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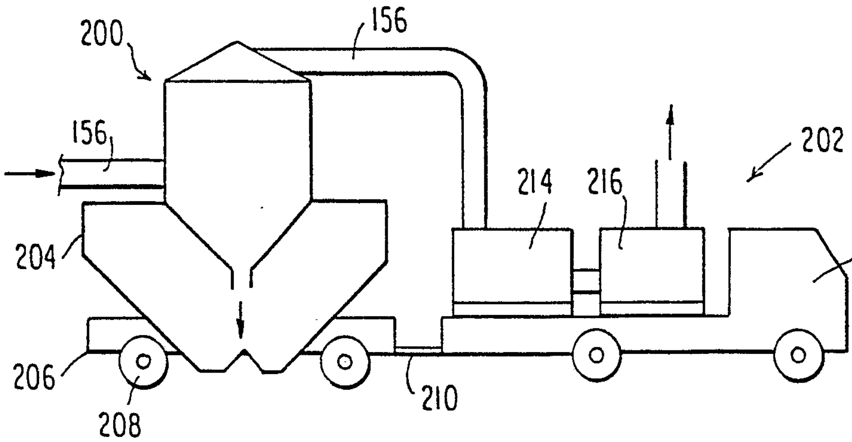

(57) Abstract

An excavation system in which fragmented excavated material is entrained in a gas and pneumatically conveyed to a desirably remote site for separation of such material from such gas. Energy is supplied to a motor to operate a gas pump (214) to induce flow through a long vacuum conduit (156). A vacuum intake end induces entrainment of fragmented material into and through such conduit (156) to one or more separators (200) communicating serially with the flow path for separating and collecting the excavated material. Then the gas is discharged to the atmosphere. At least one separator (200) includes a high frequency cyclone chamber for maintaining a gas vortex for high efficiency centrifugal separation with minimal flow resistance. In one embodiment a separator includes two cyclone stages vertically separated by a conical partition partition with a depressed apex having an aperture associated with vanes for inducing a vortex.

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EXCAVATION SYSTEM WITH PNEUMATIC CONVEYANCE AND SEPARATION OF EXCAVATED MATERIAL

This invention relates to a system for pneumatically excavating materials from the earth and the removal thereof to a site remote from the point of excavation. More particularly, in this system excavated material is entrained in a gas and pneumatically conveyed through a long enclosed flow path from an excavation site to a collection site, remote from the excavation, where such material is separated from the entraining gas and collected.

In a specific embodiment of the system, the excavated material (e.g. dirt, dust, earth, gravel, loam, sand, aggregates, soil, fill, and other solid excavated material) is fragmented, entrained in air, and pneumatically conveyed from the excavation site to a settling chamber remote from the excavation site where larger fragments are removed and collected; then fine particles are pneumatically conveyed to a high efficiency cyclone separator which separates the particles into a collection chamber; then the segregated air is discharged through an air pump into the atmosphere.

Previously, an excavation machine would fragment the excavated material by scooping it into a bucket or shovel, then swinging the bucket away from the excavation, and dumping the material into a pile or into a waiting truck for delivery to a remote collection site. Often several such machines worked in tandem, with one machine digging and dumping onto a pile, while another machine scooped up the loose excavant from the pile and dumped it into the open-top bed of a waiting dump-truck. Such trucks transported the excavant to a disposal site and then returned from the remote site to collect more excavant. Each step of handling undesirably discharged dust into the atmosphere and spread fragments in the handling area. Such dust deposited in the lungs of workers at the excavation site, contributing to health problems.

The discharge of dust during pre-construction work is becoming an increasing environmental concern.

Prior to this invention, toxic waste dump clean-up efforts resulted in toxic chemicals or radioactive substances being spread into the environment. Digging and repetitively handling the excavated waste discharged toxic dust into the atmosphere and spread fragments in the handling areas. Storing the waste in piles allowed wind to entrain dust into the atmosphere. Also, piled waste is exposed to rain and carries toxic substances into waterways and underground water.

This application describes a novel combination of pneumatic apparatus and methods which provide many advantages and contributions over previous systems for transporting excavated materials from an excavation, and for separating excavant from entraining gas. The present invention increases productivity while reducing complexity and cost of operation. Furthermore, the excavant is trapped and enclosed in the system preventing discharge of dust, spread of fragments and toxic runoff.

