Cement Process & Energy Saving

October, 2006

The Energy Conservation Center, Japan

Taichiro Kawase

Bird-eye View of Japanese Cement Factory

Layout of one Japanese cement factory

Chemical Composition of Raw Materials and Cement Product

Raw Materials						
	CaO(%)	SiO_2(%)	Al_2O_3(%)	Fe_2O_3(%)	SO_3(%)	CO_2(%)
Limestone	47-55					37-43
Clay		45-78	10-26	3-9		
Silica		77-96				
Iron-ore				40-90		
Gypsum	26-41			37-59		

Cements						
	CaO(%)	SiO_2(%)	Al_2O_3(%)	Fe_2O_3(%)	SO_3(%)	others
Portland cement	63-65	20-23	3.8-5.8	2.5-3.6	1.5-2.3	
Blended cement (BF slag)	52-58	24-27	7.0-9.5	1.6-2.5	1.2-2.6	

Temperature Profile in Wet Process Kiln

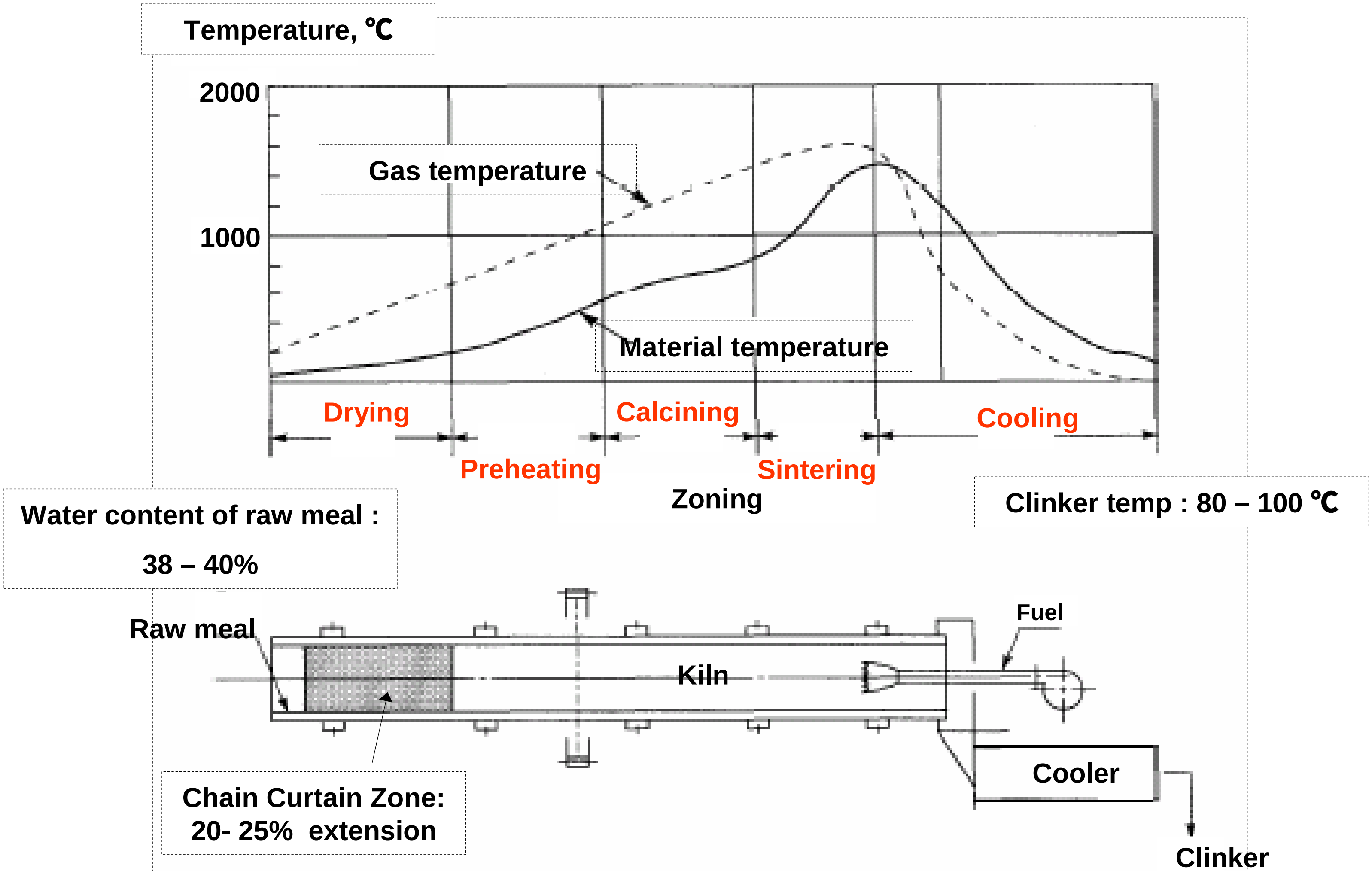


Figure 5 Temperature Profile in Wet Process Kiln

Chemistry of Cement Process

Stage	Heating (℃)	Reaction
drying	100〜110	Vaporization of physically adsorbed water
	110〜700	Vaporization of chemically bonded water
calcining	700〜750	Decomposition of $MgCO_3$
	750〜900	Decomposition of $CaCO_3$, Formation of $2CaO \cdot SiO_2$
	950〜1200	Transition to $\beta \cdot 2CaO \cdot SiO_2$
	1200〜1300	Formation of $3CaO \cdot Al_2O_3$, $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$
sintering	1300〜1450	Formation of 2CaO·SiO2, Sintering of Al2O3, Fe2O3, Na2O, K2O, etc
