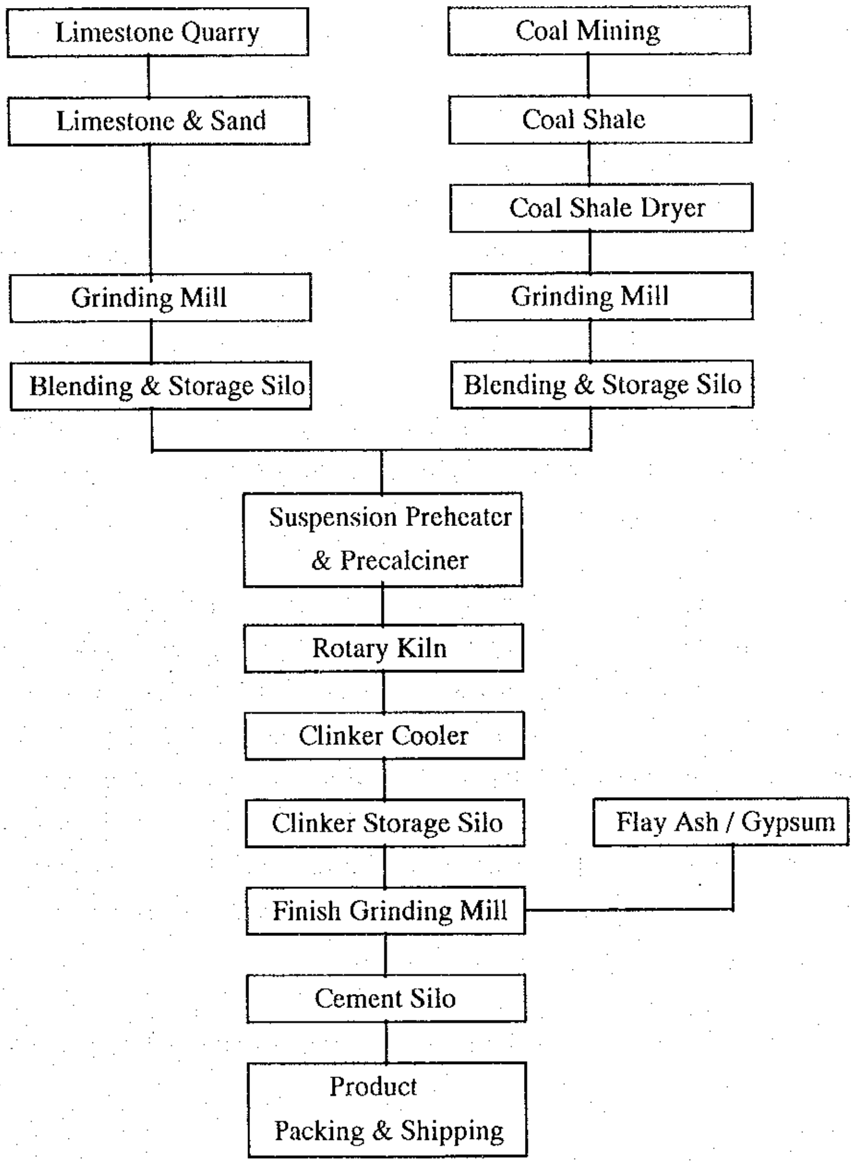
12-2-3 Outlinle of Production Process

(1) Manufacturing Process Flow Diagrams



(2) Rawang Works Dry-Process Flow Chart

Fig. 12-3 shows the material, gas and fuel flow of APMC's Rawang Works. And, Fig. 12-4 to Fig. 12-8 show the material, gas and fuel flow of each production department.

12-2-4 Brief Description of Cement Manufacturing Process

(1) Quarrying of Raw Materials

Limestone is quarried nearby and transported by dump trucks to a crusher, which reduces the size of stone to smaller than 30mm. Shale is extracted from reserves about 24 km away and transported by lorries to the works, where it is crushed and blended in a reclaimer store.

(2) Raw Material Preparation

Limestone and shale (after drying) are ground separately in the roller-press and closed circuit tube mills. Ground limestone and shale raw meals are stored separately in silos for final homogenization to ensure that the quality of raw meal is consistent with predetermined quality standards.

(3) Clinker Burning

The new 5-stage, twin-string precalciner dry-process plant at Rawang was constructed and commissioned by IHI Japan early in 1981. This 4,000 t/day SF precalciner was modified to a 5,200 t/day, 5-Stage NSF precalciner plant in 1994.

The operation of this kiln is unique. Primary raw materials, i.e., limestone and secondary raw material, i.e., coal shale blended with iron rich clay, are separately ground, blended and stored in silos. From blending and storage silos, limestone raw meal is fed to the top of a 5-stage cyclone preheater and coal shale raw meal is fed directly into a flash furnace (Precalciner) before entering a rotary kiln. Limestone raw meal flows down through cyclones and finally reaches a decarbonation temperature of 900℃ at the fifth stage cyclone, where it mixes with coal shale and enters the rotary kiln at about 88% decarbonation for conversion into cement clinker. In the kiln, successive chemical reactions occur and material is sintered to cement clinker at about 1,450℃.

(4) Clinker Cooling

Red hot clinker leaves the kiln at about 1,250℃ and is rapidly cooled in a grate-cooler before being conveyed to clinker storage silos.

(5) Cement Grinding

From the clinker silos, clinker is extracted and ground with the addition of approximately 5% gypsum in closed-circuit tube mills to produce cement. Gypsum is added to control the setting time of cement. Cement leaving the grinding mill is pumped and stored in cement silos ready for dispatch.

(6) Packing and Dispatch

Cement drawn from cement silos is fed to high-speed rotary packers in the packing plant for bagging. Bags are filled to 50 kg and discharged for loading into trucks and rail wagons. Bulk tankers are loaded directly from cement silos. Bulk cement is also loaded into rail wagons for delivery to the company's depots .

(7) Quality Control

The laboratory at Rawang Works is equipped with the latest Multi-Channel Simultaneous X-ray analyzer, automatic samplers and other test equipment. Proportioning of raw materials is strictly controlled at all stages of the process to ensure that the quality of finished product well exceeds the standards set by the Standard & Industrial Research Institute of Malaysia (SIRIM).

(8) Environment Control

The dry process plant at each location is well-equipped with high efficiency electrostatic precipitators, gravel bed filters and bag filters at various stages of the process to ensure that the dust emission level is maintained well below the limits stipulated by the authorities at all times.

12-3 Outline of Operating Conditions

The following is a summary of the operating conditions of major works facilities in the past 6 years.

(1) Trends of annual sales amount .... See Table 12-1
(2) Trends of clinker production output and operating hours per annum .... See Table 12-2
(3) Trends of raw meal production output and operating hours per annum ..... See Table 12-3
(4) Trends of cement production output and operating hours per annum.......... See Table 12-4
(5) Chemical composition of raw meal .... See Table 12-5
(6) Chemical composition of clinker and cement
(Ordinary Portland Cement).......... See Table 12-6
(7) Trends of specific heat and power consumption of major products .... See Table 12-7

From the above, an outline of works operating conditions in the past 6 years is given in Table 12-10.

Table 12-10 Malaysia APMC Rawang Works Data

Year	Cl. Production (tonnes/year)	Ratio (%)	Kiln Operation rate (%)	Heat Cons. (kcal/kg-cl.)	Power Con. (kWh/t-cem)	Labor Productivity (t/m)
1992	999,070	100	76.4	952	131.3	(1,780)
1993	1120,055	112.3	82.9	1071	137.1	-
1994	1299,175	130.3	84.5	1124	138.9	-
1995	1474,031	147.8	86.1	984	129.8	-
1996	1554,895	155.9	87.1	912	130.3	-
1997	1560,055	156.5	88.6	915	134.2	2,786
*-1 Sep. 14~19	29,045	-	98.2	970	131.4 *-2	-

Notes : *-1 Data during Energy Audit.
*-2 Data of Aug, 1998.

To meet the demand of cement in Malaysia, measures to increase production were carried out in 1993. Consequently, (1) Clinker production capacity increased from 3,701 t/d to 4,876 t/d, (2) Heat consumption decreased from 1,124 kcal/kg-cli. to 915 kcal/kg-cli. (3) Kiln operation rate improved from 76.4 % to 88.6 %.

Furthermore, dust emission from the kiln stack is maintained under 40 mg/Nm^3, while dust emission from the cooler stack is maintained at approximately 90-120 mg/Nm^3.

Table 12-1 Trends in Annual Sales Amount

(unit: ton/year)

Kinds of cement \ Year	1992	1993	1994	1995	1996	1997
(1) Ordinary portland Cement	1,096,596	1,129,533	1,161,363	1,213,085	1,256,472	1,296,728
(2) Rapid hardening Cement	—	—	—	—	—	—
(3) Sulphate resistant Cement	16,596	—	—	—	—	—
(4) Fly ash cement	86,323	160,870	197,364	341,168	383,265	435,895
(5) Masonary cement	167,741	183,634	208,035	180,592	143,230	159,614
(6) Blast furnace cement	—	—	—	—	—	—
Total	1,367,352	1,474,041	1,566,762	1,734,645	1,782,967	1,892,237

Table 12-2 Trends in the Production Output of Clinker and Operation Hours per Annum

(kiln operation performance)

Items \ Year	1992	1993	1994	1995	1996	1997
(1) Production of Clinker (ton)	997,070	1,120,055	1,299,175	1,474,030	1,554,895	1,560,055
(2) Operation hour (h)	6,707.53	7,263.30	7,398.12	7,540.61	7,654.00	7,757.64
(3) Capacity (t/day) (1) / (2)	3,567.6	3,701.0	4,214.6	4,691.6	4,875.6	4,826.4
(4) Schedule shut Down + Breakdown (h)	2,052.47	1,496.70	1,361.88	1,219.39	1,106.00	1,002.36
(5) Availability (%) (2) / (2) + (4)	76.4	82.91	84.45	86.09	87.14	88.56

Table 12-3 Trends in Production Output of Raw Meal and Operating Hours per Annum
(Raw material grinding mill operations performance)

		1992	1993	1994	1995	1996	1997
Production (ton)	L /S Mill	1,315,064	1,324,518	1,500,585	1,428,287	1,525,871	1,615,361
	C /S Mill	68,027	424,947	506,148	522,753	561,288	557,726
	Roller Press	—	197,452	283,444	527,079	524,039	487,020
	Sub Total	—	—	—	—	—	—
Operation Hours① (H – year)	L / S Mill	5,222.00	5,145.41	5,652.71	5,396.16	5,768.81	6,193.02
	C / S Mill	4,301.00	4,651.30	5,462,24	5,619.54	6,103.06	6,039.33
	Roller Press	—	1,841.54	2,826.56	4,937.14	5,270.62	5,045.12
	Sub Total	—	—	—	—	—	—
Capacity (t/h)	L / S Mill	251.8	257.4	265.5	264.7	264.5	260.8
	C / S Mill	85.6	91.4	92.7	93.0	92.0	92.3
	Roller Press	—	107.2	100.3	106.8	99.4	96.5
	Sub Total	—	—	—	—	—	—
Breakdown (H – Year)②	L / S Mill	—	—	848.04	565.23	511.19	561.44
	C / S Mill	—	—	456.27	315.33	304.74	287.88
	Roller Press	—	—	1,354.85	1,177.98	1,430.19	1,296.83
	Sub Total	—	—	—	—	—	—
Scheduled Shut down (H – Year)	L / S Mill	—	—	2,259.25	2,798.61	2,480.00	2,005.54
	C / S Mill	—	—	2,841.49	2,825.13	2,352.20	2,432.79
	Roller Press	—	—	4,578.59	2,644.88	2,059.19	2,418.05
	Sub Total	—	—	—	—	—	—
Availability (%) ①/A+②	L / S Mill	—	—	86.95	90.52	91.86	91.69
	C / S Mill	—	—	92.29	94.69	95.24	95.45
	Roller Press	—	—	67.60	80.74	79.66	79.55
	Average	—	—	—	—	—	—

Table 12-4 Trends in Product Output of Cement and Operation Hour
(Finish Grinding Mill Operation Performance)

		1992	1993	1994	1995	1996	1997
Production (A) (Ton)	No.1 Mill	142,234	170,366	175,470	199,868	184,260	206,834
	No.2 Mill	155,692	160,471	155,485	184,993	202,125	220,019
	No.3 Mill	154,813	158,488	154,871	167,879	208,097	221,768
	No.4 Mill	430,345	462,727	487,452	514,260	542,435	565,849
	No.5 Mill	477,248	484,701	488,322	548,102	524,364	553,170
	No.6 Mill	—	37,288	105,162	119,743	121,686	124,597
	Total	1,360,602	1,474,041	1,566,762	1,734,845	1,782,967	1,892,237
Operation Hours (B) (H- Year)	No.1 Mill	7348.69	7975.47	7815.70	7588.72	7588.76	8093.51
	No.2 Mill	7609.58	7710.77	7661.61	7455.80	7573,78	8229.83
	No.3 Mill	7545.90	7541.62	7791.28	7007.17	7594.98	8333.20
	No.4 Mill	6814.69	7395.71	7647.55	7752.55	7668.90	7974.12
	No.5 Mill	7528.58	7682.20	7840.66	8004.35	7483.06	8127.10
	No.6 Mill	—	2770.86	7666.35	7908.52	7501.68	7878.78
Capacity (A) / (B) (t / h)	No.1 Mill	19.4	21.4	22.5	26.3	24.3	25.5
	No.2 Mill	20.5	20.8	20.3	24.8	26.7	26.7
	No.3 Mill	20.5	21.0	19.9	24.0	27.4	26.6
	No.4 Mill	63.1	62.6	63.7	66.3	70.7	71.0
	No.5 Mill	63.4	63.1	62.3	68.5	70.1	68.1
	No.6 Mill	—	13.5	13.7	15.1	16.2	15.1
Scheduled Shut Down + Break Down (C) (H- Year)	No.1 Mill	1435.04	784.53	944.30	1171.25	1195.24	666.49
	No.2 Mill	1174.60	1049.23	1098.39	1304.20	1210.22	530.17
	No.3 Mill	1238.10	1218.38	968.72	1752.83	1186.02	426.80
	No.4 Mill	1969.31	1364.29	1112.45	1002.45	1115.10	785.88
	No.5 Mill	1255.42	1077.80	919.34	755.65	1300.94	632.90
	No.6 Mill	—	613.14	1093.65	851.48	1282.32	881.22
Availability (%) (B) / (B)+ (C)	No.1 Mill	83.66	91.04	89.22	86.68	86.39	91.77
	No.2 Mill	86.63	88.02	87.46	85.11	86.22	93.95
	No.3 Mill	85.91	86.09	88.94	79.99	86.46	95.13
	No.4 Mill	77.58	84.43	87.30	88.50	87.05	91.03
	No.5 Mill	85.71	87.70	89.50	91.57	85.19	92.78
	No.6 Mill	—	81.88	87.51	90.28	85.40	89.94

Table 12-5 Chemical Analysis of Raw Meal (Limestone and Shale) in 1997 (1/2)
(For Ordinary Portland Cement)

(A) Limestone

(Unit : wt % on dry basis)

