

Aug. 25, 1959

J. M. BOURGUET ET AL

2,901,421

METHOD AND APPARATUS FOR TRANSFER OF CONTACT MATERIALS

Filed July 12, 1952

7 Sheets-Sheet 2

Fig. 3

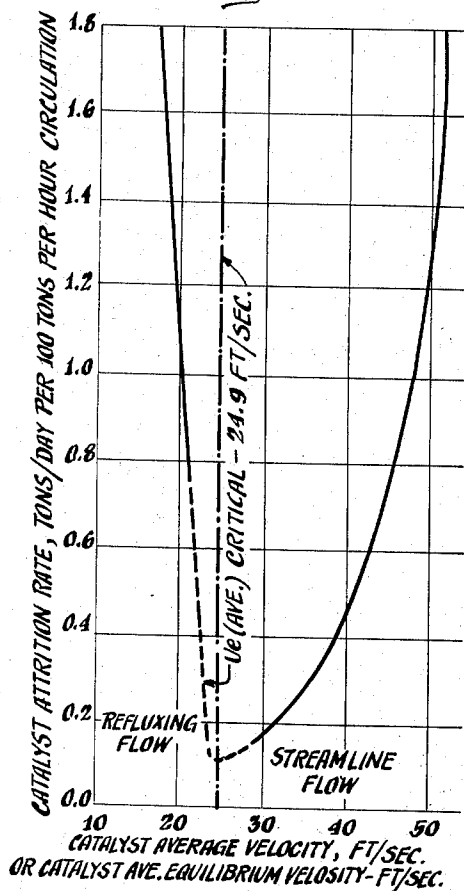


Fig. 4

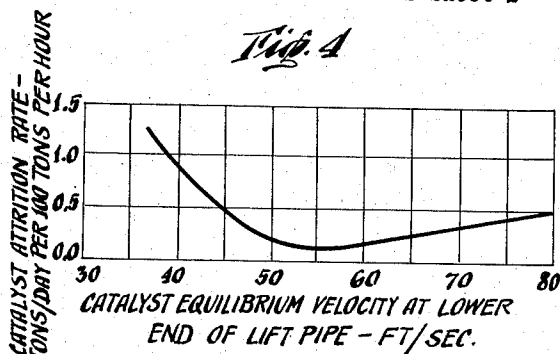


Fig. 5

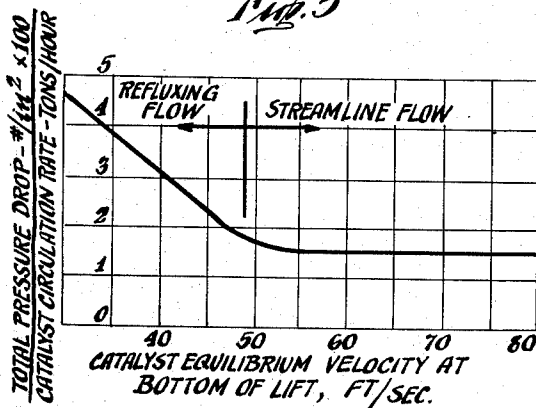
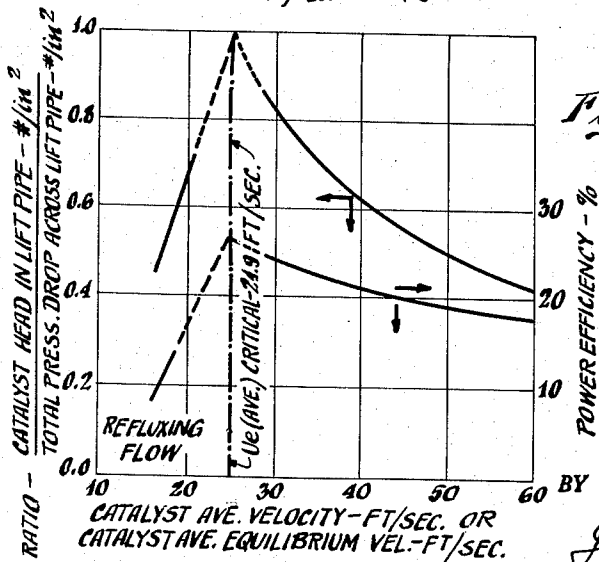


Fig. 6



INVENTORS
JEAN M. BOURGUET
ROBERT D. DREW
FREDERICK E. RAY
BY John A. Crowley, Jr.
ATTORNEY

Aug. 25, 1959

J. M. BOURGUET ET AL

2,901,421

METHOD AND APPARATUS FOR TRANSFER OF CONTACT MATERIALS

Filed July 12, 1952

7 Sheets-Sheet 3

Fig. 19

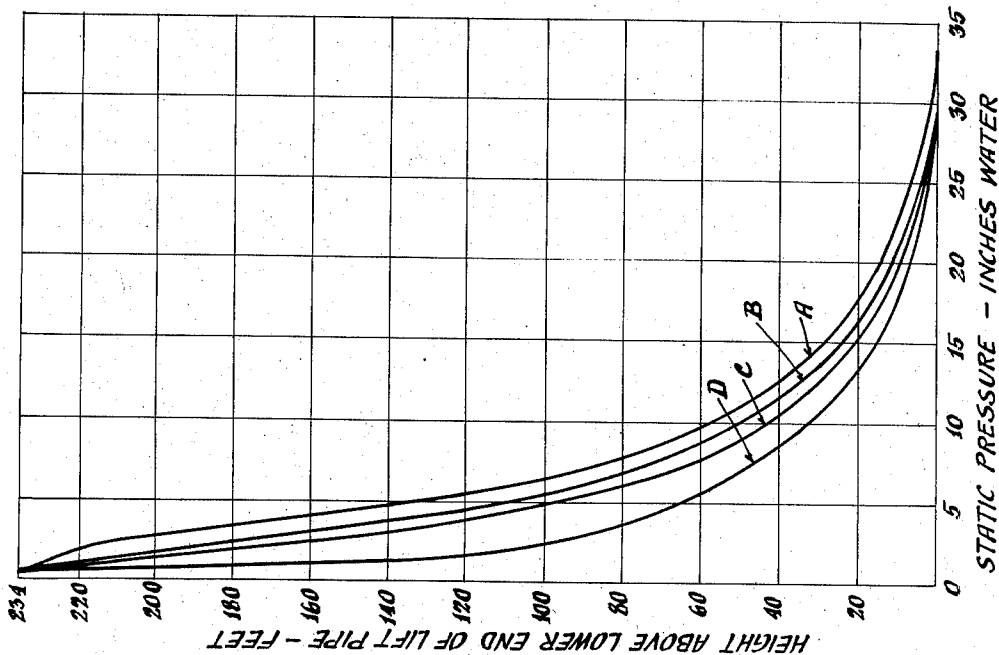
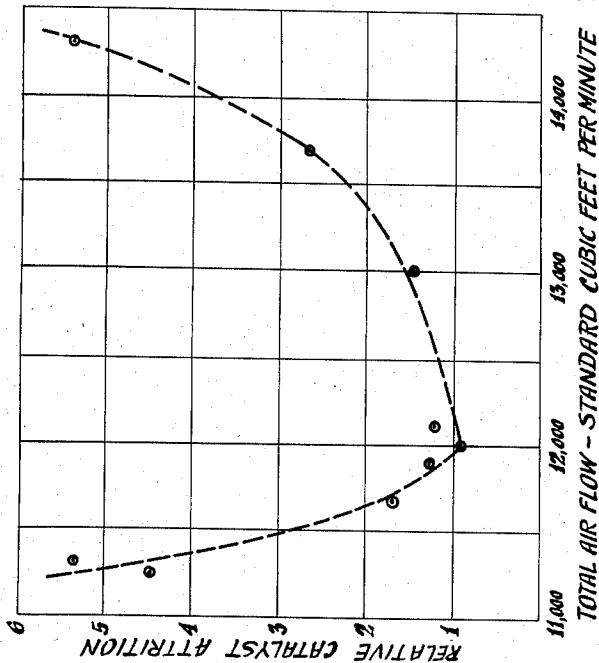


Fig. 7

INVENTORS
 JEAN M. BOURGUET
 ROBERT D. DREW
 BY FREDERICK E. RAY
 John A. Crowley, Jr.
 ATTORNEY

Aug. 25, 1959

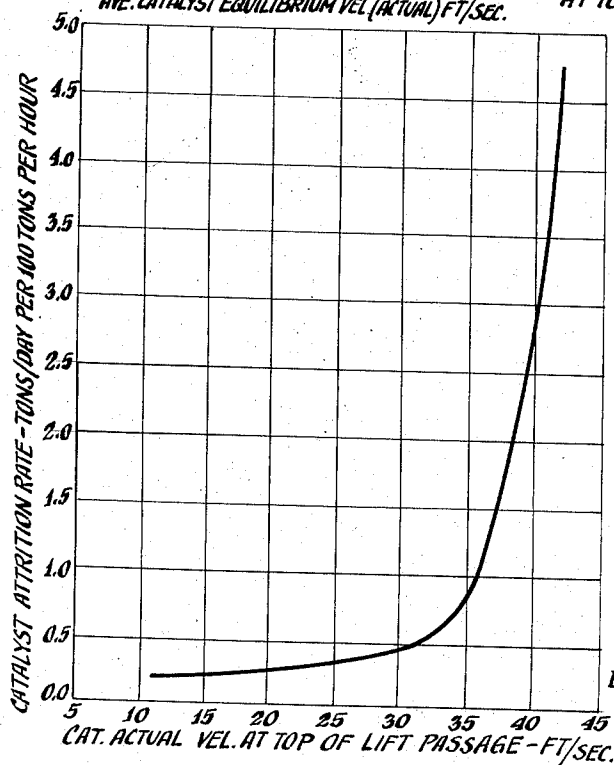
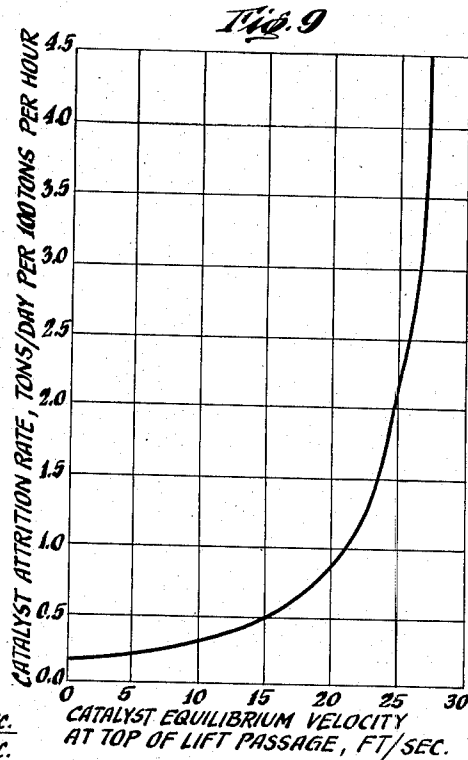
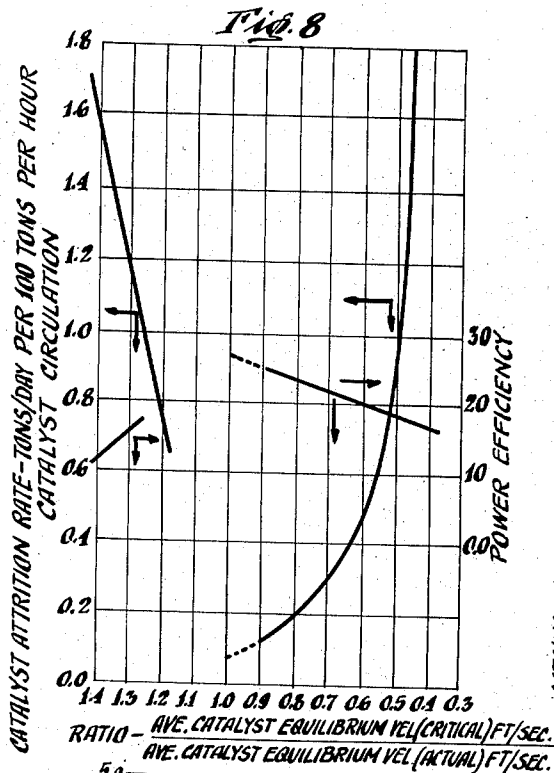
J. M. BOURGUET ET AL

