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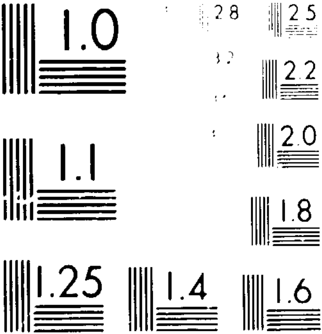
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TECHNIQUE AND ECONOMY FOR THE USE OF LIGNITE IN CEMENT ROTARY KILNS *

by

Engineers from Kay Yuan Cement Plant **

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ABSTRACTS

Using lignite as a fuel, Kai Yuan Cement Plant, Yunnan Province has succeeded in manufacturing ordinary Portland cement by wet process kiln Ø 3.3/3.0/3.3X118 m, hence creating a precedent in our country of sintering high quality cement clinker with inferior lignite and expanding the energy resources. The lignite has high moisture content and low heating value. When burned in the wet process kiln, its flame is long, its combustion temperature lower, the heating power of the kiln decreased, the heat consumption of clinker higher and the kiln output dropped by about 15%. As the counter-measures, we have to select burnability for proportioning, increase the rate of primary air and to work out adequate thermal condition and operation method. At the same time, the capacity of the drying equipment and grinding system for raw coal shall be increased. The practice of Kai Yuan Cement Plant in the past ten years proves that although the kiln output is rather low, the quality of the cement clinker is good. It has set a good example of utilizing the energy resources according to the local conditions.

Introduction

Lignite is one of the inferior fuels with a low heat value of 2,000-3,000 Kcal/kg. (practical base) Utilizing the local lignite from Hsiao Lung Tan quarry, Kai Yuan Cement Plant, Yunnan Province has succeeded in burning the ordinary Portland cement by its wet process rotary kilns, hence creating a precedent in our country, of burning high quality cement clinker with lignite and expanding the energy resources.

In Kai Yuan Cement Plant, there exist two ϕ3.3/3.0/3.3 x 118 m wet process rotary kilns and two ϕ 2.2 x 5.0 m air swept mills for feeding pulverized coal. It was designed to use a coal mixture 90% of which was the bituminous coal from Yang Chang coal quarry at Hsun Wei, and the remaining 10% was lignite from Hisao Lung Tan. The transport distance from Yang Chang quarry to the cement plant was about 500 kilometers, and the bitumite even had to be transfered to another train during the course of transport. So in 1970, the plant began to feed the kiln with lignite only. Since the content of CaO is fairly high in the pulverized lignite, the inferior marl and the overburden etc. on the limstone quarry, which was regarded as waste stone in the original plan need not be stripped off any longer, so the resources have been increased. In the past ten years, the plant has constantly increased the output and improved the quality of the products. The average strength of the cement clinker is more than 600 kg/cm^2 on dry mortar basis. (more than 514 kg/cm^2 on plastic mortar basis). At present, this plant is under extension, and is developing the capacity of producing cement with lignite so as to increase the cement output for Yunnan Province.

In this paper, a technical summary is presented to show that lignite can be used as fuel for clinker burning in the rotary kiln.

I. Brief of the lignite at Hsiao Lung Tan and the raw materials used in Kai Yuan Cement Plant.

The lignite at Hsiao Lung Tan formed in New Tertiary Miocexe is part of the continental sediment and deposited in tremendous thickness. It contains some bands of shell, gypsum and other calcareous matters, which are fairly even-distributed. It has such character as high volatile matter, high moisture content and low heat value. In addition, it also has high content of Oxygen and is easy to get weathered and burnt spontaneously. In its chemical composition of the coal ash, CaO and SO_3 content is rather high whereas Al_2O_3 and SiO_2 considerably low. Generally, the softening temperature of the coal ash is 1120-1330^{0}C.

According to the elementary analysis and proximate analysis of Hisao Lung Tan lignite, and the chemical analysis of the pulverized coal,, the fusing point of the pulverized coal is shown in Table 1 - 4.

Table I. Elementary analysis (%)

element	C^y	H^y	O^y	N^y	S^y	A^y	W^y	Total
content(%)	36.06	2.72	14.28	0.92	0.98	20.03	34.96	99.95

Y - means practical base.

Table II. Proximate analysis of the pulverized lignite (%)

Content % / Date	W^f	V^g	A^g	C^g	QYDWKcal/kg
Average content (in 1977)	24.88	45.94	13.94	39.69	2976
Average content (in 1978)	23.67	46.28	13.86	40.33	3170
Average content (in 1979)	20.79	45.74	13.92	40.45	2969

f - means analytical base (%)

g - dry base (%)

Table III. Chemical composition of pulverized lignite (%)

Content % / Data	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Total
1975	18.21	9.18	8.09	38.34	3.03	22.22	no data	99.07
June, 1976	17.81	10.58	6,84	41.92	3.62	17.17	0.74	98.18
April, 1980	14.94	9.27	7.78	46.98	2.36	17.78	no data	99.06

Table IV. Fusing point of pulverized coal.

t_1 °C deformation	t_2 °C softening temperature	t_3 °C liquefaction temperature
1190	1270	1300

The raw material for Kai Yuan Cement Plant are limestone, sandstone and iron cinder.

