Design of High Efficiency Cyclone for Tiny Cement Industry

Niki Gopani and Akshey Bhargava

Abstract— Air pollution is assuming alarming dimensions from industries, automobiles and house hold fuel burning. Cement industry can be classified as highly air polluting industry emitting PM (Particulate Matter) into the atmosphere. This pollutant is in the form of PM (Particulate Matter) is required to be control by installing air pollution control equipment like ESP (Electrostatic Precipitators), Bag houses, Wet scrubbers and cyclone. Cyclone is considered to be cheaper having low maintenance cost. The present paper aims at designing of high efficiency cyclone by using STAIRMAND METHOD for a tiny cement plant. The efficiency achieved with this design is of the order of 91.1 %.

Index Terms— Air pollution, cyclone, pm (particulate matter), tiny cement plant

I. INTRODUCTION

The tiny cement plants are having a capacity of ranging from 20tpd to 50tpd. These cement plant are either based on vertical shaft kiln or rotary kiln technologies. The predominant air pollutant emitted on from such plant is SPM (Suspended Particulate Matter). Control of SPM (Suspended Particulate Matter) can be achieved by installing ESP (Electrostatic Precipitators), Bag houses and Wet scrubbers but these equipments are highly cost intensive and may not be feasible to be installed at such small scale cement plants on techno-economical front. Hence, under the present context, installation of cyclone appears to be a reasonable proposition, which is reasonable cheaper and having low operating cost [16].

A. The salient features of the cyclone are as under [13] [14]

- 1) Structure without moving parts.
- 2) Centrifugal force created; tend to drive particles to the wall of cyclone.
- 3) Inlet velocity of gas stream transformed into a confined vortex or spiral flow downward between walls of gas discharge outlet and body of cyclone or main vortex.

II. APPLICATION OF CYCLONE

Applications of cyclone are as under [14]

- 1) Sawmill
- 2) Oil refineries
- 3) Cement industry
- 4) Feed and grain processing
- 5) Mineral processing
- 6) Paper and textile industry
- 7) Wood working industry
- 8) Vacuum cleaners and central vacuum cleaners

III. ADVANTAGE OF CYCLONE

Advantages of cyclone are as under [14]

- 1) Low initial cost
- 2) Simple construction and Operation
- 3) Low pressure drop
- 4) Low maintenance requirements
- 5) It has no moving parts
- 6) Continuous disposal of solid particulates
- 7) They can be constructed of any material which will meet the temperature and pressure requirements and the corrosion potential of the carrier gas stream

IV. DISADVANTAGE OF CYCLONE

Disadvantages of cyclone are as under [14]

- 1) Low collection efficiency for particles below 5-10 μ in diameter
- 2) Equipment is subject to severe abrasive deterioration.
- 3) Decreasing collection efficiencies for decreasing dispersoid concentration in the gas stream

V. STANDARD CYCLONE DESIGN BY STAIRMAND METHOD

Stairmand developed two standard design for gas-solid cyclones (1) High efficiency cyclone [1], figure 3(a) and (2) high gas rate cyclone, figure 3(b) [11]. The performance curve for these design, obtained experimentally under standard test conditions, are shown in figure 4(a) and D(b). [4] This curve can be transformed to other cyclone sizes and operating conditions by use of the following equation, for a given separating efficiency [2]

$$D_2 = [(DC_2/DC_1)^3 \times Q_1/Q_2 \times \Delta p_1/\Delta p_2 \times \mu_2/\mu_1]^{1/2} \quad (1)$$

where,

d_1 = mean diameter of particle separated at the standard conditions, at the chosen separating efficiency, figure 4(a) or 4(b).

