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Research Paper

DESIGN OF MATERIAL HANDLING EQUIPMENT: BELT CONVEYOR SYSTEM FOR CRUSHED BIOMASS WOOD USING V MERGE CONVEYING SYSTEM

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In the process or manufacturing industry, raw materials need to be transported from one manufacturing stage to another. Material handling equipment are designed such that they facilitate easy, cheap, fast and safe loading and unloading with least human interference. For instance, belt conveyor system can be employed for easy handling of materials beyond human capacity in terms of weight and height. This paper discusses the design calculations and considerations of belt conveyor system for biomass wood using 3 rolls idlers, in terms of size, length, capacity and speed, roller diameter, power and tension, idler spacing, type of drive unit, diameter, location and arrangement of pulley, angle and axis of rotation, control mode, intended application, product to be handled as well as its maximum loading capacity in order ensure fast, continuous and efficient movement of crushed biomass wood while avoiding fatalities during loading and unloading. The successful completion of this research work has generated design data for industrial uses in the development of an automated belt conveyor system which is fast, safe and efficient.

Keywords: Belt conveyor system, Idler, Loading, Material handling equipment, Unloading

INTRODUCTION

Different methods such as fork lifting, use of bucket elevators, conveyors systems, crane, etc. has been identified for lifting or transporting bulk materials or products from one place to another in the manufacturing industries depending on the speed of handling, height of transportation, nature, quantity, size and weight of materials to be transported. The objective of this research work is to provide design data

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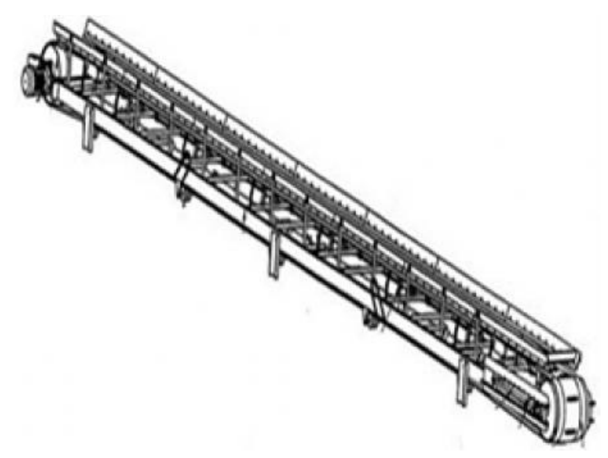
base for the development of a reliable and efficient belt conveyor system that will reduce cost and enhance productivity while simultaneously reducing dangers to workers operating them. Conveyor system is a mechanical system used in moving materials from one place to another and finds application in most processing and manufacturing industries.

It is easier, safer, faster, more efficient and cheaper to transport materials from one processing stage to another with the aid of material handling equipment devoid of manual handling. Handling of materials which is an important factor in manufacturing is an integral part of facilities design and the efficiency of material handling equipment add to the performance level of a firm. Conveyor systems are durable and reliable in materials transportation and warehousing. Based on different principles of operation, there are different conveyor systems namely gravity, belt, screw, bucket, vibrating, pneumatic/hydraulic, chain, spiral, grain conveyor systems, etc. The choice however depends on the volume to be transported, speed of transportation, size and weight of materials to be transported, height or distance of transportation, nature of material, method of production employed. Material handling equipment ranges from those that are operated manually to semi-automatic systems.

Material handling involves movement of material in a manufacturing section. It includes loading, moving and unloading of materials from one stage of manufacturing process to another. A belt conveyor consists of an endless and flexible belt of high strength with two end pulleys (driver and driven) at fixed positions supported by rollers. In this work, 3 roll idlers are required for adequate support of materials transported and protection of the belt along its length. Pulleys are used for providing the drive to the belt through a drive unit gear box powered by an electric motor. It also helps in maintaining the proper tension to the belt. The drive imparts power to one or more pulleys to move the belt and its loads. Materials are transported over the required distance as a result of friction generated between the roller surface and the moving belt set in motion by a rotating pulley (drive pulley). The other pulley (driven or idler pulley) acts as a wheel around which the material rotates and returns in a continuous process. Continuous processes are characterized by non-stop motion of bulk or unit loads along a path without halt for loading and unloading.

