Report on Energy Audit of Lao Cement Co.

1. Purpose

The PROMEEC project was started for the purpose of promotion of energy conservation in the ASEAN countries. In the Lao PDR, the first audit was made in the hydro power station located near the Nam Ngum Lake in 2001, and the second audit was made in 2004 on the same site for following up the first audit.

The past two audits were conducted in the energy generating side. This time a cement factory was selected as a place of audit in the energy consuming side. The audit has two purposes; one is an on-the-job training of audit technology to engineers in Lao PDR. The other is an information exchange and dissemination of acquired technologies among the ASEAN countries. After the energy audit, seminar/workshop was held to share an experience acquired in the audit with the engineers of Lao PDR, ASEAN countries.

2. Schedule

Oct.2, 2006	Am: Briefing of audit procedure, Interview and discussion
Oct.3	Am: Lecture on energy saving in cement factory Pm: Grouping and walk-through inspection
Oct.4	Am: Measurement and data gathering Pm: Data analysis and discussion
Oct.5	Am: Reporting to factory management
Oct.6	Am/Pm: Seminar/workshop

3. Participants

Lao PDR:
- 4 government officials including
- Mr. Khamso Kouphokham (Focal point, MEM, electrical engineer)
- Mr. Xayphone Bounsou

ASEAN(ACE):
- Mr. Ivan Ismed (Industrial Project Officer, PROMEEC)
- Ms. Evangeline L. Moises (Chief, Information & Event Division)

Malaysia(PTM):
- Mr. Zul Azri Hamidon (energy audit engineer, electrical)
- Ms. Norazean Mohd. Nnor (technical assistant, electrical)

Japan(ECCJ):
- Mr. Hideyuki Tanaka (coordinator)
- Mr. Kokichi Takeda (electric expert)
- Mr. Taichiro Kawase (heat expert)

Lao Cement Co.:

20 engineers including
Mr. Thongchan Sounaphon (No.1 plant, deputy director)
Mr. Vichith Souvannarath (No.2 plant, deputy director)

4. Outline of factory

Lao Cement Co. is a state-owned and situated in the city of Vang Vieng, 180km north of Vientiane, Lao PDR. Two kilns are built approximately 500 meter apart from in the same compound, which are substantially two plants in one factory.

	No.1 plant	No.2 plant
construction	Dec, 1994	Jan, 2002
production capacity(ton/year)	90,000	210,000
kiln type	shaft	NSP
fuel	coal	coal
employee	244	294

5. Cement production

There are three companies (5 plants) of cement manufacturing in Lao PDR, which are composed of one state-owned, one private and one joint venture of state and private. Total production capacity in the nation is 600,000 ton/year in which Lao Cement Co. occupies 50% share. On the contrary, national cement demand is 1,300,000 ton/year. The gap of demand and supply is filled by an import, mainly from Thailand and China. Consequently, a principal goal of the company is to keep a service factor of two plants as high as possible for attaining maximum production of cement. It is quite remarkable that two plants achieve an operation of more than 300 days per annum.
Two plants were constructed by Chinese contractors. Interestingly, main equipment such as precalciner and coal burner, grate cooler are supplied by Japan, USA and Europe. In the No.2 plant, three Chinese engineers are now staying to give a technical advice in the area of operation technology. Unfortunately a guidance in energy saving area is not implemented.

6. Energy conservation activity

Energy conservation activity was started after one of factory management participated in the 2004 PROMEEC seminar held in Vientiane (*1). As an energy management in terms of fuel SEC and electric SEC is carried out, it is still a early stage where energy conservation is only a concern of limited number of managerial personnel in the factory and is not shared by most of employees. An organizational provision has not yet made, for example, energy conservation committee has not been organized and no energy manager are not appointed. A small group activity such as Kaizen is not carried out(*3). A biggest interest of factory management is a production, as indicated by the daily trend graph of cement production posted on the bulletin board.

*1: Mr. Vichith Souvannarath, deputy manager of plant no.2, took part in the 2004 PROMEEC seminar, when he raised a question and acquired information on the electric SEC in the Japanese cement industry.

*2: SEC means Specific Energy Consumption, expressed as energy used per unit product (typically kWh/ton of cement).

*3: The so called Kaizen in Japan is called as KAISEN in Lao PDR. They said in the past the JICA expert visited a factory and gave a guidance on Kaizen activity.

7. Outline of energy audit work

Taking into consideration that one of audit purpose is on-the-job training (OJT) of participant engineers, and Malaysian engineers are joining the audit team, it is agreed that responsibility of audit work is put on the local team composed of engineers of Lao government, Lao Cement co. and Malaysian energy conservation center (PTM). The audit work was implemented according to the following steps;

Lecture on cement manufacturing process and its energy saving measures
Briefing on audit items, data gathering and measurement procedures
Organization of audit team (grouping and leader selection)
Data gathering and measurement work
Data analysis and preliminary reporting to factory management

In the first two steps, team members had a lecture on audit technology and a briefing with distribution of necessary documents prepared by ECCJ experts as a starting material. Kiln heat balance, prevention of air leakage and variable speed control of big rotating machineries are selected as an audit target.
After a discussion among Mr.Khamso of focal point, factory and Malaysian PTM, the audit team were organized. Most works in data gathering and measurement were conducted by themselves without an assistance of ECCJ experts. As for data analysis, after all, ECCJ experts conducted, but later in the seminar/workshop, one representative of audit team made a presentation on the result of audit.