Ping Ba San limestone quarry is of the marine deposit in mid - Triassic period. The lithological characters are very complicated. It consists of limestone, striped argillaceous limestone, marl, and flag limestone, etc.. A substantial amount of the rocky deposit is outcropped and it's overburden rather thin. The marl, a small amount of which to be blended in the raw mix, was stripped off as a waste in the original design of the limestone quarry. But since lignite is used to burn cement clinker, the marl has no longer been stripped off and is mixed completely into the raw meal.

Du Li Shu sandstone quarry: Since marl was used as a component of raw meal, the amount of sandstone used in cement production has been cut down. Recently, argillaceous sandstone, which were excavated during the expansion of the plant is used as siliceous correcting material.

Iron cinder is from sulfuric acid sludge discharged by Kai Yuan Phosphate Fertilizer Plant. The chemical composition of the raw materials are shown in Table V.

Table V. Chemical co osition of the raw materials (%).

Content % / Material	Sources of raw material	loss	SiO_2	Al_2O_3	Fl_1O_3	CaO	MgO	K_2O	Na_2C	TiC_2	CO_2
limestone	Ping Ba San quarry	41.21	4.0	1.12	0.78	52.31	0.32	0.11	0.083	0.035	
striped argillaceous	" "	39.70	6.34	2.07	2.00	48.82	0.23				
flag limestone	" "	35.96	12.33	3.27	2.38	43.88	1.20				
marl	" "	28.46	22.92	10.55	4.97	29.38	1.01	2.32	0.085	-1	
regolith	" "	10.12	40.60	27.68	14.25	2.31	1.42	3.64			
sandstone	Du Li Shu quarry	3.97	78.75	9.67	4.34	0.47	0.44	2.13	0.24		
argillaceous sandstone	earthwork construction	4.89	70.99	13.14	5.70	1.74	0.88	2.25		0.75	
sulfuric acid sludge	Phosphate Fertilizer Plant	0.29	5.32	4.34	77.06	5.75	3.24				3.35

II. The technical characters in burning cement clinker.

1. The selection of equitable raw mix proportion based on the characters of raw materials and fuel.

Since lignite has a low heating value and a high moisture content , the actual fuel consumption is great and the heat capacity of the rotary kiln is limited. When proportioning, the easy-burning mix design should be chosen. Raising Al_2O_3 content of the clinker to a certain extent to increase the liquid phase during the formation of clinker and the mineral contents of flux, the burnability of the raw mix shall be improved. Meanwhile, there must be enough C_3S in clinker so as to guarantee the strength of cement and raise a bit the lime saturation factor (KH). The productive practice of Kai Yuan Cement Plant in past ten years are shown in Table V1 in which we can see that the output and quality of itsproducts of the rotary kiln have been progressively increased.

The control rate of the chemical parameters of the clinker in the present operation of the cement plant are: Lime saturation factor (KH) 0.89-0.92, Silica Modulus (SM) 1.79-1.95, Alumina Modulus (AM) 1.4-1.6, AL_2O_3 6.2-6.5%. The output of the rotary kiln keeps at a constant rate of 13.5t/h. The strength grade of clinker has attained more rhan 600 Kg/cm^2 on dry mortor basis. (more than 514 Kg/cm^2 on plastic mortor basis). It has almost removed ring formation by burning inferior coal. The rotary kiln can thus be safely operated for a long period of time. The annual rate of the kiln operation has amounted to about 90%.

The pulverized lignite, with a higher CaO content and a saturation factor (KH) within 0.4-o7, has little effect on chemical composition of the clinker. The marl which makes up 30-50% of the raw meal has a ...

Table 6. The relation between proportion rate (clinker) and rotary kiln output and quality of products

Date	Al_2O_3 content in clinker and rate				production capacity t/h	running ratio %	Average strength grade of clinker	remarks
	Al_2O_3 %	LSF	SM	IM				
70-71.10	5.2 - 5.6	0.87 - 0.89	2.1 - 2.2	1.1 - 1.2	10.85	71.53	614	low output
71.10-72	5.8 - 6.0	0.87 -0.89	2.05-2.1	1.2 - 1.3	11.71	87.00	619	a little high production output and move ring formation.
73 - 77	6.0 - 6.5	0.88 - 0.90	1.90-1.95	1.3 - 1.4	11.75	79.73	630	the increased production output and less ring formation.
78	6.2 - 6.5	0.89 - 0.92	1.9 - 2.0	1.35-1.55	12.70	85.19	661	the increased production output and less ring formation.
79	6.2 - 6.5	0.895-0.925	1.8 - 2.0	1.35-1.55	13.27	89.02	664	the increased production output and less ring formation.
80.1-3	6.3 - 6.6	0.90 - 0.94	1.8 - 2.0	1.4 - 1.6	13.80	92.20	619	the increased production output no ring formation on the whole.

