Introduction to Pneumatic Conveying of Solids

Karl Jacob
The Dow Chemical Company
Engineering Sciences/Solids Processing
Midland, Michigan
jacobkv@dow.com

Goals for this webinar

- Understand various modes of conveying of solids
- Learn how to decide on conveying configuration
- Examine key aspects of design of conveying systems
- Recognize the various conveying system components
- Learn how to approach common conveying problems

What is pneumatic conveying?

Pneumatic conveying is the movement of solids through pipe using gas (usually air) as the motive force.   It differs from hydraulic or slurry conveying in that the gas expands continuously along the pipe length. The flow regime in the pipe depends greatly on the ratio of solids to gas and the particle characteristics.

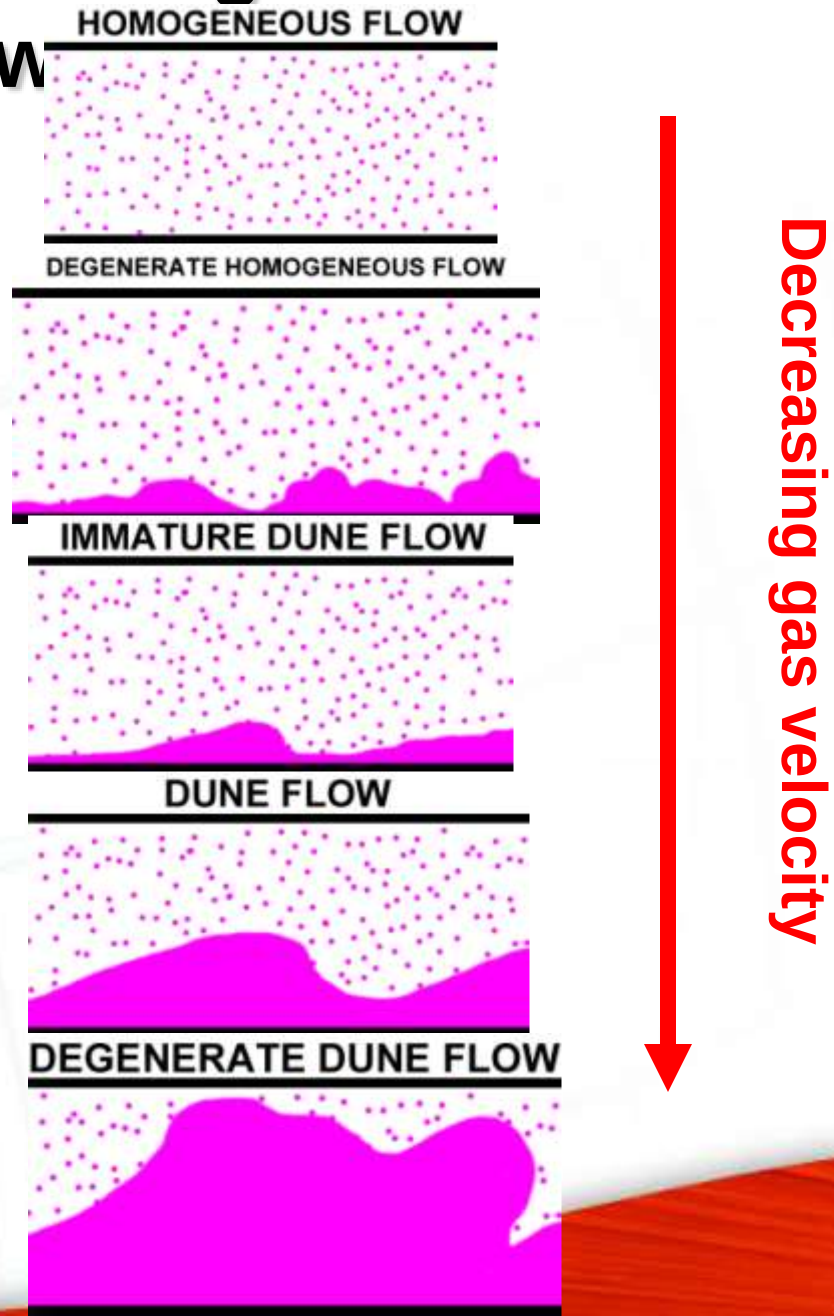
Why use pneumatic conveying to move bulk solids?

- With the appropriate choice of system, material can be transported with minimal degradation
- Little or no exposure of the product to the environment
- Can transport relatively long distances (several thousand feet)
- Excellent for multiple sources and multiple destinations
- Ability to transport material which might be air, moisture, etc. sensitive
- Compared to mechanical conveyors, relative ease in system routing especially elevation changes
- Interfaces well with a variety of transportation modes – truck, railcars, ships
- High reliability of system with comparatively few moving parts

