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DESIGN OF A MODEL PULVERIZED COAL COMBUSTION SYSTEM.

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ABSTRACT
The design of a model pulverized coal combustion system is undertaken. The system consists of a hopper, screw conveyor, blower, electric motor, among others. The design of the system focused on the following procedures in this work: The outlet of the pulverized coal from the silo opens directly into the receiving hopper of the screw conveyor. The drive of the blower is connected to the drive of the screw conveyor via bearings, pulleys, belt and gears. This means that one electric motor drives both the blower impeller and the screw conveyor shaft. The outlet of the conveyor is connected to the blower outlet hole so that the air from the blower meets the incoming pulverized coal. The air then sprays the pulverized coal into the already heated combustion chamber. The combustion chamber is heated initially with a pilot flame from burning wood so that the temperature of the chamber is elevated so as to make it easy for the pulverized particles of coal to ignite easily in the chamber. Once the combustion of the pulverized coal has started, the pilot flame can be withdrawn, combustion of the coal then continues until the content of the silo is finished. The ash formed during combustion of coal goes out through the ash exit outlet.

Keywords: *Design, hopper, screw conveyor, blower, electric motor, bearings, pulley, belt, gear and combustion chamber.*

INTRODUCTION

The technology of pulverized coal combustion system is a recent development and the design considerations according to Trinks, and Mawhinney (1967) are directed towards having a feasible and an efficient combustion system that meets energy and environmental performance standards by having a storage facility often called silo for holding the pulverized coal. The tank is normally rectangular in shape and is elevated high with a structural stand and a controlled opening is provided near the bottom of the tank from where the pulverized coal enters the screw conveyor by gravity. Screw conveyor consists of the screw, barrel, bevel gear drive mechanism, bearings and pulleys. The blower which consists of electric motor, bearings, shaft, pulley, belt, impeller, suction hole, air exit hole, involutes, structural mounting and bolts and nuts. The combustion chamber which is cylindrical in shape but opens at the top. The chamber is made of thick metal plate so as to withstand thermal degradation and it is insulated so as to avoid heat loss by conduction.

System Design Descriptions, Analyses and Calculations

The Silo

This is rectangular in shape, cut from 15mm of mild steel sheet. It is divided into two for easy dropping of the coal by gravity figure 1

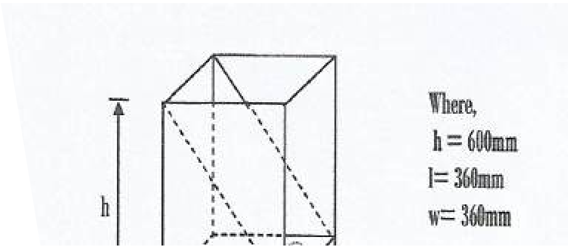


Figure 1:The Silo.

It has a height h length 1 and width w, substituting the appropriate data into

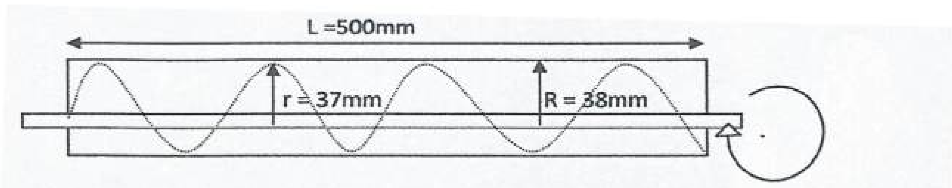
eq. (1). The volume of the silo, is given by

$$vol_s = \frac{h \times l \times w}{2} \quad \ldots\ldots(1)$$

$$vol_s = \frac{600x360x360}{2} = 0.043m^3$$

The Conveyor

The screw is housed inside a barrel of length L and radius R and the screw has a radius r and a clearance distance of 1mm from the barrel. The screw shaft rotates at 160rpm, fig 2.



160rpm

Fig 2: The Screw Conveyor

The throughput of the conveyor is given by

$Q_v = \pi L [R^2 - r^2]$ N rpm……………………………………………………..……(2)

when substituted the appropriate data

$$Q_v = 0.019m^3/min$$

$$Q_{v/second} = v = 0.000317m^3/sec$$

Mass of coal delivered by the conveyor per second is given as

$$m = vp \quad \ldots\ldots(.3)$$

Density of coal p is about 224.25kg/m^3

From eq 3.3,

$m = 224.25x0.000317 kg/sec$

$.:m = 0.071 kg/sec$

Conveyor shaft design

The forces acting on the conveyor shaft are shown in figure 3.