8. Results of energy audit

1) Kiln heat balance and estimation of maximum production capacity

A kiln heat balance was taken in order to calculate kiln gas loading flowing through units and to estimate maximum production capacity of the existing kilns. Kiln heat balance is useful for understanding what determines an energy consumption and where energy saving opportunity is located. The heat balance calculation was made on the EXCEL program prepared by ECCJ experts as shown in attached documents (Attachment 2). Various data necessary for running the EXCEL program were collected by looking at the operation log and making a measurement in the plants. Due to lack of available time, all data could not be gathered, for which assumed data were postulated. Therefore, the result is not guaranteed, but which way to go may be told. If more accurate answer is desired, more actual data should be collected.

In some cases, a consultation with process contractor is recommended. For the reference, a detail description of the EXCEL program is attached separately (Attachment 1).
Estimation of maximum production capacity is made on the assumption that production capacity is roughly proportional to gas loading flowing through units. The Japanese data was employed as a target of gas loading data. Maximum production capacity was estimated to be 266 ton/d in plant no.1 and 988 ton/d in plant no.2, while present production capacity is respectively 230 ton/d and 780 ton/d.

Principal Data Collected

Item	unit	Plant no.1	Plant no.2
Kiln type		shaft	NSP
Dry raw material (dry RM)	t/d	370	1200
Water content in wet raw material	wt% on wet RM	14	0
Clinker (t/d)	-	230	780
Coal rate (t/d)	t/d	44	122
Low heat value of coal	kcal/kg	5600	5600
Exhaust gas temp at kiln or preheater exit	degC	200	320
Vent gas fraction in cooler	%	-	10
O2 in exhaust gas	vol%	5	6

Heat Balance of Plant no.2

Heat Input		Heat Output	
Heat of combustion of fuel	873.8	Heat for clinkering	470.0
Sensible heat of fuel	0	Sensible heat of clinker at cooler exit	19.2
Sensible heat of wet raw material	0	Sensible heat of cooler exhaust vent	0
Sensible heat of combustion air	0	Heat for evaporating water in raw material	0
		Sensible heat of kiln or preheater exhaust gas	167.4
		Sencible heat of cooler vent gas	7.3
		Radiation heat on kiln surface	30.4
		Radiation heat on preheater surface	8.0
		Radiation heat on cooler surface	4.0
		Unaccountable heat losses	167.5
Input total	873.8	Output total	873.8

Base of temperature : ambient air temperature
Base of heat amount : kcal per kg of clinker (kcal/kg-cl)
Clinker cooler : grate cooler

Estimated maximum production capacity

	Plant no.1	Plant no.2
Kiln type	Shaft	NSP
Gas rate in Lao Cement Co.(m3N/kg-cl)	1.91	1.71

Design capacity (t-cl/d)	200	700
Actual capacity (t-cl/d) @ 2006.10.3	230	780
Estimated max capacity (t-cl/d)	266	988
Gas rate in Japan (m3N/kg-cl)	1.65	1.35
note1 : This is a trial calculation where many data are assumed. The result should be a reference before a detail study. note2 : m3N is a cubic meter at the normal condition, ie, 0°C and 1 atm.		

2) Prevention of air leakage

Examples of leakage-prone area are grate cooler, connecting or moving part of kiln surrounding, suspension preheater, grinding mill and electro-static precipitator. Wherever it may occur, any leakage causes an increase of power consumption of gas fans. Leakage occurring in cooler or kiln may increase fuel consumption. As a plant becomes old, possibility of air leakage rises high. Early detection of air leakage is important. In order to detect a leakage, the most reliable method is a measurement of oxygen content in the suspicious area. In the audit, oxygen content could not be measured because of a failure of oxygen meter. Oxygen content is an important data not only in air leakage detection but also as a crucial variable in heat balance calculation.

3) Variable speed control of big rotating machineries

Rotating machineries eat a large portion of electric power in cement manufacturing plant. In many cases, unduly large-sized machines are installed and consumes electric power wastefully. Even if machines are properly designed, in case that plant load is light, fan energy is spent in vain for making up for dissipated energy in valve throttling.
Whether fan energy consumption is relevant or not is understood by monitoring an opening of gas damper and/or by measuring an electric current (ampere) of fan motor.
Data collected per the above are shown in the following table;

Fan no. (*3)	service	Design ampere (Ad)	Design Voltage (Vd)	Design kW (name plate) (*1)	Actual ampere (Aa)	Elec saving (kWsaving)	Damper Opening (%)
G6	cement mill EP fan	214.8	380	(1041)	188	62	38
G14	grate cooler fan	102.6	380	55	73	31	73
G15	〃	70.6	380	37	54	18	61
G16	〃	85	380	45	48	32	60
G17	〃	86	380	45	60	26	56
G23	primary air fan	56.8	380	21.6	24	0	100
K1	coal mill fan	102.5	380	(46.5)	56	75	50
K2	〃	201	380	(87.8)	113	145	78
B26	raw mill fan	53.4	380	(41.6)	29	39	42
E13	raw mill EP fan	214.8	380	(1041)	180	0	100
F23	IDF fan	62.7	6000	630	51	0	100(*2)
						∑428	

*1 : ( ) means design kW is estimated by the following equation;

Design kW = head(Pa)x flow rate(m3/min)/60000/fan efficiency

*2 : F23 is speed-controlled by fluid coupler.

*3 : G23 is roots blower, and others are all centrifugal fans.

In general, when variable speed control is applied, energy saving amount is estimated by comparing an actual operating point with a design operating point on the fan performance curve. Unfortunately any performance curve except for F23 was not provided by the factory side. Therefore an ampere method was employed as an estimation method. This method has an advantageous simplicity at the expense of accuracy. Energy saving amount is given by the following equation;

Elec saving = design kW x {1-(actual ampere/design ampere)^3}
/fan efficiency x motor efficiency

,where efficiencies are assumed to be 0.7 for fan and 0.8 for motor.

