bulk solids handling Journal

Technical Article

Chute Design Essentials – How to Design and Implement Chutes in Bulk Solids Handling Systems

Edited by on 31. Mar. 2020
Published in bulk solids handling, Vol. 35 (2015) No. 6

Chutes are in use in almost every bulk solids handling plant. Although everybody knows them, they are mostly overlooked, except for those cases where they cause extra-attention and -work due to malfunctioning. Following you will find hints to prevent such incidents. This paper attempts to give the reader some simple rules to apply to chute design. Any discussion on chute design would normally require at least a week of deliberations, definitions, mathematics and particle theory. There are numerous papers available, many of which were presented at previous Beltcon conferences.

Fig. 1: Chutes are among the most important elements of a belt conveyor system.

However, further information and clarification is quite valid considering that the transfer of material from one belt conveyor to another is one of the most crucial design characteristics, and yet still remains one of the aspects least considered in the initial design of a system. In most instances the transfer of material between belts is the defining parameter in the selection of a suitable belt profile. It is therefore worthwhile to define and discuss some of the important parameters in chute design. Simple formulae and rules are presented that are useful in the design of efficient transfer points. Despite the many packages that allow for the simulation of the flow by computerised methods, it is of importance to be familiar with the basic formulae from which these simulations are derived in order to understand the more complex processes, many of which have been presented at Beltcon conferences in recent years. The basic formulae, to which younger engineers may not have been exposed, remain important particularly in instances where the extensive computing power required by chute design packages is not available.

1. Definition of a Chute

A chute is defined in the Oxford dictionary as “A sloping channel or slide for conveying things to a lower level”. This is a perfect definition of both a curved chute, where the chute body acts as the slide or of the sloping portion of the material in a Rock-Box type chute where the material is the slide.

2. The Problems (Challenges) with Chutes

The following list is drawn from a paper presented at the Chute Design Conference organised by the Bionic Institute in 1992. The problems as well as the solutions thereto remain essentially the same even with the passage of time. What has happened is that computer ability has increased, which allows for a quicker resolution to the problems (provided that this is correctly applied).

- Spillage
- Load zone turbulence
- Load centring
- Poor skirt board seal
- Impact idler maintenance
- Inadequate skirt board length
- Dust control

- Material degradation
- Belt tracking
- Poor provision for clean up
- Chute wear
- Inadequate provision for belt cleaning equipment
- Inadequate inspection access
- Belt damage from large lumps
- Belt wear and abuse
- Material build up – plugging
- Noise
- Structural support of chute and skirts
- Lack of attention to detail design
- Loading onto transition area
- Corrosion
- Unknown material characteristics
- Economic considerations
- Safety issues
- Housekeeping

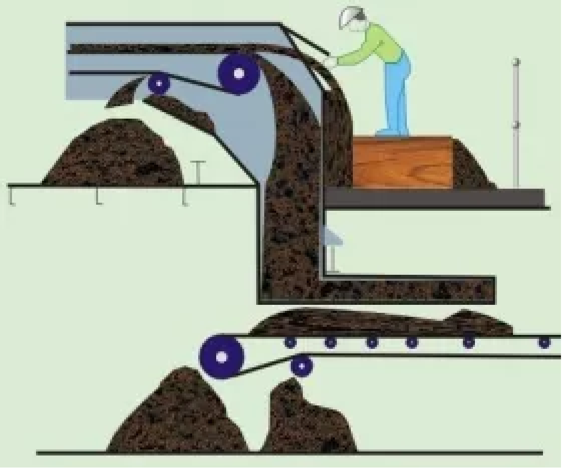


Fig. 2: How NOT TO design a chute.

Wilst many of the above are maintenance related issues there are many that can be grouped under one banner: Lack of attention to detail design.

3. The Critical Factors

There are some critical factors which are paramount in chute design. These are:

- Reduction of impact on the chute faces.
- Reduction of impact on downstream belt.
- Centralised loading onto the downstream belt.

A more complete set of design criteria that characterises an efficient chute is one that:

- is not prone to blockages.
- allows for the transfer of material with minimal wear to the chute surfaces,
- allows for the transfer of material with minimal wear to the downstream belt,
- results in minimum material degradation,
- results in minimum dust production,
- centralises the load onto the downstream belt, hence minimising belt wander, and
- results in minimum material segregation.

In order to achieve the above objectives, the designer should follow a logical design sequence as follows:

- Know and understand the properties of the material to be conveyed.
- Know and understand the nature and characteristics of the application.
- Plot the trajectory of the material.
- Design the hood (discharge collector) and define conditions for minimum wear in the chute, or, in the event that a rock box is selected, design the rock box so as to collect and transfer material in an appropriate channel.
- Design the Spoon (discharge distributor) and define conditions for minimum wear in the chute and on the downstream belt.

The process is iterative and may be affected by factors such as limitations on head room, variations in lump size or in fact, the type of material. Whilst often the designer is forced to compromise on certain design criteria (e.g. chute and belt wear and material degradation) the requirement to prevent blockages and reduce the possibility of spillage must never be compromised.

4. Indicators for Designing efficient Chutes

The following methodology has been recommended by one of our most eminent South African conveyor designers, Graham Shortt, for the design of conveyor chutes.

4.1 Chute Hoods

The chute hood should be dimensioned to cater for the following:

The side plates should clear the pulley face by a minimum of 50 mm. This distance is measured from the inside of any liner plates which may be attached to the chute hood.

The hood height at the material entrance should be at least 0.5 *W*, where *W* refers to the belt width. The height should allow sufficient space for the material burden to pass unhindered, including the possible incidence of larger rocks located on top of the normal burden. In this case, the minimum hood height should be in excess of 3 × b_L, where b_L is the maximum lump size.