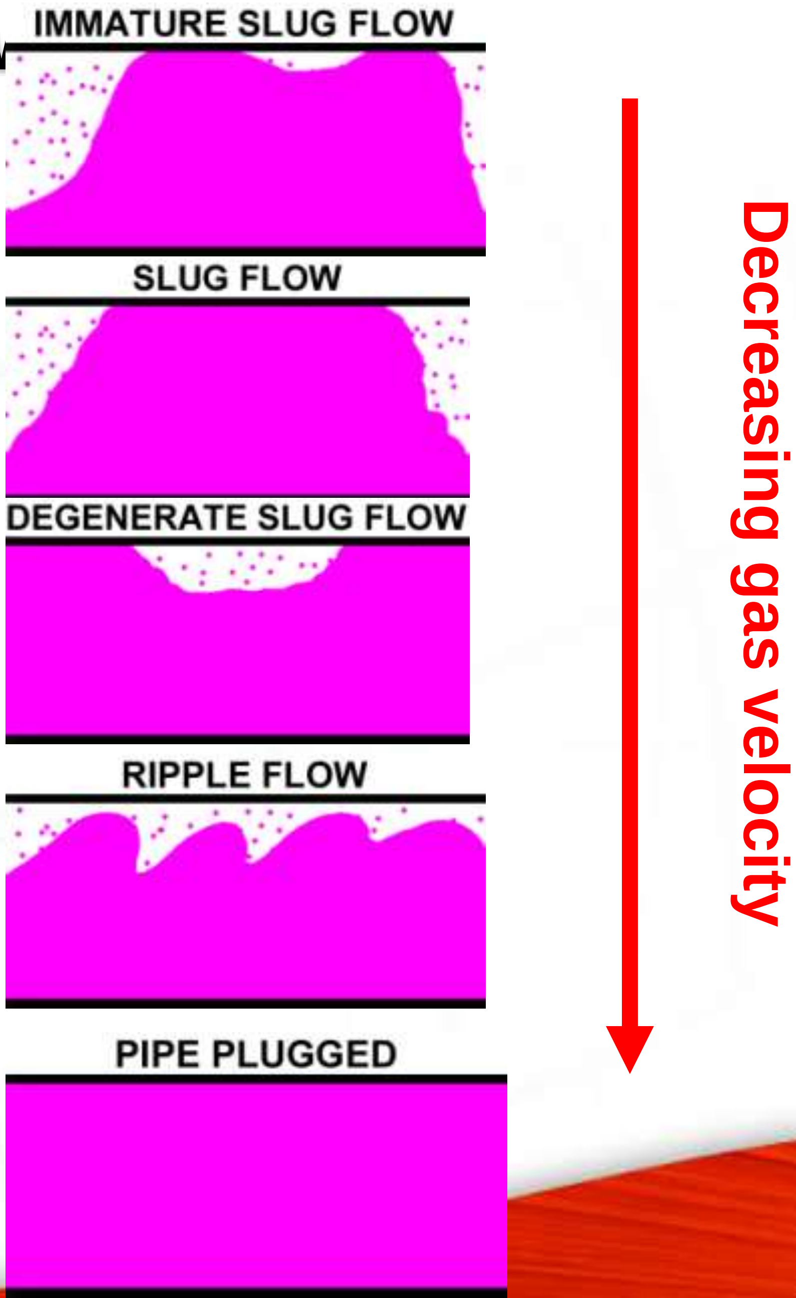
Potential disadvantages

- Product degradation as a result of incorrectly designed system
- Pipe/component wear
- Not suitable for long distance (beyond a few thousand feet) conveying – it is difficult to overcome the gas expansion issue!

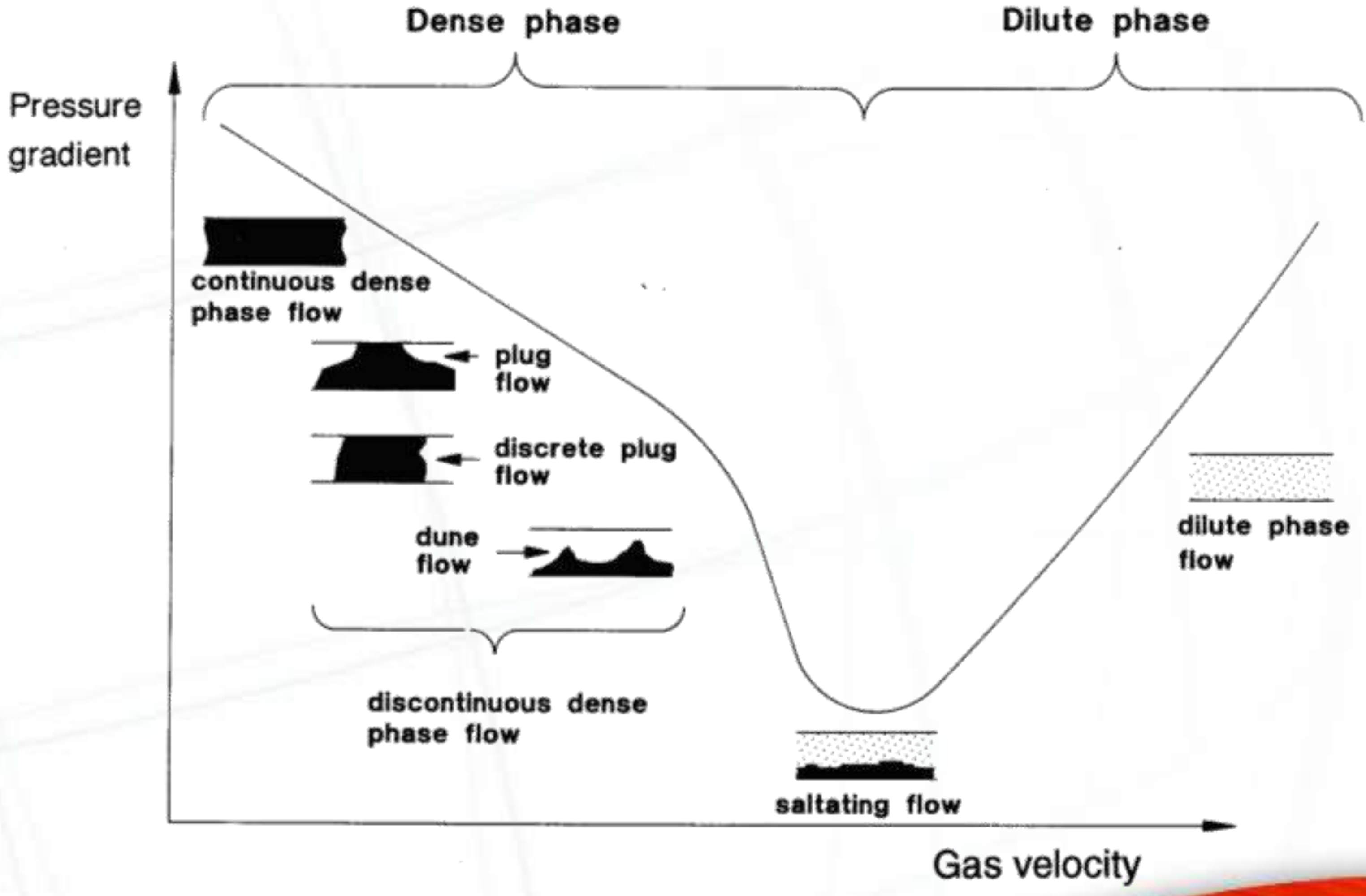
Conveying Flow Regimes
Horizontal Flow



Conveying Flow Regimes
Horizontal Flow



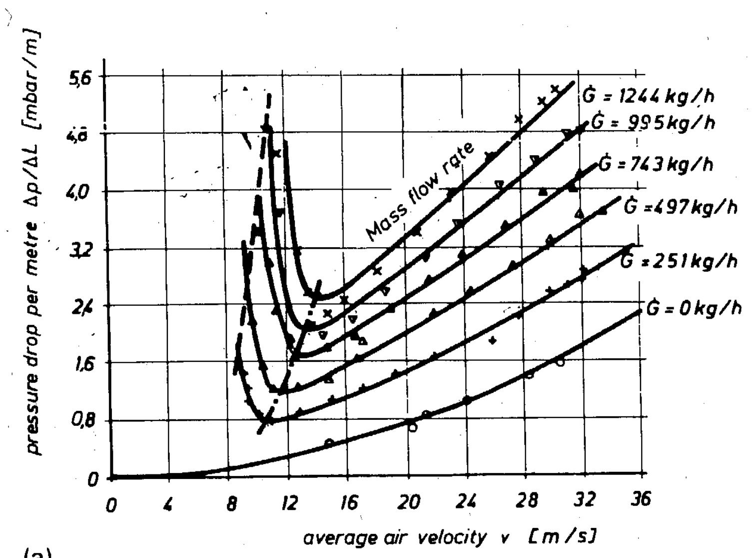
Pneumatic Conveying Phase Diagram



Dense phase vs. dilute

- Dense phase
  - Low velocity
  - Low attrition
  - High pressure
  - Comparatively high cost
  - Small pipe size
  - High loadings
- Dilute phase
  - High velocity
  - Can have very high attrition
  - Pressure typically < 15 psig
  - Low cost
  - Larger pipe size
  - Low loadings (<10)