If annual operating duration is 300 days,

annual saved electric power = 428 x 300 x 24 = 3,081,600 kWh

9. Recommendations to Lao Cement Co.

1) Maximization of cement production

As described in the previous section, the existing plants has been estimated to have a potential of 15% to 26% more cement production although there is a problem of estimation accuracy. A trial run is strongly recommended with the aim of maximization of cement production. It is noted that the trial run should be implemented by increasing production step by step and identifying bottleneck points in every step. In addition, gas loading in the kiln should be evaluated by taking a heat balance.

2) Feasibility study of variable speed control

As discussed in the previous section, several fans are operated at the conditions of damper throttling, and hundred millions of kWh of electric power are dissipated. The most economical way of reducing the power loss is an application of variable speed control, especially inverter technology. If it is successfully applied, electric SEC may decrease by approximately 13 kWh/t-clinker (*4). A feasibility study should be started soon.

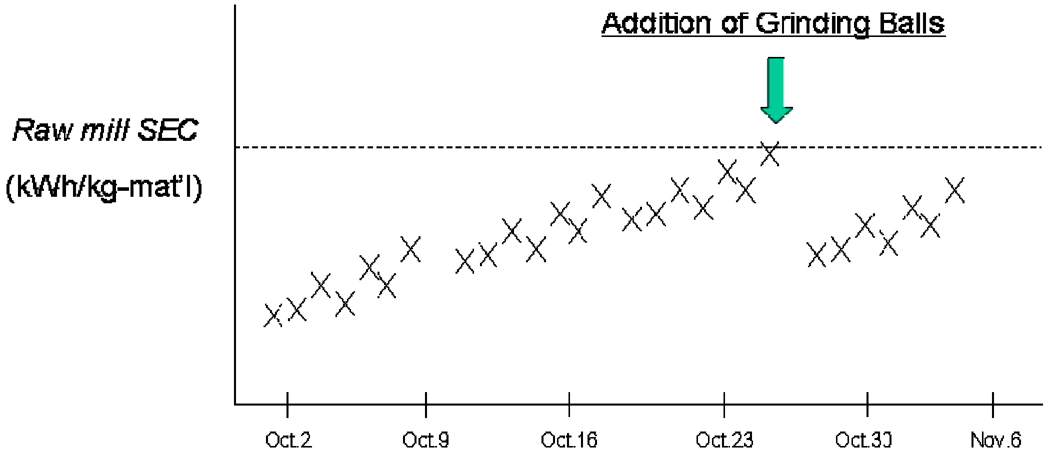
*4 : 428 kW x 24 h / 780 t-clinker/d = 13.1 kWh/t-clinker

3) Air leakage management

As mentioned before, air leakage may cause an increase of energy consumption. The most effective way of detecting air leakage is an oxygen measurement. Purchase of portable oxygen meter is strongly recommended. Zirconia type oxygen sensor is recommended because of reasonable price and long life with sufficient accuracy. The approximate equation is used for calculating an amount of air leakage, as described in Attachment 3.

4) Management of grinding media

Grinding efficiency is heavily dependent on diameter and charged volume of grinding media. Ball diameter shrinks as time passes due to erosive force, which results in a gradual degradation of electric SEC in the raw mill. Electric SEC should be monitored daily, and when SEC arrives at a certain level, grinding balls are charged up to normal level. At the same time, filling level of grinding balls is also important in maintaining an acceptable efficiency. The following graph is useful for the monitoring purpose.



5) Establishment of energy management system

An energy management system (EMS) is proven to be effective in the developed countries. Major components of EMS are shown in the following table;

Components	Activity	Examples
Organization	Organization Accountability	Energy conservation promotion committee Appointment of energy manager Employee education(awareness)
Monitoring	Monitoring Targeting	Data recording & sharing by all members Specific energy consumption (SEC) Key efficiency indicators (ex. O2%)
Technology	Evaluation	Technical review Energy audit
Operation & maintenance	House keeping	Product yield(avoid off-spec product) Preventive maintenance(avoid unscheduled shutdown)

As a first step, the following activities should be started because it does not cost so much.

