CEMENT FORMULAE HANDBOOK

VERSION 3.0 **MAY 2019**

Confederation of Indian Industry

CII - Sohrabji Godrej Green Business Centre

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FOREWORD

Growing from a capacity of 301 MTPA in 2010 to 500 MTPA in 2019, the cement industry in India has registered great progress. Cement demand will grow further, helped by the government's push on big infrastructure projects and continued focus on rural development and affordable housing schemes.

With the growth of the sector, the demand for energy will grow substantially. Efficient use and conservation of energy will remain of paramount importance for the cement industry in the future.

Cement plants are adopting the best manufacturing practices and the latest energy efficient technologies, and the industry deserves credit for growing at a fast pace while also reducing its carbon foot print. The CII-GBC has been supporting industry by sharing key insights related to energy efficiency and environment improvement.

The "Cement Formula Handbook (version 3.0)" adds to wide array of publications it has made available to important stakeholders in the cement industry. Many of these stakeholders responded encouragingly to previous editions of this handbook, and based on their feedback, this new edition has been updated to be even more useful to the cement industry professional.

I would request all the readers to make full use of this Cement Formula Handbook (version 3.0) and share it with colleagues and contemporaries. As always, your comments on this new handbook are welcome.

Philip Mathew
Chairman, Green Cementech 2019, CII-Godrej GBC &
Chief Manufacturing Officer, ACC Limited

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FORMULAE

1 QUALITY CONTROL FORMULAE

1. Loss on ignition (LOI) (CO_2 from Calcination)

Ignition loss = $0.44\ CaCO_3 + 0.524\ Mg\ CO_3 + ... +$ combined H_2O + Organic matter

LOI refers to the release of volatile matter such as CO_2, water vapor and other combustibles

2. Silica Modulus/Ratio (SM)

$$SM = \frac{SiO_2}{Al_2O_3 + Fe_2O_3}$$

Typical Range : 1.8 – 2.7

Higher the silica modulus harder to burn and exhibits poor coating properties. Lower the silica modulus there may be more melt phase and coating can become thick and leads to ring formation and low early strength (3-7days) in the cement

3. Alumina Modulus/Alumina iron ratio (AM)

$$AM = \frac{Al_2O_3}{Fe_2O_3}$$

Typical Range : 1.0 – 1.5

Clinker with higher Alumina modulus results in cement with high early strength

4. Lime saturation factor (LSF)

The ratio of the effective lime content to the maximum possible lime content in the clinker.

a. If Alumina modulus > 0.64

$$LSF = \frac{CaO}{2.8\ SiO_2 + 1.65\ Al_2O_3 + 0.35\ Fe_2O_3}$$

b. If Alumina modulus < 0.64

$$LSF = \frac{CaO}{2.8\ SiO_2 + 1.1\ Al_2O_3 + 0.7\ Fe_2O_3}$$

Typical Range : 92 - 105

When the LSF approaches unity, the clinker is hard to burn and often results in excessive free lime.

5. % Liquid

% Liquid	=	$1.13\ C_3A + 1.35\ C_4AF + MgO + Alkalies$
C_3A	:	% of TriCalcium Aluminate
C_4AF	:	% of Tetra-Calcium Alumino Ferrite

MgO Limit to a maximum of 2%

6. Bogue's formula for cement csonstituents

a. If Alumina modulus > 0.64

C_3S	=	$4.071\ CaO - (7.602\ SiO_2 + 6.718\ Al_2O_3 + 1.43\ Fe_2O_3 + 2.852\ SO_3)$
C_2S	=	$2.867\ SiO_2 - 0.7544\ C_3S$
C_3A	=	$2.65\ Al_2O_3 - 1.692\ Fe_2O_3$
C_4AF	=	$3.043\ Fe_2O_3$

b. If Alumina modulus < 0.64

C_3S	=	$4.071\ CaO - (7.602\ SiO_2 + 4.479\ Al_2O_3 + 2.859\ Fe_2O_3 + 2.852\ SO_3)$
C_2S	=	$2.867\ SiO_2 - 0.7544\ C_3S$
C_3A	=	0
$(C_4AF + C_2F)$	=	$2.1\ Al_2O_3 + 1.702\ Fe_2O_3$
Typical value		
C_3S	=	45 – 55 %
C_2S	=	20 – 30 %

7. Degree of calcination

$$C\ (\%) = \frac{(1 - LOI_{sample}) \times (100 - LOI_{feed})}{(100 - LOI_{sample}) \times (LOI_{feed})}$$

where

C Apparent percent calcination of the sample

8. Sulphur to Alkali Ratio

$$\frac{SO_3}{Alkali} = \frac{(SO_3/80)}{(K_2O/94) + (0.5Na_2O/62)}$$

Typical value ~ 1.1

$$\frac{SO_3}{Alkali} = \frac{(SO_3/80)}{(K_2O/94) + (Na_2O/62) - (Cl/71)}$$

Typical value ~ 0.8

Higher sulphur to alkali ratio leads to pre-heater buildups affecting the kiln operation

9. Free Lime

$$\%\text{ free Lime}_{1400} = \frac{0.31\,(LSF - 100) + 2.18\,(SM - 1.8)}{+ 0.73\,Q + 0.33\,C + 0.34\,A}$$

LSF : Lime saturation factor

SM : Silica modulus/ratio

Q : +45 µ residue after acid wash (20% HCl) identified by microscopy as quartz

C : +125 µ residue which is soluble in acid (ie coarse LS)

A : +45 µ residue after acid wash identified by microscopy as non-quartz acid insoluble

Note: Q, C & A expressed as % of total raw mix sample

10. Excess sulphur (gm SO_3/ 100 kg clinker)

Excess sulphur = $(1000 \times SO_3) - (850 \times K_2O) - (650 \times Na_2O)$

Limit : 250 – 600 gm/100 kg clinker

Above these limits, sulphur gives rise to coating problems in Pre-heater tower.

Degree of Sulphatisation in clinker

$DoS = 77.41 \times SO_3 / (Na_2O + 0.658K_2O)$

Typical Control Range of DoS in Clinker is 60 – 140. Higher DoS leads to blockages and ring coating formations

11. Blending ratio

Blending ratio is the ratio of estimated standard deviations of feed and product.

$$\text{Blending ratio} = \frac{\text{standard deviation of CaO in feed}}{\text{standard deviation of CaO in product}}$$

$= (N/2)$

N : Number of layers

For calculating standard deviation

Consider the feed values : $x, x_1, x_2, x_3 \ldots\ldots. x_n$

Mean for the feed values : $\frac{\sqrt{x + x_1} + x_2 + x_3 \ldots. x_n}{n} = x_a$

Standard deviation for the feed :

$\text{sqrt}\{[(x-x_a)^2+(x_1-x_a)^2+(x_2-x_a)^2+....+(x_n-x_a)^2]/n\}$

12. Raw meal to clinker factor

$$\text{Raw meal to clinker factor} = \frac{100 - \text{ash absorbtion}}{100 - \text{LOI}}$$

$$\text{Ash absorbtion} = \%\text{ of ash in fuel x specific fuel consumption}$$

$$\text{Specific fuel consumption} = \frac{\text{kg coal}}{\text{kg clinker}} = \frac{\text{Specific heat consumption}}{\text{NCV of coal}}$$

Note: LOI assumed to be negligible in clinker.

13. Kiln feed to clinker factor

$$\text{Kiln feed to clinker factor} = \frac{\text{Kiln feed (kg)}}{\text{Clinker output (kg)}}$$

Note: Considering error in kiln feeding system as negligible.

(or)

$$\text{Kiln feed to clinker factor} = \frac{\text{Raw Meal to Clinker Factor x (100)}}{\text{Top Stage Cyclone Efficiency}}$$

14. Clinker to cement factor

$$\text{Clinker to cement factor} = \frac{\text{Clinker + Gypsum + Flyash/slag + additives (kg)}}{\text{Clinker consumed (kg)}}$$

15. Insoluble residue

The material remaining after cement is treated with hydro chloric acid of specific concentration and for designed time.

(or)

Insoluble residue can be used to measure amount of adulteration or contamination of cement with sand. Cement is soluble in dilute HCl where as sand is insoluble. The amount of insoluble material determines the level of adulteration. In PPC (Fly-ash) cement, insoluble residue is used to estimate the percentage of fly-ash present in the cement.

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FORMULAE USED IN COMBUSTION CALCULATIONS

1. Conversion of gross calorific value to net calorific value

NCV	=	GCV - 51.50 H (kCal/kg)
H	:	% Hydrogen (sum total of H in the fuel & the moisture)

Gross calorific value (GCV) of a fuel is the heat evolved in its complete combustion under constant pressure at a temperature of 25°C when all the water initially present as liquid in the fuel and that present in the combustion products are condensed to liquid state

Net calorific value (NCV) of a fuel is the heat evolved in its complete combustion under constant pressure at a temperature of 25°C when the water in the system after combustion is taken as vapour.

GCV will be higher than the actual heat released during combustion as the latent heat of water vapor condensation also causes increase in temperature of jacket water surrounded in bomb calorie meter during CV testing.

2. Ultimate analysis

C + H + N + S + O + Ash	=	100 % (by weight)
C	:	% carbon
H	:	% Hydrogen
N	:	% nitrogen
S	:	% sulfur
O	:	% oxygen

The ultimate analysis is useful to calculate the theoretical combustion air required and volume of combustion gases.

3. Proximate analysis

% Volatile + % fixed carbon + % ash + % moisture = 100 %

The proximate analysis involves quantitative determination of moisture, volatile matter, carbon and ash. This analysis is used for quick preliminary appraisal of coal.

4. % Coal ash absorbed in clinker

$$X1 = \frac{CaO_{Clinker} - CaO_{raw\ mix}}{CaO_{ash} - CaO_{raw\ mix}}$$

$$X2 = \frac{SiO_{2\ Clinker} - SiO_{2\ raw\ mix}}{SiO_{2\ ash} - SiO_{2\ raw\ mix}}$$

X3 = $\frac{Al_2O_{3\ Clinker} - Al_2O_{3\ raw\ mix}}{Al_2O_{3\ ash} - Al_2O_{3\ raw\ mix}}$

X4 = $\frac{Fe_2O_{3\ Clinker} - Fe_2O_{3\ raw\ mix}}{Fe_2O_{3\ ash} - Fe_2O_{3\ raw\ mix}}$

% Coal ash absorbed in Clinker = $\frac{X1+X2+X3+X4}{4}$

5. Theoretical air required to burn fuel

Air (kg air/kg of fuel) = $\left(\frac{8}{3} C + 8\left(H_2 - \left(\frac{O_2}{8}\right)\right) + S\right) \times \frac{100}{23}$

C : Mass of carbon per kg of fuel

H_2 : Mass of hydrogen per kg of fuel

O_2 : Mass of Oxygen per kg of fuel

S : Mass of Sulphur per kg of fuel

3 FLAME MOMENTUM CALCULATION

1. Primary air momentum is calculated (% m/sec) :

$$\% \text{ m/s} = L_p \ \% \times C$$

Where :

L_p : The primary air % of the kiln $L_{min\ Flow}$

C : Primary air velocity at the burner nozzle

2. Estimated burner nozzle velocity (v)

$$v \sim 4\sqrt{P_s} \quad \text{m/sec} \quad (P_s \text{ in mmWC})$$

$$v \sim \sqrt{\frac{200 \times P_s}{\rho}} \quad \text{m/sec} \ (P_s \text{ in mbar})$$

Where P_s measured at axial air pressure point

ρ measured as Density

3. Specific impulse (N/MW) – Multi-channel Burner

$$I_s = \frac{\sum_i m_i . v_i}{P_{th}}$$

mi	:	mass flow of air flow (kg/s)
vi	:	velocity of air flow (m/s)
P_{th}	:	thermal power (MW)

Typical control range of I_s in Multi Channel Burners

Natural gas	: ~2-4 N/MW
Heavy oil	: ~4-6 N/MW
Coal/petcoke	: ~6-8 N/MW
Alternative fuels	: up to 12 N/MW

4 Flame momentum calculation of Duoflex burner.

Nozzle Velocity

$$\text{Nozzle Velocity: } c_{pr} = \sqrt{\frac{2k}{k-1} \text{ x } R \left(t_{pr} + 273.15\right) \text{ x} \left[1 - \left(\frac{p_{amb}}{p_{amb} + p_N}\right)^{\frac{k-1}{k}}\right]} \quad [m/s]$$

Flow Function

$$\psi = \sqrt{\left(\frac{p_{amb}}{p_{amb} + p_N}\right)^{\frac{2}{k}} - \left(\frac{p_{amb}}{p_{amb} + p_N}\right)^{\frac{k+1}{k}}}$$

Primary Air Calculation

$$m_{pr} = 10^{-4} \text{ x } A_N \text{ x } k_N \text{ x } \psi(p_{amb} + p_N) \text{ x } \sqrt{\frac{2k}{k-1} \text{ x } \frac{1}{R(t_{pr} + 273.15)}} \quad kg/s$$

Data:

Ambient Pressure	.... p_{amb} (mbar)
Ambient Temperature	.... t_{amb}(^{O}C)
Stroichiometric combustion airflow	.... $L_{min\ Flow}$ (kg/s)
Primary Air Flow Measured	.... m_{pr} (kg/s)
Primary Air Pressure at Nozzle	.... p_N(mbar)
Primary Air Temperature	.... t_{pr} (^{O}C)
Isentropic exponent for air	.... K˜ 1.4
Gas constant	.... R˜ 286.89 (J/kgK)
Nozzle coefficient	.... k_N
Nozzle area	.... A_{Ni}(mm^2)

Burner momentum and Primary air calculation

Kiln feed	292	TPH	Formulas
Kiln production	4380	MTPD	
Mean sea level	330	m	
Ambient pressure	972	mbar	
Amient temperature	32	^{o}C	
Burner capacity	79	MW	
Coal flow rate-C_k	7.4	MTPH	
Calorific value-N_{CV}	7650	kCal/kg	
Total heat in kiln-K_h	65.73	MJ/s	N_{CV} x C_k
Stoichiometric combustion air flow-S_a	22.17	kg/s	N_{CV} x C_k x Lmin/3600
Axial air damper	100	%	
Radial air damper	0	%	
Nozzle coefficient	0.93		
Primary air pressure at nozzle	242	mbar	Given
Primary air temperature	60	^{o}C	
Air nozzle opening	50	mm	Given
Nozzle area	11026	mm^2	From drawing
Primary air measured	3.38	kg/s	
Gas constant	287	J/kgK	
Flow Function	0.2		
Mass Flow Rate of Primary Air	2.14	kg/s	
Nozzle velocity-c_{pr}	165.6	m/s	
Primary Air %	9.6	%	m_{pr}/S_a
Primary air momentum-Pm	1598	% m/s	c_{pr} x mpr
Momentum Impulse	5.39	N/MW	c_pr x P_a/kh
Central air-C_a	5.60	%	(P_{am} - m_{pr}/S_a) x 100
Total primary air	**15.24**	**%**	**C_a + P_a**

P_{am} : Primary Air Measured

m_{pr} : Mass Flow Rate Primary Air Calculated

S_a : Stoichiometric combustion air flow

C_a : Central Air

P_a : Primary Air Percentage

1. Volumetric loading of kiln

$$\text{Volumetric Loading (tpd/m}^3\text{)} = \frac{\text{Clinker Production (tpd)}}{\pi \times (D^2/4) \times L}$$

D : Effective Diameter of the Kiln (m) (ID of kiln)

L : Length of the Kiln (m)

Typical values

Specific volumetric loading for preheater kilns : 1.6 – 2.2 tpd/m^3

Specific volumetric loading for precalciner kilns of modern design : 4.5 to 8.0 tpd/m^3

2. Thermal loading of kiln

$$\text{Thermal Loading} = \frac{\text{Clinker (tpd)} \times \text{Heat consumption} \times \text{\%firing in kiln} \times 10^3}{\pi \times (D^2/4) \times 24}$$

Thermal Loading : (kCal/hr/m^2)

Heat consumption : (kCal/kg)

D : Effective Diameter of the Kiln (m) (ID of kiln)

Specific thermal loading for precalciner kilns of modern design : 4.0 to 6.0 M kCal/hr/m^2

3. Cooler Loading

$$= \frac{\text{Clinker Production (TPD)}}{\text{(Effective grate area (m}^2\text{) of cooler)}}$$

Design : 42-44 TPD/m^2

Max : 54 TPD/m^2

4. Feed moisture evaporation rate

$$\text{Moisture (kg/hr)} = \frac{F_q \times 1000 \times (M_f - M_p)}{100 - M_f}$$

F_q : Fresh feed quantity (tph)

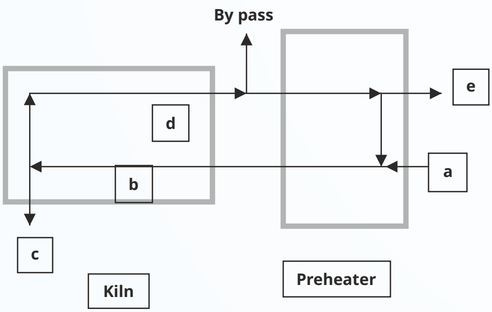
M_f : Total fresh feed surface moisture (%)

M_p : Total product surface moistures (%)

5. Evaporation ratio of kiln volatile cycle

K, Na, S & Cl are all subject to partial evaporation at kiln burning zone temperatures.

Volatization in burning zone and condensation in preheater may be represented as shown below. The external cycles through dust collector are not considered; if dust is not wasted, then virtually all "e" is returned to the kiln.



Evaporation ratio = b/d

Circulation factor = b/a

6. False air estimation O_2 method

$$X(\text{In terms of outlet}) = \frac{O_2\,(\text{outlet}) - O_2\,(\text{inlet}) \times 100\ (\%)}{21 - O_2\,(\text{inlet})}$$

False air estimation by outlet method is commonly used for calculation.

(or)

$$X(\text{In terms of inlet}) = \frac{O_2\,(\text{outlet}) - O_2\,(\text{inlet}) \times 100\ (\%)}{21 - O_2\,(\text{outlet})}$$

7. % Excess air

a. For Complete combustion (Nil CO)

$$\%\ \text{Excess air} = \frac{O_2}{21 - O_2}$$

b. For Incomplete combustion (with CO)

$$\%\ \text{Excess air} = \frac{189\,(2O_2 - CO)}{N_2 - 1.89\,(2O_2 - CO)}$$

HEAT TRANSFER

1. Temperature equivalents

^{o}F	=	$\frac{9}{5} \times {}^{o}C + 32$
^{o}C	=	$\frac{5\,({}^{o}F - 32)}{9}$
Rankine	=	$^{o}F + 459.6$
Kelvin	=	$^{o}C + 273.15$

2. Natural convection loss

Convection Loss	=	$80.33 \times ((T + T_a) / 2)^{-0.724} \times (T - T_a)^{1.333}$
Convection Loss	:	(kCal / hr m^2)
T	:	Surface temperature (^{o}K)
T_a	:	Ambient temperature (^{o}K)

3. Forced convection loss

Convection Loss	=	$28.03 \times (T + T_a)^{-0.351} \times V^{0.805} \times D^{-0.195} \times (T - T_a)$
Forced Convection Loss	:	(kCal / hr m^2)
T	:	Surface temperature (^{o}K)
T_a	:	Ambient temperature (^{o}K)
V	:	Wind speed (m/s)
D	:	Outer diameter of kiln (m)

4. Radiation loss

Radiation loss	=	$4 \times 10^{-8} (T^4 - T_a^4)$
Radiation loss	:	(kCal / hr m^2)
T	:	Surface temperature of kiln (^{o}K)
T_a	:	Ambient temperature (^{o}K)

5. Nusselt number

Nu	=	$\frac{h \times D}{k}$
h	:	fluid film coefficient ($W/m^2\,{}^{o}K$)
D	:	inside diameter of the pipe (m)
k	:	thermal conductivity (W/m ^{o}K)

6. Prandtl number

Pr	=	$\frac{\mu \times Cp}{k}$
μ	:	absolute viscosity (kg/m s)
Cp	:	specific heat (J/kg ^{o}K)
k	:	thermal conductivity (W/m ^{o}K)

6

ECONOMIC INSULATION THICKNESS

A thermal insulator is a poor conductor of heat and has a low thermal conductivity. Insulation is used in buildings and in manufacturing process to prevent heat loss or heat gain.

The insulation thickness for which the total cost is minimum is termed as economic thickness of insulation.

Example for economic insultation thickness

		Insultation thickness, inches		
Description	**Unit**	1"	2"	3"
Length of pipe, L	m	50	50	50
Bare Pipe outer diameter, d1	mm	168	168	168
Bare pipe surface area, A	m^2	26.38	26.38	26.38
Ambient temperature, T_a	^0C	30	30	30
Bare Pipe Wall Temperature, T_h	^0C	160	160	160
Desired Wall Temperature with insultation, T_c	^0C	62	48	43
Material of Insulation	Mineral Wool			
Mean Temperature of Insultation, $T_m = (T_h+T_c)/2$	^0C	111	104	101.5
Sp. Conductivity of Insulation Material, k	W/m^0C	0.044	0.042	0.04
Surface Emissivity of bare pipe		0.95	0.95	0.95
Surface emissivity of insulation cladding (typically Al)		0.13	0.13	0.13

Calculations

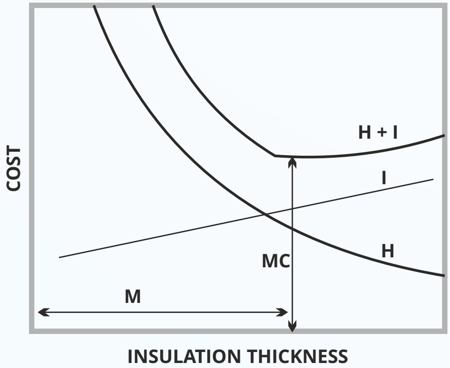
Surface Heat Transfer Coefficient of Hot Bare Surlace, h: $(0.85+0.005 (T_h-T_a))x10$	$W/m^2\ {}^0C$	15	15	15
Surface Heat Transfer Coefficient After Insulation, $h' = (0.31+0.005 (T_c–T_a)) \times 10$	$W/m^2\ {}^0C$	4.7	4	3.75
Thermal Resistance, $R_{th}=(T_h=T_c)/[h' \times T_cT_a)]$	${}^0C\text{-}m^2/W$	0.7	1.6	2.4
Thickness of Insulation, $t=kxR_{th}$: (if surface was flat)	mm	28.7	65.3	96.0
r_1=outer diameter/2 =	mm	84	84	84
$t_{eq} = r_2 \times \ln (r_2/r_1) =$ (select r_2 so that $t_{eq} = t$)	mm	28.7	65.3	106.3
Outer radius of insulation, r_2 =	mm	109.2	135.9	161.9
Thickness of insulation	mm	25.2	51.9	77.9
Insulated pipe Area, A	m^2	34.29	42.66	50.85
Total Losses From Bare Surface, $Q = hxAx(T_h-T_a)$	kW	51.4	51.4	51.4
Total Loss From Insulated Surface, $Q = h' \times A' \times (\pi a)$	kW	5.16	3.07	2.48
Power Saved by Providing Insulation, P= Q-Q'	kW	46.3	48.4	49.0
Annual Working Hours, n	hrs	8000	8000	8000
Energy Saving After Providing Insulation, E = P x n	kWh/year	370203	386892	391634

Calculations

Considering Appr. heat loss cost	₹/kg	0.70	0.70	0.70
Heat Energy Cost, p	₹/kWh	1.11	1.11	1.11
Annual Monetary Saving, S=E x p	₹	412,708	431,313	436,599
Discount factor for calculating NPV of cost of energy loss	%	15%	15%	15%
Cost of Insulation (material +labor)	₹/m	450	700	1,100
Total cost of insulation	₹/m	22,500	35,000	55,000
Annual Cost of energy loss	₹/year	46,000	27,395	22,109
NPV forof annual cost of energy losses for 5 years	₹	154,198	91,832	74,112
Total cost (insulation and NPV of heat loss	₹	176,698	126,832	129,112

Note that the total cost is lower when using 2" insulation, hence is the economic thickness.

The following curve representing the total cost reduces initially and after reaching the economic thickness corresponding to the minimum cost, it increases.