cooling	150〜200	During a course of cooling, pebble-like black colored clinker is formed, which consists of the following components;

- $3CaO \cdot SiO_2$: referred to as Alite or C_3S
- $2CaO \cdot SiO_2$: referred to as Belite orC_2S
- $3CaO \cdot Al_2O_3$: referred to as aluminate phase or C_3A
- $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$: referred to as ferrite phase or C_4AF

Raw Materials and Energy required for production of 1 ton of Cement

Raw Materials (kg)	
Limestone	1,095
Clay	204
Silica	78
Iron-ore	30
Gypsum	34
total	1,439

Energy Consumption	
Fuel (*1)	105
Electric power (kWh)	99

(*1) : kg of coal equivalent where HHV of coal is 6,200 kcal/kg.

Fuel by kind (%)	
Coal	78
Petroleum coke	13
Combustible waste	5
Heavy oil	4

Base : 1 ton of cement

Dry Process Kiln with Suspension Preheater (SP･NSP)

(Suspension) preheater:
Raw material (fine powder) is preheated in suspension state by hot gas coming from kiln.

Kiln:
Raw material is calcined and sintered by fuel burning. Calcining is CO_2 removal reaction. Sintering is formation of molten clinker by heating.

Cooler:
Molten clinker is quenched by cold air.

Pre-calciner:
A part of calcining reaction is made in pre-calciner in modern NSP process.

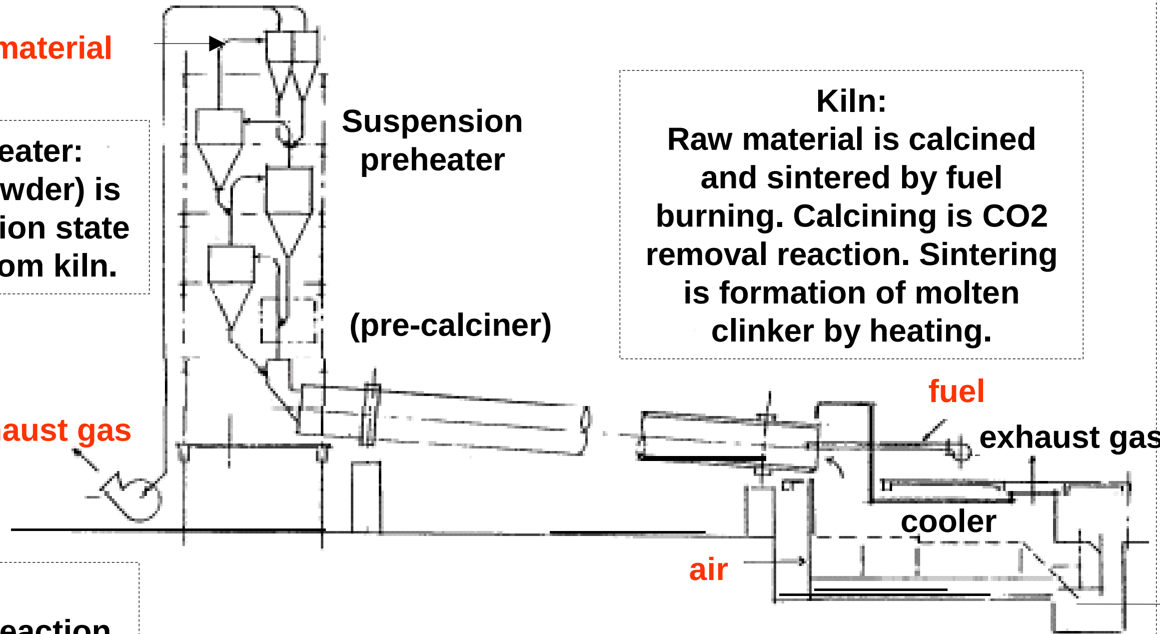
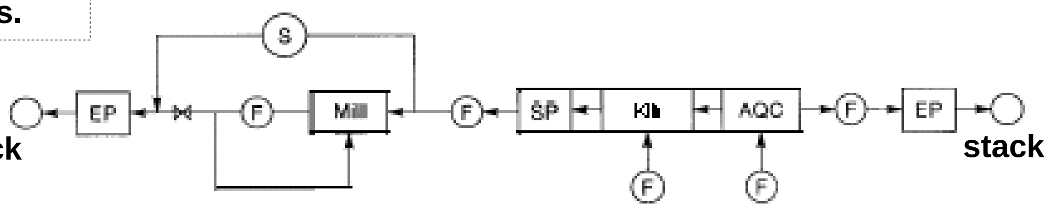


