June 7, 1955 L. D. SCHMIDT ET AL 2,710,232

METHOD FOR FILLING CAVITIES WITH GRANULAR SOLIDS

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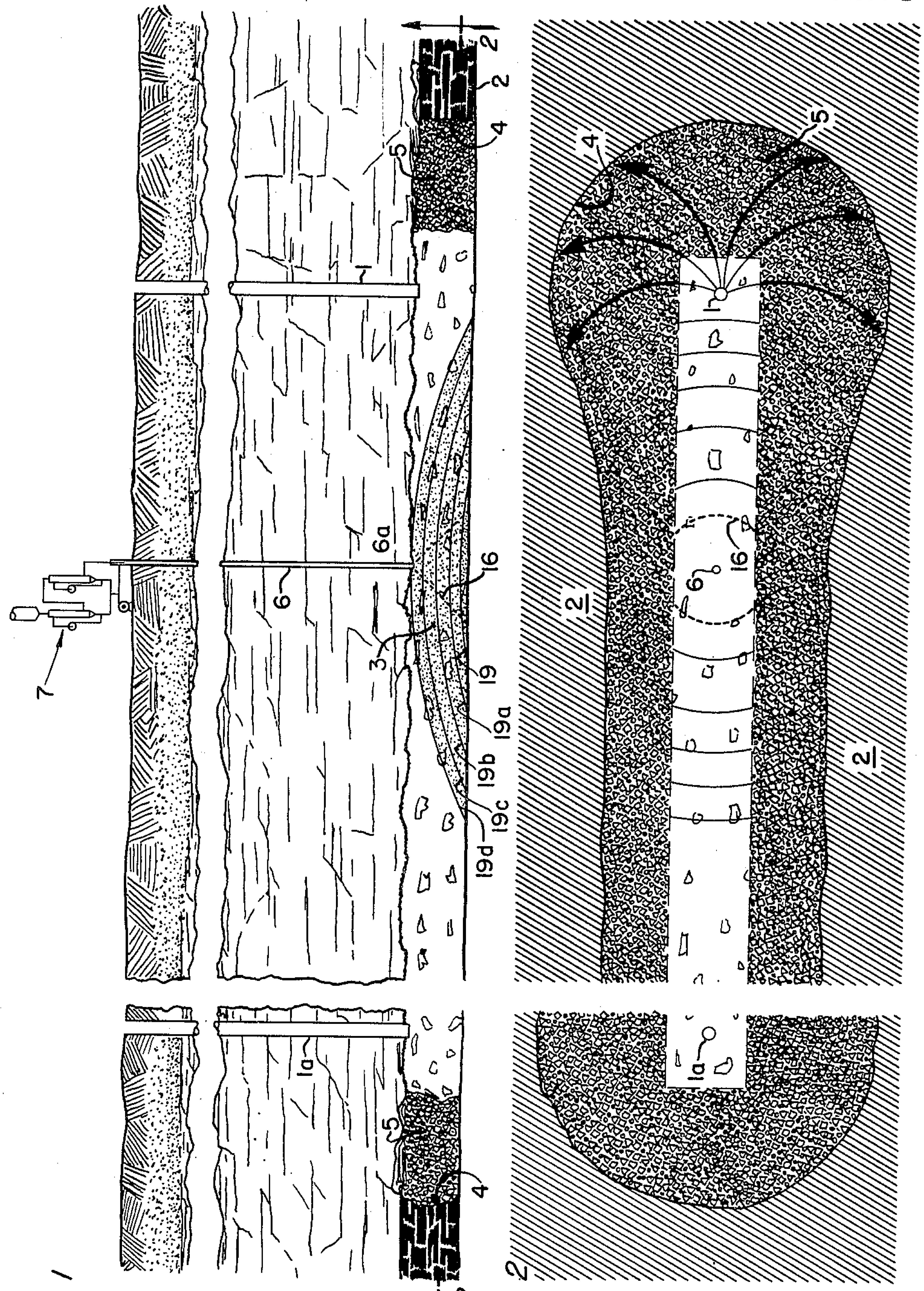