2,901,421

METHOD AND APPARATUS FOR TRANSFER OF CONTACT MATERIALS

Filed July 12, 1952

7 Sheets-Sheet 4



INVENTORS
JEAN M. BOURGUET
ROBERT D. DREW
FREDERICK E. RAY
BY *John A. Crowley*
ATTORNEY

Aug. 25, 1959

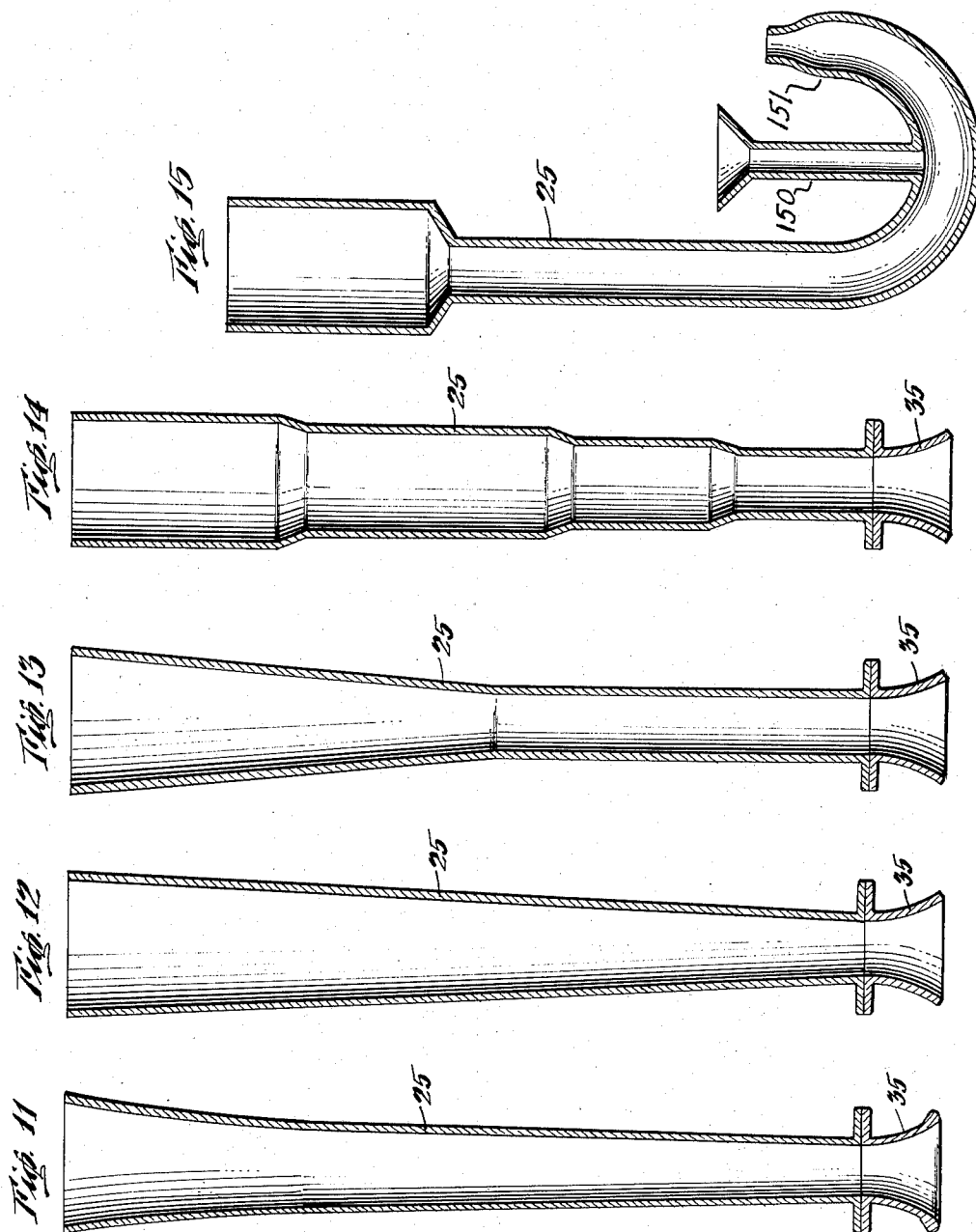
J. M. BOURGUET ET AL

2,901,421

METHOD AND APPARATUS FOR TRANSFER OF CONTACT MATERIALS

Filed July 12, 1952

7 Sheets-Sheet 5



INVENTORS
JEAN M. BOURGUET
BY ROBERT D. DREW
FREDERICK E. RAY
John A. Crowley
ATTORNEY

Aug. 25, 1959

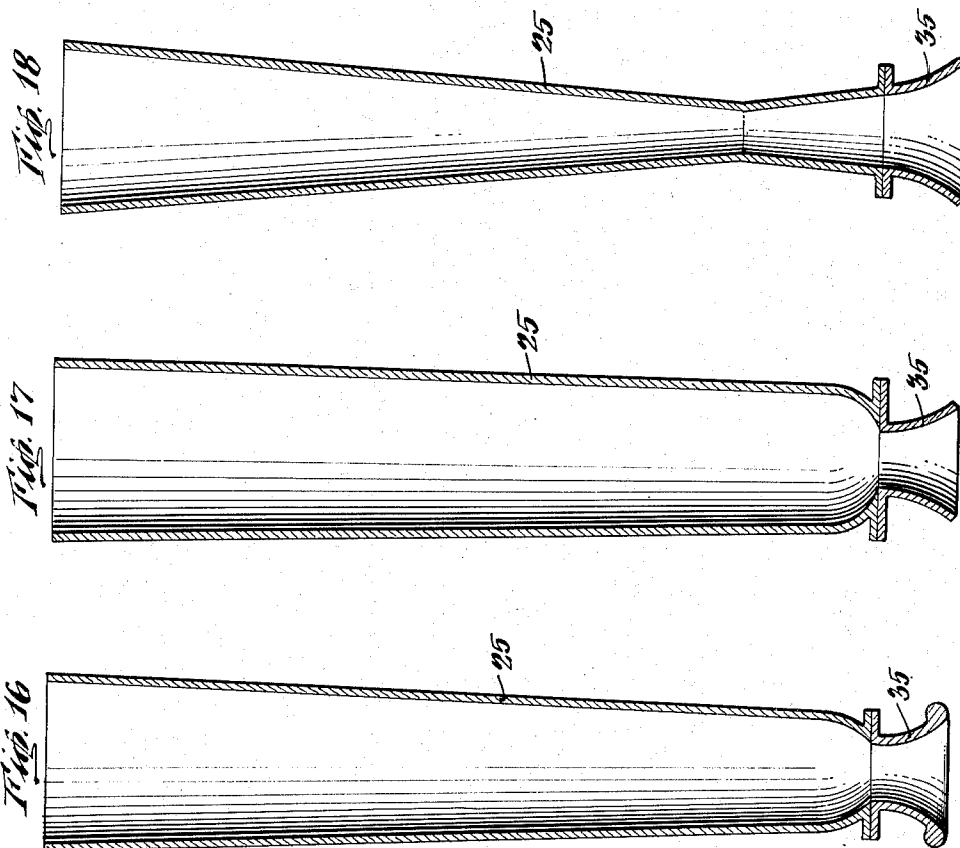
J. M. BOURGUET ET AL

2,901,421

METHOD AND APPARATUS FOR TRANSFER OF CONTACT MATERIALS

Filed July 12, 1952

7 Sheets-Sheet 6



INVENTORS
JEAN M. BOURGUET
ROBERT D. DREW
BY FREDERICK E. RAY
John A. Crowley, Jr.
ATTORNEY

Aug. 25, 1959

J. M. BOURGUET ET AL

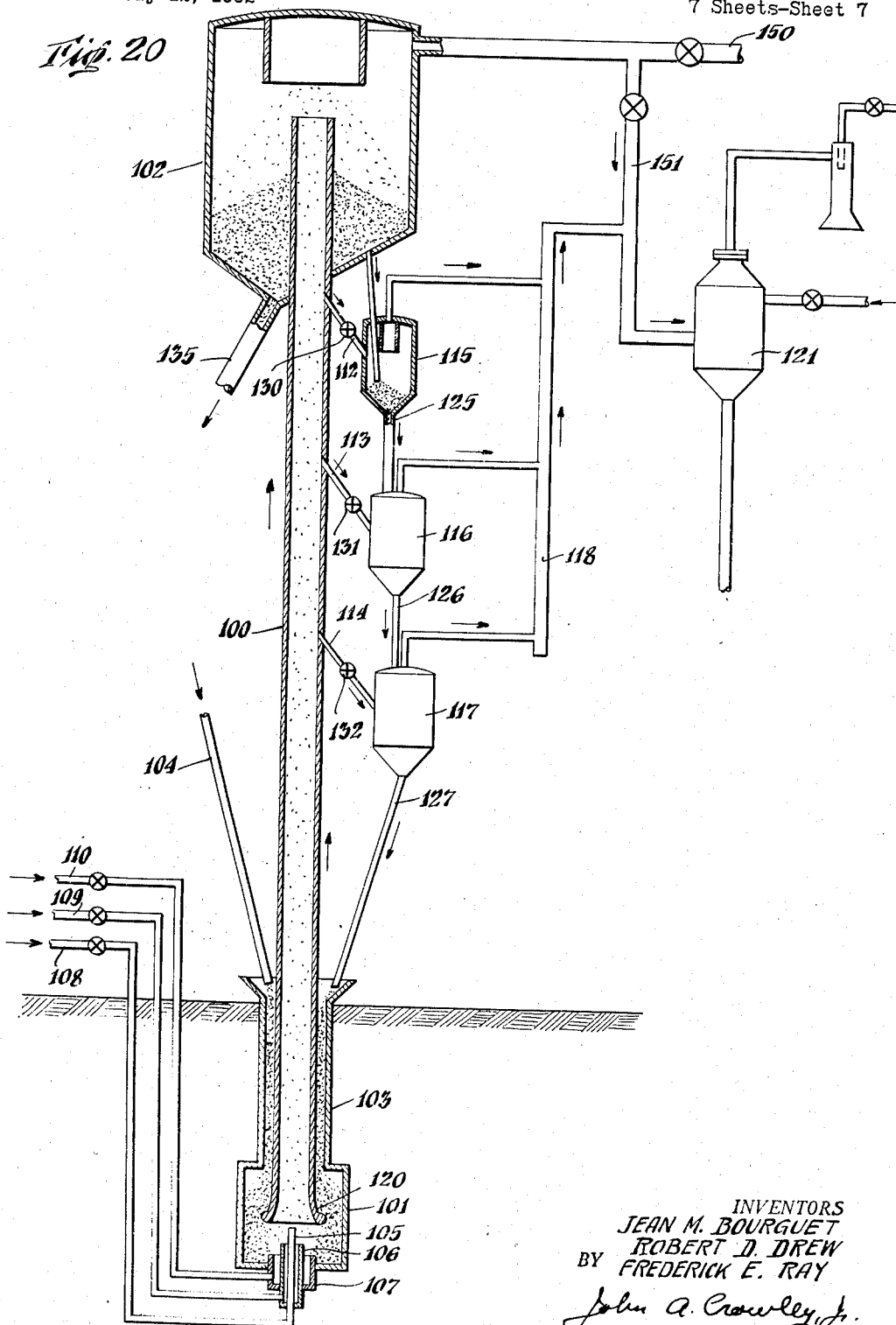
2,901,421

METHOD AND APPARATUS FOR TRANSFER OF CONTACT MATERIALS

Filed July 12, 1952

7 Sheets-Sheet 7

Fig. 20



INVENTORS
JEAN M. BOURGUET
ROBERT D. DREW
BY FREDERICK E. RAY

John A. Crowley, Jr.
ATTORNEY

1

2,901,421

METHOD AND APPARATUS FOR TRANSFER OF CONTACT MATERIALS

Jean M. Bourguet, Westville, Robert D. Drew, Wenonah, and Frederick E. Ray, Woodbury, N.J., assignors to Socony Mobil Oil Company, Inc., a corporation of New York

Application July 12, 1952, Serial No. 298,592

21 Claims. (Cl. 208—174)

This application is a continuation-in-part of our application Serial Number 210,942, filed in the United States Patent Office on February 14, 1951, now U.S. Patent No. 2,770,504.

This invention deals with a method and apparatus for transfer of granular contact materials from a given location to a higher location. It is particularly concerned with a method and apparatus for pneumatic transfer of contact material in cyclic hydrocarbon conversion systems and to an improvement in a combination method for hydrocarbon conversion in the presence of moving granular contact materials.

The invention may be applied to such processes as catalytic cracking, isomerization, hydrogenation, dehydrogenation, reforming, hydroforming, aromatization, alkylation, cyclocizing, treating and desulfurization of petroleum fractions. Also, the invention may be applied to coking of hydrocarbons in the presence of granular coke or refractory solids, viscosity reducing of petroleum residuums at elevated temperatures, pyrolytic conversion processes such as the conversion of propane and ethane to unsaturated hydrocarbons and of methane to acetylene. The invention in its broadest forms is not restricted to these processes and involves an important improvement in pneumatic conveying systems and methods generally and particularly where the transfer of granular solids with the least possible amount of breakage and attrition is involved such as the case in applications in which the solids are continuously circulated through a closed cyclic system.

The contact material involved may vary widely in its properties depending upon its use. For catalytic hydrocarbon systems the catalyst may take the form of natural or treated clays, bauxites, inert or active carriers impregnated with certain catalytically active metals or compounds thereof, or synthetic associations of silica, alumina, magnesia, chromia, molybdenum oxide, etc., or combinations thereof to which may be added small amounts of other compounds, usually but not always, metallic compounds for specific purposes. When the contact material is employed principally for heat carrying purposes as in pyrolytic conversion processes it may take the form of any of a number of refractory materials such as fused alumina, mullite, carborundum, zirconium oxide, charcoal etc., for coking processes the solid material may comprise of a low activity clay catalyst, petroleum coke, pumice or similar materials. The contact material may be in the form of pellets, spheres, tablets, pills or irregular shaped material of palpable particulate form as distinguished from powdered material. It should be understood that the term "granular" as employed herein in describing and claiming this invention is intended to broadly cover any of the above forms of contact material. The contact material involved in this invention may range in size from about 0.005 to 0.5 inch and preferably from about 4-20 mesh by Tyler Standard Screen Analysis. The density of the material as poured into a measuring container may be within the range about 20-130 pounds

2

per cubic foot, and in the case of adsorbents preferably within the range about 25-60 pounds per cubic foot.

An important application of this invention involves its integration into a continuous catalytic cracking system with a resultant greatly improved overall combination process. In such systems the contact material is passed cyclically through a conversion zone wherein it contacts a hydrocarbon feed at pressures usually above atmospheric and temperatures of the order of 700-1100° F. whereby the feed is converted and then through a regeneration zone wherein a carbonaceous contaminant deposited on the catalyst in the conversion zone is removed by burning. When granular catalysts are employed it has been found to be highly desirable to maintain the catalyst as a substantially compact bed or column of gravitating particles in the conversion and regeneration zones. Until recently, continuous bucket elevators were employed exclusively to effect transfer of the catalyst between zones in commercial units. Mechanical elevators have been found to impose certain practical limitations on the overall unit height and on the amount of catalyst circulated. As a result, heretofore all commercial continuous catalytic cracking units of the compact moving bed type have involved side by side arrangement of reactor and kiln thereby requiring two elevators and have involved relatively low catalyst circulation rates. It has been found desirable to increase catalyst circulation rates in order to permit simplification of other parts of the system; particularly the kiln and to arrange the reactor and kiln in vertical series so as to require only a single catalyst transfer step per cycle. This could not be done practically with existing mechanical transfer devices. It has been proposed from time to time to effect the catalyst transfer by pneumatic catalyst transfer lifts but the use of pneumatic transfer in these cyclic conversion systems has been entirely prevented because of the very high catalyst attrition and breakage encountered in the pneumatic transfer step, and further because of excessive power requirements.

It is a major object of this invention to provide an improved method and apparatus for transfer of granular contact materials.

Another important object is the provision of an improved cyclic method and apparatus for conversion of hydrocarbons in the presence of a moving granular contact material.

A specific object is the provision of an improved method and apparatus for pneumatic transfer of granular contact materials without excessive attrition and without excessive power requirements in a continuous cyclic process for conversion of hydrocarbons.

Another object is the provision of an improved method for operating a system for transferring granular solids by pneumatic transport.