Actual Phase Diagram - Styropor



(a)

Material: Styropor (BASF)

d_p = 2.385

ρ_p = 1050 kg/m3

D = 52.6 mm (SS)

From Pneumatic Conveying of Solids, Marcus, et. al.

Basic design issues

- Number of sources and destinations? This is usually determined by plant conditions.
- Dense phase vs. dilute phase?
- Push vs. pull?

Addressing each of the above questions will largely dictate the type of system that needs to be designed.

Push vs. Pull

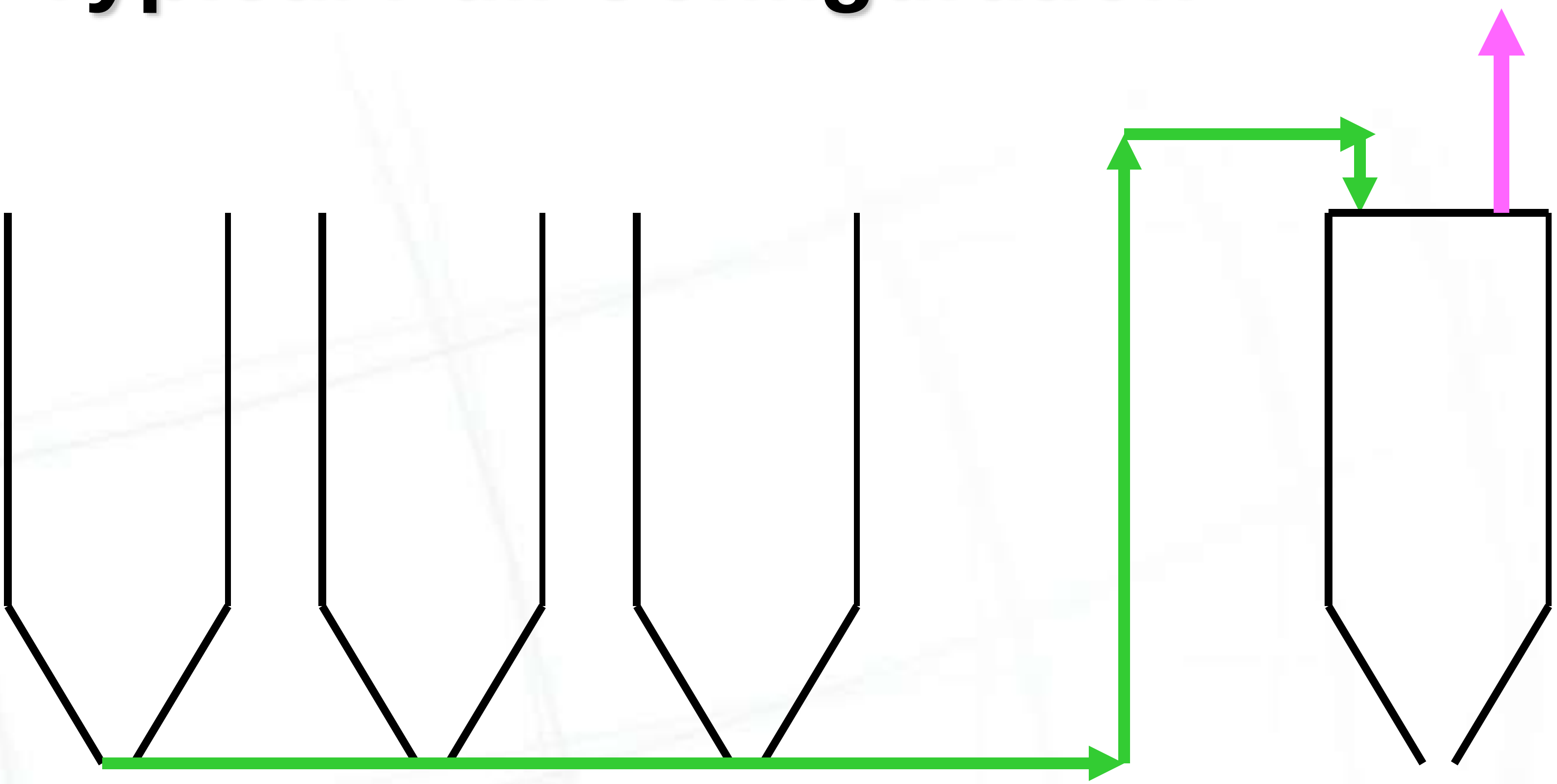
- Push – generally a pressure system operating above atmospheric pressure
- Pull – a vacuum system operating below atmospheric pressure - ~ 7 psia is practical lower limit

- Choice of push vs. pull depends greatly # of sources and destinations – some configuration