Other advantages and contributions are considered in more detail in describing the accompanying drawings, in which:

Figure 1 is a diagrammatic presentation of the excavation system of the invention;

Figure 2 is a schematic representation of a machine for continuously digging and fragmenting the excavated material sufficiently for pneumatic conveyance and for positioning the vacuum intake end of a conduit in communication with the material to be excavated;

Figure 3 is a schematic illustration of a gravity separation settling chamber for collecting the excavated material and utilizing a trailer for transporting it;

Figure 4 is a schematic representation of the high efficiency cyclone separator, pump, and HEPA filter of the system of the invention which utilizes a truck and trailer for transportation;

Figure 5 illustrates another embodiment in which a truck is utilized for transporting the cyclone separator and pump;

Figure 6 illustrates another embodiment of the gravity separation settling chamber for collecting the excavated material which utilizes a wheelbarrow for transporting it;

Figure 7 illustrates another embodiment of the gravity separation settling chamber for collecting the excavated material which utilizes a dump-truck for transporting it;

Figure 8 is an elevation partially in cross-section of the high efficiency cyclone separator of the invention;

Figure 9 is a sectional, partial plan view illustrating the tangential entry, discharge, and angled vanes of the high efficiency cyclone of Fig. 8;

Figure 10 is a sectional plan view of the angled vanes of the high efficiency cyclone of Fig. 8.

A long enclosed flow path 100 in FIG. 1 has a vacuum-intake end 102 open to the atmosphere and is locatable adjacent a pile of excavated material 104. Air flows into the intake end 102 and through the enclosed flow path with sufficiently high velocity to entrain and pneumatically convey the material into a separator 106.

Air conveys the entrained material into the enclosing shell 108 of the separator through an entrance 110. A separation apparatus 112 removes the material from the air. Discharge means 114 enables the material to be removed from the enclosure. Air entraining less of such material flow into such separator and flows out of the separator through exit 116.

The separator 106 includes multiple stages of separation such as a settling chamber, a cyclone chamber, and/or filter apparatus. It sometimes includes a material storage chamber. The discharge means 114 can be any means to periodically or continuously remove material from the separator (e.g. controls to reduce, reverse or stop air flow; and/or valve or access doors to remove excavant, clean filters, replace filters).

A source of energy 118 provides energy to motor 120 which provides rotary motion to an air pump 122. The rotary motion of pump 122 moves the air through the enclosed flow path at such sufficiently high velocity to entrain the excavated material.

Pumps capable of moving large air volumes at a high velocity through separators include, for example, lobe-type positive displacement pumps and turbines, that may be powered directly by the engine of the vehicle carrying the pump or by a separate internal combustion engine utilizing a fluid fuel. For example, a 40 HP (30,000 watt) motor is adequate to drive a lobe-type positive-displacement air pump to convey fragments of excavant and air at 800 CFM (813 l/s) (through a 4 to 6 in (100 to 150 mm) flexible conduit to a 4 ft (1.2 m) diameter high efficiency cyclonic centrifugal separator.

Additional separators can be included along the flow path either before or after the pump. Unless the quality of the fragmentation of the excavated material is well controlled, at least one separator should be placed in the flow path before the pump. This prevents any fragments large enough to damage the pump from reaching the pump.

A preferred embodiment of the system is illustrated in FIG's 2, 3 and 4. An excavating machine 150 of FIG. 2 includes a fragmenting means 152 to generate material fragments sufficiently small for pneumatic conveyance, and to move vacuum-intake end 154 of conduit 156 into communication with material 158.

The fragmenting means 152 may include, for example, mechanical (eg auger, blade, pick, or shovel), explosive, and/or hydraulic means to fragment excavant, depending upon volume requirements and the nature of the material excavated or to be excavated. For example, for a small excavation a pick or shovel could break up soil and the flexible vacuum conduit manually positioned in communication with the fragmented material for transportation away from the excavation site.

Separator 170 in FIG. 3 is a settling chamber for gravitationally separating excavated material from entraining air, and communicates serially with conduit 156. It is positioned at a site sufficiently remote from the excavation as desirable for preventing interference with work at the excavation. The separator is sufficiently close for convenient transportation to and from a disposal site and/or for minimizing flow resistance through the conduit for proper operation. Separation apparatus within the separator 170 includes a relatively coarse filter 174 which prevents larger fragments from exiting the separator. Connection means 176 at the air entrance, and 178 at the air exit, enable the separator to be disconnected for transport to a discharge site for removal of the collected material. The separator 170 is permanently mounted on a trailer with a frame 180, wheels 182, and hitch 184 for attachment to another vehicle such as a truck to tow the trailer. Discharge means 186 are controllable to enable opening at the disposal site to remove collected material and closing when collecting material and transporting the separator.

Typically the exit filter is a screen with apertures to prevent any large fragments from exiting from the settling chamber. Entrance and exit connections may be slip joints with clamps or other joint means sufficient to provide convenient connection/disconnection and to prevent leakage. Discharge means may include, for example, valves, gates, doors, or other control means which may be bottom mounted. They can coact with means to tilt the chamber for gravity discharge or may coact with pneumatic conveyance means and other means for moving the excavated material.

The addition of a settling chamber in the pneumatic excavation flow path results in increased separation efficiency. Utilization of a settling chamber allows the cyclone design to be optimized for removing the decreased quantity of smaller sized fragments. The settling chamber can be positioned at an accessible location for convenient transportation to and from the disposal site. The cyclone separator can be positioned at a less accessible location as may be required for excavation work.