	L.O.I	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Cl	Total	Fineness (90%)	Moisture (%)
Jan.	39.8	5.9	0.6	0.2	52.0	0.38	0.07	0.01	0.08	ND	99.04	10.1	0.22
Feb.	39.1	6.5	0.6	0.2	51.6	0.33	0.08	0.01	0.14	ND	98.56	10.5	0.23
Mar.	39.6	6.8	0.9	0.4	51.2	0.31	0.11	0.01	0.14	ND	99.47	10.9	0.18
Apr.	40.2	5.8	0.7	0.3	51.9	0.40	0.17	0.01	0.08	ND	99.56	11.6	0.23
May	40.0	6.5	0.7	0.4	51.4	0.48	0.10	0.01	0.07	ND	99.66	10.6	0.20
Jun.	40.4	6.4	0.8	0.4	51.4	0.50	0.10	0.01	0.10	ND	100.11	10.9	0.20
Jul.	39.8	6.3	0.7	0.5	51.5	0.46	0.09	0.01	0.08	ND	99.44	11.3	0.25
Aug.	39.2	6.6	0.8	0.3	51.4	0.35	0.08	0.01	0.08	ND	98.82	10.4	0.22
Sep.	40.2	6.6	1.2	0.5	51.0	0.36	0.11	0.01	0.13	ND	100.10	10.6	0.22
Oct.	39.9	6.6	0.9	0.3	51.4	0.36	0.08	0.01	0.09	ND	99.64	10.8	0.23
Nov.	39.8	6.2	0.8	0.3	51.6	0.36	0.07	0.01	0.11	ND	99.25	12.0	0.20
Dec.	39.6	6.4	1.1	0.3	51.4	0.45	0.08	0.01	0.08	ND	99.12	10.9	0.25
Ave.	39.8	6.4	0.8	0.3	51.5	0.40	0.10	0.01	0.10	-	99.32	10.9	0.22

Table 12-5 Chemical Analysis of Raw Meal (Limestone and Shale) in 1997 (2/2)
(For Ordinary Portland Cement)

(B) Coal Shale

(Unit : wt % on dry basis)

	L.O.I	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Cl	Total	Fineness (90%)	Moisture (%)
Jan.	26.8	38.0	14.0	10.5	8.1	0.73	0.26	0.03	1.35	ND	99.77	5.7	1.17
Feb.	25.4	40.4	14.0	10.4	7.2	0.60	0.16	0.08	1.41	ND	99.65	5.7	1.18
Mar.	24.0	41.7	14.0	10.1	8.0	0.57	0.15	0.08	1.31	ND	99.91	4.8	1.18
Apr.	26.0	38.7	15.0	11.6	6.5	0.65	0.27	0.03	1.20	ND	99.95	5.6	1.20
May	23.7	41.8	15.1	10.7	6.4	0.66	0.25	0.03	1.17	ND	99.81	6.0	1.23
Jun.	24.4	41.5	14.6	10.8	6.6	0.63	0.21	0.03	1.05	ND	99.82	5.4	1.17
Jul.	26.0	39.3	14.6	10.8	7.3	0.62	0.30	0.03	1.12	ND	100.07	4.8	1.17
Aug.	26.1	38.9	13.7	10.6	8.2	0.80	0.18	0.17	1.27	ND	99.82	5.6	1.18
Sep.	26.4	38.6	13.5	10.7	8.0	0.76	0.20	0.17	1.66	ND	99.99	5.4	1.18
Oct.	27.0	37.5	13.8	11.5	7.0	0.76	0.22	0.17	1.77	ND	99.72	5.2	1.17
Nov.	24.9	40.5	13.9	11.2	6.6	0.76	0.18	0.16	1.59	ND	99.79	5.3	1.18
Dec.	24.7	39.1	15.0	11.2	7.5	0.74	0.17	0.17	1.36	ND	99.94	5.3	1.17
Ave.	25.5	39.7	14.3	10.8	7.3	0.69	0.21	0.10	1.36	-	99.96	5.4	1.18

Table 12-6 Chemical Composition and Physical Properties of Cement/Clinker

Chemical Composition of Clinker (Ordinary Portland Cement)

	Igloss (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3(%)	CaO (%)	MgO (%)	SO_3 (%)	Na_2O (%)	K_2O (%)	HM	SM	IM	fCaO (%)
1992	—	—	—	—	—	—	—	—	—	—	—	—	—
1993	—	—	—	—	—	—	—	—	—	—	—	—	—
1994	0.0	21.8	6.0	4.0	66.5	0.6	—	—	—	2.09	2.18	1.52	—
1995	0.0	21.7	5.7	4.4	66.4	0.6	—	—	—	2.09	2.15	1.31	2.0
1996	0.0	22.2	5.9	4.8	65.3	0.6	—	—	—	1.99	2.07	1.23	1.5
1997	0.0	21.8	5.8	4.3	66.3	0.6	—	—	—	2.08	2.15	1.37	1.9

Chemical Composition of Cement

	Igloss(%)	SiO_2(%)	Al_2O_3(%)	Fe_2O_3(%)	CaO(%)	MgO(%)	SO_3(%)	Na_2O(%)	K_2O(%)	HM	SM	IM	fCaO(%)
1992	1.3	20.3	5.7	3.8	64.6	0.9	2.3	0.14	0.7	2.17	2.14	1.50	2.4
1993	1.4	20.4	5.7	3.7	64.3	0.9	2.4	0.08	0.71	2.16	2.12	1.54	1.9
1994	1.9	20.1	6.1	3.6	64.4	0.5	2.4	0.08	0.52	2.16	2.07	1.69	2.3
1995	2.2	19.8	6.5	3.8	64.6	0.6	2.3	0.08	0.69	2.22	2.13	1.45	2.4
1996	2.6	20.2	5.4	4.1	63.1	0.6	2.5	0.08	0.65	2.12	2.13	1.32	2.4
1997	3.7	19.6	5.6	3.9	63.6	0.6	2.2	0.08	0.56	2.19	2.06	1.44	2.4

Physical Property of Cement

	Blaine	Compressive Strength (N/ mm^2)				Bending Strength (N/mm^2)			
	(cm^2/g)	1 day	3 days	7 days	28 days	1 day	3 days	7 days	28 days
1992	2930	20.8	32.7	45.0	57.6	—	—	—	—
1993	3070	20.5	32.9	45.1	60.1	—	—	—	—
1994	3050	20.7	29.2	41.2	58.2	—	—	—	—
1995	2850	19.9	28.8	42.6	57.4	—	—	—	—
1996	3150	22.4	29.8	42.8	56.3	—	—	—	—
1997	3350	21.2	31.9	40.9	55.7	—	—	—	—

12-4 Trends in Annual Energy Consumption and Unit Consumption

Table 12-7 and Table 12-8 show the trends of annual energy consumption and unit consumption in latest 6 years, and the energy consumption rate by fuel and electricity in 1997.

Table 12-7 Trends in Annual Energy Consumption and Unit Consumption

Name of utility \ Year		1992	1993	1994	1995	1996	1997
(1) Fuel oil	ton	16,796	24,460	29,755	42,590	32,235	33,447
(2) Bituminous coal	ton	63,512	88,845	99,702	111,324	148,160	153,413
(3) Other fuel (Coal shale)	ton	516,682	348,967	405,282	404,651	403,514	349,017
(4) Electricity	1000 kWh	158,614	180,297	205,006	213,546	222,624	233,670
(5)Clinker Production	ton	997,070	1,120,055	1,299,175	1,474,030	1,554,895	1,560,055
	(t /day)	3,567.6	3,701.0	4,214.6	4,691.6	4,875.6	4,826.4
(6)Cement Production	ton	1,360,602	1,474,041	1,566,762	1,734,845	1,782,967	1,892,237
(7) Heat Consumption	(kcal / kg-cli.)	952	1071	1124	982	912	915
(8) Power Consumption	(kWh / t-cli.)	159.1	161.0	157.8	144.9	143.2	149.8
	(kWh / t-cem)	131.3	137.1	138.9	129.8	130.3	134.2

Table 12-8 Annual Energy Consumption (1997)

Name of Utility	Consumption (ton / year)	Heat value (kcal / kg)	Calorific value (10^9 kcal / y)	(%)	Unit price (RM / t)	Cost 10^3 RM/y (%)
Fuel oil	33,447	10,200	341.2	(21.4)	422	14,114.6 (18.6)
Coal (wet)	153,413					
(dry)	130,401	6,500	847.6	(53.0)	135	20,710.8 (27.2)
Coal Shale (wet)	349,017					
(dry)	296,664	700	207.7	(13.0)	5.7	1,989.4 (2.6)
*-1	(10^3 kWh/y)	(kcal/kWh)			Tariff E-3	
Electricity	233,670	860	201.0	(12.6)	Special	39,259.2 (51.6)
Total	—	—	1,597.5	(100.0)	—	76,074.0(100.0)

Judging from the trends of energy consumption and unit consumption, the results of completing the upgrading exercise from 4,000 t/day to 5,000 t/day of clinker production in 1993 were as follows.

(1) Clinker production increased from 3,701 t/d to 4,876 t/d (in 1996)

(2) Heat consumption decreased from 1,071 kcal/kg-cli. to 915 kcal/kg-cli.

(3) With power consumption, however, there was little change, decreasing from 137.1 kWh/t-cem to 134.2 kWh/t-cem.

Nevertheless, the above figures of unit consumption are approximately 25-30 percent higher than those of Japan.

Table 12-8 and Table 12-9 show a comparison of energy consumption in 1997.

Table 12-9 Relative Comparison of Energy Consumption (1997)

Name of utility	Calorific base (%)	Monetary base (%)	Calorie price RM/10^3 kcal	Unit price ratio
(1) Fuel oil	21.4	18.6	0.0414	2
(2) Coal	53.0	27.2	0.0208	1
(3) Coal shale	13.0	2.6	0.0081	0.4
(4) Electricity *-1	12.6	51.6	0.169-0.195	8-9
Total	100.0	100.0	–	–

Note : *-1 The price calculated assuming that the peak/ off-peak ratio is 58/42, and assuming the contracted demand charge is 30,400 kW.

(5) Consumption of electrical power is not more than 13% of total energy consumption on a calorific basis, but is shown to reach approximately 52% on a monetary basis.

(6) Consumption of oil energy is under 22% of total energy consumption on a calorific basis, and about 19% on a monetary basis. Therefore, it is desirable to reduce the use of oil.

(7) In terms of calorie price, the price of electricity is 8-9 times higher than that of coal, and the price of oil is double that of coal. Thus we can see that the price of electricity is very expensive.

12-5 Present Situation of Energy Management and Energy Efficiency Promotion

12-5-1 Status of Energy Efficiency Promotion

(1) Establishment of Targets for Energy Efficiency

At the beginning of every year, the plant's executives set targets for energy efficiency and reducing the consumption of fuel and electricity. Last year's targets were as follows.

Electricity target:	2.5% down on previous year's power consumption.
Fuel oil reduction target:	Under 2.0% of production capacity of clinker, that is, fuel oil consumption should be kept under 100 t/d.

(2) Systematical Activities for Energy Management in the Factory

Under the control of the plant manager, an energy-saving committee is organized, consisting of an operations manager, an engineering manager and some energy-related engineers.

For fuel energy management:	Operations manager and four engineers are in charge.
For electricity management:	Engineering manager (Mr. Tan Chek Luck) and six engineers are in charge.

The energy-saving committee started activities three years ago and held meetings about once every two months. But recently, a meeting has been held every month with the objectives that (1) production comes first (2) energy-saving is second.

(3) Energy Management Utilizing Data and Records

The Operation Department controls the operational data for raw material grinding mills, kiln, preheater, cooler and cement mills. Quality data such as chemical analysis data are controlled by the laboratory. Necessary data can be utilized through the Operation Department and laboratory.

For operation data: please refer to Table 12-1 – Table 12-7.

(4) Education and Training of Employees for Energy Management

Refer to section 12-2-1 (20), Employment and Training.

(5) Maintenance Management of Facilities (Equipment)

Main facilities are maintained and repaired by periodic shut-down criteria and status checks by monitoring maintenance (Ex. vibration check for fans). In addition, patrollers check each facility using a checklist.

(6) Schedule of Annual Operation and Maintenance of Major Facilities

The normal operation period is six months for the kiln, followed by ten days shut-down for maintenance. But depending on demand for cement, kiln operation is shortened to three months and preventive maintenance is carried out.

12-5-2 Actual Results and Energy Efficiency Promotion Plans

(1) Measures Carried out for Energy Efficiency Promotion and Their Effects

In order to increase production from 4,000 t/d to 5,000 t/d and conserve energy, the following measures were taken in 1992.

1) Precalciner modified from SF to NSF.
2) Direct Coal Firing System modified to Indirect Firing System.
3) Existing Cooler modified to IHI upgrade cooler.
4) IDF replaced: 2 x 2100 kW → 2 x 2300 kW
5) Capacity of Cooler Exhaust Gas Fan reinforced 1000 kW: 1300 kW
6) Roller Press installed to increase Raw Material Grinding capability.
7) Limestone Second Crusher installed.
8) Gas Conditioning Tower modified from Co-Current to Counter Current Type.
9) Existing Grate Cooler modified to F.L. Smidth's CFG Cooler.

Consequently,

(a) Clinker production capacity increased from 3,701 t/d to 4,876 t/d
(b) Heat consumption decreased from 1,071 kcal /kg-clinker to 915 kcal /kg-clinker
(c) Kiln operation rate improved from 76.4 % to 88.6 %.

Please refer to Table 12-2 and Table 12-7 for more details.

(2) Planning Measures for Energy Efficiency Promotion and Their Anticipated Effects

The Energy-Saving Committee will set up energy-saving guidelines at the end of March.

12-6 Current Conditions and Problems with Facilities

12-6-1 Major Energy-Consuming Facilities and Problems thereof

(1) Cement Grinding Department

The combination of cement mill and cyclone separator is an old system. And at the same time, cement is transported by F.K Pump. As a result, power consumption reveals the very high figure of 44-45 kWh/t-cement.

(2) Kiln Burning Department

a) Heat consumption is more than 900 kcal /kg-clinker at 5,000 t/day clinker production.

b) Preheater exhaust gas temperature in the 5-stage preheater is high at around 450℃, and preheater pressure loss is higher than 950 mmAq.

c) The fuel ratio of precalciner to kiln, that is, the precalciner fuel ratio, is high at approximately 75-80%

d) Due to a lower heat load in the kiln sintering zone, free CaO (%) in clinker is high. This comes from a lower kiln fuel ratio under 20%.

e) The necessary recouped air (tertiary air) quantity in the F.F furnace is not sufficiently maintained.

f) Limestone and coal shale as clay material are fed to the preheater separately. Therefore, there are large fluctuations in the chemical composition of kiln feed meal, and kiln operation is not stable.

(3) Coal Drying / Grinding Department

Coal grinding mill capacity is insufficient. Oil is therefore used for the precalciner (F. Furnace).

Coal drying facilities such as the dryer and related transportation equipment should be stopped to reduce power consumption, except in the rainy seasons.

(4) Coal Shale Transportation

The Coal Shale Department uses an F.K Pump for its transportation from mill to silos as well as from silos to the precalciner (flash furnace).

12-6-2 Understanding of Current Problems and Audit Items

At present, the following are considered to be major problems.

(1) Extremely high heat consumption of 900-950 kcal/kg-clinker.

(2) Extremely high power consumption of 130-135 kWh/t-cement.

Therefore, the following items should be audited.

(1) Modification of fuel ratio of precalciner to kiln

(2) Improvement of raw meal feeding method

(3) Reduction of pressure loss of preheater cyclone

(4) Improvement of transportation system of powder materials

(5) Heat recovery from kiln exhaust gas and cooler exhaust gas

(6) Improvement coal drying system

(7) Modification of cement grinding system

(8) Homogeneity of chemical composition of raw meal and clinker

12-7 Energy Audit Method and Procedure

12-7-1 General

A factory survey for the energy audit was carried out through interviews and plant observations based on questionnaires and data sheets prepared by the Study Team. As for these results, high figures were recorded for power consumption and also heat consumption at this factory in spite of the latest facilities. For this investigation, the study team carried out an energy audit concerning the energy consumption of facilities and equipment, instrumental and controlling equipment, and operations.

To conduct an energy audit at these cement works, field investigations such as the analysis of operation data is the first essential step, followed by many kind of measurements. The results of the energy audit, including on evaluation of the results and recommendations for energy efficiency, are described in this chapter.

Major items and types of energy audits in cement works are as follows.

1. Heat consumption of the burning department
   (1) Preheater and F.F furnace
   (2) Kiln
   (3) Cooler
2. Electricity consumption of the raw material grinding department
3. Electricity consumption of the coal drying and grinding department
4. Electricity consumption of the cement grinding department

12-7-2 Outline of Measuring Items, Points and Measuring Equipment

To calculate and evaluate the current condition of energy consumption and to develop an energy balance, including gas and material balance, the measurements and operation data analysis described below were conducted, according to the schedule and corresponding to major items for energy audit.

