Understanding Bends In Pneumatic Conveying Systems

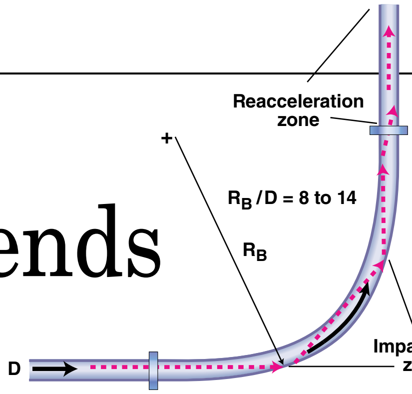

FIGURE 1. Flow in a standard, long-radius bend is illustrated here, with typical flow patterns, wear points and reacceleration zone shown

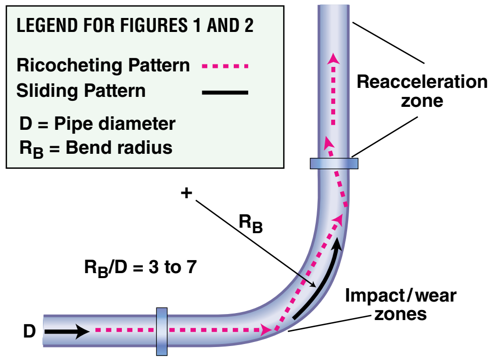

FIGURE 2. Flow in a standard, short-radius bend is illustrated here, with typical flow patterns, wear points and reacceleration zone shown

Despite their apparent simplicity, bends are often poorly understood and unless properly designed, they are potentially problematic

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Pneumatic conveying of bulk solids has been successfully practiced — in industries as diverse as chemical, agricultural, pharmaceutical, plastics, food, mineral processing, cement and power generation — for more than a century. Pneumatic conveying provides advantages over mechanical conveying systems in many applications, including those that require complex routing, multiple source-destination combinations and product containment.

Pneumatic conveying transfer lines are often routed over pipe racks and around large process equipment, giving process operators great layout flexibility. Such design flexibility is made possible by the use of bends (such as elbows and sweeps, discussed below) between straight sections (both horizontal or vertical), which enable convenient change of direction in the flow of the conveyed solids.

However, among all the components of a pneumatic conveying system, bends — despite their apparent simplicity — are probably the least understood and most potentially problematic for process operators. Findings from various research studies are often not consistent, and often times public findings do not match field experience.

The importance of bends in any pneumatic conveying assembly cannot be overstated since — if not properly selected and designed — they can contribute significantly to overall pressure drop, product attrition (degradation) and system maintenance (due to erosive wear).

Historically, a basic long-radius bend (shown in Figures 1 and 2, and discussed below) has been the bend of choice for designers of pneumatic conveying systems, for a variety of reasons:

- Long-radius bends provide the most gradual change in direction for solids, and hence are most similar to a straight section of piping
- The angle of impact on the pipe wall is relatively small, which helps to minimize the risk of attrition or erosion
- For lack of other experience, to maintain the *status quo*

Years of field experience and a variety of studies conducted to troubleshoot common problems — such as line plugging, excessive product attrition (degradation), unacceptably high bend wear and higher-than-expected pressure drop — clearly indicate that the flow through bends in pneumatic piping is very complex. One should refrain from generalizing the findings until the underlying physics are well understood.

This complexity is exacerbated when innovative designs are introduced to address existing issues with common-radius bends (also discussed below). Today, most of the data still resides with vendors and there is a need for fair, unbiased and technically sound comparative evaluation.

The purpose of this article is to summarize the key concepts, outline key metrics used to evaluate bend performance, and provide guidance for their selection. We will limit our discussion to dilute-phase conveying. (Issues related to pipe bends for dense-phase conveying systems will be addressed at a future date.)

Background

Bends are installed in a pneumatic conveying system wherever a change in direction is required along the conveying route. They can be broadly classified into three major categories:

a. Common-radius bends (including elbows, short-radius, long-radius and long-sweep bends)
b. Common fittings (including tee bends, mitered bends and elbows)
c. Specialized bends and innovative designs (such as the Gamma™ bend, Hammertek Smart Elbow™, Pellbow™, wear-back designs, and lined bends, which are described in the next section)

a. Common-radius bends. Common-radius bends (as shown in Figures 1 and 2) are made by bending standard tubes or pipes. The radius of curvature (R_B) may range from 1D to 24D (where D is the diameter of the tube or pipe). Common-radius bends can be loosely classified as follows:

Elbow:	RB/D	=	1 to 2.5
Short radius:	RB/D	=	3 to 7
Long radius:	RB/D	=	8 to 14
Long sweep:	RB/D	=	15 to 24