Push vs. Pull Selection Guide

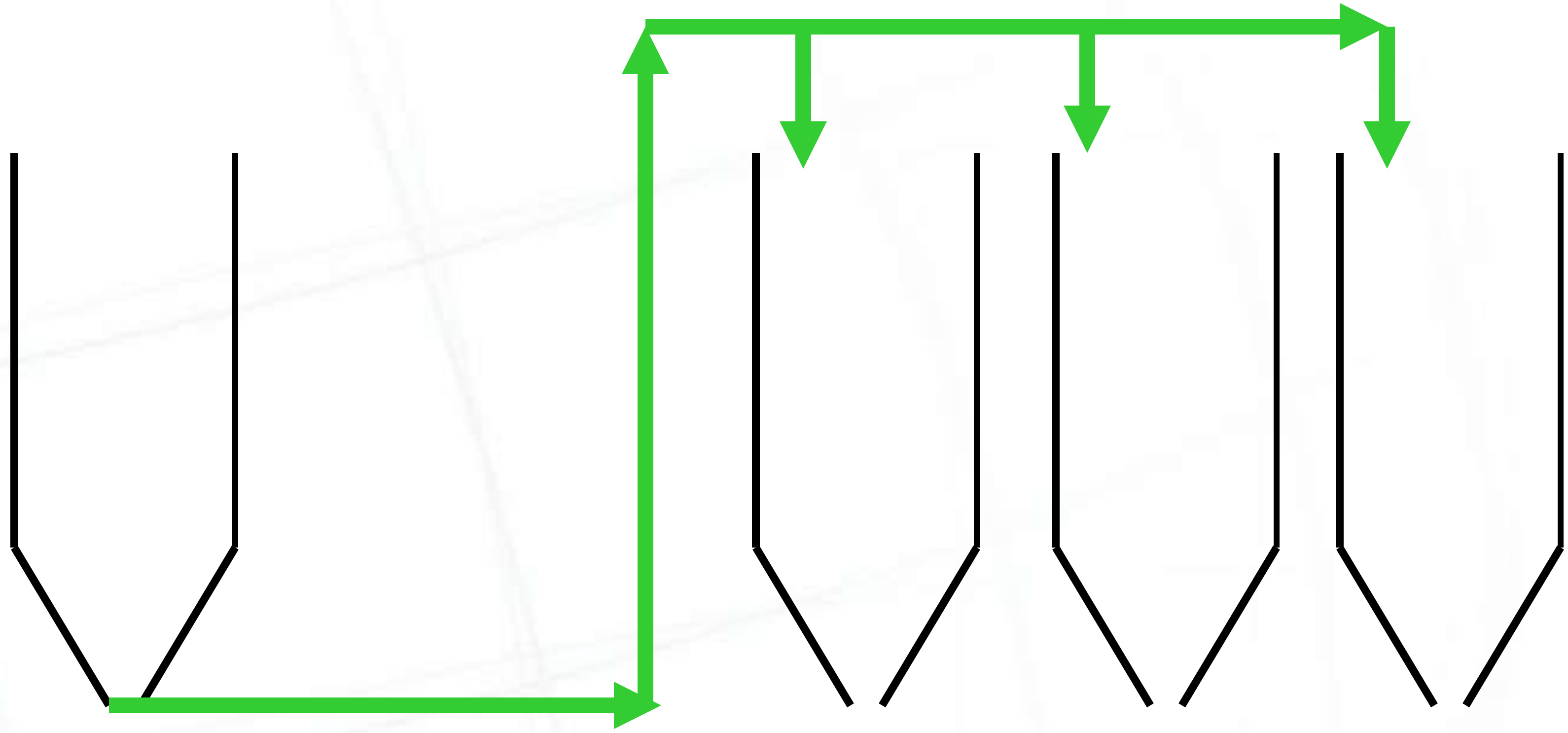
# of sources	# of destinations	Vacuum or pressure system?
1	1	either
1	Many	Pressure preferred
Many	1	Vacuum preferred
Many	Many	either

Typical Pull Configuration



Key design issue is to insure that you can pull from the “longest” pipe configuration!

Typical Push Configuration



In parallel to the pull system, it is important that the system be designed to be able to handle the required conveying rate to the furthest destination.

Conveying Fundamentals

- In contrast to fluid flow with liquids, the conveying gas expands along the length of the pipe and that has a considerable effect of the design and operation pneumatic conveying systems
- Contributions to pressure drop in a conveying system
  - Head loss due to elevation change
  - Solids acceleration
  - Gas friction loss
  - Solids friction loss
  - Bend or elbow or fitting loss

Dilute phase pressure drop

$$\Delta P_{total} = \Delta P_{accel} + \Delta P_{lift} + \Delta P_{bends} + \Delta P_{air} + \Delta P_{solids}$$

Each component of pressure drop can have a significant impact on conveying system performance

Examples

Conveying of rubber – high solids friction

Conveying of elastic materials – always accelerating

Truck unloading – high lift component

Tortuous conveying path – high bend pressure drop

Pressure drop due to air

- In this particular case, we use the conventional friction factor formulation we learned in fluid mechanics
- If the conveying line is operated as “air only”, then this number is relatively easy to check with either a gauge or hand held manometer near the blower.
- Note that the gas density needs to be evaluated at each point in the pipe – consequently, design calculations usually are done by breaking the line into many small pieces.

$$\Delta P_{air} = \frac{f \rho_g L v^2}{2D}$$

Pressure drop due to particle acceleration

- The particles are required to accelerate after being introduced into the line – note that this is a one time effect in the calculation
- Here v and u_g are the particle and gas velocities respectively

$$\Delta P_{acc} = \mu v \rho_g u_p$$

Pressure drop due to lift

- Standard treatment here as we would expect

$$\Delta P_{lift} = \rho_p (1-\varepsilon)\Delta H g$$

ε is the voidage and for dilute phase systems will tend to be 0.99 or greater

Pressure drop due to bends

- **Bends are quite common in conveying systems and numerous correlations have been developed to calculate bend pressure drop**
- **Note that when measuring pressure drop in the field, it needs to be measured several pipe diameters downstream of the exit of the elbow to properly account for particle reacceleration after the bend.**

$$\Delta P_{bend} = \frac{B(1+\mu)\rho_g v^2}{2D}$$

B is a bend factor usually taken as being 0.5 for a long radius elbow

Pressure drop due to solids friction

- The solids friction component mirrors that of gas pressure loss except for now we have a special "solids friction factor"
- There are some existing correlations for λZ both in the vertical and horizontal direction
- The friction factor can also be determined from either pilot plant work or by careful analysis of a production plant

$$\Delta P_{solids} = \frac{\mu \lambda_Z \rho_g L v^2}{2D}$$

Note the impact of system loading on pressure drop!

Saltation

- When the gas velocity is slowly decreased during dilute phase conveying, material will begin to deposit or “salt out” at the bottom of horizontal sections of the conveying system.
- Saltation is loading dependent – typically the higher the loading, the higher the saltation velocity
- No single correlation predicts saltation across all gas and particle parameters
- For plastic pellet systems, Rizk’s equation has been found to work well
- Fine particle systems tend to have cohesion and so, although it seems somewhat counterintuitive, saltation velocity will increase a function of particle size. This effect is well described by the equation of Matsumoto (1977).

Saltation Equation - Rizk

Rizk's equation

$$\mu = \frac{1}{10^{\delta}} \left(\frac{v_s}{\sqrt{gD}} \right)^{\kappa}$$

where

μ is the phase ratio (kgs of solid/kg of gas)

v_s is the saltation velocity

D is the pipe diameter

$\kappa = 1.1d_p + 2.5$

$\delta = 1.44d_p + 1.96$

Note that the particle size, d_p, must be in millimeters!!!

How do we design a system?

