TECHNICAL
PAPER

Pneumatic Conveying of Fragile Materials

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SUMMARY

PNEUMATIC CONVEYING OF FRAGILE MATERIALS

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SYNOPSIS

There are many processing industries that use or produce fragile materials. In recent years, the demand for higher degrees of dust containment, quality control and prevention of inter-batch contamination have compelled these industries to look to pneumatic conveying for their handling needs. However, a paramount concern is that of product degradation and/or generation of dust which can cause direct and indirect material loss and adverse effects on down-stream processes. It is possible to handle most fragile materials with excellent results with today's modern dense-phase systems. This paper will examine the factors which influence industries to select a particular handling method and which pneumatic systems provide for the lowest product degradation.

1. PRODUCT DEGRADATION

Product degradation is the breakdown of individual particles of bulk material. It can occur in many different forms:

Particle Fracture: The particle is broken apart by sudden impact such as the particle colliding with a pipe wall, the side of a storage bin, or another particle.

Particle Abrasion: The particle loses mass in the form of dust due to abrasion such as the effect of sliding along a pipe wall.

Separation: Some products, e.g., coated pellets, may not themselves degrade, but the coating is caused to separate by either abrasion or impacts.

Rupturing: Products such as sesame seeds, raisins and peanuts can be seriously damaged by rough handling. In the case of peanuts, for instance, oil cells in the surface layers of the peanut rupture with serious consequences for the down-stream process.

1.1 Product Degradation – Process Considerations

Product degradation has direct and indirect effect on production, both from a material loss and process disruption cost considerations. These costs can be considerable, especially when viewed in the context of life cycle cost analysis. The equipment life cycle is considered to be the planned economic life expectation. It may vary anywhere between three and twenty years, depending upon the nature of the process. Life cycle cost analysis considers not only the capital cost of the equipment, but also the total operating cost over the lifetime of the system. Operating costs will include energy consumption, the degree of automation and labor required to operate the system, wear and tear, maintenance and spare part expenditure, unscheduled down time, and material loss / damage. When a fragile material or any product that is subject to particle breakdown is a major ingredient in the process, the product loss can be a major cost factor in the life cycle cost calculation.

Product degradation can affect the process and the life cycle cost in a number of ways:

Product Loss: When a raw material or finished product suffers particle breakdown, there is a total loss of the bulk material. A fines removal process such as a screen will extract the degraded particles. However, the total weight of the product must be maintained by adding fresh product or allowing for wastage at the start of the process. This represents a direct cost to the producer.

Fines Processing: The removed fines may be disposed of or recycled. In either case, a portion of the production process must be made available for handling the fines. This can be considered either as an additional equipment cost, or a reduction in the production process in recycling the fines.

Process Disruption: A gradual build-up of fines within a plant process may have detrimental effects on the process itself. For instance, a combustion process that relies on a certain particle size may lose efficiency because it cannot completely combust the fines. This fuel is either lost or must be recycled in some way.

Maintenance: Very fine particles may escape into open areas requiring clean up. In the case of peanuts, a gradual build-up of "meal" in mechanical systems and transfer chutes can seriously disrupt the smooth running of the plant.

2. TYPES OF HANDLING SYSTEMS AVAILABLE

2.1 Mechanical Systems

The traditional method of handling bulk materials in industries where product degradation is of concern is mechanical handling systems. These types of systems were chosen because gentle handling of the product could be generally guaranteed. However, mechanical systems also have several disadvantages including the following:

Spillage and Dusting: It is difficult to completely seal mechanical conveyors, especially at transfer points. Subsequently material will spill into operating areas and /or dust will migrate to all parts of the plant. In the case of carbon-based materials, the dust may be an explosion or fire hazard. Spillage in the food processing industry cannot be tolerated, and must be cleaned up quickly. Otherwise rodent, insect and bacteriological problems will ensue.

Maintenance: Bucket elevators, bucket conveyors, screw conveyors and so on all contain many moving parts; and as the system ages, these parts are subject to breakdown and wear. Apart from spare parts usage and normal maintenance labor costs, there is always the risk of unscheduled downtime and the resultant cost to production.

Cross-contamination: This can be a serious problem in industries where manufacture is in the form of batch production, such as the animal feed industries. It can also be a problem for the food industries when multiple ingredients are used. Many materials may be cohesive, due to moisture and / or static charge, and this can cause residual accumulation in the buckets of a bucket elevator, along with spillage into the boot *(Figure 1)*. Screw conveyors can also accumulate material between the flights and trough casings. Screw conveyors are also prone to cause degradation with many materials. These accumulations continue to adhere to surfaces until there is sufficient weight to cause it to fall into the batch being conveyed *(Figure 2)*.