Fig. 1 Fig. 2

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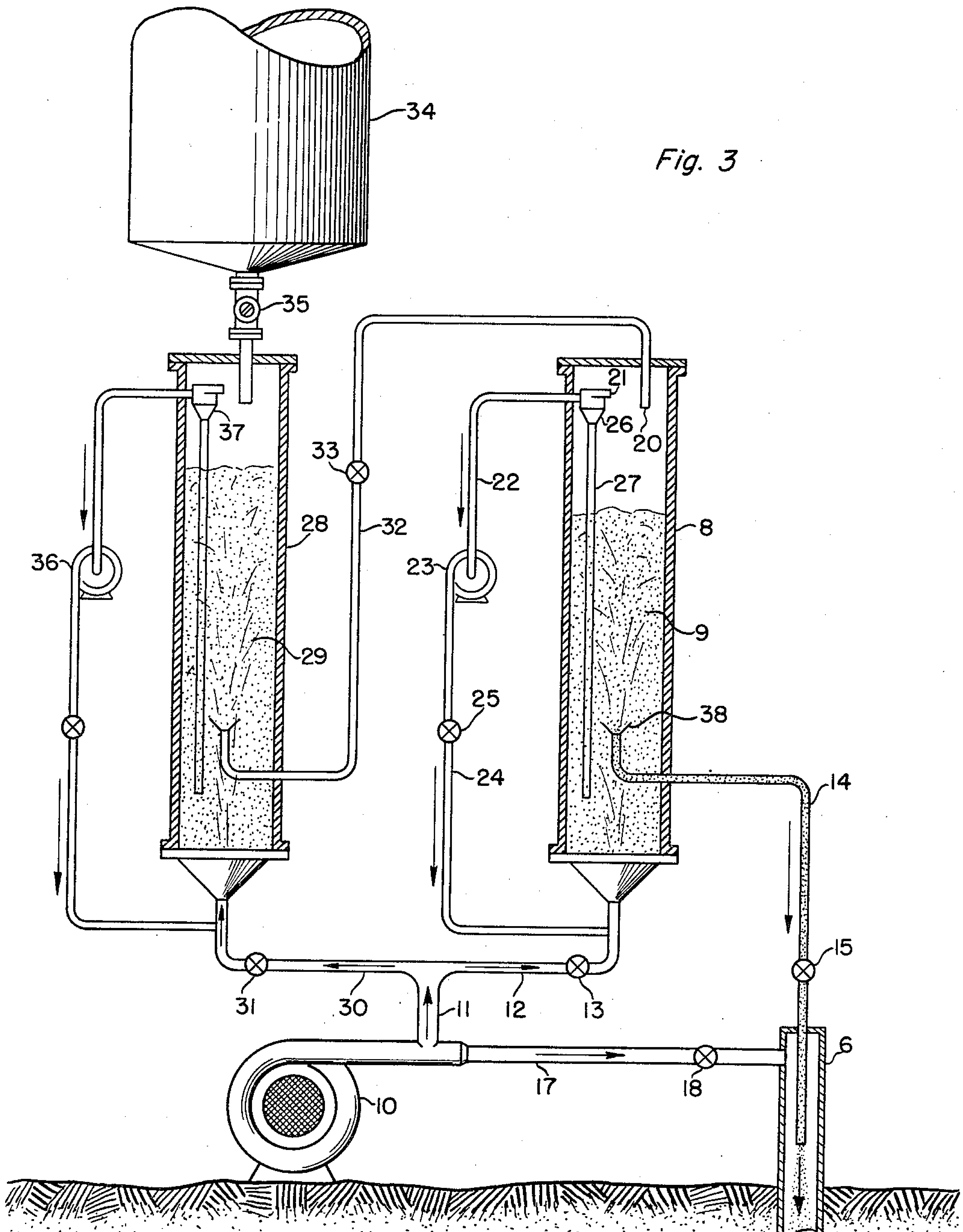

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METHOD FOR FILLING CAVITIES WITH GRANULAR SOLIDS

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(Granted under Title 35, U. S. Code (1952), sec. 266)

The invention herein described and claimed may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of royalties thereon or therefor.

This invention relates to a method for filling cavities with granular solids, and in particular, is concerned with a method in which the dispersion of granular solids within a cavity may be controlled in a simple and highly efficient manner.

The introduction of granular solids into variously shaped cavities is often a difficult problem. Elongated cavities having limited means of access, or long, tortuous, irregularly-shaped cavities, or cavities having a plurality of interstitial voids for example, present particularly difficult problems. It is often extremely difficult, and at times virtually impossible, to introduce granular solids into a cavity merely by gravity feed. Due to the extremely high resistance to flow of granular solids in the settled state, a settled stream of granuar solids fed to a cavity by gravity feed will flow but a very short distance beyond the point of its introduction to the cavity if its path of flow is constricted in any way. At the first constriction, the solid stream will bridge and pack tightly, thus effectively blocking off the path of flow. In certain instances it may be possible to assist the flow by imparting vibratory motion to the settled stream of solids to mitigate somewhat its packing and bridging tendencies, but this expedient is relatively ineffective and often impossible to apply.

A more effective method for introducing granular solids into cavities which are difficult to fill by ordinary methods of gravity feed, is to suspend the solids in a gas stream and to flow the solids-in-gas suspension into the cavity thereby achieving a much greater degree of dispersion of the solids throughout the cavity, since the resistance to flow of the granular solids is greatly reduced when in suspension. According to methods of pneumatically feeding granular solids thus far proposed, the granular solids are conveyed to and introduced into the cavity in a dilute phase, high velocity stream. The high velocity, dilute phase suspension, inherently obtained in the operation of these prior processes gives rise to a number of disadvantages. High velocities result in greater friction losses and consequently higher power requirements. Furthermore, when pneumatically conveying granular solids having appreciable abrasive properties, erosion of the conveying conduits at high velocities is quite large. In addition, the diluteness of the suspension lowers the capacity of the conveying system. The most important disadvantage, however, connected with pneumatic-conveying processes presently in use in connection with filling cavities with granular solids is the lack of any means of controlling the degree of dispersion of the granular solids within the cavity. In many cases the high velocity dilute phase suspension is blown into the cavity with too great a force causing undesirable turbulence and excessive scattering. Where it is desired to fill only a certain portion of the cavity with granular solids, present methods of pneumatic conveying offer little possibility of controlling the extent to which the cavity is filled.

In accordance with the present invention, a controlled pneumatic method for filling cavities with granular solids is provided which is superior to prior pneumatic methods for accomplishing this purpose. The method of the invention, which is particularly suitable for filling cavities which are difficult or impossible to fill by ordinary methods of gravity feed, generally requires less power for the same weight of solids handled, has a greater capacity for the same size of unit, and the unit for carrying out the method is subject to less erosion than pneumatic conveying units presently used for this purpose. In addition to these advantages, the method of the present invention affords an extremely easy and flexible means for controlling the degree of dispersion of the stream of granular solids within the cavity.

