SHAPA

SHAPA TECHNICAL PAPER 5

Understanding and Controlling Attrition and Wear in Pneumatic Conveying

DR MSA Bradley

Wolfson Centre for Bulk Solids Handling Technology
University of Greenwich

Understanding and Controlling Attrition and Wear in Pneumatic Conveying

Dr MSA Bradley
Wolfson Centre for Bulk Solids Handling Technology
University of Greenwich

Introduction

Article developed from a paper first published at a seminar entitled ***Successful Pneumatic Conveying*** *organised by the Institution of Mechanical Engineers in Coventry in February 1999*

Understanding and Controlling Attrition and Wear in Pneumatic Conveying

Dr MSA Bradley
Wolfson Centre for Bulk Solids Handling Technology
University of Greenwich

Introduction

Particle attrition, that is to say the breakage of particles in conveying usually leading to the generation of dust, and pipeline wear, usually at bends, may seem uneasy bedfellows in a single study. However, they are both caused by the same phenomenon, that is the impact of particles against the inside walls of the pipe. Consequently, the same measures are effective, in most cases, at controlling both.

This paper gives a review of the causes of these two problems, the consequences, and the techniques which may be applied to overcome them in a practical context.

1. THE PROBLEMS

Particle degradation is in most cases undesirable because it can result in

♦ Increased dust content in the product, in turn leading to
  ⇒ problems with dust emission in further handling and
  ⇒ poorer "handleability" of the material, e.g. hang-ups in hoppers, pipeline blockages etc.

♦ Structural damage to the particles, e.g. cracking the shell of grains leading to processing problems
♦ Increased breadth of particle size distribution, making segregation more severe
♦ Problems with customer perception of the product

Wear in pipelines is equally undesirable because it usually gives rise to

♦ Mess arising from spillage of material through punctures in pipes
♦ Unplanned maintenance in replacing bends and pipeline components
♦ Downtime on process (this is usually the biggest cost by far)
♦ Contamination of transported product with wear particles (usually iron, which causes "yellowing" of white materials)

Understanding and Controlling Attrition and Wear in Pneumatic Conveying

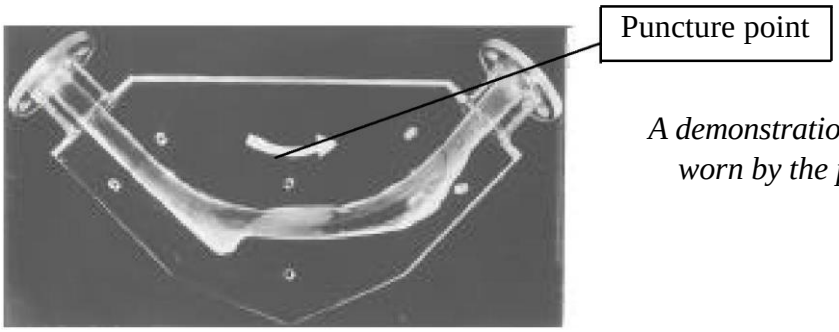

Fig. 1
A demonstration bend of solid clear acrylic, worn by the passage of alumina particles

Fig 2

Photograph of a typical pneumatic conveying line puncture (viewed from inside the pipe, and from the direction of flow)

The occurrence of these problems of wear and particle attrition in pneumatic conveying has historically been so common that it has put some users off this form of transport, or at least earned it a bad reputation. In recent years, however, the understanding of the causes of these effects, and the consequent development of techniques to overcome them, has progressed very greatly to the point where it is now possible to convey materials which would previously have caused too many problems.

2. THE MAIN ISSUES

The main mechanism of particle breakage and pipeline wear are one and the same; collisions between particles and pipe wall, especially at bends. As a particle approaches a bend, so it is travelling at almost the same velocity as the air, but once it enters the bend it tends to go in a straight line and collide with the outer wall of the bend, whereas the air is deflected around the bend. This is purely due to the inertia of the particle, and the particles have to be very small (a handful of microns) to follow the airflow instead of colliding with the bend wall.

The resulting damage to the particle and the pipe surface are dependent on a number of factors, as follows.

3. THE ROLE OF VELOCITY

Understanding and Controlling Attrition and Wear in Pneumatic Conveying

One of the main keys to avoiding the problems in question, is to understand the effect of particle velocity, which is of course closely related to air velocity.

The energy expended in a collision is a direct function of the velocity beforehand. Consequently, both particle degradation or fragmentation, and wear of the pipe surface, increases with increasing particle impact velocity. This relates directly to the deceleration forces experienced by the particles when impacting against pipeline bends, misalignments etc.