(1) Raw Material Grinding Department

1. Limestone mill : Grinding capacity & mill kW
2. Coal shale mill : Grinding capacity & mill kW; FK Pump/Compressor kW, flow rate; DTA / TG analysis of coal shale.

(2) Coal Drying & Grinding Department

1. Coal dryer : Drying capacity & kW; moisture content; exhaust gas volume / temp.
2. Coal mill : Grinding capacity & kW; moisture content; exhaust gas volume / temp.

(3) Cement Grinding Department

No.1~3 mill: FK Pump / Compressor kW, flow rate; grinding capacity & mill kW

No.4~5 mill: FK Pump / Compressor kW, flow rate; grinding capacity & mill kW

(4) Burning Department

1. Preheater Cyclone : Temperature & pressure; combustion gas ($O_2/CO/CO_2$ %) exhaust gas flow rate; dust content; surface temperature.
2. F.F furnace : Coal / oil / coal shale feed rate; conveying air volume, temperature; surface temperature; quantity of unburned carbon
3. Kiln : Coal feed rate; conveying air volume; primary air flow rate; surface temp.; combustion gas ($O_2/CO/CO_2$ %) flow rate,
4. Cooler : Cooling air flow rate; exhaust gas flow rate; recouped air flow rate/temp.; surface temperature; outlet clinker temp.
5. Clinker Quality : Chemical composition of kiln feed raw meal and clinker.

(5) General energy consumption

1. Electricity consumption
2. Fuel coal consumption
3. Fuel oil consumption
4. Coal shale consumption
5. Added limestone consumption
6. Fly ash consumption
7. Other consumption

(6) Field investigation

1. Review of equipment list
2. Investigation of drawings
3. Observation of operating conditions of equipment and facilities

Details of measurement items, points and measuring equipment are shown in Table 12-11 and Table 12-12.

Table 12-11(1) Outlines of Measurement for Energy Audit (Cement)

Major Items of Energy Audit & Subject Items and Points	Measurement or Estimate	Available Equipment of Measurement			
		Required Equipment	Entity	JICA	Local Lab
1 Raw Material Grinding Department					
1-1 Limestone Mill					
(a) Fineness of Raw Meal	Trend Data	Operation Record			
(b) Grinding Capacity(t/h)	ditto	ditto			
(c) Mill Dept. kW	T/D or M	Clip-on AC P-meter	x	x	x
1-2 Coal Shale Mill					
(a) Grinding Capacity(t/h)	Trend Data	Operation Record			
(b) Mill Dept. kW	T/D or M	Clip -on AC P-meter	x	x	
(c) C/Shale Transportation					
(1) FK Pump kW	T/D or M	Clip-on AC P-meter	x	x	x
(2) Air Volume	B				
2 Coal Drying & Grinding Department					
2-1 Coal Dryer					
(a) Drying Capacity(t/h)	Trend Data	Operation Record			
(b) Moisture Content(%)	T/D or M	ditto			
(c) Exhaust Gas Volume	ditto	Pitot Tube Flow meter	x	x	x
(d) Exhaust Gas Temp. ℃	ditto	Operation Record			
(e) Electric Power kW	T/D or M	Clip-on AC P-meter	x	x	x
2-2 Coal Grinding Mill					
(a) Grinding Capacity(t/h)	Trend Data	Operation Record			
(b) Moisture Content(%)	T/D or M	ditto			
(c) Exhaust Gas Volume	ditto	Pitot Tube Flow meter	x	x	x
(d) Exhaust Gas Temp.	ditto	Operation Record			
(e) Electric Power kW	T/D or M	Clip-on AC P-meter	x	x	x

Note: T/D .... Trend Data

M .... Measurement

B .... Brochure Data

Table 12-11 (2) Outlines of Measurement for Energy Audit (Cement)

Major Items of Energy Audit & Subject Items and Points	Measurement or Estimate	Available Equipment of Measurement			
		Required Equipment	Entity	JICA	Local Lab
3 Cement Grinding Dept.					
3-1 No. 1-3 Cement Mill					
(a) Grinding Capacity(t/h)	Trend Data	Operation Record			
(b) Fineness of Cement	ditto	ditto			
(c) Mill Dept. kW	T/D or M	Clip-on AC P-meter	x	x	
(d) Cement Transportation					
(1) FK Pump kW	T/D or M	Clip-on AC P-meter	x	x	x
(2) Air Volume	B				
3-2 No. 4-5 Cement Mill					
(a) Grinding Capacity(t/h)	Trend Data	Operation Record			
(b) Fineness of Cement	ditto	ditto			
(c) Mill Dept. kW	T/D or M	Clip-on AC P-meter	x	x	
(d) Cement Transportation					
(1) FK Pump kW	T/D or M	Clip-on AC P-meter	x	x	x
(2) Air Volume	B				
4 Burning Department					
4-1 Preheater Cyclone					
(a) Temp. & Pressure	T/D or M	Operation Record			
(b) O_2/CO content (%)					
(1) IDF inlet	ditto	Orsat / O_2 Analyser	x	x	x
(2) FF Furnace outlet	ditto	Operation Record			
(c) Exhaust Gas Volume	D or M	Pitot Tube Flow meter	x	x	x
(d) Dust Content (IDF inl)	D or M	Existing Data		x	
(e) Surface Temp.(Cylone)	M	Radiation Pyrometer		x	
4-2 F.F.Furnace					
(a) Fuel Coal/Oil/ C-Shale					
(1) Flow rate (t/h)	Trend Data	Operation Record			
(2)Air Volume(m^3/min)	B or M	H/Wire Anemometer	x	x	x
(3) Temperature	Trend Data	Operation Record			
(b) Surface Temp.	M	Radiation Pyrometer	x	x	x

Table 12-11 (3) Outlines of Measurement for Energy Audit (Cement)

Major Items of Energy Audit & Subject Items and Points	Measurement or Estimate	Available Equipment of Measurement			
		Required Equipment	Entity	JICA	Local Lab
4-3 Kiln					
(a) Fuel Coal					
(1) Feed rate (t/h)	Trend Data	Operation Record			
(2) Temperature	ditto	ditto			
(3)Air Volume(m^3/min)	B				
(b) Primary Air Air Volume & Temp.	D or M	H/Wire Anemometer	x	x	x
(c) Exhaust Gas					
(1) Temperature	Trend Data	Operation Record			
(2) O_2/CO Content(%)	ditto	ditto			
(d) Surface Temperature	D or M	Radiation Pyrometer	x	x	x
4-4 Cooler					
(a) Cooling Air Volume	Trend Data	Operation Record			
& Temp.	ditto	ditto			
(b) Exhaust Gas					
(1) Gas Volume(m^3/min)	D or M	Pitot Tube Flow meter	x	x	x
(2) Temperature	ditto	Thermocouple	x	x	x
(c) Recouped Air					
(1) Air Volume(m^3/min)	D or M	Pitot Tube Flow meter	x	x	x
(2) Temperature	T/D or M	Thermocouple	x	x	x
(3) Surface Temp.(Duct)	D or M	Radiation Pyrometer	x	x	x
(d) Clinker Temp.	Trend Data	Operation Record			
4-5 Clinker Quality					
(a) Kiln Feed Raw Meal	M*1	Sampling & Analysis	x	x	
(b) Clinker(cooler outlet)	M*2	ditto	x		

Notes: *1 Take 24 samples of kiln feed raw meal out during 2 hours at 3 minute interval.

*2 Take 24 samples of clinker out at the cooler discharge end during 2 hours at 3 minute interval, which starts after 45 minutes later of above.

Table 12-11 (4) Outlines of Measurement for Energy Audit (Cement)

Major Items of Energy Audit & Subject Items and Points	Measurement or Estimate	Available Equipment of Measurement			
		Required Equipment	Entity	JICA	Local Lab
5 General Energy Consumption *-1					
(a) Electricity	Trend Data	Operation Record	x		
(b) Fuel Coal	ditto	ditto	x		
(c) Fuel Oil	ditto	ditto	x		
(d) Coal Shale	ditto	ditto	x		
(e) Added Limestone	ditto	ditto	x		
(f) Fly Ash	ditto	ditto	x		
(g) Others	ditto	ditto	x		
6 Field Investigation *-2					
(a) Observation	Observation		x	x	x
(b) Investigation of Existing data etc.	Review	Existing drawing / data	x	x	

Note: *-1 ,*-2 ··· Gather each data during the energy audit term. (from Sep. 14th to 19th)

Table 12-12 Outlines of Equipment for Measurement

Measuring Equipment prepared by JICA	Measuring points
1 Hot wire anemometer 1 Measuring Items : Wind Velocity, Wind temp. 2 Measurable Materials : Air, Exhaust Gas 3 Measurement Range (Wind Velocity) m/s : 0-50 4 Measurement Range (Wind Temp.),℃ : 0-500 5 Indicator : Digital	(1) Kiln primary air flow rate (2) F.F primary air flow rate (A)/(B) side
2 Pitot tube gas flowmeter 1 Type, Number of Pitot tube: L-Type(4), Western Type(4) 2 Measurable Materials : Flue Gas 3 Measurement Range, m/s : 0-20 4 Measurable Tube Size, (mm)ID : 25-300 5 Indicator : Digital (ΔP, Static Pressure)	(1) Coal dryer exhaust gas (2) Coal mill exhaust gas (3) Cooler exhaust gas flow (4) Recouped air flow rate (5) IDF inlet exhaust gas flow
3 Oxygen content meter for exhaust gas 1 Measurement Range (O_2 content), Vol. % : 0-25 2 Indicator : Digital	(1) Flue gas of IDF outlet
4 CO, CO_2 content meter for exhaust gas 1 Measurable Materials : CO, CO_2 2 Measurement Range, Vol. % : CO(0-5/15),CO_2(0-5/15) 3 Standard Gas : 800 ppmCO+12%CO_2+N_2(3.41)	(1)Flue gas of IDF outlet
5 Pre-treatment unit for sampling of exhaust gas 1 Treated Materials : Combustion Exhaust Gas 2 Drying Capacity, ℃ : 1.5-2 (1.5 l/min), 6-8 (5 l/min)	- Ditto -
6 Sampling tube for exhaust gas 1 Number of Metallic Pipes : Cantal(5),SUS316(20) 2 Number of tubes : Silicone(10), Teflon (10+10)	- Ditto -
7 Surface thermometer 1 Measurement range, ℃ : -50-600 2 Indicator : Digital	(1) Cooler, (2) Kiln, (3) Duct (4) Preheater cyclone / F.F
8 Radiation pyrometer for lower temperature 1 Measurement Range, ℃ : -30-1200 2 Indicator : Digital	- Ditto -
9 Voltage-Ampere-watt meter 1 Measurement Range, V : 150/300/600 2 Measurement Range, A : 20/50/100/200/500 3 Measurement Range, kW : 300/600/900	Many items and points
10 Clip-on AC powermeter 1 Rated Voltage, Vrms : 200/600 2 Rated Current, mA/dgt : 10 3 Rated Power, W/dgt : 10	Many items and points

12-8 Measurement Procedure

12-8-1 Participants in Energy Audit

(1) APMC's Rawang Works

Tan Chek Luck:	Engineering Manager
S. Hari Krishnan:	Assistant Sr. Chemist
D. Muruganandam:	Technical Dept. Assistant Sr. Engineer (Production)
Jacob George:	Technical Dept. Production Engineer (Process)
Mohd Azhar B. Mohd. Noor:	Electrical Dept. (Assistant Engineer)
Qiu Jin Zhong:	Technical Dept. (Process Engineer)

(2) JBE&G

Teratai Zainab Leman:	Assistant Director
Mohd Elmi Anas:	Assistant Director
Nslid Asi Rasid:	Technical Assistant

(3) JICA study team

Akinori Hashimoto:	Study Team Leader
Yoshihiko Ueda:	Sector Technology (Industry)
Muneteru Yoshizawa:	Energy Audit (Heat)
Yasuo Ishibashi:	Energy Management (Electricity)

(4) Malaysian consultant for measurement (SIRIM)

Hamdan Mokhtar:	Programe Coordinator
Maznah Abdul Majid:	Senior Research Engineer
Syed Amar Srab Synid Manoor:	Research Engineer
Zulkairain Abdullah:	Assistant Researcher
Fudil Mohamad:	Assistant Researcher
Rahim Tambi:	Assistant Researcher

12-8-2 Schedule of Energy Audit

The initial schedule of energy audit for this cement works was from September 8 to 19, but was changed to September 11 to October 2 by request of the cement works.
It included measurement preparations and preliminary discussion of audit results.
The following is an outline of the schedule:

(1) Preparation

11, Sep. (Fri.): Explanation and confirmation of detailed energy audit plan and schedule

14, Sep. (Mon.): Transportation and preparation of measuring equipment
Detailed plant site observation and check of measuring points by JICA study Team. Gather operation data and existing data of plant.

(2) Energy audit

15, Sep. (Tues.): Measurement of kiln / F.F furnace primary air volume
Measurement of electrical power of Coal Shale Department facilities.

16, Sep. (Wed.): Measurement of electrical power of cement mills (No. 2 ,5 & 6)
Measurement of coal mill, dryer and cooler exhaust gas, and tertiary air volume.
Sampling and chemical analysis of kiln feed raw meal and cooler outlet clinker (24 samples each) by plant engineer.

17, Sep. (Thurs.): Measurement of electrical power of cement mills (No. 3 & 4)
Measurement of IDF inlet exhaust gas volume and O_2/CO/CO_2 gas analysis

18, Sep. (Fri.) : Measurement of surface temperature of preheater cyclone, F.F furnace, kiln, cooler, and tertiary air duct

19, 20, Sep. (Sat. & Sun.) : Summary and arrangement of measuring data, daily operation data and existing data, etc. Data input to computer.

(3) Discussion of preliminary results and transportation of measuring equipment

21, Sep. (Mon.): Package and transfer measuring equipment to sugar plant.

23, Sep. (Wed.): Discussion of preliminary results and energy efficiency promotion in the cement plant.

2, Oct. (Mon.): Summary meeting of energy audit.

Table 12-13 shows a detailed schedule of energy audit measurement.

Table 12-13(1) Detailed Schedule of Measurement (Cement)

Measuring Items	1	2	3	4	5	6	7	8	9	10	Remarks
0. Preparation	×										
1. Raw Material Grinding Dept.											
1-1 Limestone Mill											
(1) Fineness of Raw Meal (Change Level)		×	×	×							①New Feed ②Return ③Fine
(2) Grinding Capacity		×	×	×	×	×					Operation data
(3) Electric Power Consumption		×	×	×	×	×					Limestone Mill Dept.
1-2 Coal Shale Mill											
(1) Grinding Capacity		×	×	×	×	×					Operation data
(2) Electric Power Consumption		×	×	×	×	×					
(3) F.K Pump (Flow Rate)		×									From Mill to Silo / Silo to F.F,furnace
(4) Ditto (Kw)		×									
2. Coal Drying & Grinding Dept											
2-1 Coal Dryer											
(1) Drying Capacity		×	×	×							Operation data
(2) Moisture Content			×								Inlet / Outlet
(3) Exhaust Gas (Volume/Temp)			×								Inlet / Outlet
(4) Electric Power Consumption		×	×	×							
2-2 Coal Grinding Mill											
(1) Grinding Capacity		×	×	×							Operation data
(2) Moisture Content			×								Inlet / Outlet — Operation data
(3) Exhaust Gas (Volume/Temp)			×								
(4) Electric Power Consumption		×	×	×							
3. Cement Grinding Dept.											
(1) Grinding Capacity		×	×	×	×	×					No. 1~6 each Mill — Operation data
(2) Electric Power Consumption		×	×	×	×						Ditto
(3) Fineness of Cement				×							
(4) F.K Pump (Flow rate & Kw)			×	×							
4. Buring Dept.											
4-1 Preheater Cyclone											
(1) Temperature & Static Pressure		×	×	×	×	×					Inlet & Outlet of Each Cyclone
(2) Combustion Gas											
1) O2/CO/CO2 Contents		×	×	×	×	×					F.F. Furnace Outlet
2) ditto				×							IDF Inlet
3) Flow Rate (Volume)				×							IDF Inlet
4) Dust Content				×							Top Cyclone Outlet
(3) Surface Temperature					×						

N.B. ① This schedule starts from September 14th, and finishes at October 2nd.

