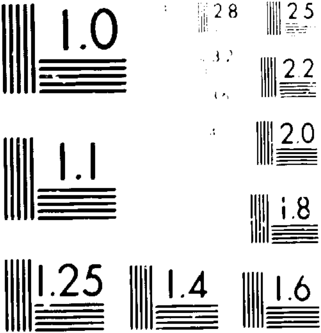
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# THE BURNING PROCESS OF CEMENT SHAFT KILNS IN CHINA *

by

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## INTRODUCTION

China is a developing country. Her shaft kiln cement works are characterized by the manufacture of cement with locally available raw material for local consumption , small investments but quick returns, sufficient utilization of local mining resources existing in small quantities, great adaptability to inferior fuel of low heat and low transport expense. Therefore, ever since 1958, various types of shaft kiln works have mushroomed. Today, there are 3,400 such works scattered all over China, with an annual output of 47 million tons, about two-thirds the total cement output of the nation. They have made considerable contribution to the capital construction of agricultural irrigation, local industry and civil engineering; and played an important role in socialist construction.

At present, more than 110 shaft kiln cement works boast a yearly output of some 100,000 tons; more than 200 cement works some 50,000 tons while another 200 have a yearly output of 10,000 - 30,000 tons each. And the rest turn out less than 10,000 tons per year.

According to operation, kilns can be divided into three kinds: common shaft kilns (manual feed and discharge), semi-mechanical shaft kilns (mechanical feed but manual discharge) and mechanical shaft kilns (mechanical feed and discharge). The products are chiefly Portland cement grade 400 (the cement grade or strength of mentioned in this paper refers to the state standard of "earth-dried" mortar test unless otherwise specified), slag Portland cement grade 400 and pozzolanic Portland cement grade 400, apart fr . Portland or slag Portland cement grade 500 produced by some cement works. The average operating data of vertical kiln cement works are that specific standard coal consumption is 145 kg/t.cl., specific power consumption 81 kwh/t. cement and the maximum output per person 115 t/year.man. The cement cost is 41% higher than those of large and medium-sized rotary kilns.

Burning processes currently employed by vertical kiln plants in China are the conventional burning process, the partial black meal burning process, the black meal burning process, the differential heat burning process and the shell process, etc.. The following is a brief introduction of burning processes being employed in China today.

## 1. Burning Process

### 1.1 Conventional Process

It has been proved in practice in China that this process is quite simple, easy to operate and control. Coal proportion can be flexibly regulated and coal size distribution reasonably selected to satisfy the demands of shaft kiln sintering. Provided that raw meal is proportioned reasonably to obtain a homogeneous and stable composition, the coal is proportioned strictly and the operation is correct, the conventional process can also prepare cement above grade 400.

The conventional process, however, has such shortcomings ans slow sintering, unstable clinker output and quality and high power consumption.

## 1.2 Differential Heat Burning Process

Heat consumption differs in the side pellets and the middle pellets as burning goes on in the shaft kiln. According to heat balance, the middle meal requires a heat supply amounting to only 650 Kcal/kg cl. or so and the side meal as much as 1,100 Kcal/kg cl. or so.

The flow sheet of the differential heat burning process can be generally divided into three sorts:

### (1) Mono-feeding system

Only one conveying and feeding system is employed to proportion coal and the raw meal of the side part and the middle part, feeding amounts being regulated by means of feeders. And then they are prepared by a disc pelletiser into nodules of the side part and the middle part to be fed separately into the kiln for burning. The mono-feeding system is suited for the differential heat burning of the conventional process and the 'partial black meal' process including the process in which the middle meal is wholly made of the black meal. The mono-feeding system is known for its simplicity of production technology and low cost of investment for equipment and construction. With slight improvement on the control of production, the conventional burning process can be converted into the differential heat burning process. However, strict proportioning of coal and feeding are essential; otherwise, the burning process will be adversely affected due to the improper mixing of the side nodules and the middle nodules.

### (2) Di-feeding system

Two conveying and feeding systems are employed, the side and middle nodules being pelleted in two disc pelletisers separately and fed into the shaft kiln through di-chutes.

This technology is reasonable and the operation and control are simple. It is suited for the differential heat burning of the conventional process and the 'partial black meal' process including the process in which the middle and meal is made entirely of the black meal.

(3) Differential heat burning system of the 'black meal' process
By this system, the 'black meals' of the side part and the middle part are pulverized separately in two mills. Therefore, two preparation systems and storage silos for the raw meal are required. This technology, which is complicated, requires high investment cost. Consequently, it is adopted by a limited number of factories.

1.3 Differential heat burning of the process in which the 'middle meal is made of the black meal'.

The differential heat burning process is extentively employed and considerably improved in China. It has been now applied to the conventional process, the 'partial black meal' process, the process in which the middle meal is made entirely of the black meal and the shell process.

The following is a detailed introduction of the application in production of the differential heat burning process of the middle meal made entirely of the black meal.

By this process is meant that the raw meal of the middle part, called the middle meal, is made entirely of the 'black meal'; to which is added a definite amount of coal particles for the preparation of the raw meal of the side part. After that they are pelletized and fed into the kiln separately for burning.

Statistics show that, in general, coal for the 'middle meal made of the black meal' is proportioned in accordance with the specific heat consumption of 750-850 kcal/kg cl. and coal for the side meal in accordance with that of 1,000-1,200 kcal/kg cl., the average specific heat consumption being 900-1,000 kcal/kg cl..