Still another object is the provision in a process wherein granular solids are transferred upwardly through a confined passage in suspension in a lift gas of an improved method for effecting separation of the elevated solids from the lift gas.

These and other objects of this invention will become apparent from the following description of the invention.

It was originally believed that in the pneumatic transfer of granular solids through an upwardly extending lift passage, maintenance of the lowest gas velocities which would permit transfer of the solids would result in the lowest possible attrition rates. It was discovered, however, that at such low rates the attrition of the granular solids was very high. In fact, the attrition in the case of catalysts of the most durable type known was far in excess of that which could be economically tolerated in commercial continuous catalytic cracking systems. Moreover, it was discovered that for a given pneumatic

lift installation the rate of catalyst attrition unexpectedly fell off very sharply as the rate of gas and catalyst flow along the lift passage increased until a critical velocity was reached at which attrition was less susceptible to velocity change. Upon further increase in velocity the attrition rate again increased but at a more gradual rate. It was found that unexpectedly the critical minimum average gas and catalyst velocity is dependent upon the length of the lift passage and that for any given lift passage the necessary delicacy of control over the attrition cannot be attained at average gas and catalyst velocities below the critical minimums. It was also discovered that the catalyst attrition rate could be further substantially reduced by maintaining the linear rate of catalyst flow as it emerges from the upper end of the lift passage below a critical maximum above which the rate of attrition increased at an extremely rapid rate. It was further discovered that for lifts above certain heights, it is necessary to effect a substantial deceleration of the catalyst in the upper portion of the lift in order to provide stream velocities both in the lower section of the lift and at the upper end thereof which together result in the lowest overall catalyst attrition rate.

In a preferred form, this invention involves a cyclic continuous catalytic conversion system in which the catalyst is passed cyclically through reaction and catalyst regeneration zones and in which the catalyst is circulated by means of a substantially vertical pneumatic lift, wherein the average rate of gas flow is maintained above a certain critical minimum which will be discussed hereinafter and below a certain maximum, while the gas flow rate is further controlled to maintain the velocity of the catalyst discharging from the upper end of the lift passage into a separation or settling chamber below a critical maximum which will be discussed in detail hereinafter.

The invention may be most readily understood by reference to the attached drawings of which:

Figure 1 is an elevational view, partially in section, of a preferred arrangement and application of this invention;

Figure 2 is a detailed sectional view of a portion of the apparatus shown in Figure 1;

Figure 3 is a graph showing the relationship between catalyst average velocity and attrition rate in the operation of pneumatic lifts of the type here involved;

Figure 4 is a similar graph showing relationship between catalyst equilibrium velocity at the bottom of the lift pipe and the attrition rate;

Figure 5 is a similar graph showing the relationship between pressure drop and catalyst equilibrium velocity;

Figure 6 is a similar graph showing the relationship between catalyst average velocity and the ratio of catalyst head in the lift pipe to total pressure drop;

Figure 7 is a graph showing the manner in which static pressure varies along the lift for several different gas flow rates;

Figures 8, 9 and 10 are graphs showing the relationship between other variables in the operation of pneumatic lifts of the type here involved;

Figures 11-18 inclusive are elevational views, in section, of a number of modified forms of the lift pipe involved in this invention;

Figure 19 is a graph showing the relationship between the total air supply rate and catalyst attrition in a typical commercial size continuous catalytic cracking system; and

Figure 20 is an elevational view, partially in section, showing still another modified arrangement of this invention.

The figures representing apparatus structure and arrangement are, of course, highly diagrammatic in form.

Turning now to Figure 1, there is shown a typical application of this invention in a cyclic continuous moving bed catalytic cracking process. In the drawing, there is shown a reactor 10 which is adapted to confine a mov-

ing compact bed of catalyst and which internally may incorporate those features by now well known to the art for accomplishing uniform flow, contacting, engaging and disengaging of the catalyst and reactant. Catalyst enters the reactor through a gravity feed leg 11, which may be of the type disclosed and claimed in United States Patent Number 2,410,309, and catalyst is withdrawn from the reactor via two or more conduits 12 and 13 from which it flows through branch conduits 14 to the upper end of a catalyst regenerator 15. The withdrawal system may be similar to that now disclosed and claimed in application Serial Number 132,067, filed in the United States Patent Office on December 9, 1949, now U.S. Patent No. 2,536,625. Vaporized hydrocarbon feed, for example, a 500-900° F. gas oil cut may enter the upper section of the reactor via pipe 17. The feed may be preheated in a heater not shown to a temperature of the order of 700-950° F. A suitable high boiling liquid hydrocarbon feed may be supplied into the reactor via pipe 18, either cold or in preheated condition. The internal liquid feed arrangement may be similar to that disclosed in application Serial Number 719,724, filed in the United States Patent Office on January 2, 1947, now U.S. Patent No. 2,574,850. The cracked lower boiling gaseous hydrocarbon products may be withdrawn from the lower section of the reactor via pipe 20. The internal arrangement associated with pipe 20 may be similar to that disclosed and claimed in United States Patents 2,458,498 and 2,459,096. A suitable inert seal gas such as steam or flue gas may be supplied to an upper seal zone in the reactor via pipe 21. The rate of seal gas supply is maintained by differential pressure controller 15 sufficient to control the pressure in the seal zone slightly above that in the reaction zone proper. Similarly, a seal and purge gas is admitted into the lower section of the reactor via pipe 22 to purge gaseous hydrocarbons from the effluent catalyst. It should be understood that the word "gaseous" as employed herein in describing and claiming this invention is intended in a broad sense as covering materials in the gaseous phase under the particular operating conditions involved regardless of what may be the phase of such materials under ordinary atmospheric conditions. The reactor may be operated at a pressure near or somewhat above or below that in the kiln. When the reactor pressure is substantially above that in the kiln it may be desirable to provide a depressuring zone in the legs 12 and 13.

While the invention is not limited thereto the kiln shown is of annular shape so as to provide a central shaft through which a lift conduit 25 extends. The kiln is provided with a central air inlet 26 and flue gas outlets 16 and 19 adjacent either end. A bank of cooling tubes is provided in the lower section of the kiln supplied with a suitable cooling liquid or gas via pipe 27. Cooling fluid leaves these tubes via pipe 28. Suitable internal arrangements for the kiln here shown are disclosed and claimed in application Serial Number 186,953, filed in the United States Patent Office September 27, 1950, now U.S. Patent No. 2,695,220, and Serial Number 186,954, filed in the United States Patent Office September 27, 1950, now abandoned.

The catalyst passes from kiln 15 via two or more pipes 30 and 31 as compact streams delivering onto compact gravity feed legs in pipes 32 and 33 respectively. These legs are vented to the atmosphere on their upper ends, and suitable flow measuring devices may be provided in association therewith.

The catalyst delivers from legs 32 and 33 onto a bed 29 thereof in a lift feed tank 34. A substantially vertical tapered lift pipe 25 extends upwardly from a location under the surface of the bed 29 and intermediate the ends of tank 34 to a location within and intermediate the ends of a combination settling-surge vessel 36 which is positioned a substantial distance above the reactor 10. A flared mouth piece 35 is connected by flange 37 to the

lower end of the lift pipe 25. This mouth piece is preferably flared outwardly along a curve, approximately a hyperbolic spiral. A detailed view, in section, of this mouth piece is shown in Figure 2. The design of the flared mouth piece is disclosed and claimed in detail in application Serial Number 211,343, filed in the United States Patent Office February 16, 1951, now U.S. Patent No. 2,770,503. It is emphasized at this point that by the expressions lower end of lift passage and lower end of lift stream as employed herein in describing this invention, the lower end of the lift pipe 25 above the flared mouth piece 35, i.e., at the level of flange 37 is intended and these expressions are not to be construed as meaning the lower end of the mouth piece.

A conduit 38 having, if desired, a perforated conical roof 201 located directly below and preferably at least partly within the flared mouth piece 35 is provided for introduction of primary lift gas substantially directly into the lift passage without the necessity of its flow through any substantial portion of the bed 29. A number of vertical cylindrical vanes 200 are arranged within and concentrically with respect to the upper discharge portion of conduit 38 so as to divide the discharge portion of conduit 38 and the roof piece 201 into a plurality of concentric passages. Rings 202 attached to the lower end of the vanes form restricted slot openings to those passages from below. This arrangement insures uniform distribution of the primary air to all portions of the lift passage cross-section. In arrangements of the type described, the width of the annular passage 203 between the mouth piece 35 and gas inlet distributor cone 201 will vary depending upon the dimensions of the lift pipe. As an example, for a 20" diameter lift pipe, 200 feet high, the width of the annular passage 203 was about 2 inches. Conduit 39 is a catalyst drain employed only when the unit is shut down. A ring partition 40 is arranged within the feed tank to provide an annular secondary gas plenum chamber 41. Secondary gas is supplied this plenum chamber from manifold 42 via pipes 43 and 44, bearing control valves 45 and 46 respectively. A downwardly facing ring type angle baffle 47 is provided to form a means for distributing secondary gas into the bed 29. Orifices 48 communicate the plenum chamber 41 with the space under baffle 47. The secondary gas in order to reach the lift passage must pass through a portion of the feed tank in which, at least in the absence of gas flow, there exists a substantial thickness of compact catalyst mass or bed between the distributors 47 and the lower end of mouth piece 35.

It has been found that the rate of catalyst entry into the lift can be regulated by control of the rate of secondary gas flow and, that once this is set, the total gas velocity, catalyst velocity and stream density in the lift can be regulated by control of the primary air supply. This method of operation is broadly disclosed and claimed in application Serial Number 76,017, filed in the United States Patent Office February 12, 1949, now U.S. Patent No. 2,666,731. The improved method of transferring catalyst from the kiln to the lift feed tank in combination with the pressure type lift is disclosed and claimed in United States application Serial Number 80,866, filed March 11, 1949, now U.S. Patent No. 2,697,685. The lift gas which may be air, steam or flue gas, for example, is drawn through conduit 50 into the blower by which it is forced through line burner 52 wherein it is heated and then via conduit 53 to supply manifolds 42 and 38. The pressure at the blower 51 is maintained constant by pressure regulating controller 54 which controls the speed of the turbine 55. Other things being equal the pressure at the inlet to the mouth piece 35 will increase with increasing catalyst throughput rates. Hence, by setting the pressure regulating controller 59 at a given pressure, the rate of secondary air flow can be maintained substantially constant through actuation of control valve 60 by controller 59. The total rate of gas

supply is maintained constant at any desired set valve by means of orifice 61, flow regulating controller 62 and control valve 63. Once the controller 62 is set, an increase in secondary air flow is accompanied by an automatic equal decrease in primary air flow. If desired for less preferable operations, the preheating of the lift gas may be omitted.

The lift pipe 25 shown is of tapered construction substantially along its entire length, having its greatest cross-section at its upper end. A partition 66 is arranged across the vessel 36 shortly below the upper end of the lift pipe to divide the vessel into an upper settling chamber 67 and a lower catalyst surge chamber 69. Three concentric rings of pipes 70, 71 and 72 extend through the partition 66 for transfer of catalyst from the settling chamber to the surge chamber. Pipes in ring 70 terminate in a plane sloping down at approximately the angle of repose of the catalyst (25-40° with the horizontal) depending upon the catalyst toward the outlet from chamber 69, which is the upper end of the gravity feed leg 11. The pipes in rings 71 and 72 terminate in their lower ends in similar planes at higher levels in the chamber 69. Flow restricting orifices (not shown) are provided within the pipes 70, 71 and 72, near the lower ends thereof. The pipes 70, 71 and 72 terminate on their upper ends in what would be the surface of a cone having its apex centrally above the upper end of the lift pipe.

In operation, the major portion of the catalyst will pass downwardly as a compact stream through the ring of pipes having their lower ends nearest above the surface level of the bed in chamber 69. The throttling orifices within the pipes in any ring of pipes 70, 71 and 72 are sized to handle most of but less than all of the total catalyst circulation, most of the remainder of the flow passing through the ring of pipes terminating on their upper ends at the next higher level in chamber 67. Only a very small flow of catalyst will occur through those pipes having their lower ends below the bed surface in chamber 69. This arrangement permits transfer of the catalyst settling on the partition 66 down onto the bed in the surge chamber as throttled compact streams, thereby avoiding the impact which would be involved in free drop of the catalyst discharged from the lift onto the bed in the surge chamber. This helps to reduce attrition and breakage of the catalyst. A ring baffle 170 extends centrally up from the partition 66 to a level which substantially corresponds to the level of the upper end of the lift pipe when the unit is in normal operation and which is above the level of the upper end of the lift pipe when temperatures in the unit are low and the lift pipe has contracted. The baffle 170 prevents overflow of catalyst into the lift pipe when the unit is shut down after operation. A sleeve 172 extends up from the bottom of chamber 69 to which it is tightly fastened to a level shortly above the partition 66. A lip baffle 73 connected to the end of pipe 25 overhangs the upper end of sleeve 172 so as to prevent catalyst escape through the sleeve. An annular passage is left between the baffles 73 and 170, which in effect serves the purpose of an overflow for catalyst when the bed level on the partition 66 becomes too high. A cylindrical baffle 74 closed on its upper end is supported centrally above the lift pipe and below the top of the settling chamber. This baffle prevents direct straight line flow between the gas outlet 75 in the top of chamber 67 and the upper end of the lift passage and provides an indirect passageway 76 for flow of gas from the separation chamber along the path indicated by the flow arrows. The lower end of the baffle 74 should preferably be sufficiently close to the upper end of the lift pipe to cause a reversal in the direction of flow of most of the lift gas before it leaves the chamber 67. The stream of catalyst suspended in lift gas is rapidly expanded as it enters the settling chamber 67 which is of substantially greater horizontal cross-sectional area than

the upper end of the lift conduit, whereby the stream velocity rapidly decreases and the catalyst shot up into the chamber 67, decelerates until it reaches a level where its direction of flow is reversed as it falls by gravity onto the accumulation on partition 66. A small side stream of catalyst may be withdrawn from the bottom of chamber 69 via pipe 30 to an elutriator not shown, for removal of any fines formed and the scrubbed catalyst is then returned to the cyclic system at a suitable location such as the feed tank 34.