Figure 9 Dry process kiln with suspension preheater



Electrostatic precipitator (EP):
Dust-containing gases are dedusted in EP or bag filter.

Figure 10 Gas flow diagram of SP kiln

SP	Suspension Preheater
EP	Electrostatic Precipitator
F	Fan
S	Stabilizer (conditioner)
AQC	(Air Quenching) Cooler

Cement Production Process

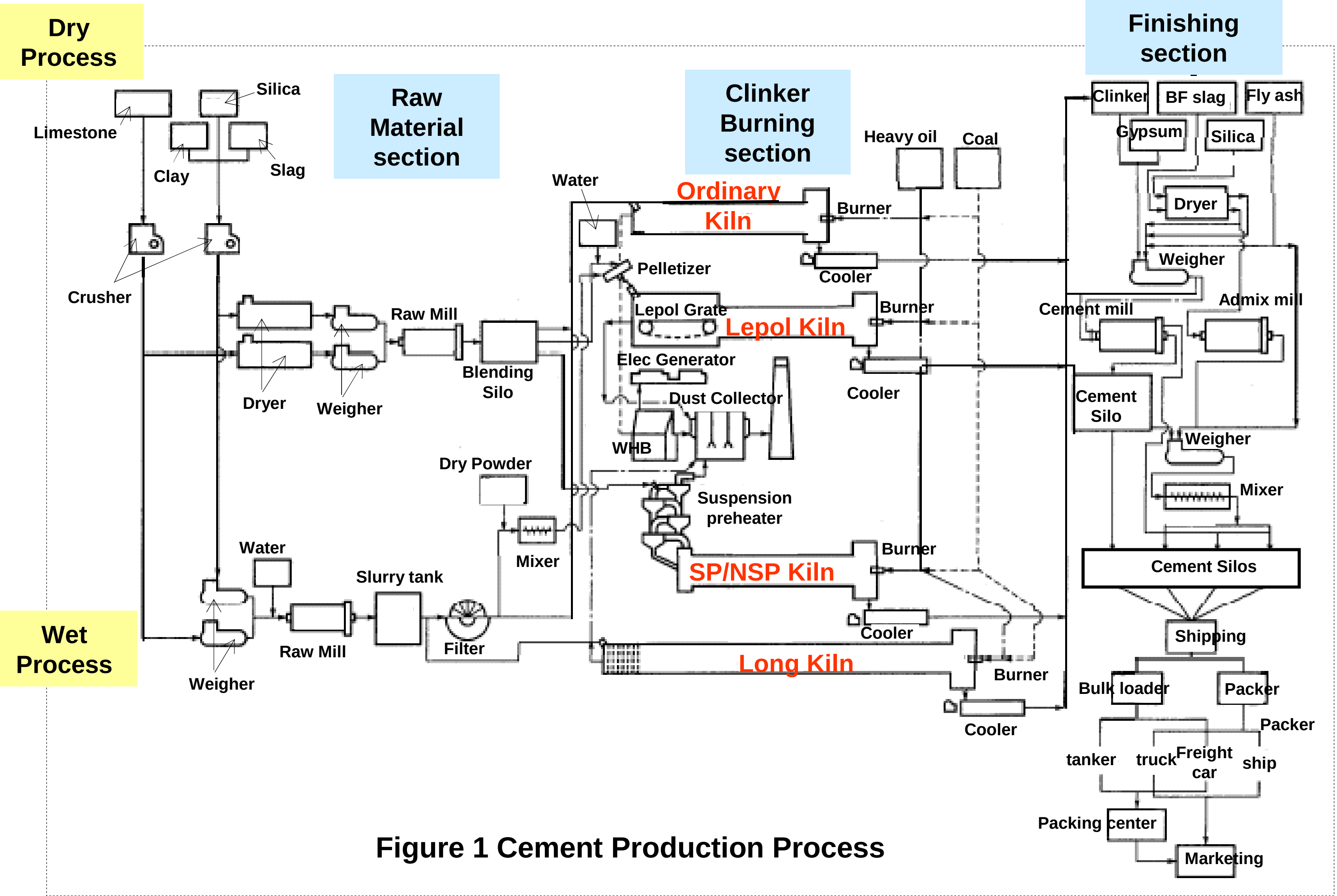


Figure 1 Cement Production Process

Factory 1

Heat Requirement in Burning Section

Kiln	kcal/kg-cl	Source(1)	$Nm^3/kg\text{-}cl(2)$
Shaft kiln	940	Yogyo Kogaku H/B	1.65
Dry long kiln	1,487	JCTA(1961)	2.62
Wet kiln	1,357	〃	2.38
Lepol kiln	954	〃	1.68
SP kiln	797	JCTA(1981)	1.40
NSP kiln	773	〃	1.35

Note 1: JCA means Japan Cement Technology Association
2: Estimated based on 1.40 Nm3/kg-cl in SP kiln

Factory 2

Dry Process Raw Material Grinding System

a. Open Circuit

Dryer and raw mill are installed separately. Dust made in milling is not recovered.

b. Closed Circuit

Separator is added. Coarse dust made in milling is separated and recycled to mill. Drying is done within mill.

c. Closed Circuit

Energy-efficient vertical roller mill (VRM) is employed. VRM is also space-saving.

