Dec. 22, 1953 D. B. ARDERN 2,663,595

TRANSPORTATION OF GRANULAR SOLIDS

Filed Sept. 13, 1950

2 Sheets-Sheet 1

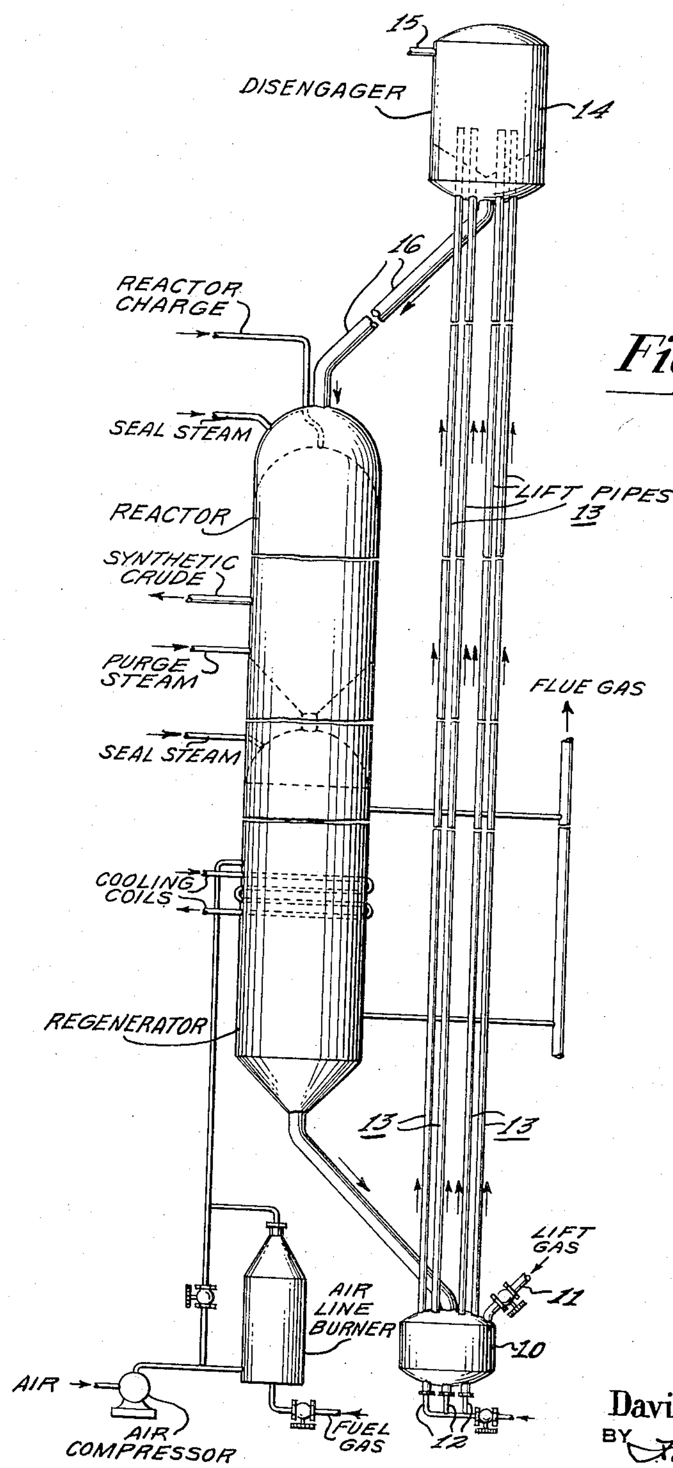

Fig. 1.

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Fig. 2.