The hood flanks and cover should extend backwards at least 850 mm from any nip point.

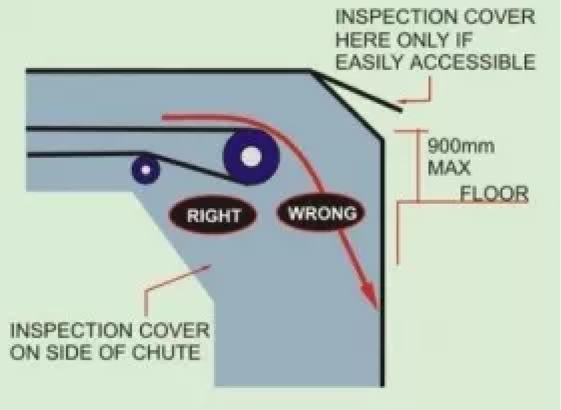


Fig. 3: Position of inspection hatches.

The hood may be provided with inspection or access openings, as required, located out of the material stream. The inspection openings should be easily and safely accessible. The inspection openings should be covered. For chutes that are de-dusted, the inspection and access openings should be designed to allow the minimum ingress of false air. The opening size must be sufficient for its purpose (see Table 1).

Where de-dusting is required, the hood should be provided with a back screen or apron seal, to limit the ingress of false air. The apron seal may be made of 3 mm (minimum) reinforced rubber cloth, attached to the chute hood entrance. The apron seal should be vertically slit to allow the material to pass. The slits are normally spaced at typically between 100 mm and 150 mm.

The hood is placed over the head or discharge pulley, which is located with respect to the equipment being fed. The location of the pulley is determined by consideration of the material trajectory over the pulley and the nature of the equipment being fed. The material trajectory is determined by the application of standard calculations. For conveyors discharging into hoppers and bins, the conveyor discharge pulley can be located to either feed the bin centrally when the bin is empty, or to allow central feed when it is full, as specified by the engineer. For cases where, for structural reasons, the bin must always be centrally loaded, the conveyor hood must be equipped with an adjustable impact plate or curved trajectory plate, in order to deflect the material stream into the desired path.

Purpose	**Height (min)**	**Width (min)**
Observation	300 mm	250 mm
Servicing belt cleaners, sprays, etc.	300 mm	350 mm
Liner replacement	450 mm	600 mm
Maintenance personnel access	650 mm	650 mm

4.2 Chute Body

The chute body should be designed to suit the transfer requirements, without changing the direction of the material severely. The area of the chute containing the body of the material flow must be at least 2.5 to 3.0 times the area of the material, based on the design capacity of the conveyor and the material speed at the point of consideration. The minimum area of the chute is then given by

$$A = \frac{2.5 \cdot C_{dc}}{3600 \cdot S \cdot D} \quad [\mathrm{m}^2] \qquad (1)$$

where:
S = Material stream speed [m/s], (which could be belt speed)
D = Bulk density of the material [t/m^3]
C_{dc} = Belt design capacity [t/h]

The chute body should be designed to centralise the material onto the downstream equipment. Material flow that tends to misalign the downstream belt is to be avoided. To this end, the use of ‘Vee’ bottom chutes is often encouraged, especially for in-line transfers from one conveyor onto another. For right-angled and skewed transfers, the use of adjustable impact plates or curved trajectory plates is recommended to change the direction of the material flow. The trajectory of the material will always impart some misalignment on a right-angle transfer. For this reason, the use of deflector plates is recommended. For material

that is wet or prone to plugging, the impact plate ought to be designed to be self-cleaning, which may involve some test work.
(Fig. 4: Typical dead box design wp_1297)

The use of drop boxes is discouraged for material having a high content of fines or moisture or both. Drop boxes are also not always acceptable on conveyors handling diamondiferous material. Drop boxes may be designed for belts of relatively high speed (belt speeds in excess of about 2.0 m/s) that carry washed and sized material of lump size greater than 30 mm. Where drop boxes are specified, they should be designed to be self-draining. The base plate of the drop box must therefore be inclined at least at 10° to the horizontal plane. The drop box is then equipped with a replaceable lip liner, located to allow the passage of water underneath it.

(Fig. 5: Multiple dead boxes to reduce impact wp_1296)

The chute should be designed to minimise the impact height from one conveyor onto another, as far as the plant layout allows. The chute should be designed to minimise impact of the material on the sides of skirts on the conveyor being fed. The rear impact point of the material onto the conveyor is normally located 150 mm upstream of the first impact idler. Loading the conveyor in the transition zone from flat to trough is to be avoided as far as possible and should only be seen as a last resort.

Where the chute sides slope, the valley angle must not be less than the minimum slope angle for the material and liner combination. The valley angle is determined from the well-known equation as[2]

$$C = \cot^2 A + \cot^2 B \qquad (2)$$

where the angles A and B (the slopes of adjoining plates) are measured from the horizontal, and angle C is the valley angle, also measured from the horizontal.
(Fig. 6: Valley angle wp_1295)

The geometry of the chutes under silos and bins, feeding onto belt or apron feeders, are normally determined in conjunction with the material flow engineer.

4.3 Chute Exit (Spoon)

The chute exit should be dimensioned to allow the unhindered passage of the material. The exit opening minimum dimension should be at least 2.5 times the maximum lump size of the material, and must have an area at least 2.5 times the area of the material, based on the design capacity of the conveyor and the belt speed, as indicated earlier. Where the chute feeds into skirts, the chute width must not be greater than the width of the skirts. Any necking or reduction in width of the chute body must comply with the chute wall slope and valley angle requirements.

The chute exit should be designed to impart to the material some velocity in the direction of flow, where the feed is onto another conveyor, wherever possible. A common specification is for the exit velocity to be within 10% of the receiving belt speed.