The present invention relates particularly to the construction of the tapered lift 25 and to the control of the operation thereof in a manner described in detail hereinafter which permit pneumatic transfer of granular contact material without excessive attrition and breakage thereof, and to the resulting overall greatly improved cyclic conversion process. It will be understood that while the system described represents a preferred form of the invention, the construction arrangement and operation of the reactor, kiln, lift feed receptacle and separator may be modified considerably within the scope of this invention. Thus, the invention is not necessarily limited to mixed vapor and liquid feeds to the reactor nor to the details of reactor and kiln design shape and relative arrangement shown. For example, the reactor and kiln may be arranged side by side and two lifts employed to effect the catalyst circulation. If desired, pressure lock systems may be employed in place of the gravity feed leg described. Also, the lift feed tank design may be modified and only a single lift gas supply employed. However, it should be understood, that because of the flexibility of the primary and secondary lift gas arrangement with respect to variation and control over the total rate of lift gas flow without necessarily affecting the rate of catalyst circulation, the use of that arrangement in connection with this invention is preferable and decidedly advantageous.

It is contemplated that means other than that disclosed may be employed for controlling the relative rates of primary and secondary gas flows such as, for example, the use of a three way valve at the junction of conduits 53, 38 and 42. Such an arrangement is shown in United States application Serial Number 76,017, filed February 12, 1949, now U.S. Patent No. 2,666,731. While the use of the flared mouth piece 35, as described, in itself helps to reduce catalyst attrition, it is contemplated that the mouth piece may be omitted or modified in shape in the broader and less preferred forms of the invention. Also, it is contemplated that a simple expanded settling chamber or even a gas-solids separator of other type, for example, an impingement separator, may be substituted for the combination separator-surge vessel in broader but less preferred forms of this invention.

It has been found that if the average gas and catalyst velocities in the pneumatic lift passage fall below a certain critical minimum which depends upon certain features of the lift pipe hereinafter discussed, the catalyst attrition rate will increase very rapidly for even small increments of gas and catalyst velocity decline. This is well illustrated by the plot shown in Figure 3 in which the abscissa represents catalyst average velocity or catalyst average equilibrium velocity and the ordinate represents catalyst attrition rate in tons per day per 100 tons per hour catalyst throughput. The catalyst average equilibrium velocity may be defined as the excess of the gas average velocity under the conditions of temperature and pressure involved over the catalyst average terminal velocity. This average terminal velocity is the averaged terminal velocity of all the particles averaged for the entire length of the lift passage. In other words, the total average linear gas velocity U_g is equal to the catalyst average equilibrium velocity plus the catalyst average terminal velocity over the entire length of the lift passage. It has been found that in general the catalyst average velocity for a given tapered lift conduit designed

in accordance with this invention is approximately equal to the catalyst average equilibrium velocity. The data plotted in Figure 3 was taken in actual operation of a 200 foot high tapered lift pipe having an internal diameter of 15 3/8 inches at its lower end and 20 1/8 inches at its upper end. As can be seen from Figure 3 in the case of this particular system, there is a definite minimum and break in the velocity-attrition curve at a catalyst average equilibrium velocity of approximately 25 feet per second. The critical average minimum gas velocity for this lift pipe is 25 feet per second plus the average terminal velocity for the particles under the average conditions in the lift pipe. It has been found from a study of a number of different lift pipes that the critical average minimum gas velocity increases with increasing overall length of lift pipe, and for a given lift pipe the critical minimum gas velocity in the lift pipe is progressively greater at successively lower levels. It has been found that for a given lift pipe the critical catalyst equilibrium velocity at the lower end of the lift pipe is substantially twice the average critical catalyst equilibrium velocity.

In Figure 4, there is shown a plot of the catalyst equilibrium velocity at the lower end of the same lift pipe involved in the case of Figure 3 against the catalyst attrition rate. The data for Figure 4 was taken at catalyst throughput rates within the range about 41-54 tons per hour.

It will be noted that above the critical minimum velocity the catalyst attrition rate gradually increases but at a substantially lower rate than below the minimum velocity. While the invention is not to be construed as restricted to any particular theory set forth herein in an attempt to explain the critical and unforeseeable results herein described, it is presently believed that the rapid increase in attrition below the minimum velocity may be due to the tendency for catalyst surging or refluxing in the lift pipe which refluxing is eliminated at and above the critical catalyst and gas velocities. Above these critical velocities the catalyst attrition rate gradually increases for two reasons, first because as will be pointed out hereinafter, it has been found that aside from attrition losses within the lift pipe itself a separate or additional catalyst attrition occurs in the catalyst-gas separation and catalyst collection step in the separator at the upper end of the lift pipe, which additional attrition increases with increasing catalyst actual velocity at the upper end of the lift pipe, and secondly because above a certain maximum velocity within the lift the attrition caused by catalyst particle intercollision and collision with the lift pipe wall becomes appreciable and rapidly increases with further velocity increase.

While in the particular apparatus tested the design was such that the attrition occurring in the lift passage itself and that occurring in the separator could not be separated, it is believed that where the design is such that attrition occurring in the separator is not appreciable, there should be a substantial range of gas velocities in the lift pipe above the critical minimum and below a maximum, within which range the rate of catalyst attrition is substantially constant or increases only at a very low rate with gas velocity increases. An indication of this may be found in Figure 5 which is a plot of catalyst equilibrium velocity at the lower end of the lift pipe vs. pressure drop across the entire length of the lift pipe per 100 tons per hour catalyst throughput. The same lift pipe is involved in Figures 3, 4 and 5.

It has been found that the point of minimum attrition also happens to be the point of minimum pressure drop as may be seen by comparison of the curves in Figures 4 and 5. This is also brought out by the curves shown in Figure 6 in which power efficiency and the ratio of the catalyst head in the same lift pipe to total pressure drop across the lift pipe are plotted against the catalyst average equilibrium velocity. By comparison of Figures 3

and 6 it will be noted that at the same critical velocity of approximately 25 feet per second at which the attrition rate is lowest in Figure 3, the ratio of the catalyst head in the lift to total pressure drop is a maximum. The catalyst head in the lift represents the weight in pounds of catalyst in the entire lift pipe at any instant divided by the average horizontal cross-sectional area of the lift in square inches. If the catalyst throughput rate is maintained constant while the gas rate is increased the pressure drop across the total length of the lift gradually decreases until it becomes substantially equal to the catalyst head. As stated, this is the critical point at which pressure drop across the lift is at a minimum, catalyst attrition is at a minimum and the overall power efficiency is at a maximum. The power efficiency is calculated by dividing the useful work done, i.e., the product of the pounds of catalyst lifted per unit of time and the distance lifted divided by the power supplied in the gas stream entering the lift feed tank, (i.e. the work per same unit of time involved in gas expansion across the lift pipe) assuming no-recoverable power in the gas withdrawn from the separator. In the curve shown in Figure 6, for operating conditions in the lift at which there is no refluxing the ratio:

$$\left(\frac{\text{Catalyst head in lift pipe}}{\text{Total pressure drop across lift pipe}} \right)$$

has been found to be equal to the ratio:

$$\left(\frac{\text{Average critical catalyst equilibrium velocity}}{\text{Average actual catalyst equilibrium velocity}} \right)$$

In view of the above, a convenient method for controlling the operation of the pneumatic lift is to set the catalyst throughput rate at the circulation rate required in the cyclic conversion system by adjusting the amount of secondary lift gas supply; and then while observing the total pressure drop across the lift pipe, adjusting the primary gas stream and thus the total gas throughput until a point of minimum pressure drop for the set catalyst flow rate is reached. Since the static pressure at the lower end of the lift pipe is proportional to the total pressure drop across the lift pipe and equal thereto when the pressure in the receiving chamber is atmospheric, the operation may be conveniently accomplished by adjusting the volumetric rate of catalyst entry into the lift passage to the desired value and then adjusting the total volumetric rate of gas supply to the lift passage to maintain the total pressure at the lower end of the lift passage substantially at a minimum. It is preferred to operate at gas flow rates at or not more than between about 2 to 20 percent and preferably between about 4 to 6 percent above those at which the minimum pressure drop is observed. It will be understood that in reaching the desirable total gas flow rate for a given fixed catalyst flow rate several adjustments in the secondary and total gas flow control valves may be necessary and the expression "regulating the rate of catalyst entry into the lower end of the lift pipe" and equivalent expression, as used herein are intended to broadly included such adjustments. It has been found that while the static pressure at the lower end of the lift stream should be maintained at the critical minimum value in order to limit catalyst attrition to a minimum, this does not necessarily correspond to the point of minimum static pressure at intermediate levels along the lift passage. This may be understood by reference to Figure 7 wherein there is shown the manner in which the static pressure varies at different levels along the lift passage for several different rates of gas flow. The data presented in Figure 7 are based on the operation of a commercial size tapered lift pipe having a diameter 25.6 inches and 39.3 inches at its lower and upper ends respectively and an overall height of 234 feet, using a bead form synthetic gel cracking catalyst. The operating conditions and data for the several curves A, B, C and D are summarized in Table I.

10
Table I

Curve	Catalyst Rate, Tons/Hour	Air Rate, s.c.f.m.	Catalyst Temp. to Lift, ° F.	Relative Attrition Rates	Operating Condition
A-----	212	11,700	884	169	Catalyst Re-fluxing.
B-----	-----	11,900	885	133	Incipient Re-fluxing.
C-----	224	12,100	875	128	Air Rate shortly above that for refluxing.
D-----	220	14,300	897	545	Excessive Air Rate.

Curve A corresponds to an operation where the air rate has dropped precisely to the point where a small amount of catalyst refluxing occurs in the lift. It will be noted that for this condition the static pressure at the base of the lift is above the minimum value and the catalyst attrition is beginning to rise. Upon a relatively small further decrease in air rate the pressure at the lower end of the lift and the catalyst attrition rate would shoot up very rapidly. It will be noted that the pressure and the attrition have reached substantially minimum values at the point of incipient refluxing, curve B, which represents the critical break point. Because of the precipitous manner in which pressure drop and attrition will rise for very small percentage decrease in air velocity below that corresponding to incipient refluxing, it has been found to be preferable as a practical matter to operate the system at air velocities slightly in excess of those corresponding to incipient surging, curve C, representing the preferred operation. It should be noted that while the pressure at the bottom of the lift is identical for curves B and C, the static pressure at intermediate points is slightly lower for curve C than for curve B. Upon further increase in air flow rate, the attrition rises at a substantial rate while the static pressure at intermediate levels drops further. Upon further very substantial increases in the rate of air flow, a point will be reached at which the static pressure at the base of the lift will increase above the minimum value. As stated above, it has been found preferable to operate at gas flow rates at or not more than 2 to 20 percent above those at which the minimum pressure drop is first observed. This corresponds to a condition of minimum static pressure at the lower end of the lift passage and to a condition of static pressure at intermediate levels along the passage which is slightly below that corresponding to the pressure at incipient surging but above the minimum which could be attained at substantially greater gas flow rates.

Expressing the desired operation in another way, the rate of linear gas flow in the lift pipe should be controlled so that the pressure drop across the lift is within a low pressure range defined on one side by a minimum gas rate below which the pressure drop increases rapidly due to increase in catalyst stream density and catalyst refluxing or surging in the lift passage and defined on the other side by a maximum above which the pressure drop increases rapidly due to factors other than the contact material flowing in the lift passage, for example power losses in gas expansion, gas friction against the walls, etc. Operations of the above type are the subject matter of claims of United States Patent Number 2,770,504.

It has been discovered that the critical catalyst average equilibrium velocity varies depending upon the length of the lift pipe and the ratio of the maximum to mean cross-section of the lift passage. For all operations where the catalyst equilibrium velocity at the upper end of the lift passage is equal to or above zero, i.e. where the lift passage does not flare out very sharply near its upper end, it has been found that in order to prevent excessive and prohibitive catalyst attrition rates the average critical

11

catalyst equilibrium velocity $U_{e(ave.)}$ should be at least equal to:

$$U_{e(ave.)} = 0.5(8.0 + 0.12H_t) \frac{A_{max.}}{A_{mean}}$$

and for still better operations at least equal to:

$$U_{e(ave.)} = 0.5(9.0 + 0.12H_t) \frac{A_{max.}}{A_{mean}}$$

and preferably at least equal to:

$$U_{e(ave.)} = 0.5(9.6 + 0.132H_t) \frac{A_{max.}}{A_{mean}}$$

Hence, the average linear velocity of the lift gas through the lift passage must be at least equal to that conforming to the expression,

$$U_{g(ave.)} = C_{t(ave.)} + 0.5(8.0 + 0.12H_t) \frac{A_{max.}}{A_{mean}}$$

Preferably the average linear gas velocity ($U_{g(ave.)}$) should at least be equal to that conforming to the expression

$$U_{g(ave.)} = C_{t(ave.)} + 0.5(9.6 + 0.132H_t) \frac{A_{max.}}{A_{mean}}$$

where H_t is the total length of the lift passage in feet, $A_{max.}$ and A_{mean} are respectively the maximum and mean horizontal cross-sectional areas in square feet for flow in the lift passage, and $C_{t(ave.)}$ is the average terminal velocity through said lift passage in feet per second of the average sized granules of catalyst. The catalyst terminal velocity is that gas velocity which will just float the catalyst granule in question under the particular operating conditions of temperature pressure and lift gas involved. The catalyst terminal velocity may be readily calculated for any given catalyst and operating conditions by use of equations and published data well known to those skilled in the art. The average catalyst terminal velocity is calculated on the basis of the average temperature and pressure in the lift passage, which in turn are averaged on a volumetric increment basis. The average linear gas velocity is calculated by dividing the average volume of the total gas throughput in cubic feet per second under the average temperature and pressure conditions in the lift pipe by the average horizontal cross-sectional area of the lift passage. The average area is the quotient of the total lift passage volume divided by the lift height.

It should be understood that unless otherwise stated, the term linear velocity as applied to gas flow in the lift passage is intended to mean actual velocity based on the total free cross section in the pipe less catalyst.

At the lower end of the lift passage the linear gas velocity should be broadly at least equal to that conforming to the equation

$$U_{g(bot.)} = C_{t(bot.)} + (8 + .12H_t) \frac{A_{max.}}{A_{mean}}$$

and preferably at least equal to that conforming to the equation:

$$U_{g(bot.)} = C_{t(bot.)} + (9.6 + 0.132H_t) \frac{A_{max.}}{A_{mean}}$$

where $C_{t(bot.)}$ is the catalyst-terminal velocity at the lower end of the lift pipe.