The high efficiency cyclone separator 200 and the flow means 202 each communicates serially with conduit 156. They are positioned at a desirably remote location from the excavation site and may also be remote from the settling chamber. Separator 200 includes a collection chamber 204 and is permanently mounted to a trailer with frame 206, wheels 208, and hitch 210 which may be connected to truck 212 for transportation to a disposal site.

Flow means 202 generates air flow through conduit 156, and includes pump unit 214 mounted on truck 212 as a single package containing a source of energy, a motor, and an air pump. Such packaging enables convenient unloading /reloading of the package at the collection site. Air is discharged from pump unit 214 through HEPA filter unit 216 to remove fine particles and toxic gases from the entraining air.

The high efficiency cyclone separator may include multiple cyclone stages and one or more stages of filter apparatus to increase separation efficiency. The HEPA filter is required where toxic or radioactive substances such as gases or fine dust must be removed from the air before discharge into the atmosphere.

Thus the excavation system of the invention encloses the excavated particles, preventing their spread into the environment, and isolating them from workers at the excavation site.

In another embodiment, shown in FIG. 5, a high efficiency cyclone separator 220 and pump 222 are permanently mounted on truck 224. Excavant collects in the bottom of the lower cyclone chamber and can be removed through discharge means 226.

In addition to discharge means discussed above, the material may, for example, be discharged locally during collection by controlling the pump motor to reduce the vacuum in the chamber sufficiently to enable the weight of the material to discharge when the valve at the bottom of the chamber is opened.

The above embodiments are sufficient to enable one skilled in the art to select a convenient arrangement for transporting the pumping and separation equipment by using a combination of vehicles and permanent or packaged systems for convenient use of the invention.

Other embodiments of the settling chamber are shown in FIG's 6 and 7. Wheelbarrow 240 in FIG. 6 can be used as a separation chamber when the volume of material is relatively small. A conduit interface 242 connects conduit 156 to air entrance 244 and air exit 246. The interface includes clamps 248 for holding the interface to the pan 250 of the wheelbarrow to form an air tight chamber for collection and for convenient clasping/unclasping. When the wheelbarrow is filled, the interface is unclamped. The wheelbarrow is pushed to the disposal site and balanced on a discharger 252 for emptying. Then, the wheelbarrow is returned to the collection site and reconnected to the interface for collection.

Dump-truck 260 in FIG. 7 includes an enclosed bucket 262 utilized as a settling chamber. A conduit interface 264 connects conduit 156 to air entrance 264 and air exit 268. The interface can be removed enabling the truck to travel to the disposal site where door 270 is opened and the bucket tips to dump the collected material. Then, the door is sealed and the truck returns to the collection site where the interface is reattached to the bucket for continued collection.

The high efficiency cyclone separator 400 of the invention is illustrated in FIG's. 8, 9, and 10. It includes a vertical cylindrical wall section 402; a bottom conical wall section 404 with depressed apex; and a top conical section 406 with raised apex to define an air tight enclosure. Excavant and entraining air flows into the separator through entrance 410, and segregated air, entraining less material than the air entering the separator, flows from the separator through an exit 412. Material collected in the bottom conical section of the separator is discharged through an aperture at the bottom of the separator which is controlled by a flapper valve 414.

The separator 400 is horizontally divided into two cyclone chambers by conical boundary wall 420 having a depressed apex. Air passes from the lower chamber to the upper chamber through an aperture 422 at the bottom of the dividing or boundary wall. Each chamber is an aerodynamically smooth vessel about a central axis 424. This aids in maintaining a vortex with high circumferential air velocity about such axis for high efficiency centrifugal separation with minimal flow resistance.

Air flows tangentially, in relation to the vertical central axis 430 of the separator (best seen in FIG. 9), into the lower chamber 432. The tangential flow generates the high speed circumferential air flow to provide a vortex rotating about the central vertical axis of the lower cyclone chamber. This centrifugally segregates the material toward the radial periphery of the vortex at 434, and segregates clean air toward the central axis.

The material at the radial periphery of the lower cyclone chamber falls along the inner longitudinal side walls 402 of the separator and collects in the conical bottom 436. The material is discharged by sufficiently equalizing the pressure differential between the interior of the cyclone separator and the atmosphere such that upon opening flapper valve 412 the weight of the material will be sufficient to discharge it through the valve. Such pressure equalization is accomplished, for example, by controlling the air pump motor or by closing valve 438 in the conduit between the separator and the air pump.

Separated air flows from the central region of the bottom chamber through passage 422 into the upper cyclone chamber 424. A coarse screen 440 across the passage prevents larger fragments from leaving the lower chamber. Angled vanes 442,444,446,448 (see FIG's 9 and 10) across passage 422 deflect the air spinning about central axis 430 to generate a high speed upper vortex for centrifugally moving material to the radial periphery of the vortex at 450, and moving clean air toward the central axis.