(Fig. 7: Typical chute outlet requirements wp_1294) For chutes exiting at right angles from screens onto conveyors, the chute should cover the full width of the screen discharge and ought to be equipped with adjustable, replaceable deflector plates, placed at approximately 70° to the horizontal, located above the conveyor belt surface. The deflector plates must be dimensioned to allow the full passage of material, without creating a cut-off area over the conveyor belt. Chute exiting screens may be provided with a cut-off or isolating mechanism, such as a clam-shell gate, or radial gate, in order to prevent flooding of the receiving conveyor under trip-out conditions, when the conveyor coasting time is less than the loaded screen run-down time. The gates may be programmed to automatically close rapidly (in less time than the conveyor coasting time), and to open smoothly and slowly, in order to deliver the screen run-off to the conveyor in a reasonably controlled manner when the system is restarted.

For chutes exiting hoppers, bins, silos and stockpiles, the chute design must accommodate the requirements of the feeding device, such as the vibrating, belt, apron or other type of feeder.

4.4 Chute Liners

Chute Hood: Under normal conditions, the chute hood side plates are not lined. If the material trajectory is such that the hood front plate or side plates will experience impact, then only the areas subject to impact should be lined, in order to minimise the mass (and cost) of the liners.

Chute Body: Only the areas where the material impacts or slides should be lined.

Chute Exit and Skirts: The exit of the chute is normally lined wherever the material impacts or slides. Skirts should be lined full length. The depth of liners should be at least equal to the depth of material contacting the skirts. In the impact and acceleration zones, the skirts should be lined full depth.

Types of Liners: The following types of liners may be considered for selection:

- VRN-500. This is preferred at locations where impact is high, or where the material lump size is greater than 100 mm – 150 mm.
- Ti-Hard, Rio-Carb or other harder grades of liner steel have high wearing properties and should be considered, based on the specific application.
- Solidur or equivalent UHMWPE. This may be specified in locations where the material is sliding. These liners should not be specified in areas of high impact, or material with large lumps and sharp edges. This material is especially useful for lining the back plates of chutes and for lining dribble chutes, in order to improve material flow.
- Ceramics. This is useful where the action of the material is largely sliding and there is a significant moisture content in the material. These liners should not be specified in areas of high impact, or where the material lump size is greater than 100 mm to 150 mm. Ceramics are best utilised where the body of the chute has a long sliding portion and where water is introduced to wash down fines collection areas.
- Rubber. These liners are best utilised in primary crushed material bins and hoppers, or where impact is likely to be high. The location of the liner with respect to the trajectory of the material must be carefully considered, in order to present the material flow normal to the surface of the liners as far as possible. Other locations where rubber may be used are in the body of the chute which may be subject to material splash, in order to reduce noise levels. Rubber liners should not be specified in areas where sliding takes place without the introduction of wash water

General

- The bare chute plate should be prepared in accordance with the requirements of the engineer. For replaceable metal liners, the chute surface should be clean and free from rust and scale. The surface to be lined may be coated with epoxy primer to 30 µm. For other methods of attachment, such as adhesives or riveting, the surface of the chute to be lined should be prepared in accordance with the requirements of the liner supplier.
- Liner plates of thickness 12 mm and above should be secured with M16 countersunk bolts.
- The minimum number of securing bolts per liner plate should be as follows:
  - For triangular sections: 3 bolts
  - For any other shape: 4 bolts

- For other lining materials, the securing bolts or rivets should be in accordance with the requirements of the liner supplier.
- Nib head bolts may be used in areas that are not subject to flexing or heavy impact. Note that cracks in the harder steel liners originate at the notch for the bolt head nib. For this reason, liners in hardened steels that are subject to flexing ought to be secured with conventional countersunk bolts, with slot heads or hexagonal socket heads. The securing bolts may be grade 4.4.
- In areas where wash down water is used, the bolt joints should be made water tight.
- The liners ought to be so patterned that the gaps between the liners are staggered in the direction of flow, in order to prevent the material fines ‘channelling’, and creating ‘pagging’ areas (the rapid build-up of very fine material). In corners, the liners must be so arranged that the edges overlap and the corners of the bare chute are protected.
- The welding of liners is unacceptable.
- The recommended thickness of steel liners shall be as follows, subject to input from the liner supplier:
  - 20 mm: on high wear, heavy impact areas and chutes handling material of average lump size greater than 100 mm to 150 mm
  - 2 mm: on surfaces subject to light impact and material sliding only, and on skirts
  - 10 mm: on fines chutes that are not subject to impact.
- The thickness of other lining materials, such as ceramics and Solidur should be as determined by the liner supplier.
- All liner plates must be sized for ease of handling, with an average mass of 30 kg and a maximum mass not exceeding 35 kg. Keep in mind that liner plates are often difficult to manipulate within the confines of the chute body. A recommendation is that liner plate could be provided with removable ‘handles’ to facilitate handling.
- Metal liners should be secured with countersunk bolts. The maximum bolt diameter is usually determined by the thickness of the liner. The countersunk holes should allow a base thickness of about 3 mm between the back of the liner and the underside of the countersink. The maximum securing bolt diameter may then be determined as

  $$d = 2 \cdot (t - 3) \quad (3)$$

  where:

  t = liner plate thickness [mm]

4.5 The ‘Between Skirts’ Dimension

A very commonly applied standard for the dimension between conveyor skirts is that the dimension between skirts should be 2/3 of the belt width. This dimension was developed for flat feeder belts and remains applicable in this case. However with ever increasing trough angles applying this simple rule often results in a very small clearance between the belt edge and the skirt rubber. A small lateral movement of the belt causes the belt to push the skirt rubber out with resultant spillage and constant belt tracking problems. G. Shortt has proposed a modified rule which is based on retaining the free-board (dimension between belt edge and skirt in this case) distance instead of the 'between skirts' dimension. in this case the free-board dimension is premised on the reliable rule for the flat belt condition of one sixth of belt width.