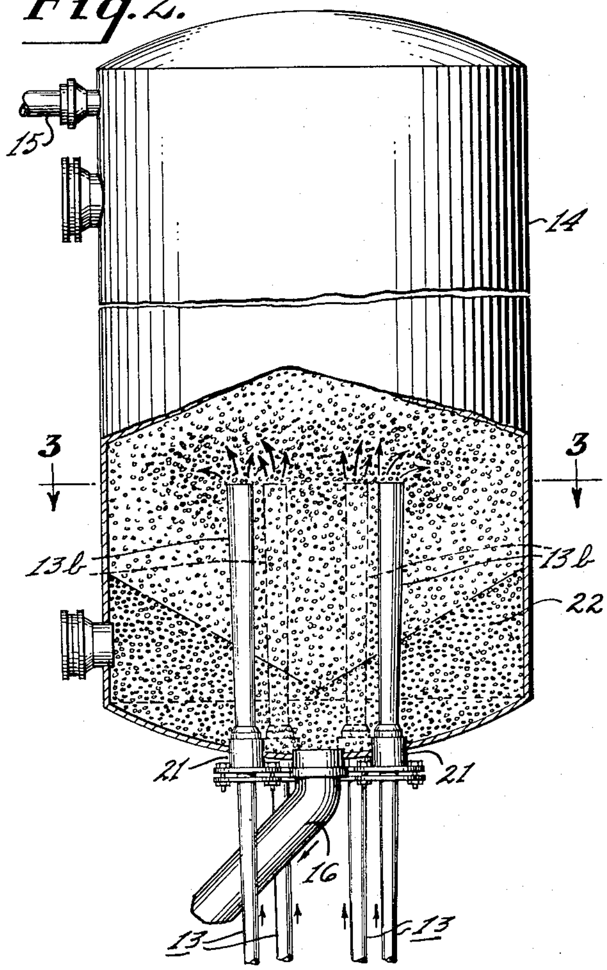
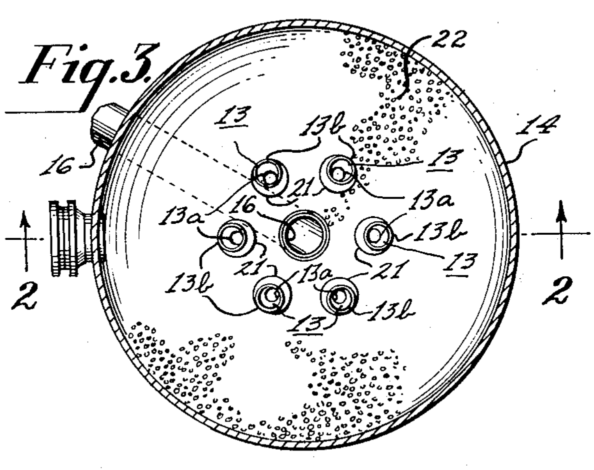


Fig. 3.



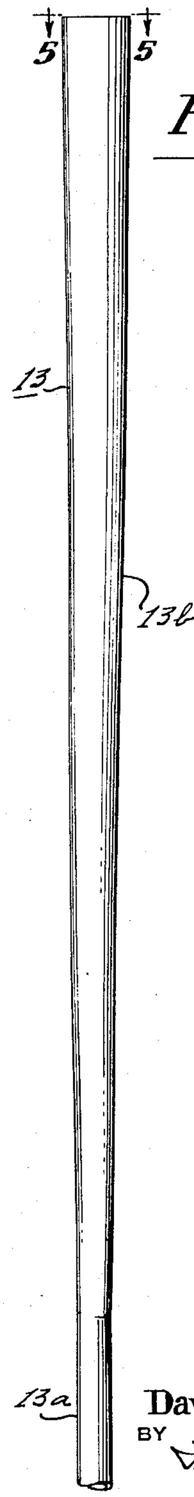


Fig. 4.

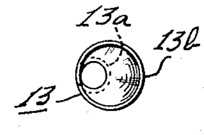


Fig. 5.

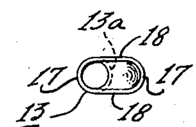


Fig. 6.

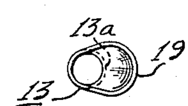


Fig. 7.

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UNITED STATES PATENT OFFICE

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TRANSPORTATION OF GRANULAR SOLIDS

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9 Claims. (Cl. 302—59)

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The present invention relates to processes or systems in which solid particles or granules of contact material circulate through a downflow path wherein they pass through a process zone and are contacted with fluid and are thereafter elevated through an upflow path for return through the downflow path. The present invention is more particularly concerned with the upflow path wherein the particles are elevated, conveyed or transported through a vertically elongated laterally confined lifting zone or conduit by a lifting fluid or gas.