2.2 Pneumatic Conveying Systems

Pneumatic conveying systems have been used as a practical alternative to mechanical systems in many industries requiring bulk material handling. The advantages include:

Totally enclosed dust-free operation. Spillage is virtually eliminated if good valving is used.

Maintenance cost savings. Most pneumatic systems use few moving parts, and therefore require less maintenance and a lower spare parts expenditure than for mechanical systems. A properly designed pneumatic system will be highly reliable with little chance of unscheduled downtime.

Less cross-contamination. Pneumatic conveying systems can be purged at the end of a batch run, virtually eliminating the problems of cross-contamination.

However, there are many pneumatic conveying systems that are not suitable for handling fragile materials, especially where product degradation is of concern. A review of the main types of system compares the ability of each to handle fragile materials.

3. TYPES OF PNEUMATIC SYSTEM

3.1 Dilute Phase

Dilute phase relies on a high velocity, so as to convey the material in a suspended flow *(Figure 3A)*. Material velocities can vary between 12 and 18 M/S at the feed end of the system, and 20-30 M/S at the terminal points. It is well known that product degradation increases substantially with higher velocities. In the case of dilute-phase, the particle breakage is caused by impacts on pipe walls and deflectors and inter-particle activity.

3.2 Continuous Dense Phase

The continuous dense phase, characterized by a moving bed type of flow *(Figure 3B)*, will provide an improvement over the dilute phase system. This is due to two factors: Firstly, average material velocities are lower, in the range of 5 to 10 M/S; secondly, there is far less material being conveyed in a suspended flow. Particle breakage is due mainly due to medium velocity impacts and abrasion as the mass of material slides along the pipe. It should also be noted that this type of flow is usually restricted to materials that are capable of fluidization and have relatively high air retention properties (see also Section 4).

3.3 Discontinuous Dense Phase

The discontinuous dense phase, characterized by a plug type flow *(Figure 3C)*, is usually ideal for conveying most fragile materials. Excellent results can be obtained due to quite low average material velocities in the 1.0 to 5.0 M/S range, and the nature of the flow in the pipeline. Since plug flow conveying provides for the material filling the entire cross section of the pipeline with plug lengths in the range of 0.5 to 10 M, much less material is exposed to contact with the pipe walls. Hence, abrasion is much reduced; and since the velocity is low, impact breakage is also substantially reduced. Inter-particle impacts due to suspended material is virtually eliminated.

3.4 Solid Flow Dense Phase

There are some materials which, due to their fragile nature, will not produce good degradation results with the discontinuous dense phase. An example of such a material is raw peanuts. Plug flow does not reduce the level of damage of the peanuts to an acceptable level. Solid flow dense phase will, however, provide good results due to the unique flow conditions in the pipeline. It is possible with certain materials, to completely pack the pipeline with material. The material tends to move through the pipeline in an extrusion type flow *(Figure 3D)*, and velocity is very low – usually in the range of 0.25 to 1.0 M/S.

4. MATERIAL CHARACTERISTICS

Before selection of a particular pneumatic regime can be made, reference must be made to the characteristics of the material to be handled. The characteristics include bulk density, particle size distribution, particle shape, moisture content, friability, and certain fluidization properties. In the context of gentle handling of fragile materials, the friability, particle size distribution and particle shape are the most influential.

Particle Size Distribution / Particle Shape. The particle size distribution is necessary to determine average particle size which, in turn, can point to the fluidization properties of the bulk material. Particle size analysis is one of the most commonly used methods of determining the level of product degradation, and this is normally carried out during material conveying tests (refer also to Section 6). Particle distribution, in conjunction with particle shape, influences the degree of fluidization of the material. Geldhart demonstrated that those materials with a particle density and average particle size occurring in a specific range are likely to readily fluidize.

It is well known that particles with a round or globular shape will also tend to fluidize more easily. Properties such as aeration factor and air retention can also be used to determine a material's fluidization potential. Work carried out by Jones and Mainwaring demonstrated that material characteristics can be used to predict if a bulk material can be fluidized. Materials that fluidize easily and have good air retention properties, such as fly ash and cement, will usually convey in a moving bed type flow; whereas materials such as sugar, salt, petroleum coke, which do not fluidize, will convey in a plug flow regime. When considering solid dense phase, it must be noted that this method of conveying cannot be applied to all materials. Experience to date has shown that only those materials with round particle shape, relatively mono-sized distributions, and large average particle size are suitable candidates.

Friability. Friability is the degree of fragility of a material. Some materials are quite hard, silica sand for example, and will be able to better resist higher velocities. Sand can be conveyed with excellent results in a plug flow regime. Sand is extensively used in the foundry industry where it is important to reduce the level of particle degradation to a minimum. Excessive degradation results in the addition of higher quantities of new sand to replace the dust that must be removed from the process. Other materials, such as peanuts, popping corn and sesame seeds, are much more fragile and will tend to not meet degradation limits using plug flow conveying methods.