Width	0°	Ratio	20°	Ratio
500	335	0.67	317	0.63
600	402	0.67	380	0.63
750	503	0.67	474	0.63
900	603	0.67	569	0.63
1050	704	0.67	664	0.63
1200	804	0.67	758	0.63
1350	905	0.67	853	0.63
1500	1005	0.67	947	0.63
1650	1106	0.67	1042	0.63
1800	1206	0.67	1137	0.63
2100	1407	0.67	1326	0.63
2400	1608	0.67	1515	0.63
Width	**30°**	**Ratio**	**35°**	**Ratio**
500	294	0.59	280	0.56
600	352	0.59	335	0.56
750	440	0.59	416	0.56
900	527	0.59	501	0.56
1050	615	0.59	584	0.56
1200	702	0.59	667	0.56
1350	790	0.58	749	0.56
1500	877	0.58	832	0.55
1650	964	0.58	915	0.55
1800	1052	0.58	998	0.55

2100	1227	0.58	1164	0.55
2400	1402	0.58	1329	0.55
Width	**45°**	**Ratio**		
500	246	0.49		
600	294	0.49		
750	366	0.49		
900	438	0.49		
1050	509	0.49		
1200	581	0.48		
1350	653	0.48		
1500	725	0.48		
1650	797	0.48		
1800	869	0.48		
2100	1013	0.48		
2400	1157	0.48		

5. Material Properties

Knowing the inherent properties of the material being conveyed is critical to the successful design of transfer chutes. The obvious properties which would probably have been used in the selection of the required belt parameters to suit the duty are:

- The type of material (e.g. coal) and whether it is abrasive or corrosive
- The particle size and particle size distribution (mm) – highly dependent on process
- The bulk density ρ [kg/m^3]
- The belt surcharge angle λ [°]
- The angle of repose θ_r [°].

Whilst many of the above material characteristics are published in manuals and catalogues it is always best to run typical bulk flow tests on the specific material to be conveyed.

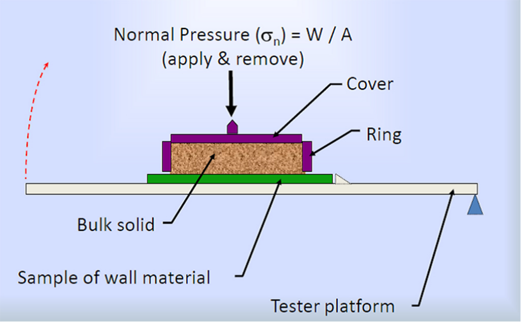


Fig. 8: Test for wall friction angle

An important property is ascertaining the point at which the material begins to slide down the chute face for different types of liner material. This is typically established by testing, utilising a system similar to the Jenike Johannsen Shear testing system – however in this case, a force is applied to a block of the material and then the pressure is released and the block tilted until it begins to slide. The test is performed at different loads and with different wall materials, effectively simulating the impact of material on the chute face and the angle at which the impacted material will slide.

6. Material Trajectory – The Starting Point

The starting point is the point at which the material leaves the discharge pulley. It is important here to identify this position as at this point mechanical interaction between material and belt is lost, and the material acts like a projectile with initial velocity subject only to the action of gravity (excluding the effects of air resistance). The material trajectory is fundamental in the design of the chute as it defines the flow of material and the requirements for first impact point and the path followed by the material until it lands. There are numerous examples available in literature defining the methodology to be followed in establishing the material trajectory. The methodology described below is based on the CMA lecture course. There are recent papers presented at Beltcon by D. Hastings which are excellent references to other methodologies and which also give a comparison of the different methods against actual results established by high speed photography. The theory being proved by the practical. The methodology proposed in the CMA Diploma Course is as follows:

- Establish the area of material flowing over the head chute;
- Establish the depth of material flowing over the head chute;
- Establish the centroid of area of the material flowing over the head chute.

The condition of material flowing over the head chute is represented in Fig. 9 for a typical three-roll idler set. Note that the troughed form now flattens out and the area of the trapezium formed when flattened should be equal to that of the troughed configuration.

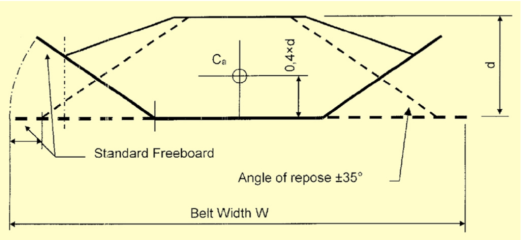


Fig. 9: Loaded belt profile at the discharge

For a belt loaded to 100% of CEMA and based on normally accepted free-board dimensions, the width of material on the flattened belt may be found from:

$$W_{wet} = (0.9W - 50)10^{-3} \qquad (4)$$

where:

W = belt width [mm]

W_{wet}= wetted area [m] (Note that units are mixed in order to simplify calculations).