Where :

I : cost of insulation

H : cost of heat loss

I + H : Total cost

M : Economic thickness

MC : Minimum cost

1. Volume changes of gas

V_2	=	$\frac{V_1 \times T_2 \times P_1}{T_1 \times P_2}$
V_1	=	$\frac{V_2 \times T_1 \times P_2}{T_2 \times P_1}$
V_2 (m^3)	:	volume of gas at pressure (P_2) & at temperature (T_2)
V_1 (m^3)	:	volume of gas at pressure (P_1) & at temperature (T_1)
T_1	:	temperature of gas at initial condition (^oC)
P_1	:	atmospheric pressure of gas at initial condition (mm WC)
T_2	:	temperature of gas at final condition (^oC)
P_2	:	absolute pressure of gas at final condition (mm WC)

2. Conversion of actual gas volume to standard gas volume

Q_o	=	$\frac{Q \times 273.15 \times (10336 \pm P_s)\ (Nm^3/hr)}{(273.15 + T) \times 10336}$
Q_o	:	Standard gas volume (Nm^3/hr)
Q	:	Actual gas volume (m^3/hr)
P_s	:	Static Pressure (mm WC)
T	:	Temperature of gas flow (^oC)

3. Conversion of standard gas volume to actual gas volume

Q	=	$\frac{Q_o \times (T + 273.15) \times 10336\ (Nm^3/hr)}{273.15 \times (10336 \pm P_s)}$
Q_o	:	Standard gas volume (Nm^3/hr)
Q	:	Actual gas volume (m^3/hr)
P_s	:	Static Pressure (mm WC)
T	:	Temperature of gas flow (^oC)

8

USEFUL FORMULAE IN KILN DESIGN & OPERATION

1. Kiln effective cross section

Effective Cross Section area (m^2) = $\frac{\pi D^2}{4}$

D : Kiln effective diameter (m) (ID of brick lined kiln)

L : Kiln length (m)

2. Kiln effective volume

Effective volume (m^3) = $\frac{\pi D^2 L}{4}$

D : Kiln effective diameter (m) (ID of brick)

L : Kiln length (m)

3. Kiln % filling

% filling = $\frac{3.2 \times \text{kiln capacity (tpd)}}{D^3 \times \text{Kiln speed (rpm)} \times \text{Kiln slope (\%)}}$

D : Kiln effective diameter (m)

Typical values : 13 – 17%

4. Water consumption in GCT

W_1 (kg/kg clinker) = $\frac{W_2 (0.248)(T_1 - T_2)}{(656.8 - T_3) + (0.48)(T_2 - 100)}$

W_1 : Water added (kg/kg clinker)

W_2 : Weight of exit dry gas (kg/kg clinker)

T_1 : Uncooled gas temperature (°C)

T_2 : Cooled exit gas temperature (°C)

T_3 : Water temperature (°C)

5. Kiln feed retention time

T = $\frac{11.2 \ L(\text{min})}{r \ D \ s}$

L : Kiln Length (m)

r : Kiln Speed (rpm)

D : Effective Diameter (m)

s : Slope (Degrees)

6. Thermal efficiency of cooler

E = $\frac{(Q_c - Q_1) \times 100}{Q_c}$

E : Thermal efficiency of cooler (%)

Q_c : Heat content of clinker, cooler in (kCal/kg)

Q_1 : Total heat losses in cooler (kCal/kg)

CYCLONE EFFICIENCY & PC VESSEL RETENTION TIME CALCULATIONS

Retention Time-Inline Precalciner Vessel

1	Diameter of vessel	m	7.5	Given
2	Effective dia-ed	m	7.072	Dia-2 x (thk)
3	Height-h	m	39.5	Given
4	Effective Volume-Ev	m^3	1551	(3.14 x (ed)2 x h)/(4)
5	Clinker Production-clp	TPD	5000	Given
6	Sp.Heat Consumption-Sp	kCal/kg clinker	680	Given
7	Kiln heat -kh	%	38	Given
8	Sp.Heat Consumption, in kiln,kkh	kCal/kg clinker	258	kh x Sp/100
9	Raw meal -rf	kg/sec.	86.81	(clp x k x 1000)/(24 x 3600)
10	Sp.Heat Consumption, in calciner,ckh	kCal/kg clinker	422	Sp x (100-kh)/(100)
11	Raw meal to clinker factor-k	mt/mt clinker	1.5	Given
12	LOI Raw meal-lrm	%	36.5	Given
13	Calcination of material entering in PC vessel cme	%	20	Given
14	Calcination of material leaving PC vessel cml	%	95	Given
15	Calciner outlet pressure-cop	mmwg	130	Given
16	Site barometric pressure-sbp	mmwg	9914	Given
17	Calciner outlet temperature-cot	^0C	900	Given
18	Kiln inlet oxygen	%	2	Given
19	Calciner outlet oxygen-coo	%	2	Given
20	Secondary air temperature	^0C	1050	Given
21	Tertiary air temperature	^0C	980	Given

22	Clinker Production-clpp	kg/Sec	57.87	(clp x 1000)/(24 x 3600)
23	Stoichiometric air kiln -sak	kg/Sec	21.23	clpp x kkh x 1.42/(1000)
24	Stoichiometric air for calciner -sac	kg/Sec	34.65	clpp x ckh x 1.42/(1000)
25	Gases from kiln coal-gkc	kg/Sec	2.05	(clpp x kkh)/(ncv x (100-cah)/100
26	Gases from calciner coal-gcc	kg/Sec	3.34	(clpp x ckh)/(ncv x (100-cah)/100
27	LOI Raw meal in kiln at kiln inlet-lrk	kg/Sec	1.58	(rf x lrm)/(100) x (100-cml)/(100)
28	LOI Raw meal in PC Vessel-lrc	kg/Sec	25.35	(rf x lrm)/(100) x (100-cme)/(100)
29	Gases at PC vessel without excess air-gwa	kg/Sec	88.20	sak+sac+gkc+gcc+lrk+lrc
30	Gases including excess air-gwe	kg/Sec	97.49	gwa x 21/(21-coo)
31	Std gas density-sgd	kg/Nm^3	1.52	Mean Average weight calc.
32	Gas Volume inside calciner-gvs at stp	Nm^3/sec.	64.14	gwe/sgd
33	Gas Volume-gvct	m^3/sec.	291.13	gvs x (273+cot)/(273 x 10336)/(sbp-cop)
34	Gas retention time	sec.	5.33	Ev/gvct

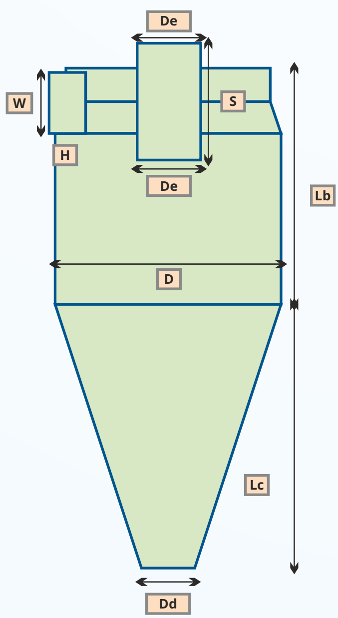
Assumptions

Fired coal details Kiln Firing & Calciner Firing		
Coal type	Imported Coal	
Carbon	%	55
Hydrogen	%	5
Oxygen	%	1
Nitrogen	%	2
Sulphur	%	1
Stoichiometric air required	kg/kg of coal	8.24
NCV of coal-ncv	kCal/kg of coal	5800
Lmin	kg air /M Cal.	1.42
Ash - cah	%	20.5
IM	%	1.5
VM	%	25
Density of combustion gas	kg/Nm^3	1.42

Cyclone Cut off Size

H	Entry height
W	Entry Width
S	Length of diptube
De	Equivalent dia of diptube
Lb	Length of Cylindrical portion
D	Dia of cyclone
Lc	Length of Conical part
Dd	Discharge dia of cone
ρ_m	density of material
ρ_g	density of gases at particular temperature
Number of turns in cyclones-N	$\frac{((Lb+Lc)/2)}{(H)}$
Velocity at inlet-Vin	$\frac{\text{Volume at cyclone inlet}}{(H \times W)}$
Gas residence time in outer vortex	$\frac{(3.14 \times D \times N)}{Vin}$
Cut off size of particle	$\frac{(9 \times \mu \times W) \times 1000000}{((3.14 \times N \times Vin \times (\rho_m - \rho_g)) \wedge 0.5)}$

Entry area dimension	H	0.80	m
	W	0.96	m
Immersion tube dimensions	S	2.26	m
	De	1.50	m
Cylindrical part dimension	Lb	5.33	m
	D	2.80	m
conical part	Lc	3.18	m
discharge dia	Dd	0.55	m
Temperature at Cyclone inlet		800	^{o}C
Pressure at Cyclone inlet		-150	mmWg
density of material		1500	kg/m^3
density of gases(NTP)		1320	kg/m^3
Viscosity of air at temp		0.000023	kg/m.s
Volume at Cyclone inlet		100500	m^3/h
density of the gas		331	kg/m^3
Number of turns in Cyclones		9.00	
Velocity at inlet		36.35	m/s
Gas residence time in outer vertex		2.18	sec
Cut off size of particle		12.82	microns



Efficiency Formulas

Efficiency %	1/(1+(cutsize / % of retained)^2)
cumulative efficiency %	% of retained x efficiency
Efficiency of cyclone	sum of cumulative efficiency

Raw mix particle size and Cyclone efficiency calculation

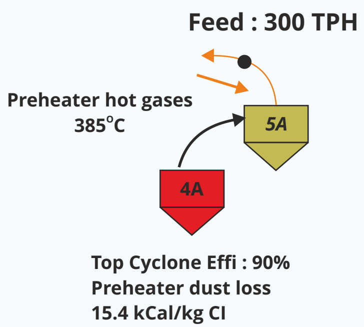
All data's are in Microns size :

Minimum sieve (microns)	maximum sieve (microns)	mean micron size	% of retained	efficiency %	Cummulative efficiency %
212	300	256	3.0	1.00	2.99
150	212	181	1.0	1.00	1.00
90	150	120	15.0	0.99	14.83
45	90	68	39.0	0.97	37.64
20	45	33	29.0	0.87	25.09
0	20	10	13.0	0.38	4.92
			100		

EFFICIENCY OF COLLECTION   86.47%

Impact of Cyclone Efficiency in thermal energy consumption

In current scenario, new cyclones are designed around 97% efficiency with low pressure drop as a consequent the thermal specific energy consumption of many plants has been changed significantly.



	Before Modification	After Modification
Cyclone Efficiency	90	96
Thermal SEC (kCal/kg clinker)	790	781
Heat loss(kCal/kg clinker)	15.4	6

Calculations

Kiln feed to clinker factor	=	1.60
Kiln Feed Rate	=	184 TPH
Kiln Running Hours	=	6000 hr/annum
Present cyclone efficiency	=	90%
Dust loss	=	10%
Material loss	=	0.10 x 1.60
	=	0.16 kg/kg clinker
After improvement	=	96%
Dust loss	=	4%
	=	0.04 x 1.60
	=	0.064 kg/kg clinker
Material gain	=	0.16-0.064
	=	0.096 kg/kg clinker
Energy saving	=	0.096 x 0.25 x 385
	=	**9.24 kCal/kg clinker**
Energy Saving	=	6375 MkCal
Cost of Fuel	=	1100 ₹/MkCal
Annual saving in lakhs	=	₹70.13
Investment in lakhs	=	₹50
Payback	=	9 months

GRINDING MILL INVESTIGATION

1. Internal volume of mill

$$V_m = \frac{\pi D^2 L}{4}$$

V_m	:	Internal volume of the kiln (m^3)
D	:	internal diameter of the mill, liner to liner (m)
L	:	internal length of mill (m)

2. Critical speed of ball mill

The critical speed Nc is the speed, where the centrifugal force at mill lining is equal to the gravitational force.

$$Nc = \frac{42.3}{\sqrt{D}} \quad \text{(RPM)}$$

Normal mill speeds are 74-76% of the critical speed.

3. Ball size calculation

Bond's ball size formula is

$$\phi \max = \frac{20.17 \times \sqrt{F} \times (W_i x \rho)^{1/3}}{\sqrt{K} (\%N_c \times \sqrt{D})^{1/3}}$$

ϕ max	:	Grinding ball Max diameter, mm
F	:	Feed size (μ)
K	:	Constant (335)
Wi	:	Work index (kWh/T)
ρ	:	Specific gravity
%Nc	:	% of critical speed
D	:	Diameter of the mill (m)
Large ball dia	:	0.8 x ϕ max
Small ball dia	:	0.4 x ϕ max

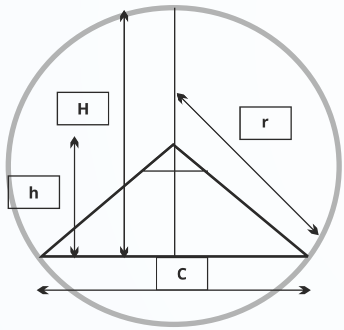
4. Separator efficiency

$$S_e (\%) = \frac{f_p (f_s - f_r) \times 100}{f_s (f_p - f_r)}$$

f_p	:	(%) passing or finish product
f_s	:	(%) passing or separator feed
f_r	:	(%) passing or rejects

Separator efficiency (S_e) is defined as the fraction of fines present in the feed which is recovered with product

5. Mill charge volume



Volume loading (%) = $\frac{100 (\pi x\ r^2 (\theta/360) – h \sqrt{(r^2-h^2)})}{\pi\ x\ r^2}$

r	:	Effective mill radius (m)
H	:	Free height (m)
h	:	H - r
C	:	Width of charge surface
C	:	$2 \times \sqrt{(r^2 - h^2)}$
θ	:	Angle subtended at mill axis by charge surface
$\cos^{1/2}\ \theta$	:	h/r

6. Grindability determined according to hardgrove

Hardgrove's grindabilty index is based on Rittinger's first law of grinding.

Equipment

Grinding bin, with 8 balls (D 25.4 mm) Grinding ring activated by 0.2 kW motor Ring load on bin approx. 29 kg

Sample: 50 g (590 < x < 1190 microns)

Test procedure

50 g of the material, with a particle size limitation of minimum 590 microns and maximum 1190 microns, is prepared and placed in the grinding bin.

After 60 revolutions, the ground material is taken out of the bin and the weight of the material passing through 74 micron sieve is determined.

Sample evaluation

The hardgrove index H may be calculated on the basis of the weight D of the material passing a 74 micron sieve.

H = $13 + 6.93 \times D$

The hardgrove index may be converted into a grindability (work) index

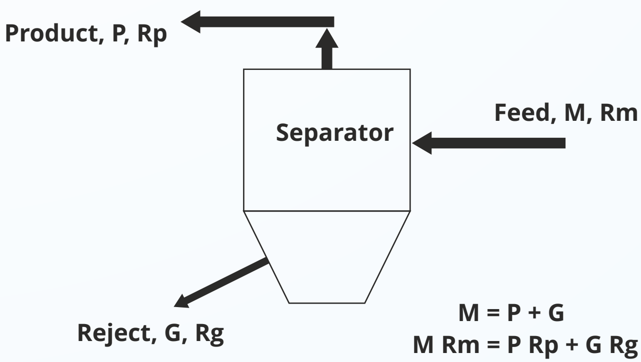
EH = $\frac{480}{H^{0.91}}$ kWh/t

TROMP CURVE CALCULATION AND SIGNIFICANCE

11

Particle size determinations (PSDs) are very useful to determine the operating efficiency of a mill system. The values of the separator product (fines), separator feed, and rejects (tails) can be used to develop a Tromp curve for the separator. The size selectivity curve or Tromp curve describes classifier performance for all particle sizes in the feed to the classifier.

The Tromp curve is a graphical representation of the probability of a particle in the classifier feed exiting with the rejects. The probability can also be expressed as probability of exiting with the product but this is not the convention in cement industry. Using particle size distributions of each of the three streams, a mass balance for incremental size fractions from 1 to 100 for cement, or 1 to 200 for raw meal is performed. Typical curves are shown for a mechanical and a high-efficiency separator respectively.



$$M = P + G$$

$$M\,Rm = P\,Rp + G\,Rg$$

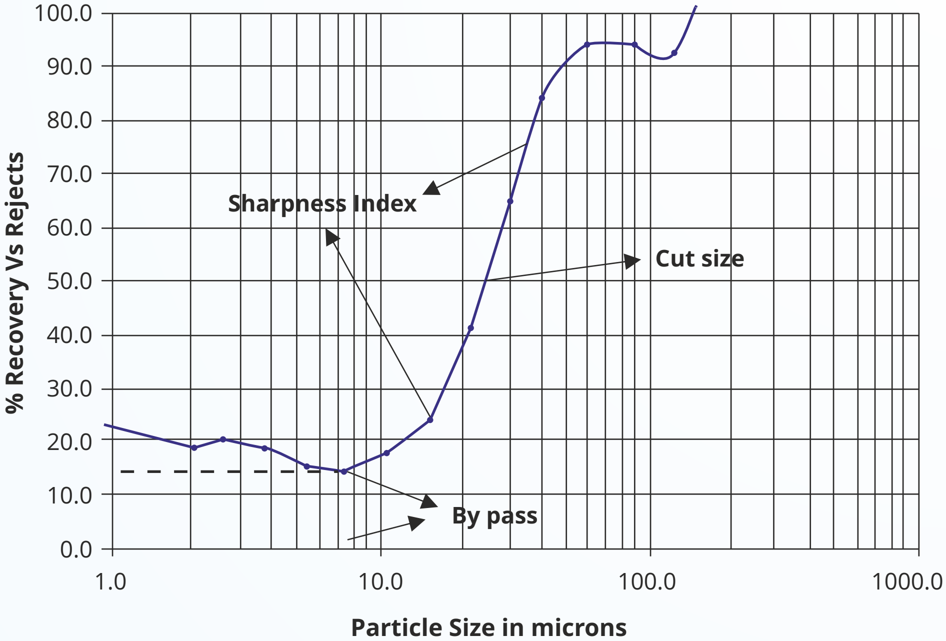
Where:

Rp : % of material retined on particular seive in products.

Rg : % of material retined on particular seive in rejects.

Rm : % of material retined on particular seive in feed.

Typical tromp curve for model PSD analysis in next page



There are three important features of the size selectivity curve,

The ***Classifier cut size(D_{50})*** is commonly defined as the particle size at which there is equal probability of the feed passing to either the coarse or fine streams. The ideal cut size is between 25 and 30 microns for cement.

The ***sharpness index*** is measured by the ratio of d_{25} / d_{75}. The nearer the ratio is to 1.0, the sharper the separation.

Ideal value	:	1.0
Normal	:	0.5 – 0.7

The ***apparent bypass(Bp)*** is the amount of feed that is not classified by the separator and therefore immediately returned to the finish mill with the rejected material.

Ideal separator	:	0
Normal	:	5 – 15%

Many tromp curves exhibit a characteristic tail at the bottom of the curve. This is often an indicator of poor dispersion of the feed in the classifying zone which may be caused either by agglomeration of the feed or by non-uniform distribution of feed in the classifying zone.

Model PSD analysis

Size in microns	Feed Material R_E	Product, R_F	Reject, R_R	Circulation factor, c	$\frac{c-1}{c}$	Tromp value	Average particle size, microns
1.8	92.6	85.6	97.2	2.5	0.60	22.7	0.9
2.2	90.7	81.9	96.6	2.5	0.60	18.9	2.0
3	87.7	75.9	95.6	2.5	0.60	20.0	2.6
4.4	83.9	68	94.4	2.5	0.60	18.9	3.7
6.2	80.4	60.6	93.5	2.5	0.60	15.4	5.3
8.6	76.7	52.9	92.6	2.5	0.60	14.6	7.4
12	72	43.6	91.2	2.5	0.60	17.9	10.3
18	64.9	30.3	88.4	2.5	0.60	23.7	15.0
25	57	18.5	83	2.5	0.60	41.0	21.5
36	43.7	6.3	68.7	2.5	0.60	64.5	30.5
45	34.2	2.1	55.3	2.5	0.60	84.6	40.5
72	15.8	0	26.5	2.5	0.60	93.9	58.5
102	7.4	0	13.3	2.3	0.56	94.3	87.0
146	2.6	0	5.9	1.8	0.44	92.5	124.0
206	0.4	0	1.8	1.3	0.22	111.8	176.0

12 ELECTRICAL ENGINEERING

1. Transformer loss

Transformer loss	=	No load loss + ((% loading/100)^2 x full load copper loss)

2. kVAr (capacitor banks) required to improve power factor

kVAr required	:	kW (tan ϕ 1 - tan ϕ 2)
ϕ 1	:	Cos-^{1}(PF1) and
ϕ 2	:	Cos-^{1}(PF2)

PF1 and PF2 are the initial and the final power factors respectively and kW is the actual loading

3. Three phase alternators

Star connected

Line voltage	=	√3 x phase voltage
Line current	=	phase current

Delta connected

Line voltage	=	phase voltage
Line current	=	√3 x phase current

Three phase power

P	=	$\sqrt{3}\, E_L\, I_L \cos\phi$
E_L	=	line voltage
I_L	=	line current
cos ϕ	=	power factor

FAN ENGINEERING

1. Fan efficiency

Mechanical η %	=	$\frac{\text{Volume } (m^3/s) \times \Delta p \text{ (mmWC)} \times 100}{102 \times \text{power input to fan shaft (kW)}}$
Δp	=	Head developed by the fan
power input to fan shaft (kW)	=	input power to motor (kW) x η_{motor}
η_{motor}	=	Motor efficiency

2. Volume, pressure, power variation with speed of fan

Volume variation with speed

$$\frac{n_1}{n_2} = \frac{Q_1}{Q_2}$$

Q	:	flow rate (m^3/hr)
n	:	fan speed (rpm)

Power variation with speed

$$\frac{n_2}{n_1} = (p_2/p_1)^{1/3}$$

n	:	fan speed (rpm)
p	:	fan horse power (kW)

Pressure variation with speed

$$\frac{n_2}{n_1} = (h_2 / h_1)^{1/2}$$

n	:	fan speed (rpm)
h	:	Head developed by fan (mm WC)

3. Volume, pressure, power variation with impeller diameter of fan

Volume variation with Impeller diameter

$$\frac{Q_2}{Q_1} = (D_2/D_1)^3$$

Q : Volumetric flow rate (m^3/h)

D : fan impeller diameter (m)

Pressure variation with Impeller diameter

$$\frac{h_2}{h_1} = (D_2/D_1)^2$$

h : Static Pressure (mm H_20)

D : fan impeller diameter (m)

Power variation with Impeller diameter

$$\frac{p_2}{p_1} = (D_2/D_1)^5$$

p : Fan horse power (kW)

D : fan impeller diameter (m)

1. Pressure Loss in pipe/ Darcy-Weisbach Formula

$$\Delta p = \frac{f \times L \times \rho \times v^2}{2 \times D}$$

Δp	:	Pressure drop due to friction (pa)
f	:	Darcy friction factor 0.01for large pipes and 0.02for small pipes
L	:	Length of the pipe (m)
D	:	Diameter of the pipe (m)
ρ	:	Density of the fluid (kg/m^3)
v	:	Average velocity of the flow (m/s)

When the fluid is flowing through pipes the major energy loss (i.e. head loss due to friction) in pipes is calculated by using Darcy - Weisbach Formula

2. Reynolds number

Reynolds number expresses the nature of flow.

When N_{Re} < 2100, it is laminar flow

When N_{Re} > 10000, it is turbulent flow

$$N_{Re} : \frac{D \times v \times \rho}{\mu}$$

D	:	diameter of the pipe (m)
V	:	velocity of fluid (m/s)
ρ	:	density of fluid (kg/m^3)
μ	:	viscosity of fluid (kg/ms)

3. Flow measurement using pitot tube

Pitot tubes are used to measure air flow in pipes, ducts, and stacks, and liquid flow in pipes, weirs, and open channels

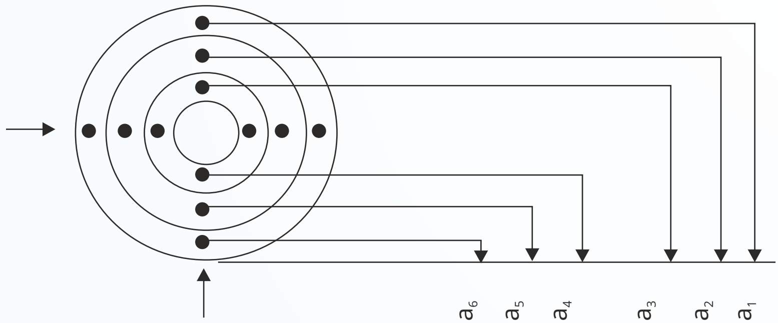
a. Norms for locating measuring point:

- Straight stretch of min 5D before & 2D after the measuring point is necessary (D= inside diameter of the duct)
- As straight stretch as possible
- No bends, flanges or dampers

b. Isokinetic point

b1. For circular ducts :

b2. Rectangular ducts:



Dia	**0<D<300**	**300<D<700**	**700<D<1500**	**1500<D<2400**	**2400<D<3400**
	2x2	2x4	2x6	2x8	2x10
A1=	0.85D	0.93D	0.96D	0.97D	0.97D
A2=	0.15D	0.75D	0.85D	0.90D	0.92D
A3=		0.25D	0.7D	0.81D	0.87D
A4=		0.07D	0.3D	0.68D	0.77D
A5=			0.15D	0.32D	0.66D
A6=			0.04D	0.19D	0.34D
A7=				0.10D	0.23D
A8=				0.03D	0.15D
A9=					0.08D
A10=					0.03D

Equivalent diameter, D = $\frac{2\,L\,W}{L+W}$

The equivalent diameter is used to find out the number of measuring points. Then divide the section into number of equal areas for the measurements.

c. Flow calculations

Barometric pressure (B) = $10336 \times e^{-(0.0001255 \times H)}$ (mm WC)

H : Height above sea level (m)

Density corrected ρ_t = $\rho_N \times \frac{273}{273 + t} \times \frac{B \pm P_s}{10336}$ (kg/m^3)

ρ_N : Normal density (kg/Nm^3)

P_s : Static Pressure (mm WC)

t : Temperature of gas flow (°C)

Velocity (m/s) = Pitot tube cons. x $\frac{\sqrt{(2 \times g \times P_d)}}{\sqrt{\rho_t}}$

g : 9.81 (m/s^2)

P_d : Dynamic pressure (mm WC)

P_t : Corrected Density (kg/m^3)

Q_o = $\frac{Q \times \rho_t}{\rho_o}$ (Nm^3/hr)

Q_o : Standard gas volume (Nm^3/hr)

Q : Actual gas volume (m^3/hr)

ρ_t : Corrected Density (kg/m^3)

ρ_o : Normal Density (kg/Nm^3)

4. Static pressure

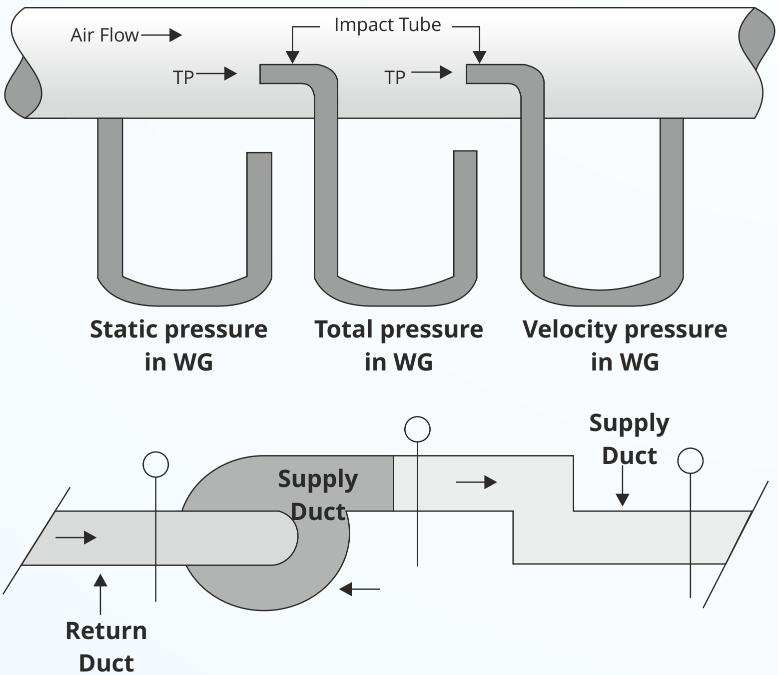
Static pressure is the potential energy put into the system by the fan. It is given up to friction in the ducts and at the duct inlet as it is converted to velocity pressure. At the inlet to the duct, the static pressure produces an area of low pressure.

