Confederation of Indian Industry
CII-Sohrabji Godrej Green Business Centre

May 2010 Version 2.0

Cement Formulae Handbook

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Published by Confederation of Indian Industry
CII - Sohrabji Godrej Green Business Centre
Survey # 64, Kothaguda Post,
R R District, Hyderabad - 500 084, India.

FOREWORD

The Indian cement industry today stands at 260 MTPA capacity, with greater growth prospects and promising future ahead. Cement industry has been an excellent example of a fast growing sector showing consistent and steady reduction in its energy consumption. This has largely been possible by steady and continuous improvement across all equipments in cement manufacturing process.

To take these initiatives forward, one of the basic essentials is availability of right information at easy disposal. CII-Sohrabji Godrej Green Business Centre, as part of its World Class Energy Efficiency initiative, has been releasing several publications, case study booklets etc. on a regular basis to make the latest information available to all stakeholders in the cement industry. One such initiative was the release of Cement Formula Handbook in 2009.

This Cement Formula Handbook was extensively circulated among the industry. The response for the handbook has been very encouraging and received positive feedback from various stakeholders. One of the strong feedback to CII-Sohrabji Godrej Green Business Centre was to sustain this activity and release updated version of Formulae Handbook on a regular basis.

The Cement Formulae Handbook (Version 2.0) is an outcome of the excellent response & feedback to the earlier handbook (2009). I would sincerely request all the readers to not only make full use of the handbook across your organizations but also to pass any comments / suggestions / feedback on Cement Formulae Handbook (Version 2.0) you may have to CII-Sohrabji Godrej Green Business Centre.

Your feedback will encourage us at CII-Sohrabji Godrej Green Business Centre to take such initiatives in future.

(G. Jayaraman)

Chairman, Green Cementech 2010, CII- Godrej GBC &
Executive President, Birla Corporation Ltd.

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FORMULAE

Chapter - I

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)

$$AM = \frac{Al_2O_3}{Fe_20_3}$$

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

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 (%)	=	$\frac{(f_i - d_i) \times 100}{f_i}$
		(or)
	=	$\frac{(1 - LOI_{sample}) \times (100 - LOI_{feed})}{(100 - LOI_{sample}) \times (LOI_{feed})}$
C	:	Apparent percent calcination of the sample
f_i	:	Ignition loss of the original feed
d_i	:	Ignition loss of the sample

8. Sulphur to Alkali Ratio

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

Typical value ≈ 1.1

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

Typical value ≈ 0.8

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

9. Free Lime

% free Lime_{1400}	=	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.

11. Blending ratio

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

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

$$= \sqrt{(N/2)}$$

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 : $\frac{x + x_1 + x_2 + x_3 \ldots x_n}{n} = x_a$

Standard deviation for the feed :

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

12. Raw meal to clinker factor

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

Ash absorbtion = % 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

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

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.

Chapter - II

Formulae used in Combustion Calculations

1. Conversion of gross calorific value to net calorific value

NCV	=	GCV - 5150 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^{o}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^{o}C when the water in the system after combustion is taken as vapour.

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 = $\dfrac{CaO_{Clinker} - CaO_{raw\ mix}}{CaO_{ash} - CaO_{raw\ mix}}$

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

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

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

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

5. Theoretical air required to burn fuel

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

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

Chapter - III

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 $L_{\text{min Flow}}$

C : Primary air velocity at the burner nozzle

2. Estimated burner nozzle velocity (v)

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

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

Where p_s measured at axial air point

Chapter - IV

Kiln Performance & Efficiency

1. Volumetric loading of kiln

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

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 7.0 tpd/m^3

2. Thermal loading of kiln

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 5.0 M $kcal/hr/m^2$

3. Feed moisture evaporation rate

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

F_q : Fresh feed quantity (tph)

M_f : Total fresh feed surface moisture (%)

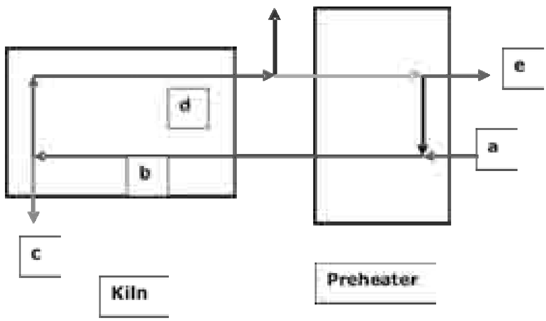
M_p : Total product surface moistures (%)

4. 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.

By pass



Evaporation ratio	=	b/d
Circulation factor	=	b/a

5. 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)

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

6. % Excess air

a. For Complete combustion (Nil CO)

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

b. For Incomplete combustion (with CO)

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

Chapter - V

Heat Transfer

1. Temperature equivalents

^0F	=	$\left(\frac{9}{5}\right) \times {}^oC + 32$
^oC	=	$\frac{5}{9} ({}^oF - 32)$
Rankine	=	$^0F + 459.6$
Kelvin	=	$^0C + 273.15$

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 (^0K)
T_a	:	Ambient temperature (^0K)

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 (^0K)
T_a	:	Ambient temperature (^0K)
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 (^0K)
T_a	:	Ambient temperature (^0K)