The degree of degradation or wear depends on the mechanical properties, shape and size of the particles and the mechanical properties and geometry of the pipe wall. However, the general trend is well documented; for example

$$\text{Erosion} = k.(\text{particle velocity})^n$$

where

k = a constant and

n = a power usually between 2.2 and 2.8 for most materials

is often used to model the rate of wear (Ref. 6), showing that for example a 25% increase in particle velocity will give rise to something between a 60% and 90% increase in rate of wear. Particle breakage is less easily quantified, but is usually recognised to follow a similar trend, i.e. increased velocity leads to disproportionately increased particle damage.

Given this type of relationship, the primary strategy for minimising the degradation and wear has to be one of reducing particle velocity as far as possible - even small reductions in velocity will always bring big reductions in these problems.

4. DILUTE AND DENSE PHASE CONVEYING

The traditional form of pneumatic conveying is where the particles are conveyed through the pipeline in suspension in the carrier gas at relatively high velocities, Fig 3 (i). This method of conveying is known variously as dilute phase, lean phase or suspension conveying. To keep the particles in suspension requires high air velocities, typically in the range 14-20 m/s minimum, depending on the particles and the pipe size.

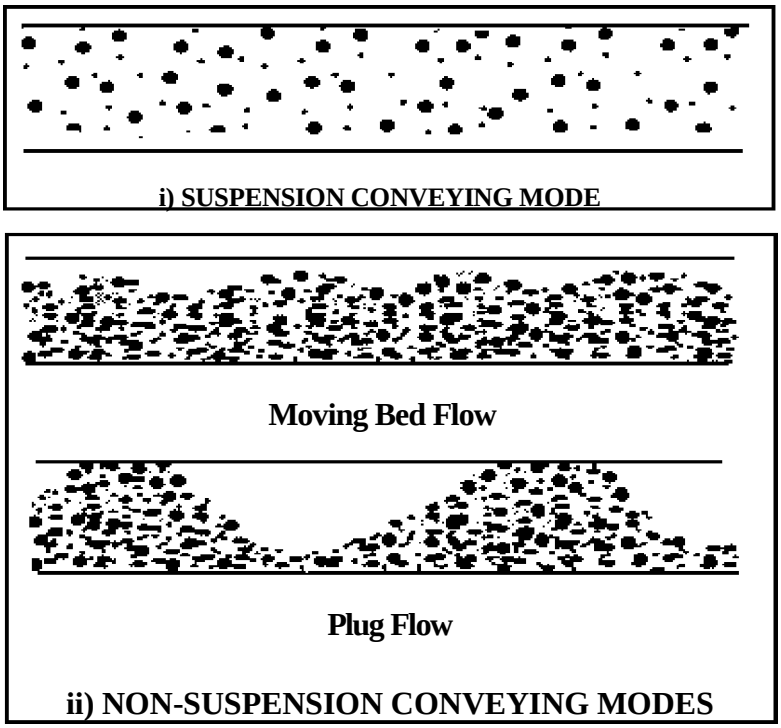

Fig. 3
Modes of flow in pneumatic conveying pipelines

However, with some materials it is possible to convey them at lower velocities than those needed for suspension flow. The mechanism by which such materials can be conveyed through a pipeline depends on the physical characteristics of the product in question, but typically is in the form of a moving bed or a slugging flow at high concentrations in the air, e.g. Fig 3 (ii). Typical air velocities would be only 2-6 m/s at the material feed point. This approach is commonly known as dense phase or non-suspension conveying. The combination of lower velocities and the fact that the majority of the particles are mutually self supported by their immediate neighbours, thereby preventing contact with the pipeline walls, means that a well designed system operating on this basis can result in a major reduction in particle degradation and pipeline wear compared with that of a dilute phase system operating at the same duty.

Hence the dense phase approach has major attractions in overcoming the problems we are trying to address. However, it should be recognised that whilst it is possible to convey virtually any material in a dilute phase mode, this is not the case with dense phase - many materials will simply block the pipe if the air velocity is not sufficient for suspension flow. Various bench type tests have been developed at The Wolfson Centre for assessing whether a product will convey in a dense phase mode (e.g. Ref 1), but the only really reliable method of making this assessment is to subject a representative sample of the product to a conveying trial in a pilot size pneumatic conveyor. This approach also has the advantage that it enables the levels of degradation and/or wear resulting from conveying at various conditions to be evaluated, as well as permitting the information necessary to the successful design and operation of such systems to be determined (Ref 2).

It must be recognised that pipeline bores and associated hardware for systems operating at the same duty but in dilute or dense phase modes are likely to be quite different. A dense phase system is likely to be built around a high-pressure blow tank feeder operating on a batch-wise basis. The pipeline will be smaller than a traditional lean phase system for the same duty, but the conveying line pressure drop for dense phase transport will be much higher, e.g. 2-6 bar compared with 0.5-1 bar. Consequently, the significantly higher expansion effects in a dense phase system means that towards the end of the conveying pipeline the air and particle velocities may be of the same order as a lean phase system operating at the same duty. Irrespective of the type of system under consideration it is possible to control air velocities and therefore particle velocities within reasonable limits by the technique described in the next section.