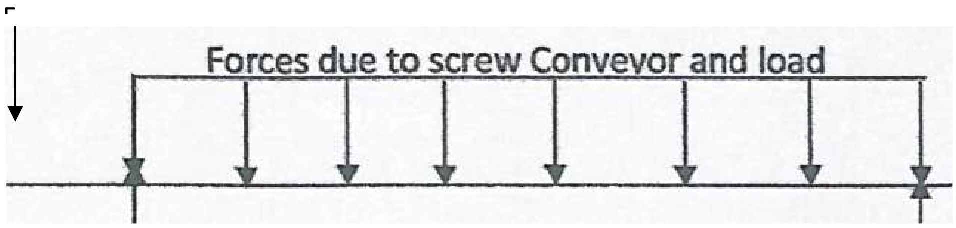


Figure 3: The Conveyor shaft design

Since the screw is delivering about 0.07*1kg/sec* of crushed coal, the weight of the shaft, screw and coal is assumed to be l0*kgf*. This load is distributed over a distance of 0.5m and 1**kgf** = 10N.
The load is changed to be a point load acting at the midpoint of shaft for ease of calculation as shown below. :. 10*kgf* 10*x*10 = 100*N*

Centrifugal force (F_c) from pulley

This is given as

$F_c = m\omega^2 r_{py}$ ....(4)

m = mass in motion, ω = angular velocity of screw, r_{py} = radius of pulley Weight of both shaft, Screw and coal = 10*kgf*

but mass = weight / Gravity = w/g = 10/10 = 1*kg*

.:m=1*kg*.

Angular velocity (ω) of screw

This is given as

$\omega = 2\pi N$ ....(5)

Putting the appropriate data into eq. (5)

ω = 2x3.142x160/60 = 16.76*rad/sec*

Radius of Gear (r_g) driving the screw conveyor

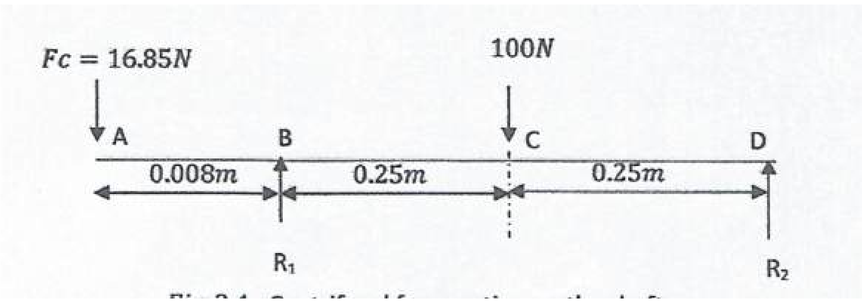
r_g=0.06m..(6)

from eq. (4) Substituting the appropriate parameters, we have that

F_c 16.85*N*

Therefore the shaft and forces acting on it are shown below in fig. 4

Figure 4: The centrifugal force acting on the shaft



For bearing reaction R_1 and R_2, it follows that vertically upward forces must balance vertically downward forces

:. $R_1 + R_2 = 116.55N$ ....(7)

Taking moments about point D on the shaft, therefore,

$R_1 = 67.1196N$

Substituting this value in eq (7) we have, $R_2 = 49.730N$

The schematic representation of the shaft with values of all the forces acting on it are shown in fig 5.