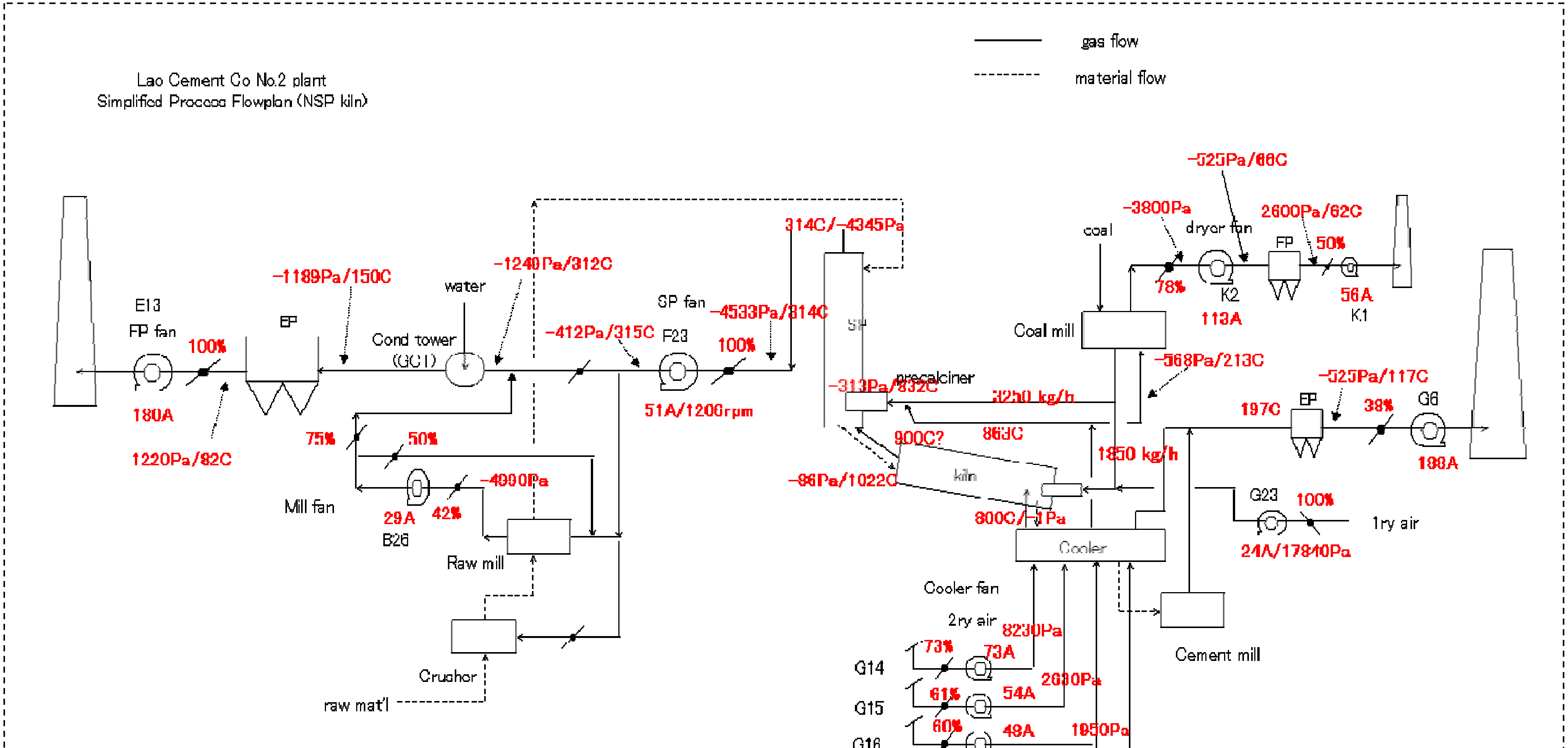
- energy conservation promotion committee
- appointment of energy manager
- employee education (attendance to seminar/workshop)
- data monitoring and reporting

In order to make successful, strong involvement and support of factory management are important.

10. Attachments

1) Calculation procedure of heat balance
2) Result of heat balance calculation for Plant no.1
3) Result of heat balance calculation for Plant no.2
4) Estimation of amount of air leakage

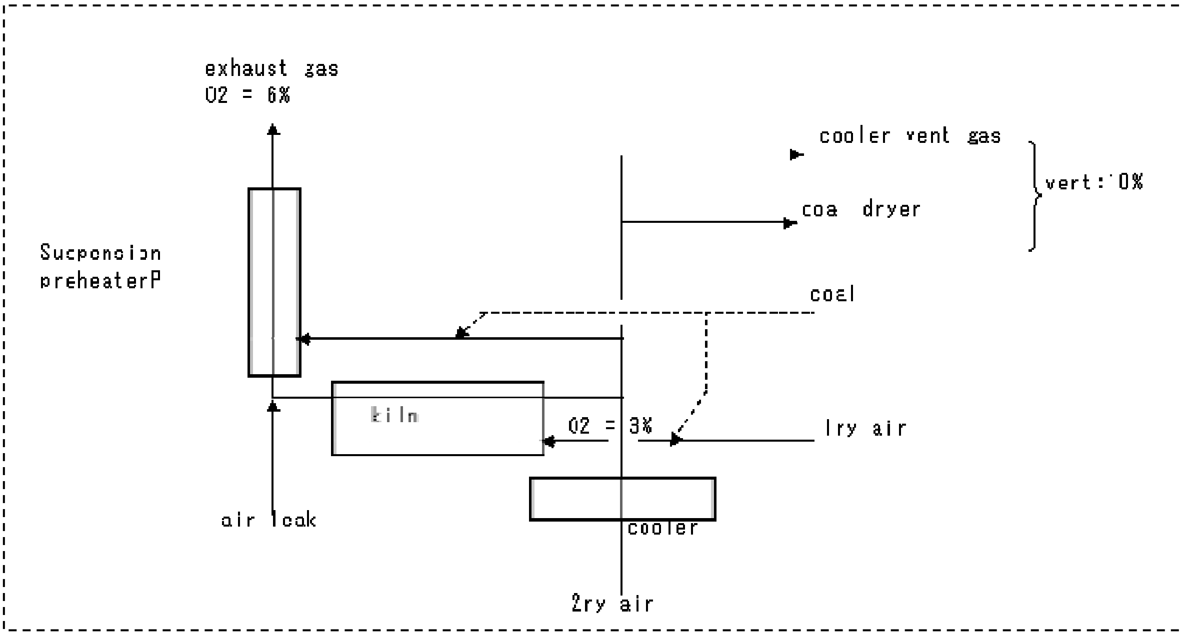
Attachment 1 Example of heat balance calculation



* Computer data are written in red.