Remarks: The average strength grade is on dry mortar basis.

high dispersivity and homogeneity . Through X-ray fluorescence analysis, it still contains about 1.0% of titanium oxide (TiO_2). The gypsum ($CaSo_4$) band in the lignite is also blended into the clinker. These minerals not only act as fluxes to reduce the melting temperature, but also stabilize C_2S to improve the absorption of CaO and facilitate the formation of C_3S in burning clinker process.

In order to study the burnability, in 1975 we made normal slurry in kiln feed semi-dried and made it into pellets of Ø 15 mm. After drying them up, we controlled temperature within 800 - 900 °C in resistance-heating electric furnace to make $CaCO_3$ partly decomposed and then removed them into the electric furnace with silicon and carbon electrode to burn at 1340 °C for 30 minutes, and thereafter took them out from it to cool under the room temperature. The pellets were black in colour and har in quality. The chemical compositions and the result of lithofacies inspection of the clinker are shown in Table 7 and Fig. 1. Comparing the result of this test with the production, the chemical composition and the result of the lithofacies inspection of the high quality cement clinker produced by the rotary kiln, are shown in Table 8 and Fig. 2.

Table 7. The chemical analysis of clinker burnt in the electric furnace with silicon and carbon electrode.

Composition% / Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	fCaO	Total
raw mix	13.39	4.27	2.65	42.06				
clinker	20.86	6.64	3.91	65.23	1.81	0.32	0.36	99.13

Table 8. Chemical analysis of the high quality clinker (%)

SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	LSF	SM	IM	Tensile strength			Compressive strenth		
								3days	7days	28days	3days	7days	28days
20.47	6.34	4.16	64,61	0.59	0.913	1.95	1.52	30.8	34.4	37.1	471	568	692

Fig. 1. Clinker etched with NH_4cl reflective magnification 250x

Fig. 2. Clinker etched with NH_4cl reflective magnification 250x

From Fig. 1 and 2 we can see that Alite crystals are fairly in good condition and are in the shape of plate and column and most of them are 15 - 30 μ. Belite crystals are finger-shaped (Fig. 1) or round-shaped(Fig. 2). Fig. 2. shows that the cross grains of the crystals are obvious in Belite and distribute in the form of small heaps in Alite. All of the dark interstitial materials are point-line shaped or small piece-shaped. The light interstitial materials are beter-distributed. In Fig. 1, we can not find fCao and periclase. fCao is rather little in Fig. 2, that shows that the raw meals are easy to burn, and they burn well.

II. The rational thermal condition and operating method for the clinker burning

(1). Increasing the proportion of primary air

Lignite has a low heat value and contains higher volatile matter. The consumption of coal in kind is about two times more than before. In order to mix the pulverized coal with air and make them burn completely, the quantity of primary air has to be increased, which amount to 40-50% of the total quantity of gas flow.

(2). The burning method of "Thin clinker layer and fast rotating" has been adopted to control the particle size and liter weight of clinker

In view of the character of lignite and raw materials, while selecting the proper plan for easy-burning mix, Kai Yuan Cement Plant has made out the burning method which is called "Thin clinker layer and fast rotating" so as to ensure the output and quality of the cement clinker and achieved good results.

The burning method of "Thin clinker layer and fast rotating" aims at increasing the heat exchange between the material and the gas flow and between the material and the kiln lining so that the utilization rate of the heat can be raised, and the formation of kiln coating avoided. The kiln speed has been controlled at 72-80 r./hr.. Under the normal operating condition of the kiln, generally, the pulverized coal burner would be properly drawn out to concentrate the heat of flames. Owing to high Al_2O_3 content in the batch, the materials , having been melted under the high temperature,have a high viscosity in the liquid phase. Simultanecusly, the particle size of the clinker is a little larger with an average liter weight of 1.5-1.6 kg.

(3). Stabilizing the sintering temperature, promoting the volatilization of SO_3 and K_2O and ensuring the quality of cement clinker

The high contents of potash feldspar and mica etc. in sandstone, overburden and marl, make the content of K_2O in the raw meal as high as 0.8-1.0%.

SO_3 in cement clinker mainly comes from lignite ash (SO_3 is 10-22%) and iron cinder (SO_3>3%). The contents of K_2O and SO_3 in the clinker have something to do with the burning temperature. The higher the volatility, the higher the burning temperature will be. K_2O/SO_3 as measured in the clinker of Kai Yuan Cement Plant is 1.1-1.3. It means that under normal burning temperature, K_2O and SO_3 mainly form K_2SO_4 (only a few Na_2SO_3) and exist in the clinker in the form of the liquid phase, and crystallize when cooling down. The existance of the alkali sulphate is helpful to drop the burning temperature and promote the early strength of the clinker. The clinker of Kai Yuan Cement Plant is characterized by early strength, which is not only related to the higher content of C_3A, but also to the presence of K_2SO_2.

