United States Patent [19]

Capes et al.

[11] **3,776,601**

[45] **Dec. 4, 1973**

[54] **METHOD AND APPARATUS FOR CONVEYING PARTICULATE MATERIAL UPWARDLY IN A GAS STREAM**

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[73] Assignee: **Canadian Patents and Development Limited,** Ottawa, Ontario, Canada

[22] Filed: **Nov. 30, 1971**

[21] Appl. No.: **203,132**

[30] **Foreign Application Priority Data**

Feb. 19, 1971 Canada 105,787

[52] **U.S. Cl.** **302/64**

[51] **Int. Cl.** **B65g 53/52**

[58] **Field of Search**....................... 138/37, 39, 140, 138/153, 172, 173; 302/17, 53, 64

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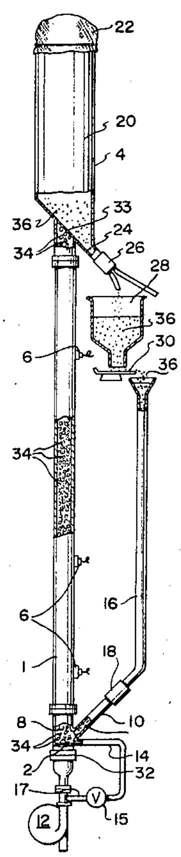
Assistant Examiner—W. Scott Carson
Attorney—James R. Hughes

[57] **ABSTRACT**

Particulate material is conveyed upwardly in a gas stream in an elongated casing, with the gas stream having a velocity less than the conventional choking velocity, by having gas and particle stream deflecting elements, such as wire mesh cylinders, randomly disposed along the length of the casing.

6 Claims, 9 Drawing Figures



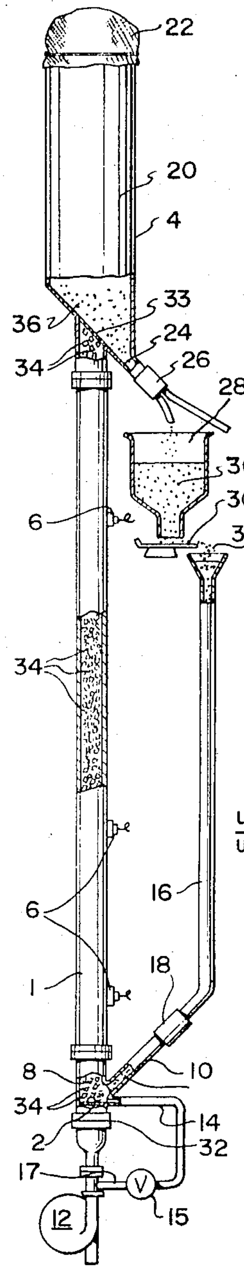


FIG. 1.

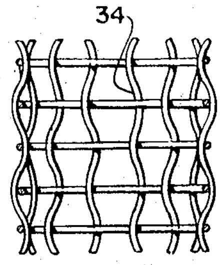


FIG. 3.

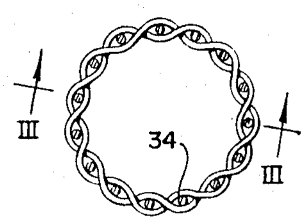


FIG. 2.

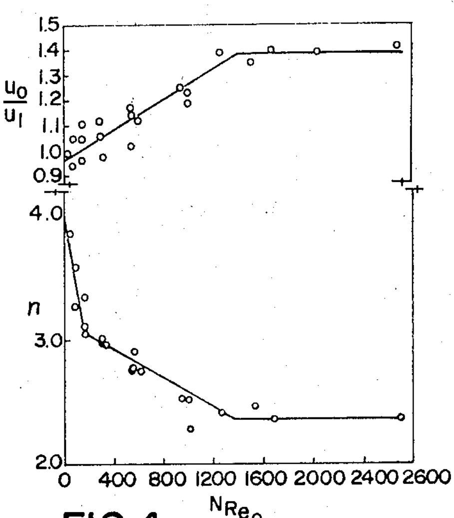


FIG. 4.