② As for item 1-1, according to the plant operating condition, this change of fineness level of limestone raw meal could not Carry out.

Table 12-13(2) Detailed Schedule of Measurement (Cement)

Measuring Items	1	2	3	4	5	6	7	8	9	10	Remarks
4-2 F. F. Furnace											
(1) Fuel Coal											
1) Feed Rate & Temp		×	×	×	×	×					Operation data
2) Conveying Air Volume/temp		×									
(2) Fuel Oil (Flow Rate & Temp)		×	×	×	×	×					Operation data
(3) Primary Air (Flow Rate & temp)		×									
(4) Coal Shale											
1) Feed Rate & Temp		×	×	×	×	×					Operation data
2) F.K Pump (Flow Rate / Kw)		×									
(5) Surface Temperature					×						
4-3 Kiln											
(1) Surface Temperature					×						Kiln Shell Surface
(2) Fuel Coal											
1) Feed Rate & Temp		×	×	×	×	×					Operation data
2) Conveying Air Volume/temp		×									
(3) Primary Air (Flow Rate & temp)		×									
(4) Exhaust Gas O_2/CO/CO_2 Content & temp		×	×	×	×	×					
(5) Secondary Air (Flow Rate & Temp)		×									Calculation Data
4-4 Cooler											
(1) Cooling Air (Flow Rate & Temp)				×							No. 1 ~ No. 9 Fan
(2) Exhaust Gas (Flow Rate & Temp)			×								
(3) Recouped Air (Tertiary Air)											
1) Flow Rate & Temp			×								
2) Duct Surface Temp				×							
(4) Clinker Temperature		×	×	×	×	×					Operation data
4-5 Clinker Quality											
(1) Kiln Feed (Chemical Composition)			×	—	—	—					× → Sampling – Analysis
(2) Clinker (Chemical Composition)			×	—	—	—					× → Sampling – Analysis

Table 12-13(3) Detailed Schedule of Measurement (Cement)

Measuring Items	1	2	3	4	5	6	7	8	9	10	Remarks
5. General Energy Consumption		×	×	×	×	×					Parallel with Items 1~4 Utilizing Operation
(1) Electricity (daily operation data)											Records and Data
(2) Fuel Coal											
(3) Fuel Oil											
(4) Coal Shale											
(5) Added Limestone											
(6) Fly Ash											
(7) Others											
6. Field Investigation	×	×	×	×	×	×					Parallel with Items
(1) Preparation of Equipment List	×	×	×	×	×	×					1~4 Review of Existing Equipment List Equipment, Facilities & Layout.
(2) Investigation of Drawings	×	×	×	×							
(3) Observation of Operating Condition	×	×	×	×	×	×	×	×			Observation Utilizing Operetion Record
7. Review and Discussion									×	×	

12-9 Measurement Results

12-9-1 Measurement Data and Consideration

(1) Raw materials, fuels and energy consumption

During the energy audit (from Sept. 14 to 19), the daily average raw materials, fuels and energy consumption were checked by operation records. Table 12-14 shows results thereof and the average values during this period are shown below.
However, in this plant, electricity consumption data is recorded monthly, not daily.
During the energy audit, clinker production was rather low and heat consumption revealed a high figure, due to unstable kiln operation.

Clinker production:	4,840.8	t/d
Heat consumption:	971.1	kcal/kg-cli.
Coal consumption:	300.6	t/d
Fuel oil consumption:	55.1	t/d

The proportion that fuel oil accounts for in fuel calories is high at 22.3% (if we include coal shale calories, it will be 12.3%). Furthermore, the average daily cement production during this period was as follows.

(a) OPC grinding capacity:	2,836.3	t/d
(b) Walcrete grinding capacity:	203.7	t/d
(c) Mascrete grinding capacity:	615.9	t/d
Total	3,655.9	t/d

(2) Measurement of air and exhaust gas volume

Measurement results of air and exhaust gas volume are shown in Table 12-15.

1) Measurement of kiln primary air volume

Specification of primary air fan : 150 m^3/min x 1,500 mmAq x 35℃

The measurement result was 46.5 – 50.7 Nm^3/min (52.2 – 61.2 m^3/min), however, this differed slightly according to the measuring points. This measurement figure was approximately 7.2 percent against the theoretical combustion air volume, (672.2 Nm^3/min) at 5.7 t/h coal feed.

2) Measurement of F.F furnace primary air volume

Primary air fans with the same specification (100 m^3/min x 1500 mmAq x 50℃) are installed for F.F furnace (A) and (B) lines. Measurement results were (A) 111.6 Nm^3/min (124.7 m^3/min) and, (B) 74.2 Nm^3/min (87.5 m^3/min), respectively. Primary air volume for (B) line was slightly lower than that of (A) line.

The total quantities of fuels fed to F.F furnace (A) and (B) lines were as follows.

Oil feed quantity:	3.4	t/h
Coal feed quantity:	8.6	t/h
Coal shale feed quantity:	77.62	t/h

Theoretical combustion air volume against the above fuel consumption is approximately 2,855.3 Nm^3/min, and the total primary air volume of (A) and (B) lines (185.8 Nm^3/min) was about 6.5 percent of the above.

3) Measurement of exhaust gas volume at coal dryer and mill outlets

Exhaust gas volume at coal dryer outlet:	249 Nm^3/min (342.5 m^3/min)
Exhaust gas volume at coal mill outlet:	282 Nm^3/min (352.3 m^3/min)

There is much data on coal dryer and coal mill exhaust gas volumes measured by APMC in the past, however, this data on dryer outlet exhaust gas volume differs somewhat according to measuring time and operating conditions, etc.

4) Measurement of cooler exhaust gas volume

The measurement value of cooler exhaust gas volume was 5,253.0 Nm^3/min (12,192.3 m^3/min). There is much data on cooler exhaust gas volume measured by APMC in the past. This data is somewhat disparate due to the cooler operation. The above measurement value was generally sound judging from cooler gas balance data.

5) Measurement of recouped air volume (tertiary air volume)

The measurement result was 1,706.0 Nm^3/min (6,994.9 m^3/min).

There is some recouped air volume data measured by APMC, however, these measurement data reveals roughly the same figures. This figure was approximately 60 percent of the theoretical combustion air volume (2,850 – 2,900 Nm^3/min) of fuel burned in the F.F furnace, and is quite low.

This is because it was being operated with the fuel ratio of kiln to preheater considerably altered from 45/55 to 18/82. This measurement result reveals that this kiln operation is rather abnormal and has some problems.

6) **Measurement of IDF exhaust gas volume**

Preheater exhaust gas fans (IDF) were installed for (A) and (B) lines, both with same specification as follows:

Specification : 7,900 m^3/min x 1,100 mmAq x 390℃ x 2,300 kW

There is much data on IDF exhaust gas volume measured by APMC, however, these measurement results reveal roughly the same figures and no significant difference compared with the current measurement result is observed.

(3) **Measurement and investigation results of cyclone outlet static pressure and igloss (LOI) of cyclone outlet raw meal**

1) **Cyclone outlet static pressure of measurement**

The measuring result of cyclone outlet static pressure is shown in Table 12-16. Compared with the normal preheater cyclone figure, the temperature and static pressure of each cyclone stage of this plant are high overall. This is due to the modification of production increase from 4,000 t/d to 5,000 t/d at 1993.

As result of measuring the pressure loss of each cyclone stage, we can see that C3 and C4 cyclone pressure loss is high. Conversely, C1 and C2 cyclone pressure loss is rather low owing to the modification of production increase.

2) **Measurement and investigation of igloss (LOI) of cyclone outlet raw meal**

The igloss % of each cyclone stage raw meal was measured and the decarbonation degree of raw meal investigated. Results are shown in Table 12-16.

The decarbonation degree of C4 cyclone raw meal is rather high about 25 percent. This is attributed to the poor collecting efficiency of the C5 (bottom) cyclone.

The result of calculating cyclone collecting efficiency based on the assumed material balance was approximately 66.3 percent.

(4) **Measurement and investigation results of O_2/CO/CO_2 %**

Measurement data of O_2/CO/CO_2 % in the kiln inlet housing, C5 cyclone (A), (B) outlet and IDF (A), (B) inlet are shown in Table 12-17. These measurement results show some differences due to operating conditions, etc., however, they are not so significant.

The recording chart of Fig. 12-9 shows the continuous recording of O_2 % contents in the kiln inlet housing and the C5 cyclone outlet during the energy audit period. We can understand the following points roughly from this chart.

(a) As to O_2 % in the kiln inlet housing, short term fluctuation thereof is around 0.6 – 1.0.and long term fluctuation thereof is approximately 1.4 – 1.6 %

(b) O_2 % in the C5 cyclone outlet changes periodically at an interval of 15 minutes. This fluctuation reveals a somewhat greater range of 0.6 – 2.5 %

(5) Analysis result of kiln feed raw meal and clinker

It is well known that fluctuations in the chemical composition of raw meal greatly affect the heat consumption of clinker. In this kiln, limestone and coal shale as clay materials are fed to the C1 (top) cyclone inlet and F.F furnace, respectively. Therefore, homogeneity in the chemical composition of kiln feed raw meal is important. To investigate this, samples of kiln feed raw meal and clinker were taken at the cooler outlet at 3 minute intervals and their chemical compositions analyzed. Results are shown in Table 12-18.

(6) Measurement of surface temperature

To investigate radiation and convection heat loss from the surface of equipment of in the burning process department, surface temperatures were measured at the measuring points of each piece of equipment, as shown in Fig 12-10,Fig 12-11 and Fig 12-12, respectively.
Measurement results are shown in Table 12-19.
Kiln shell temperature was also measured daily by APMC using an infra-red radiation pyrometer. This measurement data of temperature is shown in Fig 12-13.
On the whole, measurement results of surface temperature were the same as those of a conventional cement plant. However, the somewhat higher surface temperature at the kiln inlet part is worth noting. Calculation results of radiation and convection heat loss based on measuring results are shown in Table 12-21.

(7) Investigation of electricity consumption and unit power consumption of each piece of equipment

Investigated results on electricity consumption and unit power consumption of each department at the APMC works are shown in Table 12-20. Electricity consumption is controlled by month.
This table shows the average data for the past 6 months calculated by monthly report on electricity consumption
The results of unit power consumption for each department are as follows.

Raw Material Department	kWh/t-cli. :	35.33
Burning Department	〃	42.26
Cement Grinding Department	〃	41.26

Others	〃	17.37
Total	〃	136.22 (134.26 kWh/t-cem)

These results reveal roughly the same figures as unit power consumption for the past 6 years shown in Table 12-7. Unit power consumption of this factory is very high compared with that of Japan.

Measurement results of electricity consumption by main equipment and the calculated results of unit power consumption thereof based on measurement data are shown in Table 12-21. Measurement results of the actual electricity consumption of FK pumps and compressors for pneumatic conveyors are shown in Table 12-22.

(8) Investigation of coal shale combustion characteristics

As Table 12-24 shows, instead of clay materials, this factory have utilized coal shale, which has a calorific value of approximately 1000 kcal/kg. This coal shale is fed to the F.F furnace directly, separate from limestone raw meal.

To confirm the combustion characteristics of this coal shale, differential thermal analysis (DTA) and thermogravimetric analysis (TGA) were carried out on the following 2 samples.

(a) Coal shale (Dump shale)

(b) Coal shale blended with a little coal to adjust the calorific value (Mixed shale)

Analysis data are shown in Fig 12-16 and Fig 12-17.

< Results of Differential Thermal and Thermogravimetric Analysis >

(a) Both coal shale samples have minimal moisture content of around 1-2 (%). The loss of moisture content occurred at 80-100℃.

(b) Thermal decomposition of the organic portion occurred at 307.5℃ and 351.9℃ for dump shale and mixed shale, and weight loss due to decomposition were 10 (%) and 8 (%) for dump shale and mixed shale, respectively.

(c) Other carbonaceous residue starts to burn at 400-500℃.

(d) The evaporation of crystalline water from minerals present in the shale occurred at 540-550℃, and crystalline water loss accounted for 3 (%) and 4 (%) in dump shale and mixed shale, respectively.

(e) At 840℃, the mixed shale sample exhibited another endothermic reaction, which was most likely due to decarbonation. And weight loss due to decarbonation was 3 (%) for mixed shale.

(f) At 850℃, the total weight losses of the shale samples were 17 (%) for dump shale and 20 (%) for mixed shale, respectively.

Table 12-14 General Material and Energy Consumption (Measuring term: Sep. 14 – Sep. 19)

Measuring Item / Date		14 / Sep.	15 / Sep.	16 / Sep.	17 / Sep.	18 / Sep.	19 / Sep.
(1) Clinker Production	(t/d)	5,044.76	5,092.0	5,090.21	5,129.49	3,749.66	4,938.57
(2) Heat Consump.	(kcal/kg-cli.)	951.9	975.1	980.6	1,001.1	963.5	954.5
(3) Power Consump.	(kW/t-cem)	--	--	--	--	--	--
(4) Limestone	(t/d)	7,103.0	7,208.0	7,144.0	7,192.0	5,277.0	7,066.0
(5) Coal shale	(t/d)	1,949.0	1,933.0	1,988.0	2,010.0	1,451.0	1,803.0
(6) Fuel Coal	(t/d)	293.13	312.27	326.02	320.82	228.99	322.46
(7) Oil	(kl/d)	49.14	36.07	42.44	64.54	72.74	65.74
(8) Cement Production							
(a) OPC	(t/d)	2,595.02	3,055.66	2,785.06	3,169.0	2,601.7	2,811.61
(b) Walcrete	(t/d)	31.99	228.64	50.1	—	351.85	559.59
(c) Mascrete	(t/d)	28.82	177.8	—	794.34	1,635.26	1,058.96
Total	(t/d)	2,671.83	3,462.10	2,835.16	3,962.43	4,588.81	4,430.16
(9) Gypsum	(t/d)	155.12	124.09	74.1	146.45	196.39	160.96
(10) Limestone	(t/d)	159.55	154.67	102.02	72.0	147.22	216.24
(11) Fly Ash	(t/d)	202.24	78.15	21.81	384.56	272.11	202.13
(12) Electricity *-1	(kW/d)	--	--	--	--	--	--

Note: *-1 .... Daily electricity consumption is not recorded, although monthly consumption is recorded. Table 12-20 shows the electricity consumption and unit consumption of electricity.