An important consideration with dense phase conveying, where particle breakage or pipeline wear are important, is to avoid the tank at high pressure rapidly venting down the pipeline at the end of the conveying cycle. At this point the tank has emptied out of solids, but still contains air at high pressure and as the pipeline itself starts to empty so the reducing volume of material in the pipeline will be accelerated to high velocities by the pressure of air remaining in the tank. It has been shown that the very high air velocities present in this phase of the cycle known as "blowdown" can lead to very high wear and/or high product attrition. Avoiding blowdown means shutting off the air supply when the tank pressure begins to drop, and possibly beginning the vent the tank to another location so that there is just enough air left in the tank to complete the cycle of transport but avoid the high pressure venting along the line. With some materials, notably very permeable granular materials like plastic pellets or granulated sugar, the air can be shut off and the tank vented before the tank is empty; the material is left in the pipeline while the tank is refilled, and conveying will restart when the tank is repressurised. This is a good way of avoiding blowdown altogether. However, with many materials, this approach will result in a totally blocked conveying line which cannot be restarted. Some special conveying systems on the market incorporate air injectors at various points along the pipeline, which enables restarting of a partially filled line, even with materials which would otherwise cause blockages under such shut-down conditions, and this is an effective way of avoiding the blowdown problem. Another approach is to use two blow tanks, either in parallel or in series, to feed the line - when one tank is empty the other one takes over the feeding duty, or tops up the conveying tank, so that the line is kept operating continuously thus avoiding blowdown conditions.

5. STEPPED BORE PIPELINES

Increasing the bore of the conveying pipeline at strategic points along its length is an effective way of controlling the air velocities in the pipeline. As the conveying air flows along the pipeline its pressure decreases and, as a result, the air velocity increases. This is why it is almost always the bend at the end of the system which wears out most often! Increasing the bore of the conveying line at strategic locations along its length allows the air velocities to be kept down, thereby reducing particle attrition and wear.

The positioning of the step to the next available pipe size is crucial if the approach is to operate to maximum effect. If the step in bore is too soon the velocity will be below that for reliable conveying and a blockage is liable to result; conversely, should the step be too far down the pipeline the maximum benefit of the approach in terms of reducing particle velocities and associated attrition and wear will not be fully realised.

The advantages of this approach vary from application to application, but a design study shown in Figs 4 and 5 serves well to illustrate the point with regard to wear. This is based on a system with 15 bends conveying material at 60 tonnes per hour over a pipe run of 60 metres. The design pickup velocity was 11.8 m/s. In this study, the pipeline was feeding to a metallurgical reactor at 1.3 bar gauge, but the same principle applies if the system is exhausting to atmosphere. With a pipeline of a single bore size (100mm), the pressure drop was predicted to be 7 bar, and the outlet air velocity would have been 48 m/s; if the pipe bore was increased to 125 and then 150mm at appropriate points, the pressure drop reduced to 3.5 bar and the maximum air velocity to 18 m/s. An air velocity of 48 m/s would have caused severe wear of the bends when conveying the abrasive metal concentrate into the reactor; reducing it to 18 m/s would yield at least an eight-fold increase in the bend life!

This has most advantage with long distance or dense phase systems, where high pressure drops lead to high outlet air velocities, but the strong effect velocity has on both particle attrition and wear means it has merits even for shorter, lower pressure systems. Wherever the pressure drop in conveying is more than about 0.4 bar, this is an effective technique.

In the past, the major impediment to using stepped bores to maximum effect has been the difficulty in predicting the pressure profile of the conveying air along the pipeline and therefore the optimum position of the step to the next bore. However, a method has recently been developed that enables the benefits of the approach to be maximised (Refs 2, 3).