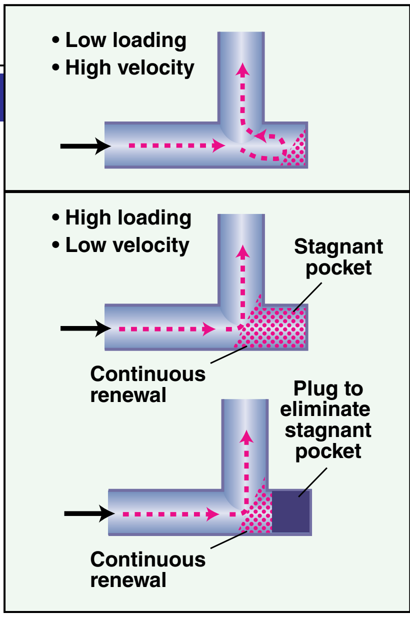

FIGURE 3. The effect of loading and gas velocity on flow patterns in a blind tee (horizontal-vertical orientation) is shown here

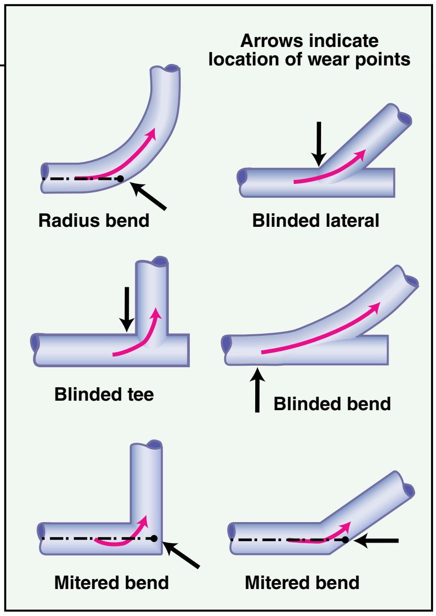

FIGURE 4. Several variations of common fittings are provided here, with typical wear points highlighted

These bends are available in wide range of materials of construction and thicknesses, similar to the straight section of pipe (tangent) that is provided on either side of the curved section. The conveyed material may undergo multiple impacts with the pipe wall, or may slide along the outer radius, depending on material properties, solids loading and gas velocity. Bend wear and material attrition comonly occur at the impact zones.

b. Common fittings. The most commonly used fitting to accomplish a change in flow direction is a blind tee bend. In this design, one of the outlets is plugged thereby allowing conveyed solids to accumulate in the pocket (Figure 3). The benefit of this design is that the accumulated pocket of material cushions the impact of the incoming material, significantly reducing the potential for wear and product attrition. The extent of accumulation in the pocket will depend on the orientation of the bend, solids loading, gas velocity and material properties (such as particle size and cohesiveness).

However, in a tee bend, the conveyed solids lose most of their momentum during the impact and thus must be reaccelerated downstream of the bend. As a result, pressure drop across a blind tee can be as much as three times that of a long-radius bend. Several variations of tee bends are shown in Figure 4.

c. Specialized bends. Today, a variety of specialized designs are available to control flow within the bend, in order to minimize attrition and wear. This is often achieved by creating a self-cleaning or replenishing pocket or layer of material, upon which the incoming stream impinges. Wear inside the piping is minimized by redirecting the gas-solid suspension away from typical wear points. Several of the most commonly used specialized bends are discussed in the following section.

Gamma™ Bend. The Gamma Bend from Coperion (coperion.com) is shown in Figure 5. Its innovative design relies on creating particle-particle impact in the impact zone and prevents sliding motion of particles along the outer radius to minimize particle smearing, so it is especially effective in preventing the formation of streamers or angel hair in polymer pellets. A minimum solids loading of 5 (defined as mass of solids/mass of air) — which depends on the bulk density of the product, is required to ensure accumulation of material in the impact zone. In the absence of this layer, the particles will directly impact the target plate within the bend and may result in both particle attrition and pipe erosion. These bends are typically fabricated from stainless steel, and provide a very tight bend radius (R_B/D = 4 to 6). The pressure drop is higher (20-40%) than that experienced by a typical short-radius bend (R_B/D = 3 to 7).

Pellbow™ Bend. The Pellbow Bend from Pelletron Corp. (pelletroncorp.com) is shown in Figure 6. It is similar to a short-radius bend but has an expanded pocket. The pocket is meant to accumulate a small amount of solids at the primary impact location so that most of the impact is between particles themselves. To ensure adequate accumulation of material in this pocket, the minimum recommended solids loading is 3 (mass of solids/mass of air). According to the vendor, pressure drop will be slight higher than that experienced by a short-radius bend. It is available in wide range of materials of construction.

Vortice-Ell Smart Elbow or Hammertek - Smart Elbow™. The Vortice-Ell Smart Elbow from Rotaval (rotaval.co.uk) and the Hammertek Smart Elbow™ from Hammertek Corp. (hammertek.com), are similar in design (Figure 7). Both have a bulbous extension on the heel. Depending on the orientation and inlet gas velocity, the incoming material will either fill the chamber or circulate within the chamber before exiting. In either case, it results in significant reduction in wear and attrition of material. It is available in 45- and 90-degree designs and in various materials of construction.

