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The Application of Life Cycle Cost Analysis to Pneumatic Conveying Systems

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SUMMARY

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The Application of Life-Cycle Cost Analysis to Pneumatic Conveying Systems

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This approach provides the decision maker with two major economic measures without regard to other possibly significant indicators of future performance of the equipment relating to its functionality and durability. Within organizations dominated by strong accounting management where little attention is given to the people who make a plant purchasing decision work, this approach may be an acceptable criteria for purchasing decision makers. However, a more analytical approach to economic comparison would be more effective and appropriate for the special conditions relating to the performance of pneumatic conveying systems. The technique known as Life Cycle Cost Analysis provides for a single all-embracing economic indicator which incorporates the special cost creating characteristics of pneumatic conveying systems.

Used as a discipline for system comparisons, the technique will impose revealing investigation of claims by system vendors. Vendor claims of system performance that cannot be verified to a relevant economic statement are of little value to the rational decision maker. It is intended that this paper will provide the components of rational economic decision making with particular regard to pneumatic conveying systems. The analytic technique may be applied to almost any other process or plant purchasing decision, providing that all aspects of the process are well understood, and particularly understood with knowledge acquired independently of the process vendors.

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1. Pneumatic Conveying Systems

This paper does not provide the independent education referred to in the preceding section. However, there are many recommended educational resources provided for this purpose. For the non-technical reader, a brief descriptive summary of pneumatic conveying system types is provided with particular reference to the cost-creating components of a system design.

A pneumatic conveying system is a process by which bulk materials of almost any type are transferred or injected using a gas flow as the conveying medium from one or more sources to one or more destinations. New bulk materials and new processes producing or using the bulk materials, together with the encouragement of regulatory authorities, are causing a growth in the utilization of pneumatic conveyors for cleaner working environments.

As with most processes, there are conceptual differences in designs of pneumatic conveying systems. The differences are provided by design engineers also motivated by economic objectives. With their intimate knowledge of the subject, they,too, attempt to achieve economic improvement associated with first-cost and operating cost.

Conceptually, all system design types convey bulk material through a pipeline using compressed or evacuated gas as the conveying medium. Air is the most commonly used gas, but may not be selected for use with reactive materials. The conveying medium may be liberally mixed with the bulk material allowing the individual particles to travel in an airborne condition along the pipeline, or the bulk material may be completely solid without any fluidization or mixing with the gas taking place. Between these extreme conveying regimes, a wide range of intermediate regimes are possible, depending upon the transfer or injection system design objectives. The pneumatic conveying system designer selects an appropriate pneumatic conveying regime to economically target the objectives of the system requirements while considering any restraints that may be imposed by the characteristics of the bulk material.

The characterization of the material to be conveyed plays a very large part in the selection of the regime. This can be understood by comparing, say cement powder, with wet lump coal. Although both materials can be conveyed pneumatically, the pneumatic conveying regime for cement powder is likely to be quite different for the regime selected for wet lump coal. The reason for this concerns the properties of the bulk material and how these properties interact during the pneumatic conveying process. For example, cement powder may be easily fluidized and mixed with air. When conveyed at high velocities, it will not degrade to the detriment of the bulk material. Wet, lump coal (2” X 0), on the other hand, cannot be fluidized without severely degrading the material to the extreme detriment of the coal product for an intended purpose. These factors affect the choice of allowable material velocities through the pipeline.

Now also consider the additional characteristic of abrasive materials in a similar comparison to wet, lump coal and cement. Many materials which are extremely abrasive will, if allowed to convey at high velocities normally employed for cement powders, will quickly erode the pipeline and much else of the system also.

In addition to the issues of (a) effect of the bulk material upon the system; and (b) effect of the system upon the material as we have discussed, there are other cost-causing conditions of the conveying process that are important. Energy consumption is an obvious cost center. The issues described relating to bulk material velocity and the selected conveying regime directly affect the gas consumption of the system. High-velocity systems may or may not use higher gas volumes than low-velocity systems. The gas source may be at a higher pressure for one particular regime than for another. The influence of transfer or injection distance required will affect the gas volume for unit volume of material conveyed. Of course, in the case of injection systems, the gas volume is also affected by any back pressure into which the injection system is operating.