In order to prevent collection of fine material in the upper chamber, a protruding venturi vent 452 is provided in the boundary wall 420 to discharge such material from the upper chamber into the lower chamber. The vent is a flap of the wall cut along the top, bottom, and one side and bent outward to form a vertical opening between the upper and lower cyclone chambers. The vent is positioned so that the air flowing into the lower chamber through entrance 410 blows across the protruding vent. This results in a venturi effect to form a region of low pressure for drawing fine particle fragments from the upper chamber at 450 through the vent into the lower chamber for separation and collection in the conical bottom region 436.

In the preferred embodiment the coarse screen 440 is a wire mesh with approximately 1/4 in (6 mm) spacing. A slit width of approximately 1/8 in (2 mm) has proved sufficient for providing a venturi effect and for removing particles from the upper chamber.

Relatively clean air flows from the center of the upper cyclone chamber up airway 460 into a filter chamber 462. The air flow passes a two stage filter across the airway. The first filter stage 464 is a fine mesh screen to prevent all but the smallest particles from exiting the upper chamber. The filter second stage 466 is a replaceable foam or fiberglass element for capturing particles that pass through the fine mesh screen. Then, the air flows through vertical candle-shaped bag filters 468 which capture any very fine dust which remain in the air flow. Air returns to the atmosphere then exits via exit 412.

Thus, the stages of filter apparatus are arranged in serial relation to the flow path and to each other. Each stage provides a different minimum particle size passage, and the filter stages are sorted in the direction of flow in order of decreasing minimum passable particle size. This maximizes or increases the period of operation between shutdowns for filter maintenance. This filter arrangement has proven to be convenient and economical.

A doorway 470 provides access into the filter chamber 462 for periodically cleaning the bag and screen filters by blowing air and replacing the foam or fiberglass filter element as required.

Angled vanes 480,482,484,486 in FIG. 10 are welded between a conical deflector 488 and the inside of the boundary wall 420. The vanes are angled to deflect the air circumferentially about the vertical central axis of the upper chamber (430 in FIG. 8) for generating a high speed vortex rotating about the central axis in the upper cyclone chamber.

The addition of such a boundary wall with deflecting vanes has proved to be an economical means for increasing separation efficiency of a cyclone separator in an excavation system. This extends the period of operation between shutdowns for filter maintenance.

While this excavation system invention has been specifically described with reference to preferred embodiments, it will be understood by those skilled in the art that changes in form and detail can depart from such embodiments without departing from the scope and spirit of the invention. For purposes of determining the scope of the invention, reference shall be had to the appended claims.

CLAIMS

1. An excavation system in which excavated material is entrained in air and pneumatically conveyed from an excavation site to a remote site, comprising:

an elongated flexible conduit forming part of a flow path for conveying entrained excavated material in an airstream, said flow path having,

an open end for introducing such material into a high velocity airstream, and a

distal open end for discharging said air into the ambient atmosphere;

means for producing said airstream with sufficient velocity to pneumatically convey said material, and

one or more separators between said open end and said distal end in communication with said flow path for separating said excavated material from said air prior to said air being exhausted from said distal end.

2. The excavation system of Claim 1, wherein at least one of said separators comprises:

a generally cylindrical shell having a top opening in communication with said distal end for the removal of air and a bottom opening for the removal of said excavated material.

3. The invention of Claim 2 further comprising:

a wall dividing said cylinder into upper and lower chambers and said wall having an access opening communicating said upper and lower chambers with one another;

an intake conduit introducing the air entrained excavated material into said lower chamber tangentially to the walls of said cylindrical shell so as to develop a vortex causing said material to move centrifugally to the exterior of said lower chamber and the remaining air to the center thereof;

an exhaust conduit removing relatively clean air from said top opening; and

deflector means disposed adjacent said opening and between said lower chamber and said upper chamber.

4. The system of Claim 3 wherein filter means are disposed between said top opening and said exhaust conduit.

5. The system of Claim 3 wherein said deflector means are a series of deflector vanes disposed across said opening for deflecting the material laden gas toward the inner surface of said upper chamber.

6. The system of Claim 5 wherein said wall has an inverted frusto-conical shape having said opening in the lower portion thereof.

7. The system of Claim 6 in which there is at least one vent in the periphery of said wall shaped so as to cause a Venturi effect forming a low pressure in the lower chamber to draw fine particle fragments of said excavated material from such upper chamber into said lower chamber for separation and collection in said lower chamber.

8. The system of Claim 7 wherein a second separator is disposed intermediate the length of said conduit to remove a substantial amount of said particulate matter from said air stream prior to said air stream entering said intake conduit of said first separator.

9. Method of excavating utilizing an excavation system in which fragmented material is entrained in a gas and pneumatically conveyed to a desirably remote site for separating such material from such gas, including the steps of:

supplying energy to a motor communicating with pump means for inducing a gas to travel through an elongated flow path with a sufficiently high velocity to pneumatically convey entrained fragmented material through such flow path;

entraining such material in such high velocity gas;

pneumatically conveying the such material entrained in such gas through the enclosed flow path from an intake end into communication with one or more separators to separate such material from such entraining gas;

at least one step of separating such material from such entraining gas including at least one step of centrifugally separating which utilizes high efficiency cyclone separation;

discharging gas from which such material has been removed from an open discharge end of the flow path into the atmosphere; and

discharging such material at each separation step from each separator.