While control of the average linear gas velocity above the minimum levels above specified will in general insure suitable minimum gas velocities all along the lift passage and the invention is considered broad thereto, nevertheless, for closer control in accordance with the preferred form of this invention the gas velocity U_g at any level along at least the lower 50-75 percent of the lift passage length and preferably along substantially the entire lift passage length from its lower end, just above the mouth

12

piece, to its upper end should be at least equal to that conforming to the relation

$$U_g = C_t + \left[H \left(\frac{8}{H_t} + 0.12 \right) \frac{A_{max.}}{A_{mean}} \right]$$

where H is the distance in feet below the upper end of said passage to the level in question, H_t is the total length of said lift passage in feet, $A_{max.}$ is the maximum horizontal cross-sectional area of said passage in square feet, A_{mean} is the mean cross-sectional area of said passage in square feet, and C_t is the terminal velocity of granular material of the average size at the level in question. Even better operation may be obtained if the minimum linear gas velocity is maintained at least equal to

$$U_g = C_t + \left[H \left(\frac{9.0}{H_t} + 0.12 \right) \frac{A_{max.}}{A_{mean}} \right]$$

The best operation and least catalyst attrition may be obtained if U_g is maintained at least equal to

$$U_g = C_t + \left[H \left(\frac{9.6}{H_t} + 0.132 \right) \frac{A_{max.}}{A_{mean}} \right]$$

It has further been found that as the catalyst average actual equilibrium velocity rises above the catalyst average critical equilibrium velocity the rate of catalyst attrition gradually rises as shown in Figure 8 in which the catalyst attrition rate and power efficiency of the pneumatic lift are plotted against the ratio of catalyst average critical equilibrium velocity to catalyst average actual equilibrium velocity.

In connection with the data plotted in Figure 8, it was found that the ratio:

$$\frac{\text{Catalyst ave. equilibrium vel. (critical)}}{\text{Catalyst ave. equilibrium vel. (actual)}}$$

was equal to the ratio:

$$\left(\frac{\text{Catalyst head \#/in.}^2}{\text{Pressure drop across lift - \#/in.}^2} \right)$$

for all values of the first ratio of 1.0 or less.

In all cases according to the present invention the average linear gas velocity in the lift passage must be maintained broadly below that conforming to the equation,

$$U_{g(ave.)} = C_{t(ave.)} + 2.5 U_{e(ave.)}$$

more advantageously below

$$U_{g(ave.)} = C_{t(ave.)} + 1.8 U_{e(ave.)}$$

and preferably below

$$U_{g(ave.)} = C_{t(ave.)} + 1.4 U_{e(ave.)}$$

where $U_{e(ave.)}$ is the catalyst average equilibrium velocity and $C_{t(ave.)}$ is the catalyst average terminal velocity and where $U_{e(ave.)}$ is broadly at least equal to:

$$U_{e(ave.)} = 0.5(8.0 + .12H_t) \frac{A_{max.}}{A_{mean}}$$

more advantageously at least equal to

$$U_{e(ave.)} = 0.5(9.0 + .12H_t) \frac{A_{max.}}{A_{mean}}$$

and preferably at least equal to

$$U_{e(ave.)} = 0.5(9.6 + 0.132H_t) \frac{A_{max.}}{A_{mean}}$$

It was also discovered that aside from the catalyst attrition arising from insufficient or excessive gas and catalyst velocities within the lift passage additional attrition is encountered in the gas-solid separation step and that this attrition skyrockets unless the actual catalyst velocity at the upper end of the lift passage is maintained below a critical maximum of about 35 feet per second. This is shown in Figures 9 and 10 in which the catalyst attrition rate is plotted against the catalyst equilibrium velocity and catalyst actual velocity respectively at the upper end of the lift passage. The velocity values given

in these curves are believed to be accurate within about ± 5 feet per second. In view of the above, in the preferred form of this invention, not only should the gas velocity be maintained above a critical minimum below which refluxing of catalyst and excessive pressure drops and attrition rates are encountered but also the flow in the upper portion of the lift passage should be controlled so that the catalyst velocity does not exceed a critical maximum above which additional excessive attrition will occur. In general, the average catalyst actual linear velocity at the upper end of the lift passage should be below about 35 feet per second and preferably below about 25 feet per second. It is preferred to maintain the average particle velocity at the upper end of the lift passage broadly above about 5.0 feet per second and preferably above about 10 feet per second. By the expression average catalyst velocity at the upper end of the lift pipe as discussed above and as employed in claiming this invention is meant the average of the linear velocities of the catalyst particles at the upper end of the lift pipe.

It has been found that if the catalyst rate is too low at the upper end of the lift passage, refluxing tends to occur in the upper portion of the lift passage with resultant increase in catalyst attrition. Thus, for a commercial tapered lift pipe having a diameter of about 39.3 inches at its upper end and employing a synthetic silica-alumina gel bead catalyst it was found that the attrition goes through an absolute minimum within the general range about 13-23 feet per second and more closely within the range about 15-20 feet per second as is shown by the data in Table II.

Table II

Catalyst Velocity at Upper End of Lift Pipe, Feet Per Second	Catalyst Consumption In TCO Unit, Tons/Day/100T/Hr. Circulation
12	1.25
17.5	0.75
22.5	1.0

The minimum required velocity at the upper end of the lift passage may be conveniently expressed in terms of catalyst equilibrium velocity and this has been found to be a function of the diameter of the upper end of the lift pipe. It has been found that, in order to prevent refluxing of catalyst in the upper section of the lift passage with resultant excessive catalyst attrition, the average catalyst equilibrium velocity at the upper end of the lift pipe should always be equal to or greater than:

$$U_{e(\text{top})} = 0.17D_{\text{top}}$$

where D_{top} is the internal diameter of the upper end of the lift pipe in inches.

Thus, according to the preferred form of this invention, the gas velocity U_g at any level along the lift passage length should be at least equal to:

$$U_g = C_t + \left[(8.0 + 0.12H_t) \frac{A_{\text{max.}}}{A_{\text{mean}}} - 0.17D_{\text{top}} \right] \frac{H}{H_t} + 0.17D_{\text{top}}$$

and preferably at least equal to:

$$U_g = C_t + \left[(9.6 + 0.132H_t) \frac{A_{\text{max.}}}{A_{\text{mean}}} - 0.17D_{\text{top}} \right] \frac{H}{H_t} + 0.17D_{\text{top}}$$

while at the same time the average velocity of the catalyst particles at the upper end of the lift passage should be maintained below about 35 feet per second and preferably below about 25 feet per second. Alternatively, the relationship between the diameter of the upper end of the lift pipe and the minimum catalyst velocity required at the upper end of the lift pipe may be expressed in terms of catalyst rise above the upper end of the lift

pipe in the expanded separation zone. For example, for diameters of 3.25 inches, 20.13 inches and 39.25 inches at the upper end of the lift pipe, the minimum catalyst velocities should be 0.5, 12 and 16 feet per second respectively. The minimum catalyst rise above the upper end of the lift pipe for the same top diameters should be 0.25-0.35 feet, 8-10 feet and 12-14 feet respectively in order to prevent the solids issuing from the pipe from settling back into the upper end of the pipe.

In the preferred form of this invention both the gas velocity along the various levels of the lift passage and also the catalyst velocity at the upper end of the lift passage are controlled within those critical ranges discussed hereinabove within which a minimum of catalyst attrition will occur. It has been found that this may be done in the case of relatively short lifts without the necessity of decelerating the catalyst prior to its issuance from the upper end of the lift. However, when an attempt was made to employ in relatively high commercial size lifts the gas velocities along the lower section of the lift and catalyst velocity at the upper end of the lift which had been found to properly restrict attrition in relatively short lifts, severe catalyst attrition rates were encountered. It was discovered as pointed out hereinabove, that unexpectedly the critical minimum gas velocity at the lower end of the lift below which catalyst attrition is excessive, is dependent upon the height of the lift so that for lifts above certain heights the gas velocity required at the bottom of the lift is so high as to result in excessive attrition promoting catalyst velocities (above 25-35 feet per second) at the top of the lift. It was then discovered that by controlling the gas velocity at the lower end of or along the lift pipe within the critical range characteristic of the particular lift height involved and at the same time effecting a deceleration of the catalyst in the upper 25-50 percent portion of the lift passage so that its velocity is within the critical range characteristic of the diameter at the upper end of the lift as discussed hereinabove, then catalyst attrition could successfully be maintained at practical overall minimum values even for lift pipes of very great height. In general, it has been found that in order to obtain the combined advantages of the several interrelated discoveries disclosed herein, provision must be made for effecting deceleration of the catalyst within an upper portion of the lift passage either by removal of gas from the stream at intermediate levels or by properly expanding the passage diameter at successively higher levels whenever the vertical height of the lift passage is in excess of that defined by the equation:

$$H_t = 7.57 \left[(25 + C_{t(\text{top})}) \frac{P_t T_b}{P_b T_t} - (9.6 + C_{t(\text{bot.})}) \right]$$

where H_t is the total vertical height of the lift passage, $C_{t(\text{top})}$ and $C_{t(\text{bot.})}$ are the terminal velocities of the average granular solids at the upper and lower ends of the lift passage respectively, P_t and P_b are the absolute pressures at the upper and lower ends of the lift passage respectively, and T_t and T_b are the absolute gas temperatures at the upper and lower ends of the lift passage respectively. While the above equation is intended to be of general application, it has been found that where the catalyst velocity at the upper end of the lift passage is to be maintained substantially above about 25 feet per second but below about 35 feet per second, deceleration of the catalyst in the lift pipe must be provided when the lift height exceeds that defined by the equation:

$$H_t = 8.32 \left[(35 + C_{t(\text{top})}) \frac{P_t T_b}{P_b T_t} - (8.0 + C_{t(\text{bot.})}) \right]$$

The limits disclosed above for catalyst velocity at the upper end of the lift passage and for gas velocity within the lift passage are broadly applicable to granular solids within the range about $\frac{1}{2}$ inch to 100 mesh Tyler (preferably 4-60 mesh), 20-130 pounds per cubic foot (pref-

15

erably 30-70 pounds per cubic foot) density, and 60-100 and preferably 80-100 hardness by the hardness test described hereinbelow. The critical maximum catalyst velocity at the upper end of the lift passage may vary somewhat for materials outside the specified hardness range, being lower for softer materials and higher for harder materials. As to the size distribution of the contact material stream to which the above discussed critical velocity limits apply, at least about 98 percent of the contact material should fall within a range of particle average diameters wherein the ratio of maximum to minimum particle average diameter is below 5 and preferably below 2.5.

The hardness test referred to above is one wherein an 80 cc.±2 cc. sample of the granular material falling within a determined screen analysis range is poured into a 3½ inch diameter, by 3¾ inch high can with full top opening friction fit lid. The wall of the can is 0.010±.001 inch thick. Eight smooth surface steel balls of 15/16 inch diameter (55±0.5 grams per ball) are added to the can. The can is then closed, positioned on a roller machine with its axis horizontal and rolled at about 80 r.p.m. about its axis for 1 hour. The sample is then screened over Tyler Standard Screen of next largest number above the number corresponding to the smallest particles in the original sample, for example, if the original sample fell within the range No. 3-5 Tyler screen size, a No. 6 Tyler screen would be used. The Hardness Index is the weight material retained on the screen in the final screen analysis (i.e. the No. 6 screen in the above example) times 100 divided by the weight of the original sample. As an example, in the case of spherical gel catalyst granules, the catalyst is tempered at 1050° F. for 3 hours in bone dry atmosphere and screened to provide a sample falling within the range No. 3-5 Tyler screen size. This sample is then rolled as described and the rolled material is screened over a No. 6 screen using a standard Ro-Top machine.

The velocity limits discussed hereinabove further apply to operations in which the stream density in the lift passage is within the range about 0.002 to 20 pounds per cubic foot and preferably within the range about 0.5-3.0 pounds per cubic foot. The average pressure drop per foot of lift pipe may range from 1.4×10^{-5} to 0.14 pound per square inch per foot of lift pipe length and preferably from 3.5×10^{-3} to 2.1×10^{-2} pounds per square inch per foot depending upon the lift height and other operating conditions. The lift passage may range from 5-400 feet and preferably from 40-300 feet high and from one inch to six feet and preferably 3"-48" diameter or equivalent thereof in cross-sectional area.

As has been pointed out hereinabove, it has been found that in some cases the required critical minimum gas velocity may be maintained within the lift pipe without exceeding the maximum critical catalyst velocity limit at the upper end of the lift passage even with a lift passage of uniform cross-section along its length, i.e.

$$\frac{A_{\max.}}{A_{\text{mean}}} = 1.0$$

For example, the equation:

$$U_s = C_t + H \left[\frac{9.6}{H_t} + 0.132 \right] \frac{A_{\max.}}{A_{\text{mean}}}$$

may be satisfied without exceeding a top catalyst velocity of 35 feet per second in lift operations where the gas expansion across the lift is 1.136 and 1.34 of its entry volume for lift pipes having lengths of about 132 and 56 feet respectively. Lift pipes longer than those mentioned in the above examples in absence of intermediate gas withdrawal discussed hereinafter, would have to be tapered in order to prevent the top catalyst velocity from exceeding 35 feet per second. In general, the lift pipe need not be tapered as long as both the equation for minimum gas velocity within the lift and the set maxi-

16

mum catalyst velocity limit at the top of the lift are both met. Usually and preferably, a tapered lift pipe is employed for the best operation even for relatively short lift pipes and when employed the ratio of

$$\frac{A_{\max.}}{A_{\text{mean}}}$$

should be broadly within the range about 1.05-3.0 and preferably within the range 1.10-1.8. Preferably the level along the lift pipe at which its cross-sectional area is equal to the average cross-sectional area for the pipe is at a level within the range 50-75 percent of the total pipe length above its lower end. The ratio of

$$\frac{A_{\text{minimum}}}{A_{\text{mean}}}$$

for tapered lift pipes should be within the range 0.3-0.95 and preferably within the range 0.6-0.9. In general, the relation between the amount of taper and the height of the lift pipe according to the preferred form of this invention may be expressed by the following equation:

$$\left[\frac{A_t}{A} = 1 + XH + YH^2 + ZH^3 \right]$$

where A^t is at the horizontal cross-sectional area of the lift pipe at its upper end in square feet, A is the area at any given level in square feet, H is the distance in feet below the upper end of the lift pipe to that given level, X is a constant within the range 1.0×10^{-3} to 8.0×10^{-3} , Y is a constant within the range 1.0×10^{-6} to 6.0×10^{-6} and Z is a constant within the range 1.0×10^{-11} to $+1.0 \times 10^{-10}$.