5. Nusselt number

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

6. Prandtl number

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

Chapter - VI

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

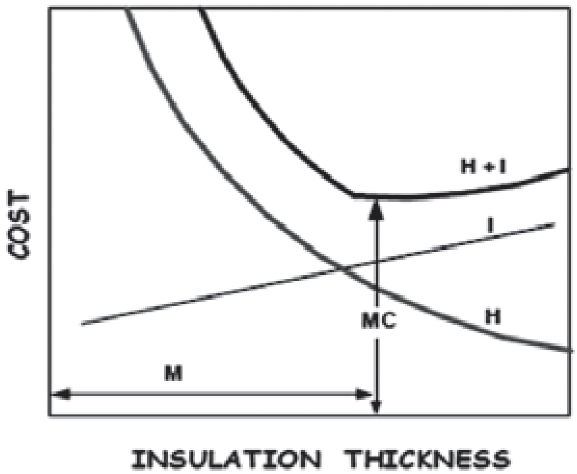
Surface Heat Transfer Coefficient of Hot Bare Surlace, h: $(0.85+0.005\ (T_h - T_a))x10$	$W/m^2\ {}^0C$	15	15	15
Surface Heat Transfer Coefficient After Insulation, $h' = (0.31+0.005\ (T_c - T_a))\ x\ 10$	$W/m^2\ {}^0C$	4.7	4	3.75
Thermal Resistance, $R_{th} = (T_h = Tc)/[h'\ x\ T_c T_a)]$	${}^0C\text{-}m^2/W$	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
$t_{eq} = r_2\ x\ In\ (r_2/r_1) =$ (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, $Q = h'\ x\ A'\ x\ (\pi a)$	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	Rs/kg	0.70	0.70	0.70
Heat Energy Cost, p	Rs./kWh	1.11	1.11	1.11
Annual Monetary Saving, S=E x p	Rs.	412708	431313	436599
Discount factor for calculating NPV of cost of energy loss	%	15%	15%	15%
Cost of Insulation (material +labor)	Rs/m	450	700	1100
Total cost of insulation	Rs/m	22500	35000	55000
Annual Cost of energy loss	Rs/year	46000	27395	22109
NPV forof annual cost of energy losses for 5 years	Rs	154198	91832	74112
Total cost (insulation and NPV of heat loss	Rs	176698	126832	129112

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

Chapter - VII
Physical Chemistry

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/hr)	:	volume of gas at pressure (P_2) & at temperature (T_2)
V_1 (m^3/hr))	:	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

$$Q_o = \frac{Q \times 273.15 \times (10336 \pm P_s)}{(273.15 + T) \times 10336} \ (Nm^3/hr)$$

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

$$Q = \frac{Q_o \times (T + 273.15) \times 10336}{273.15 \times (10336 \pm P_s)} \ (Nm^3/hr)$$

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)

Chapter - VIII

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 (ºC)

T_2 : Cooled exit gas temperature (ºC)

T_3 : Water temperature (ºC)

5. Kiln feed retention time

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

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)

Chapter - IX
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 = $\frac{42.3}{\sqrt{D}}$ (RPM)

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

3. Ball size calculation

Bond's ball size formula is

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

ϕ max : Grinding ball Max diameter, mm

F : Feed size (μ)

K : Constant (335)

W_i : Work index (kWh/T)

ρ : Specific gravity

$\%N_c$: % 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

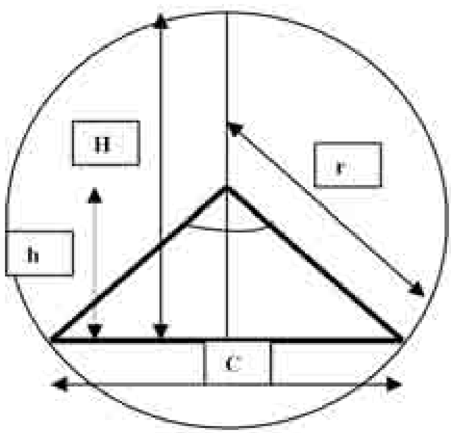
4. Separator efficiency

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

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 (%) = $\dfrac{100\,(\pi \times r^2 (\theta/360) - h \sqrt{(r^2 - h^2)})}{\pi \times r^2}$

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

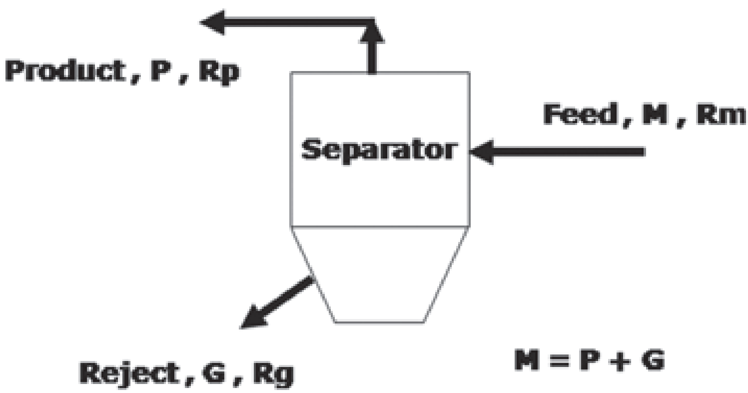
$$EH = \frac{480}{H^{0.91}} \quad \text{kWh/t}$$

Chapter - X

Tromp Curve Calculation and Significance

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**µ** for cement, or 1 to 200**µ** for raw meal is performed. Typical curves are shown for a mechanical and a high-efficiency separator respectively.



$$M = P + G$$

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

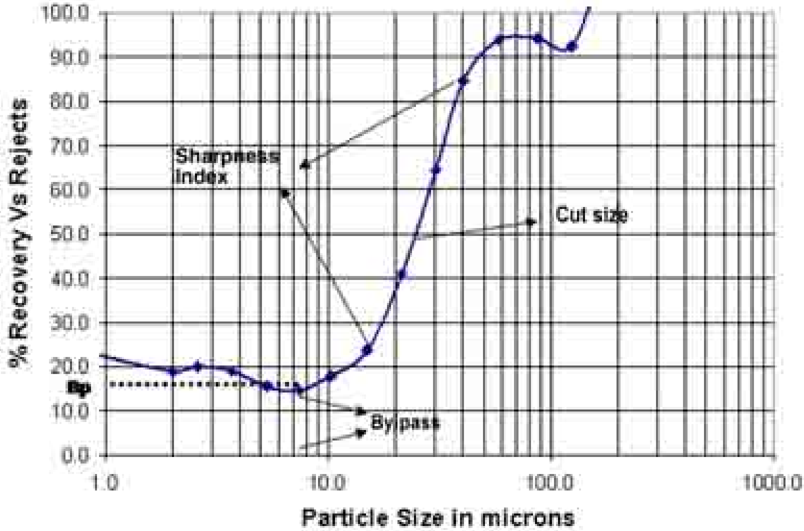
Where:

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

Chapter - XI

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

kW is the actual loading

3. Three phase alternators

Star connected

Line voltage	=	$\sqrt{3}$ x phase voltage
Line current	=	phase current

Delta connected

Line voltage	=	phase voltage
Line current	=	$\sqrt{3}$ x phase current

Three phase power

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

Chapter - XII

Fan Engineering

1. Fan efficiency

Mechanical η % = $\dfrac{\text{Volume } (m^3/s) \text{ x } (mmWC) \text{ x } 100}{102 \text{ x power input to fan shaft (kW)}}$

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)

Chapter - XIII

Fluid Flow

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 0.01 for large pipes and 0.02 for small pipes
L	:	Length of the pipe (m)
D	:	Diameter of the pipe (m)
ρ	:	Density of the fluid (kg/m³)
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)
ñ	:	density of fluid (kg/m³)
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

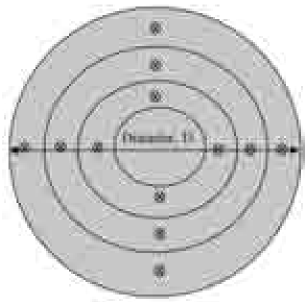
a. Norms for locating measuring point:

- ❖ 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

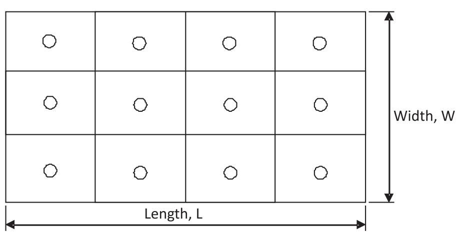
b. Isokinetic point

b1. For circular ducts :



Dia	0<D<300mm	300<D<700	700<D<1500	1500<D<2400	2400<D<3400
Points	2x2 (no. of points)	2x4	2x6	2x8	2x10
P1(from both sides)	0.85D	0.93D	0.96D	0.97D	0.97D
p2	0.15D	0.75D	0.85D	0.90D	0.92D
p3		0.25D	0.7D	0.81D	0.87D
p4		0.07D	0.3D	0.68D	0.77D
p5			0.15D	0.32D	0.66D
p6			0.04D	0.19D	0.34D
p7				0.10D	0.23D
p8				0.03D	0.15D
p9					0.08D
p10					0.03D

b2. Rectangular ducts:



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

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 = $\rho_N \times \dfrac{273}{273 + t} \times \dfrac{B \pm P_s}{10336}$ (kg/m³)

ρ_N : Normal density (kg/Nm³)

P_s : Static Pressure (mm WC)

t : Temperature of gas flow (°C)

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

g : 9.81 (m/s²)

P_d : Dynamic pressure (mm WC)

P_t : Corrected Density (kg/m³)

Q_o = $\dfrac{Q \times \rho_t}{\rho_o}$ (Nm³/hr)

Q_o : Standard gas volume (Nm³/hr)

Q : Actual gas volume (m³/hr)

ρ_t : Corrected Density (kg/m³)

ρ_0 : Normal Density (kg/Nm³)

Static pressure

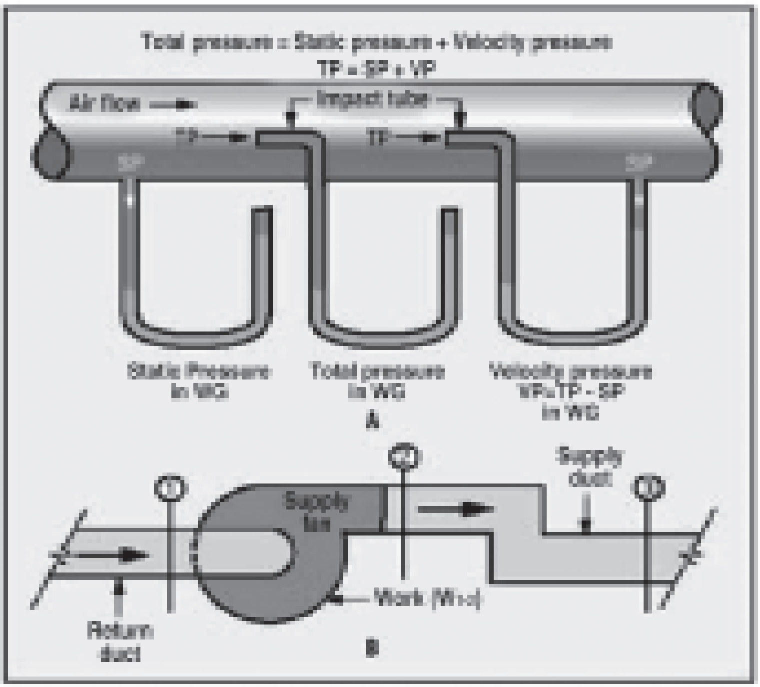
Static pressure is the potential energy put into the system by the fan. It is given up to friction in the ducts and at the duct inlet as it is converted to velocity pressure. At the inlet to the duct, the static pressure produces an area of low pressure.

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.

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.