To bring order to this vast array of variables in any system design that may be deemed appropriate for a particular requirement, a disciplined measure of the cost-creating components of the process is required to be applicable to any pneumatic conveying regime.

A basic division of pneumatic conveying system designs is considered appropriate. A fundamental understanding of two general groups is provided as representative of most pneumatic conveying processes. The division into two groups occurs for the purpose of this study around the capability of the gas source providing the motive medium for conveying. The reasons for this division based upon air source capability is due to the first cost and operating cost impact of air sources, up to 15 psi, which normally are provided by air blowers rather than higher cost rotary compressors.

The choice of air source and, therefore, system conveying pressure is vital to the performance of the system as well as the system's economic performance.

A failure to understand the capability of dense-phase pneumatic conveying systems which generally do not necessarily use gas volume flow regimes, has led to uneconomic purchasing decisions by engineers who are lured to older technology for reasons of :

(i) familiarity with older technology;
(ii) apparent lower first cost; and
(iii) poor knowledge of operating cost characteristics

Therefore, two general descriptions of pneumatic conveying system concepts are provided and should be considered as follows:

1. Dilute phase systems (generally operating at lower pressures) in which a rotary valve or other simple air lock is used to introduce the material into the system. The pressure applied in this category is below 15 PSIG.
2. Dense-phase systems (generally operating at higher pressures) in which conveying gas pressure will require the use of a pressure vessel as the means of material introduction into the system. The pressures applied to the system will normally be in excess of 15 PSIG.

For a further understanding of these two generally different approaches, the following typical descriptions are provided:

Dilute-Phase System

A typical dilute-phase system will consist of a rotary valve; pipework which would include long radius reinforced bends; a filter receiver or cyclone/filter arrangement; and PD type air blowers.

It is characterized by high-velocity conveying with low-phase density. This type of system will produce high degradation of friable products and high pipe wear with abrasive materials.

Of the various types of pneumatic systems, a dilute-phase system will generally be lowest in capital cost.

Dense-Phase System

In order to clarify certain variations that are presently available with the same broad label of dense-phase system, two fundamentally different variations are described:

Fluidizing-type System

Designed along "traditional" lines, this type of system will utilize large pressure vessels with double butterfly valves or slide gate valve in-feed arrangements. The vessels may be equipped for additional fluidization and be provided with discharge valves. Air is also injected into the pipeline via boosters.

The system is characterized by high velocities, although not as high as for dilute-phase systems. Product degradation and pipe wear may be lower.

Non-fluidizing Type System

Typically uses smaller vessels with single robust infeed valves. Vessels do not use additional fluidizing air for either the vessel or into the pipeline. The system is characterized by low velocities which generally provide for the lowest product degradation and pipe wear. These systems are usually higher in first cost than both of the above systems.

2. Life Cycle

An equipment life cycle is considered to be the **planned** economic life expectation. It may be 5, 10 or 20 years, as may be decided by management for cost analysis purposes. An accounting manager may decide to use the statutory depreciation life of the equipment. This may not be appropriate since accelerated depreciation helps the income tax return, but it may not be appropriate to the practical life expectancy.

A more appropriate life cycle for economic analysis is the life that may be anticipated for the plant process in which the pneumatic conveyor is associated. When a plant process changes, the pneumatic conveyor may become redundant, in which case the entire life value should be charged to that process. In a world in which we should manage for change, this is the most prudent lifetime criteria.

3. Life Cycle Cost

A life cycle cost is the entire known and anticipated cost of a system analyzed to a single figure. The single figure cost may be presented as a periodic lump sum, i.e., month or year, or related to the work being performed, i.e., $/ton or lbs. transferred or injected.

The life cycle cost is derived from two major categories:

1. First cost; and

2. Total operating cost

The fact that the accounting manager treats the categories in different accounts for finance purposes is independent of the life cycle cost analysis. The analysis and cost evaluation process is not concerned that the installed cost is paid by the capital budget, and the operating cost is paid by the revenue budget.