Plant : Lao Cement Co. No.2 plant

Boundary of Heat Balance:



Collected data and assumptions:

Materials and products

Cement production(t/d) : 811

Clinker production(t/h): 811/24/1.04 = 32.5

Yield of clinker (fraction to raw material) : 0.62

Raw material (dry base) (t/h) : 32.5/0.62 = 52.4

Water content in raw material (% on wet RM) : 0%

Raw material temp (°C) : 30

Raw material specific heat (kcal/kg-RM/K) : 0.192

Clinker temperature at cooler exit (°C) : 130

Clinker specific heat (kcal/kg-cl/K) : 0.192

Coal burning in kiln and precalciner

Fuel kind : coal

Low heat value of coal(kcal/kg) : 5600

Coal temperature (°C) : 30

Coal specific heat (kcal/kg/K) : 0.300

Coal consumption in kiln burner (kg/h) :1820

Coal consumption in precalciner (kg/h) :3250

O2% in kiln burner combustion gas : 3

Combustion air temperature (°C) : 30

Suspension preheater

Exhaust gas temperature (°C) : 320

O2% in exhaust gas : 6

Exhaust gas specific heat (kcal/m3N/K) : 0.338

Clinker cooler

Clinker vent gas temperature at cooler exit (°C) : 200

Fraction of cooler vent gas (%) : 10

Radiation losses from hot surfaces

	Area(m2)	Temp(°C)	Emissivity
Kiln	500	150	0.95
Preheater	400	80	0.95
Cooler	200	80	0.95

Miscellaneous data

Ambient temperature (°C) : 30

Ambient air specific heat (kcal/m3N/K) : 0.310

Calculation of components in heat balance table

Heat input:

heat of combustion of coal(kcal/kg-cl)

= total coal(kg/h)*low heat value of coal(kcal/kg)/clinker prod(kg-cl/h)

= (1820+3250)*5600/32500 = 873.8

sensible heat of coal (kcal/kg-cl)

= total coal (kg/h)*spec heat of coal(kcal/kg/K)*(coal temp-amb temp)(°C)/clinker prod(kg-cl/h)

= (1820+3250)*0.3*(30-30)/32500 = 0

sensible heat of raw material(kcal/kg-cl)

= raw material(kg/h)*spec heat of raw material(kcal/kg/ °C)*(raw material temp-amb temp)(°C)/clinker prod(kg-cl/h)

= 52400*0.192*(30-30)/32500 = 0

air ratio at burner = 21/(21-02 at burner) = 21/(21-3) = 1.17

theoret air,A0 (m3N/kg-coal)

= 0.241*LHV(MJ/kg)+0.56 = 0.241*(5600/1000*4.186)+0.56 = 6.21

theoret combust gas, G0 (m3N/kg-coal)

= 0.216*LHV(MJ/kg)+1.67 = 0.216*(5600/1000*4.186)+1.67 = 6.73

1ry combust gas(m3N/h)

= 1ry coal(kg/h)*(G0+A0*(air ratio at burner-1))

= 1820*(6.73+6.19*(1.17-1)) = 14163

2ry combust gas(m3N/h)

= 2ry coal(kg/h)*(G0+A0*(air ratio at burner-1))

= 3250*(6.73+6.19*(1.17-1)) = 25292

1ry combust air (m3N/h) = 1ry coal (kg/h)*A0 *air ratio at burner

= 1820*6.19*1.17 = 13180

2ry combust air (m3N/h) = 2ry coal (kg/h)*A0 *air ratio at burner

= 3250*6.19*1.17 = 23537

total combust gas(m3N/h)

= 1ry combust gas(m3N/h)+2ry combust gas(m3N/h) = 14163+25292 = 39455

total combust air (m3N/h)

= 1ry combust air(m3N/h)+2ry combust air(m3N/h) = 13180 + 23537 = 36717

sensible heat of total combust air (kcal/kg-cl)

= total combust air(m3N/h)* spec heat of air(kcal/m3N/ °C)*(comb air temp-amb temp)(°C)/clinker prod(kg-cl/h)

= 36717*0.310*(30-30)/32500 = 0

Heat output:

heat of clinkering(kcal/kg-cl)

= heat of calcine(kcal/kg-cl)-heat of sinter(kcal/kg-cl)= 570-100 = 470

sensible heat of leaving clinker(kcal/kg-cl)

= spec heat of clinker(kcal/kg-cl/°C)*(clinker temp-amb temp)(°C)

= 0.192*(130-30) = 19.2

CO2 from calcine(m3N/h)

= Clinker prod(kg-cl/h)*0.27(m3N/kg-cl) = 32500*0.27 = 8773

air ratio at preheater exit = 21/(21-O2% at preheater exit) = 21/(21-6) = 1.40

total combust gas rate at preheater exit(m3N/h)

= total coal(kg/h)*(GO+AO*(air ratio at preheater exit-1))

= (1820+3250)*(6.73+6.19*(1.40-1)) = 46731

water vaporized(m3N/h)

= dry raw material(kg/h)*water cont(%)/(100-water cont(%))*22.4/18

= 52400*0/(100-0)*22.4/18 = 0

preheater exhaust gas(m3N/h)

= total combust gas rate at preheater exit(m3N/h)+CO2 from calcine(m3N/h)+water vaporized(m3N/h)

= 46731+8773+0 = 55504

sensible heat of preheater exhaust gas(kcal/kg-cl)

= preheater exhaust gas(m3N/h)*spec heat(kcal/m3N/ °C)*(preheater exhaust temp-amb temp)/clinker prod(kg-cl/h)

= 55504*0.338*(320-30)/32500 = 167.4

cooler vent gas(m3N/h)

= (preh exhaust gas(m3N/h)-1ry combust gas(m3N/h))*vent gas%/100

= (55504-14163)*10/100 = 4137

sensible heat of cooler vent gas(kcal/kg-cl)