Table 12-15 Measurement Results of Air and Exhaust Gas

Measuring Point	Date Time	Area(m^2) D mmϕ	Measuring Equipment (JICA / APMC)	Measuring results			Calculated results	
				Temp. (°C)	P (mmAq)	Velocity (m/s)	Density γ (kg/Nm^3)	m^3/min **Nm^3/min**
(1) Kiln primary air	15/Sep.	① 0.1194 (390) ② 0.099 (355)	Hot-wire Anemometer Model 6162 (JICA)	① 57 ② 33	— —	8.55 8.78		61.2 **50.7** 52.2 **46.5**
(2) F.F furnace Primary air (A) (B)	15/Sep.	(A) 0.0638 (285) (B) 0.0683 (295)	Hot wire Anemometer Model 6162 (JICA)	32 49		32.57 21.35		124.7 **111.6** 87.5 **74.2**
(3) Coal dryer exhaust gas	16/Sep.	0.4301 (740)	Pitot tube flow meter Western type DP-20 (JICA)	99	8.82 (Ps=100mmAq)	(13.3)	1.35	342.5 **249.0**
(4) Coal mill exhaust gas	16/Sep.	0.3019 (620)	— Ditto —	66	19.6 (Ps=700mmAq)	(19.5)	1.35	352.3 **282.0**
(5) Cooler exhaust gas	16/Sep.	14.4347 (3.5 x 4.12)	Pitot tube flow meter L-type QP-20A (c=0.85) (APMC)	354	7.83 (Ps=100mmAq)	(14.1)	1.293	12192.3 **5253.0**
(6) Tertiary air(Recouped air)	16/Sep.	4.416 (2370)	— Ditto —	825	15.57 (Ps=200mmAq)	(26.4)	1.293	6994.9 **1706.0**
(7) IDF exhaust gas (A) (B)	17/Sep.	5.31 (2600) 5.31 (2600)	Pitot tube flow meter Western type DP-20A (JICA)	450 445	55.0 (Ps=986mmAq) 47.0 (PS=918mmAq)	(36.5) (33.8)	1.41	11628.9 **3972.0** 10768.7 **3731.0** **7703.0**

Table 12-16 Measuring Results of Static Pressure of Cyclone Outlet and Ignition Loss (LOI) of Raw Meal

Item / Measuring point	Measured at 5130 (t/d)			Data at 4000 (t/d)		Measured & calculated data		Calculated Cy Collecting Efficiency (%)
	Gas temp. Tg (℃)	Static Press -Ps (mmAq)	ΔP (mmAq)	Static Press -Ps (mmAq)	ΔP (mmAq)	LOI (%) (20 / 5 / 98')	Decarbonation degree (%)	
(1) IDF inlet (A)	437	970	—	890	—	—	—	—
(B)	439	920	—	850	—	—	—	—
(2) C1 cyclone outlet								
(A)	—	—	170	—	190	38.9	—	—
(B)	—	—	150	—	180	39.3	—	—
(3) C2 cyclone outlet								
(A)	644	800	130	700	200	37.9	2.6	—
(B)	645	770	130	670	160	38.8	1.3	—
(4) C3 cyclone outlet			*-1					
(A)	704	670	240	500	120	36.3	6.7	—
(B)	659	640	210	510	90	37.0	5.9	—
(5) C4 cyclone outlet			*-2			27/5/98'		*-3
(A)	803	430	190	380	140	29.2 (28.9)	24.9 (25.7)	**(81.0)**
(B)	792	430	180	420	165	33.7 (28.1)	14.2 (28.5)	
(6) C5 cyclone outlet						17/Sep./98		*-3
(A)	874	240	145	240	(150)	4.6 (2.79)	88.2 (92.8)	**(66.3)**
(B)	878	250	150	255	(160)	3.6	90.8	
(7) F.F. furnace outlet								
(A)	929	(95)	(75)	(90)	—	—	—	—
(B)	919	(100)	(80)	(95)	—	—	—	—
(8) Kiln inlet hood	1021	14-21	—	20	—	—	—	—

Notes: *-1 & *-2 Pressure loss of C3 / C4 cyclones are high.
*-3 Calculation figures based on an assumed material balance

Table 12-17 Measurement and Survey Results of $O_2/CO_2/CO\%$

Measuring place \ Date	17 / Sep.	*-3 15 / Sep.	*-3 7 / Jul.	*-3 23 / June	*-3 19/Nov./97
(1) Kiln inlet hood	*-1				
O_2 (%)	(4.5-5.9)	6.2	—	—	4.4
CO_2 (%)	—	16.6	—	—	12.4
CO (%)	—	—	—	—	—
(2) C5 cyclone outlet	*-1		*-4	*-4	
O_2 (%)	(8.7-9.0)	2.0	2.4 (6.8)	2.0 (3.7)	5.6
(A) CO_2 (%)	—	37.4	33.8	33.6	29.8
CO (%)	—	—	—	—	—
(3) C5 cyclone outlet			*-4	*-4	
O_2 (%)	—	3.0	2.0 (4.3)	2.0 (8.5)	3.2
(B) CO_2 (%)	—	32.0	34.0	32.0	29.4
CO(%)	—	—	—	—	—
(4) IDF inlet	*-2				
O_2 (%)	5.4	5.8	5.8	5.0	7.4
(A) CO_2 (%)	(19.5)	26.0	29.6	29.0	26.2
CO(%)	0.0637	—	—	—	—
(5) IDF inlet	*-2				
O_2 (%)	4.5	5.2	5.6	5.6	6.6
(B) CO_2 (%)	(19.5)	28.0	28.0	27.8	27.0
CO(%)	0.102	—	—	—	—

Notes: *-1 Daily operation record

*-2 Measured by JICA (1) NGK O_2 gas analyzer PA210 (O_2 0-25 vol %)

(2) Shimazu CO/CO_2 gas analyzer CGT-7000

(CO 0-5 vol %, CO_2 0-15 vol %)

*-3 Data measured by Orsat gas analyzer

*-4 Data of C/R indicator

Fig. 12-9 shows the operation record of oxygen content (%) at kiln inlet housing and C5 (bottom) cyclone outlet, respectively.

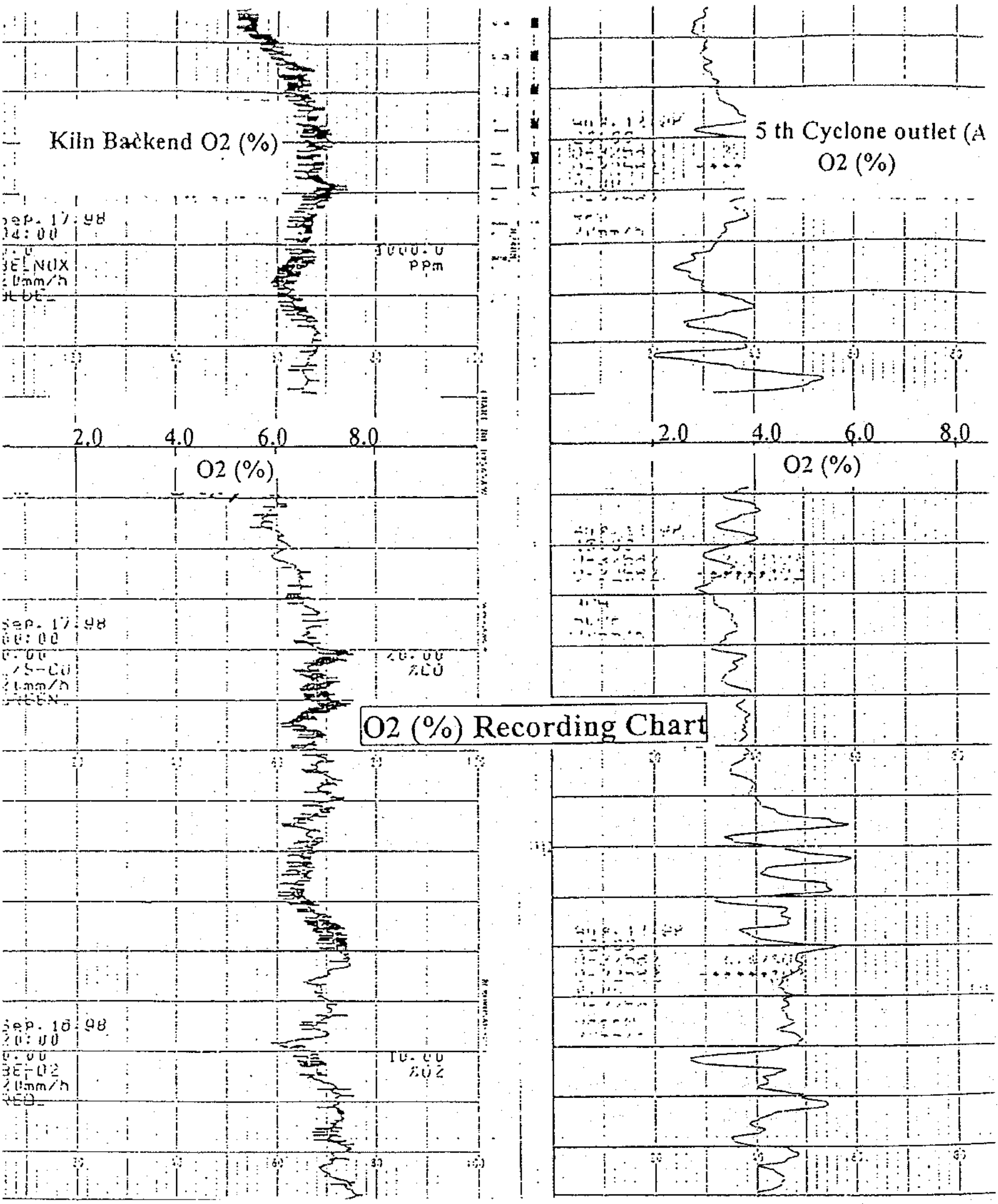


Fig. 12-9 O_2(%) Recording Chart

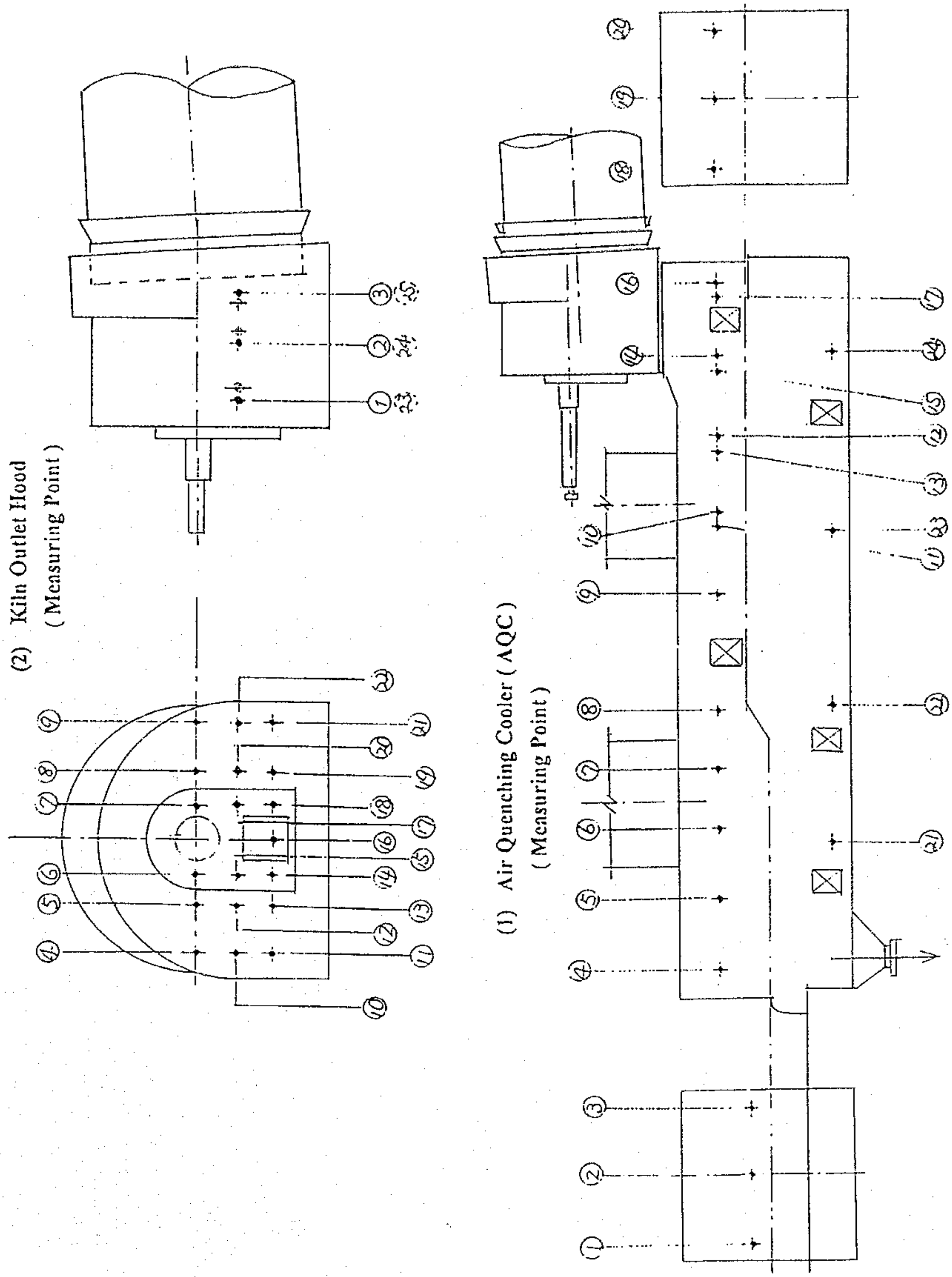


Fig. 12-10 Measuring Points of Surface Temperature
(1) Air Quenching Cooler (AQC) (2) Kiln outlet Hood

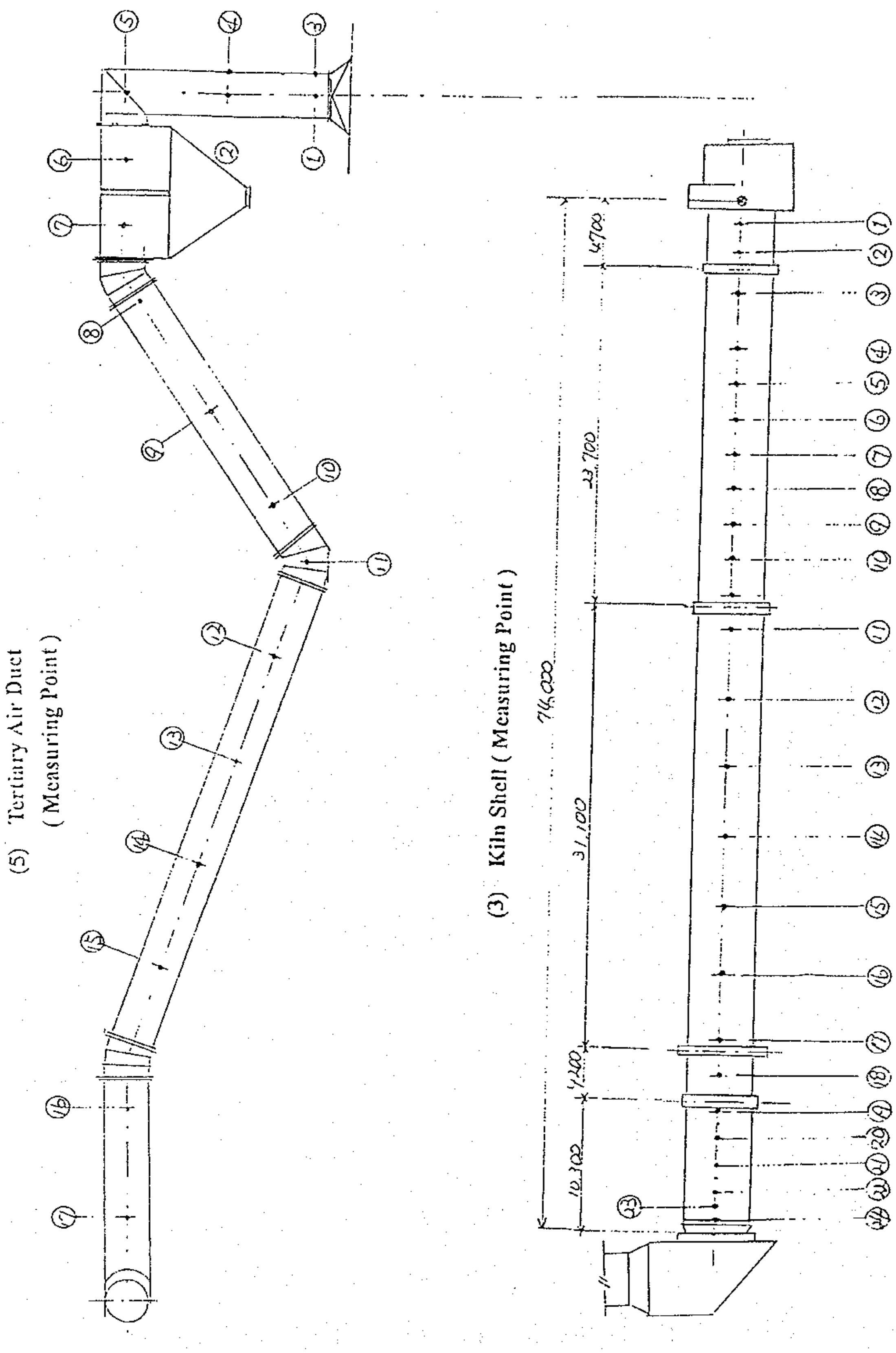


Fig. 12-11 Measuring Points of Surface Temperature

(3) Kiln Shell (5) Tertiary Air Duct

(4) Preheater Cyclone & F.F Furnace
(Measuring Point)