3.1 First Cost

First cost, otherwise known as the **investment** or **capital** cost is the acquisition cost required to establish the system in a ready-to-operate condition. This will incorporate all purchase costs, transportation to job site, installation costs, utility connection costs, and start-up fees. Site remodeling

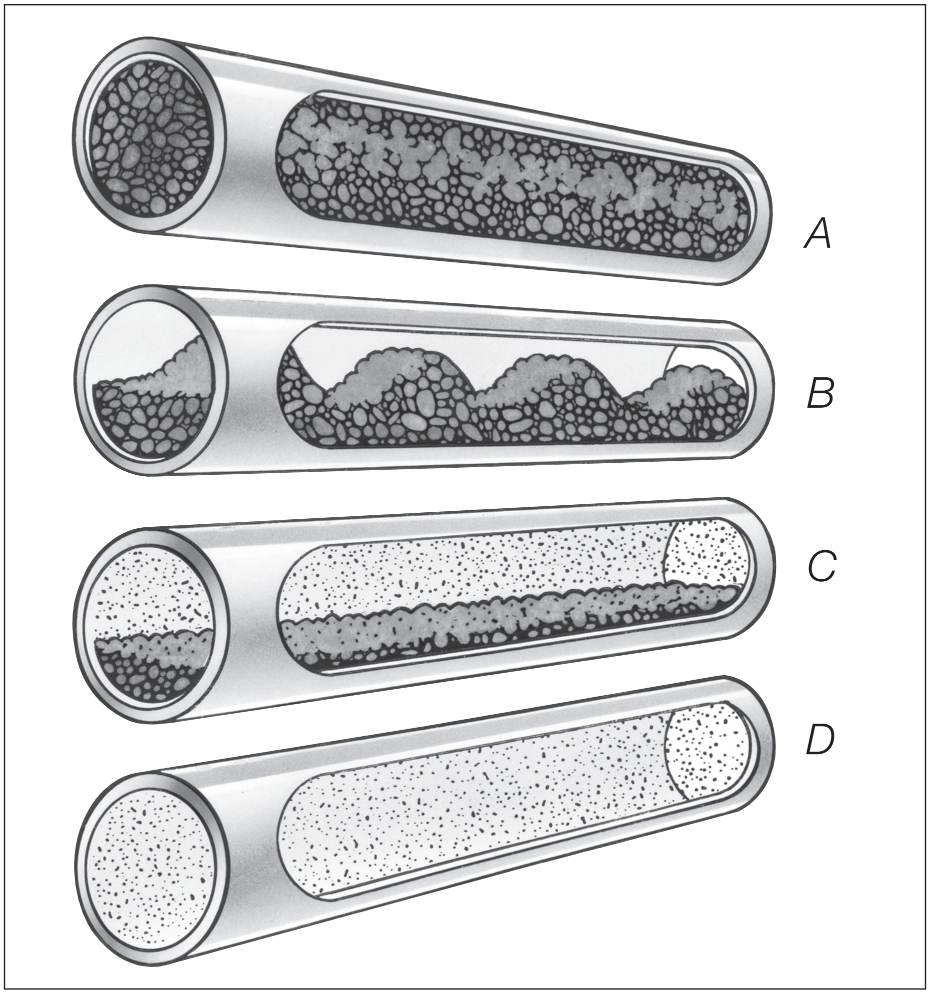


Fig. 1: Examples of the four pneumatic conveying regimes.

(A) Solid Dense Phase: Very low material velocity – pipeline almost full of material – excellent regime for fragile materials with either wide or narrow particle size distribution;.

(B) Discontinuous Dense Phase: low material velocity – pipeline almost full of material which moves in dune-like fashion – best regime for most applications in which power economy, pipe erosion and material degradation issues are important;

(C) Continuous Dense Phase: highest velocity below the saltation velocity of the material conveyed – suitable for powder and narrow particle size distribution – may not be optimum design for abrasive materials;

(D) Dilute Phase: material velocity above the saltation velocity – no upper limit to the velocity – least attractive regime for operating economy – unsuitable for abrasive materials or materials with wide particle size distribution.

costs to accept the system should also be included. This is clearly the simplest calculation, and the easiest comparison; and unfortunately still continues to be the only comparison made by many companies for much of their plant requirements.