When the burning temperature is slightly low, the volatility of K_2O and SO_3 may drop and the gypsum ($CaSO_4$) in lignite may not be completely calcined or when SO_3 content is higher in clinker, double alkali sulphate $CaSO_4 . K_2SO_4$ may be formed. During normal lithofacies inspection mineral of $KC_{23}S_{12}$: ($K_2O.23$ Ca.12SiO_2) are not discovered. It may show the mutual influences and restraints among K_2O, SO_2 and C_3A in the clinker. At different burning temperatures, there exist in clinker alkali sulphate and double alkali sulphate to varying degrees, so there is little possibility to form KC_{23} S_{12}.

Under the normal burning condition, the volatility of K_2O is more than 40% or even amounts to 70%. The K_2O content in cement clinker is 0.5-1.0%.

Through the x-ray and chemical analysis, the volatilization of the kiln dust is shwon in Table 9 and 10.

Table IX X-ray Analysis of the Kiln Dust (K_2O Content is 8.09%)

Major composition	$CaCO_3$	K_2SO_4	$\alpha-SiO_2$	$\beta-C_2S$
Secondary composition	fCaO	Fe_2O_3		

Table X Chemical composition of the kiln dust (%)

No.	Colour of the kiln dust	LOSS	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	fCaO	Total	Remarks
	Yellow	13.39	15.69	5.49	3.23	48.61	1.26	5.23	4.39	3.30	99.29	High burning temp.
	Greyish dark	14.28	11.85	4.20	2.41	33.80	0.91	15.11	17.87	0.24	99.92	Low burning temp.

During combustion, K_2O volatilized and SO_3 or CO_2 in the flue gas (when lack of SO_2) combine to form the soluble K_2CO_3, which is carried to the kiln feeding end by the flue gas, and which coagulates at low temperature to form microcrystal, which is collected by electrofilter and fed into the middle section of the kiln in which it accumulates by means of circulation.

五. Compare the thermal engineering index with that of the rotary kilns of the same capacity which burn bituminous coal

(1). High heat consumption per kilogram clinker

Kai Yuan Cement Plant determined the thermal engineering index of No.1 kiln in December 1978. Its heat consumption being 1,893 kCal/kg cl. was higher than those of Kun Ming, Yong Deng and Da Tong Cement Plants.

The heat loss by waste gas, the heat loss due to chemical and mechanical incomplete combustion of the fuel and the heat consumption for evaporating and vaporizing the moisture of the pulverized coal are rather high (see Appendix No.1 and No.2). This results from the lower heat value of lignite, high coal consumption, much resultant of the fuel gas, fast gas flow rate at the burning zone where the pulverized coal stays for a short time and the high moisture content of the pulverized coal which reduce the combustion rate and has increased the heat loss due to chemical and mechanical incomplete combustion of the fuel, even the secondary combustion probably emerge from the unburnt pulverized coal in the kiln causing the temperature of the waste gas to go up. The clinker lump discharged from the kiln sometimes bring about the spots and rings with yellow colour. This may further show that there is reducing atmosphere in the kiln from time to time. And because of dragging out a little the burner during operation and the cooling zone thus get comparatively shortened, the temperature of the clinker discharged from the kiln rises at the same time, and the heat loss may also increase slightly.

(2). Low heating capacity of the kiln and the strength of the thermal force of the burning zone (2) (3)

Calculated on the basis of specific heat consumption and output of clinker, heating capacity of the kilns at Kai Yuan and Kun Ming Cement Plants is 25.7×10^6 kCal/h and 27.07×10^6 kCal/h respectively. After deducting the heat loss due to chemical and mechanical incomplete combustion of the fuel, the actual heating capacity of the kilns at both plants is 23.3×10^6 kCal/h and 26.3×10^6 kcal/h respectively. If the length of the coating of the sintering zone is 10 m, (that of Kun Ming Cement Plant is 10 m) the actual strength of the thermal force of the burning zone is 35.2×10^4 kCal/m^3h and 39.8×10^4 kcal/m^3h respectively. But after checking the kilns during down time, it is discovered that the coating in the kiln at Kai Yuan Cement Plant, which burns lignite, is longer than that at Kun Ming Cement Plant, reaching 12-15 m. That is why the actual heating capacity of the kiln and the strength of the thermal force of the burning zone is lower as compared with that of Kai Yuan Cement Plant. The flame brightness and the thick kiln coating which is easy to form, also show that the temperature of the flame is lower than that of the flame of bituminous coal. Depending on the favourable burnability of the raw meal at Kai Yuan Cement Plant, we may think that the cement clinker of Kai Yuan Cement Plant is burnt under lower temperature.

(3) Cutting down 15% of the kiln output

According to the statistics of cement production from 1977-1979 in Appendix No.2, the heating capacity of the kilns at Kai Yuan and Kun Ming Cement Plants are bassically equal as calculated.