Such processes or systems, which are particularly adapted to the requirements of the chemical and oil refining industries, have a wide range of usefulness. Thus the granular contact material may be a porous or fused solid and may comprise or consist of a catalyst or catalytically inert material, the latter being used for heat exchange, or for the adsorption or fractionation of gases. The granular contact material can be advantageously in the form of relatively large particles or granules such as molded pellets, formed spheres and the like ranging in size from 0.05 to 0.5 inch in diameter, which, wholly or in part, gravitate through process zones as compact downwardly moving non-turbulent beds in a manner known to the art.

It has been found advantageous to transport the granular contact material for recirculation through the process zones of such systems by a pneumatic or gas lift which provides an upflow path. The system may comprise a single downflow path in which there are several process zones at different heights, through which zones the contact material flows consecutively so that the solid particles need be transported by the gas lift only once in a complete cycle of operation, or the system may comprise a plurality of gas lifts and/or downflow paths, each downflow path containing a single process zone. An exemplary system of the former type has been described in an article entitled "Houdriflow: new design in catalytic cracking," appearing in the "Oil and Gas Journal," page 78, January 13, 1949.

In such systems, the use of a gas lift for the elevation of the granular contact material, instead of the mechanical elevators formerly employed, produces many advantages both as to control of the processing variables (operating conditions) and as to efficiency of operation (including cost and maintenance) but, at the same time, creates new problems. One of the chief problems in the operation of gas lifts of the type referred to herein is that of achieving simultaneously a high rate of circulation of solid particles and easy and rapid return of solid particles from the upflow path to the downflow path, while maintaining a low rate of attrition or breakage of the solid particles during such return.

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The methods and apparatus disclosed in the prior art for effecting the necessary reversal of flow of the particles from the upflow path to the downflow path produce high attrition of the particles and/or necessitate the use of bulky and expensive equipment. Thus, when the gas lift is operated at a desirably low pressure drop between the ends of the lift, and consequently at high gas velocity, the particles passing therethrough are traveling at such high velocities as they emerge from the lift that a considerable distance is required for the particles to change their upward movement to downward movement due to the decelerating effect of gravity. Consequently, the vessel or zone surrounding the top of the lift must be tall (such a vessel is commonly referred to as the disengaging vessel, hopper or zone, since it can be and frequently is used for disengaging lifting gas from solid particles). Because the disengaging vessel is necessarily at the top of the gas lift, which may be from 100 to 200 or more feet high, the problems and expense of supporting and bracing it at such a height are multiplied as the height of the vessel increases. Consequently, the reduced height of disengaging vessels made possible by the present invention, as described below, results in considerable savings in the cost of construction of the supporting structure.

An additional difficulty is encountered in commercial applications of gas lifts which involve the transfer of very large amounts of contact material, such as from 100 to 400 tons an hour. This difficulty has been solved by employing a multiple lift in which a plurality of parallel gas lift paths or conduits are grouped or arranged equidistantly around a common vertical axis. Such a multiple lift avoids difficulties which would be encountered in a single lift of equal capacity but in turn leads to new problems. One of these problems involves the desirability of having the lift paths or pipes grouped relatively close together, such as from between about 0.5 foot to 4 feet apart, so that the lift pipes can be supported with a minimum amount of structure. When a common disengaging zone is employed for relatively closely grouped lift paths, collision in the disengaging zone or hopper of particles emerging or fountaining from adjacent lift pipes can cause considerable attrition. Even if individual disengaging vessels are employed, it is desirable to space such vessels as closely as possible in order to simplify and reduce the cost of supporting the various vessels. Another effect that occurs under some conditions with gas lift pipes of relatively large diameter is a "mushroom" effect in which the emergent particles, instead of fountaining or spraying outwardly and settling in the disengaging zone, form a relatively dense cloud or mass of particles suspended above the lift. Obviously, collision of the particles emerging from the lift with those in the cloud leads to undesirable attrition.

In accordance with the present invention, the undesirable effects noted above are minimized and/or overcome in systems of the type here involved, by passing a stream of lifting gas and of particles at substantial velocity upwardly along the lower part of the vertical extent of each of such a plurality of vertically elongated laterally confined lifting paths or conduits, said lift paths or conduits being arranged equidistantly from or around a common vertical axis, individually flowing each of said streams in the upper parts of said lift paths along median flow lines which diverge from said common axis while individually confining the flow of the portion of each of said streams nearest said common axis to a flow path parallel to said axis. Such flow can be achieved by using pipes or conduits which taper eccentrically outward from their common vertical axis.