5. **Velocity pressure**
Velocity pressure is the pressure along the line of the flow that results from the air flowing through the duct. The velocity pressure is used to calculate air velocity.

6. **Total pressure**
Total pressure is the sum of the static and velocity pressure. Velocity pressure and static pressure can change as the air flows though different size ducts, accelerating and decelerating the velocity. The total pressure stays constant, changing only with friction losses.

Total pressure + Static pressure + Velocity pressure

TP+SP+VP



Static, Total and Velocity Pressure

ECONOMIC PIPE THICKNESS

The optimum pipe diameter is the one that gives the least total cost for annual pumping power and fixed charges with the particular piping system.

1. "Rule of thumb" economic velocities for sizing steel pipelines for turblent flow

Type of fluid	Reasonable velocity, m/sec
Water or fluid similar to water	1 – 3
Low pressure steam (25 psig)	15 – 30
Hih pressure steam (100 psig and up)	30 – 60

The preceding values apply for motor drives. Multiply indicated velocities by 0.6 to five reasonable velocities when steam turbine drives are used

2. Economic velocities for sizing steel pipelines for viscous flow.

Nominal pipe diameter, inches	Reasonable velocity, m/sec		
	μc = 50	μc = 100	μc = 1000
1	0.5 – 1.0	0.3 – 0.6	0.01 – 0.1
2	0.7 – 1.0	0.4 – 0.7	0.1 – 0.2
3	1.0 – 1.5	0.7 – 1.0	0.2 – 0.3
8		1.2 – 1.5	0.4 – 0.5

Where :

μc = viscousity, centipoise

3. Formula for optimum pipe inside diameter

a) Turbulent flow in steel pipes with an inside diameter > 1 inch

$$D_{i,opt} \cong 0.363 m^{0.45} \rho^{0.13}$$

where :

$D_{i,opt}$: Optimal inside diameter (m)

m : Volumetric flow rate in m^3/s

ρ : fluid density in kg/m^3.

b) Viscous flow in steel pipes with an inside diameter > inch:

$$D_{i,opt} \cong 0.133 m_V^{0.45} \mu^{0.13}$$

where μ is the fluid viscosity in Pa.s

Note : The above equations are not dimensionally consistent, so we must convert all parameters to the specified units.

4. Economic optimum velocity for

a) Low viscosity liquids in schedule 40 steel pipe - 1.8 to 2.4 m/sec

b) Gases with density ranging 0.2 to 20 kg $/m^3$ - 40 m/sec to 9 m/sec

PIPE LOSS CALCULATION

When a fluid is flowing through a pipe, the fluid experiences some resistance due to which some of the energy of fluid is lost. The loss of energy is classified as

a) Major energy loss

b) Minor energy loss

a) Major energy head loss

Energy loss due to friction in pipe is calculated by Darcy formula

$$h_f = \frac{flv^2}{2gd}$$

where :

f = co-efficient of friction which is a function of Reynold number

$= \frac{16}{R_e}$ for $R_e < 2000$ (viscous flow)

$= \frac{0.079}{R_e^{1/4}}$ for varying from 4000 to 10^6

l = length of pipe, m

v = mean velocity of flow, m/sec

d = diameter of pipe, m

b) Minor energy head loss

1) Loss of head due to sudden expansion

V_1 = Velocity of flow in the smaller section, m/sec

V_2 = Velocity of flow in the larger section, m/sec

2) Loss of head due to sudden contraction

$$h_c = 0.5 \times \frac{2\,V^2}{2g}$$

V_2 = Velocity of flow in the smaller section, m/sec

3) Loss of head at the entrance of the pipe

$$h_i = 0.5 \times \frac{V^2}{2g}$$

V = Velocity of flow in the pipe, m/sec

4) Loss of head at the exit of the pipe

$$h_o = 0.5 \times \frac{V^2}{2g}$$

V_2 = Velocity at the outlet of the pipe, m/sec

5) Loss of head due to obstruction

$$h_o = \frac{V^2}{2g}\left(\frac{A}{C_c\ (A - a)} - 1\right)$$

V = Velocity of liquid in the pipe, m/sec
A = Area of pipe, m^2
a = maximum area of obstruction, m^2
C_c = co-efficient of contraction
C_c is the ratio of the cross-sectional area of the vena contracta(A_a) to the cross sectional area of the orifice (A_o)
$C_c = A_a/A_o$

6) Loss of head due to bend in pipe

$$h_b = \frac{kV^2}{2g}$$

V = Velocity of flow, m/sec
k = Co-efficient of bend
The value of k depends on
i) Angle of bend
ii) Radius of curvature of bend
iii) Diameter of pipe

7) Loss of head due to various fittings

$$\frac{kV^2}{2g}$$

V = Velocity of flow, m/sec
k = Co-efficient of pipe fitting

K- Values for different fittings / valves

Type of fitting / valve	Additional friction loss, equalent number of velocity heads, K
Gate Valve (100% open)	0.17
50% open	4.5
Diaphragm valve (100% open)	2.3
50% open	4.3
Globe valve - bevel seal open	6.0
50% open	9.5
Coupling	0.04
Union	0.04
45^0 ell, standard	0.35
45^0 ell, long radius	0.2
90^0 ell, stabdard	0.75

TYPICAL CHARACTERISTICS OF PNEUMATIC TRANSPORT SYSTEMS

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1. Characteristics of pneumatic conveying systems

Material	Conveying system	Conveying system type	Recommended phase density, kg material/kgair	Specific power consumption
Fine coal	FK pump	Lean phase	4- 6	4.0 – 10 kW / MT
Cement	Air lift	Lean phase	12-16	0.8 - 1.1 kW / MT /100m
Cement	Fluxo pump	Dense phase	50 -80	2.0 -3.0 kW / MT
Raw meal	Air lift	Lean phase	14-16	1.1 – 1.3 kW / MT /100m
Fly ash	Tanker unloading	Dense phase	40-50	1.4 – 1.6 kW/ MT

2. Slip ratio :

The velocity of the particles divided by the velocity of the air transporting the particles

For horizontal pipes the slip ratio : 0.8

For vertical pipes the slip ratio : 0.7

3. Solid loading ratio:

It is the ratio of the mass flow rate of the material conveyed divided by the mass flow rate of the air used to convey the material.

$$\varphi = \frac{m_p}{3.6\ m_a}$$

Where :

φ : Solid loading ratio (dimensionless)

mp : mass flow rate of material (tph)

ma : mass flow rate of air (kg/sec)

appropriate relationship between velocity and pressure drop

$$\Delta p = \frac{L \times \rho \times C^2}{d}$$

Where:

Δp : pressure drop, bar
L : length of straight pipe line, m
ρ : air density, kg/m^3
C : conveying air velocity, m/sec
d : pipeline bore, m

4. The effect of pipe bore

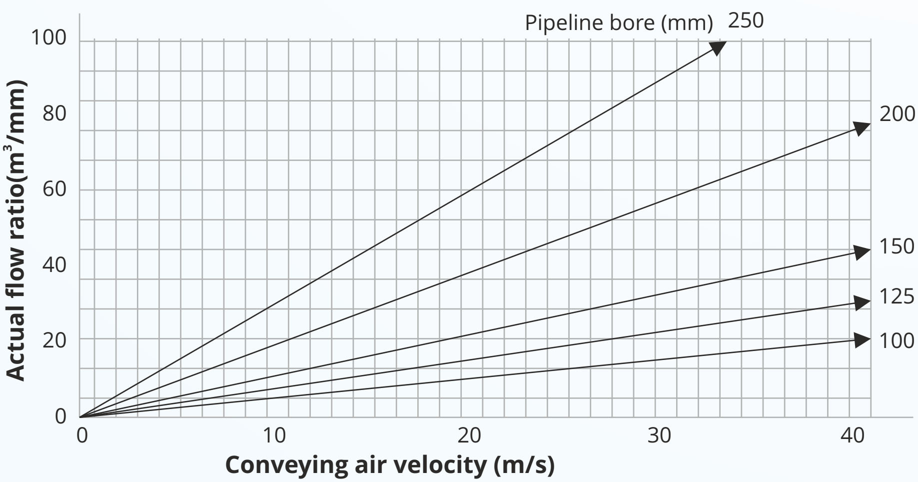
The diameter of a pipeline probably has the most significant effect of any single parameter on volumetric flow rate. The volumetric flow rate through a pipeline depends upon the mean velocity of flow at a given point in the pipeline and the pipe section area. The relationship is:

$$V = C \times A$$

$$V = \frac{\pi \times d^2 \times C}{4}$$

Where:

V : Volumetric flow rate (m^3/s)
C : Conveying air velocity (m/s)
A : Pipe section area (m^2)
d : Pipe bore (m)



The influence of air velocity and pipeline bore on volumetric flow rate

In the above graph conveying air velocities from about 2 to 40 m/s have been considered in order to cover the two extremes of minimum velocity in dense phase conveying and maximum velocity in dilute phase conveying. With pipeline bore as the family of curves this is a linear relationship.

1. Bucket elevator power

Power (kW) = $\frac{k \times C \times H}{367}$

C : load (tonnes/hour)

H : height (m)

k : coefficient varying from 1.2 for fed buckets to 2.0 for nodular material with high scooping resistance

2. Screw conveyor power

Power (kW) = $\frac{2.25 \times (L+9) \times C}{530}$

L : Length (m)

C : Load (tonnes/hour)

3. Drag chain power

Power (kW) = $\frac{C \times L}{220} + 0.8$

L : Length (m)

C : Load (tonnes/hour)

4. Pump efficiency

Pump efficiency η % = $\frac{\text{Pump output} \times 100}{\text{Pump input}}$

= $\frac{\text{Flow (LPS)} \times \text{Head (m)} \times \text{SG} \times 100}{102 \times \eta_{motor} \times \text{motor input (kW)}}$

SG : Specific gravity of working liquid

Capacity α RPM

Head α $(RPM)^2$

Power α Capacity x Head

α $(RPM)^3$

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BEST PRACTICES IN COMPRESSED AIR SYSTEM

1. Best practices in compressed air systems :

- Installing VFD and maintaining constant pressure in the system
- Installing Demand side controller
- Installing Supply side controller
- Installing Auto drain valves for moisture removal

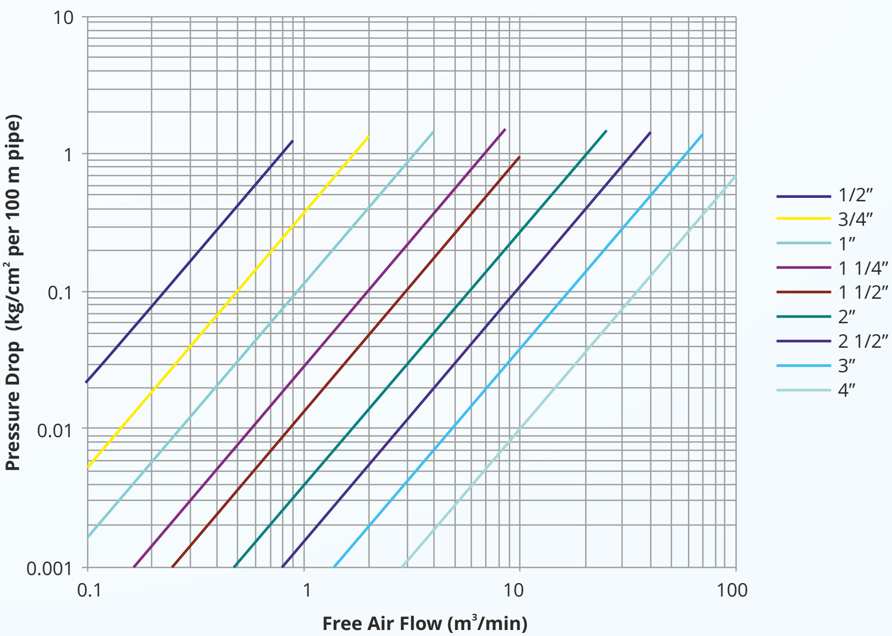
Sl no	Application	Compressed air requirement	Recommended Compressed air pressure (kg/cm^2)
1	Pulse jet Bag filter (process Application)	2.0 -3.0 Nm^3 / hr / 1000 m^3/hr of ventilation volume	5.0-5.5
2	Pulse jet Bag filter (Non process Appliction)	1.6 - 2.4 Nm^3 / hr / 1000 m^3/hr of ventilation volume	4.5-5.5
3	Fluxo pump	20 Nm^3 /tonne - 60 Nm^3 /tonne	3.0-3.5
4	Water spray system (GCT, cement mills)	135 Nm^3/hr @ 3 bar for 1.8 m^3/hr of water spray	4.5-5.0
5	Packing machine		5.0-5.5
6	General Instrumentation		5.0
7	Fly ash conveying	20 m^3/min @ 2 bar for unloading 950 kg/min of fly ash	2.0-2.5
8	Air blaster	Air blaster with 100 litres tank capacity will consume 700 litres FAD @ 7 bar	5.5-6.0

2. Thumb rules for compressed air systems :

- Water consumption/CFM = 350 LPM/1000 CFM (Typical 7.0 ksc Compressor)
- Power consumption for cooling water/CFM = 2.0 kW/1000 CFM (Typical 20 m head pump)
- The maximum pressure drop between the compressor plant and the farthest end of compressed air consumption should be 0.3 bar.
- Air Receiver volume : As per IS 7938-1976 the air receivers can be selected based on the following thumb rule.
  Volume of air receiver in m^3 = 1/10th of flow rate in m^3/min to 1/6th of flow rate in m^3/min
- Recommended velocity in compressed air line : 6 -10 m/sec

3. Pressure drop in a pipeline

Pressure drop in a pipeline is depending upon the quantity of airflow, diameter of the pipeline, pipe length and pipe geometry i.e the bends in the pipe lines.
The pipelines should be with minimum number of Joints, bends and fittings. Further to minimize the joints it should be ensured that joints are welded instead of flexible or screwed joints, wherever possible. This facilitates minimizing the leakages and pressure drop.
The maximum pressure drop between the compressor plant and the farthest end of compressed air consumption should not be more than 0.3 bar.
The pressure drop can be readily obtained from the graph given below.



4. Free air delivered measurement using pump up test method

The pump up test method is the simplest method of estimating the capacity of the compressor in the shop floor itself. The free air delivered can be measured by the plant team themselves without using any sophisticated measuring instruments. The compressor to be tested and a known volume of receiver have to be isolated separately from the main line. Totally empty the compressed air receiver and close the outlet valve of the receiver. Also it should be ensured that there is no condensate water inside the receiver and the drain valve is also fully closed.

Start the compressor and note down the time taken for raise in pressure in the receiver to the normal operating pressure (P2) from the initial pressure (P1). The same exercise can be repeated for about three times.

The free air delivered by the compressed air can be calculated using the following formula.

$$\text{Average Compressor delivery} = \frac{(P_2 - P_1) \times V_R}{P \times t} \ m^3/\text{min.}$$

P_1	:	initial pressure in receiver (kg/cm^2)
P_2	:	final pressure in receiver (kg/cm^2)
P	:	atmospheric pressure (1.033 kg/cm^2)
V_R	:	Volume of air receiver (m^3)
⊗t	:	time taken for charging the receiver from P_1 to P_2 (min)

While estimating the volume of compressed air storage the volume of after cooler, volume of pipeline from the after cooler to the receiver should be included along with receiver volume.

Also, since the compressed air temperature at discharge is higher than the ambient temperature, the free air delivered has to be multiplied by the following correction factor.

$$\text{Correction factor} = \frac{T_{atm} + 273}{T_1 + 273}$$

Where

T_1 : Temperature of compressor at discharge

T_{atm} : Ambient temperature in ^{0}C

4. Compressed air leakage test

The leakage test has to be periodically carried out to estimate the compressed air leakage in the plant. The leakage test has to be carried out, when there are no compressed air users in operation.

Run the compressor and pressurize the system to the normal pressure. Once the system reaches the normal operating pressure the compressor will get unloaded.

If there is no leakage inside the plant the compressor should remain in the unload condition and should not get loaded again. But in actual practice due to compressed air leakages the system pressure will come down and the compressor will go to load mode.

The loading and unloading of the compressor indicates the compressed air leakage inside the plant. Note down the load / unload time (take at least 3 readings)

The compressed air leakage can be estimated using the formula given below.

Air leakage quantity : $\frac{T \times Q}{T + t}$ m^3 / min

% air leakage : $\frac{\text{Air leakage quantity}}{\text{Compressor capacity}} \times 100$

T : On load time of compressor (min)

t : Off load time of compressor (min)

Q : capacity of compressor (m^3 / min)

5. Cost of compressed air leakages

One of the major opportunity for energy saving in compressed air system is to arrest air leakages. The cost of compressed air leakage at 7.0 bar pressure is given below :

Table: Cost of compressed air leakage

Orifice size(mm)	Energy loss(kW)	*Cost of air leakage(₹/year)
0.8	0.2	8000
1.6	0.8	32000
3.1	3.0	1,20,000
6.4	12.0	4,80,000

*Based on ₹3.5/kWh; 8000 operating hours; air at 7.0 bar pressure

6. Compressor power

Iso thermal Power (kW) = P1 x Q1 x $\log_e$(r/36.7)

P1 : Absolute in take pressure (kg/cm^2)

Q1 : Free air delivered (m^3/hr)

r : Pressure ratio P2/P1

7. Compressor efficiency

Isothermal efficiency, η_{iso} = $\frac{\text{iso thermal power}}{\text{Actual measured input power}}$

Isothermal power (kW) = $P_1 \times Q_1 \times \log_e (r/36.7)$

P_1 : absolute intake pressure (kg/cm^2)

Q_1 : free air delivered (m^3/hr)

R : pressure ratio P_2/P_1

P_2 : compressor delivery pressure (kg/cm^2)

Volumetric efficency,

η_{vol} = $\frac{\text{free air delivered } (m^3/min)}{\text{Compressor displacement}}$

Compressor displacement = $\frac{\pi \times D^2 \times L \times S \times \lambda \times n}{4}$

D : cylinder bore (m)

L : cylinder stroke (m)

S : compressor speed (RPM)

ë : 1 for single acting, 2 for double acting cylinder

n : number of cylinders

BAG FILTER OPTIMIZATION

Design Criteria

Air to Cloth ratio:

1.2 m^3/m^2xmin for Slag, Coal and Clinker dust

1.5 m^3/m^2xmin for limestone and Cement dust.

The minimum distance between the bags should be 50 mm.

Number of bags per row

The maximum number of bags per row should not be more than 16 bags.

Number of dust sources to vent:

Maximum 6-8 dust sources to vent should be connected to one dust collector.

Duct Slope:

Max 30 degree for limestone, cement, slag dedusting

Max 45 degree for clinker dedusting

Discharge Chute height:

At material discharge chute, drop height must be not more than 2 m if it is more than 2 m then baffle plates are provided.

Venting air volume:

Following equipment's are considered open:-

1) Apron Conveyor or feeder
2) Bucket Conveyor
3) Crushers
4) Weigh feeders
5) Belt Conveyors

Following equipment's are considered close:-

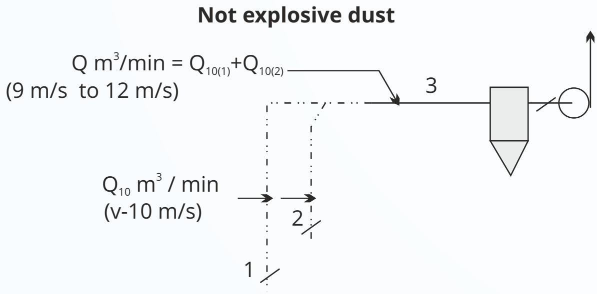
1) Drag Chain
2) Pneumatic Transport System
3) Silos
4) Screw conveyor
5) Air Lift
6) Bucket Conveyor

Velocity Vent Norms

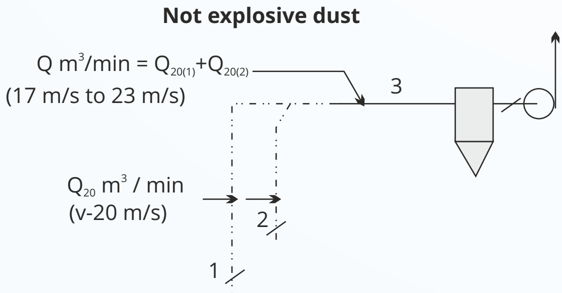
10m/s for non-explosive dust like clinker, slag and fly ash

20 m/s for explosive dust like coal.

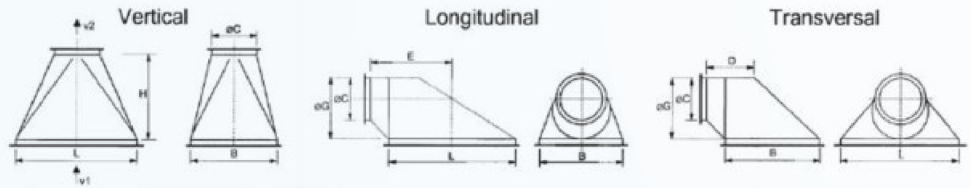
Clinker and other higher abrasive material



Non explosive dust excluding clinker:



Venting hood design Norms

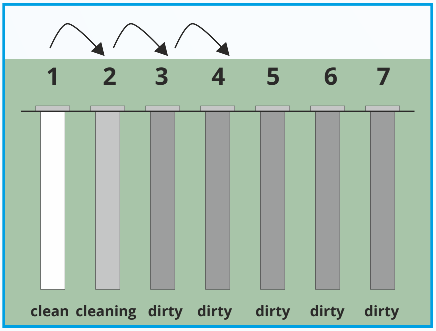


Air Quantity		V1	V2	L	B	H	OC	OG	L	B	E	D
m^3/h	m^3/min	ms-1	ms-1	mm	mm	mm	mm	mm	mm	mm	mm	mm
250	4.2	1.40	18.0	260	190	165	70.0	97	26	190	157.0	122.0
500	8.3	1.40	17.5	37.0	270	235	100.5	143	370	270	227.0	177.5
750	12.5	1.40	17.0	450	330	280	125.0	178	450	330	278.0	218.0
1000	16.6	1.40	17.2	520	380	325	143.5	207	520	380	323.5	253.5
1250	20.8	1.40	17.7	580	425	365	158.0	233	580	425	365.0	287.5
1500	25.0	1.44	17.9	630	460	400	172.0	253	630	460	396.0	311.0
1750	29.2	1.43	17.9	680	500	430	186.0	276	680	500	430.0	340.0
2000	33.3	1.39	17.9	740	540	470	198.0	299	740	540	471.0	371.0
2500	41.6	1.41	18.0	820	600	520	222.0	334	820	600	522.0	412.0
3000	50.0	1.40	17.9	900	660	570	244.0	368	900	660	574.0	454.0
3500	58.3	1.44	17.8	960	700	610	262.0	391	960	700	609.0	479.0
4000	66.6	1.40	18.0	1040	760	660	280.0	426	1040	760	666.0	526.0
4500	75.0	1.42	17.9	1100	800	700	298.0	449	1100	800	701.0	557.0
5000	83.3	1.42	17.9	1150	850	740	314.0	475	1150	850	739.0	589.0
6000	100.0	1.42	17.9	1260	930	800	344.0	524	1260	930	810.0	645.0

*Commercial Pipes and Bends
Sheet Thickness for suction hoods and ducts: 3-4 mm
Intake velocity at hoods according to above table : V1 = ~ 1.4 m/s
Air velocity in dedusting duct: V2 = >18m/s

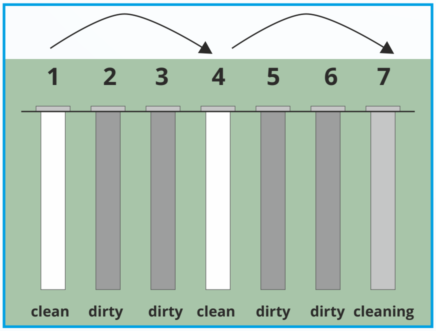
Table of Typical Characteristic							
Fabric type	Can withsatnd maximum temp.	Resistance to					
		Flex abrasion	Moisture	Acid	Base	Organic
Polypropylene	90°C	Good	Excel.	Excel.	Excel.	Excel.
Acrylic	120°C	Good	Good	Good	Good	Good
Polyester	130°C	Excel.	Fair	Fair	Poor	Good
Nomex	190°C	Good	Poor	Poor	Fair	Good
Fibreglass	260°C	Poor	Excel.	Excel.	Excel.	Excel.
PPS	180°C	Good	Good	Good	Excel.	Good

Typical cleaning sequence



Example : Typical bag cleaning sequence

Recommended cleaning sequence



Example : Recommended bag cleaning sequence

Thumb rules:

1) Static pressure below Rotary Air Lock should not be more than 6 mmwg else there is false air in the circuit.
2) Optimum pressure drop across filter 80-120 mmwg that indicates efficient utilization of bag filter capacity.
3) Recommended air pressure for purging is 4.5-5.5 kg/cm^2 and above there is loss of energy.
4) Clean air velocity is generally in the range of 16-18 m/s.
5) Velocity profile should be even in sub branches for effective utilization of bag filter.
6) Dedusting air requirement in CF or blending Silo is to be depended upon aeration as well as air slides blower.
7) Dedusting of air tight clinker silo is to be determined by following formula:-

   Q silo = D^2 x 0.055

   D = Diameter of silo in m
8) In drag chain and screw conveyors the velocity through ventilation flap is 4-6 m/s.