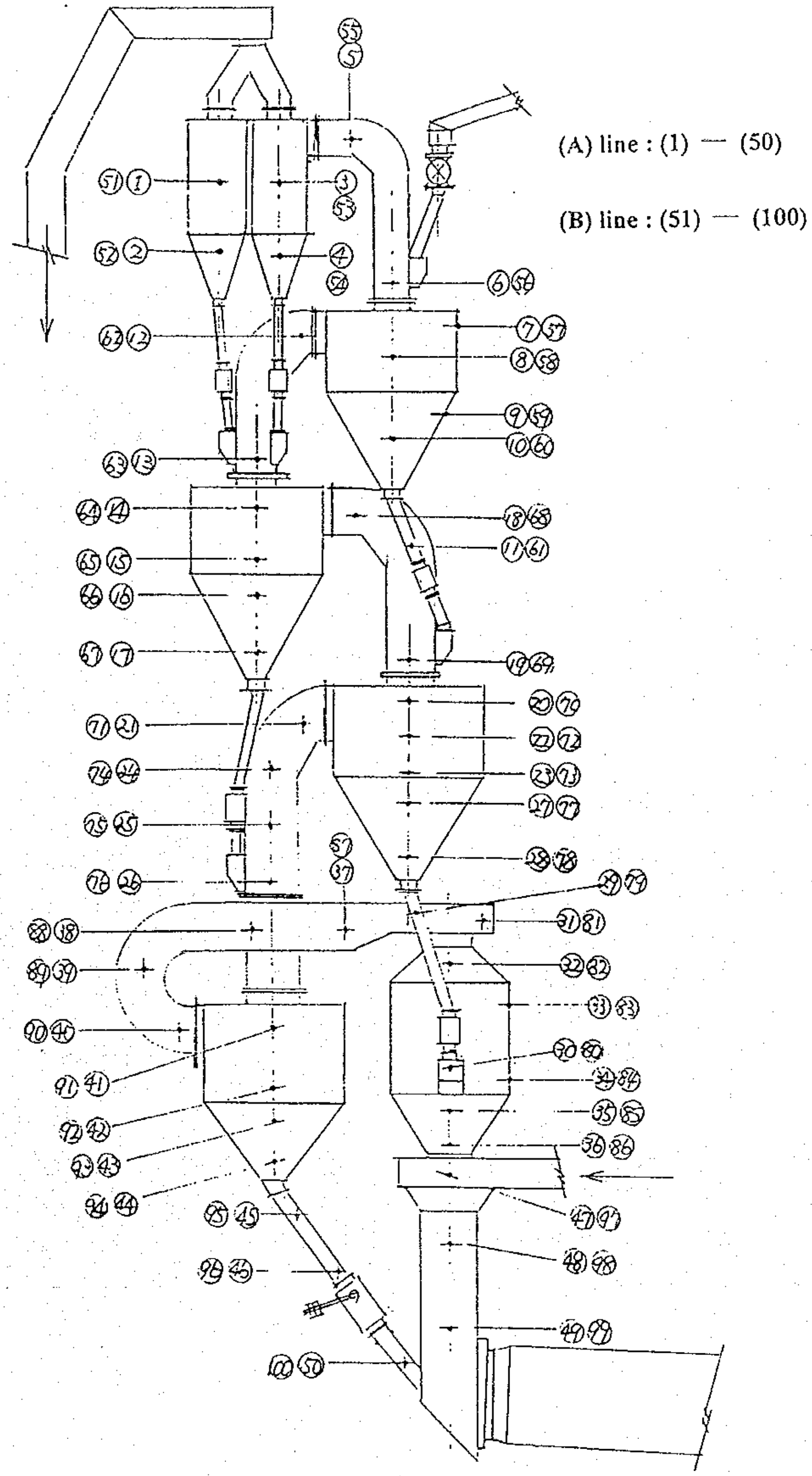


Fig. 12-12 Measuring Points of Surface Temperature
(4) Preheater Cyclone & F.F Furnace

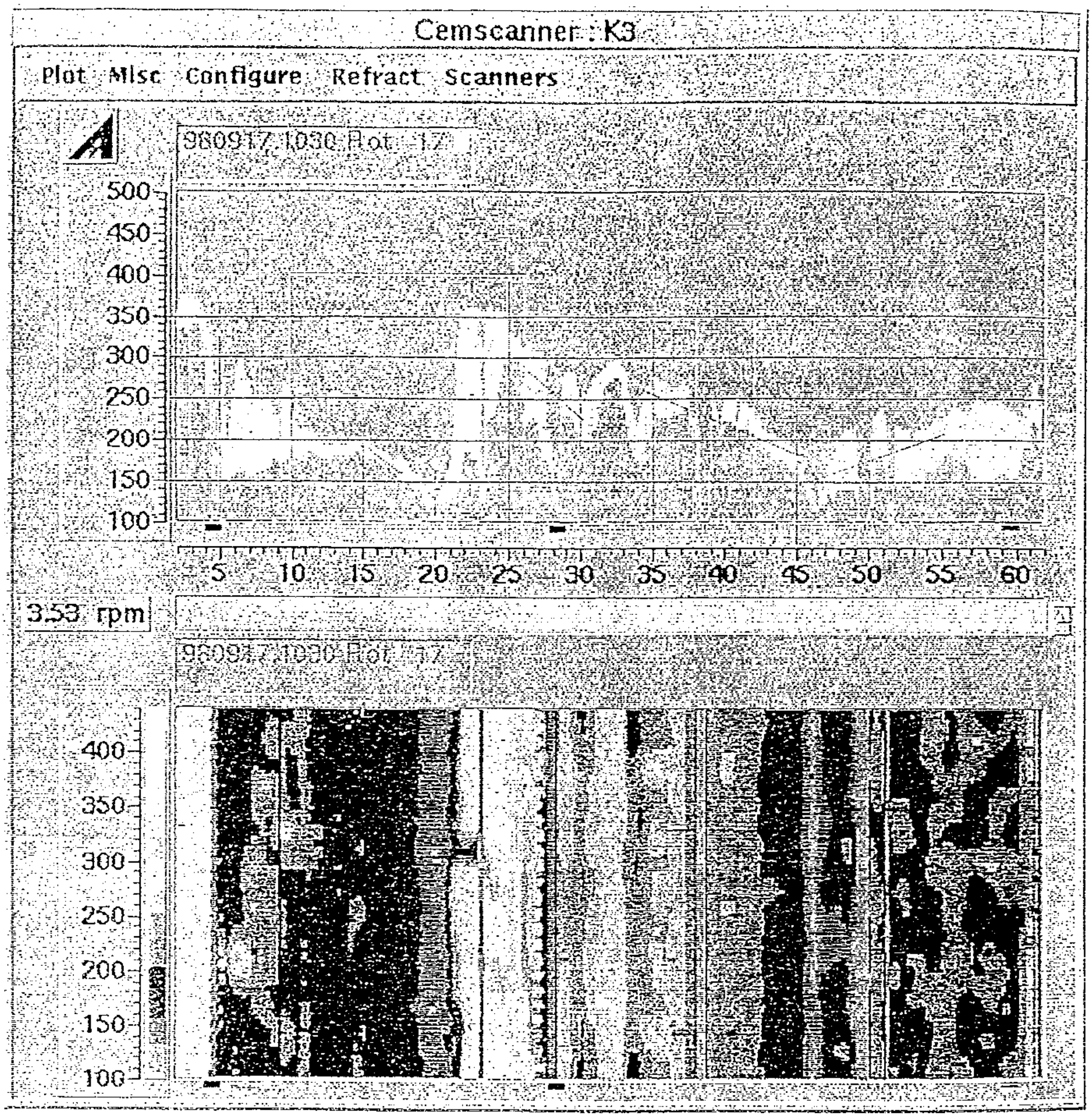


Fig. 12-13 **Measuring Points of Surface Temperature**
(APMC's Data)

Table 12-19 Measuring Data of Surface Temperature

1. AQC Shell Date : 17/Sep e=0.55

No.	1	2	3	4	5	6	7	8
Max.	147.0	116.0	105.0	82.0	76.0	72.0	70.0	47.0
Min.	143.0	114.0	96.0	77.0	73.0	66.0	67.0	40.0
Dif.	4.0	2.0	9.0	5.0	3.0	6.0	3.0	7.0
Ave.	145.8	114.5	104.2	80.5	74.2	69.6	69.6	43.3

No.	9	10	11	12	13	14	15	16
Max.	87.0	138.0	49.0		232.0	99.0	311.0	150.0
Min.	61.0	101.0	40.0		202.0	75.0	222.0	56.0
Dif.	26.0	37.0	9.0		30.0	24.0	89.0	94.0
Ave.	86.0	109.8	47.2		209.3	85.5	278.8	128.6

No.	17	18	19	20	21	22	23	24
Max.	176.0	112.0	84.0	147.0	63.0	41.0	47.0	54.0
Min.	96.0	69.0	77.0	129.0	62.0	39.0	39.0	48.0
Dif.	80.0	43.0	7.0	12.0	1.0	2.0	8.0	6.0
Ave.	128.5	80.4	72.2	131.9	62.9	40.8	44.8	48.8

2. Kiln Outlet Hood Shell Date : 17/Sep e=0.55

No.	1	2	3	4	5	6	7	8
Max.	160.0	174.0	134.0	110.0	145.0	179.0	184.0	210.0
Min.	144.0	157.0	96.0	95.0	96.0	74.0	122.0	159.0
Dif.	16.0	17.0	38.0	15.0	47.0	105.0	62.0	51.0
Ave.	139.0	166.9	107.8	106.0	135.3	128.7	170.1	180.4

No.	9	10	11	12	13	14	15	16
Max.	145.0	157.0	138.0	245.0	199.0	190.0	201.0	159.0
Min.	111.0	115.0	99.0	172.0	171.0	161.0	90.0	127.0
Dif.	34.0	42.0	39.0	73.0	28.0	29.0	111.0	32.0
Ave.	129.4	126.7	122.2	211.0	190.5	175.5	117.2	139.5

No.	17	18	19	20	21	22	23	24
Max.	180.0	126.0	394.0	273.0	170.0	184.0	149.0	183.0
Min.	136.0	97.0	134.0	246.0	117.0	159.0	143.0	146.0
Dif.	44.0	29.0	260.0	27.0	53.0	25.0	6.0	37.0
Ave.	144.1	121.8	267.7	258.8	163.8	162.5	143.9	175.0

No.	25							
Max.	161.0							
Min.	131.0							
Dif.	30.0							
Ave.	139.5							

Measuring equipment
(1) Pocket Thermometer Model 2542
(2) Radiation thermometer RT-70((-30-1200C)

3. Kiln Shell Date : 18/Sep e=0.9

No.	1	2	3	4	5	6	7	8
Max.	171	261	192	182	144	144	130	107
Min.	153	218	147	156	136	128	122	87
Dif.	18	43	45	26	8	16	8	20
Ave.	164.2	232.6	163.2	167.3	134.7	140	125.1	99.8

No.	9	10	11	12	13	14	15	16
Max.	280	300	174	196	233	164	192	179
Min.	145	249	169	154	196	144	142	121
Dif.	135	51	9	42	37	20	50	58
Ave.	214.4	276	174.3	169.6	209.5	150.5	174.1	148

No.	17	18	19	20	21	22	23	24
Max.	167	234	131	138	205	236	231	234
Min.	131	210	100	94	181	206	212	211
Dif.	36	24	31	44	24	30	19	20
Ave.	145.7	223.6	115.8	103.4	192.8	212.5	222	224.5

4. Pre - Heater Date : 18/Sep e=0.55

No.	1	2	3	4	5	6	7	8
Ave.	65.5	35.9	79.0	37.4	209.1	176.0	99.5	121.3

No.	9	10	11	12	13	14	15	16
Ave.	99.1	140.5	167.7	130.3	95.2	127.3	153.6	105.5

No.	17	18	19	20	21	22	23	24
Ave.	143.5	144.6	92.0	103.9	94.0	86.0	118.5	143.0

No.	25	26	27	28	29	30	31	32
Ave.	107.0	131.5	127.0	129.0	120.0	118.0	132.0	122.0

No.	33	34	35	36	37	38	39	40
Ave.	100.0	94.0	157.0	111.0	98.5	112.0	133.0	103.0

No.	41	42	43	44	45	46	47	48
Ave.	147.0	148.0	118.0	142.0	176.0	166.0	73.0	181.0

No.	49	50	51	52	53	54	55	56
Ave.	191.0	112.0	45.9	54.6	38.9	47.6	144.3	173.4

No.	57	58	59	60	61	62	63	64
Ave.	119.1	109.9	81.1	112.5	137.1	122.0	130.9	124.0

No.	65	66	67	68	69	70	71	72
Ave.	165.5	114.5	156.5	122.5	106.5	90.6	116.7	103.5

No.	73	74	75	76	77	78	79	80
Ave.	133.0	201.0	202.5	210.5	127.7	135.7	120.0	118.0

No.	81	82	83	84	85	86	87	88
Ave.	100.5	170.0	104.0	94.0	175.0	133.0	125.0	94.0

No.	89	90	91	92	93	94	95	96
Ave.	157.0	103.0	147.0	148.0	192.0	162.0	172.0	182.0

No.	97	98	99	100				
Ave.	65.0	161.0	200.0	160.0				

5. Tertiary air duct Date : 18/Sep e=0.55

No,	1	2	3	4	5	6	7	8
Ave	118	114	101	124	136	114	112	82

No.	9	10	11	12	13	14	15	16
Ave.	86	121	110	96	98	99	134	104

No.	17	18	19	20	21	22	23	24
Ave.	101							

Table 12-20 Electricity Consumption and Unit Consumption of Each Plant

Year/Month : Average of 6 months (Mar.'98-Aug.'98)

Plant / Process	Electricity Consump. [mWh]	Production [ton]	Run hours [h]	Unit Consump. [kWh/t]	Mill drive Electricity [mWh]	Mill unit Consump. [kWh/t]
1) L/Stone Crusher	340.07					
2) Limestone Grinding	2,581.49	137,260		18.81	1,811.5	13.20
3) Roller Press	649.07	50,290		12.91		
4) Shale grinding	975.06	48,518		20.10	949.0	19.56
5) Raw meal blending	403.81	222,289		1.82		
(1+2+3+4+5) Sub-total	4,949.49	140,085		**35.33**		
5) Preheater & kiln	2,944.18		674.67	21.02		
7) Coal firing & Intake plant	462.02			3.30		
8) Clinker cooler & Handling	1,502.91			10.73		
9) E/P & Gas conditioning	1,011.28			7.22		
(6+7+8+9) Sub-total	5,920.38	140,085		**42.26**		
10) Cement mill 1	600.58	13,205	568.69	45.48	481.15	36.44
11) Cement mill 2	647.16	16,932	630.82	38.22	539.25	31.85
12) Cement mill 3	586.84	15,439	596.99	38.01	486.79	31.53
13) Cement mill 4	1,739.55	43,824	642.96	39.69	1,397.80	31.58
14) Cement mill 5	1,849.92	44,136	641.61	41.91	1,386.33	31.41
15) Cement mill 6	359.03	8,506	556.31	42.21	261.09	30.69
(10+11+～+15) Sub-total	5,779.76	142,042		**41.26**		
16) Others	2,432.88	140,085		17.37		
17) Total	19,070.35	140,085 142,042		**136.22 kWh/t-cli.** **134.26 kWh/t-cem**		