The differential heat burning process of the 'middle meal made of the black meal' is best suited to shaft kiln burning for the following reasons:

(1) With the reduction of specific heat consumption, fuel is saved and heat loss caused by incomplete chemical combustion is reduced.

(2) As fine coal powder burns quickly, the heat capacity of the kiln increases. In addition, the short burning zone and the improved ventilation in the middle part of the shaft kiln make possible the introduction of more air and more meal into the shaft kiln, which leads to increased output.

(3) Because of the improved ventilation in the middle part, which helps to homogenize the air distribution of the whole cross section of the kiln and a greater homogeneous sintering degree, clinker quality has improved. The product is loose and porous, formed into masses in the manner of grape clusters, which is conducive to cooling and prevention of collapse.

(4) This process is particularly advantageous to utilizing inferior fuel of low heat and high ash.

A description of DFH Cement Plant, a typical plant adopting the differential heat burning process is given as follows:

Since 1977, without the introduction of more main equipment, DFH Cement Plant has increased its output by 12% due to the adoption of the differential heat burning process of 'the middle meal made of the black meal'.

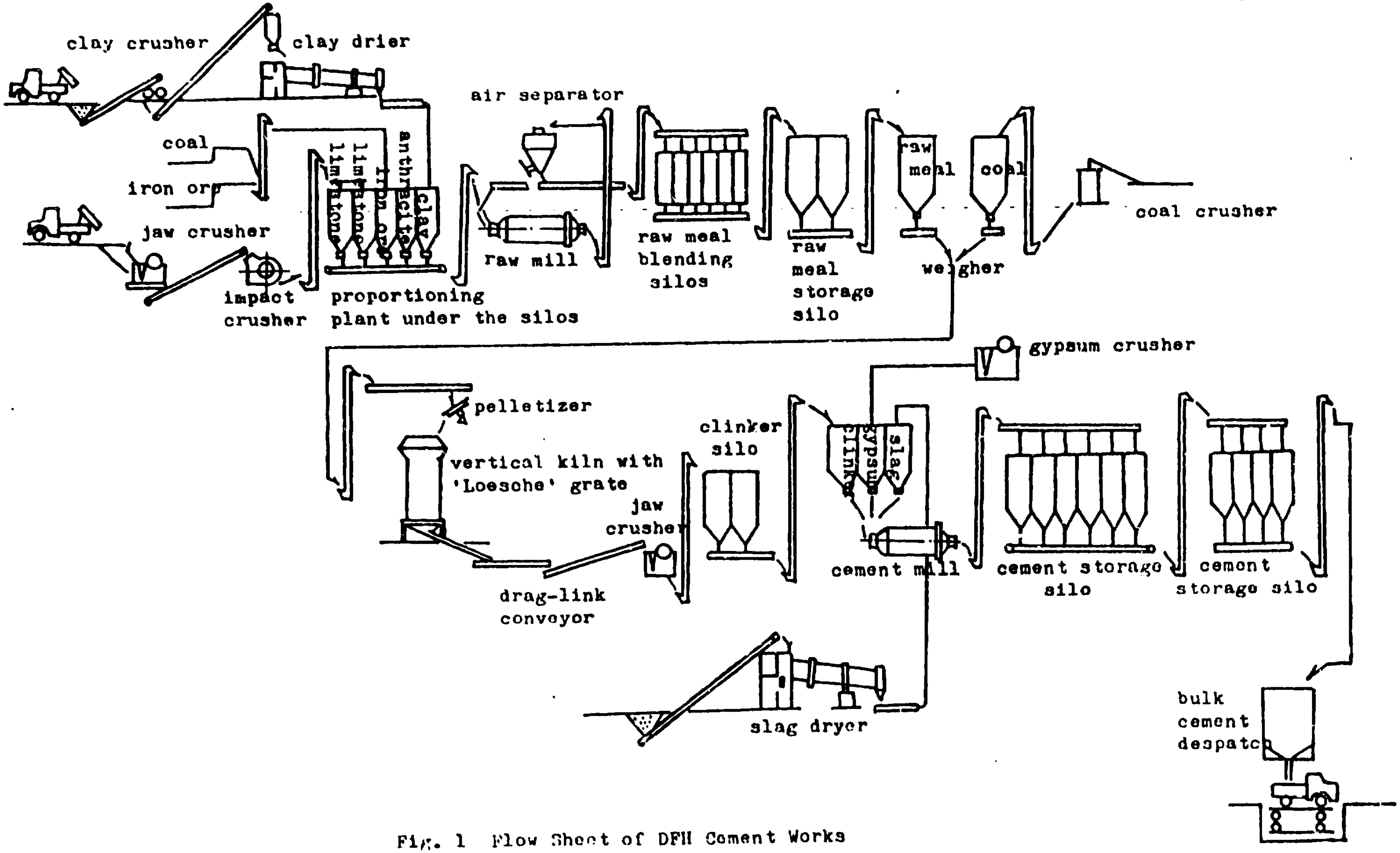


Fig. 1 Flow Sheet of DFH Cement Works

The raw meal of this plant comprises limestone, clay, cinder of pyrite and anthracite coal. Raw material and coal are proportioned by means of belt weigh-feeders under the silo and fed into the ø2.2 x 6.5 M raw mill with a 4 M air separator in close circuit. The finess of the raw meal is less than 10% residue on the 0,088 mm sieve. After grinding, the raw meal is homogenized by mechanical means before being transported to two storage silos with a capacity of 1,200 tons each. Next, the raw meal is simultaneously discharged from the two storage silos and conveyed to a storage bin above the kiln house. Finally, it is fed to the ø2.8 M pelletiser by means of a feeding screw. The differential heat burning process of the 'middle meal made of the black meal' is carried out according to the established operation system. The specific heat consumption of the 'middle meal made of the black meal' is 819 kcal/kg cl., that of the side meal 1,169 kcal/kg cl., and the average 950-994 kcal/kg cl.. The clinker discharged from the shaft kiln is fed into two clinker silos after being crushed by a jaw crusher. 65% clinker, 30% slag, 5% spoil and an optimum quantity of gypsum are proportioned by means of the feeder and fed to the two ø1.83 x 6.12 M mills in open circuit to be pulverized, the finess being less than 6% residue on the 0.088 mm sieve. After grinding, cement is conveyed for storage to the six cement silos with a total capacity of 4,800 tons. With a diameter of 2.84 m and a height of 9.5 m, the shaft kiln is provided with the 'Loesche' grate (cone grate) equipped with a four-stage turbo-blower.