Wearback designs. There are two major types of wearback elbow designs (as shown in Figure 8):

a. *Equipped with a wear plate with a sacrificial and replaceable back plate:*
   - The replaceable back plate is made from hardened material, typically with Brinell hardness greater than 400 (e.g., Ni hard)
   - Typically available in short-radius designs (R_B/D = 2 to 6) and multiple angles 22.5, 45, 60 and 90 degrees
   - Segmented designs are available, which allows for partial replacement of the elbow body
   - Commonly used in the flyash industry

b. *Tube-in-tube (pipe-in-pipe) arrangements*:
   - The space between the inner and outer casings can be left unfilled or filled with concrete or porcelain or another abrasion-resistant material
   - For the unfilled design, once the inner core wears out, the product fills the cavity. Thereafter, the material impacts on a packed bed, which continuously gets replenished. This design is not suitable for abrasive products that tend to degrade, or where cross-contamination is a concern
   - For the filled design, once the inner

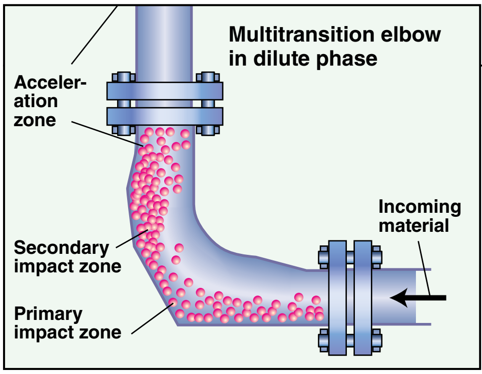

FIGURE 5. In the Gamma™ Bend design, accumulation of material in the primary impact zone prevents direct impact of material on the bend wall, reducing erosive damage to the pipe

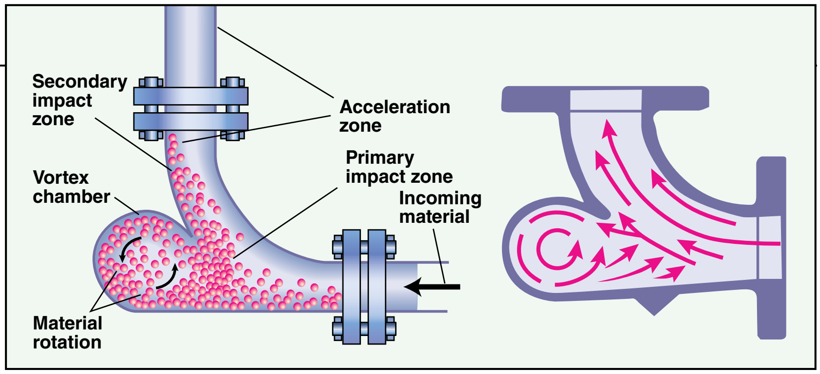

FIGURE 7. In a Vortice Ell or Hammertek Smart Elbow™ bend, a bulbous extension creates a circulating flow pattern or a pocket of material, which cushions the impact on incoming stream

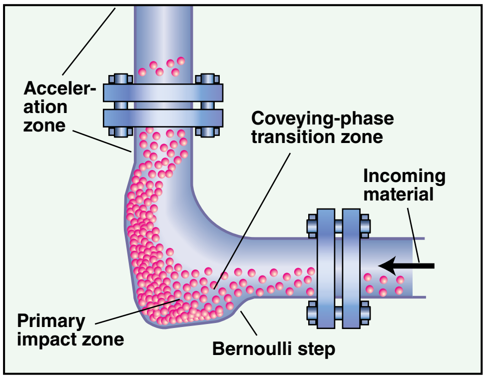

FIGURE 6. The formation of a pocket of material at the primary impact zone helps to minimize attrition and erosion in a Pellbow™ bends

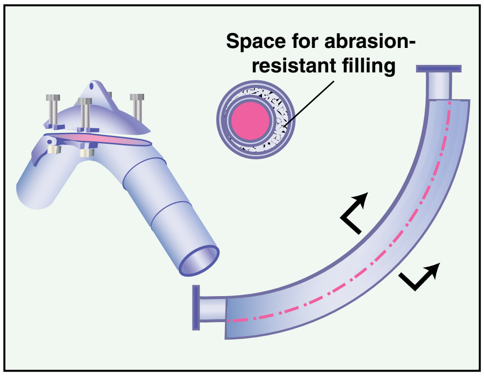

FIGURE 8. A wearback elbow design can either be a replaceable hardened piece or a wearable inner core with abrasion-resistant filling

core wears out, the abrasion-resistant filling provides a longer bend life compared with many regular bends

Bends with liners. Bends with abrasion-resistant liners are used for highly abrasive products. A wide range of proprietary lining materials are available. Examples include high-density alumina ceramics, zirconium corundum, hardened_cast iron, silicon carbide and tungsten carbide. The presence of a liner also extends the upper limit of operating temperature for the bend component.

Evaluating bend performance: Competing metrics

A variety of metrics are available to help process operators to evaluate bend performance in pneumatic conveying systems. These include:

1. Pressure drop related to the bend
2. Attrition or product degradation
3. Wear, erosion or bend life

Each is discussed below.

Method 1. Evaluating pressure drop. Single-phase flow of a fluid through a bend (or any component causing directional change) will result in additional pressure drop. This behavior is well understood and reported [2]. The pressure drop in a bend depends on the ratio of bend radius to pipe diameter (R_B/D), the gas velocity (U_g) and the internal roughness (k) of the pipe (Figure 9).