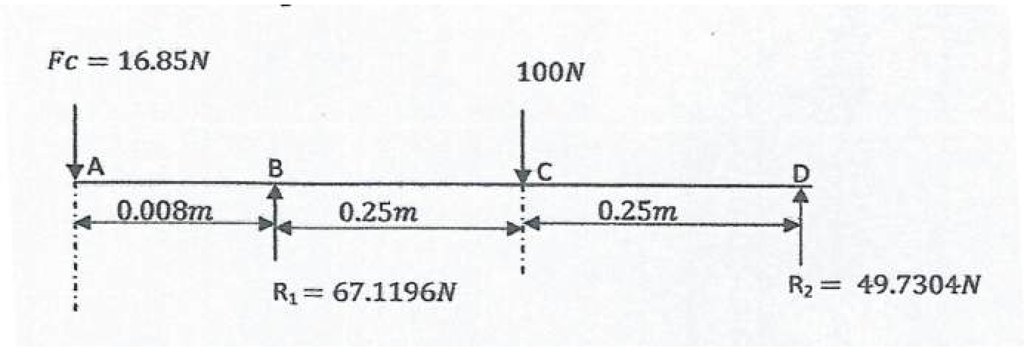


Figure 5: Values of the forces acting on the conveyor shaft

Maximum bending moment (M_{max},) from calculations

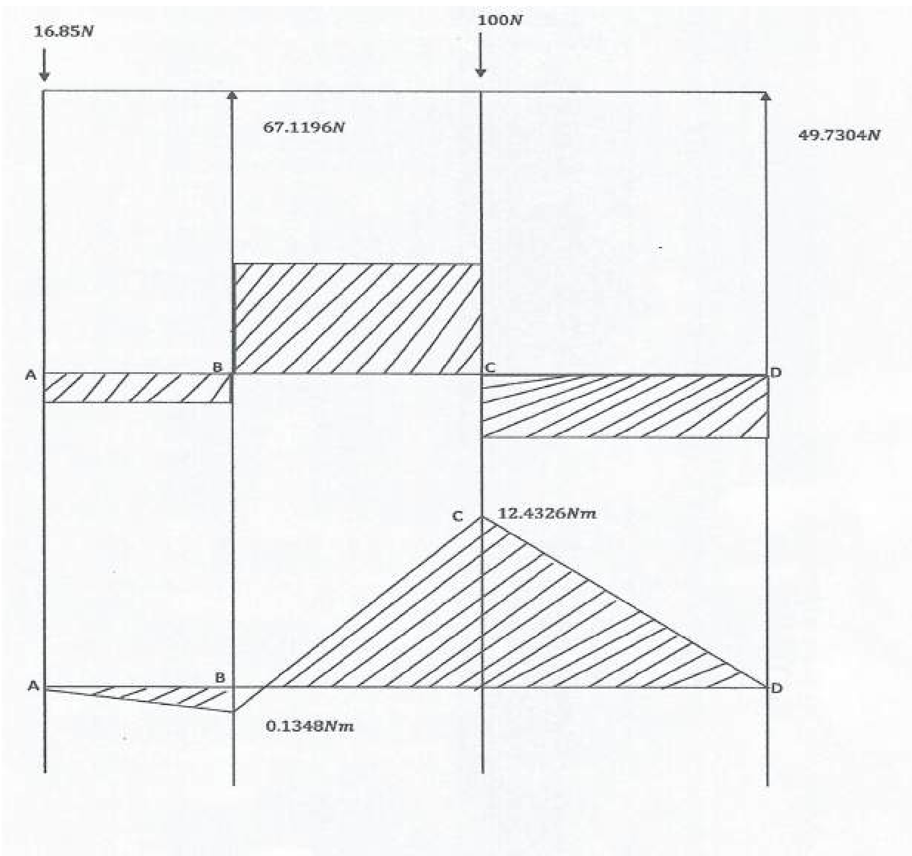
Moment at point A, $M_A = 0$

Moment at point B, M_B =O.1348NM

Moment at point C, Mc =12.4326NM

Moment at point D, $M_D = 0$

:. The maximum bending moment on the conveyor shaft occurs at Point C with a value of M_{max} = 12.4326NM



Sl

ASME code gives the equation of shaft diameter as

$$D=\left\{\frac{5.1}{\tau_d}\left[\left(C_m X M_{max}\right)^2+\left(C_T X T\right)^2\right]^{½}\right\}^{1/3} \quad \ldots\ldots (8)$$

Where τ_d = allowable shear stress

C_m = moment factor,

C_T = Torque factor,

T = Torque

ASME code further defined τ_d as

$\tau_d = 0.18\ \delta u$ or

$\tau_d = 0.3\delta y$

Where,

δu = ultimate stress of shaft material

δy = yield stress of shaft material

For rotating shafts $C_m = 1.5$ and $C_T = 1$

Torque developed by the conveyor shaft (T)

T $=F_c$ x $r_{py,}$ from eqs (3.4) and (3.5)

.: T=1.011*Nm*

Allowable shear stress (τ_d)

The shaft for the conveyor is made from high carbon steel. From high carbon steel material chart:

Material AISIOQT 1020 hot rolled has the following characteristics.