Static, Total and Velocity Pressure

Chapter - XIV

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 bv 0.6 to eive 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		
	$\mu_{c = 50}$	$\mu_{c = 100}$	$\mu_{c = 1000}$
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 :

μ_c = viscousity, centipoise

3. Formula for optimum pipe inside diameter

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

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

where :

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

m_v : 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:

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

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

Chapter - XV

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

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

$= \dfrac{0.079}{R_e^{1/4}}$ 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

$$h_c = 0.5 \times \frac{V_2^2}{2g}$$

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

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

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

Chapter - XVI

Typical Characteristics of Pneumatic Transport Systems

1. Characteristics of pneumatic conveying systems

Material	Conveying system	Conveying system type	Recommended phase density, kg material/kg air	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	Densephase	50 -80	2.0 -3.0 kW / MT /200m
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)

m_p : mass flow rate of material (tph)

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

appropriate relationship between velocity and pressure drop

$$\Delta p \propto \frac{L x \rho x C^2}{d}$$

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:

$$V = C \times A$$

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

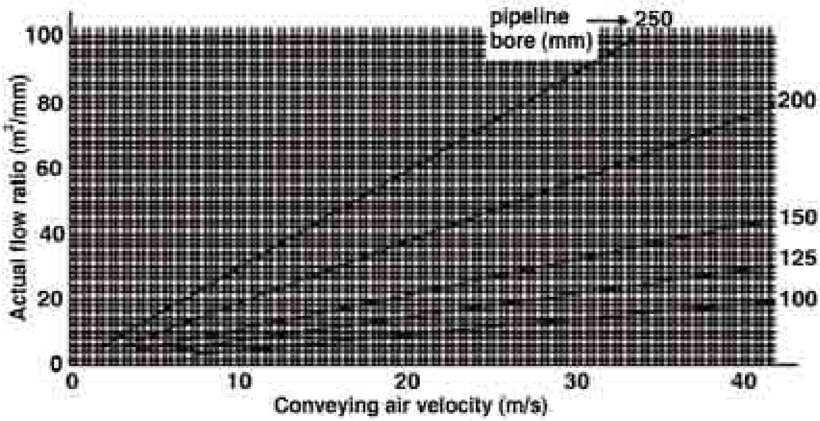
Where:

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.

Chapter - XVII
Transport Equipment

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 $(RPM)^3$

Chapter - XVIII

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	5.0-7.0
2	Pulse jet Bag filter (Non process Appliction)	1.6 - 2.4 Nm^3 / hr / 1000 m^3/hr of ventilation volume	5.0-7.0
3	Fluxo pump	20 Nm^3 /tonne - 60 Nm^3 /tonne	6.0-7.0
4	Water spray system (GCT, cement mills)	135 Nm^3/hr @ 3 bar for 1.8 m^3/hr of water spray	3.0-3.5
5	Packing machine		4.5-5.0
6	General Instrumentation		5.0-5.5
7	Fly ash conveying	20 m^3/min @ 2 bar for unloading 950 kg/min of fly ash	1.8-2.5
8	Air blaster	Air blaster with 100 litres tank capacity will consume 700 litres FAD @ 7 bar	6.0-7.0

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

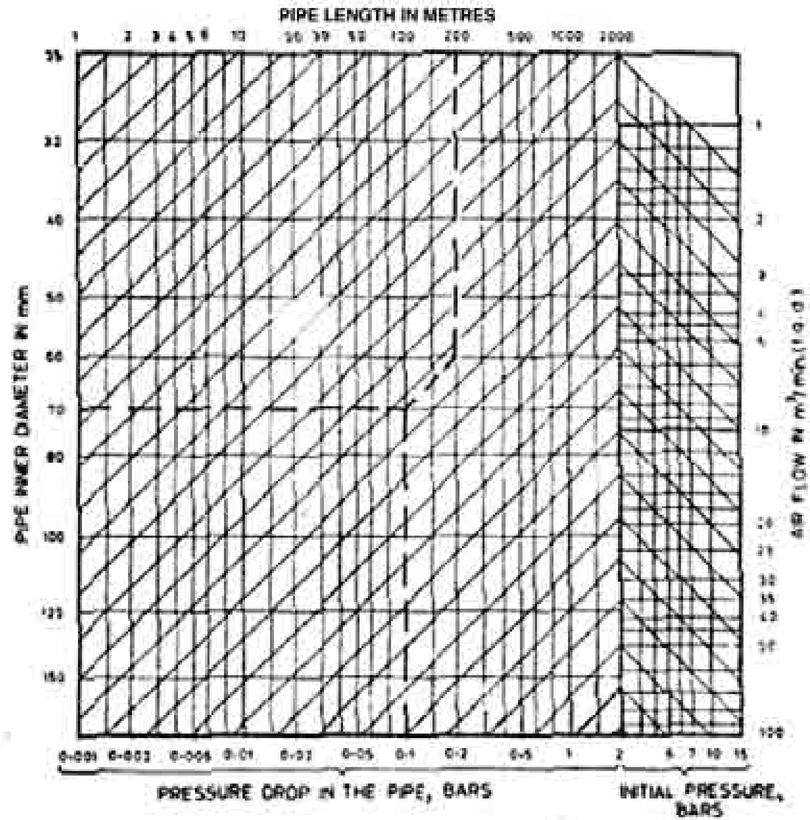
3. Pressure drop in a pipeline

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 be 0.3 bar.

The pressure drop can be readily obtained from the graph given below.



Pressure drop in a pipeline
(Source: Indian Standards IS 6206 –1985)

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 (P_2) from the initial pressure (P_1). 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.