10. The method of excavation of claim 41, further including the step of

fragmenting to produce a fragmented excavated material sized for such pneumatic conveying of such material from the excavation site through the flow path.

11. The method of excavation of claim 41, further including the steps of:

transporting the excavation system to the vicinity of the excavation utilizing means to enable one operator to control such transportation to enable such transportation in one trip;

transporting the evacuation system away from the vicinity of the evacuation utilizing means to enable one operator to control such transportation to enable such transportation in one trip.

12. The method of excavation of claim 41, in which

separating conveyed fragmented material from such entraining gas includes the step of,

gravitationally separating particles of such material from such entraining gas in a low gas velocity settling chamber to collect such material in such chamber.

13. The method of excavation of claim 41, in which

fragmented material is collected utilizing a collection chamber at the remote site which can be disconnected from the excavation system; and

such method of excavation further includes the steps of:

disconnecting the collection chamber from the excavation system;

transporting the collection chamber to a disposal site where the such material is discharged from the collection chamber;

transporting the collection chamber back to such remote site;

reconnecting the collection chamber to the excavation system.

14. The method of excavation of claim 41, in which

separating conveyed fragmented material from such entraining gas includes the step of,

filtering to separate such material from such entraining gas.

15. The method of excavation of claim 41, in which

the step of separating such material from such entraining gas includes

a plurality of filtering steps; in which

each step utilizing a separate stage of filter apparatus;

each such separate filter stage provides a which different minimum passable particle size;

and further including the step of,

selectively positioning each stage of filter apparatus in the flow path sorted in the direction of flow in order of decreasing minimum passable particle size in order to minimize filter maintenance.

16. The method of excavation of claim 41, in which the step of separating such material from such entraining gas includes the step of,

HEPA filtering to remove toxic gases and very fine toxic particles entrained in the gas flow.

17. The method of excavation of claim 41, in which separating such material from such entraining gas includes,

at least two separate steps of,

centrifugally separating such material from gas utilizing a separate high efficiency cyclone apparatus stage for each centrifugal separation step.

18. The method of excavation of claim 41 in which, separating such material from such entraining gas includes the following steps in order:

centrifugally separating such material from such entraining gas utilizing a first high efficiency cyclone apparatus stage; then

screening such material from such entraining gas to prevent large fragments of such material from departing the first cyclone chamber; then

centrifugally separating such material from such entraining gas utilizing a second high efficiency cyclone apparatus stage; and then

filtering such material from such entraining gas to collect such material particles that pass through the two cyclone stages so as to prevent discharge of such material into the environment.