= cooler vent gas(m3N/h)*spec heat of air(kcal/m3N/K) * (vent gas temp-amb temp)(°C)/clinker prod(kg-cl/h)

= 4137*0.338*(200-30)/32500 = 7.3

heat coeff of convection, hc(kcal/m2/h/K)

= 2.236*(surface temp-amb temp)^0.25

= 2.236*(150-30)^0.25 = 7.40

heat coeff of radiation, hr(kcal/m2/h/K)

= 4.876*emissivity*((surface temp+273)/100)^4-((amb temp+273)/100)^4)/(surface temp-amb temp)

= 4.876*0.95*(((150+273)/100)^4-((30+273)/100)^4)/(150-30) = 9.11

radiation loss on kiln surface(kcal/kg-cl)

= (hc+hr)(kcal/m2/h/K)*surface area(m2)*(surface temp-amb temp)(°C)/clinker prod(kg-cl/h)

= (7.40+9.11)*500*(150-30)/32500 = 30.4

heat coeff of convection, hc(kcal/m2/h/K)

= 2.236*(preheater surface temp-amb temp)^0.25

= 2.236*(80-30)^0.25 = 5.94

heat coeff of radiation, hr(kcal/m2/h/K)

= 4.876*emissivity*((preheater surface temp+273)/100)^4-((amb temp+273)/100)^4)/(surface temp-amb temp)

= 4.876*0.95*(((80+273)/100)^4-((30+273)/100)^4)/(80-30) = 6.57

radiation loss on kiln surface(kcal/kg-cl)

= (hc+hr)(kcal/m2/h/°C)*surface area(m2)*(preheater surface temp-amb temp)(°C)/clinker prod(kg-cl/h)

= (5.94+6.57)*400*(80-30)/32500 = 8.0

heat coeff of convection, hc(kcal/m2/h/K)

= 2.236*(cooler surface temp-amb temp)^0.25

= 2.236*(8-30)^0.25 = 5.94

heat coeff of radiation, hr(kcal/m2/h/K)

= 4.876*emissivity*((cooler surface temp+273)/100)^4-((amb temp+273)/100)^4)/(surface temp-amb temp)

= 4.876*0.95*(((80+273)/100)^4-((30+273)/100)^4)/(80-30) = 6.57

radiation loss on cooler surface(kcal/kg-cl)

= (hc+hr)(kcal/m2/h/K*surface area(m2)*(surface temp-amb temp)(°C)/clinker prod(kg-cl/h)

= (5.94+6.57)*200*(80-30)/32500 = 4.0

Key parameters:

exhaust gas rate per kg-cl = preheater exhaust gas(m3N/h)/clinker prod(kg-cl/h)

= 55504/32500 = 1.71

specific fuel consumption (kcal/kg-cl)

= total coal(kg/h)*LHV of coal(kcal/kg)/clinker prod(kg/h)

= (1820+3250)*5600/32500 = 873.8

Attachment 2 Result of Heat Balance Calculation for Plant no.1

Page-1 (input data)

Heat Balance Calculation (Lao Cement Plant no.1 shaft kiln/overall balance)

		Date	2006/10/3		
		Factory	1		
		Kiln	Shaft		
1. Precondition					
1.1 Preheater (or kiln) charge		units	data	Remarks	
	1) Charge rate(dry base)	t/h	15.5	limestone+clay+silica+iron-ore	
	2) Water content of dry raw material	wt% on dry charge	**2**	estimated	
	3) Water content of raw material	wt% on wet charge	**14**	log data	
1.2 Clinker					
	1) Yield of clinker		0.62	constant	
	2) Clinker output	t/h	9.6	cement production/24/1.04	
	3) Temperature	℃	115	measure or log data	
	4) Heat for clinkering	kcal/kg-cl	470	heat of calcination (570 kcal/kg-cl) - heat of sintering (100 kcal/kg-cl) = 470 kcal/kg-cl	
	5) Specific heat		0.192	constant	
	6) Cement production	t/d	240	operation target	
1.3 Coal to kiln					
	1) Kind		coal		
	2) Low heat value	kcal/kg	5600	constant	
	3) Temperature	℃	30	log data	
	4) Consumption	kg/h	1772		
	4-1) Coal consumption in Factory 1		1833	log data	
	4-2) Coal used in raw mill dryer		61		
	Dryer efficiency	%	50		
	Amount of water vaporized = Clinker/clinker yield*water cont/(100-water cont)	kg/h	317		
	5) Specific weight	-	1	constant	
	6) Specific heat	kcal/kg/K	0.25	constant	
1.4 Fuel gas to kiln					
	1) Kind		natural gas		
	2) Low heat value	kcal/$m^3{}_N$		constant	
	3) Temperature	℃		log	
	4) Consumption	$m^3{}_N$/h		log	
	5) Specific heat	kcal/$m^3{}_N$/K		constant	
1.5 Coal to calciner					
	1) Kind		coal		
	2) Low heat value	kcal/kg	5600	constant	
	3) Temperature	℃	30	log data	
	4) Consumption	kg/h		log data	
	5) Specific weight	-	1	constant	
	6) Specific heat	kcal/kg/K	0.3	constant	
1.6 Fuel gas to calciner					
	1) Kind		natural gas		
	2) Low heat value	kcal/$m^3{}_N$		constant	
	3) Temperature	℃		log	
	4) Consumption	$m^3{}_N$/h		log	
	5) Specific heat	kcal/$m^3{}_N$/K		constant	
1.7 Exhaust gas at preheater outlet					
	1) Temperature	℃	200	measure or log data	
	2) O2 content	%	**5**	measure or log data	
	3) Specific heat	kcal/$m^3{}_{N/K}$	0.338	constant	
	4) CO2 originated from clinkering reaction		0.27	constant (0.27 m3N/kg-cl)	
1.8 Exhaust gas at clinker cooler outlet					
	1) Temperature	℃		measure or log	
	2) O2 content	%		measure or log	
	3) Specific heat			constant	
1.9 Radiation heat from kiln surface					
	1) Average temperature	℃	70	measure or log	
	2) Surface area	m^2	150	constant	
	3) Convection coefficient		6.5	constant	
	4) Radiation coefficient		6.3	constant	
	5) Emissivity		0.95	constant	
1.10 Radiation heat from preheater surface					
	1) Average temperature	℃	70	measure or log	