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

P_1	:	initial pressure in receiver (kg/cm²)
P_2	:	final pressure in receiver (kg/cm²)
P	:	atmospheric pressure (1.033 kg/cm²)
V_R	:	Volume of air receiver (m³)
Δt	:	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 ^0C

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 : $\frac{T}{T + t} \times Q$ 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(Rs/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 Rs.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 efficency, η_{iso}	=	$\dfrac{\text{iso thermal power}}{\text{Actual measured input power}}$
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}	=	$\dfrac{\text{free air delivered (m}^3\text{/min)}}{\text{Compressor displacement}}$
Compressor displacement	=	$\dfrac{\pi \times D^2 \times L \times S \times \lambda \times n}{4}$
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

Chapter - XIX

Finance

1. Simple payback period

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

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.

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

CF_t : 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.

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

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.

Chapter - XX

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

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

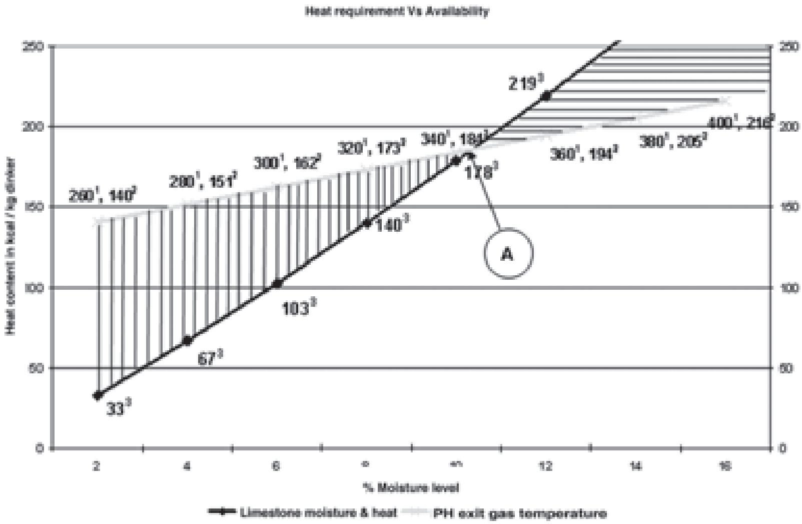
$$\text{Percent severity} = \frac{100 \times s}{s_{std}}$$

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

Chapter - XXI

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.



The graph gives the correlation between the heat content available (kcal / kg clinker) in the preheater gas for different preheater outlet temperatures (Deg C) and the heat required for Raw mill (kcal / kg clinker) for different lime stone moisture levels. The assumption made is the preheater gas volume is about 1.5 Nm^3 / kg clinker.

Notes :

1. 260 [1] - To be read as preheater exit gas temperature 260 Degree Centigrade.

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 clinker

The intersecting point (Point A) at 190 kcal / kg is the maximum point at about 340 DegC 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.

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									
Moisture in 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 / ^{0}C
    c. Temperature T_{PH1}: 316 ^{0}C
4. Cooler exit gas details :
    a. Volume (mC): 1.0 Nm3 /kg clinker
    b. Specific heat capacity CPC: 0.317 kcal / kg / ^{0}C
    c. Temperature TC : 300 ^{0}C
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 ^{0}C
18. Cooler exit temperature at AQC boiler outlet TC2 : 120 ^{0}C

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 : $m_C \times C_{PC} \times T_C$

: 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} : $m_{PH} \times C_{PPH} \times (T_{PH1} - T_{PH2})$: 1.5 x 0.36 x (316 – 240)

: 41.0 kcal / kg clinker

9. Heat recoverable in Cooler side Boiler

Q_{AQC} : $m_C \times C_C \times (T_{c1} - T_{c2})$

: 1.0 x 0.317 x (300 – 120)

: 57.0 kcal / kg clinker

1. Heat available to steam for power generation :

: $Q_{WHRB} \times EFF_{WHR} + Q_{AQC} \times EFF_{AQC}$

: 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

Chapter - XXII

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

$$\eta\ (\%) = \frac{m_s \times (h_1 - h_2) \times 100}{m_f \times \text{CV of fuel}}$$

m_s : Mass flow rate of steam (kg)

h_1 : Enthalpy of steam produced in boiler (kJ/kg)

h_2 : Enthalpy of feed water to boiler(kJ/kg)

m_f : 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 (ºC) - Cooling tower water outlet temperature (ºC)

Approach

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

Cooling tower effectiveness

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

Cooling capacity	=	m x Cp x $(T_1 - T_2)$
m	:	mass flow rate of water (kg/hr)
Cp	:	specific heat capacity (kJ/kg ^{o}C)
T_1	:	Cooling tower water inlet temperature (^{o}C)
T_2	:	Cooling tower water outlet temperature (^{o}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

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

Formula number	Source
Chapter 1	
1	Cement Manufacturer’s Handbook by Kurt.E. Perray-p3
2	FLS burner-p5
3	FLS burner-p5
4	FLS burner-p5, Duda hand book-p13
4	Cement Manufacturer’s Handbook by Kurt.E. Perray-p4
5	Cement Manufacturer’s handbook by Kurt.E. Perray-p5
6	Cement Manufacturer’s Handbook Kurt.E. Perray-p6
7	Cement Manufacturer’s Handbook by Kurt.E. Perray-p9
8	FLS burner-20
9	Cemex operations-p 139
10	Raw material mixtures & their characteristics RTC India-Page 19
11	Cemex operations-p11
Chapter 2	
1	Cement Manufacturer’s Handbook by Kurt.E. Perray-p59
2	Cement Manufacturer’s Handbook by Kurt.E. Perray-p59
3	Cement Manufacturer’s Handbook by Kurt.E. Perray-p59
4	Cement Manufacturer’s Handbook by Kurt.E. Perray-p64
5	Handbook of formulae & physical constants-p27
Chapter 3	
1	FLS communication manual-P-J1
Chapter 4	
1	RTC India Kiln operations & optimization-p49
2	RTC India Process & Kiln system-p49
3	Mathcement formula-p24
4	FLS comminution manual-p69
5	BEE manual on Boilers-p9
Chapter 5	
2	FLS burner-p60
3	FLS burner-p60
4	FLS burner-p60