The average output of the shaft kiln reaches 11 t/h. Table 1 and Table 2 show the comparison made in chemical composition of the raw meal and clinker and the strength of cement made of pure clinker before and after the adoption in this plant of the differential heat burning process of the 'middle meal made of the black meal'.

The slag Portland cement produced by this plant in 1980 is grade 425 (plastic mortar test), with its specific power consumption amounting to 79.8 kwh/t cement and cement cost 33.12 Yuan RMB/t.

Chemical compositions and moduli of raw meal and clinker <u>Table 1</u>

| Yr | raw meal | | | | | | | | | clinker | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Loss | $SiO_2$ | $Al_2O_3$ | $Fe_2O$ | CaO | MgO | KH | n | p | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | f-CaO | KH | KH⁻ | n | p |
| 76 | 36.16 | 13.23 | 3.22 | 2.56 | 41.82 | 2.01 | 0.969 | 2.29 | 1.26 | 21.71 | 5.63 | 4.06 | 62.94 | 2.77 | 4.55 | 0.859 | 0.782 | 2.24 | 1.39 |
| 77* | 39.82 | 11.99 | 3.20 | 2.56 | 38.54 | 2.60 | 0.964 | 2.08 | 1.25 | 20.64 | 5.52 | 4.31 | 62.94 | 4.24 | 4.12 | 0.909 | 0.834 | 2.10 | 1.28 |
| 78* | 39.70 | 12.39 | 3.33 | 2.53 | 38.61 | 1.89 | 0.929 | 2.11 | 1.32 | 20.91 | 5.61 | 4.28 | 63.36 | 3.14 | 3.10 | 0.898 | 0.845 | 2.11 | 1.31 |
| 79* | 39.61 | 12.29 | 3.45 | 2.43 | 38.97 | 1.52 | 0.945 | 2.09 | 1.42 | 21.00 | 5.90 | 4.17 | 63.91 | 2.52 | 2.79 | 0.896 | 0.849 | 2.08 | 1.41 |

Note: KH lime saturatrion factor $KH = \frac{CaO - 1.65\ Al_2O_3 - 0.35\ Fe_2O_3}{2.8\ SiO_2}$

n silica modulus $n = \frac{SiO_2}{Al_2O_3 + Fe_2O_3}$

p iron modulus $p = \frac{Al_2O_3}{Fe_2O_3}$

* After the adoption of the differential heat burning process of the 'middle meal made of the black meal'.

S[illegible]gth of cement made of pure clinker

Table 2

| Yr. | fineness residue on 0.088mm sieve % | specific surface $cm^2/g$ | tensile strength $kg/cm^2$ | | | compression strength $kg/cm^2$ | | | average grade | standard specific coal consumpt? kg/t.cl. | output of kiln T/H |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 3 days | 7 days | 28 days | 3 days | 7 days | 28 days | | | |
| 76 | 6.0 | 3689 | 16.9 | 17.6 | 25.2 | 300 | 369 | 520 | 365 | 143 | 8.9 |
| 77* | 6.2 | 2883 | 18.6 | 20.1 | 25.7 | 346 | 437 | 543 | 428 | 137 | 8.6 |
| 78* | 5.3 | 3032 | 20.0 | 22.0 | 27.0 | 382 | 474 | 576 | 475 | 137 | 9.6 |
| 79* | 6.4 | 3024 | 22.3 | 24.1 | 28.9 | 377 | 468 | 574 | 528 | 142 | 10.8 |

* Note: clinker produced by the differential heat burning process of the 'middle meal made of the black meal'.

1.4 Shell process

The shell process is used for the purpose of preventing and reducing the following reaction in the preheating zone of the shaft kiln: $CO_2 + C \rightarrow 2CO\uparrow$ as well as heat loss caused by CO discharge. On the other hand, since the lime saturation factor of the shell of the white raw meal is higher than that of the centrical pellet and its liquid phase quantity is low, clinker contraction decreases and clinker is not liable to form a big mass. This in turn contributes to the ventilation in the middle part.

The centrical pellet of the shell process is made entirely of the 'black meal', but sometimes coal particles are mixed into it.