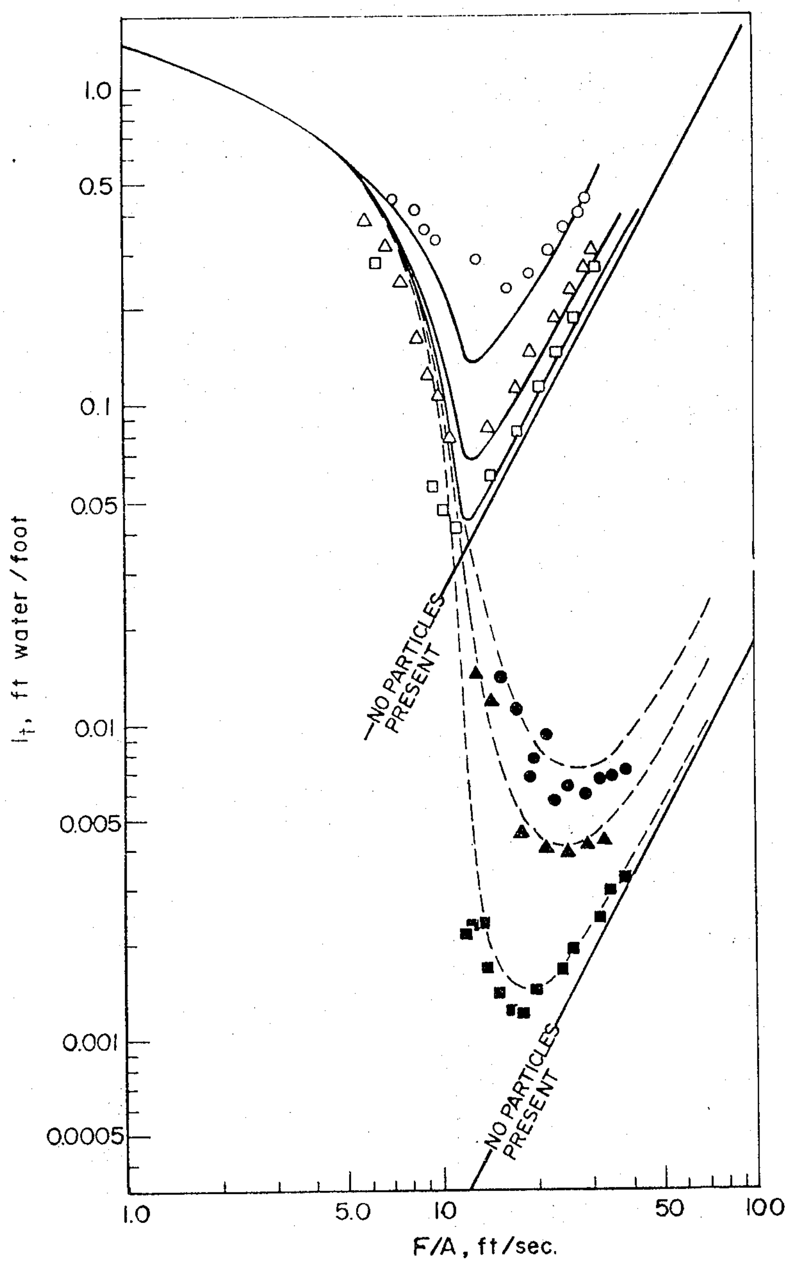

1.0
0.5
0.1
0.05
0.01
0.005
0.001
0.0005
I_t, ft water / foot
NO PARTICLES PRESENT
NO PARTICLES PRESENT
1.0
5.0
10
50
100
F/A, ft/sec.