The centroid of area of the trapezium is accepted as 40% of the height yielding

$$C_a = 0.4d \qquad (5)$$

Setting the area of the troughed belt equal to the area of the trapezium resulting from the flattened belt yields

$$d = \left(\frac{\sqrt{W_{wet} - \frac{W_{wet}^2 - 4A_{100}}{\tan\alpha}}}{2} \right) \tan\lambda \qquad (6)$$

where:

A_{100} = cross sectional area at 100% loading [m^2]

λ = angle of repose (typically 34°–37°)

With this, a profile can be defined that the centroid of material would follow around the head pulley and along its trajectory with upper and lower boundaries following this path. Note however, that in the case of the material stream comprising mainly large lumps (greater than say, 150 mm), it is normal to calculate d as a function of the lump size and typically as 60% of the lump size. The point *R* at which the material stream leaves the belt can now be defined:

$$R=(r+h+C_a)\ \ [\mathrm{m}] \qquad (7)$$

where:
r = pulley radius over lagging [m]
h = belt total thickness [m]
C_a = depth to centre of area of material burden [m]

At the point of separation, the material has the same velocity of the belt *V* [m/s].And define factor *K*:

$$K=\frac{v^2}{gR\cos\alpha} \qquad (8)$$

where:α = angle of inclination of the belt at the discharge pulleyThe location of the drop points with their dependency on belt speed is now defined asfor K > 1: drop point is at Tfor K < 1: drop point is at C

$$\theta=\sin^{-1}\left(\frac{v^2}{gR}\right) \qquad (9)$$

where θ, the angle between the horizontal and the drop point is defined as the release angle.

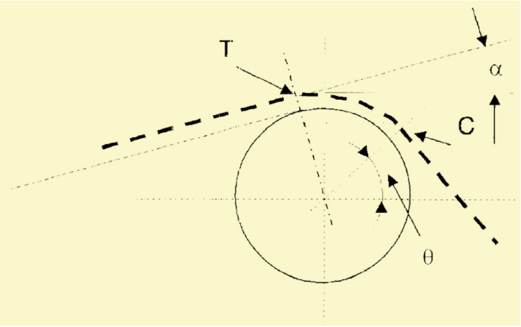


Fig. 10: Point of discharge

In the case of slow moving belts where the release angle is calculated as being less than the angle of repose of the material, it is normal to reckon the release angle as being between three and five degrees greater than the angle of repose of the material.Plotting the material trajectory can now be done.

- From the drop point determined above extend a line along the inclination θ determined.
- Decide on set-out spacing.

  $$L = Vt \tag{10}$$

  where:t = time intervals (typically seconds) and mark out

- At each spacing along the line of the release angle drop a vertical of distance

  $$H = \frac{g}{2}t^2 \tag{11}$$

- Join each end point to plot the trajectory of the centre of area of the material.

The upper and lower bounds of the trajectory will follow the upper and lower bounds of the material about the centre of area for a fall of about 2.5 m. Thereafter air-drag and wind may result in deflection of the material stream.Figs. 11 and 12 indicate the difference in material trajectory for fast and slow belt speeds.

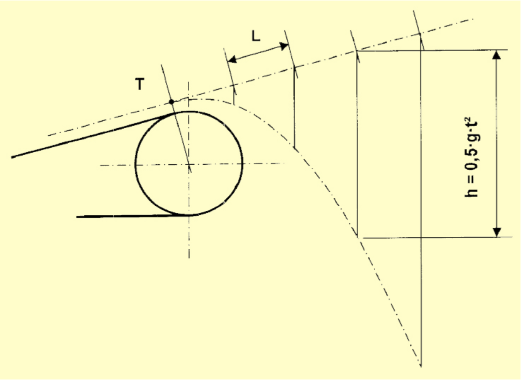


Fig. 11: Trajectory at fast belt speed

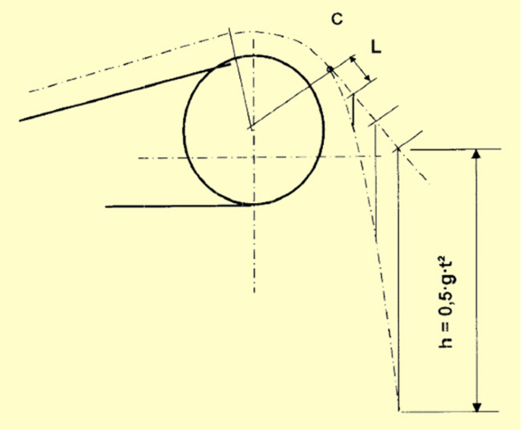


Fig. 12: Trajectory at low belt speed

Knowing the material trajectory, the flow pattern and the point of first impact can be determined. This is critical in the design of the hood. The hood directs the flow of the material towards the spoon. The material is intercepted at a tangent. The Hood should be designed such that it has the same radius of curvature at the point of impact as the trajectory, i.e. the impact angle should be as small as possible. (Fig. 13)

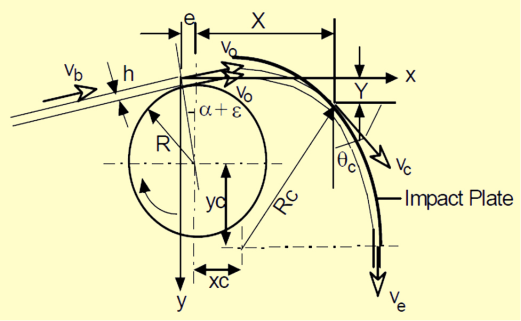
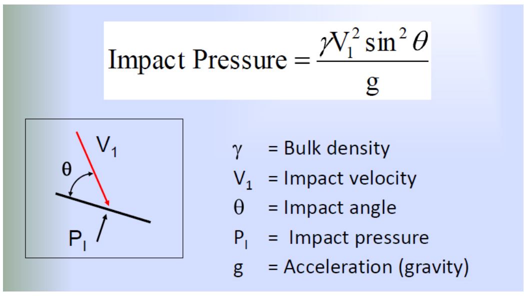


Fig. 13: Hood design

7. Design Principles For Chute Design

7.1 Design Principle 1 – Prevent Plugging At Impact Points

The chute face must be sufficiently smooth and steep to allow sliding and hence clean-off of the stickiest material that it has to handle.The impact pressure at any point that the material stream impacts the chute face is presented in Fig. 14.