Understanding and Controlling Attrition and Wear in Pneumatic Conveying

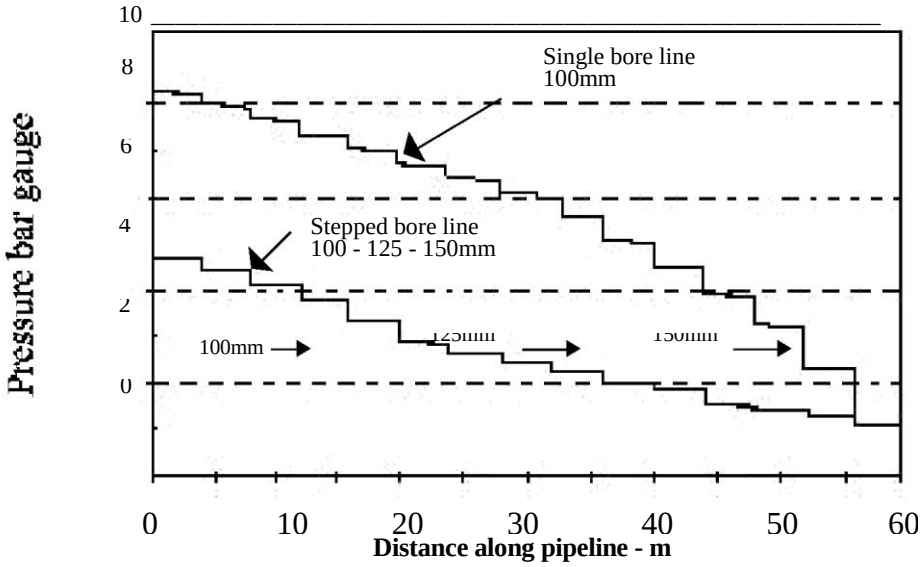

Fig. 4

Plot of pressure versus distance for pipelines of single and stepped bore size, performing the same duty. "Step" changes represent the losses caused by the bends

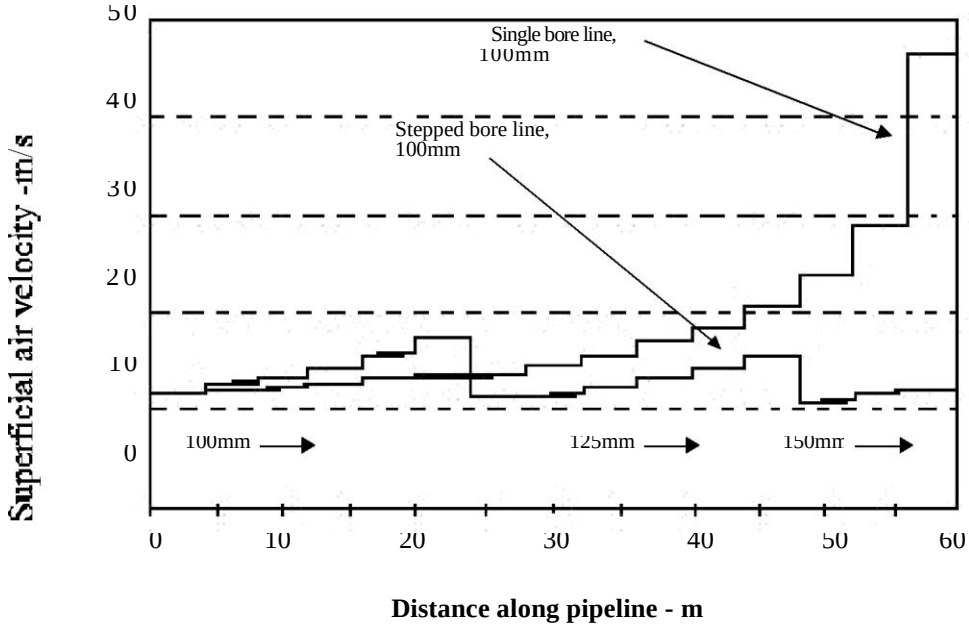

Fig. 5

Plot of superficial air velocity versus distance for pipelines of single and stepped bore size, performing same duty. Note very large changes in maximum air velocities

6. PIPELINE ROUTINGS

One of the great advantages of pneumatic conveyors is that they can go around corners without the need for transfer points which would be required for mechanical conveyors. However, this very advantage can become a source of trouble if too many bends are put into a system.

The major occurrence of collisions of particles with pipe walls is in bends, as outlined earlier in this paper. This is especially true in lean phase systems. Hence it is obvious that the greater the number of bends, the more damage there will be to the particles and the more wearing surfaces there are.

However, there is an additional effect, due to the fact that bends contribute a large proportion of the total pressure drop along such a pipeline - as much as 80% or 90% of the total pressure drop in some lean phase systems, though the proportion is less in dense phase. More pressure drop along the pipeline means a greater expansion of the air. For any given material we will always need at least a certain minimum air velocity at the pipeline inlet, for successful conveying, so the result of more bends is a higher air velocity towards the outlet end of the pipeline, especially if we do not accommodate it by expanding the pipe bore as outlined above.

Consequently, it is well worth doing everything possible to minimise the number of bends in a pipeline, especially in lean phase conveying. Money spent on getting the straightest possible alignment will give a very good return in reduced attrition and wear. In lean phase conveyors, bends close together (less than say five or six metres between their apices) should also be avoided, because to convey reliably through such bends requires an increased air velocity.

7. BEND GEOMETRY

Many conveyor suppliers specify only long-radius bends, usually with a ratio of bend radius to pipe bore of about twelve or more. However it is well known that such bends certainly do not give the lowest rate of wear. The “blind tee” bend or commercial equivalents (where the flow is put in along the run of a tee, the far end of which is capped and the flow comes out of the side branch of the tee) invariably give a longer wear life; some people hold that this is the result of the particles filling the “blind” leg of the tee and impacting on each other instead of the steel, although there are other possible explanations.