In one embodiment of the invention, the streams of particles and gas, including the portions flowing divergently outward from the common axis, are discharged from the upper end of the lift path or conduit into a common gas-solid disengaging zone or hopper having a considerably greater horizontal cross sectional area than that of the circle circumscribing the tops of said lift paths or conduits. In the disengaging zone or hopper, the various streams of particles and gas flow, fountain or spray divergently outward from the common axis with the result that there is little or no collision between particles from adjacent lift paths and subsequent disengagement and free settling of the particles is simpler. Under these conditions, attrition caused by inter-particle collision or friction is minimized.

The invention is especially applicable to systems involving the catalytic conversion of petroleum, and for the purpose of illustrating the invention, it will be described hereinafter in connection with a catalytic cracking system for the conversion of high boiling hydrocarbons to motor gasoline. Such a system is set forth in detail below in connection with the description of the drawings in which:

Figure 1 is a schematic generalized elevation of a typical system in which the present invention may be used;

Figures 2 and 3 are enlarged views, partly in section, of the upper portions of the gas lift pipes and disengaging hopper shown in Figure 1, Figure 2 being an elevation partially in section along the lines **2—2** in Figure 3, and Figure 3 being a top view of a section along the lines **3—3** in Figure 2;

Figures 4 and 5 are enlarged views of an embodiment of the present invention to be used as upper parts of the gas lifts shown in Figures 1, 2 and 3, Figure 4 being an elevation and Figure 5 being a top view;

Figures 6 and 7 are top views of modifications of the embodiment of the invention shown in Figures 4 and 5.

In Figure 1 is shown a typical embodiment of the type of system with which the present invention is concerned. Since the invention is directed primarily to the upflow portion of the system and since the operation and construction of the reactor and regenerator or kiln of the typical system shown in Figure 1 are adequately described in the aforementioned article appearing in the "Oil and Gas Journal," detailed illustration and description of the latter have been omitted for the sake of brevity. It is to be understood that various arrangements of kiln and reactor may be employed in connection with the present invention, as for example arrangements shown in the "Houdry Pioneer," vol 5, No. 1, February 1950. The system shown in Figure 1 differs from those shown in the cited publications in that a multiple lift is used in the former, while the latter employ single lifts.

As indicated in part by the labelled portions of Figure 1, relatively large particles of solid cracking catalyst, such as particles of between about 1 to 15 and preferably about 2 to 8 millimeters in diameter, flow downwardly through a reactor or cracking zone as a downwardly moving compact non-turbulent bed and contact hydrocarbons with the resultant formation of cracked products (synthetic crude) and are transferred through a conduit or seal leg to a regenerator, kiln or regenerating zone in which the coke deposited on the particles of catalyst in the cracking zone is removed. Compositions effective as hydrocarbon cracking catalysts (typically natural or synthetic aluminosilicates) and the conditions in the reactor and kiln are well known to the art and need not be repeated here.

Catalyst particles are withdrawn from the regenerator and flow downwardly in a conduit as a compact non-turbulent column to a gas lift inlet chamber or particle supply hopper **10** surrounding the bottom of a plurality of gas lifts, and are transported, lifted or elevated vertically upward as a plurality of continuous streams of solid particles by transporting or lifting gas introduced at a substantial pressure, such as from about 1 to 10 pounds per square inch gauge, to inlet chamber **10** by conduits **11** and/or **12**. The inlet chamber **10** can be of any design suitable for multiple lifts, such, for example, as that disclosed in the copending application of R. N. Shirk and C. Bruckner, Serial No. 124,874, filed November 1, 1949. Alternatively, a plurality of separate inlet chambers (one for each lift) can be employed. The gas used in lifting may be one derived from or one used later in the system, such as flue gas or hydrocarbon charge stock, either in liquid or vapor phase, respectively; or may be one used only for lifting, such as air or steam.