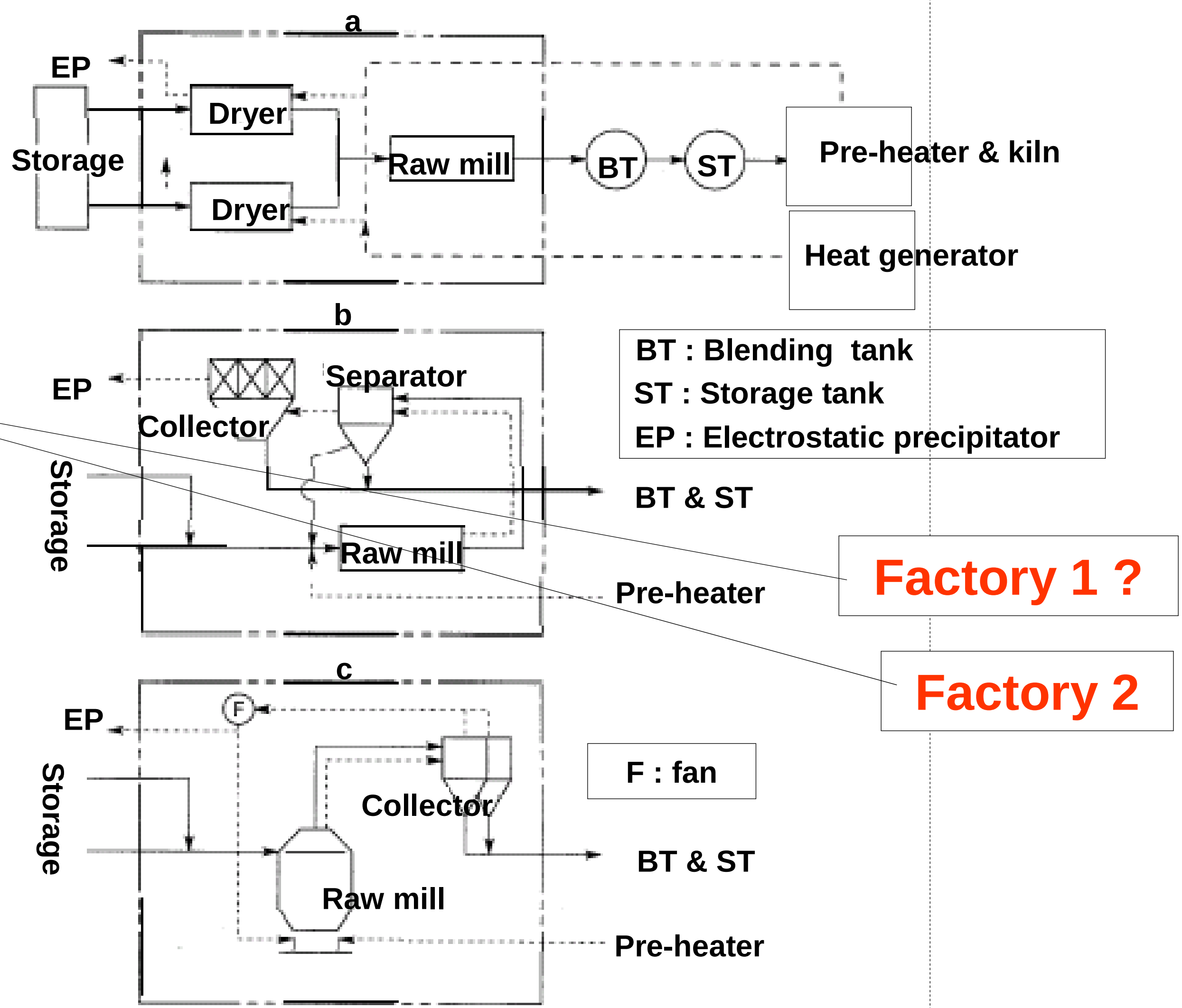


Figure 4 Dry Process Raw Material Section

Vertical Roller Mill

Lower part : Classifier

Upper part : roller mill