FIG.5

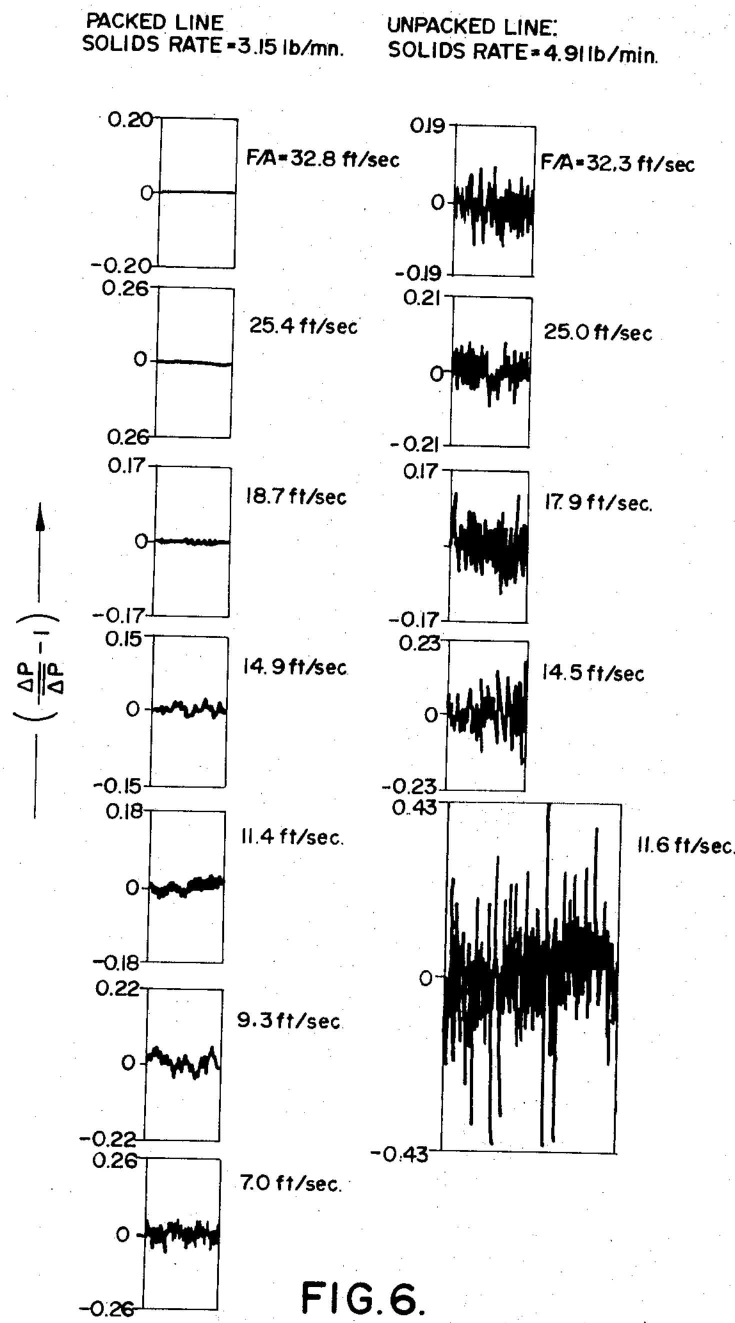

PACKED LINE
SOLIDS RATE = 3.15 lb/mn.
UNPACKED LINE:
SOLIDS RATE = 4.91 lb/min.
0.20
0
-0.20
F/A = 32.8 ft/sec
0.26
0
0.26
25.4 ft/sec
0.17
0
-0.17
18.7 ft/sec
0.15
0
-0.15
14.9 ft/sec
0.18
0
-0.18
11.4 ft/sec.
0.22
0
-0.22
9.3 ft/sec
0.26
0
-0.26
7.0 ft/sec.
0.19
0
-0.19
F/A = 32.3 ft/sec
0.21
0
-0.21
25.0 ft/sec
0.17
-0.17
17.9 ft/sec.
0.23
0
-0.23
14.5 ft/sec
0.43
0
-0.43
11.6 ft/sec.

FIG. 6.