FIG.1

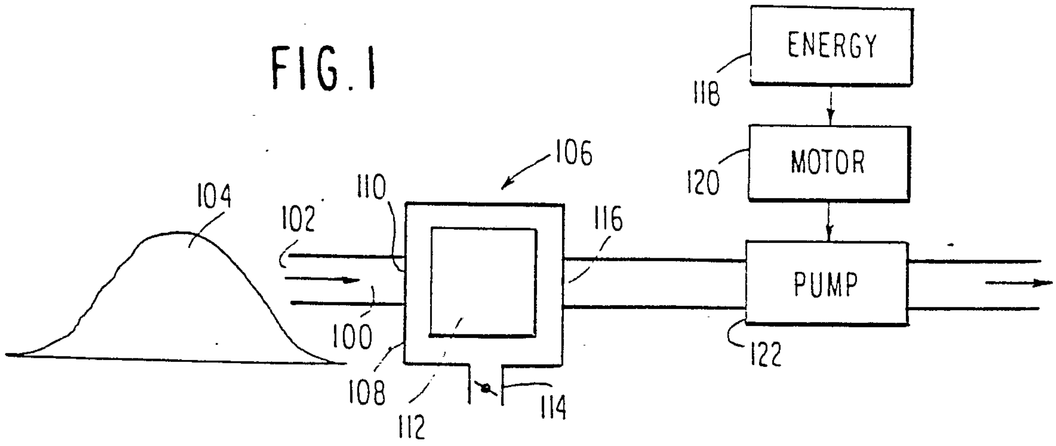


FIG.2

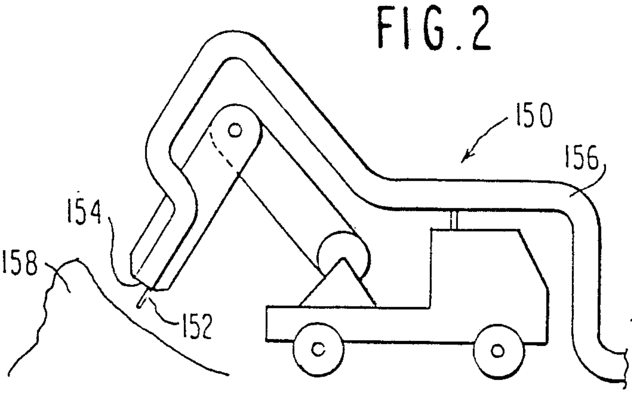


FIG.3

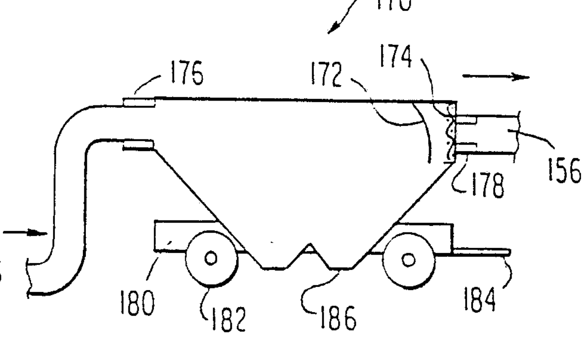


FIG.4

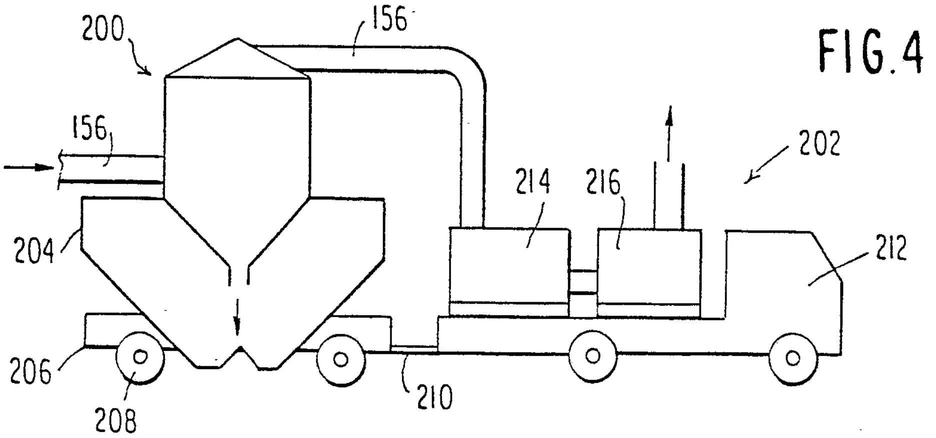


FIG.5

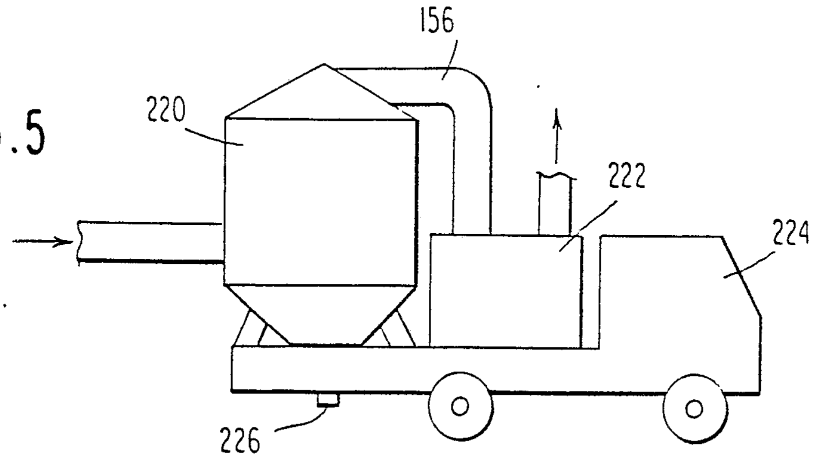
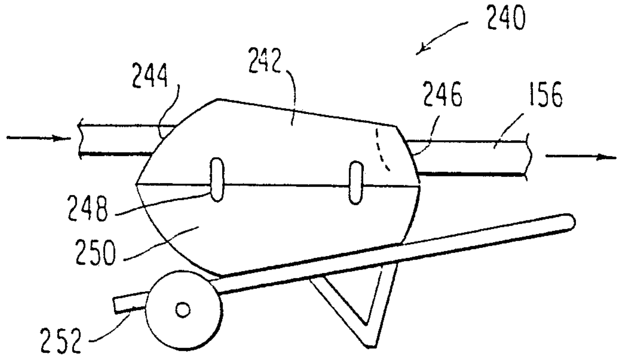