The obvious shortcoming of this single economic measure is the disregard of the operating costs of the equipment, which in the case of a pneumatic conveying system may be considerably different from one pneumatic conveying system to another. Additionally, the operating costs of a poorly designed pneumatic conveying system may considerably exceed the first-cost many times over.

3.2 Operating Cost

As stated earlier, this is the most significant and revealing consideration of total life cycle costs for pneumatic conveying systems. Each of the cost-creating components are examined in detail but are first summarized as follows:

1. Energy Consumption
2. Pipe Erosion
3. Maintenance
4. Material loss/damage
5. Production loss through unscheduled system downtime

3.2.1 Energy Consumption

Air or other gas consumption is the prime energy cost creating factor of a pneumatic conveying system. Additional energy consumed by rotary valves or control equipment may be disregarded, except perhaps in the case of high pressure rotary valves - a recent innovation in which a significant power cost is required which should be added to the compressed gas source cost.

Compressed air or other gas is an expensive conveying medium when compared with equivalent mechanical means of bulk material transfer. Energy costs for pneumatic conveying systems may be as much as five times higher than equivalent mechanical belt or other mass flow conveying systems. Accordingly, careful examination of this cost center is vital.

The compressed gas source cost may be easily established by review of the motor size and utility cost rates in the case of a dedicated gas source. In the case of a non-dedicated or shared compressed gas source, careful examination of vendor claims must be made. In the case of fluidizing dense-phase systems, the total gas consumption **including** the additional gas consumption of pipeline boosters must be calculated and verified, if possible, by pre-contract testing of representative sample materials in the vendor's test circuit.

3.2.2 Pipe Erosion

Perhaps it should be highlighted that the use of special materials of construction and reinforced bends are in effect, a treatment of the symptom of high material velocity, and not the cause. Special materials for pipework will add to the first cost of a system, but more significantly, will be confirmation by the system vendor that a high velocity regime is being proposed.

It has become well established that the cause of pipe erosion is largely due to the velocity of the material as it is conveyed. Work carried out by a number of organizations is now enabling the wear rate/velocity relationship to be quantified; although the research is being conducted on a continual basis, and new information is being published all the time.

Work carried out by Mills and Mason at Thames Polytechnic in London, and Agarwal of the Indian Institute of Technology (1), showed that a relationship between specific erosion and velocity given by:
Specific erosion = (Ratio of velocity) $^{2.65}$
In numerical terms, this would mean, for example, if a dense-phase system was operating at 500 ft./minute, and dilute-phase

system at 3500 ft./minute, the increase in wear on the pipeline using the dilute-phase system would be:

$\frac{(3500)^{2.65}}{(500)}$ or about 175 times greater!

The low-velocity, dense-phase system, therefore, is far more effective in reducing pipe wear, and in general should always be used for materials that are abrasive.

For effective life-cycle cost analysis, therefore, a careful examination of vendor claims concerning material velocity should be made. Although initial (pick-up) and terminal velocities in any pneumatic conveying system design will vary, the significant velocity value with regard to pipe erosion should be the average material velocity, i.e., (Terminal velocity - Initial velocity) 1/2. Although not an entirely precise evaluation, the expression will be common to all system types compared.

In order to relate the velocity/pipe erosion factors to an operating cost, a numerical cost equivalency must be correctly established. Mills, Mason and Agarwal have clearly shown that a straight line relationship does not exist, and wear occurs almost exponentially with velocity.

3.2.3 Maintenance

How many times has a specifying engineer responsible for “living” with a system after installation been overruled in his selection by an accountant who insists on buying “lowest dollar”, i.e., lowest first cost. When the engineer is maintaining and repairing the system at 3:00 a.m., the accountant is usually at home in bed.