The peculiarities of a belt conveyor is that it is easy and cheap to maintain, it has high loading and unloading capacity and can transport dense materials economically and at very high efficiency over long distance allowing relative movement of material. Belt conveyor can also be used for diverse materials: abrasive, wet, dry, sticky or dirty material. Only a single roller needs to be powered by driver pulley and the roller will constantly spin causing the materials to be propelled by the driving roller. Material handling equipment such as belt conveyors are designed to load and unload materials from one stage of processing to another in the fastest, smoothest, most judicious, safest, and most economical way with minimum spillage. Belt conveyors are employed for conveying various bulk and unit loads along horizontal or slightly inclined paths and for

Figure 1: Belt Conveyor



transporting articles between various operations in production flow lines. A belt conveyor can be horizontal, incline or decline or combination of all.

DESIGN CONSIDERATIONS

According to the design of an effective and efficient material handling system which will increase productivity and minimize cost, the guidelines normally followed are:

1. Designing the system for continuous flow of material (idle time should be zero)
2. Going in for standard equipment which ensures low investment and flexibility
3. Incorporating gravity flow in material flow system
4. Ensuring that the ratio of the dead weight to the payload of material handling equipment is minimum

The transportation route affects the overall cost of material handling. An efficient material handling equipment will reduce cost per volume of material transported and ensure that materials are delivered to the production line safely The design of belt conveyor system involves determination of the correct dimension of the belt conveyor components and other critical parameter values so as to ensure optimum efficiency during loading and unloading conditions. Some of the components are: Conveyor belt, motor, pulley and idlers, rollers, pneumatic cylinder, etc.

The design of a belt conveyor system takes into account the followings:

A. Dimension, capacity and speed

B. Roller diameter

C. Belt power and tension

D. Idler spacing

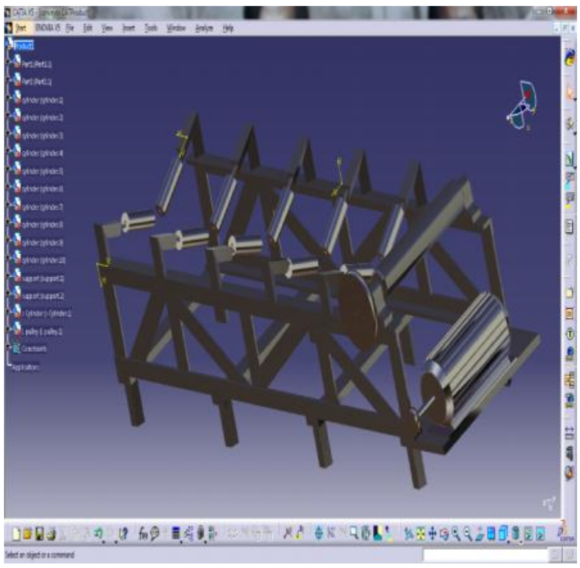
E. Pulley diameter

F. Motor

G. Type of drive unit

H. Control mode

Figure 2: CATIA Design of Belt Conveyor



Belt Dimension, Capacity and Speed

The diameter of the driver and driven pulley is determined by the type and dimension of conveyor belting. The diameter of the pulley must be designed such that it does not place undue stress on the belt. The length of a belt conveyor in meters is the length from the centre of pulley parallel to belt line. Belt length is dependent on both the pulley diameters and centre distances.

$$V = d \times \Pi \quad ...(1)$$

where

V = Belt speed;

d = diameters of rollers; and

Π = pi

Capacity is the product of speed and belt cross sectional area

Generally, belt capacity (kg/sec) is given as:

$$B.C = 3.6 \times A \times ° \times V \quad ...(2)$$

where

A = belt sectional area (m^2);

° = material density (kg/m^3); and

V = belt speed (m/s)

The mass of material Mm (live load) per meter (kg/m) loaded on a belt conveyor is given as:

$$Mm = \frac{c}{3.6 \times V} \quad ...(3)$$

where

c = Conveyor capacity (4 tones/hr); and

V = belt speed (1.25 m/s).

Mm =0.889 kg.

The magnitude of belt speed V (m/s) can be determined from equations 1, 2, 3 or 6 and can as well be gotten from the catalogue for standard belt. Belt speed v (m/s) depends on loading, discharge and transfer arrangement, maintenance standards, lump size.

The determination of belt width is largely a function of the quantity of conveyed material which is indicated by the design of the conveying belt. The value of belt capacity from Equation (2) determines the value of lump size factor.