FIG.6



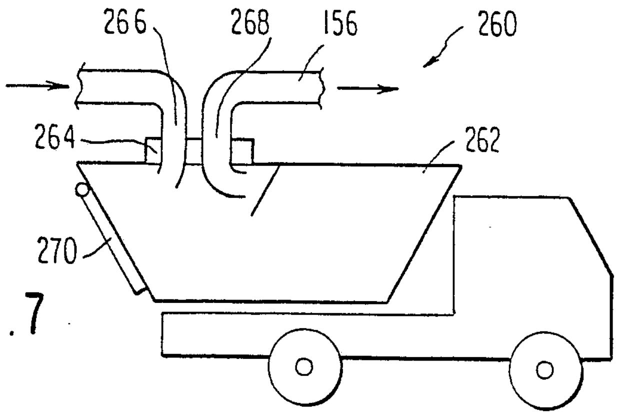
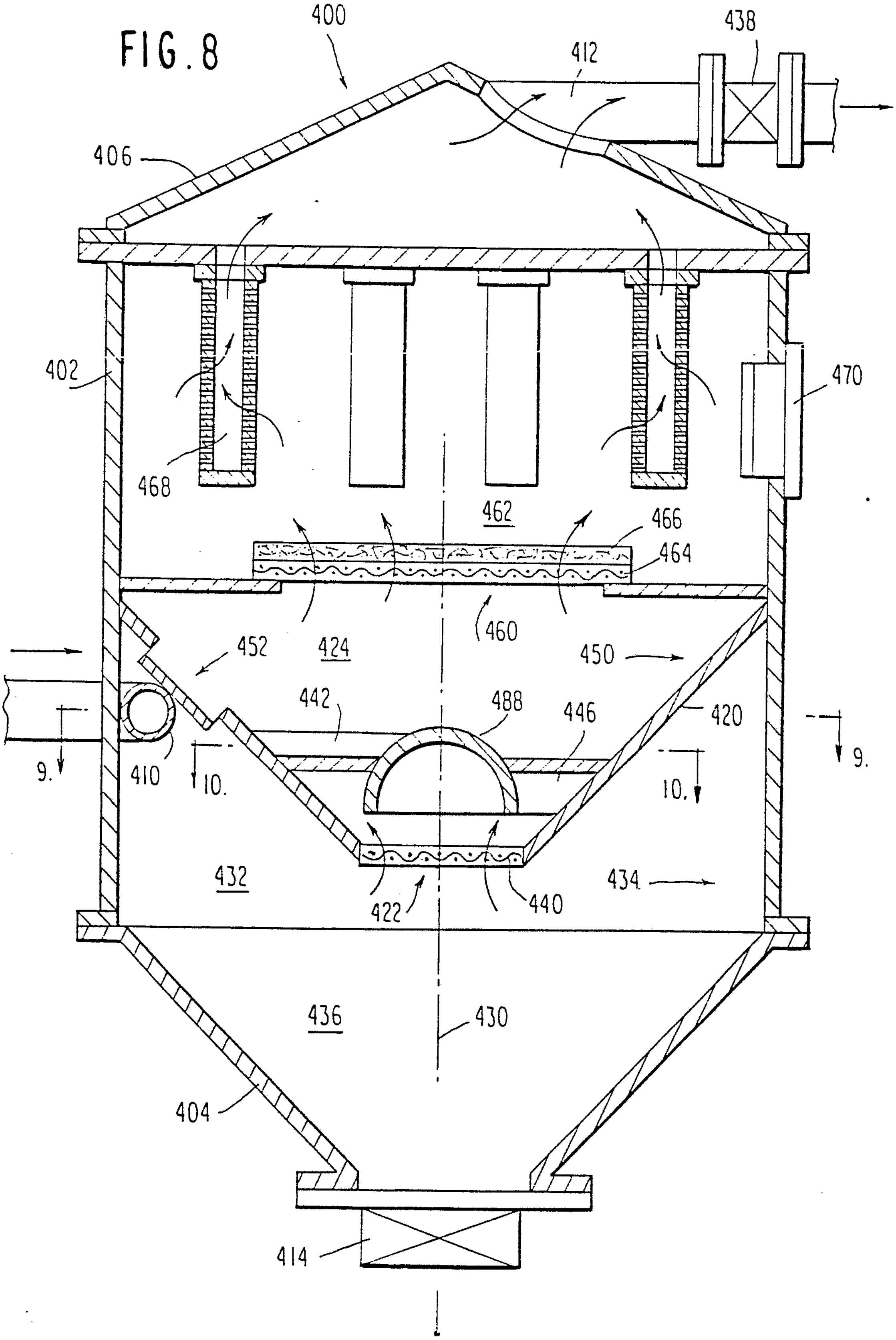