Table 12-21 Measurement of Electricity for Main Equipment (Mill)

Measuring instrument : Integrated Watt hour meter

Mill	Date	Time	Watt hour meter Reading kWh	Electricity kWh/h [kWh/t]	Remarks Grinding Cap.
(1) No.1 Limestone mill	16/Sep.	10:15	2,638,500		
		11:15	2,640,200	1,700.00	
		12:16	2,642,000	1,770.49	
			Average	1,735.25 [7.5]	(231.5 t/h)
(2) No.2 Limestone mill	16/Sep.	10.16	3,253,100		
		11.16	3,254,700	1,600.00	
		12.16	3,256,500	1,800.00	
			Average	1,700.00	—
(3) Shale mill	16/Sep.	10.17	2,009,400		
		11.16	2,010,700	1,322.03	
		12.17	2,012,200	1,475.41	
			Average	1,398.72 [14.9]	(93.93 t/h)
(4) Roller press	16/Sep.	10:19	39,594,100		
		11:17	39,595,000	931.03	
		12:18	39,596,300	1,278.69	
			Average	1,104.86 [11.2]	(98.43 t/h)
(5) Preheater main fan A	16/Sep.	11:20	3,276,500		
		12:18	3,278,400	1,838.71	
		14:20	3,282,500	2,016.39	
			Average	1,927.55 [9.1]	(212.5 t/h)
(6) Preheater main fan B	16/Sep.	11:20	9,035,900		
		12:18	9,037,600	1,758.62	
		14:21	9,041,300	1,804.88	
			Average	1,781.75 [8.4]	—
(7) Kiln drive	16/Sep.	11:32	567,810		
		12:22	568,130	384.00	
		14:25	568,880	365.85	
			Average	374.93 [1.76]	—
(8) Coal grinding plant	16/Sep.	10:36	163,300		
		11:45	164,150	739.13	
		12:34	164,800	795.92	
			Average	767.53 [49.6]	(15.47 t/h)
(8) No.1 Cement mill	—	—	Average	—	—
(9) No.2 Cement mill	16/Sep.	10:28	874,140		
		11:28	875,090	802.82	
		12:28	875,765	794.12	
			Average	798.47 [36.1]	(22.11 t/h)

Mill	Date	Time	Watt hour meter Reading kWh	Electricity kWh/h [kWh/t]	Remarks Grinding Cap.
(10) No.3 Cement mill	18/Sep.	17:00	Average	800[kW]	—
(11) No.4 Cement mill	18/Sep.	17:00	Average	2130[kW]	—
(12) No.5 Cement mill	16/Sep.	10:26	247,148,000		
		11:36	247,150,000	2,000.00	
		12:29	247,152,400	2,716.98	
			Average	2,358.49 [35.5]	(62.86 t/h)
(13) No.6 Cement mill	16/Sep.	10:30	72,988,200		
		11:40	72,990,300	1,800.00	
		12:30	72,991,900	1,920.00	
			Average	1,860.00[124.1]	(14.91 t/h)

Table 12-22 Measurement of Electricity for Pumps and Compressors

Measuring Instrument : Clamp on power tester

Equipment	Rated [kW]	V1 *-1 [V]	V2 *-1 [V]	I1 *-2 [A]	I2 *-2 [A]	Electric-ity [kW]	P.F *-3	F *-4 [Hz]
(1) Shale mill FK pump	--	396.27	397.10	77.44	71.77	38.14	0.774	49.96
(2) Shale mill Compressor	190	3,131.0	3128.7	28.45	28.50	145.9	-0.947	49.94
(3) Coal dryer	--	402.70	402.67	0.772	0.726	0.308	0.999	49.98
(4) Coal blower to Kiln	75	396.85	397.19	52.97	52.49	26.72	0.739	49.94
(5) Coal blower to F.F (A-1)	18.5	397.35	397.21	20.49	20.45	11.75	0.833	49.94
(6) Coal blower to F.F (A-2)	18.5	397.56	397.35	20.83	20.79	11.93	0.833	49.92
(7) Coal blower to F.F (B)	18.5	396.06	395.45	19.56	18.84	13.19	0.992	49.96
(8) No.1 Cement FK Pump	--	--	--	--	--	--	--	--
(9) Ditto Compressor	160	--	--	--	--	--	--	--
(10) No.2 Cement FK Pump	--	413.54	413.36	58.88	60.46	38.38	0.895	50.02
(11) Ditto Compressor	162	413.42	413.15	155.13	156.25	76.17	0.683	49.98
(12) No.3 Cement FK pump	--	415.53	415.80	120.29	120.54	72.34	0.835	49.96
(13) Ditto Compressor	150	413.98	414.91	152.92	177.54	89.49	0.736	49.96
(14) No.4 Cement FK pump	--	423.18	424.21	205.92	204.27	125.12	0.826	49.97
(15) Ditto Compressor	190	423.36	424.28	212.00	219.59	115.50	0.731	49.98
(16) No.5 Cement FK pump	--	440.25	440.52	174.47	173.75	77.68	0.585	49.94
(17) Ditto Compressor	260	3,400	3,400	53.00	52.00	215.00	0.695	
(18) No.6 Cement FK pump	--	417.65	417.62	60.67	59.79	21.19	0.487	49.90
(19) Ditto Compressor	150	417.17	417.77	228.4	227.19	109.26	0.663	49.94
(20) Shale LIW compressor (A)	160	393.01	393.33	193.69	197.82	110.42	0.842	49.96
(21) Shale LIW compressor (B)	160	393.85	393.75	159.03	157.64	100.22	0.929	49.97
(22) Shale LIW FK pump (A)	--	393.24	393.53	47.18	47.51	17.96	0.555	49.88
(23) Shale LIW FK pump (B)	--	392.58	392.72	45.46	44.87	25.61	0.855	50.02

Notes: *-1 V1 : Voltage 1 V2 : Voltage 2 *-3 P.F : Power Factor
*-2 I1 : Current 1 I2 : Current 2 *-4 F : Frequency

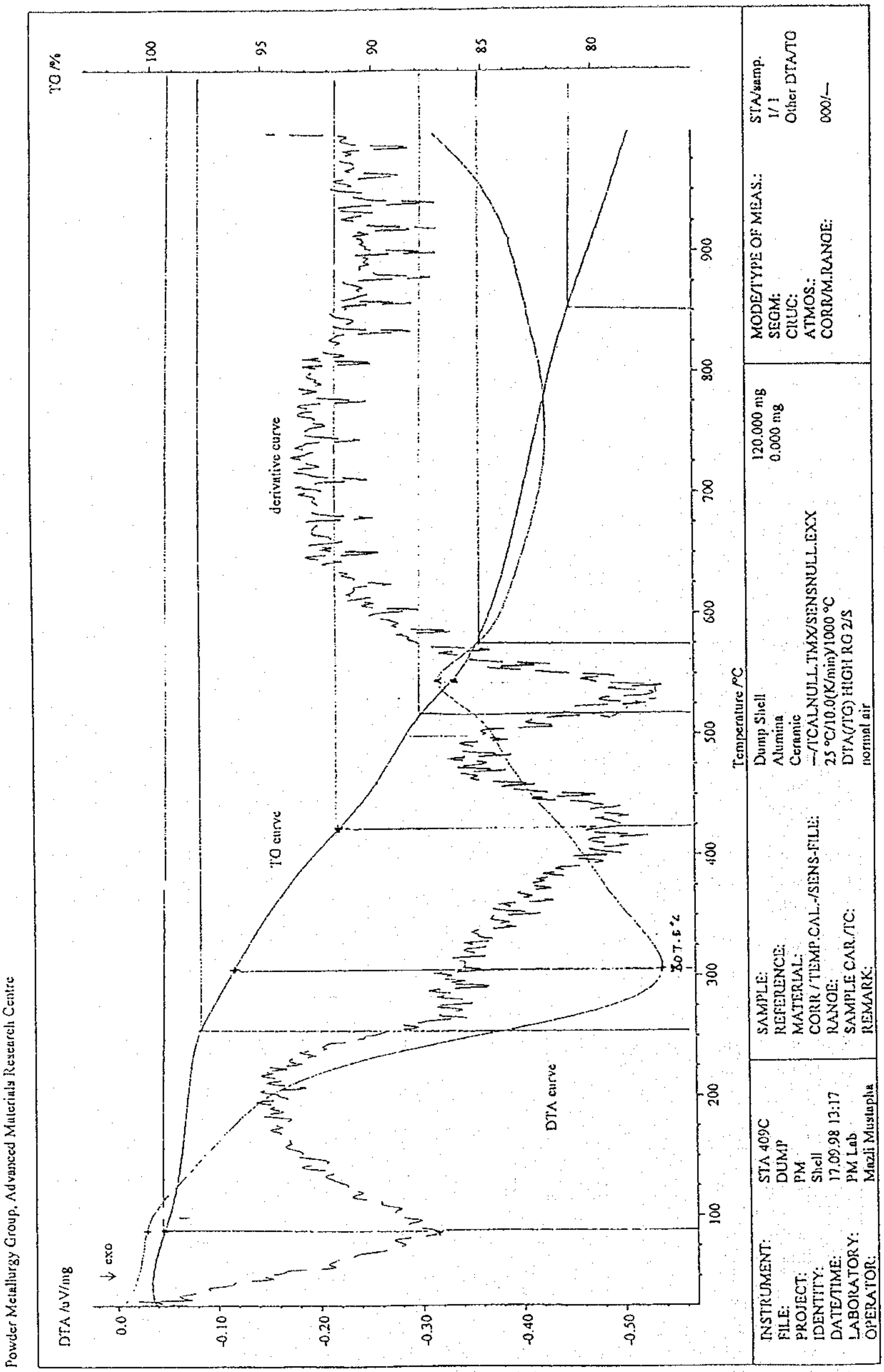


Fig. 12-16 Thermal Analysis of Dump Shale

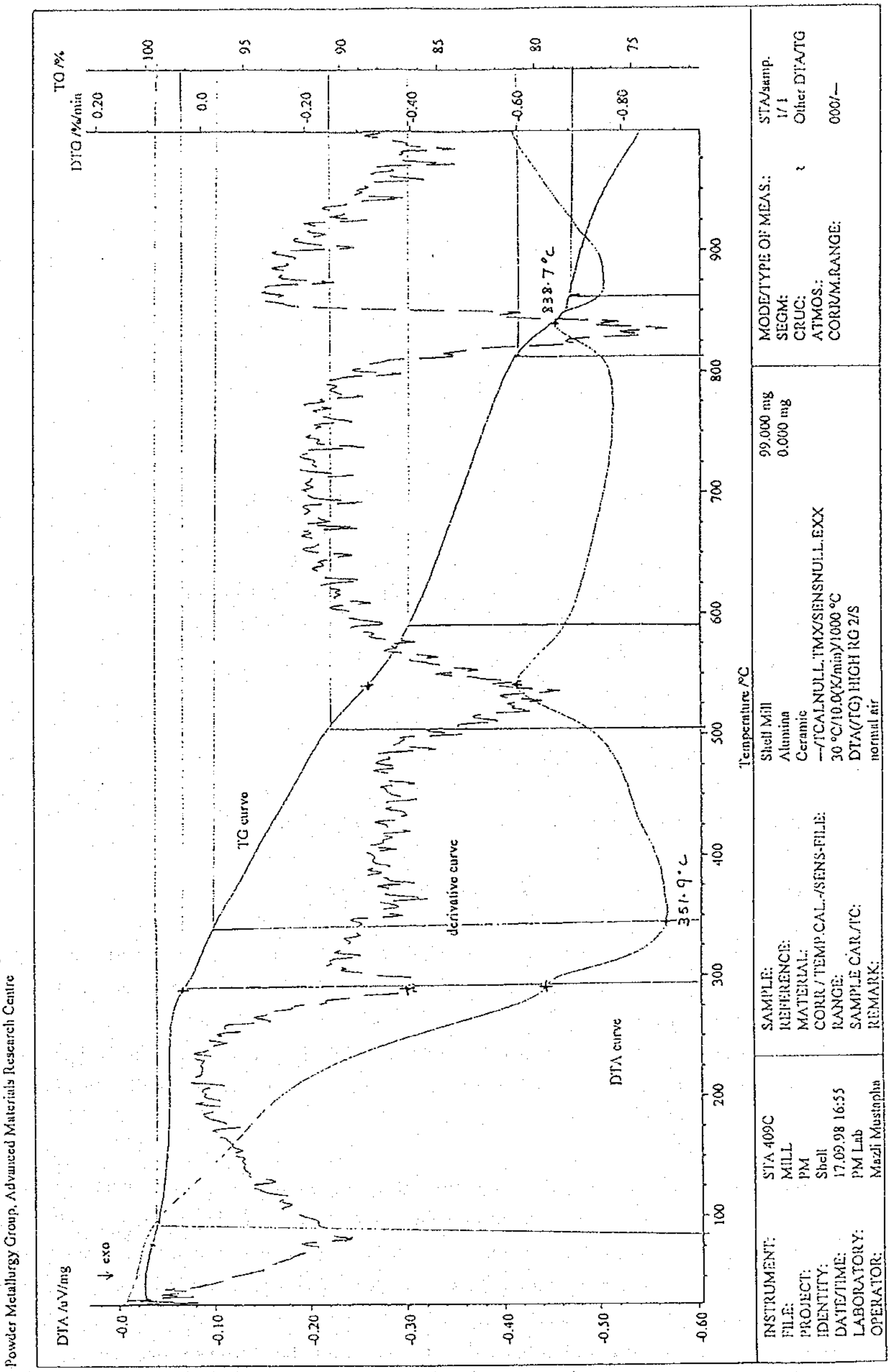


Fig. 12-17 Thermal Analysis of Mixed Shale

12-9-2 Long Term Operation Records

The first step in investigation the energy efficiency of cement works is to confirm long-term operation records. At the same time, it is important to reconfirm existing data that has been surveyed and/or measured by works engineers in the plant.
For these reasons, operational data for the past six years was collected and investigated at the first energy audit. Please refer to Chapter 12-3 "Outline of Operating Condition" and the following attached tables for details on trends in the aforementioned records of operation.

Table 12-1	Trends in annual sales amount
Table 12-2	Trends in the production output of clinker and operation hour per annum
Table 12-3	Trends in production output of raw meal and operating hours per annum
Table 12-4	Trends in production output of cement and operation hour
Table 12-5	Chemical analysis of raw meal (Limestone and Shale) in 1997
Table 12-6	Chemical composition and physical properties of cement / clinker
Table 12-7	Trends in annual energy consumption and unit consumption
Table 12-8	Annual energy consumption (1997)
Table 12-9	Relative comparison of energy consumption (1997)
Table 12-10	Malaysia APMC Rawang Works data

12-9-3 Calculations Based on Measurements and Operating Results

(1) Combustion conditions of fuel in the F.F furnace

In the cement manufacturing process, all kind of fuels burn in the burning department and are consumed as heat energy. Normally, in the NSP kiln, 55-60 (%) of total fuel feeds and burns in the precalciner installed in the preheater tower, which is the heart of plant.
In this works, however, approximately 80-82 (%) of fuel feeds and burns in the F.F furnace. Therefore, the favorability of fuel burning conditions in the F.F furnace significantly affect heat energy consumption.

Yet as Chapter 12-9 ((2) - 5) shows, the measurement result of recouped air volume was low, at approximately 60-65 (%) of theoretical combustion air volume. Judging from this result, around 35-40 (%) of fuel feeds to the kiln as unburned fuel mixed with raw meal inside the C5 cyclone. To confirm this, samples of kiln feed raw meal were taken, their calorific value measured, and their unburned carbon content estimated.