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D_2 =mean diameter of the particle separated in the proposed design, at the same separating efficiency,
 DC_1 =diameter of the standard cyclone = 8 inches (203 mm),
 DC_2 =diameter of proposed cyclone, mm,
 Q_1 =Standard flow rate:
 For high efficiency design =223 m³/h,
 For high throughput design = 669 m³/h,
 Q_2 =proposed flow rate, m³/h,
 $\Delta\rho_1$ =solid-fluid density difference in standard conditions = 2000 kg/m³
 $\Delta\rho_2$ =density difference, proposed design,
 μ_1 =test fluid viscosity (air at 1 atm,200 C) =0.0018 mNs/m²
 μ_2 =viscosity of proposed fluid.[10]

A performance curve for the proposed design can be drawn up from , figure 4(a) or 4(b) by multiplying the grade diameter at, say each 10 per cent increment of efficiency, by the scaling factor given by equation 1 as show in figure 5[5]

Fig. 1. Reverse-flow cyclones

A. Pressure Drop

The pressure drop in a cyclone will be due to the entry and exist losses along with friction and kinetic energy losses in the cyclone.[12]

The empirical equation given by Stairmand (1949) can be used to estimate the pressure drop:

$$\Delta P = \rho f / 203 \{ u_1^2 [1 + 2\phi^2 (2r_i/r_e - 1)] + 2u_2^2 \} \quad (2)$$

where,

ΔP = cyclone pressure drop, millibar,
 ρf = gas density, kg/m³,
 u_1 = D inlet duct velocity, m/s,
 u_2 =D exit duct velocity, m/s,
 r_i = D radius of circle to which the centre line of the inlet is tangential, m,
 r_e =D radius of exit pipe, m,
 ϕ = factor from Figure 2,
 Ψ = parameter in Figure 2, given by:

$$\Psi = f_c A_s / A_1$$

F_c = friction factor, taken as 0.005 for gases,
 A_s = surface area of cyclone exposed to the spinning fluid, m².

A_1 = area of inlet duct, m².

For design purposes this can be taken as equal to the surface area of a cylinder with the same diameter as the cyclone and length equal to the total height of the cyclone (barrel plus cone).

Fig. 2. Cyclone pressure drop factor

Fig. 3. Standard Cyclone dimension as per stairmand (a) high efficiency (b) high gas rate cyclone

Fig. 4(a) Performance curves for high efficiency cyclone

Fig. 4(b) Performance curves for high gas rate cyclone

Fig. 5. Scaled performance curve

VI. MONITORED DATA

An effort was made to monitor the gaseous emission emitted out from the stack attached kiln by adopting standards method for monitoring and analysis. The results of monitoring are shown below:

PM concentration without control: 1250 mg/Nm³
 Density of particle: 2500 kg/m³
 Gas Temperature=150 C
 Gas flow rate: 4000m³/hour
 Required efficiency=90 %
 Particle size distribution as under

TABLE I: PARTICLE SIZE DISTRIBUTION

Particle size, μm	Percentage by weight less than
50	90
40	75
30	65
20	55
10	30
05	10
02	04

VII. DESIGN OF HIGH EFFICIENCY CYCLONE BY STAIRMAND METHOD

As 10 per cent of the particles are below 05μm the high-efficiency design will be required to give the specified

recovery.

Flow-rate = 4000/3600 = 1.11 m³/s
 Area of inlet duct, at 15 m/s = 1.11/15 = 0.07 m²
 Duct area = 0.5 D_c x 0.2 D_c = 0.07
 So, D_c = 0.84 m

This is clearly too large compared with the standard design diameter of 0.203 m.

Flow-rate per cyclone = 4000/8 = 500 m³/h = 0.13 m³/s

Here, area if inlet ducts = 0.13/15 = 0.00925 m²

Now area of inlet duct = 0.5 D_c x 0.2 D_c = 0.1 D_c² = 0.00925
 D_c = 0.30 meter, which is comparatively safe as it is close to standard size diameter of 0.203 meter.

Density of nitrogen base gas at 150°C

= Mol. Weight of nitrogen/mol. Weight of air x T°K of air at 0°C/T°K of gases

= 28/22.4 x 273/(273+150) = 0.81 kg/m³

Which is negligible compared with solid particle density.