- Select configuration – push vs. pull
- Determine preliminary layout
- Guess pipe/tube size
- Calculate saltation
- Estimate pressure drop
- Calculate volume of blower
- Select blower
- Calculate pressure drop – check if pressure drop, velocity and pipe size agree with estimates – if not, iterate based on initial solution

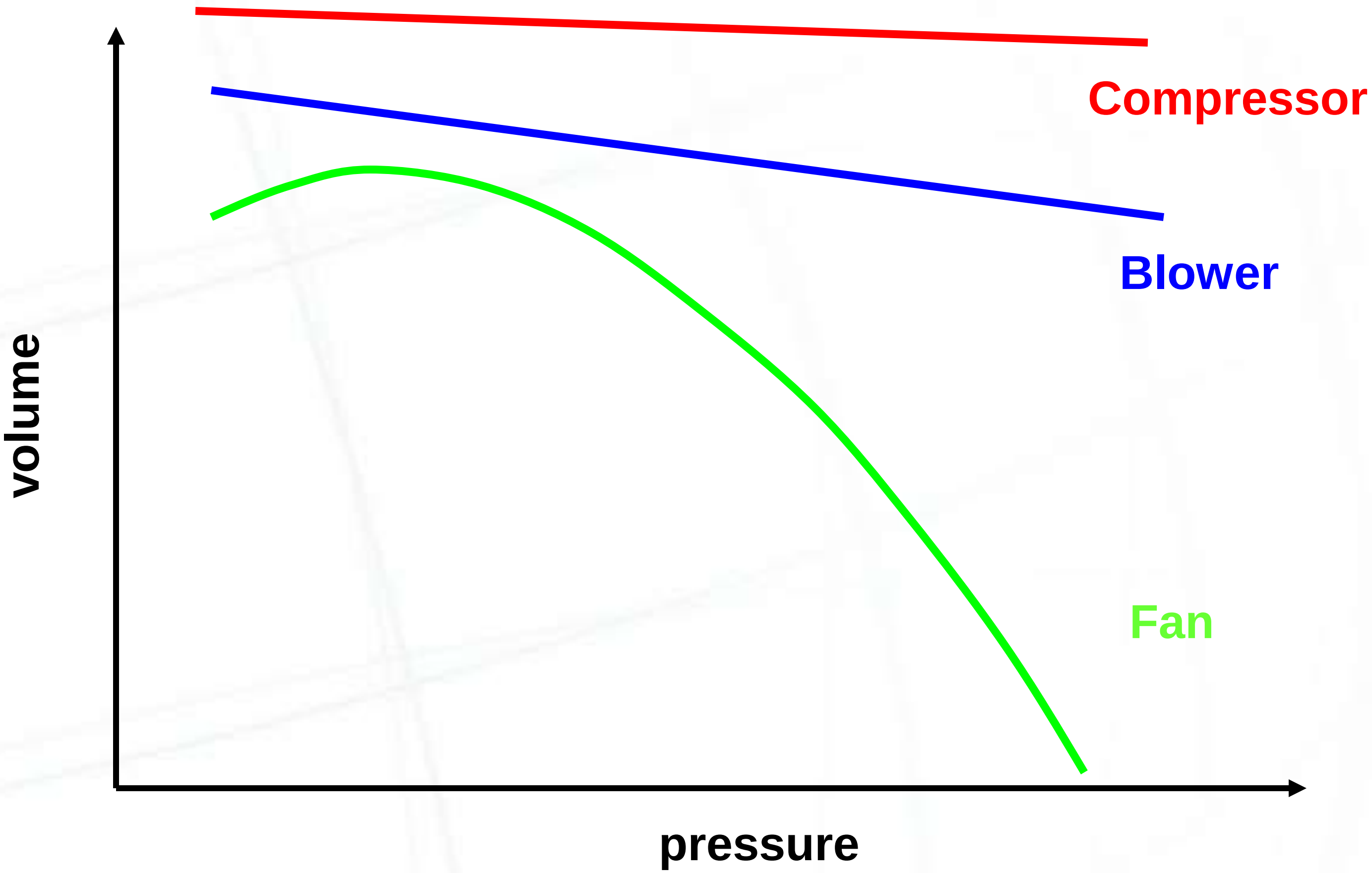
Conveying System Components

- Air Movers
- Feed systems
- Pipe/Tube
- Dust Collector
- Couplings/Flanges

Air Movers

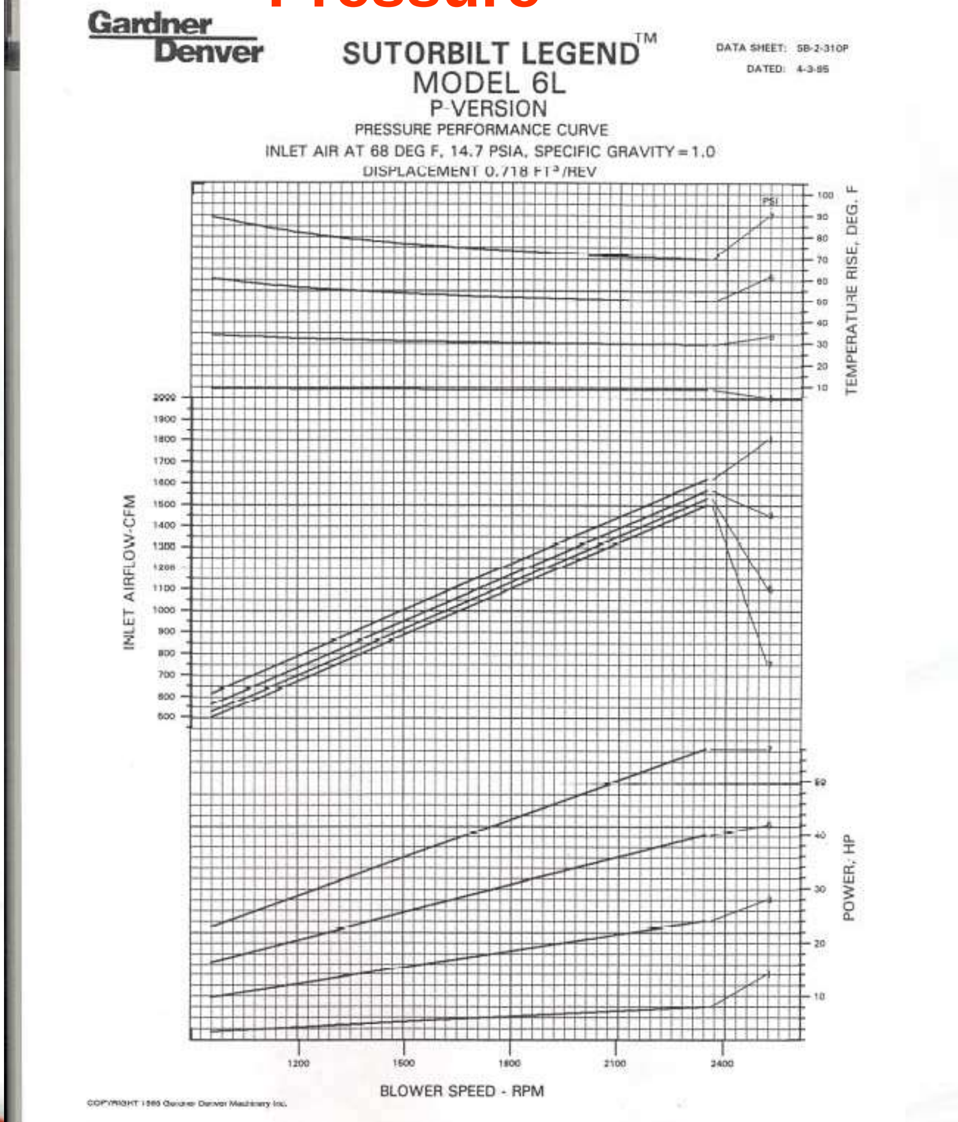
- Rotary Lobe Blowers – often called “Roots” blowers
- Fans
- Compressors