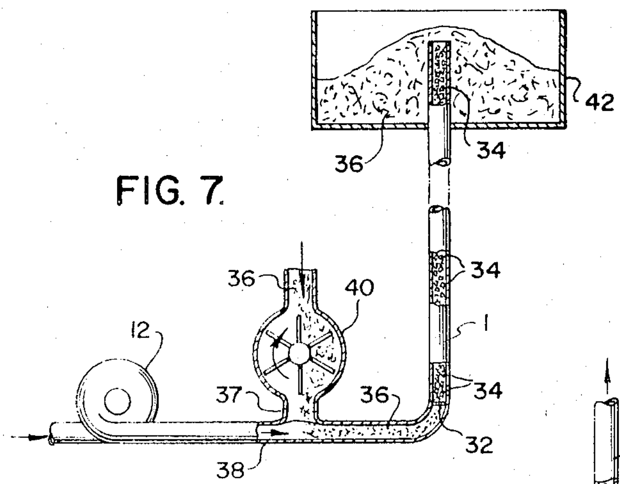


FIG. 7.

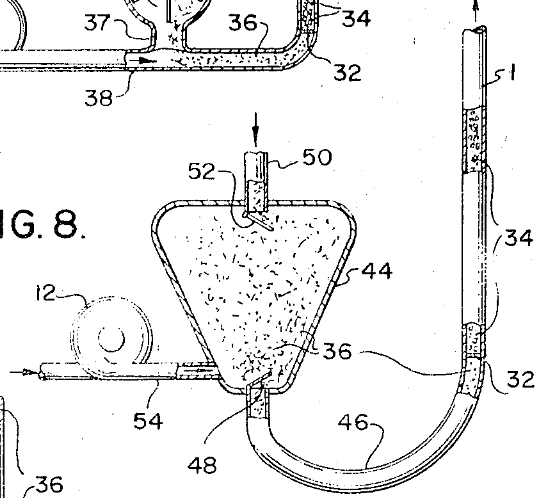


FIG. 8.

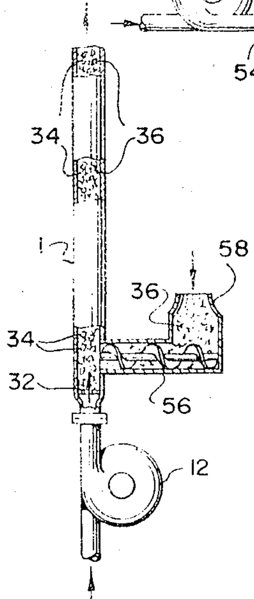


FIG. 9.

METHOD AND APPARATUS FOR CONVEYING PARTICULATE MATERIAL UPWARDLY IN A GAS STREAM

This invention relates to a method of and apparatus for conveying particulate material upwardly in a gas stream.

In, for example known types of vertical pneumatic conveying systems the velocities of the conveying gas stream must exceed a certain minimum magnitude known as the choking velocity to avoid the phenomenon known as choking. For a given particulate flow rate, when the velocity of the conveying gas stream is reduced to choking velocity the entire suspension collapses so that a condition of what is known as slug flow occurs. Slug flow particularly must be avoided in large diameter conduits because of the attendant violent vibrations which occur owing to the large changes in inventory (i.e. total volume of particulate in conduit) caused by the ejection of slugs of the particulate.

However, it has been thought to be desirable to convey particulate material in a gas stream having a velocity which is less than the choking velocity because compared with known systems operating above the choking velocity, attrition by the particulate material of, say, the conduit is reduced because of the low turbulence within the conduit, and for a given particulate material flow rate a more compact structure may be used with a consequently reduced capital investment due to the greater conveying capacity per unit line diameter of the conduit.