1. Simple payback period

$$\text{Simple payback period} = \frac{\text{Investment (₹) x 12 months}}{\text{Annual saving (₹)}}$$

Simple Payback Period (SPP) represents, as a first approximation the time (number of years) required to recover the initial investment (First Cost), considering only the Net Annual Saving

2. Internal rate of return (IRR)

This method calculates the rate of return that the investment is expected to yield. The IRR method expresses each investment alternative in terms of a rate of return (a compound interest rate).The expected rate of return is the interest rate for which total discounted benefits become just equal to total discounted costs (i.e. net present benefits or net annual benefits are equal to zero, or for which the benefit/cost ratio equals one).The criterion for selection among alternatives is to choose the investment with the highest rate of return.

The rate of return is usually calculated by a process of trial and error, whereby the net cash flow is computed for various discount rates until its value is reduced to zero.

The internal rate of return (IRR) of a project is the discount rate, which makes its net present value (NPV) equal to zero.

$$0 = \frac{CF_0}{(1+k)^0} + \frac{CF_1}{(1+k)^1} + ... + \frac{CF_n}{(1+k)^n} = \varepsilon^{n}_{t=0} \frac{CF_t}{(1+k)^1}$$

Cf_1	:	cash flow at the end of year "t"
k	:	discount rate
n	:	life of the project

CF_t value will be negative if it is expenditure and positive it is saving.

Internal Rate of Return (IRR) - measure that allow comparison with other investment options

3. Net present value (NPV)

NPV is defined as the excess difference between the present value of cash in flow and present value of cash out flow.

Net Present Value (NPV) - measures that allow financial planning of the project and provide the company with all the information needed to incorporate energy efficiency projects into the corporate financial system.

The Net Present Value of a project is equal to the sum of the present values of all the cash flows associated with it.

$$NPV = \frac{CF_0}{(1+k)^0} + \frac{CF_1}{(1+k)^1} + \text{--------} + \frac{CF_n}{(1+k)^n} = \sum_{t=0}^{n} \frac{CF_t}{(1+k)^t}$$

CF_t	: Cash flow occurring at the end of year 't'
n	: Life of the project
k	: Discount rate

The discount rate (k) employed for evaluating the present value of the expected future cash flows should reflect the risk of the project.

SAFETY FORMULAE

1. Accident frequency rate

Accident frequency rate is defined in terms of number of accidents per million man-hours worked

$$f = \frac{n \times (1 \times 10^6)}{h}$$

f	:	frequency rate
n	:	number of accidents during period under investigation
h	:	number of man-hours worked during the same period

2. Severity rate

Accident severity rate is defined in terms of the number of days lost due to accidents per 1000 man-hours worked

$$s = \frac{1000 \times d}{h}$$

s	:	severity rate (days lost/1000 man-hours)
d	:	days lost in period
h	:	total man-hours worked in same period

3. Safety performance

$$\text{Percent frequency} = \frac{100 \times f}{f_{std}}$$

$$\text{Percent severity} = \frac{100 \times s}{s_{std}}$$

f	:	frequency rate
s	:	severity rate (days lost/1000 man-hours)

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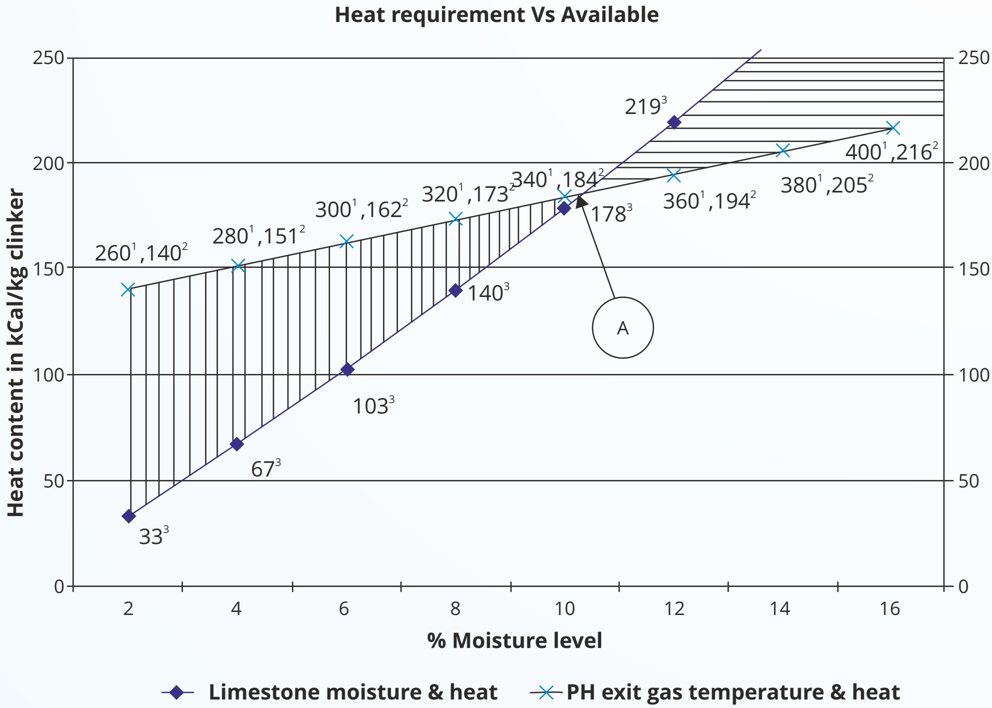
DETAILS ON WASTE HEAT RECOVERY (WHR)

Waste heat recovery is now emerging as an excellent addition to existing captive power generation. Other than reducing energy cost significantly, it can also be a reliable source of power.

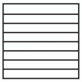


Notes:

1. 260[1] – To be read as preheater exit gas temperature 260°C
2. 140[2] – To be read as heat content available in the preheater gas in kCal / kg clinker
3. 33[3] – To be read as heat requirement for raw mill @ 2 % moisture level in kCal/kg clinkger

The interesting point (Point A) at 190 kCal/kg is the maximum point at about 340°C and 10% moisture. From this curve the following conclusions can be made:

If the operating conditions are falling under this region of vertical lines it means that waste heat is available for recovery



If the operating conditions are falling under this region of horizontal lines it means that waste heat is not at all available and we need to provide extra heat in addition to heat in preheater gas to raw mill.

- If the preheater exit temperature is less than 340, waste heat is available only if the moisture is less than 10%
- For 4% moisture content heat requirement is 67 kCal/kg clinker hence waste heat is available with almost entire range 260°C (7 stage) to 400°C (4 stage – old design). Higher the temperature more will be the heat available for waste heat recovery
- For moisture more than 10% we need to maintain minimum 340°C at preheater outlet temperature even without waste heat recovery

Heat requirement for Various Moisture levels									
Moisture in Limestone	%	2	4	6	8	10	12	14	16
Heat required for moisture drying	kCal / kg clinker	32.8	66.9	102.5	139.7	178.5	219.0	261.5	306.0

Heat available at different preheater exit temperatures									
Preheater exit temp	Deg C	260	280	300	320	340	360	380	400
Heat available in PH gas	kCal / kg clinker	140.4	151.2	162.0	172.8	183.6	194.4	205.2	140.4

Sample calculation for estimating waste heat recovery potential

1.1 Basic data & Assumptions:

1. Kiln capacity : 3000 tonnes per day
2. No of stages in the preheater : 5
3. Preheater exit gas details
   a. Volume (m_{PH}) : 1.5 Nm^3 /kg clinker
   b. Specific heat capacity($C_{P\ PH}$): 0.36 kCal / kg / ^0C
   c. Temperature T_{PH1}: 316 ^0C
4. Cooler exit gas details :
   a. Volume (mC): 1.0 Nm^3 /kg clinker
   b. Specific heat capacity CPC: 0.317 kCal / kg / ^0C
   c. Temperature TC : 300 ^0C
5. Limestone moisture content LM : 2 %
6. Raw mill running hrs : 22 hrs /day
7. Kiln running days per annum : 335 days
8. Heat transfer efficiency of WHR boiler - EFFWHR : 85 %
9. Heat transfer efficiency of AQC boiler – EFFAQC: 85 %
10. TG system efficiency EFFTG : 33 %
11. Specific heat consumption : 700 kCal / kg clinker
12. Raw coal moisture : 15 %
13. Raw meal to clinker factor : 1.55
14. Heat requirement for moisture in raw mill & Coal mill: 950 kCal / kg water
15. Calorific value of fine coal used : 5000 kCal / kg coal
16. Coal mill running hrs per day : 20
17. PH gas temperature at WHRB outlet TPH2: 240 ^0C
18. Cooler exit temperature at AQC boiler outlet TC2 : 120 ^0C

1.2 Calculations:

1. Heat available in the preheater gas :

Q_{PH}	:	m_{PH} x $C_{P\ PH}$ x T_{PH1}
	:	1.5 x 0.36 x 316
	:	170.6 kCal / kg clinker

2. Heat required for Raw mill

a. Raw mill capacity	:	3000 x 1.55 x 24 / 22
	:	5073 TPD

		:	211 TPH
		:	1.688 kg / kg clinker
	b. Moisture in raw mill	:	[211 x 100 / (100 - 2)] – 211
		:	4.3 TPH
		:	34.4 kg / MT clinker
	c. Heat requirement for raw mill	:	34.4 x 950 / 1000
		:	32.7 kCal / kg clinker
		:	33 kCal / kg clinker
3.	Heat requirement for coal mill		
	a. Coal requirement	:	
	Specific coal consumption	:	700 / 5000
		:	0.14 kg coal / kg clinker
	Coal mill capacity	:	0.14 x 125 x 24 / 20
		:	21 TPH
4.	Moisture evoparation in coal mill		
		:	{21 x 100 /(100 – 15)} – 21
		:	3.7 TPH
		:	30 kg / MT clinker
5.	Heat requirement for raw mill		
		:	30 x 950 / 1000
		:	28.5 kCal / kg clinker
		:	29 kCal / kg clinker

Excess heat available in the preheater:

Heat available in the ph gas minus heat required for Coal mill & raw mill

	Excess heat available (preheater)	:	170.6 – (29 + 33)
		:	108.6 kCal / kg clinker
6.	Heat available in the Cooler exit gas	:	
	Q_C	:	m_C x C_{PC} x T_C
		:	1.0 x 0.317 x 300
		:	95.1 kCal / kg clinker
7.	Total excess or waste heat available	:	

Extra heat available in the preheater + cooler

	:	108.6 + 95.1
	:	203.7 kCal / kg clinker

8. Heat recoverable in Preheater side Boiler

Q_{WHRB} : m_{PH} x C_{PPH} x (T_{PH1} - T_{PH2}) : 1.5 x 0.36 x (316 – 240)

: 41.0 kCal / kg clinker

9. Heat recoverable in Cooler side Boiler

Q_{AQC} : m_C x C_C x (T_{c1} - T_{c2})

: 1.0 x 0.317 x (300 – 120)

: 57.0 kCal / kg clinker

1. Heat available to steam for power generation :

: Q_{WHRB} x EFF_{WHR} + Q_{AQC} x EFF_{AQC}

: 41.0 x 0.85 + 57.0 x 0.85

: 83.3 kCal / kg clinker

10. Power generation possible :

Heat available in the steam x

TG efficiency : 83.3 x 0.33

: 27.5 kCal / kg clinker

: 0.03197 kWh / kg Clinker

: 31.97 kWh / MT of clinker

: 4.0 MW

11. Water requirement for Water cooled condenser :

Heat to be removed in the condenser :

: 83.3 x (100 – 33)/ (0.85 x 100)

: 66 kCal / kg clinker

Make up Water requirement : 56 / 540

: 0.1222 kg water / kg clinker

: 15.3 TPH

: 3.8 MT /MW

WHR Calculations for Cement Plant

Parameters	Unit	Mid Tapping to boiler from cooler	PH-1 to boiler	PH-2 to boiler
Pitot Tube Constant		0.84	0.84	0.84
MSL	mt.	440	440	440
Measured height	mt.	30.00	40.00	40.00
Barometric press	mmwg	9743.96	9731.74	9731.74
flow Temp	deg C	446.00	265.00	260.00
Temp	deg K	719.00	538.00	533.00
Static pressure (draught)	mmwg	-4.00	-438	-485
Dynamic press	mmwg	6.55	8.00	8.31
Density	kg/Nm^3	1.29	1.41	1.41
Density	kg /m^3	0.46	0.64	0.65
Velocity	m/sec	14.01	13.12	13.34
Duct C.S. dia	mt.	3.750	3.150	3.150
Duct C.S. area	m^2	11.04	7.79	7.79
Vol Flow	m^3/hr	557012	368038	374250
Vol Flow	m^3/sec	154.73	102.23	103.96
Vol Flow	m^3/min	9283.53	6133.97	6237.50
Vol Flow	Nm^3/hr	199298	167924	171488
Mass flow	kg/min	4285	3946	4030
Mass flow	kg/hr	257094	236772	241798
Mass flow	kg/s	71.42	65.77	67.17
Mass flow	T/hr	257	237	242

WHR Formulas

Parameters	UOM	Operating	Formula	Design
PH-1 Flow to Boiler	Nm^3/hr	167924		199000
PH-1 Flow Inlet Temperature	deg C	265.00		304
PH-1 Heat Input to Boiler	kCal/hr	16019909.75	0.36 x PH-1 Flow to Boiler x PH-1 Flow Inlet Temperature	21778560
PH-1 Flow Outlet Temperature	deg C	191		201
PH-1 Heat Output from Boiler	kCal/hr	11546425.51	0.36 x PH-1 Flow to Boiler x PH-1 Flow Outlet Temperature	14399640
PH-2 Flow to Boiler	Nm^3/hr	171488		199000
PH-2 Flow Inlet Temperature	deg C	260.00		304
PH-2 Heat Input to Boiler	kCal/hr	16051267.95	0.36 x PH-2 Flow to Boiler x PH-2 Flow Inlet Temperature	21778560
PH-2 Flow Outlet Temperature	deg C	173		201
PH-2 Heat Output from Boiler	kCal/hr	10680266.75	0.36 x PH-2 Flow to Boiler x PH-2 Flow Outlet Temperature	14399640
Cooler Flow Inlet to Boiler	Nm^3/hr	199298		152000
Cooler Flow Inlet Temperature	deg C	446		400
Cooler Heat Input to Boiler	kCal/hr	27732704	0.312 x Cooler Flow Inlet to Boiler x Cooler Flow Inlet Temperature	18969600
Cooler Flow Outlet Temperature	deg C	128		88
Cooler Heat Output from Boiler	kCal/hr	7959162	0.312 x Cooler Flow Inlet to Boiler x Cooler Flow Outlet Temperature	4173312
MP Steam to Turbine Flow	TPH	30		40.56
MP Steam Pressure	Bar	9.7	(Pressure kg/cm^2 + 1) x 0.9807	13
MP Steam Temperature	Deg C	362		373
MP Steam Enthalpy	kCal/kg	761	h_pt(MS Steam Pressure,MS Steam Temperature)/4.186	766
LP Steam to Turbine Flow	TPH	2.6		2.2
LP Steam Pressure	Bar	3.9	(Pressure kg/cm^2 + 1) x 0.9807	4.39
LP Steam Temperature	Deg C	210		204.6
LP Steam Enthalpy	kCal/kg	688	h_pt(LP Steam Pressure, LP Steam Temperature)/4.186	686

Heat Input to turbine	kCal/hr	24629818	(MP Steam Enthaply x MP Steam to Turbine Flow x 1000)+(LP Steam Enthailpy x LP Steam to Turbine Flow x 1000)	32579651
Steam Out to Turbine	TPH	33	MP Steam to Turbine Flow + LP Steam to Turbine Flow	42.76
Steam Out to Turbine Pressure	kg/cm^2 (a)	0.12		0.098
Steam Out to Turbine Enthalpy	kCal/kg	49.5		45.9
Heat Output from turbine	kCal/hr	1613708	Steam Out to Turbine x Steam Out to Turbine Enthalpy x 1000	1961334
Power Generation	MW	5		6.8
Turbine Heat Rate	kCal/kWh	4603.22	(Heat Input to turbine-Heat Output from turbine)/(Power Generation x 1000)	4502.69
Heat used for Power generation	kCal/hr	23016110	Heat Input to turbine-Heat Output from turbine	30618317
Waste Heat Supplied to Boiler	kCal/hr	29618028	(PH-1 Heat Input to Boiler-PH-1 Heat Output from Boiler)+(PH-2 Heat Input to Boiler-PH-2 Heat Output from Boiler)+(Cooler Heat Input to Boiler-Cooler Heat Output from Boiler)	29554128
Effective Utilization of Heat	%	77.71	Heat used for Power generation/Waste Heat Supplied to Boiler x 100	103.60
Equivalent Heat to Power Generation	kCal/hr	4300000	Power Generation x 1000 x 860	5848000
Efficiency	%	14.52	Equivalent Heat to Power Generation/Waste Heat Supplied to Boiler x 100	19.79

23 MISCELLANEOUS FORMULAE

1. COP of refrigerator

$$COP = \frac{\text{Cooling effect (kW)}}{\text{Power I/P to compressor (kW)}}$$

Cooling effect : Difference in enthalpy across the evaporator & expressed in kW

2. Boiler efficiency

$$\eta\ (\%) = \frac{ms \times (h1 - h2) \times 100}{mf \times CV \text{ of fuel}}$$

ms	:	Mass flow rate of steam (kg)
h1	:	Enthalpy of steam produced in boiler (kJ/kg)
h2	:	Enthalpy of feed water to boiler(kJ/kg)
mf	:	Mass flow rate of fuel (kg)
CV of fuel	:	Calorific value of fuel (kJ/kg)

3. Cooling tower performance

Range

Range = Cooling tower water inlet temperature (°C) - Cooling tower water outlet temperature (°C)

Approach

Approach = Cooling tower oulet cold water temperature (°C) – ambient wet bulb temperature (°C)

Cooling tower effectiveness

$$\text{Cooling tower effectiveness} = \frac{\text{Range}}{\text{Range + approach}}$$

Cooling capacity = $m \times Cp \times (T_1 - T_2)$

m	:	mass flow rate of water (kg/hr)
Cp	:	specific heat capacity (kJ/kg °C)
T_1	:	Cooling tower water inlet temperature (°C)
T_2	:	Cooling tower water outlet temperature (°C)

Evaporation loss

It is the water quantity evaporated for cooling duty.

Evaporation loss (m^3/hr) = 0.00085 x 1.8 x circulation rate x (T_1–T_2)

where :

circulation rate in m^3/hr

Cycle of concentration (COC)

It is the ratio of dissolved solids in circulating water to the dissolved solids in make up water.

Blow down

Blow down : $\frac{\text{Evaporation loss}}{\text{COC - 1}}$

CAPTIVE POWER PLANT

1 BOILER

1. Boiler Efficiency calculation by indirect method

Relationship between GCV and NCV

$$GCV = NCV + 5.84 ((9H_2\% + M\%)/100)$$

Where GCV - Gross Calorific Value

NCV - Net Calorific Value

H_2 - Hydrogen in fuel

M - Moisture in fuel

Relationship between Ultimate and Proximate Analysis

Relationship Between ultimate Analysis And proximate Analysis			
	%C	=	0.97C+0.7(VM-0.6-0.01M)
	%H	=	0.36C+0.086(VM-0.1xA) – 0.0035M2(1-0.02M)
	$\%N_2$	=	2.10-0.020 VM
Where			
	C	=	% of fixed carbon
	A	=	% of ash
	VM	=	% of volatile matter
	M	=	% of moisture

Energy Release from various combustion reactions

$C + O_2 \rightarrow CO_2$ + 8084 kCal/kg of Carbon

$2C + O_2 \rightarrow 2CO$ + 2430 kCal/kg of carbon

$2H_2 + O_2 \rightarrow 2H_2O$ + 28,922 kCal/kg of Hydrogen

$S + O_2 \rightarrow SO_2$ + 2,224 kCal/kg of Sulphur

Boiler Efficiency Calculation

Step 1

a) Theoretical air required for combustion	=	[(11.6 x C) + {34.8 x (H_2-O_2/8)} + (4.35 x S)] -100 kg/kg of fuel. [from fuel analysis] Where C, H_2 ,O_2 and S are the percentage of carbon, hydrogen, oxygen and sulphur present in the fuel.

Step 2

b) % Excess Air supplied (EA)	=	O_2% x100 [from flue gas analysis] 21-O_2%

Step 3

c) Actual mass of air supplied/kg of fuel (AAS)	=	{1+EA/100} x Theoretical air

Step 4 : Calculation of Losses

a. Dry Flue Gas Loss

$$L1 = \frac{m x C_p x (T_f - T_a)}{(GCV\ of\ fuel)} x100$$

Where,

L_1 = % Heat loss due to dry flue gas

m = Mass of dry flue gas in kg/kg of fuel

= Combustion products from fuel: CO_2+SO_2+Nitrogen in fuel + Nitrogen in the actual mass of air supplied + O_2 in flue gas. (H_2O/Water vapour in the flue gas should not be considered)

C_p = Specific heat of flue gas in kCal/kg

T_f = Flue gas temperature in ^{0}C

T_a = Ambient temperature in ^{0}C

b. Heat Loss due to evaporation of water formed due to H_2 in fuel

$$L2 = \frac{(9 \times H_2 \times \{584 + C_p(Tf - T_a)\})}{(GCV\ of\ fuel)} \times 100$$

Where,

H_2 = kg of hydrogen present in fuel on 1 kg basis

Cp = Specific heat of superheated steam in kCal/kg ^{0}C

Tf = Flue gas temperature in ^{0}C

Ta = Ambient temperature in ^{0}C

584 = Latent heat corresponding to partial pressure of water vapour in kCal/kg

c. Heat Loss due to moisture present in fuel

$$L3 = \frac{(M \times \{584 + C_p(T_f - T_a)\})}{(GCV\ of\ fuel)} \times 100$$

Where,

M = kg of moisture in fuel on 1 kg basis

Cp = Specific heat of superheated steam in kCal/kg ^{0}C

Tf = Flue gas temperature in ^{0}C

Ta = Ambient temperature in ^{0}C

584 = Latent heat corresponding to partial pressure of water vapour in kCal/kg

d. Heat Loss due to moisture present in air

$$L4 = \frac{(AAS \times humidity\ factor \times C_p \times (T_f - T_a))}{(GCV\ of\ fuel)} \times 100$$

Where,

AAS = Actual mass of air supplied per kg of fuel

Humidity factor = Kg of water/kg of dry air

C = Specific heat of superheated steam in kCal/kg ^{0}C

T_f = Flue gas temperature in ^{0}C

T_a = Ambient temperature in ^{0}C (dry bulb)

e. Heat Loss due to incomplete combustion

$$L5 = \frac{\%CO \times C}{\%CO + \%CO_2} \times \frac{5654^*}{GCV \text{ of fuel}} \times 100$$

L5 = % Heat loss due to partial conversion of C to CO

CO_2 = Volume of CO in flue gas (%) (1%=10000ppm)

CO_2 = Actual Volume of CO_2 in flue gas (%)

*Heat loss due to partial combustion of carbon, kCal/kg of carbon.

f. Heat Loss due to radiation and convection

L6 = $0.5480 \times [(T_8 / 55.55)^4 - (T_a/55.55)^4] + 1.957 \times (T_8 - T_a)1.25 \times$ sq.rt of $[(196.85V_m+68.9)/68.9]$

Where

L_6 = Radiation loss W/m^2

V_m = Wind velocity in m/s

T_s = Surface temperature(K)

T_a = Ambient temperature (K)

g. Heat Loss due to unburnt in fly ash (%)

$$L_7 = \frac{\text{Total ash collected /kg of fuel burnt x G.C.V of fly ash}}{\text{GCV of fuel}} \text{x100}$$

h. Heat Loss due to unburnt in bottom ash

$$L_8 = \frac{\text{Total ash collected /kg of fuel burnt x G.C.V of fly ash}}{\text{GCV of fuel}} \text{x100}$$

Boiler Efficiency

Boiler efficiency by indirect method = 100 – ($L_1+L_2+L_3+L_4+L_5+L_6+L_7+L_8$)

where,

L_1 Dry flue gas

L_2 Loss due to hydrogen in duel

L_3 Loss due to moisture in fuel

L_4 Loss due to moisture in air

L_5 Partial combustion of C to CO

L_6 Surface heat losses

L_7 Loss due to Unburnt in fly

L_8 Loss due to unburnt in bottom ash

2. Air Heater

Air preheater Performance

$$\text{Air preheater Leakage} = \frac{\text{AH Outlet } O_2 - \text{AH Inlet } O_2}{20.9 - \text{AH Outlet } O_2} \times 100$$

Air preheater Gas Exit Temperature corrected to no leakage

$$= \frac{\text{AH Leakage}}{100} \times \frac{CP_{air}}{CP_{gas}} \times \text{(Gas out temp – Air Inlet Temp) + (Gas out Temp)}$$

$$\text{Air preheater X Ratio} = \frac{\text{Gas inlet temperature – Gas Outlet Temperature}}{\text{Air Outlet Temperature – Air Inlet Temperature}}$$

Air preheater Gas Side Efficiency

$$= \frac{\text{Gas Inlet Temperature - Gas Outlet Temperature}}{\text{Gas Inlet Temperature – Air Inlet Temperature}} \times 100$$

3. Boiler Blowdown

$$\text{Blow down(\%)} = \frac{\text{[Feed water TDS x \% Make up water] x 100}}{\text{(Maximum Permissible TDS in Boiler water - Feed water TDS)}}$$

1. Turbine formulas

Turbine Isentropic Efficiency

Turbine stage (isentropic) efficiency, %

$$= \frac{\text{Actual enthalpy drop across the turbine, kCal/kg}}{\text{Stage (isentropic) enthalpy drop across the turbine, kCal/kg}} \times 100$$

Turbine heat rate

Turbine heat rate $= \frac{\text{Steam flow (MS Enthalpy – Feedwater Enthalpy)}}{\text{Generation}}$