Typical air mover performance curves

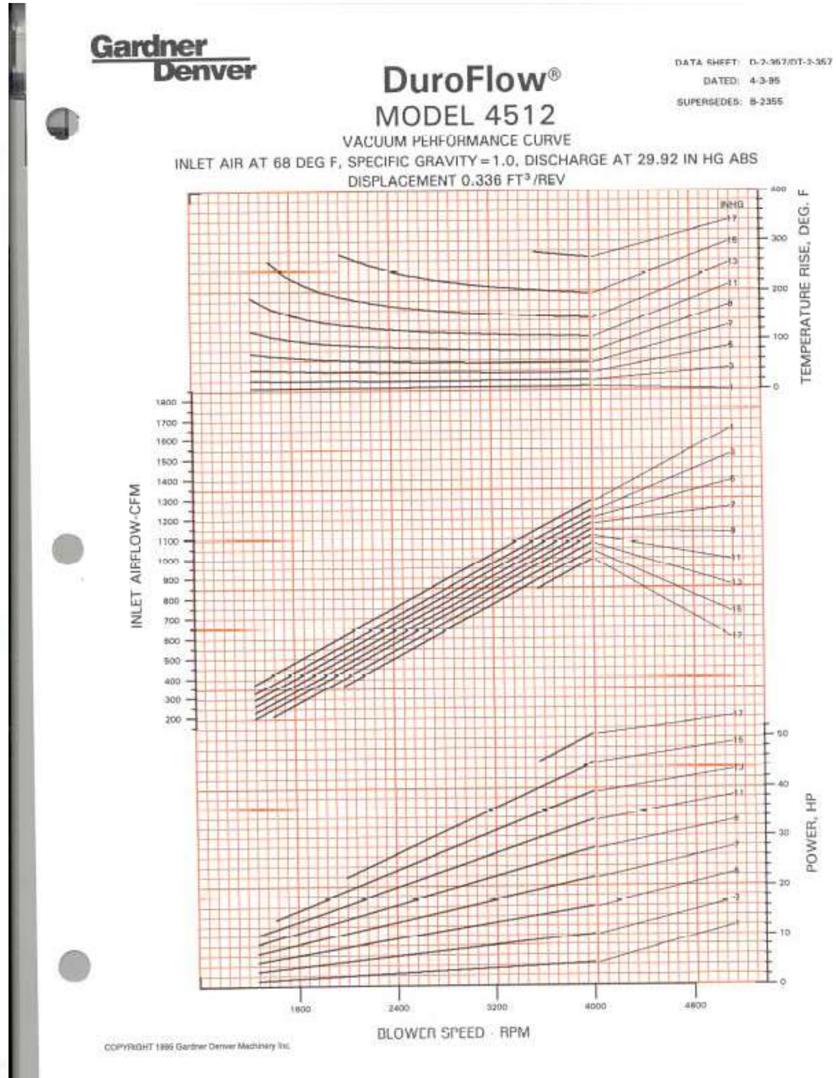


Lobe Blower Performance Curves

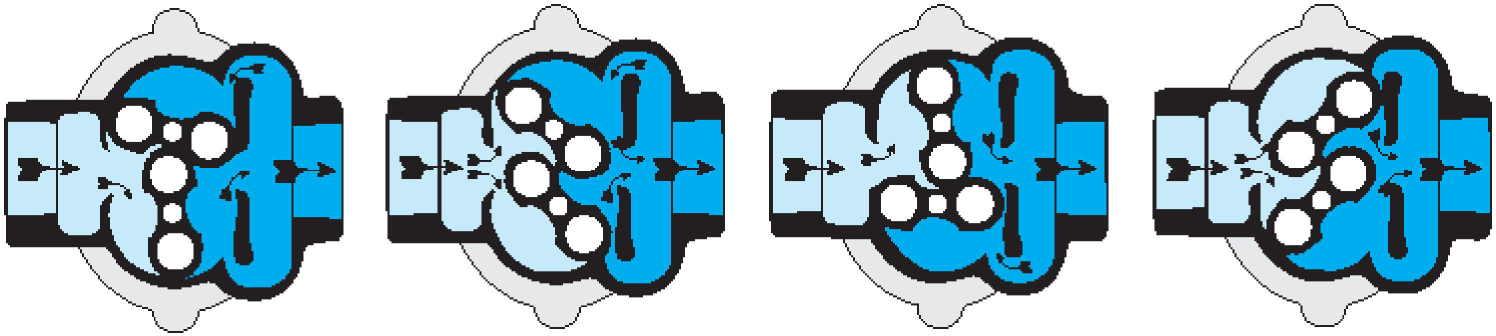
Pressure



Vacuum



Rotary Lobe Blower



These are true positive displacement devices.