Two methods of conveying particulate material in a gas stream having a velocity which is less than the choking velocity are presently used commercially. One method described by R.R. Towers in Standen, A (Ed.),"Kirk-Othmer Encyclopedia of Chemical Technology", 2nd ed., vol. 6, p. 114, Interscience Pub., New York (1965), the particulate material in a dry, finely pulverized form having a proper size distribution in one operation is compressed by a screw pump and aerated by the gas conveying stream in a mixing chamber. The compressed, aerated particulate material is then discharged from the mixing chamber and conveyed as a fluid-like mass along a pipeline by continuous displacement therealong by means of the screw pump supplying fresh particulate material to the mixing chamber. The particulate material is thus conveyed partly by the conveying gas stream and partly by the mechanical power of the screw pump. This method is restricted to particulate materials which have sufficiently fine particle size range to assume an aerated condition and then retain this condition for a substantial time.

The second method of conveying particulate material in a gas stream having a velocity which is less than the choking velocity is described by Berg in U.S. Pat. Nos. 2,684,868; 2,684,870 and 2,684,872 all dated July 27, 1954. Berg's method uses a "mass flow" technique employing co-current upflow of gas stream and particulate material in an unfluidized state produced by the restriction of the vertical column of solids at the discharge end of a lift line. The particles of the material move as a mass of porosity equal to that of a fixed or stationary bed rather than being suspended in an entrained manner in the gas stream as in conventional pneumatic conveying.

According to the present invention there is provided an apparatus for conveying particulate material upwardly in a gas stream comprising an upwardly extending, elongated casing having at the lower end a particulate material and gas stream inlet, and at the upper end a particulate material and gas outlet, gas and particle stream deflecting elements disposed along the length of the casing for restricting the mobility of particles therealong, and gas supply means connected to said inlet for supplying the conveying gas stream for the particulate material at a velocity less than the choking velocity for the particulate material.

Further according to the invention there is provided a method for conveying particulate material upwardly in a gas stream, comprising conveying the particulate material upwardly by means of a gas stream and retarding choking in the casing by restricting particle mobility by means of gas and particle stream deflecting elements in the casing.

In the accompanying drawings which illustrate, by way of example, embodiments of the invention,

FIG. 1 is a diagrammatic side view of an apparatus for conveying particulate material upwardly in a gas stream,

FIG. 2 is an end view of a cylindrical screen packing in the apparatus shown in FIG. 1,

FIG. 3 is a side view of the packing shown in FIG. 2,

FIG. 4 is a graph of the slope n and ratio of Uo/Ui as a function of N_{Re_o} as will be described later,

FIG. 5 is a graph of the gas pressure drop along the apparatus shown in FIG. 1 for various gas velocities as a function of the feed rate of the particulate material and gas, with and without deflecting elements in the apparatus,

FIG. 6 shows graphs of the gas pressure fluctuations across the 4 to 10 feet level of the conveying line with and without deflecting elements therein, and

FIGS. 7 to 9 show different embodiments of the invention to that shown in FIGS. 1 to 3.

In FIG. 1 an upwardly extending, elongated casing in the form of a conveying section 1 composed of three 3 inch diameter bore by six feet long acrylic plastic pipes was connected together between a feed section 2 and a discharging section 4. The conveying section 1 was fitted with pressure taps 6 at three feet intervals.

The feed section 2 comprised a pipe junction 8 having a ¾ inch diameter bore particulate material inlet 10 and a variable capacity gas pump 12 forming a gas supply means. The particulate material inlet 10 had a particulate material carrier air inlet 14 which was also connected to the pump 12 by means of a valve 15 and a branch pipe 17. A feed standpipe 16 of 1½ inch diameter bore copper pipe was connected to the inlet 10 by a particulate material feed rate orifice 18.

The discharging section 4 comprised a casing 20 having a filter bag 22 covering an open upper end. An inclined floor 24 of the casing 20 led to a diverting valve 26. A feed hopper 28 was mounted beneath the valve 26 for feeding particulate material by means of an adjustable vibrating feeder 30 to the feed standpipe 16.

The pipe junction 8 and discharging section 4 were fitted with wire mesh screens 32 and 33 respectively which contained open ended cylindrical screen packings 34 randomly oriented in the conveying section 1 as gas and particle stream deflecting elements for restricting the mobility of particles along the conveying section 1.