When a two-phase, gas-solid suspension undergoes a directional change, such as in a bend, the bend naturally acts as a segregator or separator of the two phases. Due to the centrifugal forces acting on the particles, they are concentrated along the outer wall of the bend. For instance, in the case of fine coal, an unusual phenomenon of "roping" (the formation of concentrated strands) is observed. Depending on material properties, solids loading, gas velocity and pipe-wall interactions, the particles may have multiple impacts within the body of the bend.

As a result of particle-particle and particle-wall impacts, and the friction along the pipe wall, the particles exit the body of the bend at a velocity that is lower than their steady-state velocity. The steady-state velocity of particles in a gas-solids suspension is typically in the range of 70–90% of gas velocity. The particles must re-accelerate to their steady-state velocity after they exit the bend. The energy required for re-acceleration manifests itself as additional pressure loss after the bend, and the extent of the pressure drop depends on the extent to which the solids have been slowed during the transit.

Simply put, the pressure drop due to a bend in gas-solid flow is due to the combination of frictional loss in the bend itself plus the energy required to re-accelerate the solids back to their steady state velocity. It should be noted that the friction coefficient within the bend will be different than the corresponding friction coefficient in adjacent straight section. Meanwhile, additional losses due to static head (e.g. in horizontal-vertical and vertical-horizontal orientation) are usually minor but must also be accounted for.

The pressure drop in a bend is most accurately quantified if the static pressures along the conveying line are measured before and after the bend location (see Figure 10). The static pressure decreases linearly in the straight section preceding the bend. The pressure gradient increases in the body of the bend and continues to be non-linear even after the flow exits the bend. It may take considerable distance downstream of the bend (up to 15-20 ft; 5-6 m) for the flow to reach steady state pressure and for the gradient to become linear again.

The pressure drop incurred by a bend can be correctly estimated by extrapolating the linear pressure gradient downstream of the bend until the imaginary outlet of the pipe bend (Figure 10). As shown in Figure 11, if two pressure taps are placed just across the body of the bend at locations C & D, an incorrect estimation of pressure drop would be made. This is a common mistake which leads to much confusion in the literature.

Calculation of bend pressure drop

(EEUA). A simple approach to estimate the pressure drop resulting from standard radius bends was proposed in "EEUA Handbook" [7]. The bend coefficient (B) can be estimated by regression using actual data. In the absence of experimental data, use the values given in Table 1.

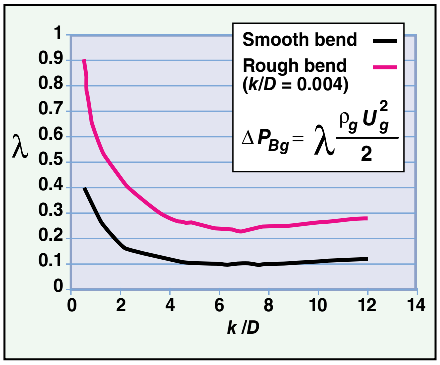

FIGURE 9. Shown is the effect of bend geometry and internal pipe roughness on the number of velocity heads (λ) for bend pressure drop

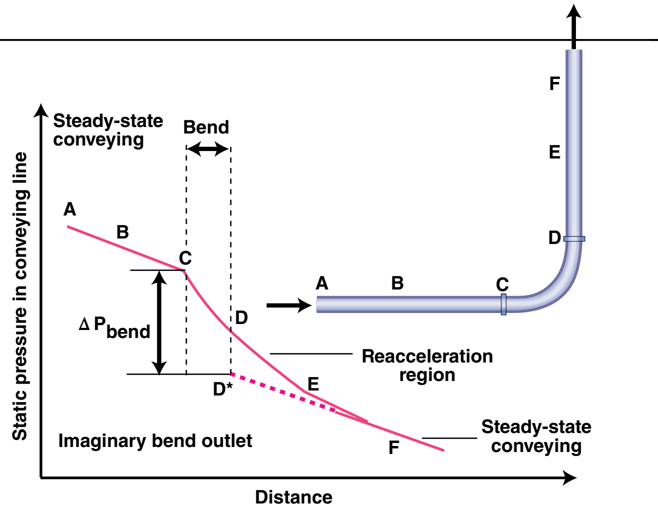

FIGURE 10. This static pressure profile in a bend region shows the pressure gradient in the bend and in the reacceleration region