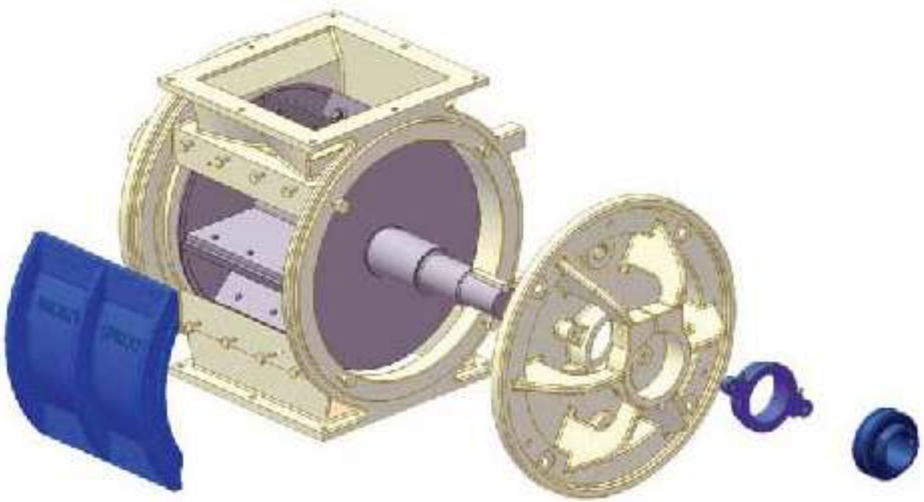
Some suppliers will provide a tri-lobe model in order to cut down on the pulsations in the flow.

Diagram from Roots

Common feed systems

- Rotary valve (also star valve) – the most common feeder used in conveying systems – considerable versatility – good turn-up/turn down
- Slide valves
- Screw feeder
- Double flapper valves
- Venturis
- Pneumatic wands

Rotary Valves



Typical cutaway view of a commercial rotary valve.

- Can be connected to fixed speed or variable speed drive
- Always need to be concerned about tip wear – typical new clearances are 4-6 mils
- Need to consider valve leakage during design – leakage can sabotage an otherwise well-designed system

http://www.andritzsproutbauer.com/airlock-rotary-valve.asp

Pipe & Tube

- Light gauge (Sch. 10) pipe or tube is routinely used for conveying systems
- Materials of construction include stainless steel, CS and aluminum
- Aluminum is frequently used in the conveying of plastics
- Particular attention needs to be given to bends/elbows where erosive wear can be an issue, even with soft products (e.g. polymers)
- With the wide selection of pipe and tube sizes, it affords the conveying system designer an excellent opportunity for optimal system design

Couplings/Flanges

- Couplings represent an inexpensive and easy choice for conveying system tube connections. They are typically used on tube systems and come in a variety of standard sizes. They are relatively easy to assemble/disassemble. However, if stressed laterally, they can be prone to misalignment.

- By comparison, flanges are used in pipe systems and commonly used on higher pressure (>15 psig) dense phase systems. A number of companies now sell self-aligning flanges which help to minimize off-grade particles and conveying system wear.

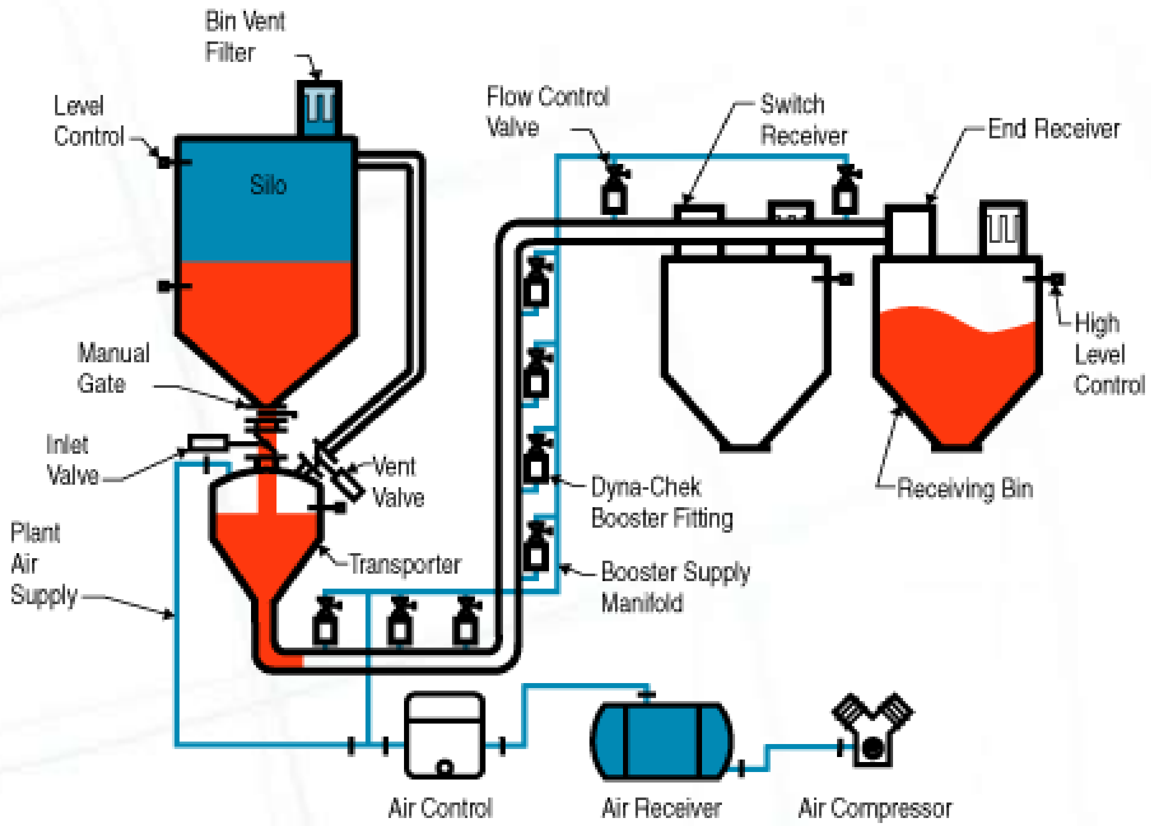
Dense phase conveying

- Dense phase is recommended when product attrition and product quality demands our utmost attention
- Typically is characterized by low velocity conveying
- Conveying mode depends greatly on particle characteristics
- Pressures in systems routinely between 1 and 6 barg
- A priori prediction of performance extremely difficult
- System performance is all about control of plugs of material
- Stresses due to large plugs in piping systems can be difficult to control

Conveying regimes for dense phase pneumatic conveying

- Three reasonably distinct conveying modes are observed when conveying bulk solids in dense phase
  - Large materials like plastic pellets will naturally form slugs of material in the conveying line interspersed between pockets of air
  - Medium sized granular materials (example 100-1000 μm) do not make well formed slugs in the line – the conveying is characterized by the formation and degradation of degenerate slugs in the line – some type of air assist is required to maintain slug control. Care must be taken that too much air isn't added to the line causing the system to be in dilute phase
  - Fine materials (<50 μm) will naturally form very long slugs in the line, consequently some sort of plug breaking mechanism must be installed in order that the pressure drop across the system does not become inordinately high