The particles of contact material pass upwardy through a plurality of vertical cylindrical pipes or conduits indicated generally by **13** to a closed disengaging vessel, hopper or separator **14** surrounding the top of lifts **13**, which vessel comprises a confined gas-solids disengaging zone common to all the lift paths. The disengaged lifting gas is thereafter removed from vessel **14**, as from the top thereof by conduit **15**.

Particles of catalyst disengaged from the lifting gas settle on the surface of a bed **22** in vessel **14**, from which bed the particles flow through a conduit or seal leg **16**, as a relatively compact non-turbulent column of particles to the reactor. It is to be understood that a particular type of separator, such as vessel **14**, is not a part of this invention and that separators other than the one illustrated which perform the function of separating the elevating gas and particles of catalyst by various specific methods, may be employed. Indeed, the gas, after disengagement from the particles of catalyst at the top of the lift path may, if desired, be passed downwardly through the bed of catalyst in the separator (as, for example, where hydrocarbons are employed as the lifting medium and cracking, in addition to that occurring in the lift, is desired), the lifting gas being finally disengaged from the particles of catalyst at the bottom of the bed in vessel 14. At any event vessel 14 is of considerably greater horizontal cross sectional area than that immediately surrounding the tops of lift paths or conduits 13, such as from 5 to 25 times the area of the circle circumscribing the tops of gas lifts 13, so that the particles spraying or fountaining out of the lift pipes do not impinge against the walls. Also, when free setting of the particles emerging from the gas lifts is employed as a means of separating the particles and lifting gas, the distance of the top of vessel 14 above that of lift pipes 13, which terminate on a common horizontal plane, should be great enough that there is little or no impact of the particles against the top of the disengaging hopper. Thus, for example, a distance of about 10 to 35 feet can be employed when the catalyst particles emerge with an average velocity of 30 feet per second from lifts of 6 to 20 inches in diameter.

As can be seen in Figures 1 and 2, lift paths or conduits 13 provide a multiplicity or plurality of vertically elongated laterally confined parallel lift paths or passageways grouped or arranged equidistantly from a common vertical axis. As shown in Figure 3, the centers of the lower parts of the lift pipes fall on a circle whose center lies on the aforesaid common vertical axis and are arranged or spaced symmetrically around the circle (i. e., equidistantly around the common vertical axis). Moreover, the center of the common disengaging zone or hopper, which is preferably circular in horizontal cross section as shown in the drawing, also lies on the vertical axis and therefore is concentric with respect to the multiplicity of lift paths.

In accordance with the embodiment of the present invention shown in the drawing, the major and lower parts 13a of the gas lifts have a constant circular horizontal cross sectional area while the upper and minor parts of the gas lifts 13b taper eccentrically outward. The eccentric taper can take various forms. For example, the top of the lift pipe or conduit shown in Figure 5 terminates in a circle 16 whose center is eccentric with respect to the center of the lower part. Alternatively, the top may have the form of two spaced semicircles 17 joined by flat parallel walls 18, as shown in Figure 6 or may have the form of an oval 19, as shown in Figure 7. The packing glands 21, which provide means for sealing vessel 14 at the locations where the lift pipes enter the vessel, are constructed to fit any particular shape of the upper parts of the lift conduits.

In all the embodiments shown, that portion of the periphery of the top of each lift that is nearest the common axis is in the same vertical line with the corresponding portion of the periphery of the lower part 13a (i. e., the portion of periphery of each lift pipe nearest the common axis is parallel to and spaced a constant distance from said axis over the entire vertical

extent of the lift pipe). Expressed differently, the horizontal cross sections of the top and bottom of the conduits 13 are tangent at the point nearest the common vertical axis of the plurality of lift conduits when the top cross section is projected vertically downward (note Figures 5, 6 and 7). As a result of this construction, only the portion of the stream of gas and of particles (in each lift path) remote from the common axis of all paths flows radially outward while the stream flows generally upward in the upper part of each lift path.