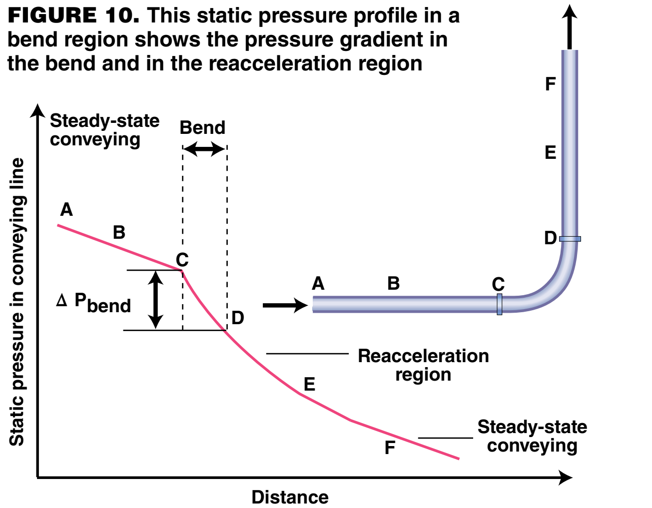

FIGURE 11. Bend pressure drop is often improperly measured (as described in the text)

$$\Delta P_B = B(1+\mu)\frac{\rho_g U_g^2}{2}$$

where,

ΔPB = Total pressure drop due to a radius bend
B = Bend loss coefficient
μ = Solids loading (mass of solids / mass of conveying gas)
ρ_g = Gas density at bend location
U_g = Superficial gas velocity at bend location

Equivalent-length approach. An alternate approach to represent the pressure drop due to a bend is to quote an equivalent length of straight section that would result in the same pressure drop as the bend in question. The total effect of bends on system pressure drop can be estimated by multiplying the number of bends by equivalent length, and adding it to the total length of straight sections (horizontal and vertical). An equivalent length of 20 ft (6 m) is a good first guess. This approach is practical and easy but difficult to generalize for new materials.

Qualitative comparison of bend pressure drop. Combining published data and practical experience, we have compiled a ranking for various types of available bends based on pressure drop characteristics (Table 2). It should be noted that several studies suggest that there is no difference in pressure drop resulting from tee bends and short-radius elbows. Also, excess pressure drop in long-sweep bends may be attributed to their greater overall physical length.

Various factors affecting bend pressure drop have been summarized in Table 3.

It is important to consider the pressure drop contribution of the bends in the perspective of the overall system pressure drop. The total contribution of bends to the overall system pressure drop will depend on the number of bends per unit length. If their contribution is relatively small, then replacing one type of bend with another will make little difference to the overall pressure drop (or on the conveying capacity). One must then select the bends based on other attributes.

Despite numerous studies on bends and the presence of large amounts of operating data, why do we still have confusion and disagreements on pressure drop that is attributable to various bend geometries (as shown in Figure 12)?

Various reasons can be cited:

- The techniques for measurement and data analysis are not standardized. Some studies use the static pressure profile approach described above, while others estimate pressure drop due to bends by swapping one bend type with the other
- It is not possible to critically evaluate all the studies since details are not always available
- Most studies are done on systems with multiple bends. The effect of location and interaction between numerous bends due to insufficient straight sections between them is a common problem
- It is difficult to generalize the results since individual studies often focus on few materials and limited range of operating conditions (e.g. solids loading, gas velocity, orientation)
- Large-scale test data sets are very few. Most studies are conducted on pilot-scale systems

Method 2. Evaluating attrition or particle degradation

The attrition or degradation of materials during pneumatic conveying is a significant concern to the industry. Attrition generally refers to the formation of "unwanted" fractions or species in the conveyed material, which may adversely affect its value.

Attrition or product degradation can manifest itself in various ways:

- Change in particle size and shape distribution
- Surface abrasion of particles resulting in a loss of gloss
- Degradation of product due to impact heating
- Smearing on the wall, which can result in cross-contamination
- Undesirable loss of surface coating or additives

Generation of fines due to breakage, chipping or surface abrasion can also

TABLE 1. EFFECT OF BEND RADIUS ON BEND LOSS COEFFICIENT (B)

R_B / D	B
2	1.5
4	0.75
>/= 6	0.50

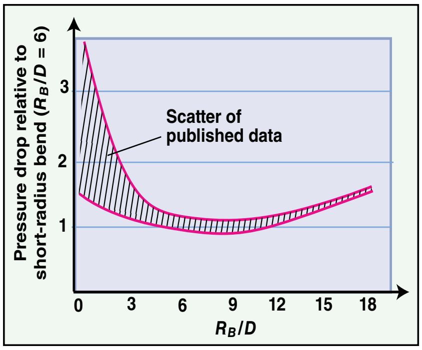

FIGURE 12. Shown here is the effect of bend curvature on pressure drop in pneumatic conveying bends

TABLE 2. COMPARISON OF PRESSURE DROP CHARACTERISTICS

Bend type	Ranking for pressure drop
Long sweep	Highest
Blind tee	I
Vortice Ell or Hammertek Smart Elbow	I
Mitered bend	I
Gamma™ bend or Pellbow™	V
Short-radius and long-radius bend	Lowest

TABLE 3. FACTORS AFFECTING BEND PRESSURE DROP

Factor affecting bend pressure drop	Effect on bend pressure drop with increase in value of factor
Gas velocity at bend inlet	↑
Solids flowrate (at constant gas velocity)	↑
Particle elasticity	↑
Particle size	↓
Pipe roughness	↑
Radius bend: R_B / D (0 - 24)	↓ (R_B/D </=12) ↑ (R_B/D >12)

create downstream processing issues, such as dusting, poor flowability and increased caking tendency. It may also lead to increased potential for dust explosion or increased exposure to respirable dust.