Referring to FIGS. 2 and 3, each of the cylindrical screen, steel packings **34** was six mesh and ¾ inch diameter × ¾ inch long.

In operation, with the apparatus arranged as shown in FIG. **1**, spherical glass beads **36** of 470 microns average diameter were fed from the feed hopper **28** into the feed standpipe **16** by means of vibrating feeder **30**. Air was passed under pressure by the pump **12** as an air stream to the feed section **2** and to the inlet **14**. The amount of air passed to the inlet **14** was adjusted to be sufficient to carry the glass beads from the feed standpipe **16** into the feed section **2**.

The glass beads **36** were carried into the feed section **2** by the air from inlet **14** were dispersed in the air stream from the pump **12** to the section **2**. The glass beads were then carried up the conveying section **1** and into the discharging section **4**. From the discharging section **4** the air stream escaped through the filter bag **22** whilst the glass beads **36** fell back on to the inclined floor **24** and then were discharged through the diverting valve **26** to the hopper **28**. The vibrating feeder **30** was adjusted to maintain a constant level of glass beads **36** in the feed standpipe **16**.

The relative humidity of the air in the conveying section was maintained at about 30 percent to overcome electrostatic effects of the glass beads **36**. The diverting valve **26** was used to measure the flow rate of the glass beads **36** along the conveying section **1**.

A number of series of experiments were carried out with the apparatus operating in the above manner, and in each series of experiments the feed rate of the glass beads **36** into the hopper **28** was of a constant magnitude. For each series the operating conditions were set for the experiment of that series with the air stream at the highest value, and then the operation was allowed to come to a steady state for approximately one hour before the pressure gradient up the conveying section **1** and the rate of flow of glass beads **36** was measured. The velocity of the air stream was then reduced to the next lowest value and the same readings were taken. The experiment was continued in this manner until all of the readings were taken.

The experiments were repeated without the packings **34** in the conveying section **1**.

With the packings **34** present it was found by experiment that a preferred upper limit for gas velocity is the normal choking gas velocity for uniformly-sized particles without the packing **34**, which may be predicted approximately from the following equation:

$$F/A = 0.97\ Uo + 32.3\ (S/A),$$

where

F is the volume flow rate of fluid, ft³/sec

S is the volume flow rate of solid, ft³/sec

Uo is the terminal falling velocity of a single particle, ft/sec

and A is the cross-sectional area of the conveying section, ft².

Uo may be calculated, for example, from the tables given in "Interaction between Fluids and Particles", page 1, Institution of Chem. Engrs. London 1962.

Further, with the packing **34** present it was found by experiment that a suitable lower limit for the gas velocity is given approximately by the equation:

$$F/A = (0.80)^n\ Ui + 4\ (S/A)$$

F, S and A have the meanings given above. The quantities n and Ui may be obtained from the graph shown in FIG. **4**, where the ratio Uo/Ui and n are plotted against N_{Re_o},

Uo has the meaning given above,

Ui is an extrapolated value of the superficial gas velocity (ft/sec) when the porosity in the conveying section **1** approaches unity,

N_{Re_o} is the particle Reynolds number under free falling conditions, and n is the slope obtained from plotting the log of the superficial gas velocity against the porosity in the conveying section **1**.

Referring to FIG. **5** there is shown graphs of the pressure gradient in feet of water per foot line of the conveying section **1** as a function of the feed rate of the glass beads **36** from the inlet **10**, and the feed flow rate of gas from the pump **12**.

With the conveying section **1** containing packings **34**,

□ represents a glass bead **36** feed rate of 0.55 lbs/min.,

△ represents a glass bead **36** feed rate of 3.15 lbs/min.,

○ represents a glass bead **36** feed rate of 12.61 lbs/min., with the conveying section **1** containing no packings **34**,

□ represents a glass bead feed rate of 0.78 lbs/min.