6	FLS burner p-61
Chapter 6	
1	Bureau of Energy efficiency - insulation and refractories-p126
Chapter 7	
1	Cement Manufacturer's Handbook Kurt E .Peray-p289
2	Cement Manufacturer's Handbook Kurt E .Peray-p273
3	Cement Manufacturer's Handbook Kurt E .Peray-p274
Chapter 8	
1	RTC India Process & Kiln system-p49
2	RTC India Process & Kiln system-p49
3	RTC India, Process & Kiln system-p63
4	Cement Manufacturer's Handbook by Kurt.E. Perray-p153
5	FLS burner-p70
6	Cement Manufacturer's Handbook Kurt.E. Perray-p158
Chapter 9	
2	FLS comminution manual-pA3
4	Cement Manufacturer's Handbook Kurt.E. Perray-p220
5	mathcement formula-p55
6	Cemex operations-p 135
Chapter 10	
1	Cemex operations book handbook-p130
Chapter 11	
3	Handbook of formulae & constants-p36
4	Handbook of formulae & constants-p36
Chapter 12	
1	Bureau of Energy Efficiency-Fans & Blowers-p17
2	cement manufacturer's handbook us-p255
3	Cemex operation handbook-p125
Chapter 13	
1	Perry chapter6-p49
3	FLS burner-37
3	FLS communition manual-pE7

Chapter 14	
1, 2	Max S.Peters, Plant design and economics for chemical engineers - p496
3, 4	Peters & Timmerhaus 5th edition (Max S. Peters, Klaus D. timmerhaus and Ronald E.West, "Plant design and economic for chemical engineers- p501
Chapter 15	
1, 2	R.K.Bansal, Fluid mechanics & hydraulic machines
	Perry's Chemical Engineers Hand Book, chapter 6
Chapter 16	
	David Mills, Pneunatic conveying design guide 2 edition.
Chapter 17	
1	Cemex operations book handbook-p131
2	Cemex operations book handbook-p131
3	Cemex operations book handbook-p132
Chapter 18	
1	CII Centrifugal Pump training module
2	BEE Compressed air systems
3	BEE manual on Compressed air system
Chapter 19	
2	BEE manual on Financial Management-p7
Chapter 20	
1	Cement Manufacturer's Handbook Kurt E .Peray-p347
2	Cement Manufacturer's Handbook Kurt E .Peray-p348
3	Cement Manufacturer's Handbook Kurt E .Peray-p348
Chapter 21	
	CII WHR manual
Chapter 22	
1	BEE-HVAC & Refrigeration system-p-84
2	Handbook of formulae & physical constants-p27
3	BEE manual on Cooling tower-p5

NORMS

Chapter - I
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

Chapter - II
Electrical Energy Consumption Target

Area of activity	Electrical consumption (kWh / Ton of OPC)**
Crushing	1.5
Raw mill	12 - 18
Kiln and Cooler	18
Coal mill	2.5
Cement mill	18
Packing	1
Miscellaneous	3.5
Total	**56-62**

**Based on the best operating plant

Chapter - III
Thermal Energy Consumption Target

Parameter	Specific Fuel Consumption (kCal / kg Clinker)*
Theoretical heat consumption	410
Pre-heater loss	105
Cooler loss (Clinker & Cooler vent gases)	90
Radiation loss	75
Heat Input	-30
Total	**650**

*Based on the best operating plant

Chapter - IV
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) Raw mill (Roller press)	21 20
4.	Coal mill (Ball mill, VRM)	21
5.	Kiln	24
6.	Cement Mill (Ball mill, VRM + Horrow mill) Cement mill (Roller press)	 21 20
7.	Packing Machine	15

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

Chapter - V
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%)

Chapter - VI
Comparison Between Different Dry Process Technologies

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	Deg C	390	360	316	282
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.

Chapter - VII
Kiln & Pre-Heater

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 ➢ Separate Line calciner ➢ Caciner with Pet coke firing	Sec.	 3.2 2.6 4.5
6.	Tertiary air temperature	^oC	850 – 1000
7.	Secondary air temperature	^oC	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

Chapter - VIII
Kiln Gas Velocities

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

Chapter - IX
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

Chapter - X
Primary Air Momentum

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%xC(%m/s)	1200-1500	1200-2000	1200-1450	1200-2000

Chapter - XI
Electro Static Precipitator

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	:	10^7 – 10^{11} 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)

Chapter - XII
Harmonic Levels at Different Section

Supply System Voltage (kV) at point of common coupling	Total Harmonic Voltage Distortion V_T (%)	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.

Chapter - XIII
Typical Data for Different Lighting- Efficacy, 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

Chapter	Source
I	Confederation of Indian Industry
II	Confederation of Indian Industry
VII	Cemex operations Handbook-P140
IX	FLS burner-p71
X	Cemex operations Handbook-P68
XI	Cemex operations Handbook-P68
XII	Confederation of Indian Industry
XIII	Confederation of Indian Industry

REFERENCE DATA

Chapter - 1

Atmospheric Pressure and Density Vs Altitude at (0^{O}C)

Altitute 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**

Chapter - 2
Specific Gravities & Grindabilities

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

Chapter - 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 % H_2O	1682

Chapter - 4
Molecular Weight of Chemicals (g/g mol)

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	$C_{12}A_7$	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	$CaSO_4\ \frac{1}{2}H_2O$	145
SrO	104	$CaCO_3.MgCO_3$	184
CA_2	260	$2C_2S.CaSO_4$	480

MWt = Molecular Weight

Chapter - 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

Chapter - 6
Angle of Repose

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

Chapter - 7
Typical Data for Solid Fuels
(% As Recd/Mineral-Matter-Free)

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 1300kilocalories 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 notexceeding 18 percent.