In general, the method of the invention for filling cavities with granular solids involves the steps of passing a gas stream, most conveniently a stream of air, upwardly through a confined mass of the granular solids at a velocity sufficient to convert the mass into a pseudo-liquid, dense phase, solids-in-gas, fluidized suspension, withdrawing a stream of this dense phase suspension from the fluidized mass, and conducting this stream to the cavity, and controlling the dispersion of the granular solids within the cavity by diluting the stream with varying quantities of additional gas added in advance of the point at which the stream flows into the cavity. With the addition of increasing amounts of diluting gas to the stream, the degree of dispersion of the solids within the cavity is increased, and conversely, decreasing the amount of diluting gas decreases the degree of dispersion of the solids within the cavity.

As distinguished from prior methods for pneumatically conveying and introducing granular solids into difficult-to-fill cavities, the method of the present invention is characterized by the employment of solids-in-gas suspensions which are relatively very dense and which move at relatively low velocities. This type of suspension requires less power and a smaller capacity unit for the same feed rate, and causes less erosion, particularly where abrasive solids are being handled, than with the use of a dilute, high velocity suspension. Over and above these advantages however, the salient feature of the invention resides in the possibility of controlling the dispersion of the granular solids within the cavity to be filled. This feature of the invention is based upon the discovery that when the initial stream of solids-in-gas suspension is very dense, it is possible to effectively control the dispersion of the stream within the cavity by decreasing the density of the initial suspension. The initial, extremely dense suspensions obtained in accordance with the method of the invention have an extremely high settling out rate and when such a suspension is introduced into a cavity the suspended solids disperse to a very limited degree. When, however, the density of the initial suspension is decreased by diluting it with additional gas before the suspension flows into the cavity, the degree of dispersion of the solids within the cavity is markedly increased with the addition of comparatively small amounts of diluting gas. When the initial solids-in-gas suspension is relatively dilute as in conventional methods of pneumatic conveying, the addition of diluting air to the stream has little effect upon the dispersion of the solids within the cavity, since the effect of dilution upon the settling-out rate of the particles in a solids-in-gas suspension tapers off sharply as the initial suspension becomes more dilute.

A further feature of the present invention, is the ease with which the stream of solids-in-gas suspension may be maintained under pressure so that it may be introduced into cavities which are under superatmospheric pressures. This is accomplished merely by maintaining the fluidized mass of granular solids in a closed vessel under a superatmospheric pressure. A stream of solids-in-gas suspension withdrawn from the fluidized mass will be under superatmospheric pressure, and may be piped into any cavity under a superatmospheric pressure lower than the pressure in the vessel containing the fluidized mass. Where the fluidized mass is maintained under superatmospheric pressure, it is preferable to recirculate excess fluidizing gas to a recirculation compressor to avoid wasting excessive amounts of compressional energy.

In accordance with another feature of the invention, it is possible to replenish the supply of granular solids in the fluidizing feeder, when operated under superatmospheric pressure, without interrupting the flow of solids-in-gas suspension from the feeder to the cavity to be filled. In this way continuous feeding may be maintained over long periods and the capacity of the feeder thus greatly increased.

For a better understanding of the invention, reference is now made to the accompanying drawings in which:

Figure 1 is a diagrammatic view illustrating the use of the method of the invention for filling an underground passage; and

Figure 2 is a section taken on the line 2—2 of Figure 1; and

Figure 3 is a diagrammatic view illustrating in detail a pneumatic feeding unit suitable for carrying out the method of the invention.

Figure 1 illustrates the use of the method of the invention for filling cavities created in the course of the underground gasification of a seam of coal to produce gases having utilizable energy content without the necessity of first mining the coal. Although the invention will be described particularly in reference to its use for filling cavities of this type, it will be understood that this is done merely to illustrate the invention, and that the invention is not limited to this use.

Referring now particularly to Figures 1 and 2, reference numerals **1** and **1***a* refer to shafts which are sunk from the surface of the ground to the level of a coal seam **2**. A horizontal passage **3** having a length, for example, of 300 ft., is driven in the coal seam and connects shafts **1** and **1***a*. The coal seam is ignited and air is blown down shaft **1**, through passage **3**, and the hot gases containing the products of combustion are withdrawn from passage **3** out through shaft **1***a*. Periodically, the direction of flow of the air is reversed. As the burning progresses, the coal face, originally defined by the perimeter of passage **3**, gradually recedes from its original boundaries. Under certain conditions of burning the pattern of the burned out area of the coal seam is of a generally dumbbell shape as shown in Figure 2. In this figure, the numeral **4** refers to the coal face after a period of burning. The darker area **5** filling the space between the passage **3** and the coal face **4** represents the burned out area.

Due to the extremely high temperatures generated during the burning of the coal, there is usually extensive expansion and caving in of the roof of the original passage **3** and of the roof of the burned out area **5**. This expansion and caving in of the roof is desirable since it tends to fill in the burned out areas and helps to prevent the air fed down into the burning mine from by-passing the coal face. This problem of air by-passing the coal face is particularly serious in respect to the central passage **3** originally driven in the coal seam. After the coal face has receded from its original boundaries, air which passes down the central corridor **3** never reaches the coal face and thus contributes nothing to the coal-gasification reaction which occurs principally at the coal face. Since the passage **3** was originally completely void, it becomes less densely filled with broken and expanded rock and earth resulting from caving of the roof than does the burned out area **5**, and thus affords an especially easy route for the by-passing air.