The failure here is the engineer’s, and his inability to present the **total cost effect** of a purchase, i.e., the life-cycle cost analysis of his alternatives (hence this paper). Maintenance is the most visible aspect of a poor purchasing decision, and normally the biggest “surprise” after the system start-up.

How is this situation avoided? The answer is really a simple one which is: Not to rely on vendor claims but to carefully examine the maintenance history of operating commercial systems performing a **similar** duty with a **similar** bulk material.

Some additional observations of a system design can be revealing:

(a) With pressure vessel systems, the sensitive maintenance item is the vessel filling valve. Examine its capability and past performance carefully. A butterfly valve (or two) operating upon the signal from a level probe in the pressure vessel clearly indicates that the valve cannot close and seal on a static or dynamic column of bulk material. This is an important disadvantage if the probe installed in the pressure vessel does not function reliably.

(b) Vessel sizes compared between system types. A large vessel compared with a smaller vessel providing the same duty will indicate that:

(i)The valve cycling frequency (probably butterfly valves) cannot be allowed to be high for reasons of poor valve durability.

(ii) A large volume transferred each cycle, by comparison with a small vessel volume, indicates the need for pipeline booster air supply to reduce line loading. Booster air supply every 10-12 feet causes high air supply, and therefore high material velocities.

(iii) The use of boosters along the pipeline will require more maintenance to the boosters than with a system that has the flow regime correctly established and does not require any boosters. (2)

(c) High material velocity systems will cause more maintenance upon pipeline distribution valves than lower material velocity systems.

(d) Pressure vessel systems which require the use of a level probe to achieve material level in the vessel for proper valve operation require more attention and maintenance than vessels that operate **without** level probes.

(e) Systems utilizing smaller pipeline diameters than systems with larger pipeline diameters will require higher material velocities than equal transfer capacity systems utilizing larger pipeline diameters. Since $Q = VA$ where:

A sensible and careful review of these, not so obvious, factors rather than a dependence on vendor claims will reveal important information that can save your company many operating cost dollars and help you rest easy with your analysis and subsequent decision.

3.2.4 Material Loss/Damage

With the growing acceptance of dense-phase, low velocity pneumatic conveying systems, industries which have traditionally used other means of handling fragile materials are now carefully considering the obvious benefits of low-velocity pneumatic conveying systems. Satisfying OSHA with clean bulk material handling systems at the expense of material loss in a pneumatic conveying system utilizing the wrong regime for a fragile product will not meet economic objectives.

The cost effect of material damage due to degradation is easily quantified from the bulk material value, but more importantly how can the correct regime for a product requirement be examined. At this time in the history of development of pneumatic conveying technology, the only answer is material testing.

Properly managed precontract testing will reveal optimum material velocity **and** conveying regime for a fragile bulk material. To be sure that a test does, in fact, optimize the study, a selection of system types in a test facility should be available in which to examine performance. Sample conveying in a single system without velocity or regime control availability is not a test, but a demonstration and therefore not an optimization.

From test results upon a system closely resembling the final system configuration and size realistic product damage can be assessed and confidently predicted.

A further area of examination should be **product loss** which may occur from incorrectly designed filter equipment in which high velocity, dilute-phase systems may cause large volumes of collected dust which may be returned to the product because of incorrect dust filter application to the transfer system.

3.2.5 Production Loss Through Unscheduled System Downtime

Realism requires that we forecast an allowance for losses due to system inoperability. An arbitrary estimate applied to a particular system design is not appropriate, however, and again, a disciplined and professional approach to establishing this estimate must be made to support your general life-cycle cost analysis.

The only effective technique to a professional analysis requires either:

(a) A careful review of existing similar installations with documented supporting data, or in the case of a first-time system.

(b) A careful review of the:
- (i) System design calculations
- (ii) Vessel valve type and size
- (iii) Vessel valve feed arrangements
- (iv) Vessel exit arrangements
- (v) Material characterization control arrangements
- (vi) Conveying gas supply system
- (vii) Pipeline design
- (viii) Distribution valve type applied
- (ix) Control and instrumentation systems
- (x) Process interface

An estimate must be made in a logical way for each alternate system being reviewed.