During pneumatic transport of bulk solids, particles undergo multiple impacts on the pipe wall, especially at the bends. The key parameters affecting particle attrition during pneumatic conveying are summarized below.

Process-related factors:

- Mode of conveying (dense vs. dilute phase)
- Gas velocity or particle velocity
- Solids concentration (or solids loading)
- Temperature of gas and solids (coupled with material properties)
- Conveying distance
- Materials of construction of straight pipeline sections and bends
- Surface finish of pipeline and bends
- Number of bends (change in direction)
- Bend geometry and flow pattern at the bend

Material-related factors:

- Particle size
- Particle shape
- Particle strength or modulus or Vicker's hardness
- Elasticity of particles
- Breakage function of material
- Attrition and degradation issues impact bend performance in several ways:

Attrition in tee bends will be low if the primary mechanism of breakage is particle fracture due to impact loading. In tee bends, the particles are essentially impacting on a loose bed of accumulated material, which acts like a cushion. However, if the process conditions do not result in the formation of a suitable bed (i.e., the stream velocity is too high, or solids loading is too low), then particle attrition can still be significant

- Attrition in short-radius bends or elbows is generally high due to impact on the bend wall
- Attrition in long-radius bends or long-sweep bends can be high if chipping or surface abrasions are primary mechanisms. Multiple impacts or ricocheting inside the bend can aggravate the problem
- Attrition in specialized transition designs, such as the Gamma Bend, or Pellbow (discussed above), tends to be low, as long as material accumulation occurs in the transition cavity. Overall performance will depend on the orientation of the bend

The specific definition of attrition varies with the application and the product being conveyed. For agricultural products, attrition may refer to damaged or split grains, whereas for polymer pellets, attrition often manifests itself in terms of the formation of polymer dust or chips during conveying.

Based on our experience, we recommend the following measures to mitigate attrition in existing pneumatic conveying systems:

- Reduce conveying velocity or increase the solids-loading ratio
- Reduce the number of bends by simplifying the line layout wherever possible
- Replace bends with designs that are less prone to attrition

Method 3. Evaluate erosion at the bends

Each time the particles impact the pipe and bend walls, energy is transferred to the point of impact. Depending on the comparative strength of particle and wall materials, either the particle is damaged (attrition) or the pipe/bend wears out.

There are numerous ways to quantify and analyze the wear data. For instance, In research studies, wear may be characterized by *erosion rate* (total mass of bend eroded), *specific erosion rate* (mass of bend eroded per unit of mass of conveyed material), *penetration rate* (depth of penetration per unit mass of conveyed material) and *bend life* (time required to lose containment).

While the conclusions reached depend on the applied metric, there is general agreement that the major factors associated with erosion in bends are:

- *Bend geometry*: Affects the number and location of impact zones
- *Orientation*: Affects the location of impact zones
- *Flow pattern inside bend*: Determines the penetration rate and uniformity of wear
- *Material of construction (hardness):* Erosion rate is inversely proportional to the hardness of bend material
- *Particle hardness*: Erosion rate is proportional to particle hardness
- *Particle size and shape*
  - † Specific erosion rate increases with particle size until a critical particle size, then the rate does not change
  - † Bend failure due to penetration occurs faster with smaller size particles
  - † Angular particles will increase erosion rate
- *Conveying velocity*: The specific erosion rate is a strong function of gas velocity ($U_g^{(2.5 \text{ to } 4)}$)
- *Particle concentration*: Significant reduction in specific erosion rate occurs at higher particle concentrations (due to greater cushioning effect)