Overall Plant heat rate

Overall heat rate $= \frac{\text{Coal Consumption x GCV}}{\text{Generation}}$

Net heat rate = Gross heat rate / (1 – APC %)

Plant Load Factor $= \frac{\text{Total Generation x 100}}{\text{Maximum Possible Generation}}$

Plant Availability Factor $= \frac{\text{Available number of hours of plant* (where it can generate power)}}{\text{Total number of hours in that time period}}$

Available Hours = Plant Running hours + Hours because of deemed loss (no schedule)

Or

= Total hours – breakdown hours (both planned and unplanned)

Auxiliary Power Consumption

$$= \frac{\text{Total Auxiliary Power Consumption}}{\text{Total Generation x 100}}$$

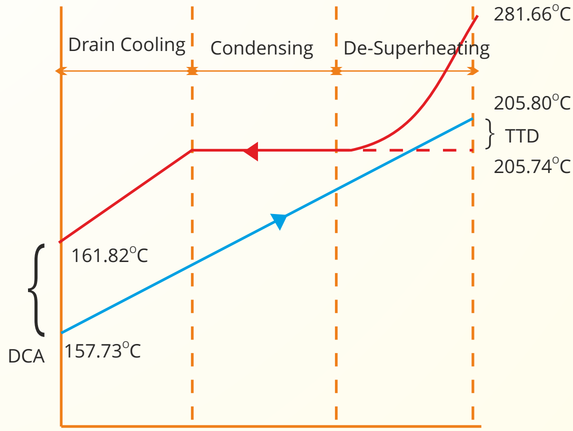
2. Typical Heat Rate deviation Sheet (Values taken for a 60 MW Power Plant)

Gross Heat Rate Deviation Analysis			
Parameter	**Variation than designed value**	**Effect on heat Rate (kCal.kWh)**	**Design / Base Value**
Heat rate deviation due to controlable parameters			
Start up loss	-	-	-
Partial Loading (Full dispatch) Partial Loading (Less dispatch)	1.0%	1kCal/kWh if partial load <20 % or 3.58 kCal/kWh if partial load is >20%	0.00
Condenser Back Pressure	`-0.01 K sc	16.00	0.9030
Main Steam temp.	-1°C	1.39	537.00
Main Steam Pressure	`-0.1kg/cm^2	0.28	90.04
DM Make-up Water	`+1%	12.00	1.00
SH Spray	`+1.0% of live steam	0.70	0.00
Excess Oxygen	`+1%	10.00	3.50
Final Feed Water Temp.	`-1°C	0.42	242.60
Flue gas Temperature (corrected to no leakages)	`+1°C	1.20	140.00
Unburnt in bottom ash	`1%	10.00	1.95
Unburnt in fly ash	`+1%	16.00	1.95

1. Heater Performance

TTD = Saturation Temperature (of Extraction Steam) – Feed water outlet temperature

DCA = Drip Temperature – Feed water inlet temperature



2. Cooling tower Performance

Cooling Tower Approach = Cooling water temperature - Wet bulb temperature

Cooling Tower Range = Cooling Tower outlet temperature - Cooling tower inlet temperature

$$\text{Effectiveness} = \frac{\text{Range} \times 100}{(\text{Range} + \text{Approach})}$$

Condenser Performance Evaluation

Parameter	Description	Values	Remarks
Condesner pressure	Design (Ps)		
Sat Temperature (Design - at vacuum)	Design (Tsd)		
CW inlet	Design (Cwid)		
CW outlet	Design (Cwod)		
Condesner pressure	actual (Pa)		
Sat Temperature (actual - at vacuum)	actual (Tsa)		
CW inlet	actual (Cwia)		
CW outlet	actual (Cwoa)		
Delta CW	Design (Δd)	Cwod-Cwid	
Delta CW	Actual (Δa)	Cwoa-Cwio	
TTD	Design	Tsd-Cwod	
TTD	Actual	Tsa-Cwoa	
Cooling water inlet Actual + Delta CW design+ TTD design	Temp1	Cwia+Δd+TTDdesign	
Corresponding Condenser pressure for above	Pexp1	Saturation Pressure @Temp 1	
Cooling Water inlet Actual + Delta CW Actual +TTD design	Temp 2	Cwia+Δa+TTDdesign	
Corresponding Condenser pressure for above	Pexp2	Saturation Pressure @Temp 2	
Cooling Water inlet actual + Delta CW Actual + TTD Actual	Temp 3	Cwia+Δa+TTDactual	
Corresponding Condenser pressure for above	Pexp3	Saturation Pressure @ Temp 3	
Effect of condener pressure due to CW inlet temp		Pexp1-Ps	negative values means improvement, +ve value means deterioation
Effect of condener pressure due to heat load /CW flow		Pexp2-Pexp1	negative values means improvement, +ve value means deterioation
Effect of condener pressure due to air ingress and dirty tubes		Pexp3-Pexp2	negative values means improvement, +ve value means deterioation

NORMS

1 MOISTURE LEVEL OF VARIOUS LIMESTONE

S.No.	Cluster	Limestone Moisture %*
1.	Junagadh-Gujarat	> 8
2.	Ariyalur-Tamilnadu	> 8
3.	Gulbarga-Karnataka	2 - 5
4.	Kota-Rajasthan	2 - 5
5.	Yerraguntla-Andhra Pradesh	2 - 5
6.	Nalgonda-Andhra Pradesh	2 - 5

*Based on the data collected for various plants

2 ELECTRICAL ENERGY CONSUMPTION TARGET

S. No	Company Name	SEC kWh/MT clinker
1	Plant 1	43.3
2	Plant 2	45.11
3	Plant 3	47.12
4	Plant 4	47.92
5	Plant 5	48.36
6	Plant 6	49.77
7	Plant 7	50.35
8	Plant 8	50.44
9	Plant 9	50.52
10	Plant 10	51.35

Source: CII National Energy Award Data

Area of activity	Electrical consumption (kWh / Ton of Clinker)**
Crushing	1.1
Raw mill	19.5
Kiln and Cooler	18.9
Coal mill	2.0
Miscellaneous	1.6
Total	43.3

**Based on the best operating plant

THERMAL ENERGY CONSUMPTION TARGET

3

Parameter	Specific Fuel Consumption (kCal / kg Clinker)*
Theoretical heat consumption	412
Pre-heater loss	137
Cooler loss	
(Clinker & Cooler vent gases)	113
Radiation loss	61
Heat Input	43
Total	680

*Based on the best operating plant

Best thermal consumption in India 2017-18

S. No	Company Name	Sp. Thermal Energy Consumption kCal/kg clinker
1	Plant 1	675
2	Plant 2	680
3	Plant 3	682
4	Plant 4	689
5	Plant 5	693
6	Plant 6	693
7	Plant 7	697
8	Plant 8	697
9	Plant 9	699
10	Plant 10	700
11	Plant 11	700

Source: CII Energy Award & Energy Audit Data

4

OPERATING HOURS

Typical operating hours to be used for sizing of the equipment

S.No.	Department	Operating hrs/Day
1.	Mines**	10
2.	Crusher**	10
3.	Raw Mill (Ball mill, VRM)	21
	Raw mill (Roller press)	20
4.	Coal mill (Ball mill, VRM)	21
5.	Kiln	24
6.	Cement Mill (Ball mill, VRM + Horrow mill)	21
	Cement mill (Roller press)	20
7.	Packing Machine	15

** 2% Handling losses and 15% safety margin should be considered while sizing Mines and Crusher.

5

DAYS OF STORAGE

S.No	Item / Equipment	Days for storages
1.	Limestone Storage/ Preblending Stockpilex	7
2.	Raw Meal Storage (Active)	1 - 1.5
3.	Clinker	7-15
4.	Cement	3-10
5.	Fuel Storage*	15-30 (depending upon lead time)
6.	Additive / corrective*	15-30 (depending upon lead time)
7.	Slag	7 - 15 (depending upon lead time)
8.	Fly ash	3 - 7 (depending upon lead time)

* Capacity calculated should be inclusive of moisture content and handling loss (2%)

COMPARISON BETWEEN DIFFERENT DRY PROCESS TECHNOLOGIES

6

S. No.	Parameter	Unit kilns	Preheater (ILC)	Preheater with precalciner		
1.	No of cyclone stages	Nos	4	4	5	6
2.	Kiln capacity range	TPD	1000 - 2500	2000 - 8000		
3.	Top stage exit temperature	°C	390	360	316	260
4.	Heat availability in preheater exhaust	kCal / kg clinker	216	180	155	140
		MkCal / hr for 1 MMTPA*	27.0	22.5	19.4	17.5
5.	Specific heat consumption	kCal / kg clinker	800	725	700	685

* MMTPA - Million Metric Tonnes per Annum.

KILN & PRE-HEATER

7

S.NO	Parameters	Unit	Norms
1.	Specific thermal loading (max)	G cal/h/m^2	4.0 - 5.0
2.	Specific volumetric loading (Sustainable)	tpd/ m^3	4.5 - 6.5
3.	Specific volumetric loading (Peak)	tpd/ m^3	7.0
4.	Percentage filling	%	13 – 17
5.	Retention time (Minimum)		
	In Line calciner		3.2
	Separate Line calciner	Sec.	2.6
	Caciner with Pet coke firing		4.5
6.	Tertiary air temperature	°C	850 – 1000
7.	Secondary air temperature	°C	1000 – 1200
8.	Burner flame momentum, (normal coal)	% m/s	1400 – 1600
9.	Burner flame momentum, (Pet coke)	% m/s	1800 - 2200
10.	Margin in Burner capacity	%	25

8 KILN GAS VELOCITIES

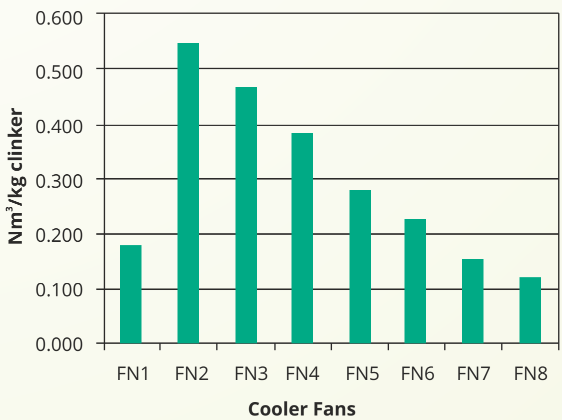
	Upper Limit-Velocity (m/s)
Through cooler grate	5
Hood	6
Under cooler bull-nose	15
Burning zone (1450 $^{\circ}$C)	9.5
Feed end transition (1000 $^{\circ}$C)	13
Riser	24
Preheater gas ducts	18
	Lower Limit-Velocity (m/s)
Tertiary air duct	25
Pulverized coal conveying	25

9 COMPARISON BETWEEN DIFFERENT TYPES OF COOLERS

S.No.	Parameter	Unit	1st Generation	2nd Generation	3rd Generation
1.	Grate plate type		Vertical aeration with holes in the plate	Horizontal aeration	Horizontal aeration
2.	Cooling air input	Nm^3/kg clinker	2.0 – 2.5	1.8 - 2.0	1.4 - 1.5
3.	Cooler exhaust air volume	Nm^3/kg clinker	1.0 – 1.5	0.9 – 1.2	0.7 – 0.9
4.	Heat availability in cooler exhaust	kCal / kg clinker	100 -120	80 - 100	70 - 80
		MkCal /hr for 1 MMTPA	12.5 – 15.0	10.0 – 12.5	8.8 – 10.0
5.	Recuperation efficiency	%	<65	<70	>73

Identification of Cooler Null Point

COOLER FANS	Mass flow rate (kg/kg clinker)	Nm^3/kg CLINKER
FN1	0.179	0.139
FN2	0.551	0.427
FN3	0.469	0.363
FN4	0.385	0.299
FN5	0.281	0.218
FN6	0.228	0.177
FN7	0.155	0.120
FN8	0.120	0.093
Total Flow	**2.37**	**1.84**



Null point for normal coal-0.75 Nm^3/kg clinker
Null point for pet coke- 0.80 Nm^3/kg clinker
From the above
Null point-FN1+FN2+FN3=0.92 Nm^3/kg clinker

Note:
For perfect cooler operation –vent air should not be more than 1.0 Nm^3/kg clinker and stoichiometric combustion air requirement as per null point.

Stack Height Calculation

Chimney Effect = 353 x Chimney Height x [1/ Stack gas temperature – 1/ Ambient Temperature]

Description	Chimney Height	Chimney Effect	Fan head	Saving Potential
	Mtr	mmWC	mm WC	kW
Present Condition	22	-10.6	95	4.7
Proposed Condition	32	-15.5	90.16	

Saving Calculations

Fan operating power	=	92.87 kW
Fan head	=	95 mmWC
Present chimney height	=	22 m
Stack gas temperature	=	260 °C
	=	260+273
	=	533 K
Ambient air temperature	=	35 °C
	=	35 + 273
	=	308 K
Chimney Effect	=	353 x Chimney Height x [1/ Stack Gas temp – 1/ Ambient Temp]
	=	353 x (1/533 – 1/308) x 22 m
	=	-10.6 mmWC
Proposed height	=	32 m
New Chimney effect	=	353 x (1/533 – 1/308) x 32 m
	=	-15.5 mmWC
Savings	=	15.5-10.6
	=	4.9 mmWC
New fan head	=	95 mmWC – 4.9 mmWC
	=	90.1 mmWC
Savings in fan head	=	4.9 mmWC
Power savings	=	$\frac{4.9 \text{ mmWC} \times 92.87 \text{ kW}}{95 \text{ mmWC}}$
	=	4.7 kW

PRIMARY AIR MOMENTUM

10

S.No.	Burner Type	Uniflow	Swirlax	Centrax	Duoflex
1.	Normal Volume % Lp	15-20 %	10-15%	4-5%	6-8%
2.	Nozzle velocity C (m/s)	60-75	125-200	320-360	200-210
3.	Fan Pressure m bar	80-100	120-250	750	250
4.	Pipe velocity m/s	25-30	25-30	25-30	25-30
5.	Momentum LP% x C(%m/s)	1200- 1500	1200- 2000	1200- 1450	1200- 2000

ELECTRO STATIC PRECIPITATOR

11

An electrostatic precipitator is a large, industrial emission-control unit. It is designed to trap and remove dust particles from the exhaust gas stream of an industrial process.

Pressure drop : 15 – 20 mm WC

Power Consumption : 0.2 – 0.3 kWh/1000m^3

Migration velocity : 0.07 - .10 m/sec

Dust resistivity : 107 – 1011 ohm-cm

Efficiency : 75 – 80% Efficiency varies with the particle size

Operation of the ESP is described by the Deutsch formula: $n= 1 – e^{-(\omega \times A/Q)}$

where:

n = efficiency (%)

ω = particle migration velocity (m/sec)

A = Area of the collecting plates (m^2)

Q = Gas flow rate (m^3/sec)

12 HARMONIC LEVELS

Supply System Voltage (kV) at point of common coupling	Total Harmonic Voltage Distortion VT (%)	Individual Harmonic Voltage Distortion (%)	
		Odd	Even
0.415	5	4	2
6.6 and 11	4	3	1.75
33 and 66	3	2	1
132	1.5	1	0.5

IEEE G.5/3 Sept. 1976 : Limits for Harmonics.

13 TYPICAL DATA FOR DIFFERENT LIGHTING- EFFICECY, LIFE ETC

Colour Rendering Index (CRI)

Description	CRI
Natural sunlight	100
GLS	Closer to 100
Color 80 series	80
T5	85
Metal halide	85
HPMV	75
HPSV	40

Type	Watt	Efficacy (Lumen/W)	Life (Hours)
GLS	100	14	1000
Fluorescent Conventional	36	68	5000
T5 Lamp	28	104	20000
HPMV	250	54	5000
HPSV	250	108	6000-12000
Metal halide	250	80	10000-15000
CFL	20	60	8000-10000

A Brief Conversion Table from Conventional Lighting to LED:

Incandescent in Watts	CFL in Watts	MH/HPS in Watts	Lumens Needed	LED Equivalent in Watts
250	65	100	4000	40
300	80	125	4800	48
400	100	150	6000	60
450	125	175	7000	70
500	150	250	8000	80
600	175	320	10000	100
1000	300	400	16000	160
2000	500	750	30000	300
NA	NA	1000	40000	400
NA	NA	1500	60000	600
NA	NA	2000	80000	800

Note: The values provided for Metal Halide Lamp is an Average Lumens that it delivers during its course of Life. As we know Metal Halides degrade or lose their lumens fast and dramatically. Usually they lose 70% of Light over their lifetime. Generally, they lose 30% of the light in the first 1000 Hours alone.

IS Standard for Average illuminance to be maintained at different Locations:

IS Standard for Average Illuminance at Different Locations	
Industrial Buildings & Processes	**Average Illuminance**
I) General Factory Areas	
a) Canteens	150
b) Clock-rooms	100
c) Entrances, corridor, stairs	100
II) Factory Outdoor Areas	
stockyards, main entrances and exit roads, car parks	
internal factory roads	20
III) Assemble shops	
a) Rough work, for example, frame assembly and assembly of	
heavy machinery	150
b) medium work, for example, machine parts, engine assembly,	
vehicle body assembly	300
c) fine work, for example, radio and telephone equipment,	
typewriter and office machinery assembly	700
d) very fine work, for example, assembly of very small precision	
mechanisms and instruments	1500
IV) Boiler House (Industrial)	
a) coal and ash handling	100
b) Boiler rooms	
i) Boiler fronts and operating areas	100+
ii) Other areas	20 to 50
c) outdoor plants:	
I) Cat Walk	20
ii) Platforms	50
V) Breweries and distilleries	
a) general working areas	150
b) brewhouse, bottling and canning plants	200
c)Bottle inspection	Special
	lighting
VI) Chemical Works	
a) Hand Furnaces, boiling tanks stationary driers, stationary or	
gravity crystallizers, mechanical driers, evaporators, filtration	
plants, mechanical crystallizing, bleaching, extractors,	
percolators nitrators and electrolytic cells	150
b) Controls, gauges, valves, etc	100
VII) Laboratories and Test Rooms	
a) General laboratories and balance rooms	300
b) Electrical and instrument laboratories	450
VIII)laundries and dry-cleaning works	

a) Receiving, sorting, washing, drying, ironing and despatch	200
b) Dry-cleaning and bulk machine work	200
c) Fine hand ironing, pressing, inspection, mending and spotting	300
IX) Machine and Fitting shops	
a) Rough bench and machine work	150
b) Medium bench and machine work, ordinary automatic	
machines, rough grinding, medium buffing and polishing	300
c) Fine bench and machine work, fine automatic machines,	
medium grinding, fine buffing and polishing	700
X) Commercial Buildings	
a) offices	
General Offices	300
Deep plan General Offices	500
Computer works station	300
Conference Rooms, Executive Offices	300
Computer and data preparation rooms	300
Filing Rooms	200
b) Drawing offices	
General	300
Drawing boards	500
Print rooms	200
Counter, office Area	300
Public Area	200
c) Retailing	
Small Shops with counters	300
Small self-service shops with island Displays	300
Super Markets-Hyper Markets	300
General	300
Checkout	300
showrooms for large objects, for example cars, furniture	300
Shopping precincts and arcades	100

REFERENCE DATA

1

ATMOSPHERIC PRESSURE AND DENSITY VS ALTITUDE AT (0^oC)

Altitude at (m)	Pressure (mmHg)	Density (kg/m^3)
0	760	1.293
100	751	1.278
200	742	1.262
300	733	1.247
400	724	1.232
500	716	1.218
600	707	1.203
700	699	1.189
800	691	1.176
900	682	1.16
1000	673	1.145
1100	664	1.13
1200	655	1.114
1400	639	1.092
1600	624	1.062
1800	610	1.038
2000	596	1.014
2200	582	0.988
2400	569	0.968
2600	556	0.946
2800	543	0.924

SPECIFIC GRAVITIES & GRINDABILITIES

2

Material	Specific Gravity (SG)	Bond Wi kW/MT	Hardgrove Hg kW/MT
Cement raw materials	2.67	10.6	43-93
Clay	2.23	7.1	97
Clinker	3.09	13.5	30-50
Coal, anthracite			30-53
bituminous	1.63	11.4	44-85
Gypsum rock	2.69	8.2	
Iron ore	4.5		38
Limestone	2.68	10.2	54-78
Sandstone	2.68	11.5	
Silica sand	2.65		24-55
Blast furnace slag	2.39		12.2

3 BULK DENSITIES OF MATERIALS FOR SILO STORAGE

Material	Bulk density (kg/m^3)
Aggregate, fine	1500
coarse	1600
Cement	1500
Clinker	1360
Coal, bituminous, bulk	850
Coal, pulverized	450
Fly-ash	550
Iron ore	2700
Limestone	1400
Raw meal	1250
Sand	1600
Shale/clay	1000
Brick (basic)	2400-2965
Brick (aluminum)	1520-1760
Brick (fireclay)	1360-1520
Clay (loose)	960- 1200
Coke	480 – 640
Concrete (Reinforced)	2325
Gravel	1760
Kiln feed (dry)	1360
Kiln feed (loose)	1040
Fuel oil	895
Shale	2480
Slurry @ 35 % H2O	1682

MOLECULAR WEIGHT OF CHEMICALS (G/G MOL)

4

Chemicals	MWt	Chemicals	Mwt
Al_2O_3	102	C_2AS	278
CaO	56	C_3A	270
Fe_2O_3	232	CA	158
Mn_2O_3	158	C_4AS	406
SO_2	64	C_4AF	486
TiO_2	80	$C_{12}A7$	1386
BaO	153	C_3S	228
Cr_2O_3	152	C_2F	272
H_2O	18	FeS_2	120
Na_2O	62	C_2S	172
SO_3	80	CAF_2	78
ZnO	81	$CaCO_3$	100
CO	28	$MgCO_3$	84
Fe_2O_3	160	$Ca(OH)_2$	74
K_2O	94	$CaSO_4$	136
O_2	32	K_2SO_4	174
Sio_2	64	Na_2SO_4	142
CO_2	44	$CaSO_4$ $2H_2O$	172
FeO	72	KCl	75
MgO	40	$2C_2S$ $CaCO_3$	444
P_2O_5	144	$CaSO_4$ 1/2 H_2O	145
SrO	104	$CaCO_3.MgCO_3$	184
CA_2	260	$2C_2S.CaSO_4$	480

Mwt = Molecular Weight

5 THERMAL CONDUCTIVITIES OF VARIOUS SUBSTANCES

Material	Coefficient of thermal conductivity W/m °C
Air	0.025 @ 25°C
Brick	0.6 @ 25°C
Concrete	0.85 @ 225°C
Copper	380 @ 25°C
Cork	0.043 @ 25°C
Glass	1 @ 25°C
Iron, cast	70 @ 125°C
Steel	60 @ 25°C
Wood	0.15 @ 25°C

6 ANGLE OF REPOSE

Material	Degree
Clinker & dry rock	30-35
Cement	20
Limestone	38

TYPICAL DATA FOR SOLID FUELS (% AS RECD/MINERAL-MATTER-FREE)

7

Typical properties of coal

	Coal A	Coal B	Coal C	Lignite	Coke	Shale	Sludge	Refuse
C, %	82.8	78.4	45	66	85.2	77.8	53	50.2
H, %	4.5	4.8	4.3	0.6	3.7	9.5	7.7	6.8
N, %	1.86	1.54	1.91	1.2	1.5	0.2	5	1.25
S, %	0.35	0.52	0.7	0.4	5.5	1.7	0.8	0.2
O, %	10.4	14.6	10.5	31.8	1.7	10.8	33.5	41.6
Cl, %	0.07							
Ash, %	8	3	12.9	16.1	0.3	47.1	37	20.8
H_2O, %	7.5	3	3.2	4.5	0.7	2	0.2	28.2
Volatiles, %	27.2	38.7	28.1	43	11	51.4		
Fixed C, %	57.3	55.3	57.1	40.9	79.1	1.5		
GCV kCal/kg	6520	7100	6500	5880	8200	2900	4440	2470
NCV kCal/kg	6280	6840	6270	5850	8040	2710	4030	2170
Air required*	10.9	10.4	10.8	7.1	11.5	12.1	8.1	7.3
Hardgrove	60	45	65	>100	60			

Coal A – Blair Athol, Australia

Coal B – El Cereon, S America

Coal C – Amcoal, S Africa

Coke – Green delayed

Shale – Oil shale, Lithuania

Sludge – Dried sewage, UK

Refuse – Domestic, USA

*Air required is theoretical mass ratio

Sl No	Class	Grade	Grade specification
1	Non-coking coal	A	Useful heat value exceeding 6200 kilocalories per kilogram
		B	Useful heat value exceeding 5600 kilocalories per kilogram but not exceeding 6200 kilocalories per kilogram.
		C	Useful heat value exceeding 4940 kilocalories per kilogram but not exceeding 5600 kilocalories per kilogram
		D	Useful heat value exceeding 4200 kilocalories per kilogram but not exceeding 4940 kilocalories per kilogram
		E	Useful heat value exceeding 3360 kilocalories per kilogrambut not exceeding 4200 kilocalories per kilogram
		F	Useful heat value exceeding 2400 kilocalories per kilogram but not exceeding 3360 kilocalories per kilogram
		G	Useful heat value exceeding 1300 kilocalories per kilogram but not exceeding 2400 kilocalories per kilogram
2	Coking Coal	Steel Grade I	Ash content not exceeding 15 percent
		Steel Grade II	Ash content exceeding 15 per cent but not exceeding 18 percent.
		Washery grade I	Ash content exceeding 18 per cent but not exceeding 21 percent
		Washery grade II	Ash content exceeding 21 per cent but not exceeding 24 percent.
		Washery grade III	Ash content exceeding 24 percent but not exceeding 28percent.
		Washery grade IV	Ash content exceeding 28 percent but not exceeding 35percent.
3	Semi coking and weakly coking coals	Semi coking Grade I	Ash plus moisture content not exceeding 19 percent
		Semi coking Grade II	Ash plus moisture content exceeding 19 percent but not exceeding 24 percent.

Notes:

1. Coking Coals are such coals as have been classified as coking coals by the erstwhile Coal Board or such coals as have been declared or may be declared as coking coal by the Central Government.