4. Life Cycle Cost Analysis and Comparison

In the following, a typical example of the preceding considerations is provided. Three alternate system design types have been proposed for an application that requires attention to both system pipewear, since it is an abrasive material, and to product degradation, since it is a material that requires to maintain its particle integrity to maintain its product value.

Material to be conveyed: Sized coke - 6 to 10 mesh - dry and free flowing.

Mass flow rate:	25 tons /hour
Conveying path: with 4 90° bends to a single reception hopper	150 feet
Coke product loss value	$20.00/ton
System utilization	2,000 hours/year

The three systems examined for this application were as previously described, i.e.:

System 1.......Dilute Phase

System 2.......Fluidizing Dense Phase

System 3.......Non-fluidizing Dense Phase

4.1 Dilute Phase System

Utilized a 6" pipeline operating with a 75 HP P.D. blower and a rotary valve. The average material velocity was calculated to be 5,000 FPM.

Cost factors:

Installed first cost	$ 45,000.00
Product degradation (rate 8% cost)	$ 80,000.00/year
Energy cost	$ 5,700.00/year
Pipe replacement (materials and labor)	$ 24,000.00/year
Maintenance (parts and labor)	$ 11,000.00/year
Unscheduled downtime (Rotary valve operating on an abrasive material)	$ 12,000.00/year

4.2 Fluidizing Dense-Phase System

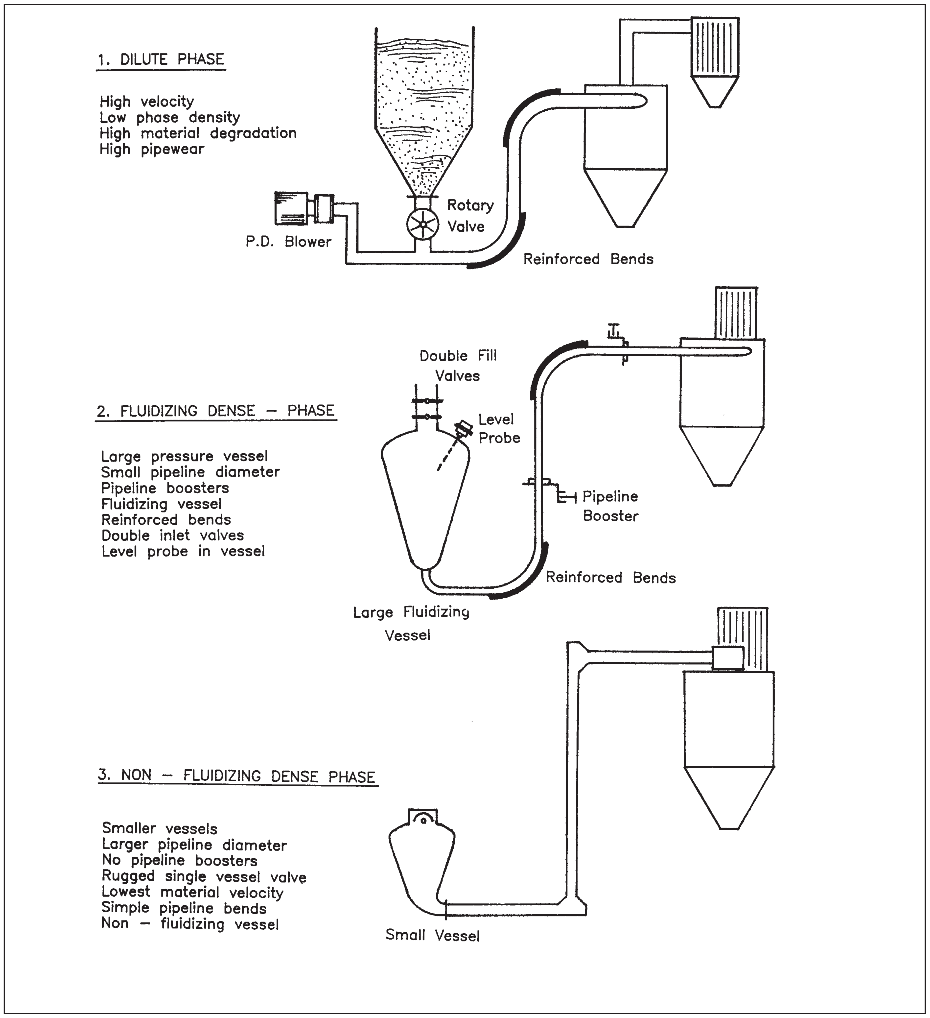
Utilized a 4" pipeline with boosters operating with a 75 HP compressor and large pressure vessel. The average material velocity was calculated to be 1800 FPM.