FIG.7

FIG. 8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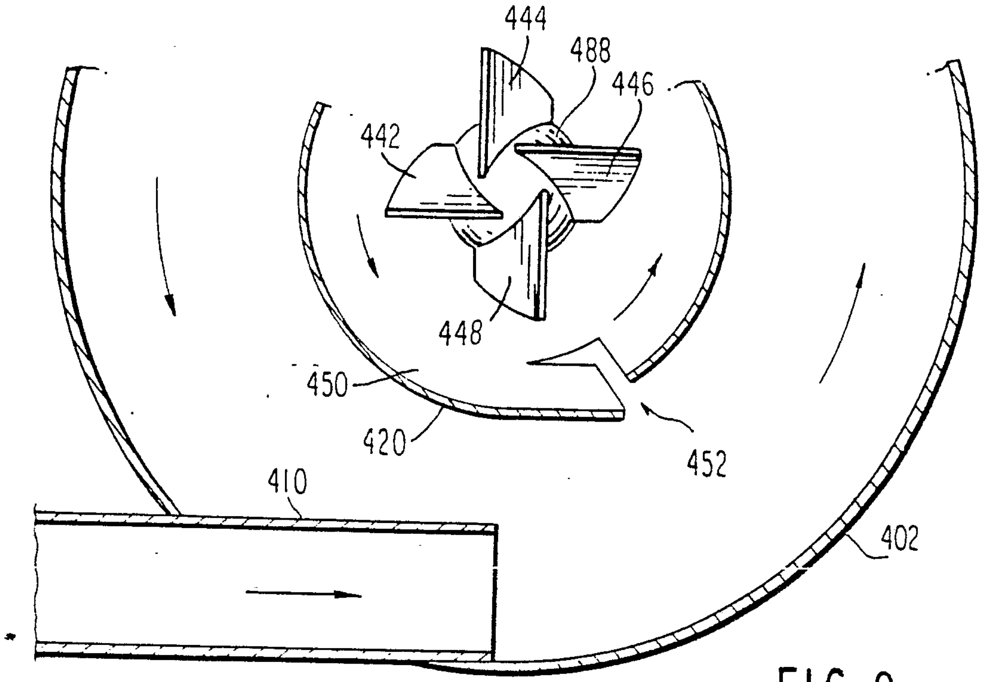
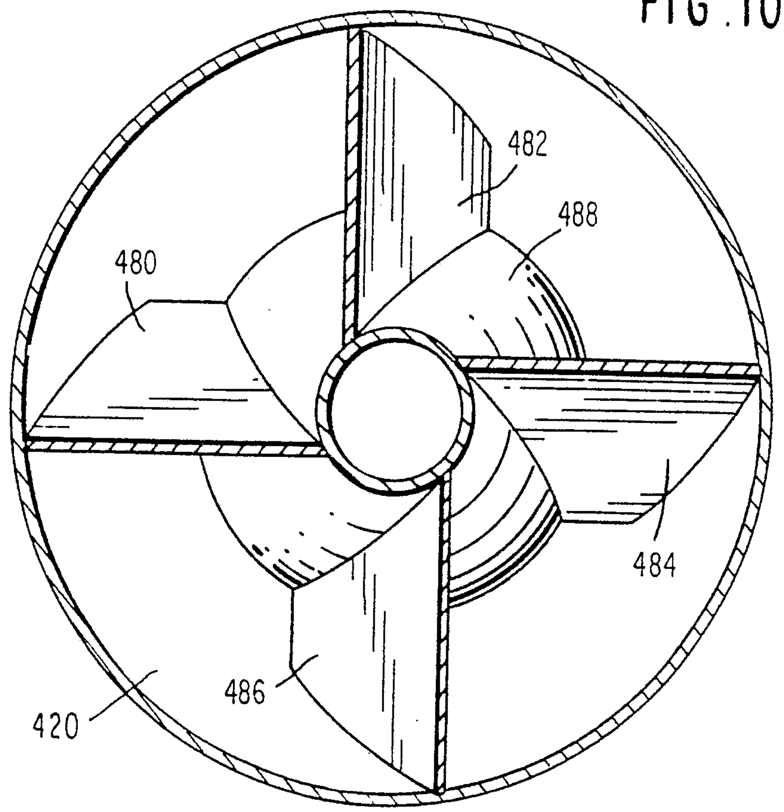


FIG. 9

FIG. 10



INTERNATIONAL SEARCH REPORT

International Application No. PCT/US91/02915

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) 6

According to International Patent Classification (IPC) or to both National Classification and IPC

INT. CL5: B65G 67/00
U.S. CLASS.: 406/173

II. FIELDS SEARCHED

Minimum Documentation Searched 7

Classification System	Classification Symbols
U.S.	406/38,39,40,168,171,172,173

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched 8

III. DOCUMENTS CONSIDERED TO BE RELEVANT 9

Category *	Citation of Document, 11 with indication, where appropriate, of the relevant passages 12	Relevant to Claim No. 13
X	US,A, 2,580,581 (NIEMITZ) 01 JANUARY 1952 SEE ENTIRE DOCUMENT	1-4,9
A	US,A, 4,913,597 (CHRISTENSON ET AL) 03 APRIL 1990	
A	US,A, 4,834,586 (DEPEW) 30 MAY 1989	
A	US,A, 4,695,205 (LEVINE) 22 SEPTEMBER 1987	
A	US,A, 4,927,298 (TUSZKO ET AL) 22 MAY 1990	

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
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ISA/US	S.P. AVILA NGUYEN NGOC-HO INTERNATIONAL DIVISION

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

V. ☒ **OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE** [1]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers , because they relate to subject matter [12] not required to be searched by this Authority, namely:

2. ☐ Claim numbers , because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out [13], specifically:

3. ☒ Claim numbers 10-18, because they are dependent claims not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☐ **OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING** [2]

This International Searching Authority found multiple inventions in this international application as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.
2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:
3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:
4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.