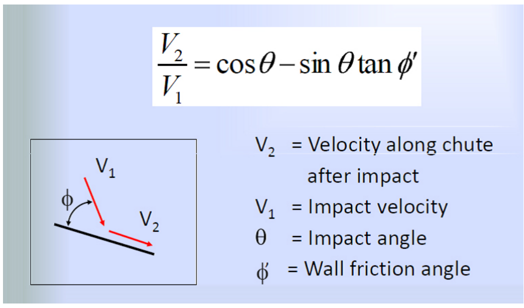


$$\text{Impact Pressure} = \frac{\gamma V_1^2 \sin^2\theta}{g}$$

γ = Bulk density
V_1 = Impact velocity
θ = Impact angle
P_I = Impact pressure
g = Acceleration (gravity)

Fig. 14: Formula for impact pressure

The velocity following an impact with the chute surface may be calculated from Fig. 15.



$$\frac{V_2}{V_1} = \cos\theta - \sin\theta \tan\phi'$$

V_2 = Velocity along chute after impact
V_1 = Impact velocity
θ = Impact angle
ϕ' = Wall friction angle

Fig. 15: Velocity after impact

Stagnation and hence plugging will occur when V_2 = 0 m/s.It is critical that the velocity at the point in question be accurately estimated.As the material moves through the chute it may be subjected to different acceleration forces such as sliding along the chute plates or free falling through the vertical section of a chute.The acceleration along a face of the chute is calculated as

$$a = g(\sin\alpha - \cos\alpha \cdot \tan\theta) \qquad (12)$$

And the velocity is calculated as

$$V = \sqrt{V_0^2 + 2as} \qquad (13)$$

where:V_0 = velocity at the start of the incline$s$ = length of the incline.For free fall the velocity is calculated as

$$V = \sqrt{V_0^2 + 2gS} \qquad (14)$$

where:S = the height of the free fall$g$ = acceleration due to gravity.For a section of the chute at a slightly different inclination, the starting velocity

$$V_3 = V_2[\cos(\alpha - \beta) - \sin(\alpha - \beta)\tan\phi'] \qquad (15)$$

where β is the inclination of the section.Acceleration over this section is

$$a = g[\sin\beta - \cos\beta \tan\phi'] \qquad (16)$$

so that the exit velocity

$$V_4 = \sqrt{2aS_2 + V_3^2} \qquad (17)$$

The stream velocity in the belt direction:

$$V_x = V_4 \cos\beta \qquad (18)$$

The vertical component is

$$V_y = V_4 \sin\beta \qquad (19)$$

The impact pressure of the stream with the belt

$$\sigma = \gamma_s \left(\frac{V_4^2 \sin\beta}{g} \right) \qquad (20)$$

7.2 Design Principle 2 – Ensure Sufficient Cross-Sectional Area

Always ensure that there is sufficient belt cross-sectional area to allow for the free flow of material through different sections of the chute.The formula given in section 5.2.1 must be valid at all sections through the chute.

7.3 Design Principle 3 – Control Stream Of Particles

It is critical to retain control of the material flow through the chute in order to ensure efficient transfer.The following figures and formulae give the design principles employed with both a material stream falling under gravity as well as that where material exits the chute with significant velocity.The case illustrated in Fig. 16 shows slow moving particles exiting the discharge chute and falling through a free-fall vertical portion of the chute onto the curved 'spoon' chute.

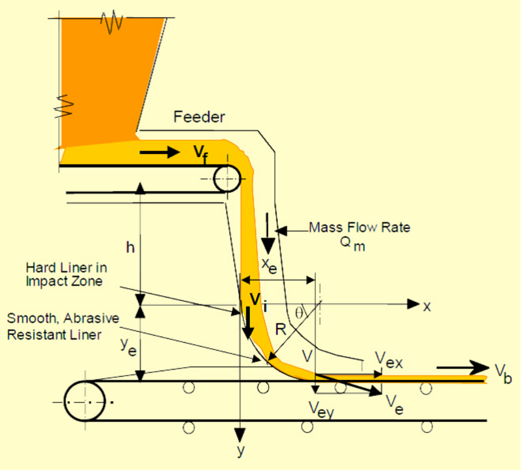


Fig. 16: Chute flow configuration - in line transfer

The flow into the curved bottom section of the chute may be illustrated by the free body diagram in Fig. 17.

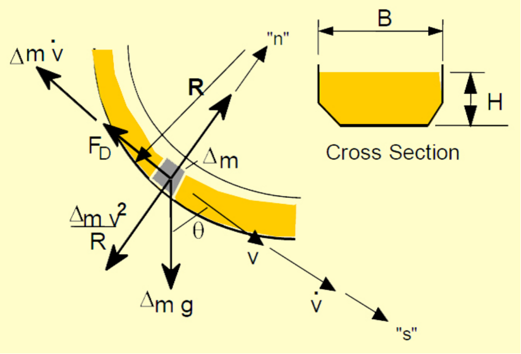


Fig. 18: Flow through an in-line transfer chute

For a chute of rectangular cross-section we find

$$C_1 = \frac{K_v V_0 H_0}{B} \qquad (21)$$

where:V_0 = initial velocity at entry to streamH_0 = initial stream thicknessAnalysing the dynamic equilibrium conditions of Fig. 16 leads to the following differential equation:

$$\frac{dV}{d\theta} + \mu_E v = \frac{gR}{v}(\cos\theta - \mu_E \sin\theta) \qquad (22)$$