5. LOW VELOCITY SYSTEMS

There are several types of dense phase systems available; however, the user should endeavor to select a system which will provide the lowest possible velocity and most stable conditions within the pipeline. Prudent selection should take into account other customer objectives such as conveying rate and system size.

Often it is not necessary to provide extremely low velocities at the expense of the conveying rate. The best way to correctly assess the velocity requirements for a particular material is to carry out full-scale tests using representative materials. The user should avoid certain system types which include the following:

Systems which rely on fluidization or pressurization of the vessel prior to opening the vessel discharge valve. This usually results in a high discharge velocity from the vessel which can not only cause degradation through high conveying velocity, but also degradation as the product leaves the vessel itself.

Air injection directly into the pipeline in the form of "boosters". This type of air injection usually increases velocity due to the addition of the air at each injection point. There is also a certain degree of turbulence at the injection point which can add to the product degradation. Some systems use internal or external air bypass systems as a defense against over-dense plugs forming and becoming potential pipeline blockages. These defensive systems often do not use additional air, but by-pass the normal conveying air from the rear of the plug to the front of the plug. Velocity in these type systems is not increased.

6. SUCCESSFUL LOW PRODUCT DEGRADATION SYSTEMS

There are a number of practical steps a user can take to optimize the system to produce the lowest level of product degradation.

Design of Feed Arrangement. Avoid the use of vibration and / or aeration as much as possible by using mass flow designs on feed bins and hoppers. Any turbulence will cause damage to the product. A vessel filling valve which has a full port is preferable (see also next paragraph). Smaller pressure vessels are also preferable since the vertical distance the material has to fall is reduced, and breakage due to impacts is minimized *(Figure 4)*.

Vessel Filling Valves. Full ported valves are preferable for two reasons: (a) mass flow conditions are promoted; and (b) impacts onto the blade, for instance of a butterfly valve, are eliminated. Slide gates should be avoided since these may cause crushing of the product when closing. Also slide gates are difficult to pressure seal.

Pipe Routing. The golden rule is to keep it simple. The fewer the number of bends, the less impact breakage will occur. Include only one vertical section of pipe, and arrange for this to occur as close to the beginning of the system as possible *(Figure 5)*. Avoid inclined sections of pipe greater than 15°. Steeply inclined pipes up to about 70°, and second vertical sections cause back-flow where a portion of the conveyed material falls or slides in a reverse direction. This will cause at the least a double handling effect and increase the breakage level. At worst, over-dense slugs will develop and the pressure in the system will rise with a subsequent detrimental effect on conveying stability and velocity.

Pipeline Connections. Good alignment of the pipeline is essential. Even at low velocity, product degradations will occur at the exposed ledges of pipe connections caused by poor pipe alignment. The preferred pipe connections are flanged joints; however, the best alignment is obtained using male / female flanges *(Figure 6)*.

Reception Bins. All reception bins should, wherever possible, be maintained in a topped up condition. High level probes can be used to maximize bin capacity without overfilling *(Figure 7)*. This arrangement reduces the vertical height the material has to fall after discharge from the pipeline. The pile of the material also tends to "cushion" the fall of the material.

Conveying into empty bins should be avoided since the vertical fall will be increased, and the product will collide with the steel walls / cone of the bin. Tangential entries to bins should also be avoided since the material will again collide with walls of the bin. For large bins which must be emptied on a regular basis for batch control purposes, a spiral letdown chute internally fitted to the bin will provide for good results *(Figure 8)*.

The Need for Testing. Before committing to any particular pneumatic system type, the user should first carry out conveying tests at one or more of the proposed vendors. The tests should be full scale, i.e., using production size equipment and with relevant conveying distances. The test program should demonstrate / determine the following:

Smooth and stable conveying conditions

Air consumption – flows and pressures

Cycle time and system capacity

Particle distribution before and after conveying over several runs using fresh material each time. It should be noted that product degradation is not always determined by particle size analysis. The user will, however, normally be able to carry out a proprietary test to determine the actual degradation caused.

Practical recommendations for optimizing the system.

7. CONCLUSIONS

Today's dense phase pneumatic conveying systems are able to provide the same gentle handling of fragile materials as mechanical systems while eliminating problems such as dusting / spillage, cross-contamination and high maintenance costs. The user should, however, be prudent and carry out full-scale tests wherever possible. The issue of material velocity and all of the factors relative to velocity control should be carefully assessed.