Cost factors:

Installed first cost	$ 65,000.00
Product degradation (rate 5% cost)	$ 50,000.00/year
Energy cost	$ 5,000.00/year
Pipe replacement (materials and labor)	r$11,000.00/year
Maintenance (parts and labor)	$ 6,000.00/year
Unscheduled downtime (Boosters, vessel filling valves, vessel level probes)	$ 5,000.00/year

4.3 Non-fluidizing Dense-Phase

Utilized a 6" pipeline without pipeline boosters, operating with a 60 HP compressor



and a smaller pressure vessel. The average material velocity was calculated to be 600 FPM.

Cost factors:

Installed first cost	$ 80,000.00
Product degradation (rate 2% cost)	$ 20,000.00/year
Energy cost	$ 4,500.00/year
Pipe replacement (materials and labor)	$ 2,000.00/year
Maintenance (parts and labor)	$ 1,500.00/year
Unscheduled downtime	$ 1,000.00/year

The cost forecasts may now be tabulated for comparison. For life-cycle cost analysis, the first cost is shown to have an annual cost using, say 10 years, therefore each first annual component will be 10 percent of the total installed cost.

LIFE CYCLE COST ANALYSIS SYSTEM COST COMPARISON

Cost Component Phase	Non-Dilute Phase	Fluidizing Dense Phase	Fluidizing Dense
First cost (10-year system life)	4,500	6,500	8,000
Product loss - degradation cost	80,000	50,000	20,000
Energy cost	5,700	5,000	4,500
Pipeline replacement cost	24,000	11,000	2,000
Maintenance cost	11,000	6,000	1,500
Unscheduled downtime cost	12,000	5,000	1,000
Total Annual Cost (Year after year)	137,200	83,500	37,000

Comparisons between the systems for the various cost creating criteria are of a generic nature and are based upon a considerable range of data available to the authors. It is intended primarily to serve the purpose of demonstrating effective life-cycle cost analysis.

The analysis shows that in this comparison the first-cost only economic evaluation - which may have been applied by your friendly account, general manager or purchasing agent - would have been inappropriate, and a poor use of investment funds.

Life-cycle cost analysis clearly shows that total cost comparison reverses the order of choice. This remains true even if your accountant wants to charge an additional 10 or 12 percent per year to the first-cost of the system for funding requirements.

Review and Conclusion

The effectiveness and importance of life-cycle cost analysis is particularly important for the review of pneumatic conveying system proposals because of the following considerations:

a) Pneumatic conveying systems use a lot of expensive energy to perform their function compared with any other form of bulk handling.

(b) It is very easy to be misled by vendor claims when vendors do not subscribe to national standards of technical terms, performance calculations, or ethical behavior (see Appendix I).

(c) Various pneumatic conveying designs can be **demonstrated** to "work", but you may not be sufficiently informed to assess the economic value of a professional **test**.

Certain well-performing international competitors of our national industrial community have been utilizing life-cycle cost analysis for more than twenty years. That is not the only reason that their industrial economy is performing better than ours. There are other reasons, but the utilization of the logic we have described certainly supports their longer term and more conservative strategies that have been so successful.

Engineers responsible for equipment selection must achieve greater control of selection criteria by presenting meaningful and supportable numerical argument. This technique will assist them in this effort, and hopefully will also help them with a better understanding of pneumatic conveying systems.

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