To prevent this by-passing, it is highly desirable to block off a portion at least of the loosely filled passage **3**. Ordinary methods of gravity fill would be ineffective. The passage is long, has a relatively small cross-sectional area and since it is partly filled with broken rock, contains thousands of interstitial voids. If a shaft were sunk from the surface of the ground and a suitable fill such as sand or earth were fed to the passage by gravity, only an extremely small portion of the passage would be filled before the end of the shaft would be completely blocked. According to the method of the present invention, a shaft **6** of relatively small diameter is sunk from the surface of the ground to a portion of the passage it is desired to fill, and sand, earth, or other suitable granular material is then fed down the shaft **6** by means of a feeding unit, generally designated by the reference numeral **7**, suitable for carrying out the method of the invention.

Referring now particularly to Figure 3, showing the feeding unit **7** in more detail, the reference numeral **8** refers to a vessel containing a mass of granular solids **9**. A blower **10** is connected to the bottom of vessel **8** by means of line **11** and line **12** which is controlled by valve **13**. By means of blower **10**, a stream of air or other suitable gas is blown into the bottom of vessel **8** and upwardly through the mass of granular material therein. The linear velocity of this upwardly flowing gas stream is so adjusted that the granular mass is converted into the so-called fluidized condition. In this condition, the mass as a whole becomes expanded appreciably, for example, from one half to twice its original volume, and behaves very much like a liquid at its boiling point. It retains a definite, although turbulent, upper surface which is the point at which the upwardly flowing gas stream becomes disengaged from the mass. It exerts a pressure similar to the hydrostatic pressure of a liquid upon the walls and bottom of the vessel in which it is contained and flows much the same way as a liquid. Although the fluidized mass as a whole behaves like a liquid, in reality, it is an extremely dense phase solids-in-gas suspension in which the volume ratio of solids to gas in the order of from 1:4 to 1:8 and in which the weight ratio of solids to gas may be as high as 600:1.

A stream of this dense phase, solids-in-gas suspension is withdrawn from the body of the fluidized mass by means of line **14**, controlled by valve **15**. A cone-shaped deflector **38** at the intake shields the intake from the upwardly flowing fluidizing gas stream and promotes uniformity of flow of the fluidized suspension withdrawn. Only a small fraction of the fluidizing gas stream admitted to the bottom of vessel **8** and flowing upwardly through the granular mass **9** passes into line **14** as the gaseous phase of the solids-in-gas suspension flowing therein. The major portion of the fluidizing gas stream, after flowing through the granular mass, flows out of the top of vessel **8**. This excess fluidizing gas may be allowed to flow freely from the open top of vessel **8** or may be recirculated to the bottom of the vessel by means of recirculating compressor **23** in a manner which will be described more in detail subsequently. The ratio of fluidizing gas (total amount fed to the bottom of vessel **8**) to conveying gas (amount withdrawn by line **14**) varies with the cross-sectional area of vessel **8**, the linear velocity of the fluidizing air, and the rate of coal feed. In a typical operation the ratio may vary from 15:1 to 30:1.

The extremely dense phase, solids-in-gas suspension flowing through line **14** flows in much the same way as a liquid. Since the fluidized mass in vessel **8** exerts a pressure similar to the hydrostatic pressure of a liquid, the fluidized suspension flows into the intake of line **14** under a pseudo-hydrostatic head equivalent to the product of the height of the fluidized mass above the intake and the bulk density of the fluidized mass. If vessel **8** is maintained under superatmospheric pressure, the solids-in-gas suspension flowing in line **14** will flow under this additional pressure head as well as under the pseudo-hydrostatic head of the fluidized mass.

The high density, relatively low velocity suspension flowing in line **14** is conducted to shaft **6** leading to passage **3**. If this extremely dense phase suspension is conducted directly into the passage **3** without any diluting air, a limited portion of the passage may be filled. Quite rapidly, however, due to the high rate of settling out of particles from a dense phase, solids-in-gas suspension, a cone-shaped pile of granular material will build up directly below the small inlet **6***a* feeding material into the passage, completely blocking off the inlet. The sides of the cone that builds up will be quite steep as indicated for instance by the dotted line **16** (see Fig. 1).

In order to increase the dispersion of the granular material fed into the passage **3** and consequently to increase the extent to which the passage is filled, the dense phase suspension flowing into shaft **6** through line **14** is diluted with additional air by means of line **17** controlled by valve **18**. The additional air fed into shaft **6** simultaneously decreases the density of the dense phase suspension and increases its velocity. Both the increase in velocity and the decrease in density have the effect of increasing the dispersion of the sand or other granular solids within the passage **3**.

With the addition of the proper amount of diluting gas, instead of forming a cone having a steep angle of repose which blocks the entrance to the passage, the granular material spreads out, forming piles **19**, **19***a*, **19***b*, **19***c*, **19***d*, etc., having very low angles of repose. The stream of granular solids flows almost like a liquid into the thousands of interstitial voids formed by the loosely piled mass of rock resulting from partial caving and expansion of the roof. Since the burned out areas **5** are more densely filled than the passage **3**, the stream of sand or earth fed into passage **3** will preferentially fill the voids in passage **3** before much of it flows into the crevices and voids in the burned out area **5**, provided the dispersion of the stream of sand is properly controlled by adding the proper amount of diluting air by way of line **17**. In some cases an excessively large amount of diluting air, giving rise to excessive dispersion of the sand may result in blowing sand through the burned out area over to the coal face.