8. REFERENCES

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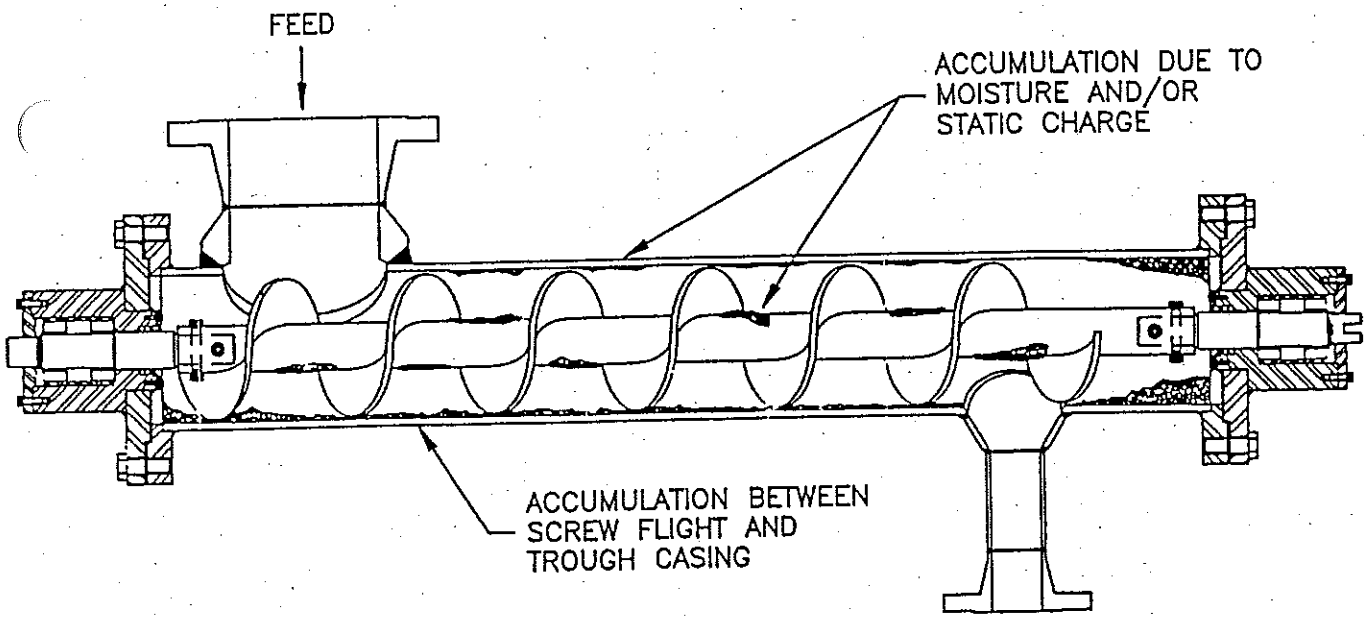

FIGURE (1)