△ represents a glass bead feed rate of 4.91 lbs/min.,

○ represents a glass bead feed rate of 10.89 lbs/min.,

These curves show that the pressure gradient decreases at first with increasing gas flow, going through a minimum, and then increasing again.

As shown by the recorded pressure fluctuations in FIG. **6**, with the gas velocity just below the level for minimum pressure gradient, choking occurs without the packings **34** in the conveying section **1**. By contrast it was found that with the packings **34** present, choking did not occur even at lower gas flow velocities.

Thus using apparatus according to the invention it is possible to use a lower rate of feed of gas to convey particulate material than is possible with a conveying line containing no packings, even though the pressure drop is greater along the conveying line.

A second, similar series of experiments was made using the same packings **34** but glass beads **36** of 120 microns average diameter. With the section **1** containing no packings **34** the observed choking velocities were:

Glass beads feed rate (lbs/min)	Choking gas velocity (ft/sec)
9.0	6–7
4.6	5.5–6.5
0.8	5–6

The same experiments were performed with the section **1** containing the packings **34**, and non-choking, steady operation was achieved at gas velocities below those which lead to choking without the packings **34** present in the section **1**.

A third series of experiments were performed to test the abrasion resistance of the packings **34**. It will be appreciated that the packings **34** must be capable of operating with little wear to yield an economical method of conveying particulate material. An experimental apparatus was used similar to the apparatus shown in FIG. **1**, but with the section **1** three inches internal diameter by six feet long, the section **1** contained the packings **34** in FIGS. **2** and **3**. In this instance the packings **34** were No. 6 mesh stainless steel cylinders ¾ inch diameter × ¾ inch long.

In the third series of experiments grit blasting silica sand was recirculated in the system at a rate of approximately three pounds per minute the air velocity from the pump **12** set at 14.2 feet per second the total weight of the packings **34** was measured after various periods, and the results were:

Days of operation	Weight of packings 34 grms
0	2029
5	2028
9	2026
17	2024
47	2021

The above results indicate that negligible wear of the packings **34** took place, although it was observed that considerable attrition of the sand took place over the same period of operation.

It will be appreciated that the design of the apparatus according to the invention should comply with good engineering practice as is now applied to conveying systems. For example, at the discharge end of the conveying section **1** provision is preferably made for dust collection if the particulate material is friable. Additionally, when operating at relatively dense conveying conditions in the conveying section **1** it may be found necessary to force feed the particulate material, by, for example, a screw conveyor to overcome the head of particulate material in the conveying section **1**,

In FIGS. **7** to **9** parts similar to those in FIGS. **1** to **3** are designated by the same reference numerals, and the previous description is relied upon to describe them.

In FIG. **7** the inlet end of the conveying section **1** is connected by a branch pipe **37** of a feed pipe **38** to a rotary vane feeder **40**. The feed pipe is connected to the pump **12**. The outlet end of the conveying section **1** is connected to a receiving tank **42**.

In operation gas is passed along the feed pipe **38** by means of pump **12**, whilst particulate material **36** is fed at a predetermined rate by the feeder **40** into the feed pipe **38**. The gas **12** entrains the particles **36** and carries them upwardly along the conveying section **1** where the packings **36** actasdeflecting elements to prevent choking. The particles overflow from the top of the conveying section **1** into the tank **42**.

In FIG. **8** showing batch operation, the conveying section **1** has a blow tank **44** connected to its inlet by means of pipe **46**. The tank **44** has an outlet valve **48**, and a particulate material inlet **50** containing a valve **52**. The pump **12** is connected to an inlet **54** to the tank **44**. The upper end of the conveying section is connected to a receiving tank **42** (FIG. **7**).

In operation valve **48** is closed and particulate materials **36** is fed into the tank **44** through the inlet **50**. Valve **52** is closed and valve **48** opened. Particulate materials **36** becomes entrained in gas from the pump **12** through the inlet **54**. The entrained particulate material **36** leaves the tank **44** and passes along the pipe **46** to be conveyed upwardly along the conveying section **1** to emerge therefrom at the upper end. This embodiment is particularly suitable for batch feeding the particulate material **36** to the conveying section **1**.