Page-2 (calculation)

Heat Balance Calculation (Lao Cement Plant no.1 shaft kiln/overall balance)

2. Heat balance table

No.	Item	kcal/kg-cl	%	Remarks	
	Input heat				
I1	**Heat of combustion of fuel**	**1032.1**	100.0		
	=(kiln+precal)*LHV/rm charge/cl yield/1000				
I2	Sencible heat of fuel	0.0	0.0		
	=(kiln+precal)/charge*fuel SG*fuel Cp*(fuel temp-amb temp)/1000				
I3	Sensible heat of wet raw material				
I4	Sensible heat of combustion air				
	Total	1032.1	100.0		
	Output heat				
O1	Heat for clinkering	470.0	45.5		
O2	Sensible heat of clinker at cooler exit Qcl out	16.3	1.6		
	=Cl Cp*(cl temp-preh exhaust)				
O3	Sensible heat of cooler exhaust vent				
	=G*Cp*(tin-tout)				
O4	Heat for evaporating water in raw material				
	=kg-water/kg-cl*539kcal/kg-water	17.7	1.7		
	Water amount in raw material = w/(100-w)/clinker yield	0.03			
O5	Sensible heat of kiln or preheater exhaust gas	109.7	10.6		
	=(comb gas+decomposed+water evap'ed)*Cp*(tin-tout)/clinker rate				
	m =21/(21-O_2)	1.31			
	LHV(MJ/kg-fuel)	23.44			
	A0 =0.241*LHV+0.56	6.2			
	G0 =0.216*LHV+1.67	6.7			
	Comb gas, G = (G0+(m-1)*A0)*fuel rate	15371			
	Decomposed CO2 = 0.270*cl-kg	2596			
	Water vaporized = dry material*1000*w/(100-w)*22.4/18	394			
	Exhaust gas rate (m^3_N/kg-cl)	**1.91**			
O6	Radiation heat on kiln surface	7.8	0.8		
	=(hc+ ε *hr)*A*delT/(cl kg*1000)				
O7	Radiation heat of preheater surface	0.0	0.0		
	=(hc+ ε *hr)*A*delT/(cl kg*1000)				
O8	Radiation heat on cooler surface	0.0	0.0		
	=(hc+ ε *hr)*A*delT/(cl kg*1000)				
O9	Unaccountable heat losses	410.5	39.8		
	Total	1032.1	100.0		

fuel SEC (kcal/kg-cl)

gas loading (m3N/kg-cl)

Attachment 3 Result of Heat Balance Calculation for Plant no.2

Page-1 (input data)

Heat Balance Calculation (Lao cement co. Plant no.2 / overal balance)

		Date	2006/10/3		
		Factory	2		
		Kiln	NSP		
1. Precondition					
1.1 Preheater (or kiln) charge		units	data	Remarks	
	1) Charge rate(dry base)	t/h	52.4	(limestone+clay+silica+iron-ore)	
	2) Water content , w	wt% on wet charge	0	estimated	
	3) Raw material specific heat	kcal/kgK	0.192	constant	
	4) Raw material temperature	℃	60	estimated	
1.2 Clinker					
	1) Yield of clinker		0.62	constant	
	2) Clinker output	t/h	32.5	cement production/24/1.04	
	3) Temperature	℃	130	estimated	
	4) Heat for clinkering	kcal/kg-cl	470	heat of calcination (570 kcal/kg-cl) - heat of sintering (100 kcal/kg-cl) = 470 kcal/kg-cl	
	5) Specific heat	kcal/kgK	0.192	constant	
	6) Cement production	t/d	811	production target	
1.3 Coal to kiln (1ry burner)					
	1) Kind		Coal		
	2) Low heat value	kcal/kg	5600	actual of LCC	
	3) Temperature	℃	30	log data	
	4) Consumption	kg/h	1820	log data	
	5) Specific heat	kcal/kgK	0.3	constant	
	6) O2%		3	estimated	
	7) Combustion air temperature	℃	30		
1.4 Fuel gas to kiln					
	1) Kind		natural gas		
	2) Low heat value			constant	
	3) Temperature	kcal/m^{3}N		log	
	4) Consumption	℃		log	
	5) Specific heat	m^{3}N/h		constant	
1.5 Coal to calciner					
	1) Kind		Coal		
	2) Low heat value	kcal/kg	5600	actual of LCC	
	3) Temperature	℃	30	log data	
	4) Consumption	kg/h	3250	log data	
	5) Specific heat	kcal/kgK	0.3	constant	
1.6 Fuel gas to calciner					
	1) Kind		natural gas		
	2) Low heat value	kcal/m^{3}N		constant	
	3) Temperature	℃		log	
	4) Consumption	m^{3}N/h		log	
	5) Specific heat	kcal/m^{3}NK		constant	
1.7 Exhaust gas at preheater outlet					
	1) Temperature	℃	320	log data	
	2) O2 content	%	6	log data	
	3) Specific heat	kcal/m^{3}NK	0.338	constant	
	4) CO2 originated from clinkering reaction		0.27	constant (0.27 m3N/kg-cl)	
1.8 Exhaust gas at clinker cooler outlet					
	1) Temperature at front	℃	863	measure or log	
	2) Temperature at end	℃	200		
	3) O2 content of precal combust gas	%	21	measure or log	
	4) Specific heat		0.338	constant	
1.9 Radiation heat from kiln surface					
	1) Average temperature	℃	150	measure or log	
	2) Surface area	m^2	500	constant	
	3) Convection coefficient		7.40	constant	
	4) Radiation coefficient		9.10	constant	
	5) Emissivity		0.95	constant	
1.10 Radiation heat from preheater surface					
	1) Average temperature	℃	80	measure or log	
	2) Surface area	m^2	400	constant	
	3) Convection coefficient		5.95	constant	
	4) Radiation coefficient		6.58	constant	
	5) Emissivity		0.95	constant	