EXAMPLES OF RESIDUAL ACCUMULATION
IN SCREW CONVEYOR

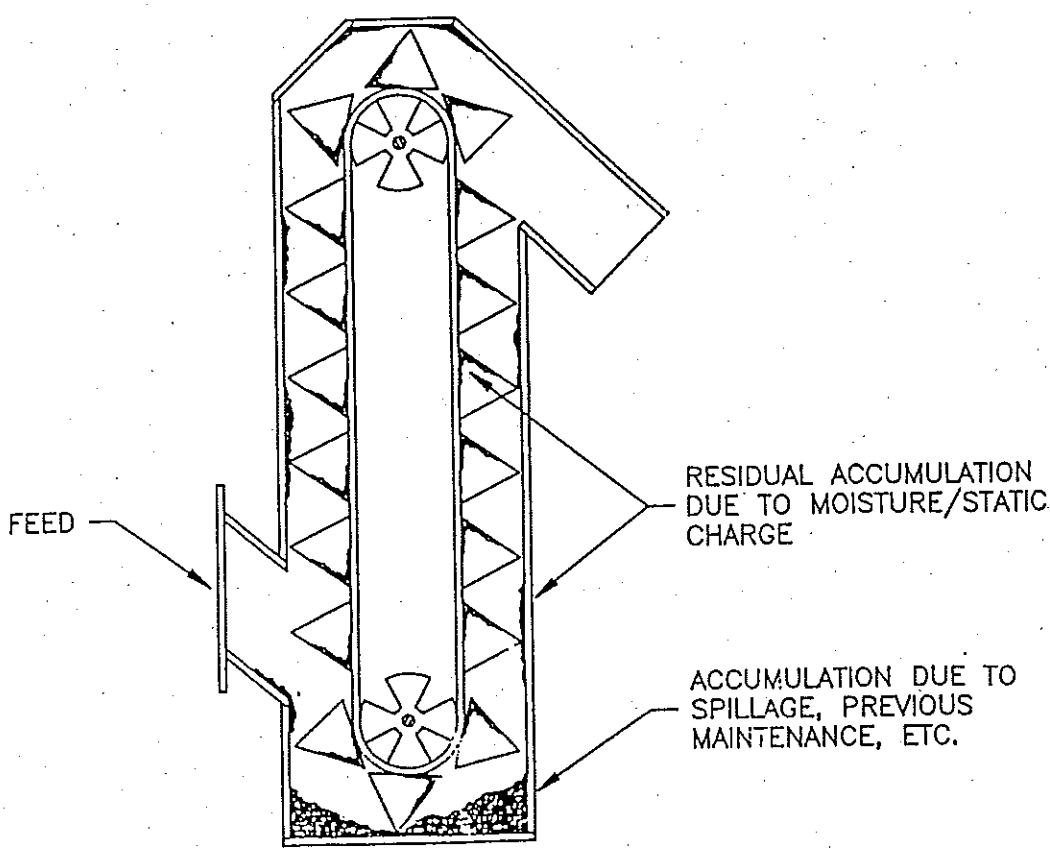

FIGURE (2)