A preferred form of lift pipe is shown in Figure 11, in which the lift pipe 25 is gradually tapered along its entire length above the mouth piece 35. In this form, a convenient design may include a lower 50-75 percent portion of the form of an inverted hollow frustum of a cone and an upper 25-50 percent portion having its sides flared along the arc of a circle. The ratio of the cross-sectional area at the base of the frusto-conical section to the upper end of said section should be within the range about 0.3-0.95 and preferably within the range 0.6-0.9. The ratio of the areas at the upper extremity to that at the lower extremity of the 25-50 percent upper portion of the lift pipe mentioned above should be within the range 1.05-3.0 and preferably within the range 1.10-1.8.

One example of a lift pipe of the type shown in Figure 11 involved a lift pipe having a lower frusto-conical portion extending 65 percent of the upper length. In this example, the diameter of the lift passage was 25.65", 27", 29", 31.7" and 39.3" at the lower end, 50 feet up, 100 feet up, 150 feet up and 237 feet up (upper end) respectively. The mean diameter was 30.9". For this lift pipe the ratio of maximum to mean cross-sectional area was 1.62 and the ratio of minimum to mean cross-sectional area was 0.7. The critical minimum catalyst equilibrium velocity at the lower end of this lift pipe and the average for the lift pipe were about 67.2 feet per second and 33.6 feet per second respectively. In a typical operation, transferring a bead form catalyst of 0.142 inch average particle diameter, and 42 pounds per cubic foot settled bed density, (i.e. density measured as poured into a receptacle without further packing) 12,120 cubic feet per minute (standard conditions) air was employed to transfer 256 tons of catalyst per hour at a temperature of about 810° F. The total pressure drop across the lift pipe was about 1.14 pounds per square inch. The linear gas velocities at the lower and upper ends of the lift pipe were 141 and 59 feet per second respectively. The catalyst equilibrium velocity at the lower and upper ends of the lift pipe were 90.6 and 8.8 feet per second respectively. The catalyst velocities in the lift pipe were 46.5 feet per second average, 68.0 feet per second maximum and 17.5 feet per second at the upper end of the lift passage. The

flowing density of the lift stream was about 0.58 pound per cubic foot. The attrition at the time of an early run on a new catalyst was about 0.75 ton per day for each 100 tons per hour of catalyst passed through the lift pipe and this corresponds to about 0.53 ton per day on the basis of an "equilibrium catalyst", i.e., a catalyst which has been circulated through the unit for a period of time so that it becomes more resistant to attrition. The catalyst involved in this example was a synthetic silica-alumina gel prepared in the manner described in United States Patent No. 2,384,949, issued September 18, 1945.

Referring to Figure 19, there is given a plot of data obtained during the operation of the above described lift pipe showing the manner in which catalyst attrition is affected by variation of the total volumetric rate of gas flow to the lift passage. In this case, it will be noted that a change in total gas feed rate for a given fixed lift not only affects the gas velocity along the lift but also the catalyst velocity at its upper end. The resulting attrition variation is, therefore, due to both factors in this case.

In another and preferred example of a pneumatic transfer device of the type shown in Figure 11, the diameter at the bottom, 50 feet up, 100 feet up, 150 feet up and 200 feet up (upper end) were 15 $\frac{3}{8}$ ", 16 $\frac{1}{4}$ ", 16 $\frac{3}{4}$ ", 18" and 20 $\frac{1}{8}$ " respectively. The critical minimum catalyst equilibrium velocity at the bottom of this pipe was 49–50 feet per second (See Figure 5). The critical minimum average catalyst equilibrium velocity for the full length of the lift pipe was about 25 feet per second, as shown in Figure 3.

Typical examples of the operation of this lift pipe are given in Table III below. In Table III, runs A, B and C represent operations on the same synthetic silica-alumina gel bead catalyst mentioned in the example above, while run D involved an operation on a natural montmorillonite clay type pelleted catalyst of about 0.165 inch mean diameter, and about 44 pounds per cubic foot loose density as poured into a measuring container.

Table III

Catalyst Throughput Tons/Hour	Average Catalyst Velocity At Upper End of Lift Pipe, Ft./Sec.	Lift Stream Density, #Cu. Ft.	Steam Lift Gas #/Hr.	Average Lift Gas Linear Velocity, Feet/Sec.	Average Temperature, °F.	Pressure in Lift Pipe, Inches of Hg			Catalyst Attrition Rate, Tons/Day Per 100 Tons Throughput	Run
						Top	Bottom	ΔP		
52-----	8	0.61	8,515	101.4	727	20.8	22.6	1.80	0.130	A
100-----	16	1.08	8,520	103.1	728	19.1	22.72	3.62	0.199	B
154-----	25	1.41	8,498	112.3	705	16.5	22.42	5.92	0.375	C
114-----			8,680	109	708	17.34	20.88	3.54	0.40	D

If desired, the lift passage may be of frusto-conical form all along its length as shown in Figure 12 or along an upper portion of its length with the lower portion being of uniform cross-section as shown in Figure 13. Alternatively, the lift pipe may be made of two or more uniform sections of different diameter, connected together by suitable adapter members, the sections being so arranged that sections of progressively increasing diameter are located at successively higher levels. Such an arrangement is shown in Figure 14. A similar two section lift pipe 25 with suitable catalyst supply pipe 150 and gas supply bend 151 is shown in Figure 15. In a proposed lift pipe of this type the lower portion was 5 inches diameter and 29 feet long and the upper portion was 6 inches in diameter and 14 feet long. The adapter piece was 2 feet long. The catalyst transfer may be effected by applying suction to the separator surrounding the upper end of this lift pipe so that the pressure at the upper end of the lift pipe is about 14.2 pounds per square inch absolute and that at the lower ends is about 14.7 pounds per square inch absolute. In order to transfer 4 tons per hour of the catalyst mentioned in the previous examples the following operating conditions are recommended: air rate 2400 pounds per hour at atmospheric temperature;

air velocity at the lower end of the lift pipe 56 feet per second; and the catalyst velocity at the upper end was 10 feet per second. The critical minimum bottom linear gas velocity for this lift pipe is about 50 feet per second.

Turning to Figure 16, there is shown a lift pipe which may be similar to those shown in Figures 11 or 12 except for curvature at the lower end designed to maintain the gas velocity at that location equal to rather than substantially above the critical minimum. In Figure 17 there is shown a lift pipe having a very rapid expansion in cross-section near its lower end. This lift pipe is designed specifically for use where a cold lift gas is employed to convey an initially hot catalyst. In the case of the lift pipe shown in Figure 18 while the passage is in the main of progressively larger cross-section at successively higher levels there is an intermediate section of restricted cross-section near its lower end. This is designed to provide the proper gas velocity all along the lift pipe when an initially hot lift gas is employed to transfer an initially cold granular material.

While this invention in a preferred form involves lift pipes which are tapered substantially all along their entire lengths as shown in Figures 11 and 12, for example, or along at least a substantial upper portion of their lengths as shown in Figure 13, it should be understood that the expression "progressively increasing horizontal cross-sectional area at successively higher levels," is employed herein in describing and claiming this invention in a sense sufficiently broad to include any of the forms of the invention shown in Figures 11–18.

While the catalyst deceleration in the upper 25–50 percent of the lift passage length is preferably accomplished by tapering the lift passage, it is also contemplated within the broad scope of this invention that the catalyst deceleration may be accomplished by withdrawal of a portion of the lift gas from one or more points along the lift stream, particularly along the upper portion thereof. A suitable arrangement for this method of operation is

shown in Figure 20. In Figure 20, there is shown a lift pipe 100 of uniform cross-sectional area along its length extending upwardly from a mixing chamber 101 to a separator 102. The chamber 101 is a sufficient distance below ground level to permit feeding contact material thereto through a gravity feed conduit 103 of sufficient length to provide a contact material head greater than the pressure in the mixing chamber. The conduit 103 is open to the atmosphere on its upper end which is shortly above ground level and contact material from one of the contacting vessels is supplied thereto via pipe 104. In this arrangement, three concentrically arranged cylindrical nozzles of different diameter and lengths are connected through the bottom of chamber 101. Each of the nozzles 105, 106 and 107 is provided with an independent gas supply pipe 108, 109 and 110 respectively. Only one air stream is employed at any one time and the rate of catalyst transfer for a given amount of gas flow depends upon the nozzle in use, being greater the greater the gap between the upper end of the nozzle and the lower end of the lift pipe mouth piece 120. When a pressure type pneumatic conveyor is employed the separated lift gas passes from separator 102 to a stack or to a secondary separator via pipe 150. If desired, the pneumatic con-

veyor may be a vacuum lift instead of a pressure lift in which case the lift gas may be a condensible vapor such as steam which passes via pipe 151 to barometric condenser 121 wherein it is condensed to produce the vacuum for effecting the contact material transfer. The use of steam or a condensible lift gas in conjunction with a barometric condenser in a pneumatic transfer system is disclosed and claimed in United States patent application Serial Number 75,642, filed February 10, 1949, now U.S. Patent No. 2,684,927. A number of downwardly sloping pipes 112, 113 and 114 extend downwardly from vertically spaced points along an upper portion of the lift pipe to separators 115, 116 and 117 respectively. These separators have gas outlet connections terminating in gas outlet manifold 118. Sufficient gas is withdrawn through one or more of the outlet pipes 112, 113 and 114 to maintain the catalyst velocity at the desired level at the upper end of the lift pipe, but care is taken not to reduce the stream velocity at the points of gas withdrawal to a level which would cause serious refluxing of contact material in the lift passage. The rate of gas withdrawal may be controlled by valves 130, 131 and 132 on pipes 112, 113, and 114, respectively or by valves (not shown) on the gas outlet lines from the several separators. It has been found that very little catalyst is entrained in the gas withdrawn through pipes 112, 113 and 114 provided that these pipes connect into the vertical lift passage either at right angles or preferably with a downward slope from the horizontal. Any material which is entrained passes via pipes 125, 126 and 127 back to the feed leg 103. Transferred contact material passes from the bottom of separator 102 via pipe 135 either to a surge chamber or contacting vessel. The specific method of controlling the velocity of the contact material at the upper end of the lift passage and at points along the lift passage by withdrawal of gas at one or more intermediate points along the lift pipe is disclosed and claimed in copending United States patent application Serial Number 211,344, filed February 16, 1951, now abandoned.

Typical examples of the operation of a straight 3" diameter, 40 feet high lift pipe having intermediate gas outlet ports, similar to the lift pipe shown in Figure 20 are set forth in Table IV. This lift pipe utilized air supplied under the required pressure as the transfer gas and employs the type of lift feed tank shown in Figure 1.

Table IV

Catalyst Throughput, Tons/Hour	Average Catalyst Velocity At Upper End of Lift Pipe, Feet/Sec.	Air Lift Gas Charge, Std. Cu. Ft./Min.	Average Lift Gas Linear Velocity, Feet/Sec.	Average Temperature, °F.	Pressure in Lift Pipe, Inches of Hg		ΔP	Catalyst Attrition Rate, Tons/Day Per 100 Tons Throughput	Lift Stream Density, #/Cu. Ft.
					Top	Bottom			
7.85-----	8.6	122	40.9	69	30	38	8	0.028	9.8
8.0-----	10.8	137.5	42.9	72	30	38.2	8.2	0.111	8.0
12.7-----	11.0	134	43.0	70	30	41	11	0.104	12.4

This invention is in its broadest form considered to be generic to control of the catalyst velocity at the upper end of the lift pipe both by withdrawal of gas at intermediate points and by gradual expansion in the lift stream horizontal cross-section. It will be noted that in its preferred form this invention differs radically from previous pneumatic transfer methods in that whereas in previous methods the rate of catalyst and gas flow gradually increase toward the upper end of the lift passage as the gas expands due to pressure drop across the lift passage, by the preferred method of this invention the rate of catalyst and gas flow gradually decrease as the upper end of the lift passage is approached. In other words, in the preferred method of this invention the catalyst being transferred is forced into the lower end of a lift passage suspended in a lift gas, rapidly accelerated in a lower portion of the lift passage by means of the gas so that the granules quickly reach a minimum velocity below which

the catalyst would tend to reflux then the catalyst is substantially decelerated in an upper portion of the lift passage and the decelerated catalyst stream is discharged into an expanding settling zone in which the stream is further decelerated to effect separation of the catalyst from the lift gas.

It is to be understood that the specific examples of apparatus design and arrangement and of operation and application of this invention are intended only as illustrative and it is intended to cover all changes and modifications of the examples of the invention herein chosen for purposes of the disclosure, which do not constitute departures from the spirit and scope of the invention.

We claim:

1. A method for transfer of granular solid material from one level to a higher level without excessive attrition and breakage of the granular material which comprises: mixing said granular material with a lift gas in a zone at the lower level and passing the granular material suspended in said lift gas upwardly as a confined substantially vertical stream into a separation zone of substantially greater horizontal cross section than said confined stream; effecting rapid acceleration of the granular material in the lower portion of said stream to a linear velocity above that at which excessive refluxing of the material in the lift would be encountered by controlling the rate of lift gas supply to maintain the linear velocity of the lift gas, U_g , at the lower end of said stream at least equal to that required by the equation,

$$U_{g(\text{bot.})} = C_{t(\text{bot.})} + (8 + .12H_t) \frac{A_{\text{max.}}}{A_{\text{mean}}}$$

where $A_{\text{max.}}$ is the maximum horizontal cross-sectional area of said lift stream, and A_{mean} is the mean horizontal cross-sectional area of said lift stream, and $C_{t(\text{bot.})}$ is the terminal velocity of the average sized contact material at the lower end of said stream under the conditions involved, and H_t is the vertical length of said lift stream above its lower end and is in excess of that expressed by the equation,

$$H_t = 8.32 \left[(35 + C_{t(\text{top})}) \frac{P_t T_t}{P_b T_b} (8.0 + C_{t(\text{bot.})}) \right]$$

where $C_{t(\text{top})}$ and $C_{t(\text{bot.})}$ are the terminal velocities of the average granular solids at the upper and lower ends

of said lift stream respectively, P_t and P_b are the absolute pressures at the upper and lower ends of said lift stream respectively and T_t and T_b are the absolute gas temperatures at the upper and lower ends of the lift passage respectively; and causing the granular material to decelerate at least along an upper portion of said lift stream so that it reaches a velocity at the upper end of said stream which is substantially below the maximum velocity attained by said granular material in the lift stream and which is below about 35 feet per second but above about 5 feet per second; discharging said stream upwardly from said confined stream into said separation zone, whereby its velocity decreases and the granular material drops into a lower portion of said separation zone and is separated from the lift gas; and withdrawing the lift gas from said separation zone separately of the granular material.