2. 'Semi coking coals' and 'weakly coking coals' are such coals as were classified as 'Blendable coals' by the erstwhile Coal Board or as may be declared as 'Semi coking' or 'weakly coking coals' by the Central Government.

3. Coals other than coking, semi coking or weakly coking coals are non-coking coals.

4. 'Useful heat value' is defined by the following formula
   HU = 8900 – 138 (A + M)
   Where HU = Useful heat value in kilo calories per kilogram
   A = Ash content in percentage
   M = Moisture content in percentage.

   In the case of coal having moisture less than 2 per cent and volatile content less than 19 per cent the useful heat value shall be the value arrived at as above reduced by 150 kilocalories per kilogram for each one percent reduction in volatile content below 19 percent fraction pro- rata.

   Both moisture and ash shall be determined after equilibrating at 60 per cent relative humidity and 40^0C temperature as per relevant clauses of Indian Standard Specification No.IS:1350 - 1959.

5. Ash percentage of coking coals shall be determined after air-drying as per IS: 1350-1959. If the moisture so determined is more than 2 percent, the determination shall be after equilibrating at 60 per cent relative humidity at 40^0C temperature as per IS:1350-1959.

6. Run of Mine coal is coal comprising of all sizes comes out of the mine without any crushing or screening.

7. The fraction of the Run of Mine coal as is retained on a screen when subjected to screening or is picked out by a fork shovel during loading is called steam coal.

8. The fraction that remains after steam coal has been removed from the Run of Mine Coal is called slack coal.

9. If Run of Mine Coal is subjected to successive screening by two different screens of different apertures resulting in segregation into three different sizes, the fraction that is retained on the screen with the largest aperture, shall be termed Steam coal, the fraction passing through the screen but retained on the screen with the smaller aperture, shall be termed Rubble coal and the fraction passing through both the screens shall be termed Slack Coal.

10. Coking coal, weakly coking coal, semi coking coal which fall outside the categorisation shown above shall be treated as non coking coal for the purpose of pricing and classified accordingly.

11. ' Long Flame Coals ' are defined by the parameters laid down in ' General classification of coals (Revised)' of Indian Standard Specification No. IS: 770 – 1964. The relevant part is extracted below:

Group present (mineral)	Volatile matter present (unit coal basis)	Range of gross CV, kCal /kg (Unit coal basis)	Range of dried Moisture at 60 % RH at 40°C (Free Coal Basis)
B4	Over 32	8060 to 8440	3 to 7
B5	Over 32	7500 to 8060	7 to 14

The determination of volatile matter and moisture shall be carried out on coal samples as per procedure laid down in Indian Standard Specification No. IS: 1350 (Part - I) 1984. Determination of gross calorific value shall be carried out in accordance with procedure laid down in IS: 1350 (Part-II) 1970 dated April 1971 or any subsequent revision thereof.

This is as per the Govt. Notification No. S.O. 453 (E) dated 16.06.1994 as modified by

Govt. Notifications Nos. S.O. 190 (E) dated 12.03.1997 and S.O. 136 (E) dated 24.02.1999.

TYPICAL DATA FOR LIQUID FUELS

8

	Kerosene	Gas Oil	Heavy Fuel Oil
C, %	85.8	86.1	85.4
H, %	14.1	13.2	11.4
S, %	0.1	0.7	2.8
O, %			
N, %			0.4
Cl, %			
Ash, %			0.04
H_2O, %			0.3
V, Ni, etc, ppm		5 – 70	70 – 500
SG (water = 1)	0.78	0.83	0.96
Viscosity, cSt @ 380°C	1.48	3.3	862
GCV, kCal/kg	11,100	10,250	10,250
NCV, kCal/kg	10,390	9,670	9,670
Air required, kg/kg	14.7	13.8	13.8

PHYSICAL DATA OF PRE-HEATER EXHAUST GAS WITH VARIOUS LEVELS OF EXCESS AIR (DRY)

9

	Density kg/Nm^3	Specific heat cal/g/°C	Dew point °C
0% O_2	1.487	0.216	38
2% O_2	1.469	0.218	36
5% O_2	1.441	0.221	33
10% O_2	1.395	0.226	26

10 TYPICAL SPECIFICATIONS USED BY VENDORS FOR BURNERS WITH INDIRECT FIRING SYSTEMS

	FLS "Duoflex"	Pillard "Rotoflam"	KHD "Pyro-jet"
PF conveying air	2%	2%	3.80%
Total primary air (axial+swirl)	6-8%	8%	4.30%
Axial velocity, m/sec	140 – 160	200 – 230	350 - 450
Swirl velocity, m/sec	(combined)	100 – 200	100 - 200

Low NOx Burner

Technical Specification	FLS-Jet flex	Fives Pillard Novaflam	KHD-Pyrojet	Thyssenkr-upp
Primary Air % to Stoichiometric reqt, Max	4-6%	4-6%	4-6%	4-6%
Primary air pressure (mbar)	700	500	Jet-900, swirl-160	Jet-900, swirl-100

11 GROSS CALORIFIC VALUES OF FUEL

Fuel Oil	GCV (kCal/kg)
Kerosene	11,100
Diesel oil	10,800
LDO	10,700
Furnace oil	10,500
LSHS	10,600

PROXIMATE & ULTIMATE ANALYSIS OF COAL

12

Typical Proximate analysis of Indian Coal (%)

Parameter	Indian coal
Moisture	5.98
Ash	38.63
Volatile matter	20.70
Fixed carbon	34.69

Typical Ultimate analysis of Indian Coal (%)

Parameter	Indian coal
Moisture	5.98
Ash	38.63
Carbon	41.11
Hydrogen	2.76
Nitrogen	1.22
Sulphur	0.41
Oxygen	9.89

13 BALL MILL STUDY & DATA

Ball Weight & Surface Area

Diameter (mm)	kg/ball	No of balls/MT	Surface area m^2/MT
20	0.033	30,600	38.46
25	0.064	15,700	30.77
30	0.11	9,100	25.64
40	0.261	3,830	19.23
50	0.511	1,960	15.38
60	0.882	1,130	12.82
70	1.4	710	10.99
80	2.09	480	9.60
90	2.977	336	8.55
100	4.084	245	7.69

Steel density is assumed 7.8 g/cm^3
Bulk density of a mixed ball charge may be taken as 4550 kg/m^3.

Ball Mill Charge Volume

H/D	VL %
0.211	24%
0.202	25%
0.194	26%
0.185	27%
0.177	28%
0.168	29%
0.16	30%
0.151	31%
0.143	32%
0.135	33%
0.127	34%
0.119	35%
0.11	36%
0.102	37%
0.094	38%
0.086	39%

H = Free height, m
D = Diameter of the mill, m
VL = Charge loading, %

Useful Data For Grinding Mill Study

Material	Grindabiltiy factor
Rotary kiln clinker	1
Shaft kiln clinker	1.15 – 1.25
Blast furnace slag	0.55 – 1.10
Chalk	3.7
Clay	3.0 – 3.5
Marl	1.4
Limestone	1.2
Silica sand	0.6 – 0.7
Coal	0.8 – 1.6

Mill output when other than clinker are ground in the same mill

Ball Mill Charging Data

An equilibrium charge is the distribution of ball sizes that will be realised when operating a ball mill for a long time, compensating the wear by adding balls of the specific size, and removing the balls, which are smaller than half the diameter of the ball size used for compensation.

The equilibrium charge is characterised by the diameter of the ball size used for compensation.

Equilibrium charges may be mixed to adjust the required piece weight and surface area. Two or more ball sizes are then used for compensation.

The average piece weight and the specific surface of an equilibrium charge with normal steel balls can be calculated according to:

$$i = 0.001913 \times D_c^3$$

where

D_c is the diameter in mm of the ball size used for compensation.

Recommended initial charges for equilibrium -large balls

Compensation size*			120		110		100		90	90		80		70
		MM	110	110	100	100	90	90	80	70	80	70	70	60
		Max	120	110	110	100	100	90	90	90	80	80	70	70
Ball size in chamber		Min	50	50	50	50	50	40	40	40	40	40	30	30
120mm	7085g	6.4m²/t	9											
110mm	5457g	7m²/t	23	19	10									
100mm	4100g	7.7m²/t	24	28	24	21	10							
90mm	2989g	8.5m²/t	18	21	26	31	27	23	12	12				
80mm	2099g	9.6m²/t	12	14	18	22	27	32	29	16	26	13		
70mm	1406g	11m²/t	8	10	12	14	18	21	28	25	36	32	29	15
60mm	886g	12.8m²/t	5	6	7	9	11	14	18	25	22	31	37	36
50mm	513g	15.4m²/t	1	2	3	3	7	8	10	15	13	17	21	30
40mm	262g	19.2m²/t						2	3	7	3	7	11	16
30mm	111g	25.6m²/t											2	3
Piece weight initial		G	2750	2393	2116	1925	1582	1300	1123	880	1004	808	612	505
		G	2877	2546	2185	1913	1613	1395	1151	892	979	786	656	507
Specific surface initial		m²/t	8.4	8.8	9.2	9.5	10.1	10.8	11.3	12.2	11.8	12.7	13.8	14.7
		m²/t	8.9	9.3	9.7	10.2	10.7	11.3	12	12.9	12.7	13.6	14.5	15.8

***where two sizes for compensation are stated , they are introduced in equal amounts by weight**

Recommended initial charges for equilibrium -large balls

Compensation size*				60		50		40		30		25		20	
		MM	60	50	50	40	40	30	30	25	25	20	20	15	15
		Max	60	60	50	50	40	40	3	30	25	25	20	20	15
ball size in chamber		Min	50	30	25	25	20	20	15	15	10	10	10	10	5
60mm	886g	12.8m²/t	35	18											
50mm	513g	15.4m²/t	40	41	42	21									
40mm	262g	19.2m²/t	20	32	42	47	51	26							
30mm	111g	26m²/t	5	9	13	24	33	35	35	18					
25mm	64g	31m²/t			3	8	13	27	40	40	40	20			
21mm	33g	38m²/t					3	12	21	31	41	46	51	26	
15mm	14g	51m²/t							4	11	17	30	43	53	62
10mm	4g	77m²/t									2	4	6	21	36
5mm	0.5g	154m²/t													2
Piece weight initial		G	418	329	246	178	127	83	53	40	28	21	16	10	5.8
		G	413	303	239	162	122	73	52	38	30	20	15	9.1	6.5
Specific surface initial		m²/t	15.8	17.1	18.8	21	23	27	31	34	38	42	46	53	63
		m²/t	17	18.7	20.4	23	25	30	34	37	41	46	51	59	68

***where two sizes for compensation are stated , they are introduced in equal amounts by weightŚ**

BALL MILL FORMULAS

S.No	Description	Symbol	
1	Arm of gravity	**a**	**0.666 x (1 - 4 x R^2)1.5** **TAN^{-1} [0.5 / R x (1 - 4 x R^2)0.5] - [2 x R x (1 - 4 x R^2)0.5]** h-Centre Distance (from mill centre to media top layer), mts D-Mill effective diameter, mts R-h/D, ratio of centre distance to mill effective diameter
2	Power consumption, net	**Pn (Kw)**	**0.514 x F x u x n x D x a** F-Grinding media weight ,tons u-Torque factor n-Mill speed, rpm D-Mill effective diameter, mts Arm of gravity
3	Power consumption, gross	**Pg (kW)**	**Pn x 100 x 100/ Em x Eg** **Em** -Motor efficiency, % **Eg** -Gearbox/girth gear efficiency, %
4	New production rate (Mill output Vs. Blaine)	**NPB (tph)**	**Formula1** **OPB/ Exp ((NB - OB) x 0.49 / 1000)** **OPB**-Old production rate, tph **OB**-Old blaine, cm2/gm **NB**-New blaine, cm2/gm **Formula 2** **OPB x (OB / NB)$^{1.3}$**

S.No	Description	Symbol	
5	New Specific power cons. (sp. power Vs. Blaine)	**NPR(tph)**	**$E1=E\,(S1 / S)^n$** **E1**-New specific power **E**-Old specific power **S1**-New Blaine **S**-Old Blaine **n**-Mill exponent for close ckt = 1.3
6	New production rate (mill output Vs. residue)	**NPR(tph)**	$\dfrac{OPR \times (2 - \log(OR))}{(2 - \log(NR))}$ **OPR**-Old production rate, **OR**-tph Old residue, % **NR**-New residue, %

BIS SPECIFICATION OF ADDITIVES

15

Specification of Slag (IS: 12089-1987)

SN	Sl. No.	Constituent	Percent
A	1	Lump exceeding 50 mm	<5
		Moisture content	Not mandatory
		Manganese oxide (MnO) max	5.5
		Magnesium oxide (MgO) max	17.0
		Sulphide sulphur (S) max	2.0
		Insoluble residue max	5
B		Oxide ratios (To satisfy at least one of the two)	
	1	$CaO + MgO + 1/3Al_2O_3\ SiO_2 + 2/3Al_2O_3$	>1.0
	2	$CaO + MgO + Al_2O_3$ SiO_2	
			>1.0
C		When MnO in slag is more than 2.5	
		$CaO + CaS + 1/2MgO + Al_2O_3\ SiO_2 + MnO$	>1.5
D		Glass content	>85

BIS specifications for Fly-ash to produce Fly-ash cement

Chemical requirements-Gravimetric analysis

S. No	Characteristics	Requirement
1.	$SiO_2 + Al_2O_3 + Fe_2O_3$ (max)	70
2.	SiO_2 (max)	35
3.	MgO (max)	5
4.	Total sulfur as SO_3 (max)	2.75
5.	Available alkalies as Na_2O (max)	1.5
6.	LOI (max)	12

Chemical requirements

S. No.	Characteristics	Requirement	
		Sample I	Sample II
1.	Fineness-specific surface cm^2/g (min)	3200	2500
2.	Lime Reactivity-average compressive strength N/m^2 (min)	4	3
3.	Compressive strength 28 days N/m^2 (min)	Not less than 80% of corresponding plain cement mortar cubes	
4.	Drying shrinkage % (max)	0.15	0.10
5.	Soundness by autoclave test expansion of specimen % (max)	0.8	0.8

Physical Testing of Cement

Types of test

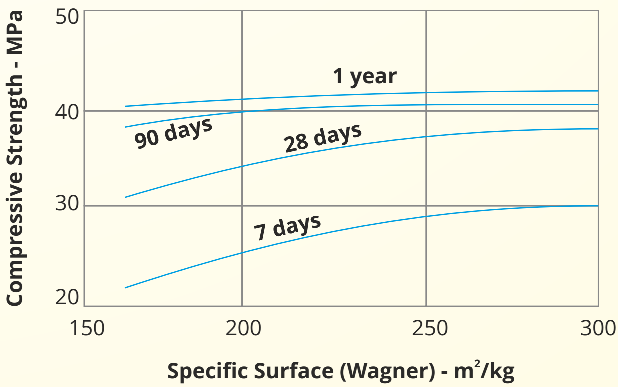
1) Fineness test
2) Standard consistency test
3) Setting time test
4) Soundness test
5) Compressive strength Test

Fineness Test

- The fineness of cement has an important bearing on the rate of hydration, rate of gain of strength, evolution of heat.
- Finer cement offers greater surface area.
- Disadvantage of fine grinding is that it is susceptible to air set & early deterioration.

Fineness of cement is tested in two ways

1) By sieving
2) By determination specific surface by air permeability



Principle of air permeability method is in observing the time taken for a fixed quantity of air to flow through compacted cement bed of specified dimension and porosity.

Procedure

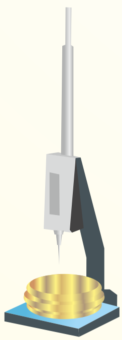
1) Cement required to make a cement bed of porosity 0.475 calculated.
2) Pass on the air slowly at constant velocity.
3) Adjust the rate of air flow until the flowmeter shows a difference in level of 30-50cm.
4) Repeat these observation for constant h1/h2.specified air flow

Standard consistency test

The standard consistency of a cement paste is defined as that consistency which will permit a Vicat plunger having 10 mm diameter and 50 mm length to penetrate to a depth of 33- 35 mm from the top of the mould.

Application

Used to find out the percentage of water required to produce a cement paste of standard consistency. This is also called normal consistency .



Vicat Apparatus

Procedure

1) For first trial, take about 500gms of cement & water of r%.
2) Fill it in Vicat's mould within 3-5min.
3) After filling, shake the mould to expel air
4) A standard plunger, 10 mm diameter, 50 mm long is attached and brought down to touch the surface of the paste and quickly released.
5) Note the reading according to depth of penetration of the plunger
6) Conduct trials continuously by taking different water cement ratios till the plunger penetrates for a depth of 33-35mm from top.
7) This particular percentage is known as percentage of water required to produce cement paste of standard consistency. This is usually denoted as 'P'.

Suitable Conditions:

Conducted in a constant temperature of 27^0c

Constant Humidity 90%.

Setting time test

An arbitrary division has been made for the setting time of cement as

1) Initial setting Time

2) Final setting time

Initial setting Time

The time elapsed between the moment that the water is added to the cement, to the time that the paste starts losing its plasticity.

- Normally a minimum of 30min has maintained for mixing & handling operations.
- It should not be less than 30min.

Final setting time

The time elapsed between the moment the water is added to the cement, and the time when the paste has completely lost its plasticity and has attained sufficient firmness to resist certain definite pressure. It should not exceed 10hours, So that it is avoided from least vulnerable to damages from external activities.

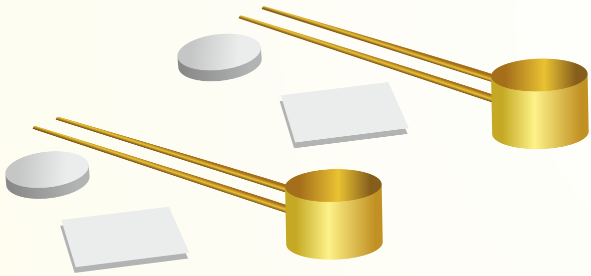
Procedure

1) Vicat apparatus is used for finding the setting time
2) Take 500gms of cement and add about 0.85 P
3) The paste should be filled within 3-5 minutes.
4) Initial and final setting time is noted

Soundness test

1) It is very important that the cement after setting shall not undergo any appreciable change of volume
2) This test is to ensure that the cement does not show any subsequent expansions
3) The unsoundness in cement is due to the presence of excess of lime combined with acidic oxide at the kiln.
4) This is due to high proportion of magnesia & calcium sulphate,
5) Therefore magnesia content in cement is limited to 6%.

Procedure



1) It consists of a small split cylinder of spring brass.
2) It is 30mm diameter & 30mm high.
3) Cement is gauged with 0.78 times & filled into the mould & kept on a glass plate & covered with another glass plate.
4) This is immersed in water at a temperature 270c-320c for 24 hours.
5) Measure the distance between indicators.
6) Heat the water & bring to boiling point of about 25-30min.
7) Remove the mould from the water after 3 hours.
8) Measure the distance between the indicators.
9) This must not exceed 10mm for ordinary, rapid hardening, low heat Portland cements.
10) If this expansion is more than 10mm the cement is said to be unsound

Compressive strength Test

1) This is the most important of all properties of hardened cement.
2) Due to excessive shrinkage and cracking the strength tests are not made on heat cement paste.
3) Standard sand is used for finding the strength of cement.

Procedure

1) Take 555gms of standard sand. 185gms of cement (i.e., 1:3 ratio of cement and sand)
2) Mix them for 1min, then add water of quantity (P/4)+3.0%.
3) Mix three ingredients thoroughly until the mixture is of uniform colour.

4) The time of mixing should not be<3min and >4min.

5) Then the mortar is filled into a cube mould of 7.06cm and area of 50 cm2.

6) Compact the mortar.

7) Keep the compacted cube in the mould at a temperature of 27°C ± 2°C and at least 90 per cent relative humidity for 24 hours.

8) After 24hours the cubes are removed & immersed in clean fresh water until taken for testing.

9) The cubes are tested for compressive stress for 3, 7 and 28 days.

10) The comp. stress of OPC is16, 22 and 33 MPA FOR 3, 7 & 28 days.

17 BIS SPECIFICATIONS FOR VARIOUS CEMENTS

Ordinary Portland cement 53 (OPC 53) (IS 269:2015)	
Particulars	BIS Specification
Fineness (m^2 / kg)	Minimum 225
Soundness	
Le chatelier expansion (mm)	Max. 10
Auto-clave expansion (%)	Max. 0.8
Setting Time (Mins)	
Initial	Minimum 30
Final	Max. 600
Compressive Strength (MPa)	
3 days	Min.27.0
7 days	Min.37.0
28 days	Min. 53.0

Ordinary Portland Cement 43 (OPC 43) (IS 269:2015)	
Particulars	BIS specification
Fineness (m^2/ kg)	Minimum 225
Soundness	
Le chatelier expansion (mm)	Max. 10
Auto-clave expansion (%)	Max. 0.8
Setting Time (Mins)	
Initial	Minimum 30
Final	Max. 600
Compressive Strength (MPa)	
3 days	Min.22.0
7 days	Min.33.0
28 days	Min. 43.0-58

Ordinary Portland Cement 33 (OPC 33) (IS 269:2015)	
Particulars	BIS specification
Fineness (m^2 / kg)	Minimum 225
Soundness	
Le chatelier expansion (mm)	Max. 10
Auto-clave expansion (%)	Max. 0.8
Setting Time (Mins)	
Initial	Minimum 30
Final	Max. 600
Compressive Strength (MPa)	
3 days	Min.16.0
7 days	Min.22.0
28 days	Min. 33.0-48

Blended Cement

Pozzolana Portland cement(IS 1489(Part1):2015	
Particulars	BIS specification
Fineness (m2 / kg)	Minimum 300
Pozzolana (%)	15-35
Soundness	
Le chatelier expansion (mm)	Max. 10
Auto-clave expansion (%)	Max. 0.8
Setting Time (Mins)	
Initial	Minimum 30
Final	Max. 600
Compressive Strength (MPa)	
3 days	Min.16.0
7 days	Min.22.0
28 days	Min. 33.0

Sulphate Resistance Cement

Compressive Strength (MPa)	
3 days	Min.11.0
7 days	Min. 22.0
28 days	Min. 33.0

Portland Slag Cement	
Particulars	BIS specification
Fineness (m^2 / kg)	Minimum 300
% Slag in PSC	25- 65 %
Soundness	
Le chatelier expansion (mm)	Max. 10
Auto-clave expansion (%)	Max. 0.8
Setting Time (Mins)	
Initial	Minimum 30
Final	Max. 600
Compressive Strength (MPa)	
3 days	Min.16.0
7 days	Min.22.0
28 days	Min. 33.0

Composite Cement

Composite cement	
Particulars	BIS specification
Portland Cement clinker	35-65%
% Fly ash	15-35%
% Slag	20- 50 %
Soundness	
Le chatelier expansion (mm)	Max. 10
Auto-clave expansion (%)	Max. 0.8
Setting Time (Mins)	
Initial	Minimum 30
Final	Max. 600
Compressive Strength (MPa)	
3 days	Min.16.0
7 days	Min.22.0
28 days	Min. 33.0
LOI(%) by mass	5
Total Sulphur(SO_3) content% by mass	3.5 max
Chloride content% by mass	0.1 max

18 THERMO PHYSICAL PROPERTIES OF DIFFERENT INSULATING MATERIALS

Physical properties of different insulating materials

Sl. No	Material	Thermal Conductivity W/m °C	Density kg/m^3	Service temperature °C
1	Mineral or glass fibre blanket	0.039	10 -80	370
2	Cellular glass	0.058	100 - 128	370
3	Cork board	0.043	180 – 220	180
4	Glass fibre	0.036	64 - 144	180
5	Expanded polystyrene (smooth) – Thermocole	0.029	15 – 30	180
6	Expanded polystyrene (cut cell) – Thermocole	0.036	15 – 30	120
7	Expanded polyurethane	0.017		
8	Phenotherm (Trade name)	0.018		

Emission Norms in Cement plants

a) Cement plant without co-processing

Sl No	Industry	Parameter	Standards		
1	2	3	4		
		A – Emission Standards			
		(i) Rotary kiln – without co processing			
"10	**Cement plant (without co-processing, standalone clinker grinding plant or blending plant)**		**Date of Commissioning**	**Location**	**Concentration not to exceed, in mg/Nm³**
		Particulate matter (PM)	on or after the date of notification (25.8.2014)	anywhere in the country	30 (with effect from 01.01.2016)
			before the date of notification (25.8.2014)	Critically polluted area or urban centres with population above 1.0 Lakh or within its periphery of 5.0-kilometre radius	50 (with effect from 01.01.2015)
				Other than critically polluted area or urban centres	30 (with effect from 01.06.2016)

<table>
<tr><th>Sl No</th><th>Industry</th><th>Parameter</th><th colspan="3">Standards</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th colspan="3">4</th></tr>
<tr><th></th><th></th><th colspan="4">A – Emission Standards</th></tr>
<tr><td rowspan="5">“10 A</td><td rowspan="5">Cement plant (without co-processing, standalone clinker grinding plant or blending plant</td><td colspan="4">(i) Rotary kiln – without co processing</td></tr>
<tr><td></td><td>Date of Commissioning</td><td>Location</td><td>Concentration not to exceed, in mg/Nm³</td></tr>
<tr><td>Sulphur Dioxide (SO_2)</td><td>Irrespective of the date of commissioning</td><td>Anywhere in the country</td><td>100, 700 and 1000 when pyrite sulphur in the limestone is less than 0.25%, 0.25 to 0.5% and more than 0.5% respectively</td></tr>
<tr><td rowspan="2">Oxides of Nitrogen (NO_x)</td><td>After the date of notification (25.8.2014)</td><td>Anywhere in the country</td><td>(1) 600</td></tr>
<tr><td>Before the date of notification (25.8.2014)</td><td>Anywhere in the country</td><td>(2) 800 for rotary kiln with in line calciner (ILC) technology