Sl No	Class	Grade	Grade specification
		Washery grade I	Ash content exceeding 18 per cent but notexceeding 21 per cent
		Washery grade II	Ash content exceeding 21 per cent but notexceeding 24 per cent.
		Washery grade III	Ash content exceeding 24 percent but notexceeding 28 percent.
		Washery grade IV	Ash content exceeding 28 percent but notexceeding 35 percent.
3	Semi coking and weakly coking coals	Semi coking Gr. I	Ash plus moisture content not exceeding 19percent
		Semi coking Gr. II	Ash plus moisture content exceeding 19 percentbut 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^{0}C 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^{0}C 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^{0}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.

Chapter - 8
Typical Data for Liquid Fuels

	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 @ 38^{0}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

Chapter - 9
Physical Data of Pre-heater Exhaust Gas With Various Levels of (Dry) Excess Air

	Density kg/Nm^3	Specific heat cal/g/^{o}C	Dew point ^{o}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

Chapter - 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

Chapter - 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

Chapter - 12
Ball Mill-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.

Chapter - 13
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, %

Chapter - 14
Useful Data for Grinding Mill Study

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

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

Chapter - 15
Ball Mill Charging

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

			120		110		100		90	90		80		70
Compensation size*		Mm	110	110	100	100	90	90	80	70	80	70	70	60
Ball size in chamber		Max	120	110	110	100	100	90	90	90	80	80	70	70
		Min	50	50	50	50	50	40	40	40	40	40	30	30
120 mm	7085 g	6.4 m^2/t	9											
110 mm	5457 g	7 m^2/t	23	19	10									
100 mm	4100 g	7.7 m^2/t	24	28	24	21	10							
90 mm	2989 g	8.5 m^2/t	18	21	26	31	27	23	12	12				
80 mm	2099 g	9.6 m^2/t	12	14	18	22	27	32	29	16	26	13		
70 mm	1406 g	11 m^2/t	8	10	12	14	18	21	28	25	36	32	29	15
60 mm	886 g	12.8 m^2/t	5	6	7	9	11	14	18	25	22	31	37	36
50 mm	513 g	15.4 m^2/t	1	2	3	3	7	8	10	15	13	17	21	30
40 mm	262 g	19.2 m^2/t						2	3	7	3	7	11	16
30 mm	111 g	25.6 m^2/t											2	3
Piece weight initial		G	2750	2393	2116	1925	1582	1300	1123	880	1004	808	612	505
Piece weight equilibrium		G	2877	2546	2185	1913	1613	1395	1151	892	979	786	656	507
Specific surface initial		M^2/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
Specific surface equilibrium		m^2/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-small balls

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

Chapter - 16
BIS Specification of Additives

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	$\frac{CaO + MgO + 1/3Al_2O_3}{SiO_2 + 2/3Al_2O_3}$	$\geq$1.0
	2	$\frac{CaO + MgO + Al_2O_3}{SiO_2}$	$\geq$1.0
C	When MnO in slag is more than 2.5		
		$\frac{CaO + CaS + 1/2MgO + Al_2O_3}{SiO_2 + MnO}$	$\geq$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	
		I	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

Chapter - 17
BIS Specifications For Various Cements

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

Ordinary Portland cement 53 (OPC 53)	
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)	
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

Ordinary Portland Cement 33 (OPC 33)	
Particulars	BIS specification
Fineness (m^2 / kg)	Minimum 300
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

Blended cement

Pozzolana Portland cement	
Particulars	BIS specification
Fineness (m^2 / kg)	Minimum 300
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

Chapter - 18
Thermo Physical Properties of Different Insulating Materials

Physical properties of different insulating materials

Sl. No.	Material	Thermal Conductivity W/m °C	Density, kg/m³	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		

Bureau of energy efficiency

Chapter - 19
Pollution standards
(Stack, Ambient air and Water)

Emission standards

Emission CEMENT INDUSTRY : EMISSION STANDARDS		
Plant Capacity	Pollutants	Emission limit (mg/Nm^3)
200 tonnes per day and less (All Sections)	Particulate Matter	400
More than 200 tonnes per day (All Sections)	Particulate Matter	250

National ambient air quality standards

S. No.	Pollutant	Time Weighted Average	Concentration in Ambient Air		
			Industrial Residen-tial, Rural and other Area	Ecologi-cally Sensitive Area (notified by central Govt.)	Methods of Measurement
1	Sulphur Dioxide (SO_2), Pg/m^3	Annual*	50	20	- Improved West Gacke
		24 hours**	80	80	- Ultraviolet flore-scence
2	Nitrogen Dioxide (NO_2), µg/m^3	Annual*	40	30	- Modified Jacob & Hochheister (Na-Arsenite) - Chemilumine-cence

S. No.	Pollutant	Time Weighted Average	Concentration in Ambient Air		
			Industrial Residen-tial, Rural and other Area	Ecologi-cally Sensitive Area (notified by central Govt.)	Methods of Measurement
3	Particulate Matter (size less than (10µm) or PM10 µg/m³	Annual* 24 hours**	60 100	60 100	- Gravimetric - TOEM - Beta attenuation
4	Particulate Matter (size less than 2.5µm) or PM_{25} µg/m³	Annual* 24 hours**	40 60	40 60	- Gravimetric - TOEM - Beta attention
5	Ozone (O_2) µg/m³	8 hours** 1 hour**	100	100	- UV photometric - Chemilumine-scence - Chemical Method
6	Lead (Pb) µg/m³	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/m³	8 hours** 1 hour**	02 04	02 04	- Non Dispensive Red (NDIR) spectroscopy