Since the lignite for Kai Yuan Cement Plant has such characters as low heat value, high moisture content and high volatile matter, it brings about low actual heating capacity, low flame temperature and high specific heat consumption. The production practice in the past ten years enables Kai Yuan Cement Plant at present to keep the average output for both kilns at 13.5 t/h or so. In original design, the bituminous coal would be used and the normal output of the cement clinker would be 16 t/h. The output is reduced by 15% against the designed capacity. But with the reduction of heat consumption, it is possible to further increase the kiln output.

(4). The requirements of the quality of lignite for burning high quality cement clinker

Using lignite to burn clinker is the major reason causing reduction of output of the rotary kiln.

The ash and moisture content of lignite with low heat value may also contribute to cut down the heat value and heating capacity of the kiln, and bring about the difficulties for burning cement clinker. The production experiences accumulated by Kai Yuan Cement Plant show: when the content ash on dry basis (Ag) is more than 17%, and the low calorific value (QYDW) is less than 800 kCal/kg, the kilns may probably operate in bad order, the output and quality of the cement clinker may get reduced, rings may form at frequent intervals, the thick kiln coating may get increased and the running period of the kiln may be shortened. The moisture content of the pulverized coal to be fed into the kiln must be kept close to its regular value so that it will be favourable to increasing the heat value and raising the heating capacity of the kiln thus creating the conditions for increasing the output and improving the quality of the product and reducing the heat consumption.

IV. Technical measures for lignite burning technological system

(1). Using the coal preparation equipment with larger production capacity and kiln hood blower

Since the fuel consumption will be increased by burning the lignite, it is necessary to select coal mill with larger specification and appropriate cyclone separator for air-swept mill coal mix preparation system. To meet the requirement of increasing the primary air, the blower with large specification must be used.

(2). The addition of the drying equipment for lignite and the storage yard for dried coal

The moisture content of pulverised coal directly affects the combustion condition. A little moisture of the coal may raise the flame temperature and increase the strength of heat radiation. But if the moisture content of the coal is too high, it may reduce the flame temperature. The calculation shows that the reduction of 1% of moisture will cause the increase of 50 kCal/kg to heat value. For lignite with 40% moisture content, it is essential to add coal drying system and the storage yard for dried coal.

(3). Air-exhausting measure must be considered for the air-swept mill system

The air-swept mill system has much more air intake than the primary air for the kiln. Since the raw coal has a high moisture content, the heated air also contains much moisture. If all taken into the kiln as primary air, the amount of air intake is not only too much but also may affect the stability of the thermal condition. Therefore, the coal grinding system must be provided with air-exhaust equipment so as to release the excess air and to decrease the moisture content of intake hot air and all these provide a favourable condition for burning.

(4). Prevention of lignite self-combustion and explosion-proof and dust prevention in coal drying system and coal grinding system

Comparing with bituminous coal, lignite has the following characters: loose structure with porosity, small volume weight, high volatile matter, low ignition point, high activity and easy self-combustion. These characters will increase the ash content and decrease the heat value of the coal. In the drying and the air-swept mill systems, the temperature must not be kept too high so as to prevent explosion.

Based on such characters of lignite as light weight and easy burning, appreciate dust prevention measures shall be made and dust collecting equipments shall be selected to avoid pollution by pulverized coal and protect the environment.

V. Economical effects in burning cement clinker with lignite

The statistical data of cement production from 1976-1979 of Da Tong, Yong Deng, Kun Ming and Kai Yuan Cement Plants of same capacity ha.. shown (see Fig. 3 and Fig. 4) using of lignite to burn cement clinker, Kai Yuan Cement Plant has the lowest kiln output per hour among the four, but a considerable high quality of its clinker. The average strength grade of its cement is 610-664 kg/cm^2 (on dry mortar basis)(equivalent to 523-568 kg/cm^2 on plastic mortar basis). The clinker quality of Kai Yuan is superior to that of Da Tong and Kun Ming Cement Plants and is about the same of that of Yong Deng Cement Plant. In fact, it is one of the advanced cement plants in our country in recent years for long-period of running rotary kiln safely and production of superior quality clinker.

Conclusion

1. The production practice in the past ten years by wet process rotary kilns at Kai Yuan Cement Plant show that lignite with low heat value on practical basis (QYDw) of more than 2,800 kCal/kg and the ash content on dry basis (Ag) of less than 17% can be used for burning the clinker of ordinary Portland cement. When the raw mater``ls and chemical composition of coal ash are desirable, the high quality cement clinker could be burnt. Thus the energy resources could be used in many ways.

2. s compared with bituminous coal, when lignite is used for burning cement clinker, the heating capacity of the burning zone of the kiln

is quite low. The heat loss and the specific heat consumption are rather high and the kiln output has reduced about 15%. Larger coal mill and the blower at kiln discharging end shall be needed. In addition, the coal drying equipment and storage shall be provided in order to suit the condition of burning lignite.