The gas lifts shown in the drawing are operated by introducing particles and lifting gas to the bottom of each lift path from chamber 10, the amount and velocity of said gas being sufficient to accelerate the upward movement of said particles to a substantial velocity, as discussed more fully below. A stream of gas and of particles flows upwardly at substantial velocity through the lower part of each lift path, which has a constant circular flow area, until it reaches the upper part of the lift path 13b. Because the portion of the periphery of each of the lift paths remote from the common vertical axis of all the lift paths tapers outwardly, each of the streams of gas and of particles individually flows along a median flow line which diverges from said common axis (i. e., the point of average distribution of the particles in each stream continuously moves away from the common axis as the stream travels upwardly). The streams will therefore discharge from the tops of the lift paths so that they diverge from the common axis and the center of vessel 14. As a result, lift conduits of sizes useful in commercial size systems, such as from about 3 to 25 inches in diameter in the lower part, can be spaced around a circle of relatively small radius, such as preferably from about 1 to 5 feet without encountering interference caused by collision of the relatively central portions of the various streams.

In a specific aspect, the present invention can be employed to aid in controlling the velocity of the gas and hence of the particles in the upper part of each gas lift, which velocity increases in lift paths having a constant cross sectional area. Such increase in velocity is produced by the expansion of the gas resulting from the reduction in gaseous pressure that occurs as the stream of gas moves upwardly. It will be noted that, in the present invention, the horizontal cross sectional area of the conduit (i. e., the flow area of the stream of gas and of particles) gradually increases or expands in the upper part of each lift until it reaches a maximum at the top. The expansion in flow area is produced by spacing the flow path boundaries most remote from the common vertical axis at distances which constantly and continuously increase in relation to the proximity to the tops of the lift paths, while the flow path boundaries nearest said common axis are spaced a constant distance therefrom. Depending upon the size relationship between the additional area provided by the expansion of the horizontal cross sectional area of the upper part of each lift and the constant horizontal cross sectional area of the lower part of each lift, the velocity of the stream of gas and of particles as a whole can increase to a slight extent, remain constant or substantially decrease throughout the upper part of each lift.

Thus the particles may be smoothly decelerated in the upper part of each lift so that they discharge from the top thereof at a velocity substantially less than the maximum velocity attained in the lift, such as from about 10 to 40 percent of said maximum velocity, which is realized generally at about the point when the particles enter the upper and tapered part or section. Deceleration is achieved smoothly and without slugging (formation of spaced relatively dense bodies or clouds of particles which move intermittently up the lift) in accordance with the present invention. Such deceleration can be achieved by using relatively small angles of taper, such as from about 0.2 to 5 degrees (the angle of taper being measured as the inclination of the outside wall to the vertical axis of the lift conduit indicated by angle A in Figure 5) extending over relatively long upper sections, such as from about 10 to 30 feet. When, alternatively, relatively sharp angles of taper, such as from about 10 to 30 degrees, are employed, it is preferred that the taper extend over a relatively short portion of the lift path such as from about 2 to 5 feet. (The term "lift path" as used herein is applied to the path extending from the bottom to the top of conduits 13.) Somewhat smaller angles of taper and/or shorter distances over which they extend should be employed when it is desired to maintain the velocity of the stream of gas and of the particles constant or to decrease the rate at which they would otherwise accelerate so that the velocity increases only slightly.

Although the drawing shows the tapered walls as being straight it is within the scope of the present invention to have it curved so that the outer periphery of the lift conduit is somewhat trumpet shaped. In general, it is preferred to construct the lift conduits so that the ratio of the horizontal cross sectional area of the top of the conduit to that of the bottom is between about 1.3 to 5, the upper portion of this range, such as from about 1.5 to 3, being preferred when it is desired to decelerate the particles in the upper part of the lift.

Deceleration of the particles in the upper part of the lift paths is especially advantageous when the maximum velocity of the particles attains a value of over about 30 feet per second. Any substantial increase in maximum velocity above this value results in a considerable increase in the height of the disengaging vessel. By means of the present invention, higher maximum velocities can be used without increasing the height of the disengaging vessel by decelerating the particles in the upper part of the lift path, thereby avoiding the expense resulting from tall disengaging vessels, as pointed out above.

In all of the embodiments shown, a substantial fraction of the particles have a small outward lateral component of velocity as they emerge from the tops of the lift paths. This effect tends to move particles from immediately above the lift path in a manner such that the density of particles in this region is considerably diminished with a resulting diminution in any tendency of the particles to form a mushroom or cloud.