$\delta u = 379$ Mpa,

δy=207Mpa

.: $\tau_d = 0.18x379$,

$\tau_d = 0.3x207$

τ_d=68.22Mpa

τ_d== 62.1Mpa

ASME code defined further that the smaller of the two values should be adopted as τ_d.

.: τd=62.1Mpa

From eq (3.8), the diameter of the screw conveyor shaft is given as D = 12mm

Approximating to the nearest diameter in the catalogue, D = 17mm.

Bearing selection

For bearing selection, in 1989 Shigley stated that, the appropriate equations used are

$XVF_r+YF_aP_B$ ……………………………………………………………..(9)

$$L_{10}=\left\{\frac{C}{P_B}\right\}^3 \quad \text{………………………………………………………………………(10)}$$

Where:

F_r= radial load, F_a = axial load, V = radial load factor, Y= axial load factor,

X= Bearing rotation factor, C = Basic load rating, P_B =total load acting on the bearing

L_{10}= Bearing life in million revolutions.

Where:

X,V,Y are all = 1

Bearing life in million revolutions (L_{10}).

Using basic load rating from bearing catalogue.

In this design, all the forces acting on them are radial forces; there is no axial load from eq (9)

YF_a= 0……………………………………………………………………………(9)

Deep groove ball bearings are specially manufactured for carrying radial loads, therefore deep groove ball bearing is recommended for this design.

Bearing numbers:

For bearing at point B on the shaft, after second trial of C,

using C_1 = 1320 and C_2 = 17600 from catalogue and P_B = 67.1196 *using* eq. (10).

L_{10} = 18.02975912 $\mathbf{M}_{revs,}$ this value is the closet to the estimated value of L_{10} using simple calculation. The corresponding bearing number to this basic load rating is 6403

For bearing at point D on the shaft:

Same as at point B but C_1 1320 and C_2 = 10400, P_B =497304

L_{10} = 9.1460624M_{revs}. The bearing corresponding to the basic load rating is 6303.

The required bearing number for point D on the screw conveyor shaft is 6303

Gear Drive:

In this design two bevel gears are used in connection with the drive pulley to convert the motion from the electric motor to the screw conveyor.

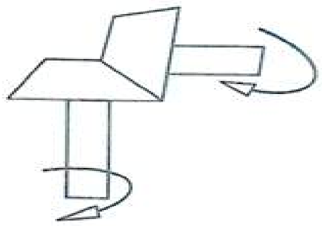


Figure7: Gear Drive Arrangement

The gear has the following characteristic:-
Pinion gear (smaller gear) driver gear.
Diameter D = 80*mm*, *number of teeth* = 9, *rpm* = 300, *module* = 5.

Larger gear (driven gear)
Diameter = 120*mm*, *number of teeth* = 16,*rpm* = 160, *module* = 5

Velocity ratio

For two gears in transmission, the velocity ratio is given as

$$\frac{\omega_1}{\omega_2} = \frac{n_I}{n_2} = \frac{N_1}{N_2} = \frac{D_2}{D_1}$$

Where ω_1 = angular velocity of driver
ω_2 = angular velocity of driven
N_1 = rpm of driver, N_2 = rpm of driven
n_i = no of teeth of driver, n_2 = no of teeth of driven
D_1 = diameter of driver, D_2 = diameter driven
For this two bevel gears the velocity ratio is 300: 160=2:1