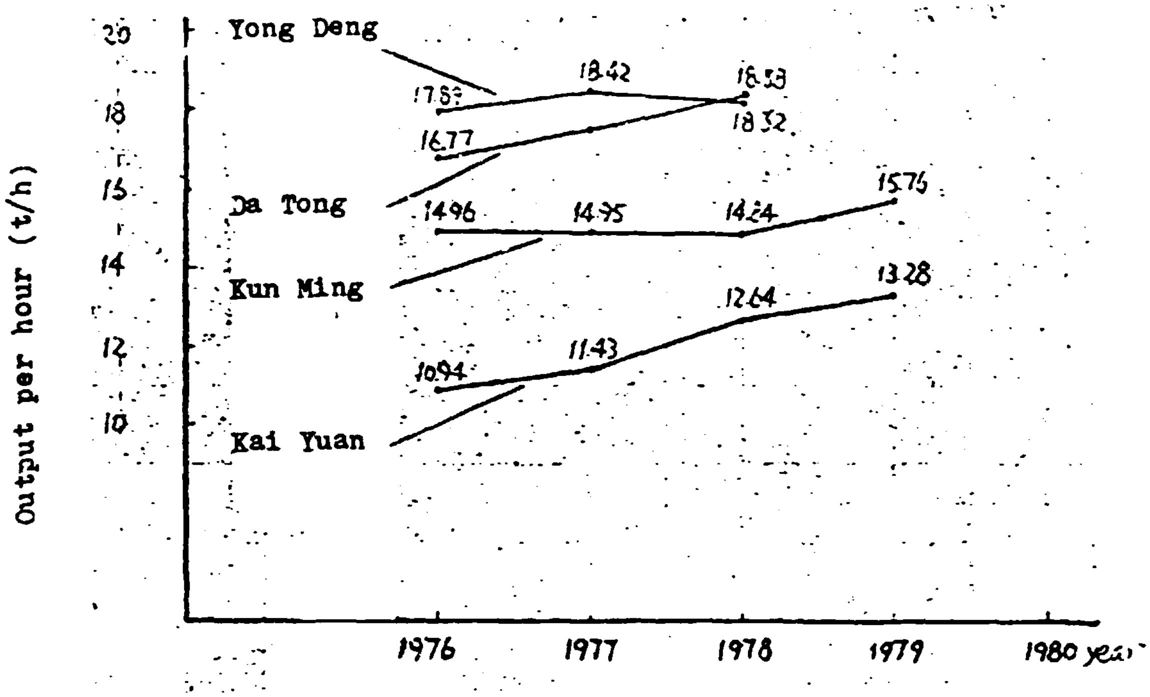

Fig. III. Output per hour of each rotary kiln in 4 cement plants of equipment with same specification.

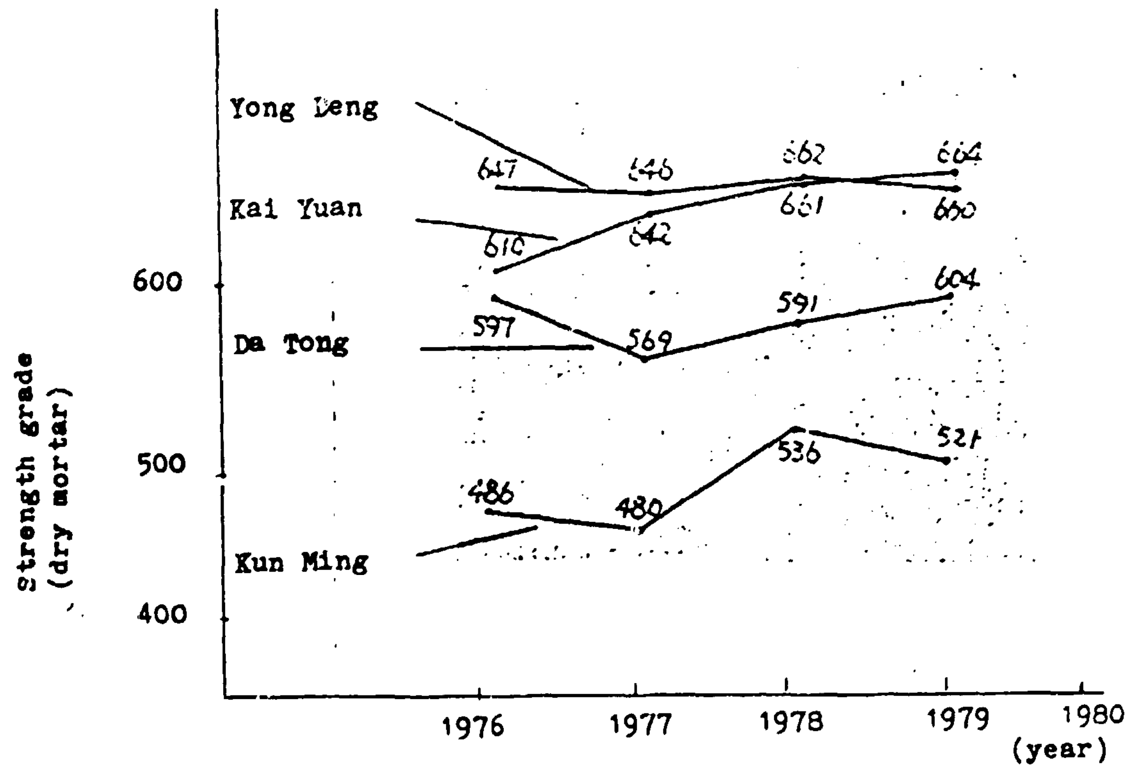

Fig. IV. The clinker quality of the 4 cement plants of equipment with same specification