Depending upon the amount of diluting air added to the dense steam of fluidized solids, the length of passage that is filled may, within limits, be varied at will. As the amount of diluting air increases, the piles of granular material collecting beneath the shaft **6** spread out further before piling up high enough to block off the point at which the stream feeds into the passage. Using this method, a substantial length of passage may be filled from the floor substantially to the roof. The fill made in this manner is uniformly dense, substantially all of the interstitial voids being completely filled.

Even when the pile of solids builds up so as to block off the inlet **6***a*, filling may be continued by increasing the pressure in vessel **8** and by adding additional diluting air by way of line **17**. The additional pressure and additional diluting air helps the stream to push a passage through the pile of solids already deposited. This may be continued until a section of the passage is filled with sand or other granular solids from the floor of the passage tightly against its roof.

Under some conditions, the feeding unit may be operated under atmospheric pressure, but where the cavity which is being filled is under superatmospheric pressure, or where there is excessive resistance to flow, the vessel **8** must be kept at a pressure somewhat greater than this order to overcome the back pressure. Thus, for example, a burning underground mine may be under static pressure of 4 or 5 pounds per square inch above atmospheric. It is desirable to plug the passage **3** while the

gasification operation is in progress and it is thus necessary to operate the feeding unit at a somewhat elevated pressure, for example, 30 lbs. gage.

If the feeder unit is operated under pressure, it is preferable to recirculate the excess fluidizing gas in order to avoid excessive waste of compressional energy. To this end, a disengaging zone **20** is provided above the fluidized mass of granular solids in vessel **8**. Excess fluidizing gas passing upwardly through the fluidized mass becomes substantially disengaged from the dense phase suspension and is withdrawn from the upper portion of the vessel by duct **21** leading into line **22**. The gas withdrawn from the upper portion of the vessel **8** is at a pressure lower than the gas entering the bottom of the vessel by an amount equal to the pressure drop through the fluidized mass. The gas withdrawn from the upper portion of the vessel is recompressed by means of recirculating compressor **23** back to its original pressure and recycled to the bottom of vessel **8** by line **24** controlled by valve **25**.

When fluidizing a granular mass of solids of fairly wide size distribution, the establishment of a dense, pseudo-liquid fluidized phase will also result in the establishment of an entrained dilute phase of fine particles in the space above the dense fluidized phase. In order to prevent the carry over of these entrained fines into the recirculating compressor **23**, cyclone separator **26** is provided, which delivers a substantially solids-free gas to line **22**. Standpipe **27** returns the separated solids back into the body of the fluidized mass.

As previously mentioned, the feeding unit may be operated at atmospheric pressure, in which case there is no need for recirculating excess fluidizing gas. The vessel **8** may in this case be open at the top and the excess fluidizing gas wasted to the atmosphere.

When operated at atmospheric pressure, with vessel **8** open at the top, there is no problem in replenishing the supply of granular solids in the vessel **8**. The supply may be replenished intermittently or continuously merely by dropping in additional solids at top of the vessel **8**. However, where the feeder is operated under superatmospheric pressure, special means must be taken to replenish the supply of granular material in the vessel **8** without interrupting the flow of the fluidized suspension from the vessel to the cavity being filled. Figure 3 illustrates one method of accomplishing this.

A vessel **28**, similar to vessel **8**, contains a mass of granular material for replenishing the supply in vessel **8**. A stream of fluidizing air from blower **10** is conducted into the bottom of vessel **28** by line **30** controlled by valve **31**. The velocity of the gas stream flowing upwardly through the granular mass **29** is adjusted to effect fluidization thereof. The static pressure in vessel **28** is adjusted so as to be somewhat higher than that in vessel **8**, and a stream of fluidized solids is forced from vessel **28** into the upper portion of vessel **8** by line **32** controlled by valve **33**. The rate of flow of solids from vessel **28** to vessel **8** is proportional to the pressure differential between the two. When the supply of granular solids in vessel **28** becomes depleted, valves **33** and **31** are closed off, and vessel **28** is recharged by means of gravity feed hopper **34**. When vessel **28** has been recharged, valve **35** of batch feed hopper **34** is closed, and vessel **28** is repressurized and the granular mass fluidized by opening valve **31**. Valve **33** may then be reopened and charging of vessel **8** continued. During the period in which vessel **28** is recharged, the level in vessel **8** may drop somewhat but may be restored by feeding at an initially increased rate. Since vessel **28** also operates under pressure when charging material to vessel **8**, recirculating compressor **36** provided with cyclone separator **37** are provided to recirculate excess fluidizing air back to the bottom of the vessel.

Means other than that illustrated may be employed to replenish the supply of granular material in vessel **8** without interrupting the flow of the solids-in-gas suspension to the cavity being filled. For example, additional solids may be injected into vessel 8 by means of a screw feeder, or any other suitable mechanical means employed for injecting solids into the vessel 8 without loss of the static pressure therein.

The delivery rate, or the weight of granular solids delivered per unit time depends chiefly upon the cross-sectional area of the delivery tube 14 and the differential in the pressure existing in vessel 8 and at the point of delivery of granular solids into the cavity. The delivery rate is roughly proportional to the cross-sectional area of delivery tube 14 and thus may be very conveniently controlled by valve 15. The delivery rate is also roughly proportional to the square root of the pressure differential and consequently the delivery rate may be increased by increasing the pressure differential.