It is to be understood that the present invention is applicable to a wide range of velocity conditions and particle concentration or density in the lifting zone. Various velocities and concentrations can be obtained by varying the amount and pressure of the lifting gas such as by controlling either the total or relative amounts of lift gas introduced by conduits 11 or 12. An effective range or particle concentration for commercial operation involving the size of particles referred to above is from about 0.5 to 20 percent

of the apparent bulk density of the particles (i. e., the density of the packed mass of particles). For present commercial catalyst having apparent bulk densities of from about 40 to 55 pounds per cubic foot, average concentrations of about 1 to 7 pounds per cubic foot have proven particularly advantageous. Experience has shown that an advantageous range of particle velocities is about 20 to 60 feet per second (based on the average velocity of the particles at complete acceleration), although lower velocities may be employed, generally in relatively short lifts, such as those of 50 feet or less.

Although the invention has been described in connection with a system employing a common disengaging zone, it can also, as pointed out above, be usefully applied to systems employing individual disengaging zones or hoppers for each lift. By disposing each lift eccentrically in each individual disengaging zone or hopper (i. e., near one side thereof), the group of disengaging zones can be spaced advantageously within the minimum circumscribing area. Under these conditions, the stream of gas and of particles discharge into each disengaging zone so as to spray or fountain divergently outward from the wall of the disengaging zone nearest the common vertical axis of the group of lifts. Because of the close spacing of the individual disengaging zones permitted by such an arrangement, all of the disengaging vessels can be supported by a single unitary structure at relatively low cost compared to the cost of individually supporting these vessels.

Obviously many modifications and variations of the invention as hereinbefore set forth may be made without departing from the spirit and scope thereof, and therefore only such limitations should be imposed as are indicated in the appended claims.

I claim as my invention:

1. Apparatus for elevating granular material by fluid lifting medium comprising a plurality of vertically elongated conduits grouped about a common vertical axis and terminating in a common horizontal plane, said conduits defining passageways for streams of granular material and fluid lifting medium; and a disengaging chamber surrounding the tops of said conduits and providing a confined space for disengaging said granular material and said lifting medium; the upper portion of each of said conduits tapering eccentrically outward from said common axis.

2. Apparatus for elevating granular material by fluid lifting medium comprising a plurality of vertically elongated conduits grouped about a common vertical axis and terminating in a common horizontal plane, said conduits defining passageways for streams of granular material and fluid lifting medium; and a disengaging chamber surrounding the tops of said conduits and providing a confined space for disengaging said granular material and said lifting medium; the upper portion of each of said conduits tapering outward along that part of its periphery remote from said common axis while that part of its periphery nearest said axis extends vertically upward in parallel relation to said axis.

3. Apparatus for elevating granular material by fluid lifting medium comprising a plurality of vertically elongated conduits grouped about a common vertical axis and terminating in a common horizontal plane, said conduits defining passageways for streams of granular material and fluid lifting medium; and a disengaging cham-

ber surrounding the tops of said conduits and providing a confined space for disengaging said granular material and said lifting medium; the upper portion of each of said conduits being arranged to discharge said granular material and fluid along a median line of discharge which is divergent with respect to said vertical axis.

4. In apparatus for elevating granular material by means of a gaseous lift medium the combination of: a plurality of upright elongated lift conduits of uniform circular cross section over the substantial major portion of their length and having their upper end portions tapered to provide a gradual increase in flow area, the median lines of said tapered portions being slightly inclined to the axes of the portions of uniform circular cross section, and a common disengaging vessel containing the upper end portions of said lift conduits.

5. Apparatus as defined in claim 4 wherein each of said tapered portions of said lift conduits has one side forming a straight longitudinal extension of a side of its associated portion of uniform circular cross section.

6. Apparatus as defined in claim 5 wherein said tapered portions of said lift conduits are frustoconical sections.

7. Apparatus as defined in claim 4 wherein the cross-sectional areas of said tapered portions of said lift conduits have major and minor axes of different size.

8. Apparatus as defined in claim 4 wherein said plurality of lift conduits are grouped about a common vertical axis, which vertical axis lies in each of the separate planes containing the main axis and the tapered-section median line of each of said lift conduits.

9. Apparatus as defined in claim 4 wherein said lift conduits are parallel and each of said tapered portions has one side forming a straight longitudinal extension of a side of its associated portion of uniform circular cross section.

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