For some particulates, especially plastic granules or pellets, blind tee bends can give substantially reduced particle breakage compared with radiused bends, as the particles are better able to withstand square-on impact with the blind end of the tee than the “smearing” impact

with the outside of a long sweep. Recent detailed work at The Wolfson Centre (Ref 4) has shown this advantage to be very product-specific, for example with rice blind tees gave the lowest degradation, whereas with sugar and barley radiused bends gave by far the lowest degradation. In due course it may be that some simple guidance on choice of bend geometry for minimum degradation will emerge, however in the mean time when faced with a choice of bend geometry for minimal degradation, it remains important to undertake some short tests on a rig such as used in this work (Fig. 6).

The drawback of using blind tee bends is that they give rise to substantially higher pressure drops, in turn leading to greater air expansion along the pipeline, resulting in higher air velocities and greater wear towards the end of the pipeline. In a system with perhaps just two or three bends they are worth considering, but where there are more than this, blind tees can introduce more problems than they solve.

Blind tees should never be used in dense phase conveyors, as the increased pressure drop is far too great when the material is flowing in “slugs”.

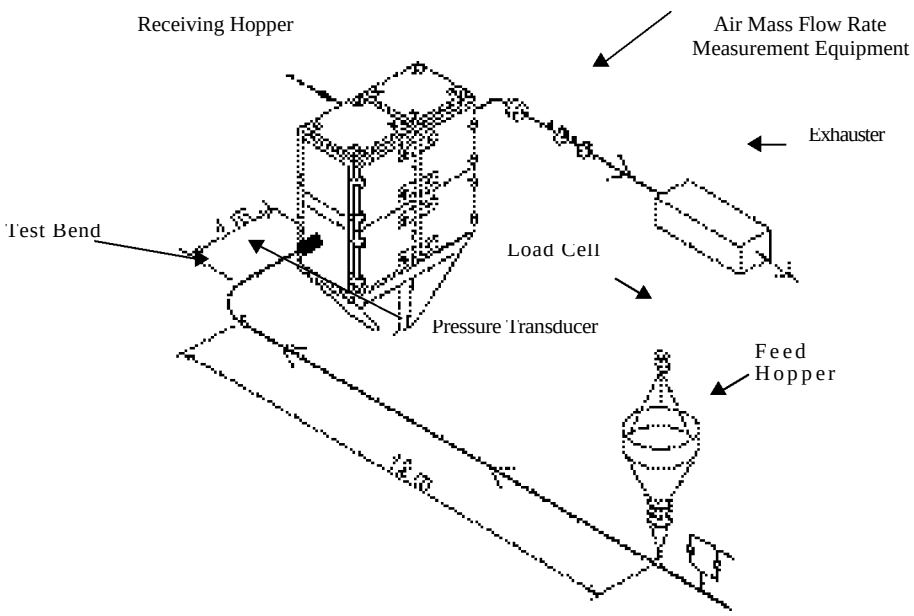

Fig. 6

Schematic of the test rig used for investigation of the effect of bend geometry on particle attrition.

8. BEND MATERIAL

Understanding and Controlling Attrition and Wear in Pneumatic Conveying

Different materials perform very differently when subject to impact erosion. Extensive studies of the wear resistance of various materials have been undertaken at many laboratories over the past decades using a variety of different erosion testing machines, however the machine which appears to have emerged as offering the best chance of obtaining meaningful results is that illustrated in fig. 7 below, originally developed by Kleis in Tallinn, Estonia, and improved by Burnett and Deng at Greenwich.