On conditon that the curved section of the chute is of constant radius R and assuming that μ_E remains constant at an average value for whole of the stream, it may be shown that the solution of the above equation leads to Eq. 23 for the velocity at any location

$$v = \sqrt{\frac{2gR}{4\mu_E^2+1}[(1-2\mu_E^2)\sin\theta + 3\mu_E\cos\theta] + Ke^{-2\mu e\theta}} \qquad (23)$$

For $v = v_0$ at $\theta = \theta_0$

$$K = \left\{ v_0^2 - \frac{2gR}{4\mu_E^2+1}[(1-2\mu_E^2)\sin\theta_0 + 3\mu_E\cos\theta_0] \right\} e^{\mu_E\theta_0} \qquad (24)$$

Special case:when $\theta_0 = 0$ and $v = v_0$, then

$$K = v_0^2 - \frac{6\mu_E gR}{1+4\mu_E^2} \qquad (25)$$

Equation 23 then becomes

$$v = \sqrt{\frac{2gR}{4\mu_E^2+1}[(1-2\mu_E^2)\sin\theta+3\mu_E^2\cos\theta]+e^{-2\mu e\theta}\left[v_i^2-\frac{6\mu_E gR}{1+4\mu_E^2}\right]} \qquad (26)$$

In the generalised case of a belt conveyor transfer point the material leaves the discharge pulley with some inertia in the horizontal direction and hence the material stream has to be channelled into a cohesive stream and controlled through the vertical section and onto the spoon chute. This is illustrated in Fig. 18.

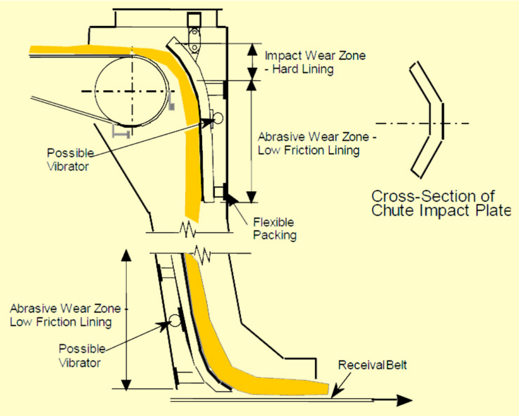


Fig. 17: Spoon chute flow model

Hence the material flow in the upper hood portion is represented by the free body diagram in Fig. 19.

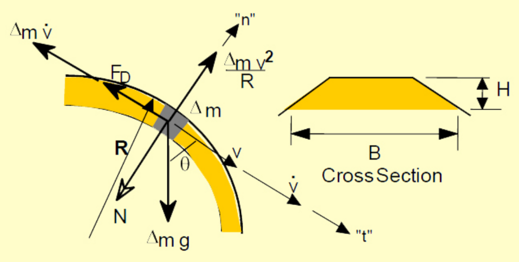


Fig. 19: Flow model in hood portion

The formulae developed for the spoon section may be developed for the hood section as

$$-\frac{dV}{d\theta}+\mu_E v=\frac{gR}{v}(\cos\theta-\mu_E\sin\theta) \qquad (27)$$

For a constant radius and assuming μ_E is constant at an average value for the stream, the solution for the velocity equation (17) is

$$v = \sqrt{\frac{2gR}{4\mu_E^2+1}[(2\mu_E^2-1)\sin\theta + 3\mu_E\cos\theta] + Ke^{2\mu_e\theta}} \qquad (28)$$

For $v = v_0$ at $\theta = \theta_0$ then

$$K = \left\{ v_0^2 - \frac{2gR}{4\mu_E^2+1}[3\mu_E\cos\theta_0 + (2\mu_E^2-1)\sin\theta_0 \right\} e^{-2\mu_E\theta_0} \qquad (29)$$

The above principles may also be applied to the case of a convex curve in the chute as indicated below.

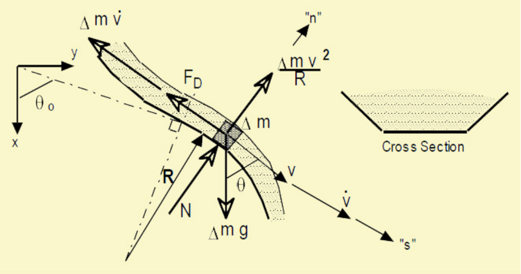


Fig. 20: Flow in a convex section

$$\frac{dV}{d\theta} - \mu_E v = \frac{gR}{v}(\cos\theta - \mu_E\sin\theta) \qquad (30)$$

This is applicable for sin θ ≥ v_2/Rg.It is noted that Fig. 19 also applies in this case with the vertical axis now representing the maximum value of the velocity for chute contact.For a constant radius and assuming μ_E is constant at an average value for the stream, the solution for the velocity equation (28) is

$$v = \sqrt{\frac{2gR}{4\mu_E^2+1}[(2\mu_E^2+1)\sin\theta + 3\mu_E\cos\theta] + Ke^{2\mu_e\theta}} \qquad (31)$$

For $v = v_0$ at $\theta = \theta_0$ then

$$K = \left\{ v_0^2 - \frac{2gR}{4\mu_E^2+1}[(2\mu_E^2+1)\sin\theta_0 - \mu_E\cos\theta_0] \right\} e^{-2\mu_E\theta_0} \qquad (32)$$

7.4 Design Principle 4 – Minimise Abrasive Wear of Chute Surface

A critical aspect in the efficient design of transfer chutes is the wear that is imposed on the chute surface by the abrasive nature of material flowing on the chute surface.

1. Wear on Chute Bottom

Consider the generalised case of flow through the spoon as indicated in Fig. 21.