S. No.	Pollutant	Time Weighted Average	Concentration in Ambient Air Industrial Residen-tial, Rural and other Area	Ecologi-cally Sensitive Area (notified by central Govt.)	Methods of Measurement
8	Ammonia (NH_3) µg/m³	Annual* 24 hours**	100 400	100 400	- Chemilumine-scence - Indophenol blue method
9	Benzene (C_2H_6) µg/m³	Annual*	05	05	- Gas chromalo-grapy based continuous analyzer - Adsorption and Desorption followed by GC analysis
10	Benzo(O)Pyrene (BaP)-particulate phase only, µg/m³	Annual*	01	01	-Solvent extraction followed by HPLC/ GC analysis
11	Arsenic (As), µg/m³	Annual*	06	06	-AAS / ICP method after sampling on EPM 2000 or equivalent filter paper
12	Nickel (Ni), µg/m³	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 Wild life 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.

1. 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.

Chapter - 20
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:

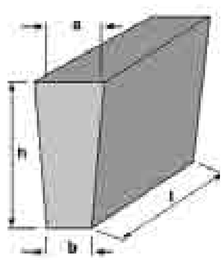
kVA rating (Watts)	No-load loss (Watts)	Full load loss at 75°C (Watts)	Impedance
(%)			
160	425	3000	5
200	570	3300	5
250	620	3700	5
315	800	4600	5
500	1100	6500	5
630	1200	7500	5
1000	1800	11000	5
1600	2400	15500	5
2000	3000	20000	6

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.

Chapter - 21
Bricks per Ring



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.

Chapter - 22
Emissivity Values of Surfaces

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

xEmissivity varies with purity

Chapter - 23
Conversion Factor

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 k Cal	1000 cal
1 BTU	252 cal
1 joule	0.2388 cal

Chapter number	Source
1	Cemex operations Handbook-P149
2	Cemex operations Handbook-P147
3	Cemex operations Handbook-P147
4	Cement plant operations handbook-p118
5	Handbook of formulas and physical constants-p28
6	Cemex operations Handbook-P147
7	Cemex operations Handbook-P144
8	Cemex operations Handbook-P144
9	Cemex operations Handbook
10	Cemex operations Handbook-P32
11	BEE manual on Fuel & Combustion-p3
12	Cemex operations Handbook-P133
13	Cemex operations Handbook-P136
14	Cement Manufacturer's Handbook-P226
15	FLS comminution manual - pA8
16	Source:http://www.cmcl.co.in/cement/media/ Article%20Indian%20Cement%20Review%5B1%5D.pdf
17	Source:www.shyamgroup.com/cement.html
	www.indiacements.co.in
	CO_2 Baseline Database for the Indian Power Sector, User Guide, Version4, September 2008, Central Electricity Authority
18	BEE manual on Insulation & Refractories
19	www.cpcb.nic.in

Chapter - 24
Heat Balance Calculation

The soft copy of the (heat balance.xls) is uploaded in the Cement Forum @ **www.greenbusinesscentre.com**

Members of the forum can download the file by signing in and clicking on the "Files" link, where you will be able to see a folder titled **"Heat balance calculator".** The file in this folder can be downloaded.

Link : **http://www.greenbusinesscentre.org/site/forum/index.jsp**

Conclusion

We feel that this Formula Handbook Version 2.0 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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About CII

The Confederation of Indian Industry (CII) works to create and sustain an environment conducive to the growth of industry in India, partnering industry and government alike through advisory and consultative processes.

CII is a non-government, not-for-profit, industry led and industry managed organisation, playing a proactive role in India's development process. Founded over 115 years ago, it is India's premier business association, with a direct membership of over 7800 organisations from the private as well as public sectors, including SMEs and MNCs, and an indirect membership of over 90,000 companies from around 396 national and regional sectoral associations.

CII catalyses change by working closely with government on policy issues, enhancing efficiency, competitiveness and expanding business opportunities for industry through a range of specialised services and global linkages. It also provides a platform for sectoral consensus building and networking. Major emphasis is laid on projecting a positive image of business, assisting industry to identify and execute corporate citizenship programmes. Partnerships with over 120 NGOs across the country carry forward our initiatives in integrated and inclusive development, which include health, education, livelihood, diversity management, skill development and water, to name a few.

Complementing this vision, CII's theme for 2009-10 is 'India@75: Economy, Infrastructure and Governance.' Within the overarching agenda to facilitate India's transformation into an economically vital, technologically innovative, socially and ethically vibrant global leader by year 2022, CII's focus this year is on revival of the Economy, fast tracking Infrastructure and improved Governance.

With 64 offices in India, 9 overseas in Australia, Austria, China, France, Germany, Japan, Singapore, UK, and USA, and institutional partnerships with 221 counterpart organisations in 90 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), a division of Confederation of Indian Industry (CII) is India's premier developmental institution, offering advisory services to the industry on environmental aspects and works in the areas of Green Buildings, Energy Efficiency, Water Management, Renewable Energy, Green Business Incubation and Climate Change activities.

The Centre sensitises key stakeholders to embrace green practices and facilitates market transformation, paving way for India to become one of the global leaders in green businesses by 2015.

The centre is housed in a green building which received the prestigious LEED (Leadership in Energy and Environmental Design) Platinum rating in 2003. This was the first Platinum rated green building outside of U.S.A and the third in the world.

The centre was inaugurated by H.E Shri A P J Abdul Kalam, the then President of India, on July 14, 2004. CII-Sohrabji Godrej Green Business Centre is a unique and successful model of public-private partnership between the Government of Andhra Pradesh, Pirojsha Godrej Foundation and the Confederation of Indian Industry (CII), with the technical support of USAID.

CII

Confederation of Indian Industry

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