EXAMPLES OF RESIDUAL ACCUMULATION
IN BUCKET ELEVATORS

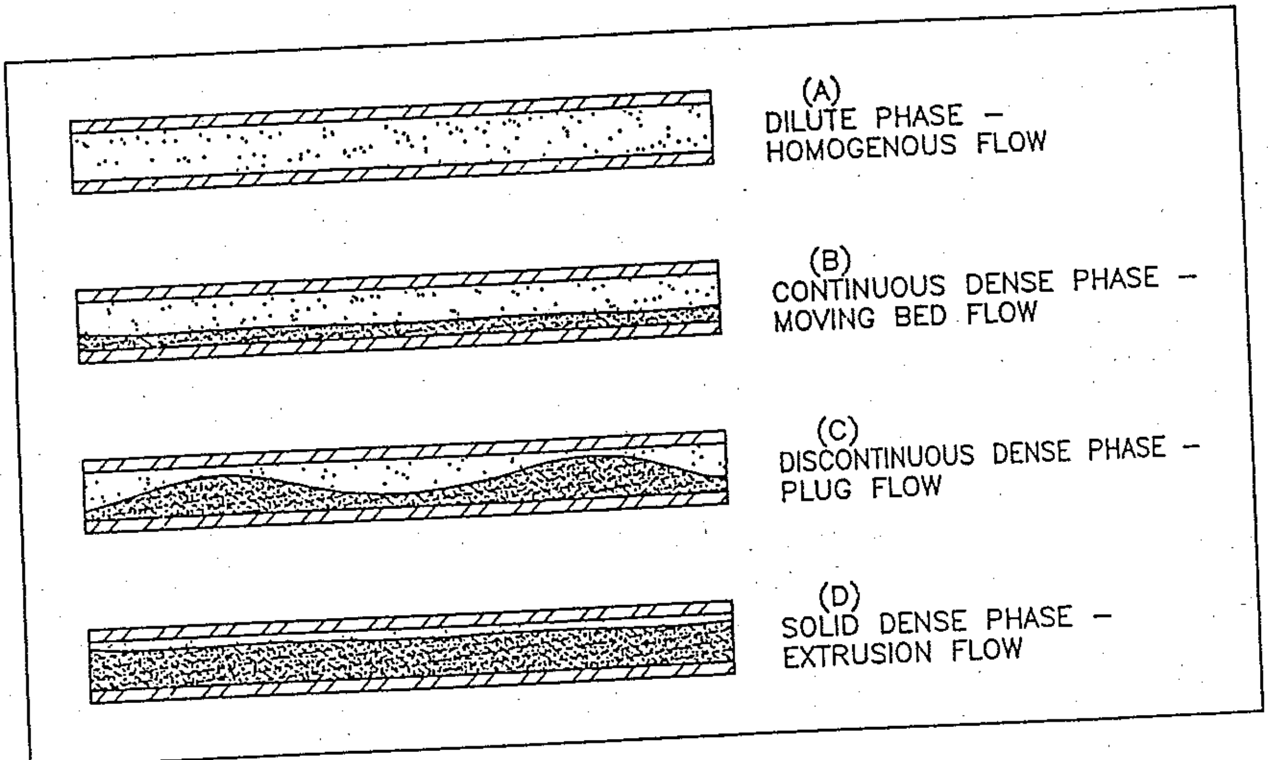

FIGURE (3)
JODLOWSKI'S STABLE FLOW CLASSIFICATION

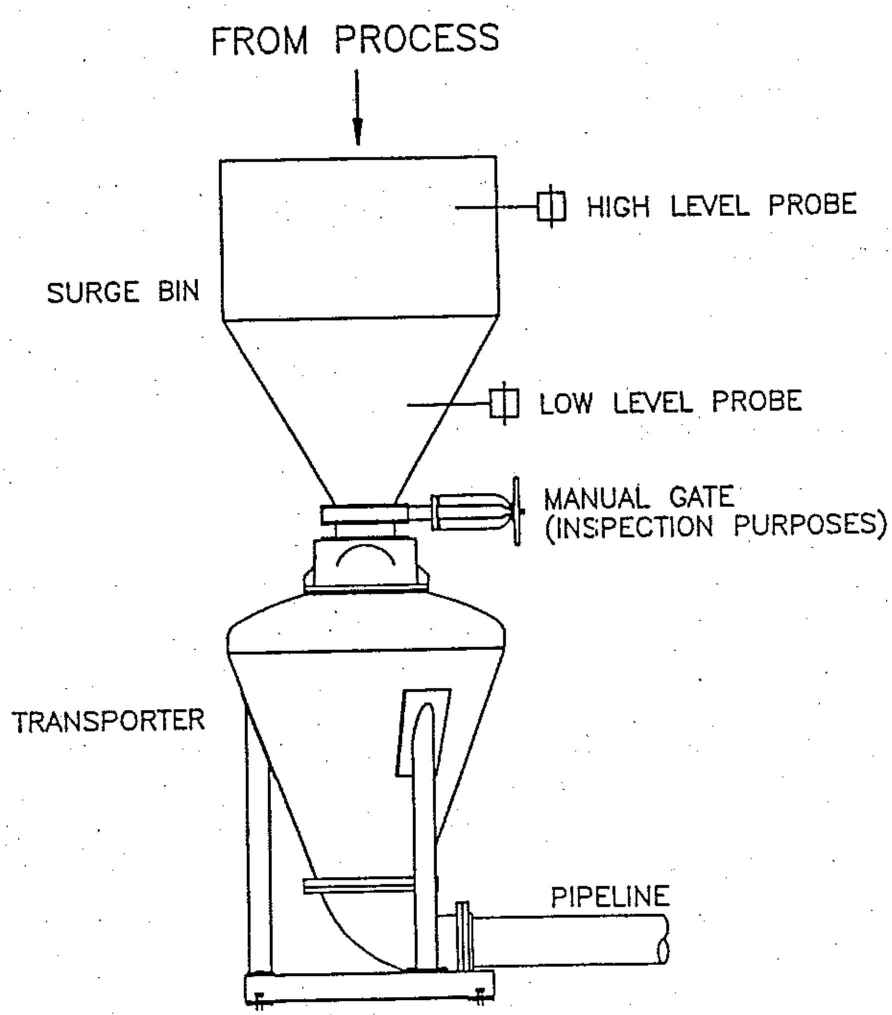