(3) 1000 for rotary kiln using mixed stream of ILC, Separate line calciner (SLC) and suspension pre-heater technology or SLC technology alone or without calciner</td></tr>
</table>

b) Cement plant with co-processing of waste

Sl No	Industry	Parameter	Standards		
1	2	3	4		
		A – Emission Standards			
"10 A	**Cement plant with co-processing of wastes**	(I) Rotary kiln			
			Date of Commissioning	**Location**	**Concentration not to exceed, in mg/Nm^3**
		Particulate matter (PM)	on or after the date of notification (25.8.2014)	anywhere in the country	30
			before the date of notification (25.8.2014)	Critically polluted area or urban centres with population above 1.0 Lakh or within its periphery of 5.0-kilometre radius	30
				Other than critically polluted area or urban centres	30
		SO_2	Irrespective of the date of commissioning	Anywhere in the country	100, 700 and 1000 when pyrite sulphur in the limestone is less than 0.25%, 0.25 to 0.5% and more than 0.5% respectively

Sl No	Industry	Parameter	Standards		
1	2	3	4		
		A – Emission Standards			
"10 A	**Cement plant with co-processing of wastes**	(I) Rotary kiln			
			Date of Commissioning	**Location**	**Concentration not to exceed, in mg/Nm^3**
		NO_x	After the date of notification (25.8.2014)	Anywhere in the country	(1) 600
			Before the date of notification (25.8.2014)	Anywhere in the country	(2) 800 for rotary kiln with in line calciner (ILC) technology
					(3) 1000 for rotary kiln using mixed stream of ILC, Separate line calciner (SLC) and suspension pre-heater technology or SLC technology alone or without calciner
		HCL		10 mg/Nm^3	
		HF		1 mg/Nm^3	
		TOC		10 mg/Nm^3	
		Hg and its compounds		0.05 mg/Nm^3	
		Cd and Tl and their compounds		0.05 mg/Nm^3	
		Dioxins and Furans		0.1 ngTEQ/Nm^3	

(1)	(2)	(3)	(4)
"10 A	Cement plant (with & without co-processing)	Rotary kiln based plants (Particulate matter from raw mill, kiln and pre-heater calciner system put together)	0.125 kg/tonne of clinker

National ambient air quality standards

SL. NO.	Pollutant	Time Weighted Average	Concentration in Ambient Air		
			Industrial Residential Rural and other Area	Ecologically Sensitive Area (notified by central Govt.)	Methods of Measurement
1	Sulphur Dioxide (SO_2), Pg/m_3	Annual* 24 hours**	50 80	20 80	• Improved West Gacke • Ultraviolet florescence
2	Nitrogen Dioxide (NO_2), µg/m_3	Annual*	40	30	• Modified Jacob & Hochheister (Na- Arsenite) • Chemiluminecence

SL. NO .	Pollutant	Time Weighted Average	Concentration in Ambient Air		
			Industrial Residential Rural and other Area	Ecologically Sensitive Area (notified by central Govt.)	Methods of Measurement
3	Particulate Matter (size less than (10µm) or Pm10 µg/m^3	Annual* 24 hours**	60 100	60 100	• Gravimetric • TOEM • Beta attenuation
4	Particulate Matter (size less than 2.5µm) or PM25 µg/m^3	Annual* 24 hours**	40 60	40 60	• Gravimetric • TOEM • Beta attention
5	Ozone (O_3) µg/m^3	8 hours** 1 hour**	100	100	• UV photometric • Chemiluminescence • Chemical Method
6	Lead (Pb) µg/m^3	Annual* 24	0.50 1.0	0.50 1.0	• AAS/ICP method sampling on EPM 2000 or equivalent filter paper • ED-XRF using Teflon filter
7	Carbon Monoxide (CO) µg/m^3	8 hours** 1 hour**	02 04	02 04	• Non Dispensive Red (NDIR) spectroscopy

SL. NO.	Pollutant	Time Weighted Average	Concentration in Ambient Air		
			Industrial Residential Rural and other Area	Ecologically Sensitive Area (notified by central Govt.)	Methods of Measurement
8	Ammonia (NH_3) µg/m^3	Annual* 24 hours**	100 400	100 400	• Chemiluminescence • Indophenol blue method
9	Benzene (C_2H_6) µg/m^3	Annual*	05	05	• Gas chromalograpy based continuous analyzer • Adsorption and Desorption followed by GC analysis
10	Benzo(O)Pyrene (BaP)-particulate phase only, µg/m^3	Annual*	01	01	• Solvent extraction followed by HPLC/ GC analysis
11	Arsenic (As), µg/m^3	Annual*	06	06	• AAS / ICP method after sampling on EPM 2000 or equivalent filter paper
12	Nickel (Ni) µg/m^3	Annual*	20	20	• AAS/ICP method after sampling on EPM 2000 or equivalent filter paper

* Annual arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.

** 24 hourly or 08 hourly or 01 ourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

Water quality standards

Designated	Best	Use Class of water Criteria
Drinking Water Source without conventional treatment but after disinfection	A	• Total Coliforms Organism MPN/100ml shall be 50 or less • pH between 6.5 and 8.5 • Dissolved Oxygen 6mg/l or more • Biochemical Oxygen Demand 5 days 20°C 2mg/l or less
Outdoor bathing (Organised)	B	• Total Coliforms Organism MPN/100ml shall be 500 or less pH between 6.5 and 8.5 Dissolved Oxygen 5mg/l or more • Biochemical Oxygen Demand 5 days 20°C 3mg/l or less
Drinking water source after conventional treatment and disinfection	C	• Total Coliforms Organism MPN/100ml shall be 5000 or less pH between 6 to 9 Dissolved Oxygen 4mg/l or more • Biochemical Oxygen Demand 5 days 20°C 3mg/l or less •
Propagation of Wildlife and Fisheries	D	• pH between 6.5 to 8.5 Dissolved Oxygen 4mg/l or more • Free Ammonia (as N) 1.2 mg/l or less
Irrigation, Industrial Cooling, Controlled Waste disposal	E	• pH between 6.0 to 8.5 • Electrical Conductivity at 25°C micro mhos/cm Max. 2250 • Sodium absorption Ratio Max. 26 • Boron Max. 2mg/l
	Below- E	Not Meeting A, B, C, D & E Criteria

Ambient air quality standards in respect of noise

Area Code	Category of Area/Zone	Limits in dB(A)Leq*	
		Day Time	Night Time
A	Industrial area	75	70
B	Commercial area	65	55
C	Residential area	55	45
D	Silence Zone	50	40

Note:

1. Day time shall mean from 6.00 a.m. to 10.00 p.m.

   Night time shall mean from 10.00 p.m. to 6.00 a.m.

2. Silence zone is an area comprising not less than 100 metres around hospitals, educational institutions, courts, religious places or any other area which is declared as such by the competent authority

3. Mixed categories of areas may be declared as one of the four above mentioned categories by the competent authority.

   * dB(A) Leq denotes the time weighted average of the level of sound in decibels on scale A which is relatable to human hearing.

   A "decibel" is a unit in which noise is measured.

   "A", in dB(A) Leq, denotes the frequency weighting in the measurement of noise and corresponds to frequency response characteristics of the human ear.

   Leq: It is an energy mean of the noise level over a specified period.

20

CO_2 EMISSION INTENSITY (SCOPE 1 EMISSION)

CO_2 Emission Intensity

Plant	kg CO_2/MT Cement	Overall clinker factor
Plant 1	326	0.40
Plant 2	358	0.43
Plant 3	394	0.44
Plant 4	398	0.48
Plant 5	391	0.48
Plant 6	463	0.56
Plant 7	462	0.58
Plant 8	475	0.60
Plant 9	501	0.60
Plant 10	509	0.63

CO_2 Emission Intensity : PPC

Plant	CO_2 Emission intensity kg CO_2/MT Cement (PPC)	PPC Clinker factor
Plant 1	475	0.60
Plant 2	501	0.60
Plant 3	509	0.63
Plant 4	526	0.65
Plant 5	529	0.65
Plant 6	551	0.67
Plant 7	558	0.71

CO_2 Emission Intensity : PSC

Plant	kg CO_2/MT eq cement (PSC)	PSC Clinker factor
Plant 1	326	0.40
Plant 2	394	0.44

CO_2 Emission Intensity of Indian Cement Plant (Average 2016-17 Data)

Direct CO_2 emissions intensity 588 kg CO_2/MT cement

CO_2 emissions intensity including onsite /captive power plant is 670 kg CO_2/MT cement

CO_2 Emission list for fuels

Sl No	Type of Fuel	GCV	Carbon %	Sulphur %	Nitrogen %	CO_2 emission	gm SO_2/ kg fuel	gm NO_2/ kg fuel
		(kCal/ kg fuel)	%	%	%	(kg CO_2/kg fuel)	gm / kg Fuel	gm / kg Fuel
1	Acetylene	11900	92.00	0.00	0.00	3.60		
2	Bagasse	2300	40.94	0.04	0.23	0	0.80	2.46
3	BioDiesel	10700		0.00	0.00	1.91	0.00	0.00
4	Blast furnace gas	970	CO : 27, H2 : 2, CH4: 0	0.00	0.00	0.64	0.00	0.00
5	Briquettes	4200	42.50	0.00	0.00	0	0.04	0.01
6	Charcoal	6300	93.00	1.50	0.00	3.30	30.00	0.00
7	Coal - Imported Indonesian	5500	65.50	1.36	1.70	2.35	27.20	18.21
8	Coal - Imported Other	5700	67.88	0.56	1.02	2.58	11.20	10.93
9	Coal - Imported South African	6000	70.00	0.70	1.60	2.69	14.00	17.14
10	Coal - Indian A Grade	6500	69.30	1.00	1.65	2.46	20.00	17.68

Sl No	Type of Fuel	GCV	Carbon %	Sulphur %	Nitrogen %	CO_2 emission	gm SO_2/ kg fuel	gm NO_2/ kg fuel
		(kCal/ kg fuel)	%	%	%	(kg CO_2/kg fuel)	gm / kg Fuel	gm / kg Fuel
11	Coal - Indian B Grade	6252	63.80	1.20	1.60	2.35	24.00	17.14
12	Coal - Indian C Grade	5823	61.00	0.60	0.90	2.29	12.00	9.64
13	Coal - Indian D Grade	5343	57.06	0.39	0.88	2.11	7.80	9.43
14	Coal - Indian E Grade	4707	49.80	0.41	0.86	1.95	8.20	9.21
15	Coal - Indian F Grade	4095	41.11	0.41	1.22	1.70	8.20	13.07
16	Coal - Indian G Grade	3489	36.02	0.80	1.07	1.45	16.00	11.46
17	Coal - Lignite	3400	35.30	0.88	0.46	1.20	17.60	4.93
18	Coal gas or Coke oven gas	9250	CO : 2, H_2 : 54, CH_4: 28	0.00	0.00	1.72	0.00	0.00
19	Coal+Char Blend						0.00	0.00
20	Coal+Flyash/ Bottom Ash Blend						0.00	0.00
21	Coke	6200		0.36	0.10	3.02	7.20	1.07
22	Diesel - Light Diesel Oil (LDO)	10700	68.00	3.00	0.00	3.07	60.00	0.00
23	Diesel Oil	10700	68.00	1.80	0.50	3.15	36.00	5.36
24	Dolachar	4753	49.10	0.47	0.71	0	9.40	7.61
25	Furnace Oil	10050	65.00	4.00	0.50	3.15	80.00	5.36
26	Hydrogen	33500	0.00	0.00	0.00	0	0.00	0.00
27	Kerosene	11100	85.80	0.10	0.00	3.15	2.00	0.00
28	Low Sulphur Heavy Stock (LSHS)	10600	86.70	1.00	0.00	2.96	20.00	0.00
29	Mixed Fuel						0.00	0.00

Sl No	Type of Fuel	GCV	Carbon %	Sulphur %	Nitrogen %	CO_2 emission	gm SO_2/ kg fuel	gm NO_2/ kg fuel
		(kCal/ kg fuel)	%	%	%	(kg CO_2/kg fuel)	gm / kg Fuel	gm / kg Fuel
30	Oil gas	11300	CO : 8.3, H_2 : 50.3, CH_4:16.2	0.00	0.00	2.98	0.00	0.00
31	Petrol	10900	65	1.50	1.60	3.07	30.00	17.14
32	Producer gas	3500	CO : 29, H_2 : 12, CH_4:2.6	0.00	0.00	1.22	0.00	0.00
33	Rice Husk	3568	34.72	0.05	0.45	0	1.00	4.82
34	SoyDiesel	6500				1.91	0.00	0.00
35	Straw	3600	33.95	0.09	0.91	0	1.80	9.75
36	Water gas	3500	CO : 41, H_2 : 49, CH_4:0.8	0.00	0.00	1.22	0.00	0.00
37	Wood	4700	45.6	0.07	0.45	0	1.40	4.82
38	Other						0.00	0.00
39	Natural Gas	12500	65.00	0.50	1.00	2.69	10.00	10.71
40	LPG	11000	65.00	0.00	0.00	2.98	0.00	0.00
41	Indian coal	4000	41.11	0.41	1.22	3.77	8.20	13.07
42	Imported coal	5500	59.00	0.56	1.02	3.93	11.20	10.93
43	HSD	10700	68.00	1.80	0.50	2.33	36.00	5.36
44	Pet coke	8000	76.00	6.00	1.50	3.48	120.00	16.07
45	Electricity	860	40.00	0.60	0.25	0.82	12.00	2.68

Sl No		SPM - Based on LCI data set value	kg fuel / MTOE	SO_2 Reduction per MTOE	NO_2 Reduction per MTOE	SPM Reduction per MTOE	Source
		gm / kg Fuel		Mt / MOTE	Mt / MOTE	Mt / MOTE	
1	Acetylene						IPCC 2006 (V2; C1 and C2)
2	Bagasse	1.08	4348	0.003478	0.010715	0.004696	Carbon Neutral; IPCC
3	BioDiesel	1.08	935	0.000002	0.000000	0.001010	IPCC 2006 (V2; C1 and C2)
4	Blast furnace gas	0	10309	0.000000	0.000000	0.000000	IPCC 2006 (V2; C1 and C2)
5	Briquettes	1.08	2381	0.000095	0.000026	0.002571	Carbon Neutral; IPCC
6	Charcoal	2.166	1587	0.047610	0.000000	0.003437	IPCC 2006 (V2; C1 and C2)
7	Coal - Imported Indonesian	2.166	1818	0.049450	0.033114	0.003938	CIL Coal Grade Reports; IPCC 2006 (V2; C1 and C2)
8	Coal - Imported Other	2.166	1754	0.019645	0.019169	0.003799	CIL Coal Grade Reports; IPCC 2006 (V2; C1 and C2)

Sl No		SPM - Based on LCI data set value	kg fuel / MTOE	SO_2 Reduction per MTOE	NO_2 Reduction per MTOE	SPM Reduction per MTOE	Source
		gm / kg Fuel		Mt / MOTE	Mt / MOTE	Mt / MOTE	
9	Coal - Imported South African	2.166	1667	0.023338	0.028577	0.003611	CIL Coal Grade Reports; IPCC 2006 (V2; C1 and C2)
10	Coal - Indian A Grade	2.166	1538	0.030760	0.027190	0.003331	CIL Coal Grade Reports; IPCC 2006 (V2; C1 and C2)
11	Coal - Indian B Grade	2.166	1600	0.038400	0.027429	0.003466	CIL Coal Grade Reports; IPCC 2006 (V2; C1 and C2)
12	Coal - Indian C Grade	2.166	1717	0.020604	0.016557	0.003719	CIL Coal Grade Reports; IPCC 2006 (V2; C1 and C2)
13	Coal - Indian D Grade	2.166	1872	0.014602	0.017650	0.004055	CIL Coal Grade Reports; IPCC 2006 (V2; C1 and C2)

Sl No		SPM - Based on LCI data set value	kg fuel / MTOE	SO_2 Reduction per MTOE	NO_2 Reduction per MTOE	SPM Reduction per MTOE	Source
		gm / kg Fuel		Mt / MOTE	Mt / MOTE	Mt / MOTE	
14	Coal - Indian E Grade	2.166	12125	0.017425	00.01958	0.004603	CIL Coal Grade Reports; IPCC 2006 (V2; C1 and C2)
15	Coal - Indian F Grade	2.166	2442	0.020024	0.031920	0.005289	CIL Coal Grade Reports; IPCC 2006 (V2; C1 and C2)
16	Coal - Indian G Grade	2.166	2866	0.045856	0.032857	0.006208	CIL Coal Grade Reports; IPCC 2006 (V2; C1 and C2)
17	Coal - Lignite	2.166	2941	0.051762	0.014495	0.006370	CIL Coal Grade Reports; IPCC 2006 (V2; C1 and C2)
18	Coal gas or Coke oven gas	0	1081	0.000000	0.000000	0.000000	IPCC 2006 (V2; C1 and C2)

Sl No		SPM - Based on LCI data set value	kg fuel / MTOE	SO_2 Reduction per MTOE	NO_2 Reduction per MTOE	SPM Reduction per MTOE	Source
		gm / kg Fuel		Mt / MOTE	Mt / MOTE	Mt / MOTE	
19	Coal+Char Blend	0					Blending composition required
20	Coal+Flyash/ Bottom Ash Blend	0					Blending composition required
21	Coke	2.166	1613	0.011614	0.001728	0.003494	IPCC 2006 (V2; C1 and C2)
22	Diesel - Light Diesel Oil (LDO)	1.08	935	0.056100	0.000000	0.001010	IPCC 2006 (V2; C1 and C2)
23	Diesel Oil	1.08	935	0.033660	0.005009	0.001010	IPCC 2006 (V2; C1 and C2)
24	Dolachar	2.166	2104	0.019778	0.016005	0.004557	Carbon Neutral; IPCC
25	Furnace Oil	1.08	995	0.079600	0.005330	0.001075	IPCC 2006 (V2; C1 and C2)
26	Hydrogen	0	299	0.000000	0.000000	0.000000	Carbon Neutral; IPCC
27	Kerosene	1.08	901	0.001802	0.000000	0.000973	IPCC 2006 (V2; C1 and C2)
28	Low Sulphur Heavy Stock (LSHS)	0	943	0.018860	0.000000	0.000000	IPCC 2006 (V2; C1 and C2)

Sl No		SPM - Based on LCI data set value	kg fuel / MTOE	SO_2 Reduction per MTOE	NO_2 Reduction per MTOE	SPM Reduction per MTOE	Source
		gm / kg Fuel		Mt / MOTE	Mt / MOTE	Mt / MOTE	
29	Mixed Fuel	0			0.000000	0.000000	Blending composition required
30	Oil gas	0	885	0.000000	0.000000	0.000000	IPCC 2006 (V2; C1 and C2)
31	Petrol	1.08	917	0.027510	0.015720	0.000990	IPCC 2006 (V2; C1 and C2)
32	Producer gas	0	2857	0.000000	0.000000	0.000000	IPCC 2006 (V2; C1 and C2)
33	Rice Husk	0	2803	0.002803	0.013514	0.000000	Carbon Neutral; IPCC
34	SoyDiesel	0	1538	0.000000	0.000000	0.000000	IPCC 2006 (V2; C1 and C2)
35	Straw	0	2778	0.005000	0.027086	0.000000	Carbon Neutral; IPCC
36	Water gas	0	2857	0.000000	0.000000	0.000000	IPCC 2006 (V2; C1 and C2)
37	Wood	2.166	2128	0.002979	0.010260	0.004609	Carbon Neutral; IPCC
38	Other	2.166					Fuel Ultimate Analysis Required

Sl No		SPM - Based on LCI data set value	kg fuel / MTOE	SO_2 Reduction per MTOE	NO_2 Reduction per MTOE	SPM Reduction per MTOE	Source
		gm / kg Fuel		Mt / MOTE	Mt / MOTE	Mt / MOTE	
39	Natural Gas	0	800	0.008000	0.008571	0.000000	IPCC 2006 (V2; C1 and C2)
40	LPG	2.166	909	0.000000	0.000000	0.001969	IPCC 2006 (V2; C1 and C2)
41	Indian coal	2.166	2500	0.020500	0.032679	0.005415	
42	Imported coal	2.166	1818	0.020362	0.019868	0.003938	
43	HSD	1.08	935	0.033660	0.005009	0.001010	
44	Pet coke	2.166	1250	0.150000	0.020089	0.002708	
45	Electricity	2.166	11628	0.139536	0.031146	0.025186	

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TRANSFORMER LOSS

Transformer loss = No load loss + ((% loading/100)^2 x full load copper loss)

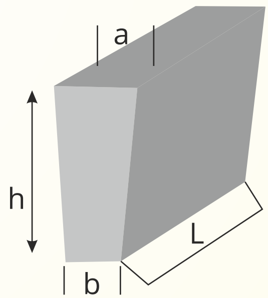
The core loss & the full load copper loss for transformers are specified in the transformer test certificate. The typical values of no-load and the full load losses are given in the following table:

kVA rating (Watts)	No-load loss (Watts)	Full load loss at 75°C (Watts)	Impedance
(%)			
160	425	3000	5
200	570	3300	5
250	620	3700	5
315	800	4600	5
500	1100	6500	5
630	1200	7500	5
1000	1800	11000	5
1600	2400	15500	5
2000	3000	20000	6

Transformer type	Core loss as a % of full load copper loss	Loading at which max. Efficiency is achieved (%)
Distribution transformer	15-20 %	40-60 %
Power transformer	25-30 %	60-80 %

As per IS 2026, the maximum permissible tolerance on the total loss is 10 %. The permissible limit for no-load and full load loss is + 15 %.

There will be a little variation in actual no-load and load loss of transformer. The exact values can be obtained from the transformer test certificate.



ISO Key Bricks

Type	Dimensions			
	a	b	h	L
Bp16	54	49	160	198
BP+16	64	59	160	198
Bp18	54	49	180	198
BP+18	64	59	180	198
Bp20	54	49	200	198
BP+20	64	59	200	198
Bp22	54	49	220	198
BP+22	64	59	220	198
Bp25	54	49	250	198
BP+25	64	59	250	198
A230	103	72	300	198
A330	103	82	300	198
A430	103	87.5	300	198
A630	103	92.5	300	198
A730	103	94	300	198
A830	103	95	300	198
P30	83	72.5	300	198
P+30	93	82.5	300	198

ISO Bricks

Type	Dimensions			
	a	b	h	L
216	103	86.0	160	198
316	103	92.0	160	198
416	103	94.5	160	198
616	103	97.5	160	198
716	103	98.3	160	198
318	103	84.0	180	198
418	103	93.5	180	198
618	103	97.0	180	198
718	103	97.7	180	198
220	103	82.0	200	198
320	103	89.0	200	198
420	103	92.5	200	198
520	103	94.7	200	198
620	103	96.2	200	198
820	103	97.8	200	198
222	103	80.0	220	198
322	103	88.0	220	198
422	103	91.5	220	198
522	103	94.0	220	198
622	103	95.5	220	198
822	103	97.3	220	198
225	103	77.0	220	198
325	103	85.5	250	198
425	103	90.0	250	198
625	103	94.5	250	198
825	103	96.5	250	198

VDZ Bricks

Type	Dimensions			
	a	b	h	L
B216	78	65	160	198
B416	75	68	160	198
B218	78	65	180	198
B318	76.5	66.5	180	198
B418	75	68	180	198
B618	74	69	180	198
B220	78	65	200	198
B320	76.5	66.5	200	198
B420	75	68	200	198
B620	74	69	200	198
B222	78	65	220	198
B322	76.5	66.5	220	198
B422	75	68	220	198
B622	74	69	220	198
B822	73	69	220	198
B425	76	67	250	198
B616	74	69	160	198
B718	78	74	180	198
B720	73.5	69.5	200	198
B722	73.5	69.5	220	198
B725	74	69	250	198
B820	78	74	200	198

VDZ Key Bricks

Type	Dimensions			
	a	b	h	L
P11	83	79	114	198
P+11	93	89	114	198
P13	83	78.5	130	198
P+13	93	88.5	130	198
P15	83	78	150	198
P+15	93	88	150	198
P16	83	77.5	160	198
P+16	93	87.5	160	198
P18	83	77	180	198
P+18	93	87	180	198
P20	83	76.2	200	198
P+20	93	86.2	200	198
P22	83	75.5	220	198
P+22	93	85.5	220	198
P25	83	74.5	250	198
P+25	93	84.5	250	198
P140	65	56	200	198
P240	79	70	200	198
P340	91	88	200	198
P146	70	60	230	198
P246	90	80	230	198

Example:

No of bricks per ring for VDZ shape

Kiln diameter (id shell) : 3800 mm

Lining thickness : 200 mm

Kiln diameter (id brick) : 3400 mm

Shapes considered : B320, B620

Shape	a in mm	b in mm	No. of bricks per ring
B320	76.5	66.5	X
B620	74	69	Y

$76.5\ X + 74\ Y = 3800 \times \pi$

$66.5\ X + 69\ Y = 3400 \times \pi$

Solving this equation

We get

X = 93

Y = 65 numbers per ring.

Guidelines for selection of refractory quality material

1) Raw materials and raw mix design
2) Kiln size and system design
3) Operating conditions
4) Lining design
5) Installation techniques.

Chemical Factors

1) Use of fuel rich in Sulphur and chlorine.
2) Use of high ash coal
3) Frequent change of fuel
4) Disturbance of the $SO_3/(K_2O+Na_2O)$ equilibrium
5) High concentration of chlorides (KCl) in kiln atmosphere.
6) Variations in cement raw material
7) Grain size of SiO_2 component.
8) Change between reducing and oxidizing atmosphere.

Types of refractories

1) Chrome free basic bricks
2) Dolomite refractory or Basic bricks
3) Silicon carbon based low cement castables
4) Zircon based bricks and low cement castables.
5) High Alumina bricks
6) Fire Clay Bricks

Refractory Type	Characteristics
Chrome free basic bricks	Characterized by high resistance to thermo mechanical stresses Successfully used in upper and lower flanks of burning zones. Eco friendly as free from chrome.
Dolomite refractory	Used in burning zone; ability to pick up and hold firm coating. Limited shelf life due to hydration Zirconia enriched dolomite bricks developed.
Silicon carbide castable	Helps in overcoming clogging in preheater and precalciner.
Zircon based castable.	Characterized by improved resistance to abrasion and thermal shocks. Successfully used in high capacity cement rotary kilns.
High Alumina Bricks	Superior mechanical strength and abrasion resistance. Alumina content 50-85% by mass.
Fire Clay bricks	Lower thermal conductivity significantly reduces kiln shell temperature, a major advantages over tyre and temperature resistance upto 1000^0C.