Boosters – Air Injection Systems



http://www.dynamicair.com/es/graphics/systems/conventionalfill.gif

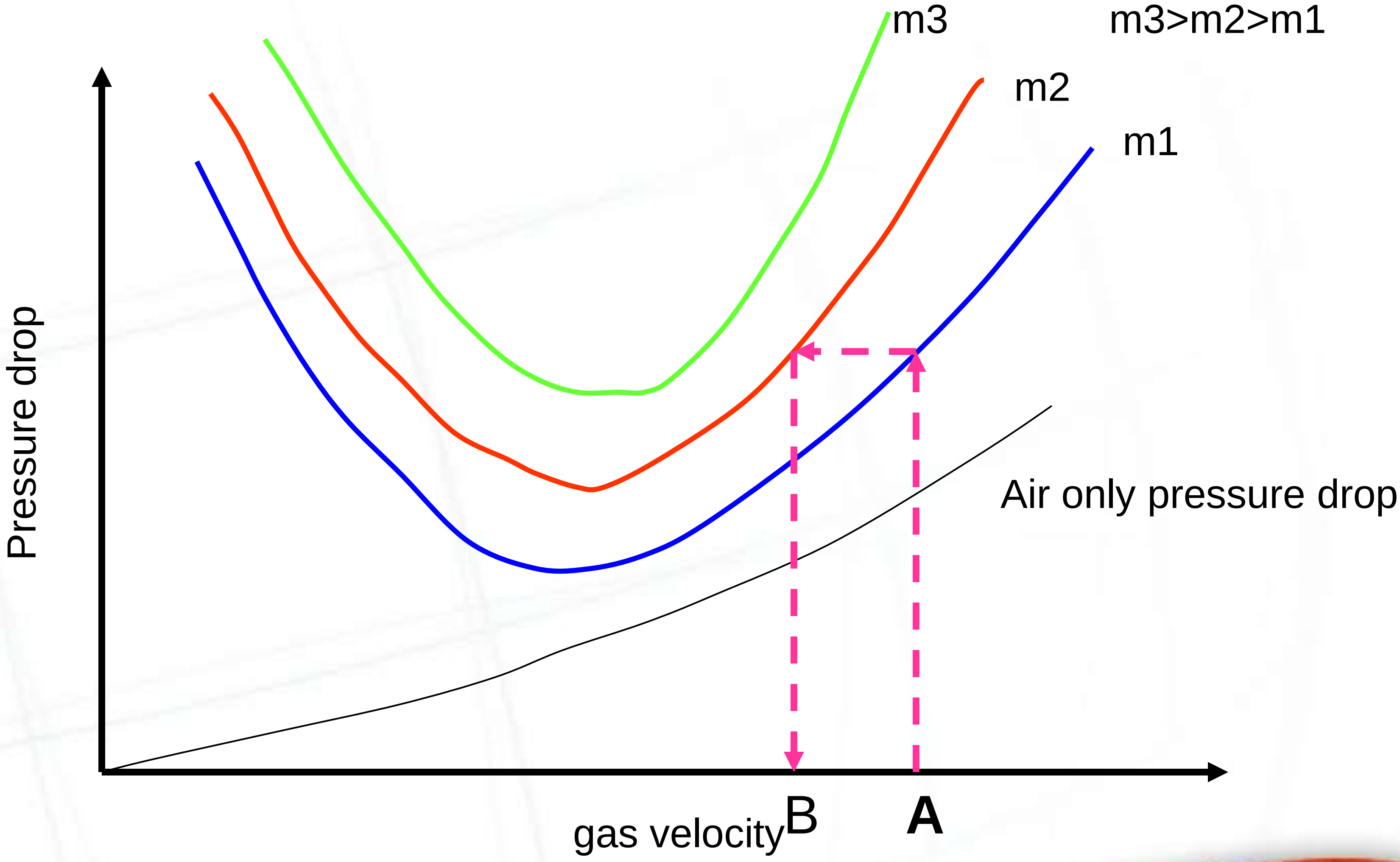
Commonly encountered problems

- Increasing conveying system throughput
- Attrition/floss formation/pipe erosion
- Line failure in dense phase systems
- Plugging due to poor layout

Increasing system throughput

- **Quite commonly, the capacity of a dilute phase conveying system needs to be increased. Take, for example, a system operating at ~12 psig, near the relief of the positive displacement blower. The velocity at the pick-up point (where the solids are introduced into the system) is 5000 fpm, well above the saltation velocity of 4000 fpm. What should she or he do?**

Phase Diagram



Attrition/Floss formation

- Attrition is a key issue in the conveying of solids and can lead to any of the following issues:
  - Poor product performance
  - Environmental, Safety and Health issues
  - Changes in the flow properties of material
- Polymeric materials can be problematic due to the formation of either dust or floss (also streamers or angel hair)
- The key in these situation is velocity control!! Typically attrition is a strong function of velocity. If the velocity in a dilute phase system can be reduced, this represents a legitimate option for reduction of attrition.

$$\textbf{Attrition } \alpha \textbf{ velocity}^{3\text{-}5}$$

Line failure in dense phase systems

- This can be a very SERIOUS issue.
- During the dense phase conveying, it is not unusual to see the line moving or vibrating as slugs make their way through the conveying line.
- Tremendous forces are encountered as a plug switches directions, particularly around horizontal elbows – example, in large systems it is not uncommon to see individual plug weights on the order of 500 lbs.
- These forces have been and can be very destructive (up to and including complete line failure)
- In this particular case, it is ***highly*** recommended to work with a reputable conveying supplier who understands the issues around this problem

Plugging due to line layout

- Often piping designers assume that conveying systems are just like conventional liquid and gas piping runs, consequently it is not unusual to have multiple elbows back to back
- The particles need some distance to reaccelerate
- Even though the system may be designed to be above the saltation velocity, the particle will simply fall out of suspension and the line will plug

- Two choices to fix this type of problem
  - Increase the gas flow – downsides are potential attrition and reduction in system throughput
  - Re-route the line – this is not always the most economical in the short term but represents the best solution to the problem

Poll Question

- We've had three webinars this year on various topics of solids processing/particle technology (introduction, bins and hoppers, pneumatic conveying).   Our next webinar is scheduled for January 19, 2011.   Which of the following topics would you most like to hear about next time (please vote for one)?

- Fluidization/fluid bed technology
- Gas solid separation (cyclones, dust collectors, bag houses, wet scrubbers)
- Classification of particles (screeners, air classifiers)

Summary

- With proper care and thought, pneumatic conveying systems can be designed and operated to give excellent performance with minimal product degradation
- There is considerable SCIENCE behind how these systems work

- Thanks for listening!!