The following is a specific illustrative example of the use of the method of the invention for plugging underground passages in connection with the underground gasification of coal. In this case, the passage cut in the coal seam between the vertical shafts 1 and 1*a* was 300 ft. long, 4 ft. high, and 10 ft. wide. As the burning proceeded, and the coal face receded from its original position, analyses of the effluent gas began to show higher percentages of oxygen and lower percentages of carbon dioxide indicating that some of the air fed into the mine was bypassing through the original passage without ever reaching the coal face. Two shafts similar to shaft 6 were driven from the surface of the ground to the passage, the shafts being located near the opposite ends of the passage. Sand having a particle size through 8 mesh, and ranging from about 8 to 200 mesh with a major portion of the particles in the coarser range, was fed down each of these shafts into the passage at the rate of 1 or 2 tons an hour. The static pressure in the mine ranged from about 5 to 10 lbs. above atmospheric and the pressure in the feeder vessel 8 averaged about 30 lbs. gage. The delivery pipe 14 was ¾ in. in diameter while the pipe 6 leading to the passage was 1 in. in diameter. The passage 3 was approximately 150 ft. below the surface of the ground. When no diluting air was added to the dense phase suspension, the sand settled out very quickly at the bottom of the shaft and quickly coned up and blocked off the flow. When however, diluting air was added to the dense phase suspension at a point above the surface of the ground at a rate of about 2 to 50 standard cu. ft. per minute of air at 30 lbs., the average rate of feed of diluting air being about 10 standard cu. ft. per minute, the sand was well dispersed throughout the passage and it was possible to add a volume of sand approximately equal to about ¼ the original volume of the passage without drilling further shafts. The volume ratio of solids:gas in the dense phase suspension before dilution was about 1:4 while after dilution, the volume ratio ranged as high as 1:50.

Operating in this manner substantially complete plugging of the passage 3 was accomplished as indicated by analysis of the effluent gas which showed a decrease in the percentage of oxygen and an increase in the percentage of carbon dioxide thus indicating that by-passing of the gas through the central passage had been eliminated. When the initial, dense phase suspension was diluted with too much additional air, the sand scattered over an excessively large area. If the addition of the sand had been continued using a dilute, widely scattering stream, it would have been necessary to fill an extremely large area of the passage before being able to form a complete plug across its width, consequently requiring greatly increased quantities of sand to accomplish the plugging. Using the method of the invention, however, and controlling the degree of dispersion of the sand, it is possible to form two plugs at opposite ends of the passage, and thus prevent by-passing of air with the use of a minimum of sand.

The method of the present invention is generally applicable to all types of granular solids that are susceptible of being converted into a fluidizing condition. The method of converting a mass of solid granular material into the so-called fluidized state in itself is well known and has been investigated by a number of workers. See for example, the articles by Leva, Grummer, Weintraub, and Pollchik, Chem. Eng. Prog. 44, 511 to 520 (1948); ibid., pages 619 to 626; and the article by the same authors appearing in Ind. and Eng. Chem., vol. 41 pages 1206 to 1212 (June 1949). When a gas stream is passed upwardly through a confined mass of granular solids, with increasing linear velocity the mass will first become expanded and a certain limited agitation of the individual particles will be observed. At a certain higher velocity which varies with the density, size, and shape of the particles comprising the mass, the individual particles in the mass appear to become disengaged sufficiently from one another to permit internal motion thereof within the mass. At this point fluidization has been reached and the mass as a whole assumes the appearance and many of the properties of a liquid at its boiling point. The mass exerts a pressure similar to a hydrostatic pressure on the base and sides of the vessel in which it is contained, and will flow with many of the properties of a liquid under the influence of this pseudo-hydrostatic pressure head. The mass retains a definite, though turbulent upper surface which is the point where the gas stream becomes disengaged from the dense phase, fluidized suspension. The space above the surface of the fluidized mass is comparatively free of solid particles, and at the most, there is in this space a dilute phase of entrained fine particles.

The linear gas velocity required to fluidize a granular mass of particles depends chiefly upon the density and size of the particles, higher fluidization velocities being required for larger particles and for particles which are more dense. Granular masses of widely varying particle size including powders having an average particle size through 200 mesh, as well as particles the size of walnuts, have been successfully fluidized. When the particles become too large, difficulties occasioned by excessively high fluidization velocities are encountered; when the particle size becomes too small, it is difficult to maintain a uniformly fluidized condition.

A granular mass containing particles of wide size distribution is generally more difficult to uniformly fluidize than a granular mass where the particles are of a more uniform size. At the linear velocities to fluidize the larger particles, a portion of the smaller particles will become entrained and carried out of the dense phase fluidized mass. Although granular materials of any range of particle sizes that may be successfully fluidized may be used in the process of the invention, the particle sizes that can be most successfully handled range from about ⅓ of an inch to sizes through 300 mesh.

Any type of granular solid, including the type of solids that flow fairly freely, such as dry sand, and those having packing tendencies such as moist earth, may be successfully fluidized and may be successfully conveyed in a dense phase stream so long as the granular mass is sufficiently non-cohesive as to break up into separate particles in the fluidizing gas stream.

The fluidized suspension is an extremely dense, solids-in-gas suspension wherein the volume ratio of solids:gas is in the range of 1:4. The weight ratio of solids:gas, of course, will depend upon the density of the solids. In the case of coal particles, the weight ratio of solids:gas in the fluidized suspension may range as high as 400:1 although generally is in the order of 200:1. The linear fluidizing velocity has an effect upon the density of the suspension, the suspension becoming progressively less dense as the linear gas velocity approaches entrainment velocities. Within a practical range of fluidization velocities, however, ordinarily the bulk density, that is, the volume ratio of solids:gas, will not vary much outside the limits of 1:4 to 1:8.