Another important factor in determining the belt capacity is the toughing angle. Belts are troughed to allow the conveyor load and transport materials. As trough angle increases, more materials can be transported. For standard 3 idler rollers of equal length the most common trough angle is 350.

The belt width must be wide enough to deal with the material lump size.

Angle of surcharge is one of the most important characteristics in determining the carrying capacity as it directly governs the cross sectional area of material in the belt and hence the volume being conveyed. The surcharge angle depends on friction between the belt and the material and how the material is loaded. The steeper the conveyor, greater the belt capacity and the lesser the surcharge angle.

Since the limestone to be handled is abrasive, heavy, with specific gravity between 1.5-2 tones/m^3 and lump size up to 75 mm, a belt of minimum width of 1200 mm and speed of 1.25 m/s is preferred according to design values. For 3 equal roll idlers with surcharge angle of 250 and toughing angle of 350 the capacity factor is 1.08. The capacity in tones/hr of a conveyor consisting of 3 equal roll idler is given as.

$$C = \frac{c_T \times ° \times c_f \times V}{1000} \quad ...(4)$$

where

C = Capacity in tones/hr of a belt conveyor consisting of 3 equal roll idler;

c_T = Capacity of troughed belts for 3 roll equal length idler (175);

° = material density in kg/m^3 (1000);

c_f = Capacity factor (1.08); and

V = Belt speed in m/s (1.25)

From Equation (2.4), the overall capacity of the belt conveyor consisting of 3 equal roll idler is 4 tones/hr.

For belts running horizontally and loaded evenly, the volumetric belt load also is given as:

$$V_L = \frac{L_c}{C} \quad ...(5)$$

where

V_L = Volumetric belt load (m^3/hr);

L_c = Load capacity of the belt conveyor (tones/hr); and

W = Specific Weight of the conveyed material (tones/m^3)

As belt tend to wander a bit in operation, the overall face width of the pulley should exceed the belt width by 150 mm, if serious edge damage is to be avoided.

For haulage efficiency, conveyors should be operated fully loaded at the maximum recommended speed and capacity.

Roller Diameter

The roller support belt and facilitates easy as well as free rotation of the belt conveyor in all direction.

The correct choice of roller diameter must take into consideration the belt width. The relationship between the maximum belt speed, roller diameter and the relative revolution per minute is given as:

$$n = \frac{V \times 1000 \times 60}{D \times ®} \quad ...(6)$$

where

n = no of revolution per minute;

D = roller diameter (mm); and

V = belt speed (m/s)

The belt width is designed as 1200 mm, the belt speed is 1.25 m/s, the roller diameter is therefore designed as 108 mm.

From Equation (6), the no of revolution per minute n = 220 rpm

$$The\ conveyor\ lengt = \frac{horizontaldis\ \tan ce}{in\ clination\ angle^{-}} \quad ..(7)$$

The inclination angle is 100, the conveyor length is 100 m, and the conveyor height is 10 m.

Belt basic length = 2 × length along conveying route ...(8)

From Equation (8), basic belt length = 2 × 14 = 28 m

The roll diameter for belt is given as

$$D = \sqrt{d^2 + (0.001273 \times L \times G)} \quad ...(9)$$

where

D = overall diameter (m);

D = core diameter (m);

L = Belt length (m); and

G = Belt Thickness (mm)

The length of a belt on roll is given as:

$$L = \left(d + \left(\frac{D - d}{2} \right) \times ® \times N \right) \quad ...(10)$$

where

D = outside diameter of the roll (m);

d = diameter of the roll centre (m);

N = no of wraps of the belt

® = 3.1416

Belt Power and Tensions

The longer the length of the belt, the more the power required for the conveyor and the higher the vertical distance of the lift, the higher the magnitude of power required.

The power P_p (kW) at drive pulley drum is

$$P_p = \frac{F_u \times V}{1000} \quad ...(11)$$

where

F_u = Total tangential force at the periphery of the drive pulley (N);

V = Belt speed (1.25 m/sec); and

$$F_u = \frac{P_p \times 1000}{V} \quad ...(12)$$

where

P = power required for conveyor (kW);

C = conveyor capacity (4 tones/hr) = (3.9375 kg/sec); and

L = Lift (1.5 m)

P = 3.7 kW.