Since the shell process was adopted in clinker burning in LS, GZ and CZ Plants, better results have been achieved in production, as shown in Table 3. It can be seen from the data as indicated in Table 3 that the shell process contributes to

(1) increase in clinker output

According to statistics, the use of the shell process shows an increase of 18-28% in output as against that of the conventional process.

(2) improvement of clinker quality

Clinker appears in the form of grape clusters or black particles. The quantity of the free lime (f-CaO) in clinker is low and the strength of cement made of pure clinker has increased to some extent;

(3) decrease in specific coal consumption

In general, specific coal consumption of clinker decreases by 20%. The shell process has opened up a broad vista for utilizing such inferior fuel as coal shell and spoil as well as bituminous coal etc..

Comparison between shall process and others in clinker output, quality and specific coal consumption

Table 3

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| LS | Ø1.45x6 Common shaft kiln | Conventional process | 11.0 | | 400 | | 135 | | anthracite coal |
| | | Shell process | 13-14 | 18.2-27.3 | 500 | 25 | 104 | 23 | ditto |
| GZ | Ø2.5x10 shaft kiln with 'Loesche' grate | Black meal | 48.0 | | 400 | | 185 | | bituminous coal |
| | | Shell | 66.7 | 27.9 | 400 | 0 | 135 | 37 | ditto |
| CZ | Ø2.5x10 Shaft kiln with 'Loesche' grate | Conventional | 48.0 | | 400 | | | | ditto |
| | | Shell | 60.9 | 26.8 | 450-500 | 12.5-25 | 129 | | ditto |

1. Plants
2. Dimension of shaft kiln (m)
3. Production process
4. Output T/8h
5. Increase in output %
6. Clinker grade
7. Increase in grade
8. Standard specific coal consumption kg/t cl.
9. Decrease in specific coal cons'n %
10. Coal used

## 2. Air Supply of the Shaft Kiln

### 2.1 Choice of blower

The following types of blowers are usually selected for use in shaft kilns in China:

Blower for Use in vertical kiln Table 4

| Dimension of shaft kiln (M) | Quantity of air $M^3$/min | Pressure of air mm WG | Type | Drive motor (KWH) |
|---|---|---|---|---|
| ø 1.7 x 7 | 60-90 | 1,000 | LG D36x60 | 55 |
| ø 2.0 x 8 | 120-150 | 1,000-1,500 | LG D60x48 | 75 |
| ø 2.5 x 10 | 200-250 | 2,500 | LG D60x90 | 215 |

The centrifugal blower may also be used in the shaft kiln requiring an air pressure less than 1,400 mm WG. Besides, multistage turbo-blowers are used in a few shaft kiln cement works.

### 2.2 Air blowing

(1) Blowing air from the bottom

(2) Blowing air from the lateral of the lower part

Because of low resistance presented by the bed of pellets, blowing air from the lateral of the lower part contributes to homogenizing air distribution, and to reducing air leakage at the outlet of discharge.

(3) Blowing air from the lateral

Experiments made in production show that in order to enable input air to reach the central part of the kiln, the optimum air velocity at the nozzle outlet should be 20-30 M/sec. for kilns with a diameter of 2-2.5 M and 30-40 M/sec. for kilns with a diameter of 2.5-3.0 M.

(4) Blowing air from the center

By this is meant that an air pipe equipped with a blast cap is stretched into the center of the middle part of the kiln, as shown in Fig. 2.

In some common kilns the air pipe passes through the grate on the bottom and stretches upward to the center of the kiln. In general, the air pipe used to blow air from the center is placed at 40% of the height of the kilns from the bottom.

Table 5 shows the size of the blast cap and air pipe of TS, ES Plants.

Size of blast cap and air pipe in TS, ES Plants

Table 5

| 1 | 2 | 3 | 4 | | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| | | | from | $\alpha$ (°)* | | | | | |
| TS | 1.86 | Y Nor.9 | cone | 55 | 0.5 | 1:3.7 | 6x60 | 350 | 1.2 |
| ES | 2.4 | LG D36x60 | cone | 60 | 0.5 | 1:5.0 | 15x'0 | 400 | 1.1 |

*$\alpha$ - top angle of blast cap

1. Plants
2. Diameter of shaft kiln (m)
3. Type of blower
4. Form of blast cap
5. Diameter of blast cap (m)
6. Diameter of blast cap/ diameter of kiln
7. Size of ventila'n hole(mm)
8. Diameter of air pipe (mm)
9. Ratio of ventila'n area