Appendix 1. Determination of thermal condition of ø 3.3/3.0/3.3 X 118 m wet process rotary kiln

Item		Unit	Kun Ming No. 1	Kai Yuan No.
			Determined in April 1980	Determined in June 1978
production capacity	production capacity per hour	t/h	16.76	13.56
	Production capacity per interior specific surface area	$kg/m^2 . h$	17.35	14.03
	production capacity per specific volume	$kg/m^3 . h$	24.29	19.64
	production capacity per specific area of burning zone	$t/m^2 . h$	2.54	2.05
heat consumption	coal consumption in kind	kg/t. k	343	610
	consumption of standard coal	〃	230	270
	heat consumption (based on pulverized coal)	Kcal/kg. K	1615	1893
thermotechnical index	heat generating capacity	Kcal/h	27.07×10^6	25.7×10^6
	strength of the thermal force per specific volume at burning zone.	$Kcal/m^3 . h$	28.8×10^4	27.54×10^4
	strength of the thermal force per specific section area	$Kcal/m^2 . h$	4.1×10^6	3.88×10^6
	strength of the thermal force per specific volume at sintering zone	$Kcal/m^3 . h$	4.1×10^4	38.8×10^4
heat loss	heat abduction at kiln shell	Kcal/h	401.46×10^4	190.1×10^4
	heat taken away by kiln shell cooling water	Kcal/h		25.3×10^4
	heat abduction at cooling tank	Kcal/h	120.47×10^4	102.4×10^4
	total	Kcal/kg.k	521.93×10^4	317.8×10^4
	heat loss per unit product	〃	311.41	234.1
material consumption	estimated material consumption	kg/kg.k	1.434	1.466
	actual material consumption	〃	1.549	1.509
	moisture content of coal meal	%	35.5	36.0
	moisture content of raw coal	%	1.58	27.5
		%	9.2	36.6

Item		Unit	Kun Ming No. 1	Kai Yuan No. 1
			Determined in Aiprl 1980	Determined in June 1980
Primary air	Temperature	^oC	24	60
	static pressure	mmWS	308.5	620
	gas flow (under working condition)	m^2/h	12511	16350
	gas flow (under standard condition)	Nm^3/h	9488	12640
	percentage of total gas flow	%	26.21	40.6
	nozzle velocity (under working condition)	m/s	54.5	76.3
	coal density	kg/Nm^3	0.345	0.573
	volatile matter density	"	0.075	0.181
Secondary air	temperature	^oC	424	443
	gas flow (under working condition)	m^3/h	50344	49500
	gas flow (under standard condition)	Nm^3/h	15671	16750
	percentage of total gas flow	%	43.29	53.6
Air-leak	air-leakage at kiln charging end	Nm^3/h	14913	1810
	percentage of total gas flow	%	30.5	5.8
Waste gas of kiln-end	temperature	^oC	207	287
	gas flow (under working condition)	m^3/h	137494	129000
	gas flow (under standard condition)	Nm^3/h	62148	55700
	waste gas flow per specific product (under standard condition)	$Nm^3/kg.$ k	3.71	4.11
	vapour content (under standard condition)	Nm^3/h	23890	18940
	percentage of waste gas flow	%	38.44	34.0
	dust content	g/m^3	10.87	17.6

	Item	Unit	Kun Ming Cement Plant No. 1 Determined in April 1980		Kai Yuan Cement Plant No. 1 Determined in June 1980	
cooler	inlet temperature of clinker	°C	1026		1154	
	outlet temperature of clinker	°C	280		281	
	cooling efficiency	%	47.19		52.75	
	raw material balance		kg/kg. k	%	kg/kg. k	%
kiln feed material	dry raw meal with slurry		1.549	26.56	1.509	24.57
	physical moisture content with slurry		0.853	14.63	0.948	15.43
	flue dust feed into the middle section of kiln		0.322	5.52	0.176	2.87
	pulverized coal blown into kiln		0.315	5.41	0.535	8.70
	primary air		0.732	12.55	1.207	19.65
	seconday air		1.209	20.73	1.595	25.96
	false air		0.852	14.6	0.173	2.82
	vapour with primary air					
	total		5.832	100.00	6.143	100.00
discharged materials	clinker quantity		1.00	17.18	1.00	16.13
	quantity of flue dest escaped		0.411	7.06	0.216	3.48
	waste gas at kiln discharge end		4.41	75.76	4.984	80.39
	total		5.821	100.00	6.200	100.00
	difference		+0.011		-0.057	
	relative error			+0.19		-0.93