The belt of the conveyor always experience tensile load due to the rotation of the electric drive, weight of the conveyed materials and due to the idlers. The belt tension must be great enough to prevent slippage between the drive pulley and the belt. Belt tension at steady state is given as:

$$T_s = 1.37 \times f \times L \times g\left[2 \times M_i + (2 \times M_b + M_m)\cos(¯)\right] + (H \times g \times M_m) \quad ...(13)$$

where

T_s = Belt tension at steady state (N);

f = Coefficient of friction (0.02)

L = Conveyor length (14 m);

(Conveyor belt is approximately half of the total belt length)

g = Acceleration due to gravity $\left(9.81 \frac{m}{\sec^2}\right)$;

M_i = Load due to the idlers (170 kg);

M_b = Load due to belt (177.5 kg);

M_m = Load due to conveyed materials (18.88 kg);

¯ = Inclination angle of the conveyor (100); and

H = Vertical height of the conveyor (2 m).

T_s = 71 KN

During the start of the conveyor system, the tension in the belt will be much higher than the steady state. The belt tension while starting is

$$T_{ss} = T_s \times Ks \quad ...(14)$$

where

T_{ss} = Belt tension while starting (N);

T_s = Belt tension at the steady state (1.5 KN); and

Ks = Start up factor (1.08).

T_{ss} = 76.68 KN

For inclined belt, the drive at head pulley is:

$$T_{\max} = T_e + T_2 \quad ...(15)$$

While the drive at tail pulley is

$$T_{\max} = T_e + T_2 \quad ...(16)$$

T_e is effective tension (KN)

T_e = *Total empty friction + Load friction + load slope tension* ...(17)

$$Total\ empty\ friction = F_e \times (L + t_f) \times W \times 9.81e^{-3} \quad ...(18)$$

$$Load\ friction = F_e \times (L + t_f) \times \frac{c}{3.6 \times V} \times 9.81\, e^{-3} \quad ...(19)$$

$$Return\ side\ tension = F_e \times W \times L \times 0.4 \times 9.81\, e^{-3} \quad ...(20)$$

$$Load\ slope\ tension = \frac{C \times H}{3.6 \times V} \times 9.81\, e^{-3} \quad ...(21)$$

where

F_e = Equipment friction factor (0.0225);

C = Belt Conveyor capacity (6.5 tones/hr);

V = Belt speed (1.25 m/sec);

t_f = Terminal friction constant (3 m);

W = Weight of material and belt in (0.0635 kg/m);

L = Length of conveyor (14 m); and

H = Height of conveyor (2 m)

From Equation (21), total empty friction is 16.86 N.

From Equation (22), load friction is 6.24 N.

From Equation (23), return side tension is 0.795N

From Equation (24), load slope friction is 1.09 N

The effective tension Te according to Equation (20) is

16.86 + 6.24 + 1.09 = 24.19N.

For horizontal and elevating conveyors, the terminal friction constant tf, expressed in meters of centre to centre distance up to 30 m centre = 6 m

And the equipment friction factor F_e = 0.0225.

Maximum tension ($T_{\max}$) is the belt tension at the point where the conveyor experiences the greatest stress. $T_{\max}$ can be found at different sections in the belt.

$$T_{\max} = (1 + K) \times T \quad ...(22)$$

where

K = Drive factor

T = Tension at a particular point (KN)

However, unitary maximum tension $T_{U\max}$ (N/mm) of the belt is defined as:

$$T_{U\max} = \frac{T_{\max} \times 10}{b} \quad ...(23)$$

where

$T_{\max}$ = Tension at the highest stress point of the belt or steady state tension in a conveyor (1.5 KN); and

b = Belt width (1200 mm).

$T_{U\max}$ = 0.25 KN.

The belt power (kW) is given as

$$P_b = T_e \times V \quad ...(24)$$

T_e = effective tension (1.141 KN)

V = Belt speed (1.25 m/sec)

P_b = 1.43 kW

Belt tension of a conveyor system is of a varying value along the system flight and is governed by the following influencing factors: length and track of the system, number and arrangement of pulley, characteristics of the driving and braking equipment, type and location of the belt take up devices and operating and loading state of the system.

Idler Spacing

Idlers are installed at graduated spacing to ensure that the sag as a result of load varies inversely with the tension in the belt.