Belt Drive

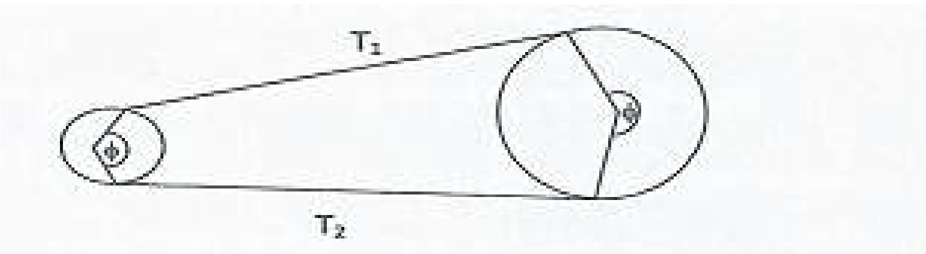


Figure 8:Two pulleys in transmission using a belt

In the same year (1989) Shigley reported that, for two pulleys in transmission using a belt,

$$\frac{T_1}{T_2} = e^{\mu\Phi} \quad \ldots\ldots(11)$$

Or

$$\frac{T_1 - T_c}{T_2 - T_c} = e^{\mu\Phi} \quad \ldots\ldots(12)$$

Where: T_1 = tension on tight side of belt,
T_2 = tension on slake side of belt
T_c = centrifugal tension,
μ= coefficient of friction between belt and pulley
$T_c = m_b{}^2$, and v= ωr, v = linear velocity of belt

T_c = centrifugal tension, m_b = mass of belt.

The belt used here is V-belt and the mass is very small.
The masses of the pulleys used are equally taken into consideration.
Aluminum pulleys are used and are very light in weight.
Therefore total mass displayed by the transmission including that of screw conveyor and blower impeller is put at 1.5*kg*.

Evaluation of the parameters

$$v = \omega r \quad \ldots\ldots(13)$$

$$T_c = m_b\, v = T_1/3 \quad \ldots\ldots(14)$$

$$V = \frac{2\pi N \times r}{60} = \frac{2x3.142x1440x0.05}{60}$$

$V = 7.54\,m/sec.$

$T_c = 1.5 \times 7.542$

$T_c = 85.2774N$

From $T_c = \frac{T_1}{3}$

Substituting for T_c

$T_1 = 255.8322N$

For v - belts

From eq(3.12) and substituting for T_1 and T_c

$T_2 = 142.129N$

Belt length (L_b)

Equation (3.15) gives the belt length, according to Shigley (1989)

$$L_b = \frac{\pi}{2}[D + d] + \frac{[D-d]^2}{4C_{by}} + 2C_{by} \quad \ldots\ldots(15)$$

Where C_{by}, = center distance between the pulleys
For this design C_{by} = 650*mm*
The speed ratio between the two pulleys is 1:4.8
Diameter of pulley attached to electric motor = 100*mm*
Diameter of pulley attached to pinion gear 480*mm*.
.:d= 100*mm* and D = 480*mm*
Substituting the values into eq (15)
L_b=89.218=89"
Belt recommended is B 89"

Power developed (P):
The power developed during motion transmission is calculated thus:

$$P = (T_1 - T_2)V \quad \ldots\ldots(16)$$

Substituting the values ofT_1, T_2 and V as gotten from eqs 3.11 and 3.13
P = 857322128 *watts*
But 750 watts=1hp.
.:P=1.1431hp
Therefore the power requirement for this design is put at between 1-2 hp

Blower design

The blower supplies a moderate volume of air needed to spray the pulverized coal inside the combustion chamber.

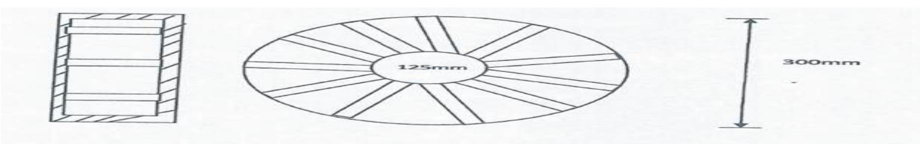


Figure 9: Impeller arrangement

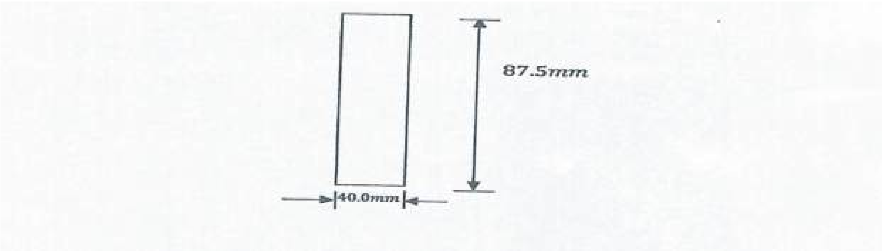


Figure 10: Dimensions of a single blade

The sketches in fig. 8 & 9 show the impeller arrangement and the dimensions of a single blade.
From the sketch the impeller has 11 equal sections.