1) Measurement results of unburned carbon content in kiln feed raw meal

(a) Method : Measurement of the calorific value of C5 cyclone outlet raw meal (kiln feed raw meal)

(a) Measuring Apparatus : Bomb calorimeter

(b) Sampling : 16, Sep C5 (A) line, 19, Sep C5 (A),(B) line

(c) Results : C5 cyclone (A) line : 147 kcal/kg, 191 kcal/kg

(B)line : — 300 kcal/kg

Average calorific value of kiln feed raw meal : 213 kcal/kg

2) Calculation of unburned carbon content

(a) Total heat intake Hi (kcal/kg-cli.) of F.F furnace

Oil:	5.7 kl/h →	139.7 kcal/kg-cli.
Coal:	8.6 t/h →	252.9 kcal/kg-cli.
Coal shale:	77.6 t/h →	374.0 kcal/kg-cli.
Total		Hi = 766.6 kcal/kg-cli.

(b) Total calorific value of kiln feed raw meal Hf (kcal/kg-cli.)

Hf = 1,260 kg/kg-cli. x 213 kcal/kg = 268 kcal/kg-cli.

(c) Unburned carbon content w (%)

w = Hf / Hi = 0.3496 → about 35 (%)

3) Rough material balance — C5 cyclone and F.F furnace —

4) Calculation of (Gas) retention time of F.F furnace

According to the following figures, retention time is calculated based on the calculated inner volume of the F.F furnace and trunk duct.

(a) Inner volume of F.F furnace : V = 830.8 m^3

(b) F.F furnace outlet gas temperature : tg = 930-950 °C

(c) Volume of exhaust gas from kiln : Gk = 988 Nm^3/min

(d) Volume of exhaust gas in F.F furnace : Gf = 6482 Nm^3/min

combustion gas → 5312 Nm^3/min

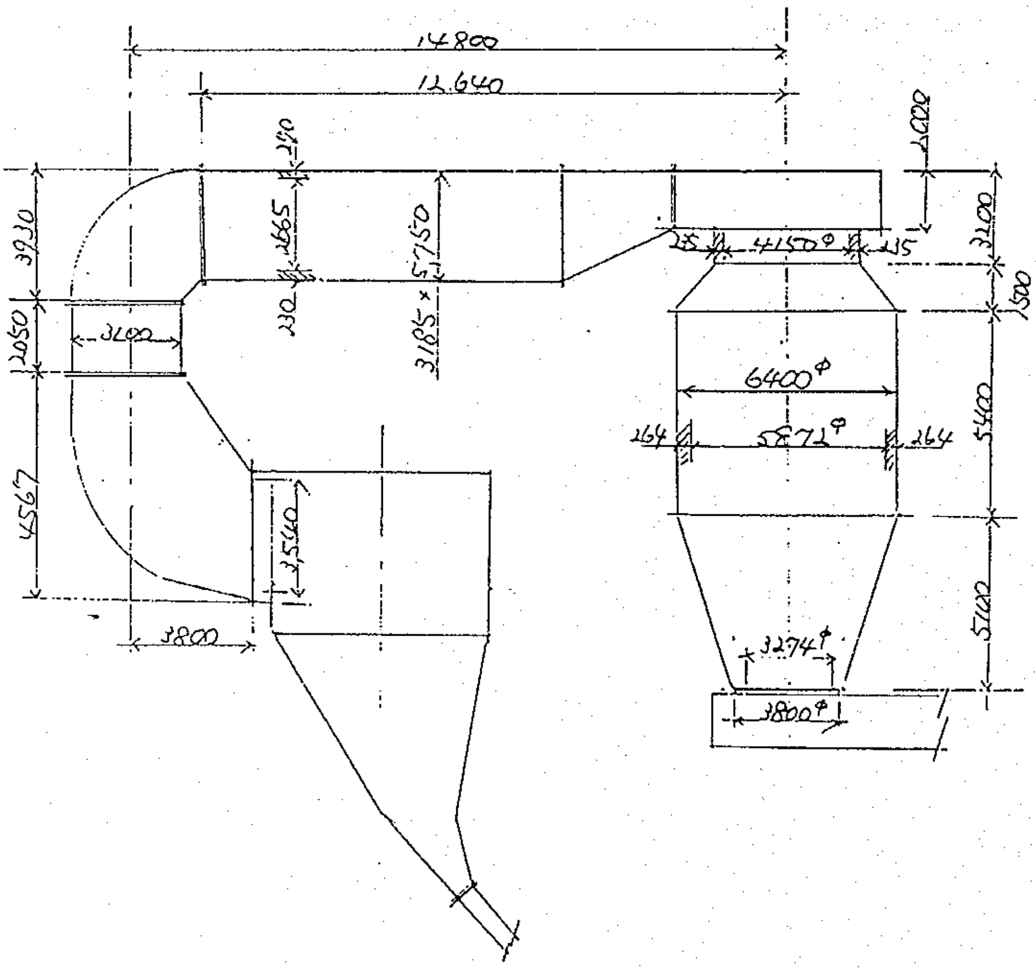
$V_{H2O} + V_{CO2}$ → 41 + 1129 = 1170 Nm^3/min

Total gas volume : G = 7470 Nm^3/min → calculate by 7188 Nm^3/min

(e) Retention time T (sec) **T** = V (m^3) / G (m^3/s) = **1. 53 (sec)**

Considering the burning of pulverized coal, the above retention time is somewhat short.

<Outline drawing including size of F.F furnace and Trunk duct>



(2) Calculation of radiation and convection heat loss

In heat balancing thus far, heat loss from the shell has been treated as a part of miscellaneous heat loss that is considered as the difference from the thermal input. Miscellaneous heat loss varies greatly according to the case since it includes heat loss due to kiln operation.
If an approximate value of heat loss from the shell is obtained, the true value of miscellaneous heat loss can also be obtained. This allows such defects as misoperation or mismeasurement to be estimated, and the value of heat balancing to be understood.
As for the method of measuring the amount of heat dissipation, a heat flow-meter, a remarkable instrument developed recently, is convenient and provides accurate measurement, however, heat loss was calculated this time using a radiation thermometer to measure surface temperature.

[Relating to radiation heat and convection heat from kiln]

The general formula relating to heat dissipation from the kiln shell is as follows :

$$Q = \Sigma F \cdot \alpha \ (ts - ta)$$

Where, Q : total heat released per 1 hour (kcal/h) {kJ/h}
F : surface area per section (m^2)
α : heat transfer coefficient from surface (kcal/h) {kJ/h}
ts : surface temperature of shell (℃)
ta : outside air temperature (℃)

α is the total of convection transfer coefficient and radiation coefficient, and varies to some degree according to the literature.
To obtain radiation heat and convection heat, the following formula is usually given.
<Radiation heat loss>

$$Hr = \varepsilon \ \alpha \ T^4 \quad (kcal / m^2h)\{ kJ / m^2h \}$$

ε : Emissivity
α : Stefan-Boltzmann constant 4.9×10^{-8}
T : absolute temperature (K) (273 + t ℃)

<Convection heat loss>

$$Hc = C \times 1.66 \times (t - ts)^{5/4} \quad (kcal / m^2h)\{ kJ / m^2h \}$$

t : surface temperature of radiator (℃)
ts : outside air temperature (℃)
C : constant of convection loss (depending on state of surface)
In the case of a vertical surface in still – air : C = 1.0
In the case of a horizontal cylinder 1 m or more in length: C = 1.2

Using the above formula, heat loss is calculated based on the measurement results of surface temperature shown in Table 12-19. Calculation results are shown in Table 12-23.

Table 12-23 Calculating Results of Radiation and Convection Heat Loss

[A] Operating condition ; Limestone = 7,192 t/d, Coal shale = 2,010 t/d Clinker production = 5,130 t/d
Fuel oil = 64.54 kl/d Fuel coal = 320.82 t/d Heat consumption = 980.6 kcal/kg-cli.

[B] Calculating condition ; Assumption of emissivity ; e = 0.9 (kiln shell), e = 0.55 (cooler / preheater / tertiary duct)
Coefficient of convection loss C= 1.2 (kiln/tertiary air duct), 1.0 (cooler/preheater cyclone/ etc.,)
Atmospheric temperature = 35ºC
Radiation heat loss ; $Hr = 4.9x10^{-8} \cdot e \cdot A \cdot (T^4 - Ts^4)$
Convection heat loss ; $Hc = C \cdot 1.66 x (T - Ts)^{5/4}$

Measuring place	Surface Area (m^2)	Ave surface Temp (℃)	Hr (kcal / m^2h)	Hc (kcal / m^2h)	Hr + Hc		H (10^3 kcal/kg-cli)
					(kcal / m^2h)	(kcal / h)	
[A] Kiln Part							
Kiln hood	186.1	157	678.8	807.8	1,486.6	276,656.3	1.29
Kiln shell 0 – 5 (m)	86.75	320 (198)	5,061.0	2,332.6	7,393.6	641,394.8	
5 – 10 (m)	86.75	210 (165)	2,007.6	1,267.9	3,275.5	284,149.6	
10 – 15 (m)	86.75	190 (138)	1,634.1	1,089.4	2,723.5	236,263.6	
15 – 25 (m)	173.5	210 (179)	2,007.6	1,267.9	3,275.5	568,299.3	
25 – 35 (m)	173.5	250 (172)	2,907.0	1,640.0	4,547.0	788,904.5	
35 – 45 (m)	173.5	225 (180)	2,320.0	1,405.2	3,725.2	646,322.2	
45 – 55 (m)	173.5	180 (163)	1,464.6	1,002.3	2,466.9	428,007.2	
55 – 65 (m)	173.5	210 (173)	2,007.6	1,267.9	3,275.5	568,299.3	
65 – 74 (m)	156.15	220 (179)	2,212.7	1,359.1	3,571.8	557,736.6	
Sub-total	1,283.9	224 (172)	—	—	—	4,719,377.1	22.08
[B] Cooler Part							
Cooler ceiling / under kiln hood	186.9						
Cooler both side walls	524.4						
Cooler front / back side walls	94.0						
Sub-total	805.3	118	390.1	415.9	806.0	648,991.2.	3.04
[C] Tertiary Air Duct		143	567.3	693.5	1,260.8	65,561.6	
Outlet duct / dust chamber	202.0	113	358.5	461.8	820.3	123,045.0	
Tertiary air duct	704.0	110	340.0	439.7	779.8	548,979.2	
Sub-total	906.0	(122)	—	—	—	737,585.8	3.45

Measuring place	Surface Area (m^2)	Ave surface Temp (℃)	Hr ($kcal / m^2h$)	Hc ($kcal / m^2h$)	Hr + Hc ($kcal / m^2h$)	Hr + Hc (kcal / h)	H ($10^3 kcal$ / kg-cli)
[D] Preheater cyclone							
(1) Top cyclone (A) Inlet duct	118.8	193	1031.0	1,115.9	2,146.9	255051.7	
Body / chute	357.1	55	72.1	84.3	156.4	55850.4	
(2) Top cyclone (B) Inlet duct	118.8	159.	698.8	824.3	1,523.1	180,944.3	
Body / chute	357.1	47	42.8	44.5	87.3	31,174.8	
(3) C2 cyclone (A) Inlet duct	150.7	113	358.5	461.8	820.3	123,619.2	
Body / chute	187.5	126	443.2	559.9	1,003.1	188,081.3	
(4) C2 cyclone (B) Inlet duct	150.7	126	443.2	559.9	1,003.1	151,167.2	
Body / chute	187.5	112	352.3	454.4	806.7	151,256.3	
(5) C3 cyclone (A) Inlet duct	98.0	118	390.1	499.0	889.1	87,131.8	
Body / chute	188.6	133	492.4	614.2	1,106.6	208,704.8	
(6) C3 cyclone (B) Inlet duct	98.0	115	371.0	476.6	847.6	83,064.8	
Body / chute	188.6	140	544.2	669.5	1,213.7	228,903.8	
(7) C4 cyclone (A) Inlet duct	167.1	119	396.5	506.6	903.1	150,908.0	
Body / chute	297.1	115	371.0	476.6	847.6	251,822.0	
(8) C4 cyclone (B) Inlet duct	167.1	183	925.4	1,028.3	1,953.7	326,463.3	
Body / chute	297.1	118	390.1	499.0	889.1	264,151.6	
(9) C5 cyclone (A) Body / chute (Bottom cyclone)	272.0	144	575.1	701.6	1,276.7	347,262.4	
(10) C5 cyclone (B) Body /chute (bottom cyclone)	272.0	166	761.1	882.8	1,643.9	447,140.8	
(11) Trunk duct (Outlet duct of F.F furnace)	380.4	116	377.3	484.1	861.4	327,676.6	
(12) F.F Furnace (A) line	245.0	117	383.6	491.5	875.1	214,399.5	
(B) line	245.0	135	506.9	629.9	1,136.8	278,516.0	
(13) Rising Duct (include kiln inlet hood)	227.1	186	956.4	1,054.4	2,010.8	456,652.7	
Sub-total	4,771.3	(129)	—	—	—	4,809,943.3	22.51
Total	7,952.5	—	—	—	—	11,192,552.0	**52.38**

Radiation and convection heat loss varies according to kiln production capacity. Therefore, the following table shows heat dissipation loss in comparison with the typical data of kilns in Japan with the same production capacity.

[Unit : kcal / kg-cli.]

Kiln / Items	APMC (5000 t/d Capacity)	Typical Example (4000 t/d Capacity)	Typical Example (5000 t/d Capacity)
Kiln	22.1	26.4	24.8
Preheater (Incl. Precalciner)	22.5	19.1	18.0
Cooler, Kiln hood Recouped air duct	7.8	8.4	7.0
Total	52.4	53.9	49.8

By calculating radiation and convection heat loss based on the measurement data of surface temperature, the following results are obtained.

a) About 52.4 kcal/kg-cli. of radiation and convection heat loss from the burning facility of this factory represents an average figure for a cement plant.

b) Judging from the above table, heat dissipation loss from the kiln shell is rather low, but, that from the preheater part is rather high.

c) However, the kiln surface temperature at the kiln inlet part is somewhat higher than that of a normal kiln.

12-9-4 Data Analysis and its Conclusion

From the measurement results carried out in the energy audit and the results of investigating and analyzing existing data, the following items became evident concerning the facilities and operation of this factory.

(a) Heat consumption is high, at 950 – 970 kcal/kg-cli.

(b) The measurement result of recouped air (tertiary air) volume was around 60 (%) of the necessary air volume (2,900 Nm^3/min) for combustion of fuel feed to the F.F furnace. This shows that the combustion air volume for burning fuel is around 40 (%) less than required.

(c) Gas, material and heat balance was calculated and its result is shown in Table 12-24. Main data are as follows.

1) Heat consumption : 924.7 kcal / kg-cli.
2) Cooler heat recovery efficiency : 52.8 (%)
3) Sensible heat taken away by cooler exhaust gas : 145.2 kcal / kg-cli.
4) Sensible heat taken away by preheater exhaust gas : 315.1 kcal / kg-cli.

This sensible heat taken away by exhaust gas 3) + 4) = 460.3 kcal / kg-cli. is extremely high. It is better to recover this heat by waste heat recovery power system

(d) Compared with other cyclones, pressure loss of C3 and C4 cyclones is rather high. It is desirable to consider measures to counter the pressure loss of these cyclones.

(e) The calculation result of the collecting efficiency of C5 (bottom) cyclone is low, at approximately 66.3 (%). If it is possible to improve the collecting efficiency of the cyclone, power consumption will increase in proportion to the increased pressure loss, while heat consumption will decrease by the fall in exhaust gas temperature.

(f) The following items can be confirmed from the recording chart of O2 (%) (Fig 12-9),

1) O2 (%) at kiln inlet housing: Short-term fluctuation is around 0.6-1.0 (%) and long-term fluctuation is 1.4-1.6 (%).
2) O2 (%) at C5cyclone outlet: Fluctuates at 15-minute intervals at a rate of around 0.6-2.5 (%)

These fluctuations are attributed to the feeding accuracy of the coal feeding apparatus and the fluctuation of preheater and kiln line exhaust gas volume,

(g) To confirm the burning conditions of fuel in the F.F furnace, the calorific value of kiln feed raw meal was measured. The average measurement result was 213 kcal/kg. Calculation based on the material balance as per Chapter 12-9-3 (1)-3), indicate that around 35-40 (%) of unburned carbon is generated. This coincides with the result of (b) above. Calculation results are show in Chapter 12-9-3 (1)