Live load is calculated as 78.88 kg from Equation (3.3)

Total live load (kg)

$$T_L = L_L \times L_c \quad ...(25)$$

L_c = is conveyor length (100 m)

T_L = 7.88 KN

Dead load is the load consisting of weight of roller, belt and drive pulley.

The idler spacing at any point can be obtained from:

$$I_s = \frac{8 \times T \times S_g}{M_{\circ} \times 9.91 e^{-3}} \quad ...(26)$$

where

$M_{\circ}$ = Mass of belt and live load (656.38 kg/m);

T = Tension at a particular point (KN); and

S_g = Percentage of the idler spacing (0.01)

An idler spacing of 1.0 m is recommended for a belt conveyor system conveying a material of 1500 kg/m^3 and on a belt width of 1200 mm.

Pulley Diameter

Pulleys are manufactured in a wide range of sizes. The selection of pulley takes into account the wrap angle (180°), belt speed (1.5 m/sec), method of belt strain, belt tension T, belt width (1200 mm) and type of splice of the conveyor belt. The pulley diameter is obtained from standard value from the catalogue. Once the pulley diameter is determined, the size of the coupling can also be decided from the catalogue.

Pulley wraps length at terminals = 2 × Π × D ...(27)

where

Diameter of pulley (800 mm).

Pulley wraps length at terminals = 5 m.

Drive pulley can be lagged to increase friction and improve transmission between belt and pulley.

Elastic lagging helps to keep pulley clean so as to increase duration of friction while grooved lagging helps in removal of moisture so as to improve friction.

The effective pull $F_U(N)$ is given as

$$F_U = «_T \times g\left(M_m + \frac{M_B}{2}\right) + «_R \times g\left(M_i + \frac{M_B}{2}\right) \quad ...(28)$$

where

$«_T$ = Coefficient of friction with support rollers (0.033)

$«_R$ = Coefficient of friction with skid plate (0.33)

g = Acceleration due to gravity (9.8 m/s^2)

M_m = Total load of conveyed materials (78.88 kg)

M_B = Mass of belt (577.7 kg)

M_i = Mass of roll idlers (570 kg)

F_U = 2.9 KN

Recall from Equation (9), the power P_p (kW) at drive pulley drum is

$$P_p = \frac{F_u \times V}{1000}$$

Recall Equation (10)

where

F_u = Total tangential force at the periphery of the drive pulley (2.9 KN);

V = Belt speed (1.25 m/sec); and

From Equation (3.9), P_p = 3.62 kW.

The acceleration of the conveyor belt is given as:

$$A = \frac{T_{ss} - T_s}{\left[L \times \left(2 \times M_i + 2 \times M_b + M_m\right)\right]} \qquad ...(29)$$

where

T_{ss} = Belt tension while starting (1.15 KN);

T_s = Belt tension at the steady state (1.5 N);

L = Conveyor length (14 m);

M_i = Load due to the idlers (570 kg/m);

M_b = Load due to belt (577.5 kg/m);

M_m = Load due to conveyed materials (78.8 kg/m);

The acceleration A (m/sec^2) of the conveyor belt is 2.39e^{-5} m/sec^2.

Belt breaking strength $B_{bs}(N)$ parameter decides the selection of the conveyor belt. Belt breaking strength can be calculated as:

$$B_{bs} = \frac{C_r \times P_p}{C_v \times V} \qquad ...(30)$$

where

C_r = Friction factor;

C_v = Breaking strength loss factor (0.75);

P_p = Power at drive pulley (3.63 kW); and

V = Belt speed (1.25 m/sec)

The breaking strength is 58.08

Motor

The minimum motor power for sizing of the motor is

$$P_{\min} = \frac{P_p}{¦} \qquad ...(31)$$

where

$P_{\min}$ = Minimum motor power (kW);

P_p = Power at drive pulley (1.43 kW); and

¦ = Efficiency of the reduction gear (0.9)

$P_{\min}$ = 4.022 kW.

The next standard motor greater than $P_{\min}$ will be sufficient.

A standard motor of 5.0 kW is chosen.

Alternatively,

To determine the motor horse power: $hP_{\min}$

$$hP_{\min} = \frac{HP_{req}}{¦} \qquad ...(32)$$

where

$$HP_{req} = HP_e + HP_m + HP_j \qquad ...(33)$$

where

HP_e = Horse power required to drive the conveyor empty

HP_m = Horse power required to move material horizontally

HP_j = Horse power required to elevate material.