FIGURE (4)
TYPICAL FEED ARRANGEMENT

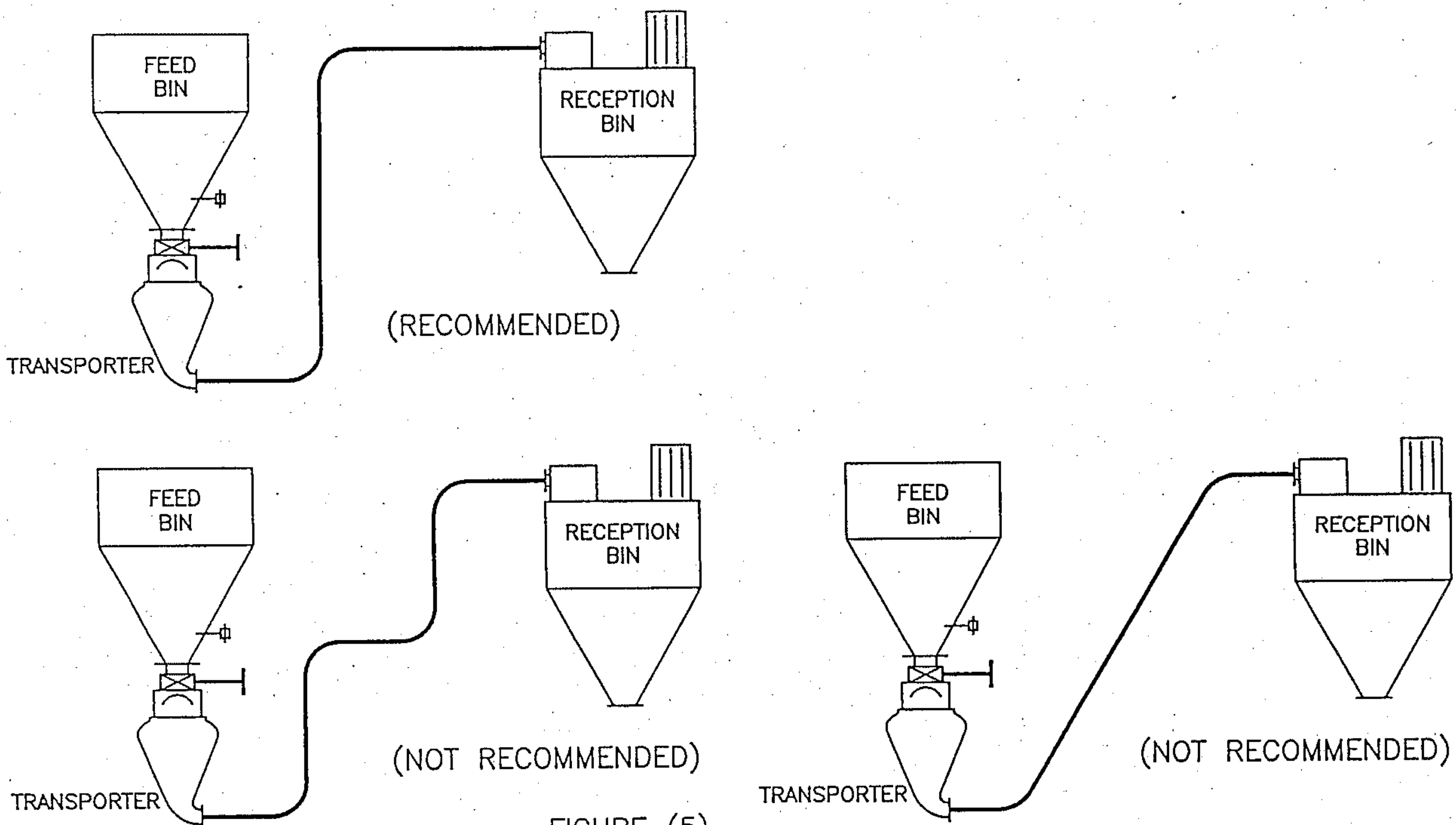

FIGURE (5)
PIPE ROUTING

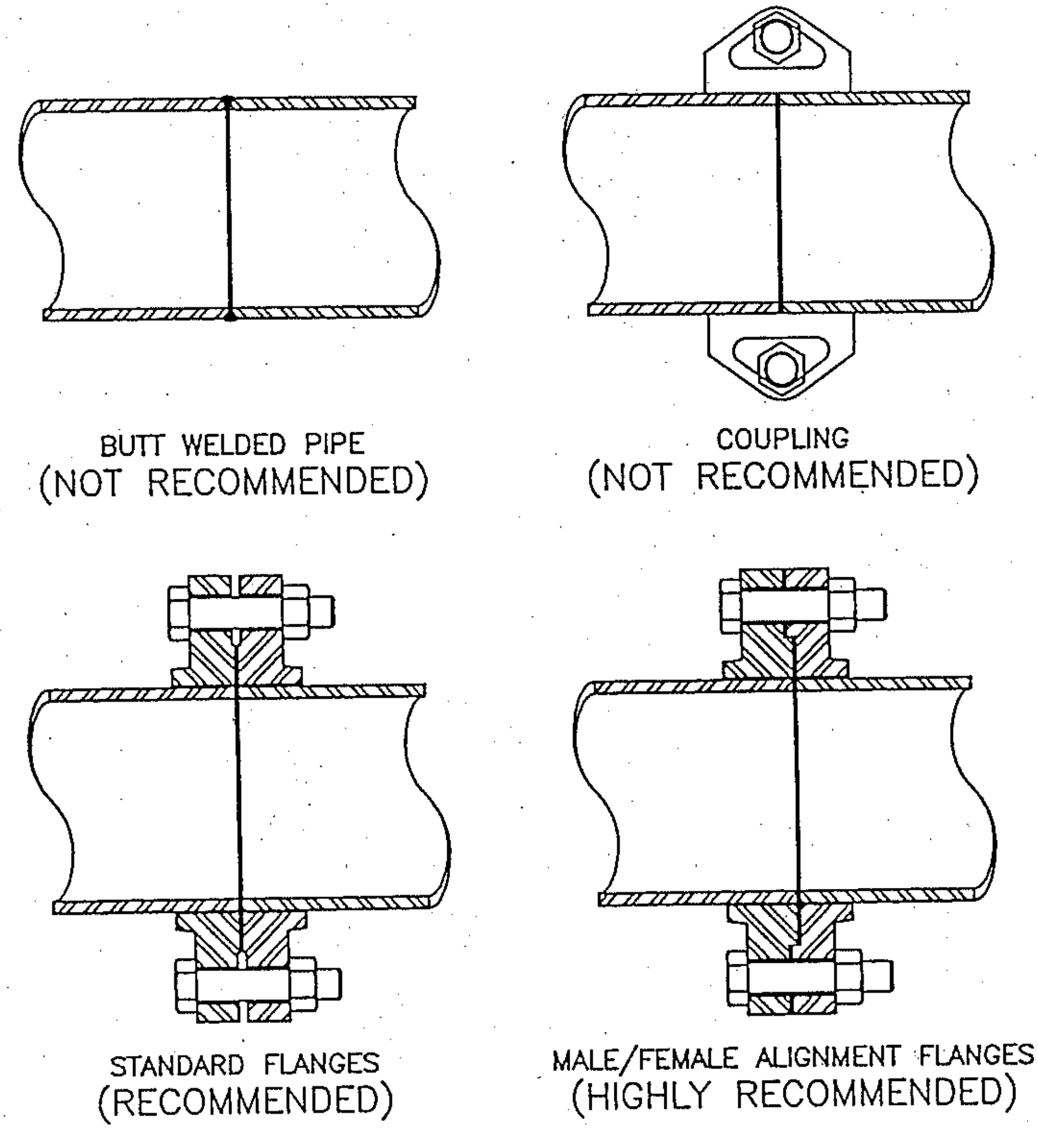

FIGURE (6)