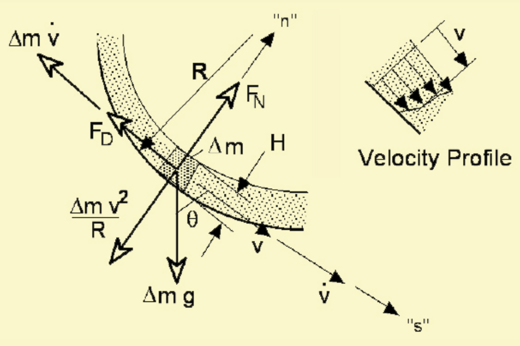


Fig. 21: Flow through spoon

An abrasive wear factor W_c may be determined as:

$$W_c = \frac{Q_m g K_c \tan\varnothing}{B} N_{WR} \qquad (33)$$

where:

W_c = abrasive wear factor [N/ms]
N_{WR} = non-dimensional abrasive wear number

N_{WR} is given by:

$$N_{WR} = \frac{v^2}{Rg} + \sin\theta \qquad (34)$$

The various parameters are:

$\varnothing$ = chute friction angle [°]
B = chute width [m]
K_c = ratio v_s/v
V_s = velocity of sliding against chute surface
Q_m = throughput [kg/s]
R = radius of curvature of the chute [m]
V = average velocity at section considered [m/s]
θ = chute slope angle measured from the vertical [°].

The factor $K_c < 1$. For fast or accelerated thin stream flow, $K_c = 0.6$. As the stream thickness increases, K_c will reduce. Two particular chute geometries are of practical interest: straight inclined chutes and constant radius curved chutes.

2. Wear on Chute Side Walls

Assuming the side wall pressure increases linearly from zero at the surface of the stream to a maximum value at the bottom, then the average wear may be estimated from

$$W_{cSW} = \frac{W_c K_v}{2K_c} \qquad (35)$$

K_v and K_c are as previously defined. If, for example, $K_v = 0.8$ and $K_v = 0.4$, then the average side wall wear is 25% of the chute bottom surface wear.

3. Impact Wear

Impact wear in transfer chutes may occur at points of entry or at points of sudden changes in direction. For ductile materials the greatest wear occurs when impingement angles are low, say 15° – 30°. For hard, brittle materials the greatest impact damage occurs at steep impingement angles of the order of 90°.

7.5 Design Principle 5 – Minimise the Wear of the Belt

A critically important aspect in the design of transfer chutes is to reduce the effects of the material stream on belt wear and damage. The primary objectives are to:

- match the horizontal component of the exit velocity as closely as possible to the belt speed,
- reduce the vertical component of the exit velocity so as to reduce abrasive wear due to impact, and
- load the belt centrally so that the load is evenly distributed in order to avoid belt mistracking and spillage.

The transfer of material onto the belt is illustrated in Fig. 22.

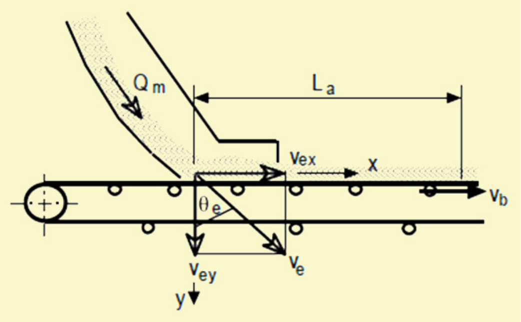


Fig. 22: Feed onto the belt

The following formulae have been developed as a means of estimating belt wear at a transfer point:

$$p_{vi} = \rho v_{ey}^2 \tag{36}$$

where:

ρ = bulk density
V_{ey} = vertical component of the exit velocity

The abrasive wear parameter W_a:

$$W_a = \mu_b \rho v_{ey}^2 (v_b - v_{ex}) \quad \left[\mathrm{kPa}\frac{\mathrm{m}}{\mathrm{s}}\right] \tag{37}$$

where:

μ_b = friction coefficient between bulk solid and conveyor belt
V_b = belt speed

The wear will be distributed over the acceleration length L_a. The wear parameter may then be expressed as

$$W_a = \mu_b \rho v_e^3 K_b \tag{38}$$

with:

$$K_b = \cos^2\theta_e \left(\frac{v_b}{v_e} - \sin\theta\right) \tag{39}$$

where:

θ_e = chute slope angle with respect to vertical at exit
K_b = non-dimensional wear parameter.

In Fig. 23 K_b is plotted for a range of v_b/v_e values.

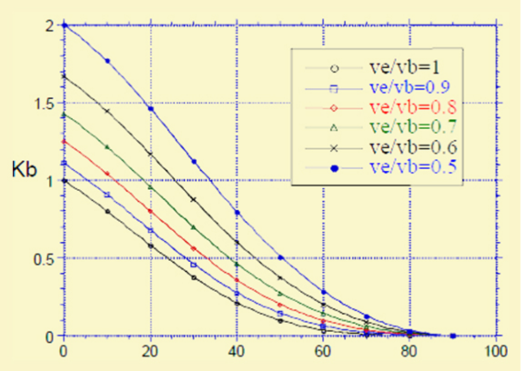


Fig. 23: Non-dimensional wear parameter versus slope angle

As shown, the wear is quite severe at low chute angles but reduces significantly as the angle θ_e increases. For the chute to be self-cleaning, the slope angle of the chute at exit must be greater than the angle of repose of the bulk solids on the chute surface. It is recommended that

$$\theta_e \geq \tan^{-1} \mu_g + 5^\circ$$

8. Conclusion

This collection of rules and formulae has been presented as a reminder to the industry that chute design requires a lot more attention that it is currently given. While sophisticated computer software is an essential tool in modern materials handling, the basic design of particulate flow is equally essential where the software is not available. The application of the equations and principles presented should provide the designer and plant engineer with the means to apply these principles in a practical manner and with sufficient accuracy to confidently predict the performance of the chutes.