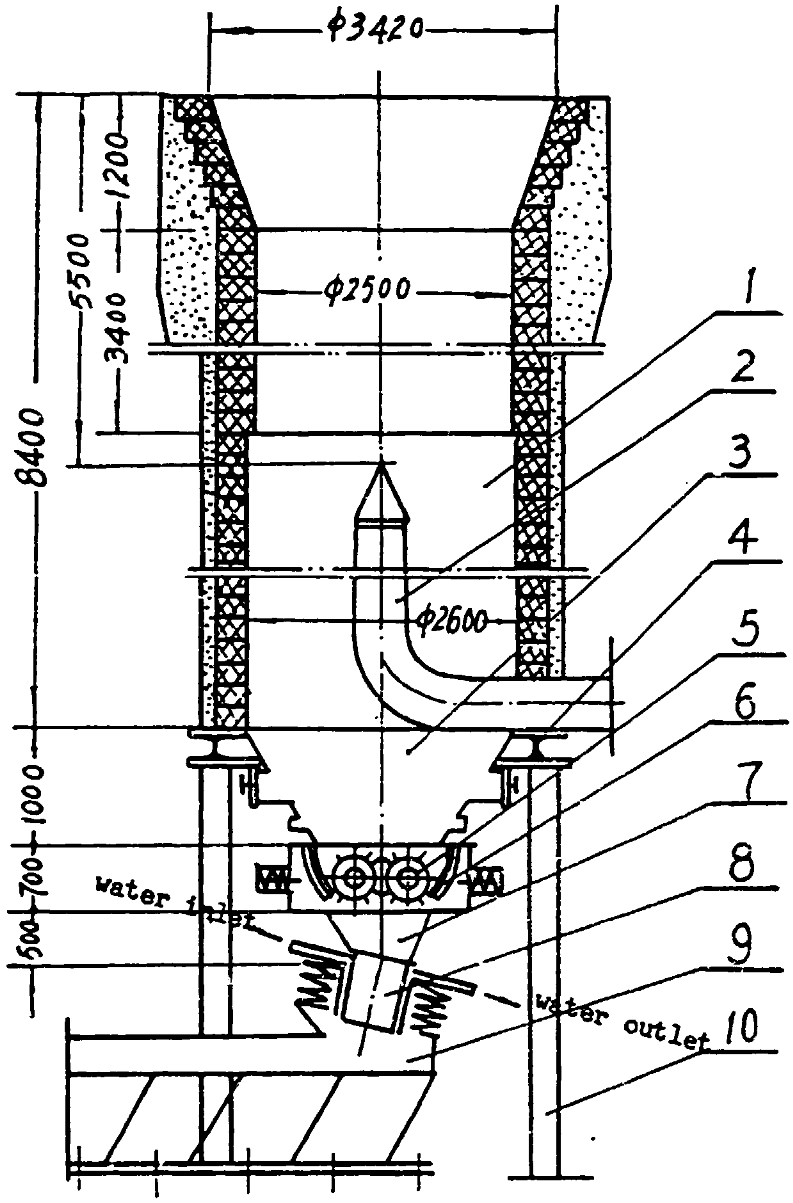


Fig.2 Vertical kiln with roller discharger

1. vertical kiln
2. air pipe
3. hopper
4. support
5. convex roller
6. lining of crusher
7. hopper
8. flexible connector
9. vibration conveyor
10. column

## 3. Technical Means to Reduce Free Lime (f-CaO)

Feed material movement in the shaft kiln is different from that in the rotary kiln. This leads to inhomogeneous heating. For this reason plus improper operation, the product tends to be in the form of grey-black solid mass, grey-black grape clusters, grey-black particles, white mass, yellow pellets and yellow powder etc.. Consequently, the free lime to be found in the product may be divided into several categories.

(1) Under-burned f-CaO, which exists mainly in yellow pellets and yellow powder.

(2) F-CaO (known as the first f-CaO) which fails to be combined after sintering and which generally exists in normal clinker.

(3) F-CaO (know as the second f-CaO) which is decomposed after sintering and which generally exists in clinker of the brown mass after slow cooling in the condition of reduction.

For the purpose of reducing f-CaO in clinker the following measures are taken:

(1) addition of mineralizers such as fluorspar, gypsum, phosphogypsum and copper slag. Generally speaking, the amount of fluorspar to be added is preferably 0.25-1.0% of the weight of the raw meal.

Effect on clinker quality of varying amount of added $CaF_2$ Table 6

| Sample No. | $CaF_2$ in raw meal % | f-CaO in clinker % | Soundness of clinker | Average grade of clinker |
|---|---|---|---|---|
| A1 | 0 | 3.41 | collapse | 393 |
| A2 | 0.38 | 2.97 | loose | 443 |
| A3 | 0.61 | 2.56 | crisp | 498 |
| A4 | 0.75 | 1.47 | complete | 578 |
| A5 | 0.92 | 0.78 | complete | 635 |

As the practical experience of some cement plants shows, the optimum amount of $CaF_2$ to be added can come up to 0.9% (see Table 6) and be effected by the lime saturation factor (KH) of clinker (Table 7).

Effect of the same amount of $CaF_2$ on burnability of raw meal with different KH Table 7

| $CaF_2$ % | KH of clinker | | f-CaO | Soundness of clinker | Average grade |
|---|---|---|---|---|---|
| | KH | KH⁻ | | | |
| 0.87 | 0.84 | 0.80 | 2.35 | crack | 400 |
| 0.87 | 0.89 | 0.87 | 1.99 | crisp | 503 |
| 0.87 | 0.91 | 0.89 | 0.73 | complete | 640 |

When the KH value is increased up to 0.9, the operation of the kiln can be facilitated and outward appearance of clinker improved. Thus it can be seen that the amount of $CaF_2$ to be added must be proportionate to the KH value of the raw meal.

(2) stabilization of the raw meal composition

In general, control is exercised over the titer of $CaCO_3$ ($TCaCO_3 \pm 0.5\%$) of the raw meal in China's small-sized cement plants. The index of the qualified ratio should be above 80%. The relationshop between the qualified $TCaCO_3$ ratio of the raw meal fed to the kiln and clinker quality is shown in Table 8 and Table 9.