Arc length of sector $\frac{\pi D}{11} = \frac{3.142x0.3}{11} = 0.0856m$

Volume of a sector = width x height x length of sector
= 0.04x0.0875x. 0.0856
= $0.0002996m^3$

Volume of 11 sectors = 0.0002996x11 = $0.0032956m^3$

The blower impeller is rotating at 1440rpm, the expected air volume output per second is calculated thus

$(Va)m^3/min = 00032956x1440 = 0.0791m^3/min$

Volume per second = $\frac{0.0791}{60} = 0.00131831m^3/sec$

Velocity of air from the blower (V_p)

The air from the blower impeller leaves the blower peripherally. It means that the peripheral velocity of impeller (V_p) = exit velocity of the air.

.:$V_p = \omega_p x r_p$ ……………………………………………………………………(17)

Where, ωp = angular velocity of impeller
rp= radius of impeller

$\omega_p = \frac{2 \pi N}{60} = \frac{2x3.142x1440}{60} = 150.816 rad/sec$

Radius of impeller $r_P = \frac{300}{2} = 150mm = 0.15m$

:. $V_p = 22.6224m/sec$ {from eq (17)}

Combustion chamber design specifications capacity (C_c)

Based on the choice of the combustion chamber size, the following parameters are selected for the design, height of the combustion chamber h_{cc} = 260mm:

Internal radius of combustion chamber; r_{c1} = 100mm; internal radius of insulating lining, r_{c2} =155mm, measured external temperature of the chamber,

T_0= 40°c, measured internal temperature of combustion chamber, T_1 =1,350°C, thermal conductivity of fiber glass, k 0.037W/MK.

Thermal Analysis

The radial conduction heat flow for a hollow cylinder is expressed by the Fourier's law as:

$$Q_r = -KA\, dT/dr \qquad (18)$$

Where: K is the thermal conductivity of the cylinder material; A is the area of the walls of the cylinder heating chamber across which heat transfer occurs; and dT/dr is the radial temperature gradient across the walls.

For a steady heat flow in which Q_r is independent of r and $T_i > T_0$, the equation can be integrated and rearranged to become

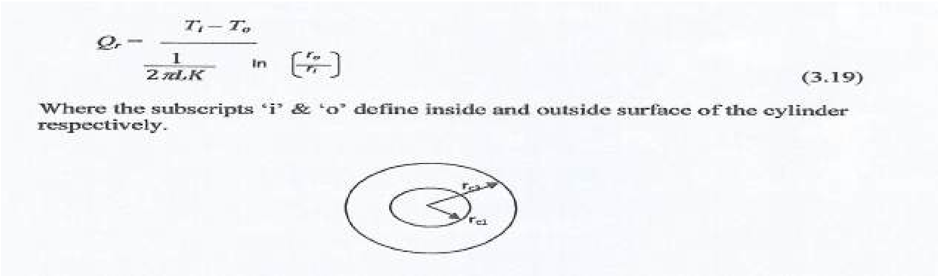


Figure 11: The Composite Cylinder

For a composite cylinder (see Fig.11) with known inside and outside surface temperatures and having 1 layer of material (fiberglass) the form of Eq. (19) is

$$Q_r = \frac{T_1 - T_2}{\frac{1}{2\pi L K} \ln \left\{ \frac{r_{c2}}{r_{c1}} \right\}} \qquad (20)$$

Conclusion

The design of the system is good and it can be attributed to a number of factors. Such factors include the following: the design is a good life cycle which makes system durable and affordable. Secondly, the system insulation that reduces the heat loss across the walls of the combustion chamber by conduction, convection and radiation, and enhances a good proportion of heat to be conserved within the chamber. The size of the chamber is small and the heat generated is high, this tends to promote a high concentration of heat in the chamber. About all the ASME code was used which gives the design international acceptance.

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