2. A method for transfer of granular solids from one level to a higher level without excessive attrition of the

solids which comprises, passing said granular solids suspended in a lift gas upwardly through a confined lift passage to a receiving zone at the higher level, and maintaining the linear velocity, U_g , of said gas at every level along the lower half of said lift passage approximately equal to that defined by the equation,

$$U_g = C_t + \left[H \left(\frac{9.6}{H_t} + 0.132 \right) \frac{A_{\max.}}{A_{\text{mean}}} \right]$$

where C_t is the characteristic terminal velocity of the average sized granular solids under the conditions involved, H is the distance in feet below the upper end of said lift passage at any given level, H_t is the total length of said lift passage in feet and is in excess of that which will require a velocity U_g along a lower portion of the lift sufficient to accelerate the granular solids to a linear velocity substantially in excess of 25 feet per second, $A_{\max.}$ is the maximum horizontal cross-sectional area of said lift passage in square feet and A_{mean} is the mean horizontal cross-sectional area of said lift passage in square feet, and substantially decelerating the flow along the upper portion of said passage to maintain the average linear velocity of the granular solids at the upper end of said lift passage within the range about 10 to 25 feet per second.

3. A method for transfer of granular solid material from one level to a higher level without excessive attrition and breakage of the granular material which comprises: mixing said granular material with a lift gas in a zone at the lower level and passing the granular material suspended in said lift gas upwardly as a confined substantially vertical stream into a separation zone of substantially greater horizontal cross section than said confined stream; causing the granular material to accelerate in the lower portion of said stream to a velocity in excess of 25 feet per second and controlling the rate of lift gas supply to maintain the linear velocity of the lift gas U_g at any level along said confined stream at least equal to that required by the equation,

$$U_g = C_t + \left[H \left(\frac{9.6}{H_t} + 0.132 \right) \frac{A_{\max.}}{A_{\text{mean}}} \right]$$

where C_t is the terminal velocity at the level in question of granular material of the average size material under the conditions involved, H is the distance in feet below the upper end of said stream to the level in question, $A_{\max.}$ is the maximum horizontal cross-sectional area of said stream in square feet, A_{mean} is the mean horizontal cross-sectional area of said stream in square feet, and H_t is the total length of said stream in feet and is in excess of that defined by the equation,

$$H_t = 7.57 \left[(25 + C_{t(\text{top})}) \frac{P_t T_b}{P_b T_t} - (9.6 + C_{t(\text{bot.})}) \right]$$

where $C_{t(\text{top})}$ and $C_{t(\text{bot.})}$ are the terminal velocities of the average granular solids at the upper and lower ends of said stream respectively, P_t and P_b are the absolute pressures at the upper and lower ends of said stream respectively, and T_t and T_b are the absolute gas temperatures at the upper and lower ends of the lift passage respectively; decelerating the catalyst flow along an upper portion of said stream to maintain the average velocity of the granular material at the upper end thereof below about 25 feet per second; reversing the direction of the granular material flow after it discharges into said separation zone and dropping it down onto a bed thereof maintained in said separation zone.

4. A method for transfer of granular solid material from a zone at one level to a second zone at a higher level without excessive attrition and breakage of the granular material which comprises: mixing said granular material with a lift gas in said first zone and passing it, suspended in said lift gas, upwardly therefrom as a confined, substantially vertical stream discharging at a higher level into said second zone; effecting rapid ac-

celeration of the granular material to a velocity substantially in excess of 35 feet per second which is sufficiently high to avoid substantial refluxing of the granular material in the lower section of said confined stream, causing the gas to progressively decelerate in linear velocity as it passes upwardly to higher levels in both the lower and upper halves of said stream and maintaining the average linear velocity of said lift gas over the total length of said lift stream at least equal to that expressed by the equation,

$$U_{g(\text{ave.})} = C_{t(\text{ave.})} + 0.5(9.6 + 0.132H_t) \frac{A_{\max.}}{A_{\text{mean}}}$$

and below that expressed by the equation,

$$U_{g(\text{ave.})} = C_{t(\text{ave.})} + 0.7(9.6 + 0.132H_t) \frac{A_{\max.}}{A_{\text{mean}}}$$

where H_t is the total length of said lift stream in feet, $A_{\max.}$ and A_{mean} are respectively the maximum and mean cross-sectional area for flow in said lift stream in square feet, and $C_{t(\text{ave.})}$ is the average terminal velocity through said lift stream in feet per second of the average granular solids, and further controlling the flow along the upper portion of said stream to cause the granular solids to decelerate to a velocity within the range about 5-35 feet per second as the granules reach the upper end of said stream; reversing the direction of the granular material flow after it discharges into said second zone and dropping it down onto a bed thereof maintained in said second zone.

5. A method for transfer of granular solid material from one level to a higher level without excessive attrition and breakage of the granular material which comprises: mixing said granular material with a lift gas in a zone at the lower level and passing the granular material suspended in said lift gas upwardly as a confined substantially vertical stream into a separation zone of substantially greater horizontal cross-section than said confined stream; controlling the rate of lift gas supply to effect rapid acceleration of the granular material in the lower portion of the confined lift stream to a linear velocity above that at which excessive refluxing of the granular material would occur along said stream and to maintain the average linear velocity $U_{g(\text{ave.})}$ of said lift gas over the total length of said confined stream at least equal to that required by the equation,

$$U_{g(\text{ave.})} = C_{t(\text{ave.})} + 0.9(9.6 + 0.132H_t) \frac{A_{\max.}}{A_{\text{mean}}}$$

and below that conforming to the expression,

$$U_{g(\text{ave.})} = C_{t(\text{ave.})} + 0.9(9.6 + 0.132H_t) \frac{A_{\max.}}{A_{\text{mean}}}$$

where $C_{t(\text{ave.})}$ is the average terminal velocity of the average contact material granules over the total length of said lift stream under the conditions involved, $A_{\max.}$ is the maximum cross-sectional area of said lift stream in square feet, A_{mean} is the mean cross-sectional area of said lift stream in square feet, and H_t is the total elevational rise of the lift stream in feet and being in excess of that which would require in the first named equation a value of U_g which would cause a granular material velocity within a lower portion of said stream in excess of 25 feet per second; effecting a deceleration of the granular material along an upper portion of said stream to provide an average velocity of the granular material at the upper end of said stream within the range about 10-25 feet per second, said velocity range being attained in part by control of the rate of gas supply to the confined lift stream and in part by expanding the lift stream in horizontal cross-section at least along an upper portion of said stream so that the ratio

$$\frac{A_{\max.}}{A_{\text{mean}}}$$

is within the range 1.05–3.0 and the ratio of the minimum stream cross-sectional area to its mean cross-sectional area is within the range 0.3–0.95; reversing the direction of the granular material flow after it discharges into said second zone and dropping it down onto a bed thereof maintained in said second zone.

6. In a hydrocarbon conversion process wherein a granular contact material is passed cyclically through at least two contacting zones, one being a reaction zone wherein it flows downwardly as a substantially compact column while contacting a fluid hydrocarbon charge to effect conversion of said charge to gasiform products and the other zone being a reconditioning zone wherein the contact material flows downwardly as a substantially compact column while being contacted with a suitable gas to effect its reconditioning for reuse in said conversion zone, the improved method for effecting transfer of contact material from one of said contacting zones to the other which comprises: withdrawing contact material downwardly from the lower section of one of said contacting zones as a substantially compact gravitating stream of sufficient length and sufficiently restricted cross-section to prevent substantial escape of gas from said contacting zone; delivering said stream to a location where it is mixed with a suitable lift gas to effect its suspension therein; then passing said contact material suspended in said lift gas upwardly as a confined, substantially vertical stream, causing the contact material to rapidly accelerate in the lower section of said stream to a linear velocity which is in excess of 35 feet per second, causing the contact material to substantially decelerate from its maximum linear velocity by gradually increasing the horizontal cross-sectional area of said confined stream at least along the upper portion thereof; controlling the rate of expansion of stream cross-section and the rate of lift gas supplied to said stream to maintain the average linear velocity of the contact material at the upper end of said stream below about 35 feet per second and further to maintain the gas velocity U_g at all levels along the stream at least equal to that required by the equation,

$$U_g = C_t + \left[H \left(\frac{8.0}{H_t} + 0.12 \right) \frac{A_{\max.}}{A_{\text{mean}}} \right]$$

where C_t is the terminal velocity at the level in question of granular material of the average size material under the conditions involved, H is the distance in feet below the upper end of said stream to the level in question, H_t is the total length of said lift stream in feet, $A_{\max.}$ is the maximum horizontal cross-sectional area of said stream in square feet and A_{mean} is the mean horizontal cross-sectional area of said stream in square feet and the ratio

$$\frac{A_{\max.}}{A_{\text{mean}}}$$

is within the range of 1.05–3.0; discharging the mixed gas and contact material from the upper end of said stream upwardly into a separation zone of substantially greater horizontal cross-sectional area than said stream, whereby the contact material settles in said separation zone and is separated from the lift gas; and flowing the separated contact material downwardly to the other of said contacting zones.

7. In a process wherein a granular contact material is passed cyclically through two contacting zones, one being a reaction zone wherein it flows downwardly as a substantially compact column while contacting a fluid hydrocarbon charge to effect conversion of said charge to gasiform products and the other being a reconditioning zone wherein the contact material flows downwardly as a substantially compact column while being contacted with a suitable gas to effect its reconditioning for reuse in said reaction zone, the improved method for effecting transfer of contact material from one of said contacting zones

to the other as a confined pneumatic lift stream through a vertical distance in excess of that defined by the equation,

$$H_t = 7.57 \left[(25 + C_{t(\text{top})}) \frac{P_t T_b}{P_b T_t} - (9.6 + C_{t(\text{bot.})}) \right]$$

where $C_{t(\text{top})}$ and $C_{t(\text{bot.})}$ are the terminal velocities of the average granular solids at the upper and lower ends of said lift stream respectively, P_t and P_b are the absolute pressures at the upper and lower ends of said lift stream respectively, and T_t and T_b are the absolute gas temperatures at the upper and lower ends of the lift passage respectively, which method comprises flowing said contact material downwardly as a substantially compact, continuous stream from one of said contacting zones to a location where its suspension in a stream of lift gas is effected, passing the contact material suspended in the lift gas upwardly through a confined lift passage while rapidly accelerating the upward contact material flow in a lower portion of said lift passage, until the contact material reaches a velocity above that at which it will reflux in said lift stream, said velocity being well in excess of 25 feet per second, thereafter decelerating the contact material flow in an upper portion of said lift passage and discharging it from the upper end of said passage at an average within the range about 10–25 linear velocity feet per second into a separation zone, further decelerating the upward velocity of the contact material in said separation zone so that the contact material drops downwardly in said zone, and then flowing the contact material downwardly through the other of said contacting zones.

8. In a process wherein a granular solid material is pneumatically transferred upwardly through a confined lift passage from a first level to a higher level suspended in a stream of lift gas and wherein the height of said lift passage is such as to require linear velocities of the solid material in the lower portion of said lift passage substantially in excess of 35 feet per second in order to prevent refluxing of the solid material, the improved method for separating the granular material from the lift gas which comprises, effecting deceleration of said stream to reduce the average velocity of the granular material particles to a level below about 35 feet per second but above about 5 feet per second before said material leaves said lift passage, then discharging the decelerated stream upwardly into an enlarged settling zone where the velocity is further rapidly decelerated until the granular material reverses its direction of flow and begins to fall, permitting the granular material to fall onto a receiving surface so as to become separated from the lift gas and separately withdrawing the lift gas from said settling zone.

9. A method for transfer of granular solids from a first level to a second higher level without excessive attrition and breakage which comprises, mixing said granular material at said first level with a suitable lift gas to effect its suspension therein, passing the mixed granular material and gas upwardly from said first level as a confined, substantially vertical stream, while controlling the gas velocity to provide rapid acceleration of the granular material in a lower section of said stream to a velocity above the minimum at which substantial refluxing of the granular material in the stream would occur which velocity as required by the height of the confined lift stream is above about 25 feet per second, gradually expanding the confined stream in lateral size at successively higher levels to such an extent that the granular material substantially decelerates in velocity in an upper section of said stream, discharging the decelerated stream into an enlarged separation zone after it has been decelerated to a velocity which will project the granular material upwardly only a short distance in said separation zone above the level of its entry thereto before it starts to drop and catching the dropping granular material on the surface of a bed maintained in said separation zone only a short distance below said level of entry into said separation zone.

10. A method for pneumatically transferring granular solid material from a zone at one elevation to a second zone at a higher elevation without excessive attrition and breakage of the solid granules which comprises, forcing the solid material from said first zone into the lower end of a confined lift passage extending upwardly to said second zone, rapidly accelerating the solid material granules by means of a suspending lift gas so that they quickly reach a minimum velocity above about 35 feet per second below which refluxing of the solid material flow would occur, and gradually expanding the cross-section of said stream so that the solid granules are decelerated before they discharge from the upper end of said lift passage to an average linear velocity above 5 feet per second and below 35 feet per second, discharging the decelerated solid material into an expanded settling zone in which the solid material rises a short distance and then falls onto an accumulation thereof maintained below in said settling zone and withdrawing the lift gas from the upper section of said settling zone.

11. An improved apparatus for pneumatic transfer of granular contact material comprising a lift feed chamber, means to supply contact material to said feed chamber, a separation chamber having a gas outlet near its upper end positioned a substantial distance above said feed chamber, a substantially vertical lift conduit, open on its ends, extending upwardly from a location within said feed chamber intermediate its ends to a location within said separation chamber, intermediate the ends thereof, said conduit taking approximately the form of an inverted hollow frustrum of a cone along at least the lower 50-75 percent portion of the length of said conduit and having its sides along the remaining upper 25-50 percent portion of its length flared approximately along the arc of a circle, the ratio of the horizontal cross-sectional area of said conduit at the base thereof to that at the upper end of said lower portion of said conduit being within the range about 0.3-0.95 and the ratio of the horizontal cross-sectional areas at the lower end to that at the upper end of said upper portion of said conduit being within the range 1.05-3.0, the upper end of said lift conduit being of substantially less horizontal cross-sectional area than said separation chamber, and means to supply a lift gas to the lower end of said lift conduit.