TABLE 4. COMPARISON OF BENDS		
Bend type	**Advantages**	**Disadvantages**
Blind tee	• Low cost • Erosion / wear resistant • Short turn radius; compact design • Easy to retrofit • Low particle attrition (no chipping or surface abrasion)	• High pressure drop • Not suitable for moist, cohesive or sticky materials • May result in cross-contamination if the pocket does not clean
Blind radius bend	• Better erosion resistance than radius bend	• Same as blind tee • Secondary impact (wear) zone on the inner radius
Blind lateral	• Better erosion resistance than blinded radius and significantly better than radius bends	• Same as blind tee
Mitered bend	• Short turn radius	• High particle attrition (due to particle impact breakage) • Not suitable for moist, cohesive or sticky materials
Elbow ($R_B/D < 3$)	• Short turn radius	• High particle attrition (due to particle impact breakage) • Not suitable for moist, cohesive or sticky materials
Radius bend: Short radius ($R_B/D = 3 – 7$)	• Available in various materials of construction and radius • No accumulation in the bend – less chances of cross-contamination • Pressure drop comparable to long radius bend	• High product degradation / attrition due to impact • Low wear resistance
Radius bend: Long radius ($R_B/D = 8\text{-}14$)	• Available in various materials of construction and radius • No accumulation in the bend, so less chance of cross-contamination • Pressure drop comparable to short-radius bends	• Extended particle contact on the pipe wall can result in smearing (e.g. streamers with polyethylene pellets) • Erosive wear on ductile materials due to low impact angle • Large space requirements
Radius bend: Long sweep ($R_B/D = 15 – 24$)	• Available in many materials of construction and radius dimensions • No accumulation in the bend, so less chance of cross-contamination • Highest pressure drop among bends	• Extended particle contact on the pipe wall can result in smearing (e.g. streamers with polyethylene pellets) • Erosive wear on ductile materials due to low impact angle • Large space requirements
Radius bends with liners	• Longer wear life than comparable bends • Liner material can be chosen to minimize abrasion, and thus minimize product contamination • No accumulation or cross-contamination • Suitable for high-temperature applications	• High cost • Difficult to replace • Could be heavy and may need additional line support
Radius bend with wearable backing	• Less expensive than lined bends • Easy to replace wearable backing • Easy to maintain	• Potential for product contamination due to wearable backing • Difficult to predict failure • Potential for spillage
Radius bend with internal baffles	• Erosion / wear resistant • More expensive than conventional bends	• Higher pressure drop • Not suitable for moist, sticky or cohesive materials • Cross-contamination
Short-radius bends with pocket for material (Vortice Ell, Hammertek Smart Elbow, Pellbow™)	• Erosion / wear resistant • Short-turn radius • Generally low particle attrition • The pocket will clean out when flow stops • Low noise	• Higher cost than radius bends and blind tees • Pressure drop comparable to blind tees • Not suitable for moist, sticky and cohesive materials
Transition designs (mitered, expansion-cavity and flow-redirection, such as the Gamma ™ bend)	• Short turn radius, good for layout • Low particle attrition (no chipping or surface abrasion) • Prevents streamer generation during conveying of plastic pellets; unlike radius bends, does not requre treatment (shotpeening) to prevent streamers • Self cleaning • Erosion/wear resistant if a stable material layer can be formed • Low noise	• Higher cost • Pressure drop slightly higher (20-40%) than short-radius bends • Minimum solids loading ratio 5:1 (solids:air) recommended for proper operation; depends on the bulk density of material
Rubberized or flexible bends	• Excellent for soft sticky powders to prevent buildup • Good wear resistance	• Potential for product contamination due to wearing of the rubber lining

From a wear standpoint, bends can be classified into three groups:

Class I (Most resistant to erosion): Blind tee, Vortice Ell or Hammertek Smart Elbow™, Pellbow™, Radius bends with abrasion-resistant liners, wearback designs

Class II (Medium resistance to erosion): Mitered bend, Gamma™ bend, Long sweep

Class III (Very susceptible to erosion): Common-radius bends (short and long)

It should be noted that significant wear can sometimes be observed in the straight section downstream (up to 10 pipe diameters) of a bend depending on the flow pattern within the bend.

The impact of bend location

Regardless of the type of conveying system (pressure or vacuum) or the mode of conveying (dense or dilute phase), *the pressure always decreases from pickup location to destination.* As dictated by the Ideal Gas Law, the gas velocity will proportionally increase from pick up location to the destination (see Figure 13). Therefore, any bends located toward the end of the conveying system will experience velocities (gas and particle) that are higher than those closer to the pickup location.

TABLE 5. BEND SUITABILITY BASED ON MATERIAL CHARACTERISTICS

Bend type	Cohesive or sticky or moist	Fragile or friable solids	Hard and abrasive solids	Soft and rubbery solids	Product purity required / no cross contamination
Blind tee	NS	S*	S	NS	NS
Blind radius bend / blind lateral	NS	S	S	NS	NS
Mitered bend	S	NS	S	S	S
Elbow (R_B/D < 3)	NS	S	NS	S	S
Radius bend: Short radius (R_B/D = 3 - 7)	S	NS	NS	S	S
Radius bend: Long radius (R_B/D = 8-14)	S	S	NS	S	S
Radius bend: Long sweep (R_B/D = 15 - 24)	S	S	NS	S	S
Radius bends with liners	S*	NR	S	S	S
Radius bend with wearable backing	S	NR	S	NR	NS
Radius bend with internal baffles	NS	NS	S	NS	NS
Short-radius bends with pocket for material (Vortice Ell, Hammertek Smart Elbow)	NS	S	S	S	S
Transition Designs (Mitered, expansion-cavity and flow-redirection (Gamma Bends and Pellbow)	S	S	S*	S	S
Rubberized or Flexible Bend	S	S	S	NR	S

S = Suitable NS = Not Suitable
S* = Suitable under limited conditions NR = Not Required