Vertical roller mill (VRM) is energy-efficient and also space-saving.

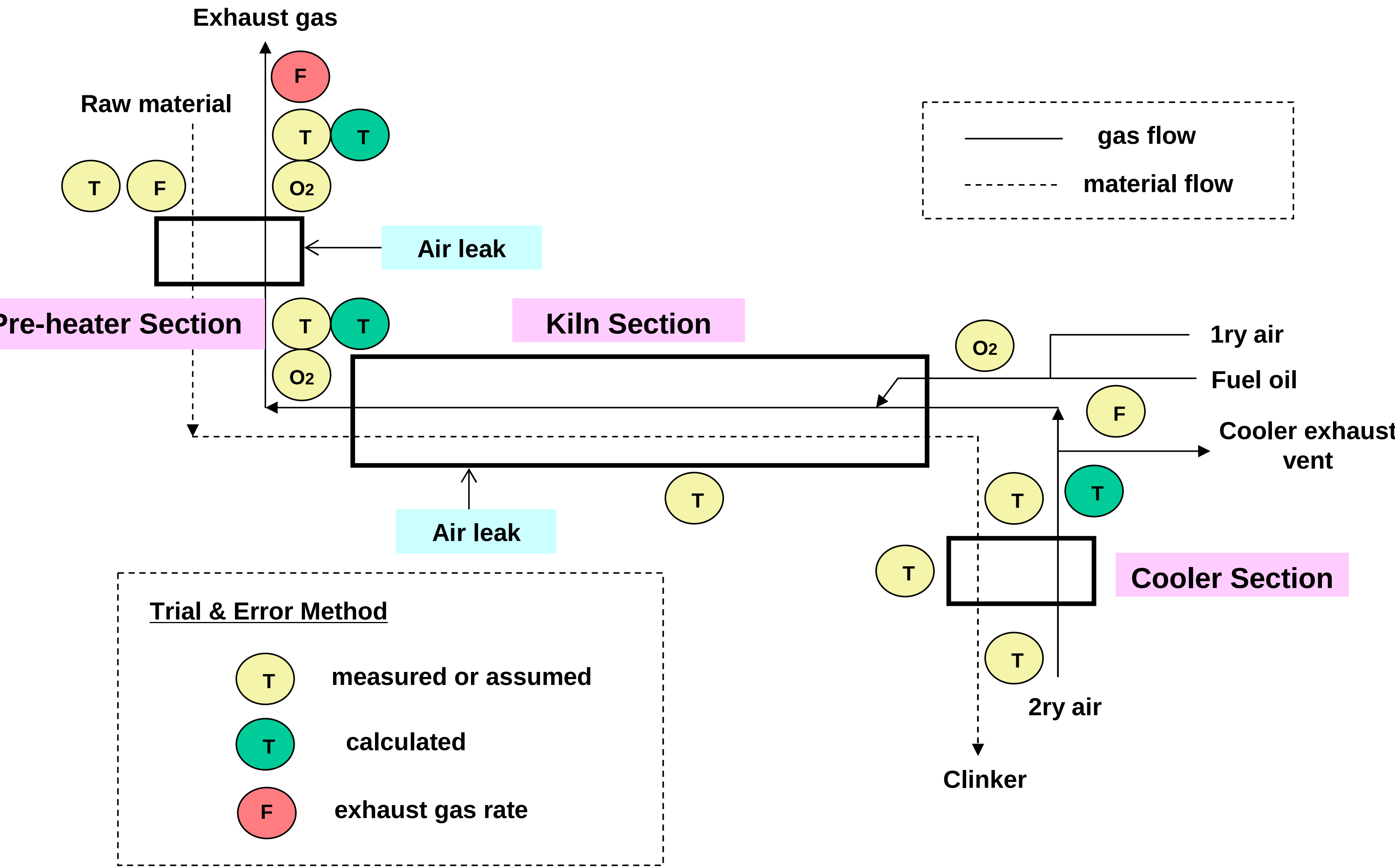
Energy Management System
(Cement Factory)