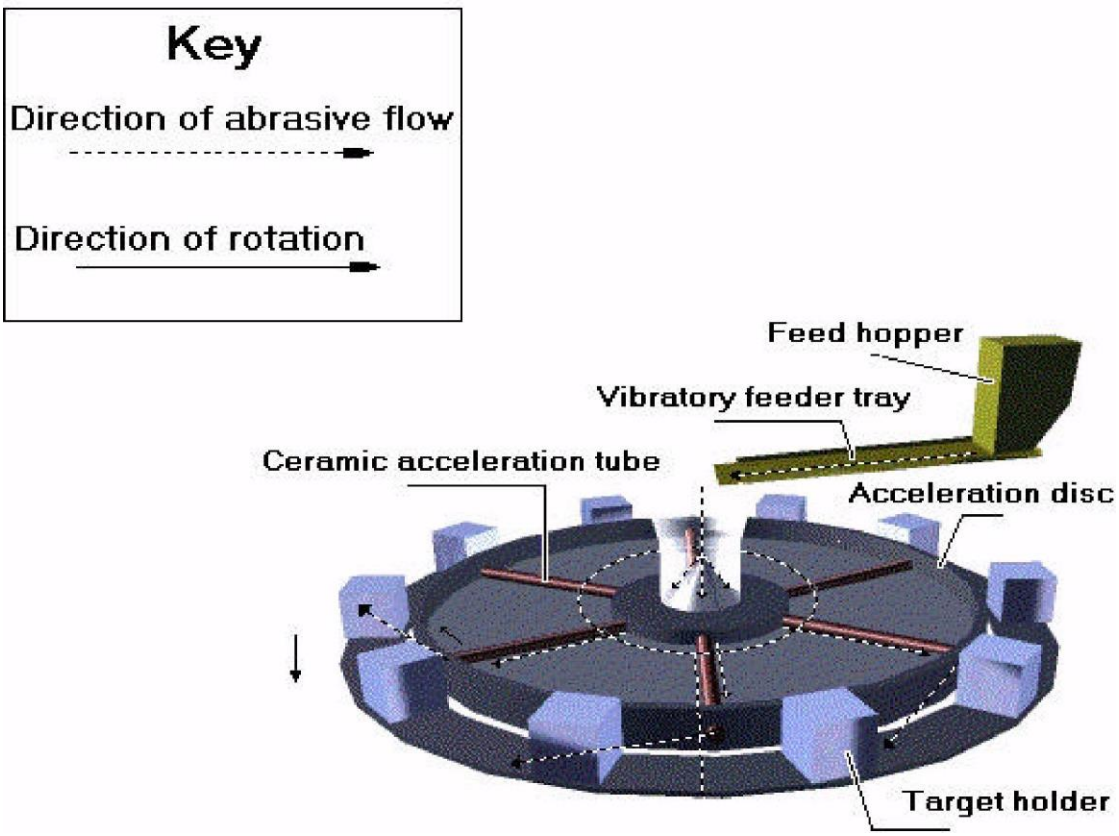

Fig. 7 (above)

Essential components of the spinning-disc erosion tester used in the studies reported in this paper. Particles fed into the centre of the spinning disc are accelerated along the radial tubes and flung out against targets of test material (steel, basalt etc.) ranged in a circle around the disc

High performance steels

Special steels are probably the most commonly used wear resistant materials. Considerable work has been done to investigate what mechanical properties determine the erosion resistance of steels, using the erosion test rig depicted in Fig. 7, and the results have been perhaps surprising; Fig 8 shows the results of a plot of erosion rate of several steels subject to low-angle impact from sand particles, versus steel hardness (Ref. 5). The lack of any correlation will be

obvious. Since hardness is such a poor indicator of wear resistance, there is no substitute for undertaking an erosion test to assess the usefulness of a proposed steel.

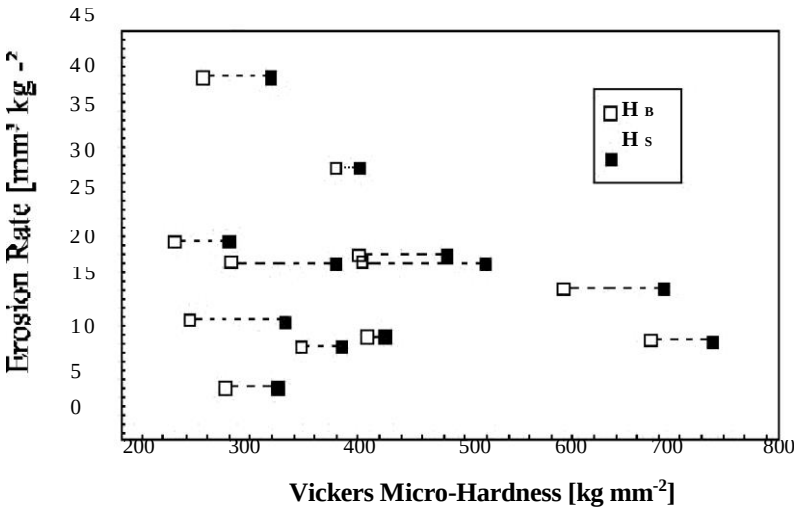

Fig. 8

Graph of erosion rate versus indentation hardness measured in the bulk of the steel (H_B) and at the worn surface (H_S) after erosion testing. Tested at 35 m/s impact velocity, 8 degree impact angle

Polymers

Many other bend materials are used. Since wear is caused by particle impacts in bends, is not unreasonable to propose that the use of rubber bends to absorb some of the energy at impact should go some way to alleviate the problems. This has been known to yield a significant reduction in attrition with some products, and indeed a longer wear life than steel bends where hard, rounded particles are handled. However, where sharp particles are conveyed these can rapidly cut into such bend materials, resulting in a very short service life. The type of rubber is very influential in determining the wear life, and experience generally shows that tough nitrile or urethane rubbers are usually better than natural rubbers. Generally, the higher the impact angle, the more suitable is rubber. Similar comments apply to other polymers such as ultra-high molecular weight polyethylene, which is highly resistant to wear in high-angle applications, but less so in low-angle impact – this makes it of questionable suitability for reducing wear in pneumatic conveyors, though it is very long lasting as impact plates in chutes etc. Again an erosion test is needed to establish the usefulness of such a material.