Torsional moment is given as

$$M_t = \frac{1}{2} \times D \times (F + «Wg) \qquad ...(34)$$

where

D = Diameter of pulley (m);

F = Force (N);

« = Coefficient of friction;

W = Weight of material and Belt (kg/m); and

g = Acceleration due to gravity (m/sec^2)

The number of revolution per minute (n) of the motor is given as

$$n = \frac{9500 \times 1000 \times P}{M_t} \qquad ...(35)$$

where

P = Power (kW); and

M_t = Torsional moment (N/mm)

The cycle time of conveyor is given as:

$$C_t = \frac{2L}{V} \qquad ...(36)$$

where

L = Length of conveyor (28 m); and

V = Belt speed (1.25 m/sec)

The cycle time of the conveyor is 160 sec^{-1}

Torque (KNm) is calculated as:

$$T = \frac{9.55 \times P}{pully\ rpm} \qquad ...(37)$$

where

P = power required for the conveyor (1.43 kW)

Pulley rpm = 26.2

T = 1.35 KNm

Shaft Design

Shaft design consists primarily of determination of the correct shaft diameter that will ensure satisfactory rigidity and strength when the shaft is transmitting motion under different operating and loading conditions. The values of belt width and pulley diameter helps in selecting the size of shaft diameter from different conveyors hand book.

Control

Compact Programmable Controllers otherwise known as application controllers can be used for the control of the system. These controllers can e used for time control and supervisory functions such as: conveyor speed control, speed control of individual drives, speed and belt slip control, load equilibration between two driving drum and speed difference control between two motors on one driving drum.

RESULTS

The followings are designed values were obtained for belt conveyor system for limestone using 3 roll idlers.

Table 1: Design Values for Belt Conveyor System

S. No.	Parameter	Values
1.	Belt width (mm)	1200
2.	Length of Conveyor (m)	14
3.	Basic belt length (m)	28
4.	Belt speed (m/sec)	1.25
5.	Angle of inclination (degree)	100
6.	Conveyor capacity (tones/hr)	4
7.	Belt tension while starting (KN)	1.15
8.	Belt tension at steady state (KN)	1.5
9.	Power at drive pulley (kW)	1.75

Table 1 (Cont.)

S. No.	Parameter	Values
10.	Minimum motor power (kW)	1.25
11.	Idler spacing (m)	0.2
12.	Diameter of pulley (mm)	2200
13.	Belt power (kW)	1.43
14.	Power required by conveyor (kW)	1.43
15.	Belt thickness (mm)	1000
16.	Torque (KNm)	1
17.	Breaking strength	0.5

LIMITATION OF STUDY

The construction of a belt conveyor system requires high capital base. This is a major constraint that limits this work to design only and as such performance evaluation cannot be carried out on the belt conveyor system. However, the research work provides design data for development of belt conveyor system for industrial uses.

CONCLUSION

Using the designed values above, a belt conveyor system with 3 roll idlers can be developed for conveying crushed biomass wood efficiently without belt spillage and fatalities. A PN 450 double weave standard rubber belt with the specifications above will sufficiently convey the crushed limestone. The belt conveyor system is designed with high degree of automation, loading, movement and unloading efficiency. It is also very flexible, safe, with low initial, operational and maintenance cost while eliminating repetitive short distance movement in the manufacturing industry.

REFERENCES

1. "ABB-Process Industries Variable-Speed Drives for Belt Conveyor Systems", pp. 1-7, (2000).
2. Anath K N and Rakesh V (2013), "Design and Selecting Proper Conveyor Belt", *Int. Journal of Advanced Technology*, Vol. 4, No. 2, pp. 43-49.
3. Besser Service Bulletin (2006), "Conveyor Belt Basic Rules and Procedure for Tracking", pp. 1-7.
4. "Conveyor Equipment Manufacturers Association (CEMA)", *Belt Conveyors for Bulk Materials*, 6th Edition, pp. 200-205.
5. Fenner Dunlop (2009), "Conveyor Handbook", *Conveyor Belting Australia*, pp. 1-70.
6. "Phoenix Conveyor Belt Systems", *Design Fundamentals Hamburg*, pp. 1-16 (2004).
7. Richardson J F, Harker J H and Backhurst J R (2002), *Particle Technology and Separation Process*, 5th Edition, Vol. 2, pp. 29-35, Elsevier Publisher, New Delhi, India.