Aspect		Major Activity
Organization	Accountability	Employee education (awareness)
	Organization	EE&C promotion committee Energy manager
Monitoring	Monitoring	Data recording & reporting to employee
	Targeting	Specific energy consumption (SEC) Key efficiency parameters
Technology		Technical review (energy audit)
Operation & maintenance (O&M)	House keeping	Product yield (avoid off-spec product) Preventive maintenance (avoid unscheduled shutdown)

Energy Saving Measures in Cement Factory

	Raw material section	Clinker burning section	Finishing section
First step	1)Selection of raw materials 2)Management of particle fineness 3)Management of grinding media	1)Prevention of unscheduled shutdown 2)Selection of fuel 3)Prevention of leakage	1) Management of particle fineness 2) Management of grinding media
Second step	1)Replacement of fan rotor 2)Improvement of temperature and pressure control system 3)Improvement of mixing & homogenization system 4)Installation of closed circuit mill (separator)	1)Use of industrial waste (waste tire, etc) 2)Heat recovery of pre-heater exhaust gas and cooler exhaust gas (drying of raw material and generation of electricity) 3)Replacement of cooler dust collection from multiclone to EP	1)Installation of closed circuit mill (separator) 2)Installation of feed control system
Third step	1)Conversion from wet process to dry process 2)Replacement of ball or tube mill by vertical roller mill 3)Pneumatic transfer of raw material to mechanical transfer	1)Conversion of fuel from petroleum to coal 2)Conversion of SP to NSP 3)Conversion of planetary cooler to grate cooler	1)Use of industrial waste (slag, pozzolan)