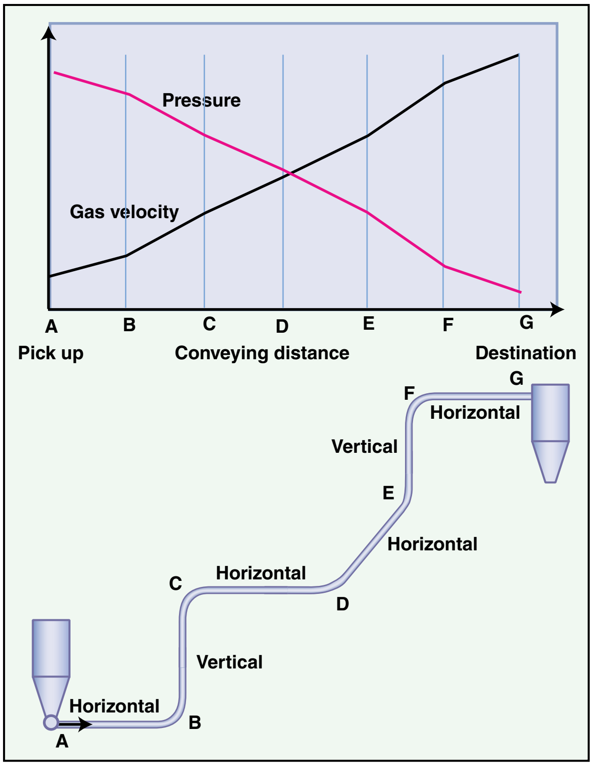

FIGURE 13. Gas velocity increases as the pressure in the system decreases from pickup to destination. The local gas velocity at each bend will depend on its location

Since pressure drop, attrition and erosion are all strongly affected by gas and particle velocity, bends that are of similar geometry but located toward the end of the system will incur higher pressure loss, and thus will experience greater attrition and wear. It should be noted that the solids loading (mass of solids/mass of air) in the entire system remains constant, and does not depend on the location.

The increase in gas velocity (from pick up to destination) is greater when the system is operating in pull mode (vacuum system) versus push mode (pressure system). A simple set of calculations (assuming isothermal conditions), shown below and referring to Figure 13, highlights the point.

As can be seen, the velocity at the exit (at location g) for a vacuum system is 42% higher than that for a pressure system. Therefore, a higher level of attrition and wear can be expected in a vacuum system, as compared to that expected in a pressure system with similar layout and overall pressure drop.

Pressure system (push mode):
Conveying pressure (at location a)
= 8 psig (55.1 kPa gage)
Pick up velocity (at location a)
= 4,000 ft/min (20.3 m/s)
Pressure in the destination receiver
= 0.05 psig (0.35 kPa gage)
Velocity at the exit (at location g)
= 6,177 ft/min (31.4 m/s)
Vacuum system (pull mode):
Conveying pressure (at location a)
= 0 psig = 14.7 psia (101.3 kPa abs)
Pick up velocity at location a)
= 4,000 ft/min (20.3 m/s)
Pressure in the destination receiver
= - 8 psig = 6.7 psia (46.2 kPa abs)
Velocity at exit (at location g)
= 8,776 ft/min (44.6 m/s)

Selection of bends

The following key issues must be considered while selecting bends for pneumatic conveying applications:

1. Type of conveying: Dilute- versus dense-phase
2. Product characteristics
   a. Particle size and shape
   b. Particle hardness (erosive wear)
   c. Friability (attrition) or fines generation
   d. Cohesive / stickiness
3. Process requirements
   a. Free of cross-contamination
   b. Minimization of pressure drop or power consumption
   c. Layout constraints
   d. Consequences of wear or material leakage to environment
   e. Minimize fines generation or product degradation
   f. Materials of construction
   g. Minimize downtime (frequency of replacement)
4. Industry-specific practices

The purchase cost of a bend and its geometry (which affects the layout of the process) has a direct impact on the cost of any pneumatic conveying project. It is prudent to consider the long term cost of ownership of a bend. For instance, a low-cost bend that results in product degradation or higher energy cost due to increase pressure drop will be more expensive in the long run.

Table 5 summarizes the suitability of competing bends, based on product characteristics.

Installation guidance

By following these recommendations, process operators can minimize problems with pneumatic conveying systems.

- Minimize the number of bends in the transfer system
- Do not install a long-radius bend (horizontal to vertical) within 20 feet of the pick up location
- Back-to-back bends are not advisable. Avoid three bends in close proximity, if possible

- More bends toward the end of the transfer will increase pressure drop, erosion and attrition. Consider directional changes earlier in the layout, if possible. Consider stepping up the line size, if the pressure ratio permits, to minimize the velocity toward the end of the system
- Misaligned bends will increase attrition and wear
- Install critical bends such that they can be easily serviced (accessible and replaceable)
- Consider insulating pipe and bends when noise is an issue (esp. indoors) or select appropriate type of bends. For outdoor installations, insulation can reduce the tendency of the material (e.g. plastic pellets) to smear inside the bend
- Pay close attention to the direction of flow in specialized bends during installation

Final thoughts

Bends are a critical aspect of any pneumatic conveying system layout, and selection of the most appropriate bend configurations is a critical aspect of system design and operation. Improper selection of bends can result in conveying capacity limitations (due to excessive pressure drop), high product degradation/attrition, and high wear rates, which can create additional maintenance, safety and environmental issues.

Optimal longterm cost of ownership can be achieved if the product characteristics and process constraints are more appropriately matched. A thorough evaluation often reveals that specialized bends may not be the best option.

Available information on pipe bends in the open literature can be confusing, and these findings often conflict with field experience. Industry need to continue studying various aspects of pneumatic flow using modern tools for flow visualization and computational fluid dynamics for modeling. ■

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