Page-2 (calculation)

Heat Balance Calculation (Lao cement co. Plant no.2 / overal balance)

2. Heat balance table

No.	Item	kcal/kg-cl	%	Remarks	
	Input heat				
I1	**Heat of combustion of fuel**	**873.8**	98.9		
	=(kiln+precal)*LHV/rm charge/cl yield/1000				
I2	Sencible heat of coal	0.0	0.0		
	=(kiln+precal)/charge*fuel SG*fuel Cp*(fuel temp-amb temp)/1000				
I3	Sensible heat of wet raw material	9.3			
I4	Sensible heat of combustion air	0.0			
	Total	883.1	98.9		
	Output heat				
O1	Heat for clinkering	470.0	53.2	constant	
O2	Sensible heat of clinker at cooler exit Qcl out	19.2	2.2		
	=Cl Cp*(cl temp-preh exhaust)				
O3	Sensible heat of cooler exhaust vent				
	=G*Cp*(tin-tout)				
O4	Heat for evaporating water in raw material				
	=kg-water/kg-cl*539kcal/kg-water	0.0	0.0		
	Water amount in raw material = w/(100-w)/clinker yield	0.00			
O5	Sensible heat of preheater exhaust gas	167.4	19.0		
	=(comb gas+decomposed+water evap'ed)*Cp*(tin-tout)/clinker rate				
	m =21/(21-O_2) at preheater exhaust	1.40			
	LHV(MJ/kg-fuel)	23.44			
	A0 =0.241*LHV+0.56	6.21			
	G0 =0.216*LHV+1.67	6.73			
	Combustion gas, G = (G0+(m-1)*A0)*fuel rate	46731			
	Decomposed CO2 = 0.270*cl-kg	8773			
	water vaporized = dry material*1000*w/(100-w)*22.4/1	0.0			
	Exhaust gas rate (Nm3/kg-cl)	**1.71**		total exhaust gas(m3/min)	2009
Q5-1	Sensible heat of exhaust venting gas from clinker cooler	7.3	0.8		
	Fraction of cooler vent gas (%)	10		estimated	
	m =21/(21-O_2) at kiln burner	1.17			
	(Preheater exhuast - kiln burner G0)*vent gas fraction	4137		1ry air(m3/min)	244
				2ry air (m3/min)	815
O6	Radiation heat on kiln surface	29.6	3.4		
	=(hc+ ε *hr)*A*delT/(cl kg*1000)				
O7	Radiation heat of preheater surface	7.5	0.8		
	=(hc+ ε *hr)*A*delT/(cl kg*1000)				
O8	Radiation heat on cooler surface	3.8	0.4		
	=(hc+ ε *hr)*A*delT/(cl kg*1000)				
O9	Unaccountable heat losses	178.3	20.2		
	Total	883.1	100.0		

fuel SEC (kcal/kg-cl)

gas loading (m3N/kg-cl)

Attachment 4 Estimation of amount of air leakage

Legend:

C : coal firing rate (kg/d)

LHV : low heating value of coal (MJ/kg-coal)

02 at gas : oxygen content in the gas (vol%)

02 at burner : oxygen content in the combustion gas at burner (vol%), typical value is 3% to 5%.

A0 : theoretical air rate (m3N/kg-coal)

G0 : theoretical gas rate (m3N/kg-coal)

m : air ratio (-)

A at gas : actual air rate in the gas (m3N/kg-coal)

A at burner : actual air rate at burner (m3N/kg-coal)

G at gas : actual gas rate in the gas (m3N/kg-coal)

G at burner : actual gas rate at burner (m3N/kg-coal)

⊿air : air leakage (m3N/h)

Calculation:

$m \text{ at gas} = 21/(21-02 \text{ at gas})$

$m \text{ at burner} = 21/(21-02 \text{ at burner})$

$A0 = 0.241*LHV+0.56$

$G0 = 0.216*LHV+1.67$

$A \text{ at gas} = A0 \text{ x } m \text{ at gas x } c \ / \ 24 \ (m3N/h)$

$A \text{ at burner} = A0 \text{ x } m \text{ at burner x } c/24 \ (m3/h)$

$G \text{ at gas} = G0 + (m \text{ at gas} - 1) \text{ x } A0 \text{ x } c/24 \ (m3N/h)$

$G \text{ at burner} = G0 + (m \text{ at gas} - 1) \text{ x } A0 \text{ x } c/24 \ (m3N/h)$

$⊿air = A \text{ at gas} - A \text{ at burner} \ (m3N/h)$