The linear fluidization velocity required, and consequently the density of the suspension, does not vary with the pressure of the fluidizing gas. Thus it is possible to maintain high static pressures over the fluidized mass without altering the density of the suspension.

As previously stated, when a stream of solids-in-gas suspension is drawn from beneath the surface of a fluidized mass, it flows under the influence of the pseudo-hydrostatic head of the mass itself and a pressure head due to the static pressure in the fluidization vessel with substantially the same properties of flow of a liquid in a closed pipe. Since the typical fluidized dense phase suspension has a weight density 10 to 30 times as great as the usual solids-in-gas dilute phase suspension, the linear velocity of the stream under a given pressure differential will be much lower. Similarly to a liquid flowing in a closed pipe, at a given pressure differential, the linear velocity of the stream is inversely proportional to the square root of its density. The low velocity flow of the solids-in-gas suspension obtained in accordance with the method of the invention, results in decreased friction and consequently lower power requirements and less erosion of the conveying conduit, particularly in the feeder portion of the system where the problem of erosion is most troublesome. Since the losses due to friction go up roughly as the square of the velocity, and since the initial velocity of the stream of solids-in-gas suspension is from ⅕ to ⅒ the velocity of that encountered in conventional methods of pneumatic conveying, the savings in power, and the decreased losses due to erosion are quite significant. Furthermore, since the initial density, and in most cases the final density, of the solids-in-gas suspensions characteristic of the method of the present invention is many times greater than the density of the suspensions encountered in conventional pneumatic conveying methods, a feeding unit operated according to the method of the invention has a higher capacity than a feeder operated according to conventional methods. That is, for the same diameter conveying tube and for the same pressure differential between the intake and delivery ends of the tube, the throughput is higher in the case of a denser suspension since under these circumstances the delivery rate is roughly proportional to the square root of the density of the suspension.

In addition to the foregoing advantages, the most significant advantage of the method of the invention for filling cavities with granular solids is the extremely easy and flexible manner in which the dispersion of the granular solids within the cavity may be controlled. There are two factors which chiefly control the degree of dispersion of a stream of granular solids introduced into a cavity, namely the velocity of the stream and the density of the stream, both of which factors may be easily controlled in accordance with the method of the invention. By adding diluting gas to the dense phase, solids-in-gas suspension before it flows into the cavity, its density is decreased, and simultaneously its velocity is increased (since its velocity is inversely proportional to the square root of its density.)

It is important to note that the possibility of effective control of dispersion of the solids within the cavity depends upon the fact that the initial stream of solids-in-gas suspension is an extremely dense, low velocity stream. As previously mentioned, the solids:gas volume ratio of a typical fluidized suspension ranges in the order of 1:4 to 1:8. In conventional methods of pneumatic conveying, on the other hand, the initial solids:gas volume is usually in the order of 1:100. It is only when diluting gas is added to a solids-in-gas suspension having a high initial density that any appreciable control of the degree of dispersion is obtained. An undiluted suspension having the density of the order of that found in a fluidized mass has an extremely high settling out rate as the suspension flows out of the conveying tube and the conveying gas is allowed to expand into open space, this resulting, of course, in a very low degree of dispersion of the granular solids. With the addition of a comparatively small amount of diluting air however, to give a less dense suspension, the dispersibility of the granular solids is very markedly increased. When the suspension is extremely dense, for example, having a solids:gas volume ratio of 1:4, the effect of diluting gas upon the dispersibility of the suspension is most pronounced. In general, as the suspension becomes less and less dense, the effect of additional diluting air upon the dispersibility of the suspension decreases. When the density of the suspension decreases to the values encountered in conventional methods of the pneumatic conveying, that is, a solids:gas volume ratio the order of 1:100, the addition of diluting gas to the solids-in-gas stream has little or no effect upon the dispersibility of the stream. The range of densities over which the most effective control of the dispersibility of the suspension can be exercised usually lies in the range of higher densities corresponding generally to solids:gas volume ratios in the range of from 1:4 to 1:50.

Starting with a solids-in-gas suspension having a solids:gas volume ratio in the order of 1:4 to 1:8, with the addition of increasing amounts of diluting air, the solids:gas volume ratio may be progressively decreased until a dilute phase suspension characteristic of conventional pneumatic conveying methods is obtained. The rate of increase of dispersibility is high at first and progressively drops off as the diluteness of the suspension increases. When a dilute phase suspension having a solids:gas volume ratio in the order of 1:100 is reached, the addition of further quantities of diluting gas has little significant effect upon the dispersibility of the suspension. Since the power requirements and the amount of erosion go up with increased diluteness of the suspension, from this point of view, it is preferable to operate with as dense a suspension as possible consonant with the degree of dispersion desired.

From the above description it is apparent that by means of the method of the invention, the dispersion of a stream of granular solids within variously shaped cavities may be controlled over a wide range. Where low dispersibility and rapid settling out with a minimum of scattering is desired, the initial, extremely dense phase suspension may be utilized. Starting with a suspension of these characteristics, the dispersibility of the solids-in-gas stream may be increased by infinitely small steps if desired, up to the point where further dilution of the stream has little effect upon its dispersibility. The amount of diluting gas admitted may be controlled by a valve, such as valve **18**, on the diluting gas supply line. This valve, if desired, may be calibrated for a given type of granular solids to indicate the degree of dispersion corresponding to the admission of a given quantity of diluting gas.