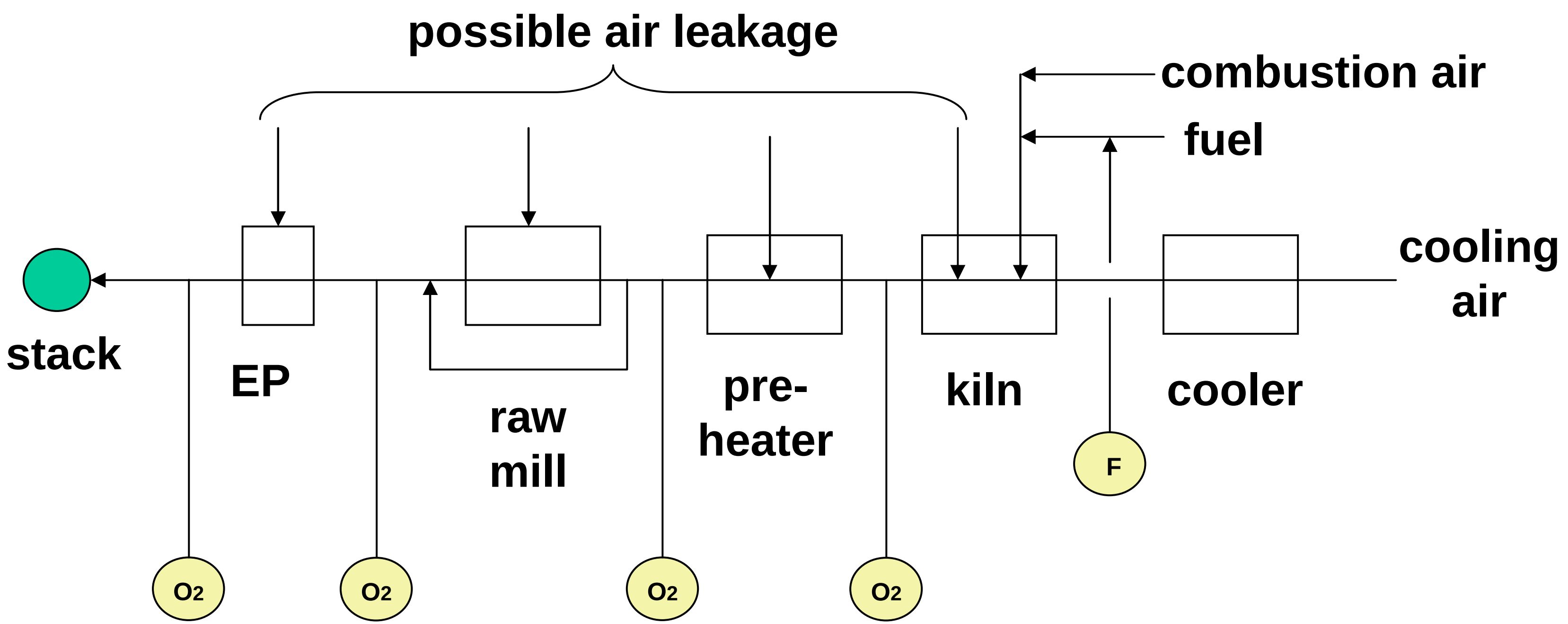
Boundary of Heat Balance (Measurement)



Prediction of Maximum Attainable Production Capacity (Tool : Heat Balance Method)

1	**Principle of prediction:** **Production capacity is approximately proportional to exhaust gas rate which flows through kiln.**
2	**Calculate exhaust gas rate at pre-heater exit or kiln exit (m^3N/kg-cl) by heat balance method**
3	**Compare with exhaust gas rate of well-designed kiln as shown below;** **- SP kiln with Grate cooler : 1.4 m^3N/kg-cl** **- SP kiln with Satellite cooler : 2.0 m^3N/kg-cl** **- Dry kiln : 2.6 m^3N/kg-cl** **- Wet kiln : 2.4 m^3N/kg-cl**

Air Leakage Measurement



Air leakage may bring about an increase of both fuel consumption and fan power consumption.

Air leakage occurred in kiln and pre-heater increases fuel consumption in order for heating leaked cold air up to process temperature.

However, air leakage in EP and raw mill does not normally increase fuel consumption, but it increases required power of fan motor.

Calculation of Energy Loss due to Air Leakage

Location	Leak Amount (m3N/h)	Fuel Increase (kg-oil/h)	Elec Power Increase (kWh/h)
Burner	0		
Kiln Exit	5530	48.9(*1)	18.7(*2)
Preheater Exit	8690	76.8(*1)	29.3(*2)
Raw Mill Exit	36340		28.2(*3)
EP exit	57670		33.1(*4)

Calc Equation of Fuel Loss :
(*1)⊿ fuel = Leak (m3N/h) x 0.31 kcal/m3N・degC x (320 – 30) (degC) /10170
Calc Equation of Elec Power Loss :
(*2) ⊿ elec (kiln fan) = Leak (m3N/h)/60 x (320+273)/273 x 400mmAq /6120 /0.7
(*3) ⊿ elec (RM fan) = Leak (m3N/h)/60 x (90+273)/273 x 150mmAq /6120 /0.7
(*4) ⊿ elec (EP fan) = Leak (m3N/h)/60 x (130+273)/273 x 100mmAq /6120 /0.7
Note : LHV of fuel oil = 10170 kcal/kg
⊿P mmAq Kiln fan(50) Preheater(400) Raw Mill(150) EP(100)

Monitoring of SEC & Key Variables

Section	Monitored Item	Unit
Raw Mill	SEC = Electric Power / Raw Material Charge	(kWh/kg-raw mat'l)
Clinker Burning	SEC = Fuel / Clinker production O2% of Kiln Exhaust Gas	(kcal/kg-cl) (%)
Cement Mill	SEC = Electric Power / Cement Production	(kWh/kg-cement)