Relationship between qualified $TCaCO_3$ ratio of raw meal fed to the kiln and f-CaO of clinker Table 8

| | | | |
|---|---|---|---|
| Qualified $TCaCO_3$ ratio (%) | 32.8 | 65.6 | 75.0 |
| f-CaO in clinker (%) | 1.46 | 0.70 | 0.55 |

Relationship between qualified $TCaCO_3$, ratio of raw meal fed to the kiln and strength of clinker Table 9

| Qualified $TCaCO_3$ ratio % | Clinker modulus | | | Average clinker grade |
|---|---|---|---|---|
| | KH | n | p | |
| 50 | 0.87 | 2.10 | 1.32 | 330 |
| 72.5 | 0.88 | 2.12 | 1.38 | 403 |
| 92.5 | 0.90 | 2.06 | 1.40 | 483 |

To improve the qualified ratio of $TCaCO_3$ in the raw meal fed to the kiln, the following measures are taken:

a. The proportioning of the different raw materials is controlled by such weighing equipment as the program control weigher, the weigher-type electronic belt feeder and the electronic belt weigh-feeder so that they are proportioned as required when fed to the mill and this in turn increases the qualified $TCaCO_3$ ratio of the raw meal.

b. The raw meal discharged from the silos is coveyed to another silo by mechnical means or mixed in the blending silo equipped with aeration pads for homogenization. Since blending silos with aeration pads were used in GJ Cement Plant, the qualified $TCaCO_3$ ratio of the raw meal has not failed to reach 100%.

(3) The optimum fineness of the raw meal is controlled

As shown by the experiments conducted by some research institutions, f-CaO in clinker increases as the amount of particles with the size of 0.088-0.2 m/m (especially quartz particles) grows (see Table 10).

Relationship between fineness of raw meal (residue on 0.088 mm sieve) and f-CaO in clinker Table 10

| | | | | |
|---|---|---|---|---|
| Residue on 0.088 mm sieve (%) | 0.90 | 1.40 | 2.42 | 3.06 |
| f-CaO in clinker (%) | 0.76 | 0.84 | 1.57 | 2.24 |

It is, therefore, desirable that the residue of the raw meal on the 0.2 m/m sieve should be in general less than 1% and the raw meal should consist largely of particles smaller than 0.083 m/m. Thus the burnability may greatly be improved. For this reason, the raw meal fineness should be approximately 10% residue on the 0.088 m/m sieve. The relationship between the fineness of the raw meal (residue on the 0.083 m/m sieve) and f-CaO of clinker is shown in Table 11.

Relationship between raw meal fineness (residue on 0.088 mm sieve) and f-CaO of clinker　　Table 11

| | | | | | | |
|---|---|---|---|---|---|---|
| Residue on 0.083 mm sieve (%) | 13.62 | 12.50 | 11.62 | 10.70 | 9.29 | 5.12 |
| f-CaO of clinker (%) | 2.15 | 1.03 | 1.04 | 0.94 | 0.67 | 0.44 |

In QD Plant, the raw mill in open circuit has been converted into one with the air separator in close circuit. As a result, particles of the raw meal are made more homogeneous, and the content of coarse particles is greatly reduced. On the basis of the same fineness, not only has the output increased by 27%, but also the residue on the 0.2 m/m sieve has dropped from 1.6% to 0.21%. Under the condition that the lime saturation factor remains the same, f-CaO in clinker has dropped from 3.6% to 2.4%, and clinker quality has improved.

(4) adoption of the 'black meal' process

Table 12 shows the effect on clinker quality of the 'partial black meal' process and the 'black meal' process applied to one and the same kiln.

Comparison of clinker quality before and after adoption of 'black meal' process

Table 12

| Raw meal used | KH | $KH^-$ | n | p | f-CaO | Average grade |
|---|---|---|---|---|---|---|
| Partial black meal | 0.880 | 0.82 | 1.37 | 1.02 | 3.25 | 432 |
| Black meal | 0.925 | 0.89 | 1.88 | 1.28 | 2.20 | 517 |

Practice in BC Plant proves that since the 'black meal' process was applied, not only has clinker quality improved, but also the kiln output has made a corresponding increase. The output of the shaft kiln with the rotary grate (Ø2.5x10 M) has increased from 8.5 t/h to 10.5 t/h. The output of the shaft kiln with the 'Loesche' grate (cone grate) has consistently been maintained at 9.5 t/h and above. Its specific standard coal consumption is about 132 kg/t.cl., which is considered not high.

(5) application of the differential heat burning process, the process of the 'middle meal made of the black meal', and air blowing from the lateral or from the center. These measures taken have improved the ventilation in the center of the kiln and reduced f-CaO content in clinker.

## 4. Height/Diameter Ratio (H/D) of the Shaft Kiln and the Kiln with a Large Diameter

### 4.1 Determination of the height/diameter ratio of the shaft kiln

The problem of the height/diameter ratio of the kiln is in fact one of the height of the kiln. The reason is that after the output, the specific heat consumption, the relative velocity of the kiln gas and the specific air consumption are defined, the diameter of the shaft kiln can be determined according to a particular formula, followed by the selection of suitable H/D data, which means that the height of the kiln should be reasonable, and checked by the amount of time that the raw meal will spend in the preheating, burning, and cooling zones of the kiln.