Ceramics

The use of hard non-metallic bend materials to resist wear is well established, and this can be quite effective with some conveyed particles. Ceramics are the largest group and range from relatively cheap cast basalt rock through more expensive fused aluminas to exotic carbides of silicon and boron. The problem is that here again, hardness is a very poor indicator of wear resistance in an erosion situation.

Fig. 9 shows a plot of measured erosion resistance of five commonly used materials under impact from sand (Ref. 6), with again perhaps somewhat surprising results. For example, cast basalt eroded several times faster than mild steel, in spite of it being much harder (two to four times the hardness of steel). Basalt is often specified for pneumatic conveyor bends - the relative success of this material arises from the fact that it is cannot be cast in sections less than about 30mm, ie about six times as thick as steel! The basalt was of a similar hardness to the particles.

Results of erosion rate tests on five different bend materials at 30 degree impact angle

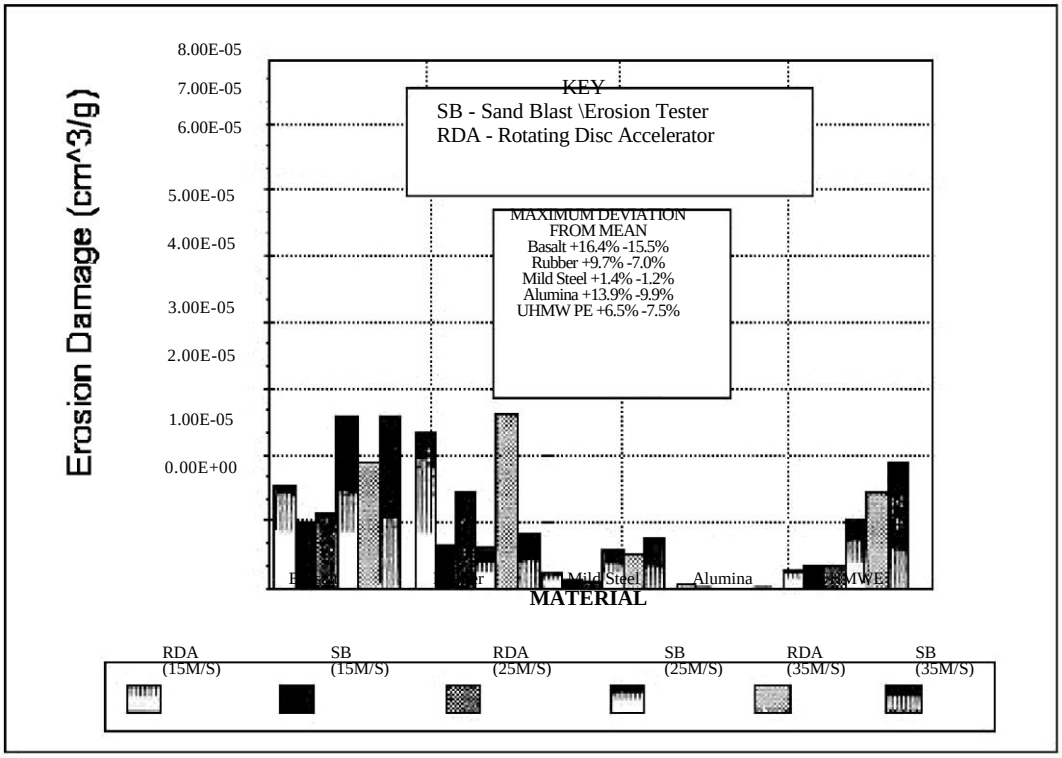

Fig. 9

Fused alumina ceramic, as can be seen, suffered very little wear with these eroding particles (sand) as it was substantially harder than the particles. Normally, if the bend material can be made significantly harder than the conveyed particles, wear is reduced dramatically provided the particles are not too large and especially if the impact angle can be kept fairly low. However, most wearing materials contain silica so to achieve this difference in hardness usually requires the use of a fairly advanced ceramic material, which tend to be brittle; impacts from large particles at

high angles tend to break the surface of the ceramic and cause high wear. In many instances the relatively high cost of such ceramics can be recouped fairly quickly through the avoidance of downtime and unplanned maintenance; reduced lifetime cost can often result through the use of these slightly more expensive materials in conjunction with good design.

In the instance shown, both rubber and polyethylene also eroded at high rates compared with mild steel.

In the absence of general rules for predicting erosion resistance, the best way of choosing a bend material for minimal operating cost for the time being remains the use of a characterisation test in a rig such as that shown in Fig. 7.

9. PIPE FITTING

The importance of accurate alignment of pipeline components is often overlooked; yet it is quite common for severe wear to occur just after joints in a long straight pipe, where particles have hit the edge presented by misaligned sections and bounced across to the other side of the pipe, causing wear and eventually puncture. The same misalignment is also likely to increase particle degradation. To minimise this it is well worthwhile expending some effort on accurate alignment to avoid such edges against the flow. When using flanged joints, the clearance between flange and pipe o/d, and clearances in the boltholes, will make it impossible to ensure truly accurate alignment. In this respect, slip-on strap-clamp type couplings are better as they go straight on to the outside of the pipe and ensure no misalignment of the pipe ends. Using such couplings will often give rise to the need for secure pipe support, as they mostly do not give as positive a location of bends as do flanged joints.