Recording of SEC on the Graph

Watch raw mill SEC daily and add grinding balls in right timing

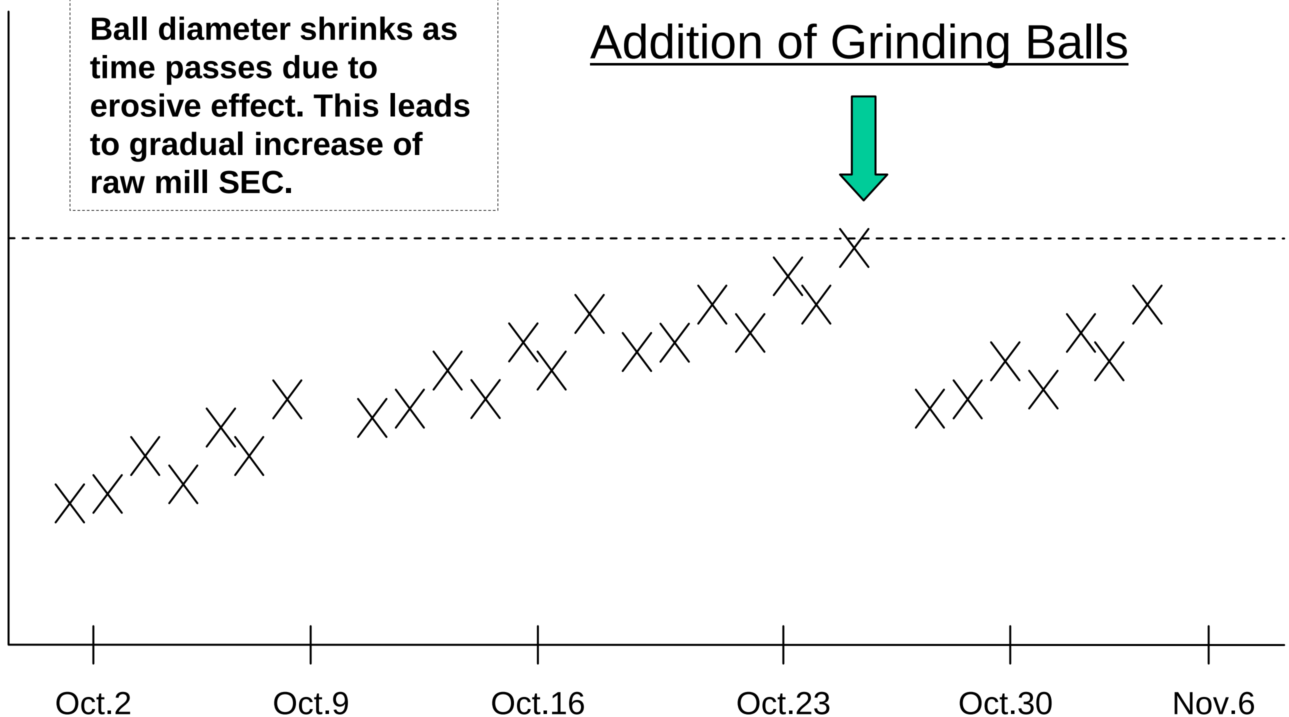
→ 10% energy saving expected

SEC should be monitored daily, and when SEC arrives at certain level, grinding balls is compensated.

Ball diameter shrinks as time passes due to erosive effect. This leads to gradual increase of raw mill SEC.

Raw mill SEC

(kWh/kg-mat'l)



Filling level of grinding balls is also important in grinding efficiency. Optimum level of filling should be maintained.

Example of Monitoring Sheet (Wet Process)

	Eng. unit	10/2	10/3	10/4	10/5	10/6	10/7	10/8
Raw Material Charge	ton/d	760						
Clinker Production	ton/d	500						
Cement Production	ton/d	520						
Elec Cons in Raw Mill	kWh/d	38000						
Fuel Cons in Kiln	10^3xkcal/d	750						
Elec Cons in Cement Mill	kWh/d	36000						
O2 in Kiln Exhaust Gas	vol%	4.5						
SEC of Raw Mill Sect.	kWh/kg-rm	50						
SEC of Kiln Sect.	kcal/kg-cl	1500						
SEC of Finishing Mill Sect.	kWh/kg-ce	69.2						