The length of time spent by clinker in the kiln can be defined either by calculation of the heat balance or through practice. China's shaft kiln works have rich experience in the latter practice. Air blowing from the center and from the lateral as practiced in common shaft kilns proves that the air pipe can be raised to approximately 40% of the height of the kiln and that it is desirable to define at 2.3 the effective height/diameter ratio, i.e. the ratio of the distance between the air outlet and the kiln feed inlet (as represented by H) to the diameter of the reduced part of the kiln (as represented by D).

As a result, more than 20 shaft kilns(Ø2x5 M, Ø2.5x6.2 M) have been designed and built in China. It has been proved in practice that the optimum H/D ratio of the kiln is from 2.5 to 3.0. Such kind of shaft kilns are termed "short and broad kilns" (i.e. short in height and broad in diameter).

4.2 "Short and broad kilns" in production practice

The technical and economic indexes of China's typical "short and broad kilns" are shown in Table 13, while Table 14 is the comparison of the technical and economic indexes between the two kilns with the same diameter and different height, built in one and the same plant.

Generally speaking , in comparison with the conventional kiln whose H/D is 4, the " short and broad kiln " has nearly reached the former's standard of production in terms of output, quality and specific consumption. Besides, it enjoys the following good qualities:

(1) Sintering mass has been decreased, fluid resistance in the kiln reduced and air distribution has improved. According to the measurements taken by a certain factory, the kiln with a diameter of 2.5 M and a height of 10M presents a resistance of 1800-2400 m/m W.G. while the kiln with the same diameter as the above but with a reduced height of 6.2 M presents a resistance of 900-1300 m/m W.G, which has dropped almost by half.

(2) The ability to discharge has improved and the life of the grate has been prolonged. As clinker does not sinter in a mass, most of it can be discharged intact from the kiln, thus improving the ability to discharge, reducing the wear of the grate and prolonging its life.

(3) The costruction of a " short and broad " kiln requires less investment and consumes less steel, a drop of 10% each as compared with its tall counterpart (H/D- 4).

Our experience shows that in using the " short and broad kiln " , care must be taken that:

(1) The differential heat burning process of the middle meal made of the black meal' is adopted.

(2) The flame can hardly be seen but is shallow in the course of operation. The thickness of the wet pellet layer does not exceed 30cm,

Technical and economic indexes of "short and broad kiln" and conventional kiln in China  Table 13

| Name of plants | dimension of kiln | grate for discharge | H/D | air blowing | type of blower | output (t) | | specific output (kg) | | clinker quality | | specific heat consumpt'n kcal/kg cl. | burning process |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | per day | per hr. | per cross area ($M^2$) | per volume ($M^3$) | f-CaO% | av. grd. | | |
| ZTC | Ø2.5 x 6.2 m | back & forth | 2.48 | blowing air from bottom | LG 200 | 163 | 6.79 | 1385 | 208 | 3.14 | 492 | 1020 | differential heat |
| BL | Ø2.1 x 5.0 m | do. | 2.38 | do. | Y nor.9 | 100 | 4.17 | 1205 | 221 | 1.42 | 550 | 945 | dif. heat of middle meal made of black meal |
| MP | Ø2 x 5 m | do. | 2.5 | do. | do. | 115 | 4.79 | 1525 | 277 | 3.16 | 475 | 980 | do. |
| UX | Ø2 x 8 m | four rollers | 4.0 | do. | 8-18-11 nor.8 | 102 | 4.24 | 1350 | 167.6 | 4.27 | 430 | 800 | differential heat |
| RM | Ø2.2 x 8.0 m | back & forth | 3.6 | do. | Y nor.9 | 120 | 5 | 1310 | 164.5 | | | | do. |

Technical and economic indexes of "short and broad kiln" and conventional kiln in TC Plant

Table 14

| | | | |
|---|---|---|---|
| Dimension (M) | | ø2.5 x 6.2 | ø2.5 x 9.4* |
| grate for discharge | | back & forth | vib. roller |
| feed end of shaft kiln | diameter (M) | 3.3 | 3.5 |
| | height (M) | 1.4 | 1.4 |
| | enlarged angle | 14° | 19.7° |
| burning process | | differential heat process | |
| average output (t) | per hour (t/h) | 7 | 6.45 |
| | per day (t/d) | 168 | 154.8 |
| specific volume capacity (kg/$M^3$H) | | 209 | 132 |
| specific cross section capacity (kg/$M^2$H) | | 1340 | 1320 |
| operation ratio (%) | | 81 | 76 |
| specific standard coal consumpt'n (kg/t) | | 145.4 | 145.4 |
| f-CaO (%) | | 3.14 | 3.70 |
| product ratio (%) | | 100 | 100 |
| average clinker grade | | 493 | 473 |
| blower | type | LG 200 | LG 200 |
| | rotation per min. (rpm) | 960 | 960 |
| | drive motor (kw) | 240 | 250 |
| | quantity of air ($m^3$/min) | 200 | 290 |
| | operating quan. of air " | 164 | 152 |
| | pressure of air (mm WG) | 5000 | 5000 |
| | operating pressure of air (mm WG) | 900-1300 | 1800-2400 |
| air blowing | | blowing air from bottom | blowing air from bottom |
| weight (t) | | 17** | 42.3 |
| price (ten thousand Yuan YRMB) | | 9.2 | 9.98 |

Note: 1. The output of this kiln is average in China.

2. Some used material has been employed.

and the sintering zone in the middle part of the kiln 2 M. Improper operation, which results in a long sintering zone, will bring about an increase in the temperature of clinker discharged from the kiln.