12. An improved apparatus for pneumatic transfer of granular contact material comprising, a feed chamber adapted to confine a bed of contact material, conduit means to supply contact material into the upper section of said feed chamber, a receiving chamber positioned at a higher level than said feed chamber, a gas outlet connected to said receiving chamber near its upper end, an outlet for contact material connected to said receiving chamber near its lower end, a tapered lift pipe extending upwardly from a location within the lower section of but above the bottom of said feed chamber to a location within said receiving chamber intermediate the upper and lower ends thereof, said lift pipe taking approximately the form of a hollow frustrum of an inverted cone along at least the lower 50-75 percent portion of its length and having its sides along the remaining upper 25-50 percent portion of its length flared approximately along the arc of a circle, the ratio of the horizontal cross-sectional area at the lower end of said conduit to that at the upper extremity of said lower frustrum portion being within the range about 0.6-0.90.

13. An improved apparatus for pneumatic transfer of granular contact material comprising, a feed chamber; means to supply contact material to said feed chamber; a separation chamber positioned a substantial distance above said feed chamber; a lift conduit communicating on its lower end with said feed chamber and extending upwardly to a location within said separation chamber, said lift conduit having a gradually increasing cross-sectional area at successively higher levels along at least an upper 25-

50 percent portion in conformance with the relation expressed by the equation,

$$\frac{A_t}{A} = 1 + XH + YH^2 + ZH^3$$

where A_t is the cross-sectional area in square feet at the upper end of said lift conduit, A is the area in square feet at any level along at least an upper portion of said lift conduit, H is the distance in feet below the upper end of the lift pipe to that given level, X is a constant within the range 1.0×10^{-3} to 8.0×10^{-3} , Y is a constant within the range 1.0×10^{-6} to 6.0×10^{-6} and Z is a constant within the range 1.0×10^{-11} to $+1.0 \times 10^{-10}$; and passage defining means exclusive of said feed chamber defining a confined passage for gas supply extending from a location outside of said feed chamber to the lower end of said lift conduit.

14. An improved apparatus for pneumatic transfer of granular contact material comprising, a feed chamber; means to supply granular material to said feed chamber; a separation chamber positioned a substantial distance above said feed chamber; a gas outlet conduit connecting into the upper section of said separation chamber; a tapered lift pipe extending upwardly from a location within the lower section of but above the bottom of said feed chamber to a location within said separation chamber intermediate the upper ends thereof, said lift pipe having its maximum cross-section at the upper end and being tapered substantially along its entire length in conformance with the relationship,

$$\frac{A_t}{A} = 1 + XH + YH^2 + ZH^3$$

where A_t is the cross-sectional area in square feet at the upper end of said lift conduit, A is the area in square feet at any level along at least an upper portion of said lift conduit, H is the distance in feet below the upper end of the lift pipe to that given level, X is a constant within the range 1.0×10^{-3} to 8.0×10^{-3} , Y is a constant within the range 1.0×10^{-6} to 6.0×10^{-6} and Z is a constant within the range 1.0×10^{-11} to $+1.0 \times 10^{-10}$; and passage defining means exclusive of said feed chamber defining a confined passage for gas supply extending from a location outside of said feed chamber to the lower section of said lift conduit.

15. In a system wherein a granular contact material is passed cyclically through two contacting chambers, one being a conversion chamber wherein it flows downwardly as a substantially compact column while contacting a fluid hydrocarbon charge to effect conversion of said charge to gasiform products and the other zone being a reconditioning chamber wherein the contact material flows downwardly as a substantially compact column while being contacted with a suitable gas to effect the reconditioning for reuse in said conversion chamber, the improved apparatus for effecting transfer of contact material from one of said contacting chambers to the other which comprises in combination; a lift feed chamber located below one of said contacting chambers; conduit means for flow of contact material from said contacting chamber to the upper section of said feed chamber; a separation chamber having a gas outlet near its upper end positioned at a location elevationally above the other of said contacting chambers; members defining a passage for contact material flow from the lower section of said separation chamber to said other contacting chamber; a substantially vertical lift conduit, open on its ends, extending upwardly from a location within said feed chamber intermediate its ends to a location within said separation chamber, intermediate the ends thereof, said conduit having a substantially smaller cross-sectional area at its upper end than said separation chamber and being tapered outwardly at

successively higher levels substantially along its entire length in conformance with the relationship,

$$\frac{A_t}{A} = 1 + XH + YH^2 + ZH^3$$

where A_t is the cross-sectional area at the upper end of said lift conduit, A is the area at any level along at least an upper portion of said lift conduit, X is a constant within the range 1.0×10^{-3} to 8.0×10^{-3} , Y is a constant within the range 1.0×10^{-6} to 6.0×10^{-6} and Z is a constant within the range 1.0×10^{-11} to 1.0×10^{-10} ; a baffle member supported within said separation chamber shielding said outlet from the upper end of said lift conduit; a flared mouth piece connected to the lower end of said lift conduit having its downwardly facing lower end open to the feed chamber at a location above the bottom of said chamber; members defining a passage for gas introduction into said feed chamber, which passage terminates within said flared mouth piece; members defining a separate passage for gas introduction to said feed chamber intermediate the ends thereof and laterally displaced from said flared mouth piece; and separate flow throttle means associated with said first and second named passage defining members.

16. A method for pneumatically transferring granular solids from one level to a substantially higher level which comprises, suspending said granular solids in a suitable carrier gas and passing it upward as a confined stream, controlling the velocity along said stream to prevent substantial refluxing of the granular solids therein, the vertical height of said stream being such that the solids must reach a velocity in excess of 35 feet per second in a lower portion of said stream in order to avoid refluxing, effecting a deceleration of the solids in an upper portion of said stream so as to reach a velocity below about 35 feet per second at the upper end of said stream, expanding said stream into an enlarged settling zone so that the granular material rises a short distance therein and then drops to a lower section of said zone.

17. A method for transfer of granular solid material from a zone at one level to a second zone at a higher level without excessive attrition and breakage of the granular material which comprises: passing said granular material suspended in a lift gas upwardly as a confined lift stream from said first zone to said second zone, rapidly accelerating the solid material granules by means of the lift gas to a velocity substantially in excess of about 35 feet per second, the linear velocity, U_g , of said lift gas being maintained at every level along said confined lift stream at least equal to that expressed by the equation,

$$U_g = C_t + \left[H \left(\frac{8.0}{H_t} + 0.12 \right) \frac{A_{\max.}}{A_{\text{mean}}} \right]$$

where C_t is the terminal velocity at the level in question of granular material of the average size material under the conditions involved, H is the distance in feet below the upper end of said lift stream in feet, H_t is the total length of said lift stream in feet, and is in excess of that which will require a velocity U_g along a portion of said lift stream sufficient to cause the granular material to accelerate to a velocity substantially in excess of about 35 feet per second, $A_{\max.}$ is the maximum horizontal cross-sectional area of said stream in square feet and A_{mean} is the mean horizontal cross-sectional area of said stream in square feet, decelerating the solid material granules in the upper portion of said confined lift stream before discharge into said second zone to a velocity substantially below about 35 feet per second and further decelerating the granules by expansion of the stream in said second zone and causing the granules to drop downwardly therein.

18. In a process wherein a granular contact material is passed cyclically through two contacting zones, one being a reaction zone wherein it flows downwardly as a substantially compact column while contacting a fluid

hydrocarbon charge to effect conversion of said charge to gasiform products and the other being a reconditioning zone wherein the contact material flows downwardly as a substantially compact column while being contacted with a suitable gas to effect its reconditioning for reuse in said reaction zone, the improved method for effecting transfer of contact material from one of said contacting zones to the other which comprises: flowing said contact material downwardly to a location where it is mixed with a lift gas to effect its suspension therein and then passing the contact material suspended in the lift gas upwardly as a confined substantially vertical stream; controlling the rate of flow of said lift gas to maintain its linear velocity at any level along said lift stream at least equal to that required by the equation,

$$U_g = C_t$$

$$+ \left[(9.6 + .132H_t) \frac{A_{\max.}}{A_{\text{mean}}} - 0.17D_{(\text{top})} \right] \frac{H}{H_t} + 0.17D_{(\text{pt.o})}$$

where C_t is the terminal velocity at the level in question of granular material of the average size material under the conditions involved, H is the distance in feet below the upper end of said stream to the level in question, H_t is the total length of said lift stream in feet, $D_{(\text{top})}$ is the diameter of said lift stream at its upper end in inches, $A_{\max.}$ is the maximum horizontal cross-sectional area of said stream in square feet and A_{mean} is the mean horizontal cross-sectional area of said stream in square feet, whereby the contact material is rapidly accelerated to a linear velocity at which excessive refluxing of the contact material is avoided and which is in excess of 25 feet per second; gradually expanding the horizontal cross-section of said stream at successively higher levels to an extent which will substantially decelerate the gas velocity along at least an upper portion of the stream within the limits of the above equation and which will effect deceleration of the contact material flow within the upper portion of the stream so that the average linear contact material velocity at the upper end of said confined stream is substantially less than the maximum velocity attained by the contact material in said stream and less than about 25 feet per second; discharging the contact material from the upper end of said stream upwardly into a confined separation zone having a substantially greater horizontal cross-sectional area than said stream, whereby the rate of gas and contact material flow in an upward direction is rapidly decreased and the contact material drops downwardly in said separation zone; separating the lift gas from said contact material and flowing the separated contact material downwardly to the other of said contacting zones.

19. The method of claim 16 further characterized in that the deceleration of said stream prior to discharge into the settling zone is effected by gradually expanding the stream in lateral size at successively higher levels at least along an upper portion thereof.

20. A method for pneumatically transferring granular solids from one level to a substantially higher level which comprises, suspending said granular solids in a suitable carrier gas and passing it upward as a confined stream, controlling the velocity along said stream to prevent substantial refluxing of the granular solids therein, the vertical height of said stream being such that the solids must reach a velocity in excess of 25 feet per second in the lower portion of said stream in order to avoid refluxing, effecting a substantial deceleration in the linear velocity of the solids along an upper portion of said stream but avoiding deceleration to a point of causing substantial refluxing of the solids along said upper portion and discharging the decelerated solids upwardly into an expanded settling zone and permitting the solids to settle therein.

21. A method for transfer of a granular contact material from one level to a higher level without excessive attrition and breakage of the contact material which

comprises: flowing said contact material downwardly to a location where it is mixed with a lift gas to effect its suspension therein and then passing the contact material suspended in the lift gas upwardly as a confined lift stream to a separation zone at a substantially higher level, said separation zone having a substantially greater horizontal cross-sectional area than the upper end of said confined lift stream, effecting rapid acceleration of the granular material in the lower section of said lift stream to a linear velocity sufficiently high to avoid substantial refluxing of the granular material within the lift stream, said velocity being substantially in excess of 35 feet per second and maintaining the average linear velocity $U_{g(ave.)}$, of said lift gas over the total length of said lift stream at least equal to that conforming to the equation,

$$U_{g(ave.)} = C_{t(ave.)} + 0.5(8.0 + 0.12H_t) \frac{A_{max.}}{A_{mean}}$$

and below that conforming to the equation,

$$U_{g(ave.)} = C_{t(ave.)} + 0.9(8.0 + 0.12H_t) \frac{A_{max.}}{A_{mean}}$$

where $A_{max.}$ and A_{mean} are respectively the maximum and mean cross-sectional area for flow in said lift stream in square feet, $C_{t(ave.)}$ is the average terminal velocity through said lift stream of the average granular solids in feet per second and H_t is the total length of the lift stream in feet and is in excess of that defined by the expression,

$$H_t = 8.32 \left[(35 + C_{t(top)}) \frac{P_t T_b}{P_b T_t} - (8.0 + C_{t(bot.)}) \right]$$

where $C_{t(top)}$ and $C_{t(bot.)}$ are the terminal velocities of the average granular solids at the upper and lower ends

of said lift stream respectively, P_t and P_b are the absolute pressures at the upper and lower ends of said lift stream respectively, and T_t and T_b are the absolute gas temperatures at the upper and lower ends of the lift passage respectively; further controlling the flow at least along an upper portion of said confined stream to effect a substantial deceleration of the contact material to an average velocity at the upper end of said stream below about 35 feet per second while maintaining the gas velocity at the upper end of said stream above that defined by the equation,

$$U_{g(top)} = C_{t(top)} + 0.17D_{(top)}$$

where $D_{(top)}$ is the diameter of the lift stream at its upper end in inches; reversing the direction of contact material flow after its discharge into said separation zone to effect separation thereof from said lift gas and flowing the separated contact material downwardly through the other of said contacting zones.

References Cited in the file of this patent

UNITED STATES PATENTS

1,339,977	Pruden	May 11, 1920
1,619,577	Jensen	Mar. 1, 1927
2,398,759	Angell	Apr. 23, 1946
2,541,077	Leffer	Feb. 13, 1951
2,542,887	Watson	Feb. 20, 1951
2,548,286	Bergstrom	Apr. 10, 1951
2,624,695	Ivey et al.	Jan. 6, 1953
2,684,390	Bills	July 20, 1954
2,684,872	Berg	July 27, 1954

FOREIGN PATENTS

180,397	Great Britain	May 11, 1922
472,385	Italy	June 16, 1952

UNITED STATES PATENT OFFICE
Certificate of Correction

Patent No. 2,901,421

August 25, 1959

Jean M. Bourguet et al.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 16, line 25, for "A:" read $-A_t-$; column 22, lines 47 to 49, Claim 5, the first equation should read as shown below instead of as in the patent:

$$U_{z(ave.)} = C_{t(ave.)} + 0.5(9.6 + 0.132H_t) \frac{A_{max.}}{A_{mean}}$$

column 28, line 19, Claim 18, in the equation, for " $+0.17D_{(pto)}$ " read $-+0.17D_{(top)}-$.

Signed and sealed this 22nd day of March 1960.

[SEAL]

Attest:

KARL H. AXLINE,
Attesting Officer.

ROBERT C. WATSON,
Commissioner of Patents.