ITEM	Kun Ming Cement Plant No. 1 Determined in April, 1978		Kai Yuan Cement Plant No. 1 Determined in June, 1978	
	Kcal/kg. C	%	Kcal/kg. C	%
Heat balance				
Chemical energy of the pulverized coal	1615	95.75	1893	94.75
physical heat of the pulverized coal	3.64	0.21	15.7	0.79
physical heat of the slurry	31.25	1.85	39.4	1.97
physical heat of returned dust	4.89	0.29	2.21	0.11
physical heat of primary air	4.21	0.25	17.6	0.88
physical heat of secondary air	10.73	0.64	25.8	1.29
physical heat of false air	16.92	1.01	4.1	0.21
total	1686.64	100.00	1997.81	100.00
clinker formation	388.62	23.14	400.00	20.03
evaporating the moisture of slurry	507.54	30.23	564.6	28.35
clinker discharging	57.40	3.24	68.5	3.44
kiln dust discharging	6.34	0.38	12.2	0.61
decomposition of kiln dust	9.46	0.56	3.28	0.16
waste gas from the kiln charging end	353.97	21.08	417.0	20.94
moisture of the pulverized coal			100.4	5.04
draught at the kiln discharging end			10.3	0.52
radiation loss of returned dust in kiln			1.8	0.09
radiation loss at kiln shell surface	311.41	18.55	234.1	11.75
chemical incomplete combustion of the pulverized coal	21.75	1.29	137.8	6.92
mechanical incomplete combustion of the pulverised coal	22.68	1.35	41.75	2.10
total	1679.17	100.00	1991.73	100.00
difference	+7.47		+6.08	
relative error		+0.44	+0.3	

Appendix 2. Index of Techno-Economy and Thermal Engineering for ∅ 3.3/3.0/3.3 x 118m Wet process Rotary Kiln at Home (1977 - 1979)

Plant name	Number of production line	Time	Techno-economical index: output per hour t/h	output per interior surface area $kg/m^2.h$	output per effedine volume $kg/m^3.h$	output per section area $t/m^2.h$	coal consumption: consumption of coal standard kg/t.k	coal consumption: coal consumption in kiln kg/t. k	heat consumption Kcal/kg/k	heat generating capacity Q Kcal/k	strength of the thermal force per volume Qv $Kcal/m^3.h$	strength of the thermal force per section area QA $Kcal/m^2.h$	average strenth grade of cement clinker (dry mortar) kg/m^2
Kai Yuan	2	1977	1[illegible].43	11.83	16.56	1.73	303	668	2121	$24.24x10^6$	$26.00x10^4$	$3.67x10^6$	642
		1978	12.70	13.15	19.41	1.92	265	617.65	1855	$23.56x10^6$	$25.28x10^4$	$3.56x10^6$	661
		1979	13.27	13.73	19.23	2.01	256.31	604.63	1794	$23.81x10^6$	$25.55x10^4$	$3.60x10^6$	664
Kun Ming	2	1977	14.95	15.43	21.67	2.26	253.63	381.38	1775	$26.54x10^6$	$28.28x10^4$	$4.02x10^6$	485
		1978	14.84	15.36	21.50	2.25	232.74	381.23	1629	$24.17x10^6$	$25.75x10^4$	$3.66x10^6$	534
		1979	15.76	16.31	22.84	2.38	228.97	354.21	1603	$25.26x10^6$	$26.91x10^4$	$3.82x10^6$	520
Da Tong	4	1977	17.51	17.72	24.59	2.38	210.74	239.4	1475	$25.83x10^6$	$26.41x10^4$	$3.51x10^6$	569
		1978	18.38	18.60	25.81	2.49	206.6	234.04	1446	$26.58x10^6$	$27.58x10^4$	$3.61x10^6$	591
Yong Deng	4	1977	18.42	18.81	25.87	2.50	224.77	299.3	1573	$28.97x10^6$	$29.62x10^4$	$3.94x10^6$	646
		1978	18.32	18.71	25.71	2.49	224.30	292.4	1570	$29.41x10^6$	$29.41x10^4$	$3.91x10^6$	662

The shell No. 2 kiln at Da Tong Cement Plant was enlatged to 3.8/3.3/3.3x118m in 1972. As there is no seperate statistical data for eac' the kiln, the data in the table is average value calculated for the four kilns.

Appendix III

Conversion Table of Strength Grade from Dry Mortar Basis to Plastic Mortar Basis (q)

Conversion Equation

ordinary Portland cement $R \frac{\text{dry mortar}}{\text{28 d compressive strength}}$

$$= 1.2\, R \frac{\text{plastic mortar}}{\text{28 d compressive strength}} - 17$$

s: cement $R \frac{\text{dry mortar}}{\text{28 d compressive strength}}$

$$= 1.16\, R \frac{\text{plastic mortar}}{\text{28 d compressive strength}} + 50$$

Strength Grade on plastic mortar basis	Strength Grade (kg/cm^2) on dry mortar basis	
	ordinary Portland cement	slag cement
625	733	
525	613	659
425	493	543
325	373	427
275	313	369
225	253	311