Viscosity of nitrogen at 150°C

= viscosity of standard air x 28/22.4 = 0.018 x 28/22.4
 = 0.023 mNs/m²

From equation (1)

D₂ = [(D_{c2}/D_{c1})³ X Q₁/Q₂ X Δp₁/Δp₂ X μ₂/μ₁]^{1/2}

Scaling factor

= [(0.30/0.203)³ x 223/500 x 2000/2500 x 0.023/0.018]^{1/2}
 = 1.20

The performance calculations, using this scaling factor in the table below:

TABLE II: OVERALL COLLECTED EFFICIENCY[6]

Particle size (μm)	Percent in range	Mean particle size ÷ Scaling factor	Efficiency at scaled size %	Collected (2) x (4)/100
>50	10	41	99	9.90
50-40	15	37	98	14.70
40-30	10	29	97	9.70
30-20	10	21	96	9.6
20-10	25	12	94	23.5
10-5	20	06	88	17.6
5-2	06	03	85	5.1
2-0	04	01	25	1
	100			91.1

Over all collected efficiency = 91.1% [6]

Hence, the above design of cyclone is safe, as the designed efficiency is more than 90%.

Thus, the dimension of the design cyclone is as under [8][9]:

D_c =diameter of cyclone=0.30 m
 Height of inlet duct= $H_i=0.5 D_c=0.5 \times 0.3=0.15$ m
 Width of inlet duct= $w_i=0.2 D_c=0.2 \times 0.3=0.06$ m
 Diameter of out let duct= $D_o=0.5 D_c=0.5 \times 0.3=0.15$ m
 Diameter of dust outlet= $D_d=0.375 D_c=0.375 \times 0.3=0.11$ m
 Length of cyclone main body = $(1.5 D_c)=1.5 \times 0.3=L_1=0.45$ m
 Length of cyclone hopper = $2.5 D_c=2.5 \times 0.3=L_2=0.75$ m
 Total length of cyclone= $L_1+L_2=1.2$ m

A. Pressure Drop Calculation

Area of inlet duct $A_i = H_i \times w_i = 0.15 \times 0.06 = 0.009 \text{ m}^2$

Cyclone surface area $A_s = \pi D_c \times (L_1 + L_2)$
 $= 3.14 \times 0.30 \times 1.35 = 1.272 \text{ m}^2$

F_c taken as 0.005

$\Psi = f_c A_s / A_i$
 $= 0.005 \times 1.272 / 0.009$
 $= 0.70$

Here,

$r_1 = D_c - w_i / 2 = 0.30 - 0.06 / 2 = 0.27$

And $r_c = H_i = 0.15$

Thus $r_1 / r_c = 0.27 / 0.15 = 1.8$

From, fig. 2. $\phi = 0.9$

U_1 = inlet duct velocity = Flow of air / inlet duct area
 $= 0.13 / 0.009$
 $= 14.44 \text{ m/s}$

Area of exit duct = $\pi D_o^2 / 4 = 3.14 \times 0.15^2 / 4 = 0.017 \text{ m}^2$

U_2 = exit velocity = $0.13 / 0.017 = 7.64 \text{ m/s}$

From equation 2

$\Delta P = \rho f / 203 \{ U_1^2 [1 + 2\phi^2 (2r_1/r_c - 1)] + 2U_2^2 \}$
 $= 0.81 / 203 [14.44^2 [1 + 2 \times 0.9^2 (2 \times 0.27 / 0.15 - 1)] + 2 \times 7.64^2]$
 $= 4.80 \text{ millibar}$
 $= 480 \text{ N/m}^2$

B. Power Requirement

$W = Q \times \Delta P$
 $= 1.11 \times 4.80$
 $= 5.33 \text{ watt}$

Fig. 6. Proposed Cyclone Design

VIII. CONCLUSION

The designed high efficiency cyclone gives an efficiency of 91.1 % as against the desired 90 % which is safe design for controlling air pollutant concentration in the form of SPM from kiln attached to the cement plant. The monitored PM concentration is 1250 mg/Nm^3 without control and with 91.1 % efficiency, the outlet emission after control would be 111.25 mg/m^3 , which is much safer as against the mandatory standards of 150 mg/m^3 .

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