Properties of refractories

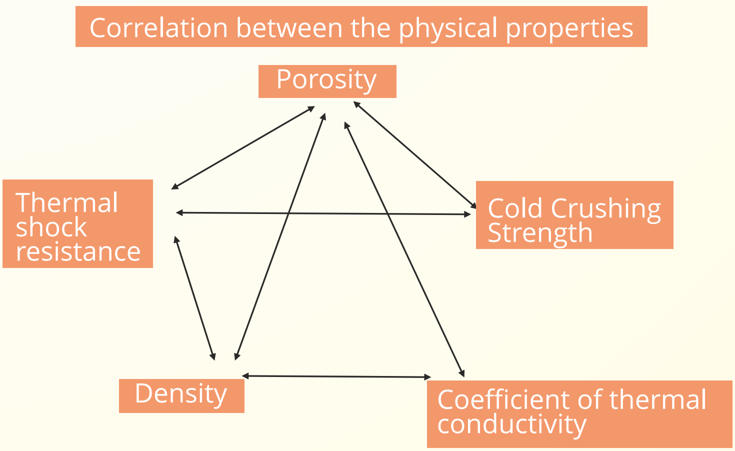
Physical

- Porosity
- Bulk density
- Cold crushing strength

1) Thermal

- Refractoriness under load(RUL)
- Permanent linear change(PLC)
- Thermal shock resistance(spalling resistance)
- Thermal conductivity
- Reversible thermal expansion (RTE).
- Pyrometric Cone equivalent (PCE).

2) Chemical Composition



Porosity	High bulk density = heat capacity
Bulk density	Low porosity = less penetration of molten material
Cold crushing strength	Capacity to withstand mechanical load
RUL	Indicates resistance of refractory to combined effect of load and temperature. Higher the RUL better the load bearing characteristic.
PLC	Expansion or contraction percentage on heating to specified temperature. Lower the PLC better.
Thermal shock resistance	Cracking and flacking of the brick when Subjected to sudden temperature change.
Thermal conductivity	Higher porosity will result in lower thermal conductivity.
RTE	Expansion is reversible and linear. Percentage of ratio of the length of the test piece after heating and original value of the length.
PCE	Pyrometric cone equivalent-depends upon quality of refractory and amount of impurities. Higher the PCE-Higher the temperature material softens.

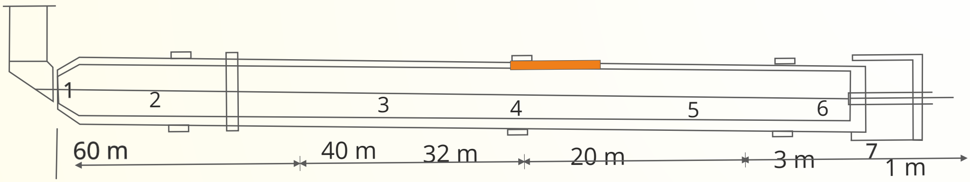
Application of refractories

- Preheater
- PC Vessel
- Smoke Chamber
- Kiln
- Cooler
- TAD

Preheater-Cyclones	20% to 40% alumina with insulation backup
PC Vessel	40% to 60% alumina with insulation backup
Smoke Chamber	40% to 60% alumina or silicon carbide castable for anticoating with insulation backup.
Cooler	40% to 90% alumina with insulation backup.
TAD	40% to 60% alumina with insulation backup

Types of refractory material for different locations inside the kiln

Location	Type and composition	RUL, °C
Cooling zone	High alumina (>70%) bricks or mag-chrome bricks	1500
Burning zone	Dolomite bricks (MgO >96%)	1600 - 1700
Transition zone	Alumina or high alumina bricks; mag-chrome bricks (MgO > 65%)	1600
Preheating zone	Fireclay brick with Al_2O_3 content decreasing towards feed end; lightweight bricks	1350



Runnning Meter (m)	
From	**To**
0.0	0.6
0.6	5.0
5.0	18.0
18.0	25.0
25.0	30.0
30.0	40.0
40.0	44.0
44.0	60.0

REFACTORY USED
CASTABLE
HA-70 BRICK
IMP.BASIC BRICK
NCB-AZRBRICK
IMP.BASIC BRICK
IIA-60 BRICK
HA-40 CLOG BRICK
HA-60 BRICK

EMISSIVITY VALUES OF SURFACES

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Surface	Emissivity
Steel plate (oxidized)	0.9
Mild steel	0.3 – 0.5
Stainless steel (polished)	0.1
Aluminium (polished)	0.1 x
Brass (roughened surface)	0.2
Copper (polished)	0.05 x
Fire clay	0.75
Concrete	0.7

x Emissivity varies with purity

CONVERSION FACTOR

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Linear measures

	Meter
1 mm	10^{-3} m
1 cm	10^{-2} m
1 km	10^{3} m
1 inch	2.54×10^{-2} m
1 ft	30.48×10^{-2} m
1 yd	0.92 m

Weights

	kg
1 g	10^{-3} kg
1 quintal	100 kg
1 MT (metric tonne)	1000 kg
1 lb (pound)	0.454 kg

Pressure

	Atmosphere, atm
760 mm Hg	1 atm
14.696 psi	1 atm
29.921 in. Hg	1 atm
33.899 ft of H_2O	1 atm
10336 mm of H_2O	1 atm
1.01325 bar	1 atm
1013250 dyne/cm^2	1 atm
1.033 kg/cm^2	1 atm
101325 pa	1 atm
760 torr	1 atm

	mm WC/mm WG
1 mm Hg	13.6 mm WC
1 psi	703.32 mm WC
1 in Hg	345.44 mm WC
1 bar	10200.8 mm WC
1 dyne/cm^2	0.0102 mm WC
1 kg/cm^2	10005.81 mm WC
1 pa	0.102 mm WC

Power

	W
1 kW	1000 W
1 HP	746 W

Heat Energy

	Cal
1 Mtoe	10^{10}
1 k Cal	1000
1 BTU	252
1 joule	0.2388

PAT NORMALIZATION FACTORS

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1. Product Mix

1.1 Conversion of Cement Equivalent to major grade =

$$\frac{\text{Cement production of a particular grade} \times \text{CF* of same grade}}{\text{CF* of major grade}}$$

1.2 Total Cement Production Equivalent to major grade

= Production of all grades of cement equivalent major grade + (exported clinker equivalent to major grade Cement)**

*CF (Clinker Conversion Factor) = Clinker used for x grade/Cement Production of x grade

**Conversion of exported clinker to equivalent major grade cement = Clinker exported/CF of major grade cement

2. Energy Mix

2.1 Specific Energy Consumption (SEC) =

$$\frac{\text{Net energy input into the designated consumer's boundary}}{\text{Total quantity of output exported from the designated consumers' boundary}}$$

3. Equivalent Major Grade of Cement Production

i. Conversion of Ordinary Portland Cement (OPC) production equivalent to major product

$$\text{Equivalent Major Product [Lakhs Tons]} = \frac{\text{OPC Produced (Lakh Tons)} \times \text{Conversion factor of OPC}}{\text{Conversion factor of major product}}$$

ii. Conversion of Portland Pozolona Cement (PPC) production equivalent to major product

$$\text{Equivalent Major Product [Lakhs Tons]} = \frac{\text{PPC Produced (Lakh Tons)} \times \text{Conversion factor of PPC}}{\text{Conversion factor of major product}}$$

iii. Conversion of Portland Slag cement (PSC)/any other variety of Cement production equivalent to major product

Equivalent Major Product [Lakhs Tons]

$$= \frac{\text{PSC or any other variety of cement Produced (Lakh Tons) x Conversion Factor of PSC or any other variety of cement}}{\text{Conversion factor of major product}}$$

iv. Conversion of Total exported clinker to equivalent to major product

$$\text{Equivalent Major Product [Lakhs Tons]} = \frac{\text{Total Exported Clinker (Lakh Tons)}}{\text{Conversion factor of major product}}$$

v. Conversion of Total Imported clinker to equivalent to major product

$$\text{Equivalent Major Product [Lakhs Tons]} = \frac{\text{Total clinker imported (Lakh Tons)}}{\text{Conversion factor of major product}}$$

Total Equivalent Major Product of Cement = (i) + (ii) + (iii) + (iv)

Note: Sl. No (v) is already accounted in major product

4. Calculation for Gate to Gate Specific Energy Consumption (SEC)

4.1 Total Thermal Energy Consumption (Kiln + power Generation)

Total Thermal Energy Consumption [Million kCal] = [{Fuel Consumed (Kiln + Power generation) (in Lakh Tons) x Gross Calorific value of respective fuels (kCal/kg) x 100} – Electricity Exported to Grid (Lakh kWh) x 2717) (kCal/kW))/10}]

Where: 2717 kCal/kWh is the National Average Gross Heat Rate of Thermal Power Stations in the country in 2007

4.2 Energy for Imported Electricity Consumption

Energy for Imported Electricity consumption

Total energy for Imported Electricity [Million kcal] = [{Imported Electricity (Lakh kWh) x (3208 – 860) (kCal/kWh)} / 10]

4.3 Notional/ Normalization energy for imported electricity from Grid

Notional/ Normalization energy for imported electricity = [{Imported electricity (Lakh kWh) x (3208 – 860) (kCal/kWh)} / 10]

Where: 3208 kCal/kWh is the weighted average heat rate of captive power plants in all DCs in cement sector.

4.4 Notional/ Normalization energy for grinding of exported Clinker

Notional Energy [Million kCal] = [{Total exported clinker to major product (Lakh Ton) Electrical SEC of cement grinding (kWh / ton of cement) x Weighted Average Heat Rate (kCal/kWh)} / 10]

Where: -Weighted Average Heat rate (kCal/kWh) = [{Imported Electricity (Lakh kWh) x 3208 (kCal/kWh)} + {DG generation (lakh kWh) x DG heat rate (kCal/kWh)}

4.5 Notional/ Normalization energy for clinkerization of imported Clinker

Notional Energy [Million kCal] = Total Clinker imported (Lakh ton) x [(Thermal SEC of Clinkerization, kCal/kg clinker x 1000)+{electrical SEC of clinkerization (kWh/ton of clinker)x Weighted Average Heat Rate (kCal/kWh)}]/10

4.6 Gate to Gate (GtG) Energy Consumption

GtG Energy Consumption [Million kCal] = {4.1} + {4.2} + {4.3} + {4.4} + {4.5}

4.7 Gate to Gate (GtG) Specific Energy Consumption

GtG SEC [kCal/kg of equivalent cement]

$$= \frac{\text{GtG Energy Consumption (Million kCal)}}{\text{Total Equivalent Major Product of Cement (Lakh Ton) x 100}}$$

5. Normalization

There are several factors that need to be taken into consideration in the assessment year such as Change in product mix, capacity utilization, change in fuel quality, import/export of Power etc influenced by external factor i.e., factors beyond the controlled by Plant, in calculating the Specific Energy Consumption (SEC) of the plant within the boundary

5.1 Normalization Calculation on capacity decrease for Kiln Heat Rate

5.1.1 Normalization of Thermal SEC up to Clinkerisation

Notional energy reduction due to loss in kiln TPH (Million kCal)

= (Heat rate of AY- Heat rate of BY) x Clinker Production in AY/1000

Where

Heat rate of AY- Heat rate of BY = 0.4673 x (TPH BY- TPH AY)

AY = Assessment year

BY = Baseline Year

TPH = Tonnes per hour of kiln

Kiln Heat Rate = Total Thermal Energy consumed in kiln (kCal) / Clinker Production (kg) in kCal/kg

5.1.2 Normalization of Electrical SEC up to Clinkerisation

Notional energy reduction due to loss in kiln TPH (in Million kCal)

= (SPC of AY- SPC of BY) x Clinker Production in AY X Wt. Heat Rate/10^6

Where

SPC of AY- SPC of BY= 0.0943 x (TPH BY- TPH AY)

AY = Assessment year

BY = Baseline Year

TPH = Tonnes per hour

SPC = Specific Power Consumption

5.2 Normalization Calculation on Kiln Cold Start up

Notional Energy to be subtracted w.r.t. additional Kiln Cold startup for Thermal Energy Consumption (in Million kCal)

= (0.1829 x TPH in AY + 197.41) x (Nos of Cold Startup in AY-Nos of Cold Startup in BY)

Where

AY = Assessment year

BY = Baseline Year

TPH = Tonnes per hour

5.3 Normalization for Product Mix- Grinding Energy

The difference of grinding Energy between Actual Production Vs Equivalent Cement Production of Baseline and Assessment year will be subtracted in total energy in the assessment year considering Clinker Export also as per following equation

Notional Energy (Million kCal) = {[(E–F-W) x G x H]- [(A-B-V) x C x D]}/10

Where

A = Equivalent Major Cement production in assessment year

B = Reported cement production in assessment year

C = Electrical SEC of cement grinding (kWh/Ton of cement) for assessment year

D = Weighted average CPP Heat/Grid Heat Rate (kCal/kWh) in the assessment year

E = Equivalent Major Cement production in baseline period

F = Reported cement production in baseline period

G = Electrical SEC of cement grinding (kWh/Tone of cement) for baseline period

H = Weighted average CPP/Grid Heat Rate (kCal/kWh) for baseline period

V = Equivalent major Cement production from Exported Clinker in Assessment Year

W = Equivalent major Cement production from Exported Clinker in Baseline Year

5.4 Normalization for Product Mix- Additives

Notional Energy for Clinker Produced due to change in Additives/Clinker Factor (Million kCal) =

J x [K x L + M x 1000]/10

J = Clinker produced due to change in Additives / Clinker Factor (Lakh Ton)

K =Electrical SEC (Up to Clinkerisation) (kWh/ton of cement) for assessment year

L= Weighted average CPP/Grid/DG Heat Rate (kCal/kWh) in the assessment year

M=Thermal SEC of Clinker for assessment year (kCal/kg of clinker)

Where J=J1+J2

J1: Clinker produced due to change in Additives/Clinker Factor (Lakh Ton) for PPC =

PPCPrAY x {(OPCCFAY-PPCCFAY)-(OPCCFBY –PPCCFBY)}

PPCPrAY =PPC Production in the assessment year (lakh Ton)

OPCCFAY = OPC Clinker factor in the assessment year

PPCCFAY = PPC Clinker Factor in the assessment year

OPCCFBY = OPC Clinker factor in the baseline year

PPCCFBY = PPC Clinker Factor in the baseline year

J2: Clinker produced due to change in Additives/Clinker Factor (Lakh Ton) for PSC/Others =

PSCOPrAY x {(OPCCFAY-PSCOCFAY)-(OPCCFBY –PSCOCFBY)}

PSCOPrAY = PSC/Others Production in the assessment year (lakh Ton)

OPCCFAY = OPC Clinker factor in the assessment year

PSCOCFAY = PSC/Others Clinker Factor in the assessment year

OPCCFBY = OPC Clinker factor in the baseline year

PSCOCFBY = PSC/Others Clinker Factor in the baseline year

5.5 Power Mix Normalization Calculation

5.5.1 Normalization for Power Sources

Normalised Weighted Heat Rate for Assessment year (kCal/kWh):

J = A x (D/G) + B x (E/G)+C x (F/G)

Where

A = Grid Heat Rate for Assessment year (AY) in kCal/kWh

B = CPP Heat Rate for AY in kCal/kWh

C = DG Heat Rate for AY in kCal/kWh

D = Grid Energy consumption for Base Line Year (BY) in Million kWh

E = CPP Energy consumption for BY in Million kWh

F = DG Energy consumption for BY in Million kWh

G = Energy Consumed from all Power sources (Grid, CPP, DG) for BY in Million kWh

Boiler Efficiency = $92.5 - \frac{[50 \times A + 630 (M + 9 H)]}{G.C.V}$

Where:

A = Ash percentage in coal

M = Moisture percentage in coal

H = Hydrogen percentage in coal

G.C.V = Gross calorific value in kCal/kg

Station Heat Rate (kCal/kWh) = Turbine Heat Rate/Boiler efficiency

5.5.2 Pet coke Utilization in Kiln

a. Normalization calculation for Kiln Heat Rate

Normalized kiln Heat rate with Petcoke consumption in assessment year = Heat rate at baseline year + 0.0954x Difference in Percentage of petcoke consumption from the baseline to assessment year

Kiln HRAY=Kiln HRBY + 0.0954 x (% PC ConsAY-% PC ConsBY)

AY = Assessment year

BY = Baseline Year

TPH = Tonnes per hour

Kiln HR =Total Thermal Energy consumed kiln/Clinker Production in kCal/kg

PC Cons=Pet-coke Consumption

b. Normalization calculation for Kiln Specific Power consumption

Normalized Electrical SEC Upto clinkering in assessment year = Electrical SEC up to clinkering at baseline year + 0.022 x Difference in Percentage of petcoke consumption from the baseline to assessment year

Kiln SPCAY = Kiln SPCBY +0.022 x (% PC ConsAY -% PC ConsBY)

AY = Assessment year

BY = Baseline Year

TPH= Tonnes per hour

SPC= Specific Power Consumption

PC Cons=Petro-coke Consumption

5.6 Low PLF compensation in CPP

% increase in Heat Rate due to decrease in Loading =

= 0.0016 x (%Loading)^2-0.3815 x %Loading +21.959

Notional energy reduction due to low PLF

= Total Generation x (Actual Gross HR-Normalized Gross HR)

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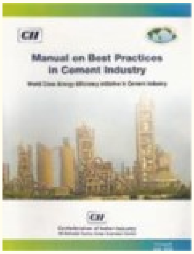
ABBRIVATIONS

AAS	Atomic absorption spectroscopy
AM	Alumina Modulus
APC	Auxiliary Power Consumption
AQC	Air Quenching Chamber
BEE	Bureau Of Energy Efficiency
BIS	Bureau of Indian Standards
CF	Cash Flow
CF	Clinker Factor
CFL	Compact Fluorescent Light
CFM	Cubic Feet Per Minute
CIL	Coal India Limited
COC	Cycle Of Concentration
COP	Coefficient Of Performance
CPP	Captive Power Plant
CRI	Colour Rendering Index
DG	Diesel Generator
FAD	Free Air Delivery
GCT	Gas Conditioning Tower
GCV	Gross Calorific value
GHG	Green House Gases
GLS	General Lighting Service
HCL	Hydrochloric Acid
HPMV	High Pressure Mercury Vapour
HPSV	High Pressure Sodium Vapour
HR	Heat Rate
HSD	High Speed Diesel
ID	Internal Diameter
IEEE	Institute of Electrical and Electronics Engineers
ILC	In Line Calciner
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organization
LDO	Light Diesel Oil
LED	Light Emitting Diode
LOS	Loss On Ignition
LP	Low Pressure
LPG	Liquefied Petroleum Gas
LSF	Lime Saturation Factor

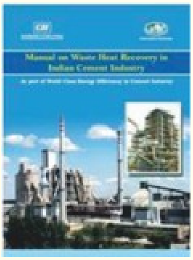
LSHS	Low Sulphur Heavy Stock
MP	Medium Pressure
MPN	Most Probable Number
MTOE	Metric Tonne of Oil Equivalent
MTPA	Metric Tonne Per Annum
MTPD	Metric Tonne Per Day
NCV	Net Calorific Value
NDIR	Non Dispersive InfraRed
NPV	Net Present value
OPC	Ordinary Portland Cement
PAT	Perform Achieve and Trade
PC	Pre Calciner
PCE	Pyrometric Cone equivalent
PH	Preheater
PLC	Permanent linear change
PLF	Plant Load Factor
PPC	Portland Pozzolana Cement
PPC	Portland Pozzolana Cement
PSC	Portland Slag Cement
PSDs	Particle Size Determinations
RPM	Rotations Per Minute
RTE	Reversible thermal expansion
RUL	Refractoriness under load
SEC	Specific Energy Consumption
SLC	Separate Line Calciner
PM	Particulate Matter
SM	Silica Modulus
SP	Static Pressure
TAD	Tertiary Air Duct
TOEM	Tapered Element Oscillating Microbalance
TP	Total Pressure
TPH	Tonne Per Hour
TSR	Thermal Substitution Rate
UV	Ultra Violet
VP	Velocity Pressure
VRM	Vertical Roller Mill
WHR	Waste Heat Recovery

Publications by CII-GBC as part of World class Energy Efficiency in Cement Plants



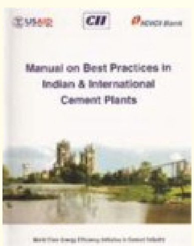
Manual on Best Practices in Cement Industry

The publication details the best practices followed by the Indian plants in the areas of energy efficiency, quality and productivity improvement.



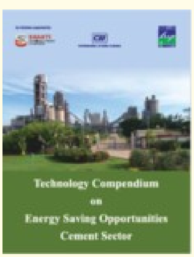
Manual on Waste Heat Recovery in Indian Cement Industry

The manual focuses on description of technologies available for Waste Heat Recovery Potential and installations in the Indian Cement Plants. This also discusses the advantages and also the barriers towards the deployment of WHR Technologies.



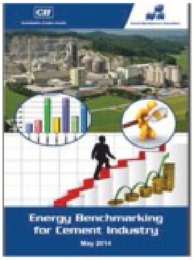
Manual on Best Practices in Indian & International Cement Plants

The publication was bought out as part of world class energy efficiency which covers the energy conservation measures carried out in the six cement plants as part of the mission and the experience and learning on Waste Heat Recovery from international mission carried out in Germany, Belgium, UK, Switzerland and Japan cement plants.



Technology Compendium on Energy Saving Opportunities-Cement Sector

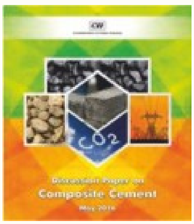
CII – Godrej GBC undertook the initiative of preparing Technology Compendium on Energy Saving Opportunities: Cement Sector. The Technology Compendium comprises of various thermal and electrical energy efficiency improvement opportunities. The compendium was launched in August 2013, by Dr. Ajay Mathur, Director General, BEE, during the CII Energy Efficiency Summit at Hyderabad.



Energy Benchmarking for Cement Industry

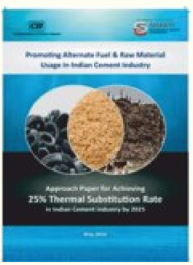
With an objective to further increase the knowledge transfer among the cement industry, CII – Godrej GBC has prepared the benchmarking manual for the Indian Cement Industry.

The manual includes best achieved specific energy consumption values over a wide range of plant configurations. The manual also includes various best practices and latest technologies adopted for achieving lower specific energy consumption.



Discussion paper on Composite Cement

This publication focuses on composite cement manufacturing standards, monetary and environmental benefits and feasibility of locations where it can be produced. It analyses the slag & fly ash availability for increasing the composite cement production in Indian Cement Industry by 2025.



Approaching paper for achieving 25% Thermal Substitution Rate in Indian Cement Industry by 2025

This paper is an attempt to investigate and discuss on availability of potential waste streams for Co-processing in Indian Cement Industry. Aim of this paper is to estimate the quantity of waste & energy that could be available from the different waste streams by the year 2025 to achieve 25% TSR which will support the industry & country in moving towards low carbon economy.

About CII

The Confederation of Indian Industry (CII) works to create and sustain an environment conducive to the development of India, partnering industry, Government, and civil society, through advisory and consultative processes.

CII is a non-government, not-for-profit, industry-led and industry-managed organization, playing a proactive role in India's development process. Founded in 1895, India's premier business association has around 9000 members, from the private as well as public sectors, including SMEs and MNCs, and an indirect membership of over 300,000 enterprises from around 276 national and regional sectoral industry bodies.

CII charts change by working closely with Government on policy issues, interfacing with thought leaders, and enhancing efficiency, competitiveness and business opportunities for industry through a range of specialized services and strategic global linkages. It also provides a platform for consensus-building and networking on key issues.

Extending its agenda beyond business, CII assists industry to identify and execute corporate citizenship programmes. Partnerships with civil society organizations carry forward corporate initiatives for integrated and inclusive development across diverse domains including affirmative action, healthcare, education, livelihood, diversity management, skill development, empowerment of women, and water, to name a few.

India is now set to become a US$ 5 trillion economy in the next five years and Indian industry will remain the principal growth engine for achieving this target. With the theme for 2019-20 as 'Competitiveness of India Inc - India@75: Forging Ahead', CII will focus on five priority areas which would enable the country to stay on a solid growth track. These are - employment generation, rural-urban connect, energy security, environmental sustainability and governance.

With 66 offices, including 9 Centres of Excellence, in India, and 10 overseas offices in Australia, China, Egypt, France, Germany, Singapore, South Africa, UAE, UK, and USA, as well as institutional partnerships with 355 counterpart organizations in 126 countries, CII serves as a reference point for Indian industry and the international business community.

About CII-Godrej GBC

CII-Sohrabji Godrej Green Business Centre (CII-Godrej GBC) was established in the year 2004, as CII's Developmental Institute on Green Practices & Businesses, aimed at offering world class advisory services on conservation of natural resources. The Green Business Centre in Hyderabad is housed in one of the greenest buildings in the world and through Indian Green Building Council (IGBC) is spearheading the Green Building movement in the country. The Green Business Centre was inaugurated by His Excellency Dr. A. P. J. Abdul Kalam, the then President of India on 14 July 2004.

The Services of Green Business Centre include- Energy Management, Green Buildings, Green Companies, Renewable Energy, GHG Inventorization, Green Product Certification, Waste Management and Cleaner Production Process. CII-Godrej GBC works closely with the stakeholders in facilitating India emerge as one of the global leaders in Green Business by the year 2022.

Conclusion

We feel that this Formula Handbook Version 3.0 for Cement Industry would have given you useful tips / information and helpful for you in your day to day energy conservation activities. We invite your valuable feedback for any corrections / suggestions to be added for updating the details in the future version of this handbook.

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