TYPES OF PIPE CONNECTIONS

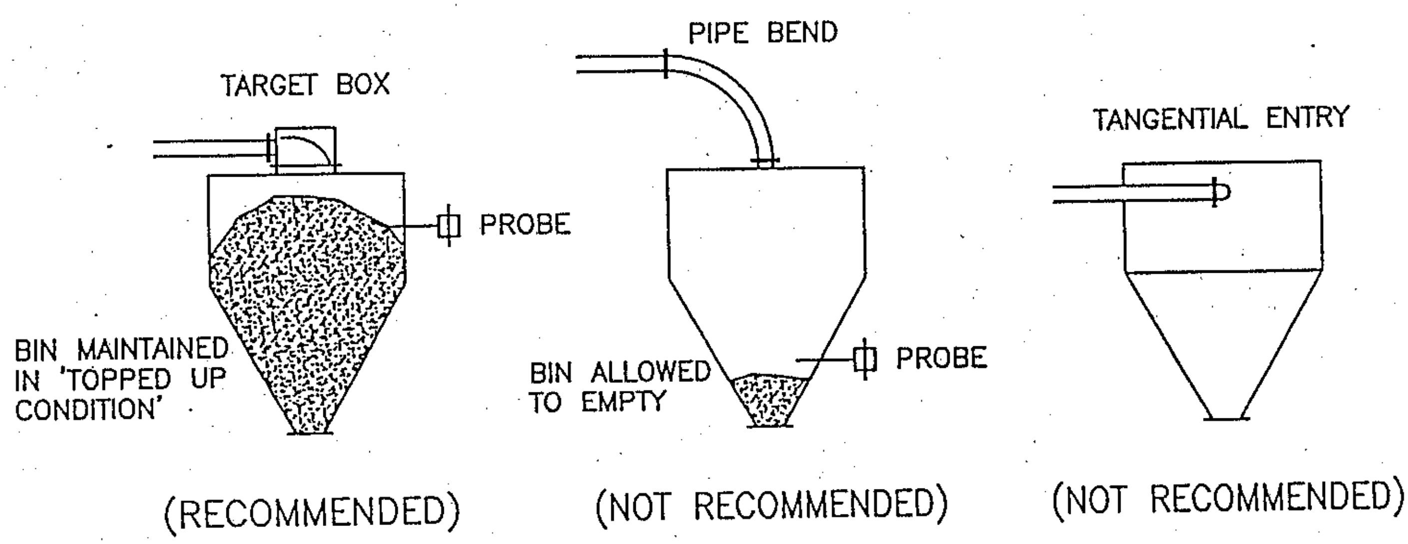

FIGURE (7)
RECEPTION BIN ARRANGEMENTS

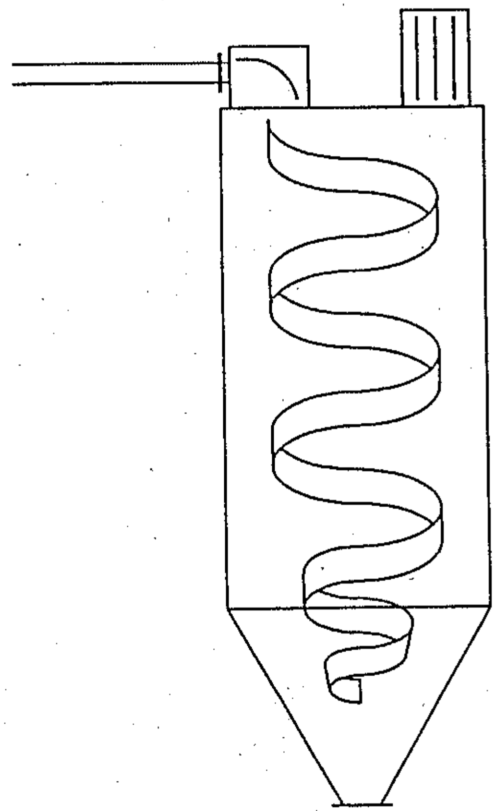

FIGURE (8)
RECEPTION BIN WITH SPIRAL CHUTE