The invention has a great variety of applications. For example, the method described may be used in filling fissures and cracks in walls and floors where the use of a dilute high velocity uncontrolled suspension would scatter the stream and fail to deposit the granular solids within the fissures. In filling mold cavities with granular molding material or in lining furnace walls with granular refractory, or in any application where a controlled dispersion and settling rate of the particles in the cavity is desired, the method of the invention would be useful. The method of the invention has been found to be very uniquely suited for use in the field of underground gasification wherein burned out areas may be plugged off in a controlled manner using sand, earth, or other suitable fill as described above. It will also be found useful in filling mined-out areas in general to prevent subsidence of the surface particularly for example where it is desired to build heavy structures over the mined-out area.

It is to be understood that the above description and drawings are intended to be illustrative only, and that the invention is not to be limited thereby, nor in any way except by the scope of the appended claims.

We claim:

1. A controlled method for filling a cavity with noncohesive granular solids comprising the steps of continuously passing a gas stream under superatmospheric pressure upwardly through a confined mass of noncohesive granular solids at a velocity sufficient to continuously maintain said mass as a fluidized, dense phase, solids-in-gas suspension resembling a liquid at its boiling point, continuously withdrawing a stream of said dense phase suspension from an intermediate zone in said mass and conducting said stream to the cavity, and controlling the dispersion of said granular solids within said cavity by diluting said stream with varying quantities of additional gas before the point at which said stream flows into said cavity, the degree of dispersion increasing with the addition of increasing amounts of diluting gas to said stream.

2. A controlled method for filling a cavity with noncohesive granular solids comprising the steps of continuously passing a gas stream under superatmospheric pressure upwardly through a vessel containing a mass of non-cohesive granular solids at a velocity sufficient to continuously maintain said mass as a fluidized, dense phase, solids-in-gas suspension resembling a liquid at its boiling point, continuously withdrawing the major portion of said fluidizing gas stream substantially free from solids, from the upper portion of said vessel, recompressing said withdrawn gas to restore it to its original pressure and recirculating said recompressed gas to the bottom of said vessel, withdrawing a stream of said dense phase, solids-in-gas suspension from said vessel at an intermediate zone of said suspension and conducting said stream to the cavity, and controlling the dispersion of said granular solids within said cavity by diluting said stream with varying quauntities of additional gas before the point at which said stream flows into said cavity, the degree of dispersion increasing with the addition of increasing amounts of diluting gas to said stream.

3. A controlled method for filling a cavity with granular solids comprising the steps of continuously passing a gas stream under superatmospheric pressure upwardly through a confined mass of noncohesive granular solids at a velocity sufficient to continuously maintain said mass as a fluidized, dense phase, solids-in-gas suspension resembling a liquid at its boiling point, continuously withdrawing a stream of said dense phase suspension from said mass at a point intermediate the top and bottom thereof, continuously conducting said stream to the cavity, controlling the dispersion of said granular solids within said cavity by diluting said stream with varying quantities of additional gas before said stream flows into said cavity, the degree of dispersion increasing with the addition of increasing amounts of diluting gas to said stream and continuously adding fresh granular solids to said suspension substantially at the rate at which solids are withdrawn therefrom.

4. A controlled method for filling a predetermined portion of an elongated cavity with noncohesive granular solids comprising the steps of continuously passing a gas stream upwardly through a confined bed of noncohesive granular solids at a velocity sufficient to continuously maintain said bed as a fluidized, dense phase, solids-in-gas suspension resembling a liquid at its boiling point, continuously withdrawing a stream of said dense phase suspension from an intermediate point in said fluidized bed, conducting said stream to a portion of said cavity it is desired to fill, and controlling the extent to which said cavity is filled by diluting said stream with varying quantities of additional gas before the point at which said stream flows into said cavity, whereby increasingly greater portions of said cavity are filled by the addition of increasing amounts of diluting air to said stream.

5. A controlled method for filling underground cavities having a plurality of interstitial voids with noncohesive granular solids comprising the steps of continuously passing a gas stream upwardly through a confined mass of noncohesive granular solids at a velocity sufficient to continuously maintain said mass as a fluidized, dense phase, solids-in-gas suspension resembling a liquid at its boiling point, continuously withdrawing a stream of said dense phase suspension from said fluidized mass from a point above the bottom thereof, conducting said stream to a point of access to said cavity, and controlling the dispersion of said granular solids among the interstitial voids in said cavity by diluting said stream with varying quantities of additional gas before said stream flows into said cavity, the degree of dispersion increasing with the addition of increasing amounts of diluting gas to said stream.

6. A controlled method for filling underground cavities which are under superatmospheric pressure with noncohesive granular solids such as sand, earth, and the like, comprising the steps of continuously passing an air stream at a superatmospheric pressure greater than the pressure in said cavity upwardly through a vessel containing a mass of said noncohesive granular solids at a velocity sufficient to continuously maintain said mass as a fluidized, dense phase, solids-in-gas suspension resembling a liquid at its boiling point, continuously withdrawing the major portion of said fluidizing gas stream, substantially free from solids from the upper portion of said vessel, recompressing said withdrawn gas to restore it to its original pressure, and recirculating said recompressed gas to the bottom of said vessel, withdrawing a stream of said dense phase suspension at superatmospheric pressure from a point intermediate the bottom and upper portions of said vessel, conducting said stream to the cavity, and controlling the dispersion of said granular solids within said cavity by diluting said stream with varying quantities of additional gas before said stream flows into said cavity, the degree of dispersion increasing with the addition of increasing amounts of diluting gas to said stream.

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