In FIG. **9** the conveying section **1** has particulate material screw feeder **56** connected to it. The feeder has an inlet **58** for the particulate material **36**. The pump **12** is connected directly to the lower end of the conveying section **1**. The upper end of the conveying section **1** is connected to a receiving tank similar to the receiving tank **42** (FIG. **7**).

In operation particulate material **36** is fed into the inlet **58** and conveying section **1**. Gas from the pump **12** conveys the particulate material up the conveying section **1** where it emerges therefrom at the upper end.

It will be appreciated that in other embodiments the conveying section **1** is of a flexible material, for example a plastic such as a polyamide, and may be capable of connection to a number of, say, receiving tanks above the conveying section **1**. Thus the conveying section may be used to transport particulate material to any one of the receiving tanks.

In different embodiments of the invention different packings to the packings **34** may be used, made, for example, from plastic, wire, stamped metal sheet, or ceramic material, packings known as "Pall Rings", "Tellerettes", or "Lessing Rings" may be used.

The packing should preferably occupy a very small proportion of the internal volume of the section **1**, the packing occupying about 5 or 6 percent or less of the internal volume of the section **1** has been found to be suitable.

We claim:

1. Apparatus for conveying particulate material upwardly in a gas stream, comprising an upwardly extending, elongated casing having at the lower end a particulate material and a gas stream inlet, and at the upper end a particulate material and gas stream outlet, gas and particle stream deflecting elements disposed along the whole length of and extending across the whole width of the casing as a filling therein, the gas and particle stream deflecting elements being discrete elements whose maximum dimension is substantially less than half the diameter of said casing, said elements being randomly oriented in the casing and occupying up to 6 percent of the internal volume of the elongated casing, for restricting the mobility of particles therealong, and gas supply means connected to said inlet for supplying the conveying gas stream for the particulate material at a velocity less than the choking velocity for the particulate material.

2. Apparatus according to claim **1**, wherein the flow rate of the conveying gas stream is substantially within the range.

$$F/A = (0.80)^n \, Ui + 4 \, (S/A), \text{ and}$$

$$F/A = 0.97 \, Uo + 32.3 \, (S/A),$$

where

F is the volume flow rate of gas stream in ft^3/sec

S is the volume flow rate of particulate material in ft^3/sec

A is the cross-sectional area of the casing in ft^2

Uo is the terminal falling velocity of a single particle of the particulate material in ft/sec

and *n* and Ui are quantities derived from the graph FIG. **4**, of the specification.

3. Apparatus according to claim **1**, wherein the deflecting elements each comprise an open ended, cylindrical screen packing and are randomly oriented in the casing.

4. Apparatus according to claim **1**, wherein a blow tank is connected to the inlet for conveying the particulate material to the casing entrained in the gas supply.

5. A method for conveying particulate material upwardly in a gas stream in a casing, comprising conveying the particulate material upwardly by means of a gas stream, and retarding choking in the casing by restricting particle mobility by means of deflecting elements disposed along the whole length of and extending across the whole width of the casing as a filling therein and being discrete elements whose maximum dimension is substantially less than half the diameter of said casing, said elements being randomly oriented in the casing and occupying up to 6 percent of the internal volume thereof.

6. A method according to claim **5**, wherein the flow rate of the conveying gas stream is substantially within the range,

$$F/A = (0.80)^n\ Ui + 4\ (S/A),\ \text{and}$$

$$F/A = 0.97\ Uo + 32.3\ (S/A),$$

where:

F is the volume flow rate of gas stream in ft^3/sec

S is the volume flow rate of particulate material in ft^3/sec

A is the cross-sectional area of the casing in ft^2

Uo is the terminal falling velocity of a single particle of the particulate material in ft/sec

and *n* and Ui are quantities derived from the graph FIG. **4**, of the specification.

* * * * *