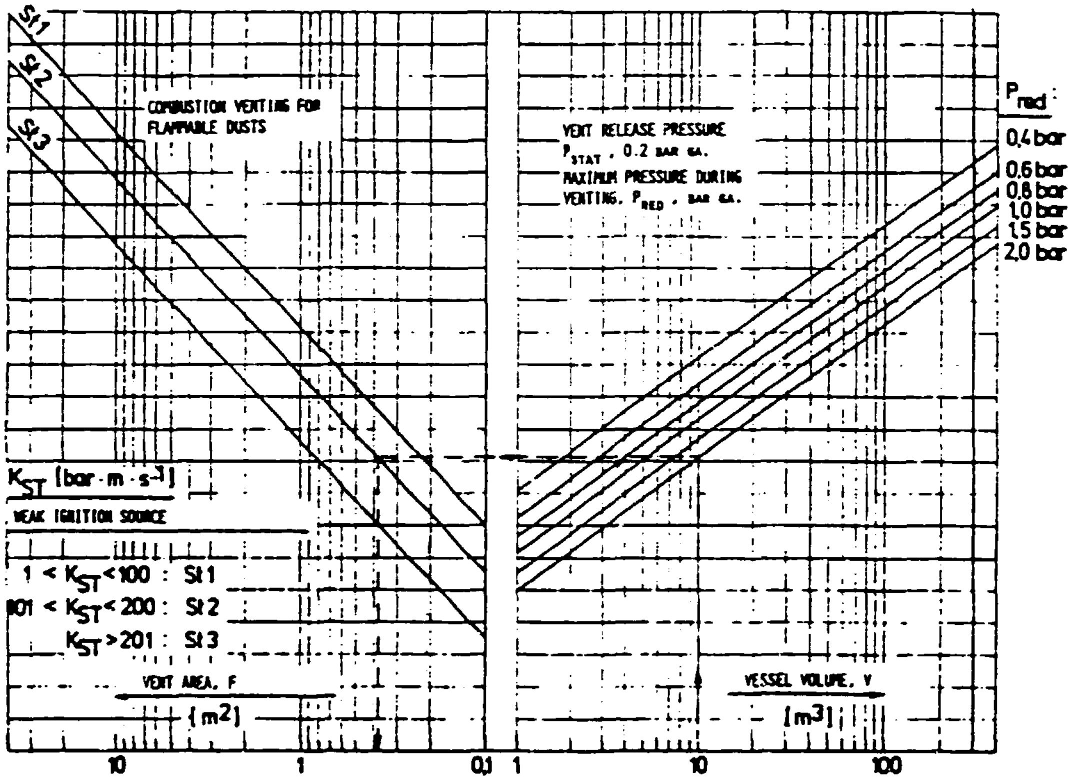
1. Installation and Operation of Pulverized Fuel Systems (1978)
   National Fire Protection Association (NFPA 85F).

2. Explosion Venting (1978)
   NFPA 68.

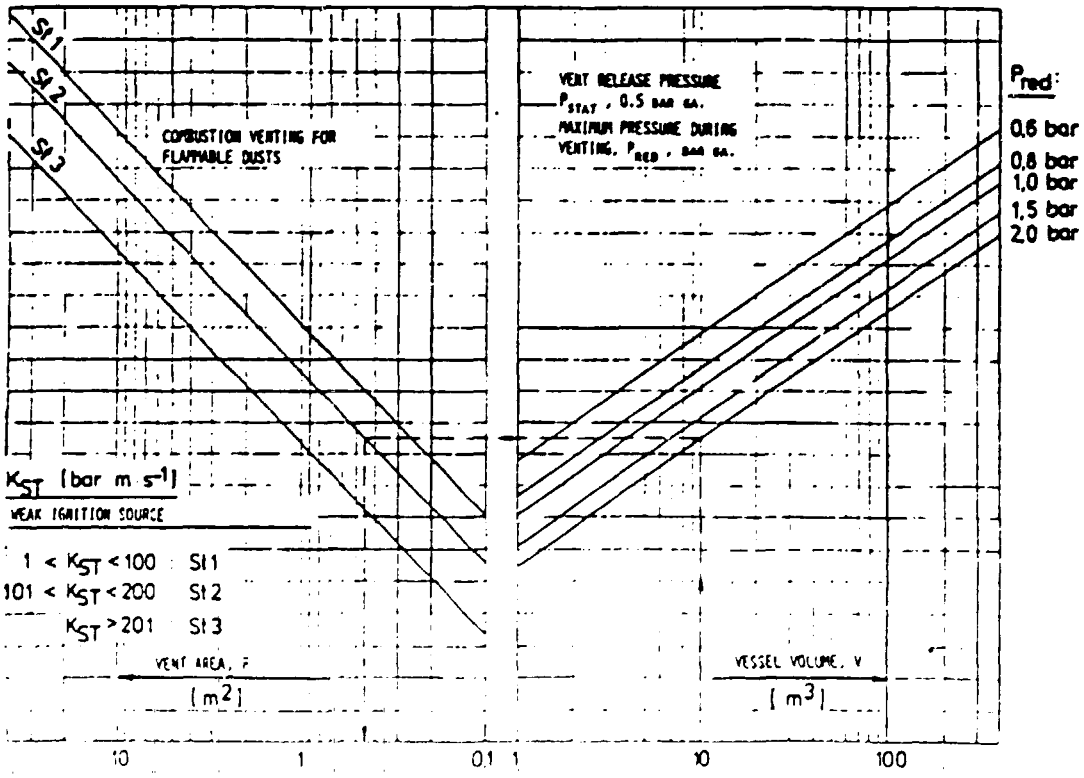
3. Explosion Prevention Systems (1978)
   NFPA 69.

Dimensioning of Explosion Vents

(VDI 3673)
(NFPA 68)



Nomograph B



Nomograph C

Coal Dust Hopper

Safety Equipment According to W. German Standards