(3) Coal particles to be added are not larger than 5 m/m.

(4) The maximum amount of air is supplied during operation so as to raise the sintering zone and accelerate clinker cooling.

4.3 Larger diameter shaft kilns in production practice

To meet the requirements of cement works of a growing size, large-scale cement equipment is being developed. Over the past twenty years, the output of the unit shaft kiln has considerably increased, although it is still below 300t/day and the diameter of the kiln 3m.
The main obstacle to establishing kilns with a large diameter is the problem of homogenous air distribution on the cross section of the shaft kiln. It is considered by some people that the homogeneity of air distribution can not be guaranteed in the kiln with the diameter exceeding 3 M. During the last ten years or so, experts on the shaft kiln in the Soviet Union, West Germany and Czechoslovakia have put forward the suggestion of establishing kilns with a large diameter. Designs and experiments have been made, only to prove that it is feasible to further increase the diameter of the shaft kiln. However, quite a number of people are still doubtful about the homogeneity of air distribution in the shaft kiln with a large diameter. That explains the reason why the suggestion for the establishment of such kilns has not been put into practice.

Two " short and broad shaft kilns " (ø3.6x10 M, H/D 2.78) equipped with the ' Loesche' grate were set up in China's TJ Cement Plant in

Oct. 1978. Of such kilns completed and put into production in the world, they have the largest diameter and capacity. After being put into operation for over a year, they are believed to have achieved the anticipated results, the average output of the kiln being 16t/h or 384 tons per day and the average clinker produced being above grade 400. While slag cement grade 400 is the chief product, slag cement grade 500 and Portland cement grade 400 have been produced in a planned way. Table 15 shows the comparison of the technical and economic indexes between the shaft kiln with a large diameter and the conventional shaft kiln.

In order to overcome inhomogeneous air distribution on the cross section, the following measures were taken:

(1) Proportion of the raw meal was readjusted, with $Fe_2O_3$ decreasing from 4.5% to 3.5%. The sintering zone was thus made short, and complete and difficult to break.

(2) Much attention was paid to operation with emphasis laid on the position and thickness of the sintering zone, which was 1.5-1.8 M under kiln feed end. When the sintering zone was steady and complete, the maximum amount of air was supplied.

(3) The size of coal particles was reduced and coal in the "partial black meal" increased. Coal particles were smaller than 5mm.

It can be seen from the above that the height/diameter ratio of kilns with a diameter smaller than 3 M can be reduced to 2.5 to 3 and that as the diameter of the kiln grows, the H/D should make a corresponding decrease.

The practice in TJ Cement Plant proves that it is possible to use kilns

Comparison of technical and economic indexes between large diameter shaft kiln (Ø3.6 x 10 M) and shaft kiln (Ø2.5 x 10 M) is TJ Cement Plant Table 15

| dimension | Ø 3.6 x 10 M | Ø 2.5 x 10 M |
|---|---|---|
| grate for discharge | 'Loesche' grate (cone grate) | rotary grate (disc grate) |
| output per hour (t/h) | 16.2 | 9.5 |
| specific volume capacity (kg/H.M$^3$) | 170 | 180 |
| specific cross section capacity (kg/H.M$^2$) | 1590 | 1940 |
| specific standard coal consumption (kg/t.cl.) | 139 | 130 |
| f-CaO (%) | 2.23 | 3.0 |
| average clinker grade (earth dried mertar test) | 450 | 400 |
| number of blower | 2 | 1 |
| type of blower | LG 250 | LG 250 |
| operating guantity of air from blower (M$^3$/min.) | 250 + 170 | 250 |
| operating pressure of air from blower (mm WG) | 1700-2000 | 1500-1800 |
| air blowing | blowing air from botton | blowing air from bottom |
| weight of shaft kiln (t) | 120 | 68 |
| investment cost (ten thousand Yuan YRMB) | 77.46* | 17.7 |
| output per day (t/d) | 389 | 228 |

* The cost of this trial product is high, but the expense will show a significant decrease after the product is put into formal production.

with a diameter of more than 3 M.

But this vertical kiln has not been put to use for long and its capacity has not been brought into full play. Improvements are being made on the kiln whose potential remains to be released.

CONCLUSION

Vertical kiln plant in China, which vary in kiln type, and structure, production technology, burning process, and air blowing, have accumulated abundant experience in clinker burning.

For the purpose of boosting output, improving quality and reducing burning consumption, China has successfully employed and developed in vertical kilns such technology as differential heat burning process, the ' black meal' process as well as the shell process. Meanwhile, researche and trial production have been conducted on the kiln type and structure. Bold experiments have, in particular, been made on the height/diameter ratio of the vertical kiln, resulting in the " short and broad "kilns. It is believed through experimenrs in production that it is possible for the H/D ratio to be smaller than 3 but greater than 2.5.

The Ø3.6 x 10 M " short and broad shaft Kilns " with the ' LOESCHE ' grate designed and made in China, which have been in production for over a year, have proved to be capable of steady operation and preparation of clinker that is up to standard.

In the above, an introduction has been made of China's small-sized cement enterprises and the new attempts made on the burning process of the shaft kiln cement plants. We hope that in promoting the cement industry the developing countries will benefit from our endeavours and that we will offer enthusiastic co-operation with those who take an interest in our work in this field.