10. SUMMARY OF DESIGN FOR MINIMISING PARTICLE ATTRITION AND BEND WEAR

The key points to note for either effect are:-

- ⇒ Use the lowest possible air velocity for reliable flow (this is by far the biggest effect)
- ⇒ Convey in dense phase if possible (sadly for many materials this is not possible; there is no point in trying to “force” a material to convey in dense phase if it won’t do so reliably)
- ⇒ Use stepped bore pipelines if the pressure drop is more than about 0.4 bar
- ⇒ Minimise the numbers of bends
- ⇒ Choose appropriate geometries of bends if this helps with the product in question
- ⇒ Ensure correct pipe alignment to eliminate edges against the flow
- ⇒ Prevent a blow tank from venting its charge of air along the pipeline as it empties
- ⇒ Choose bend materials for wear resistance if necessary; consider polymers, metals and ceramics but commission a wear test before making a decision.

To amplify the latter point, the effectiveness of the lining material should be tested to ensure it has a beneficial effect, since the benefit is very dependent on the particles being conveyed. Alternatively, allow for easy replacement if cheap steel bends are used and regarded as regular maintenance items.

11. RESEARCH FOR THE FUTURE

Recent efforts in this area have focussed on developing the characterisation side, i.e. improving the accuracy and understanding of the erosion and particle attrition test rigs which are in use to produce "erosiveness" figures for bulk solids against bend materials and "friability" figures for the particles. Currently, attention is turning to the use of these figures to make more accurate predictions of expected bend life and levels of particle damage in the plant pipelines.

For wear, Research Council funding was allocated some three years ago to pursue a joint project between Cambridge and Greenwich Universities and four industrial sponsors, to develop just such a design and troubleshooting tool for engineers to use. Erosion testing rigs at the Department of Materials Science at Cambridge and The Wolfson Centre at Greenwich are being used, together with a full industrial scale pipeline test rig at The Wolfson Centre, to produce erosion data, explore the mechanics of particle transport, and test predictions; the Centre for Numerical Modelling at Greenwich is undertaking particle trajectory modelling. The industrial sponsors bring experience in designing, supplying and using pneumatic conveying systems, and the facilities to test bend life predictions.

The ultimate goal of the team is to produce a simple spreadsheet model, PC-based, which can be used by non-specialist engineers to optimise the costs of operating pneumatic conveying systems in the field. This will have benefits for anyone who uses blowing lines for transporting hard particles, especially in the minerals, power, port, food and many other industries.

Currently the project is approaching fruition, and a test protocol and software tool will be available in the near future. In the mean time, users should take some comfort in the fact that the current state of knowledge is at least sufficient to enable significant improvements to plants which have serious wear problems, and allow some forward planning to minimise problems on new plants.

With regard to particle breakage, work being undertaken through the "QPM" (Quality in Particulate-Based Manufacturing) project being pursued collaboratively between the universities of Greenwich and Surrey, and eight industrial partners, has resulted in a version of the rotating disc erosion tester for measuring the friability of particles in handling; this

work is being validated at present and the technique will be available shortly. This tester supersedes the rig shown in fig. 6, and enables the breakage tendency of particles to be measured much more quickly and cheaply. Predictions of breakage in a plant can then be made even before the plant is built; this will enable much more effective elimination of such problems before major costs are incurred..

More information on these developments can be obtained from The Wolfson Centre, University of Greenwich (www.bulksolids.com).

Understanding and Controlling Attrition and Wear in Pneumatic Conveying

REFERENCES

1 Mainwaring, NJ, 'The Effect of the Physical Properties of Bulk Solid Materials on Modes of Dense Phase Pneumatic Conveying'., PhD Thesis, Thames Polytechnic, 1988.

2 Bradley, MSA, 'An Improved Method of Predicting Pressure Drop Along Pneumatic Conveying Pipelines', Proc. 3rd Int. Conf. on Bulk Materials Storage, Handling and Transportation, Newcastle, Australia, June 1989.

3 Bradley MSA, Pittman, AN, Woodhead SR, ‘Practical Experience with the Design and Analysis of Pneumatic Conveying Pipelines: Advantages of Employing the Latest Methods’, Proc 8th Int. Sypm Freight Pipelines, Pittsburgh, USA, Sept 1995

4 The Analysis of Particle Degradation in Pneumatic Conveyors Utilising a Pilot Sized Test Facility, Accepted for future publication in Proc IMechE Part E

5 O’Flynn DJ, PhD Thesis 1998, University of Greenwich

6 Burnett AJ, PhD Thesis 1996, University of Greenwich