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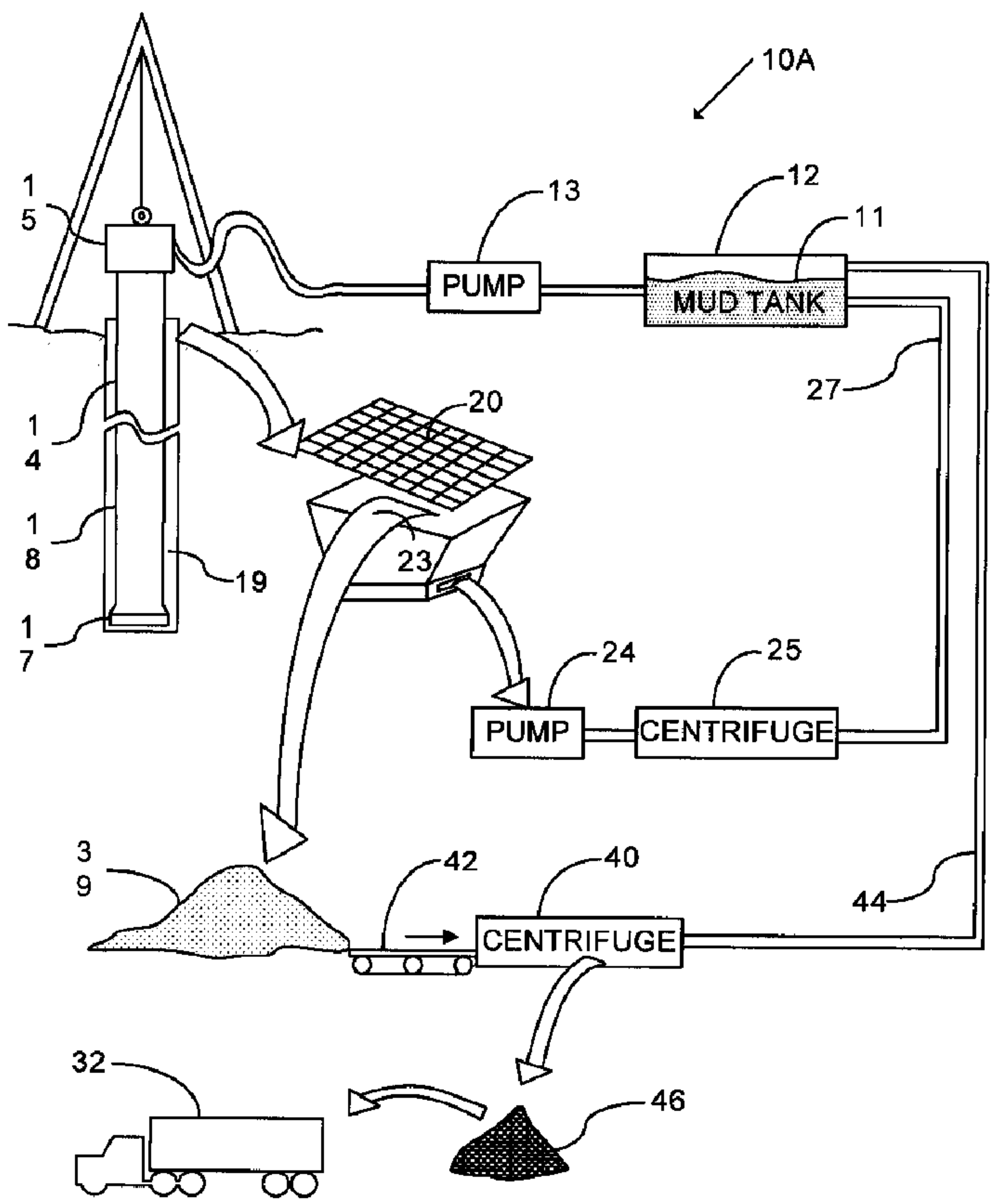
(54) Titre : APPAREILLAGE ET METHODES DE REMEDIEMENT AUX DEBLAIS DE FORAGE ET AUTRES MATERIAUX PARTICULAIRES

(54) Title: APPARATUS AND METHODS FOR REMEDIATING DRILL CUTTINGS AND OTHER PARTICULATE MATERIALS



(57) Abrégé/Abstract:
Apparatus for separating liquids, such as oils from solids, such as drill cuttings, comprises a decanter-type centrifuge. In example implementations the centrifuge has a bowl angle of four degrees or less and a low fluid depth of two inches or less. A material

(57) Abrégé(suite)/Abstract(continued):
conveyor such as an auger is provided to carry material having a relatively high initial solids content, such as 50% or more into the centrifuge. The apparatus may comprise heaters to heat the material. In example implementations the decanter-type centrifuge processes solids from a main centrifuge and/or a shale shaker.

ABSTRACT OF THE DISCLOSURE

Apparatus for separating liquids, such as oils from solids, such as drill cuttings, comprises a decanter-type centrifuge. In example implementations the centrifuge has a bowl angle of four degrees or less and a low fluid depth of two inches or less. A material conveyor such as an auger is provided to carry material having a relatively high initial solids content, such as 50% or more into the centrifuge. The apparatus may comprise heaters to heat the material. In example implementations the decanter-type centrifuge processes solids from a main centrifuge and/or a shale shaker.

APPARATUS AND METHODS FOR REMEDIATING DRILL CUTTINGS AND OTHER PARTICULATE MATERIALS

Cross-Reference to Related Application

[0001] This application claims priority from United States application No. 60/896,818 filed 23 March 2007.

Field of the Invention

[0002] This invention relates to removing oily residues from particulate materials. The methods and apparatus may be applied to separating oil-based drilling fluids from drill cuttings.

Background

[0003] Drilling fluids are used in drilling deep wells, such as wells for extraction of oil or natural gas. The drilling fluids help to keep the well bore open and also flush cuttings made by the drill bit to the surface. In a typical drilling operation, drilling fluid (also called drilling mud) is pumped down through the bore of a drill string to a drill bit. The drilling fluid exits through apertures in the drill bit and returns to the surface in an annular space between the drill string and a wall of the drill bore. The drilling fluid carries with it cuttings of rock or other material that is being drilled through.

[0004] At the surface, the cuttings are separated from the drilling fluid so that the drilling fluid may be reused. This separation may occur in several stages. In a typical operation, the drilling fluid is first passed through a shale shaker. The shale shaker comprises a vibrating screen. Large cuttings do not pass through the screen whereas the drilling fluid and small particles pass through the screen. The drilling fluid is then typically passed through a centrifuge. In most cases the centrifuge is a horizontal decanter-type centrifuge. The centrifuge separates smaller particulate solids from the drilling fluid. The drilling fluid is then returned to a tank from which it can be reused.

[0005] Various types of drilling fluid are used. Oil-based drilling fluids are used in some circumstances. Such oil-based drilling fluids have properties that are desirable in some applications. One difficulty that occurs, particularly with oil-based drilling fluids, is that the separation of particles from the drilling fluid is not perfect. Particles that have been separated by a shale shaker or a centrifuge typically carry some drilling fluid with them. Oily materials can constitute environmental hazards. In most jurisdictions it is not legal to dump cuttings or other soil which is contaminated with oil. Thus, disposing of cuttings in cases where an oil-based drilling fluid has been used can be very expensive.

[0006] In some cases, the oil content of the cuttings is sufficiently high that regulations govern the transportation of the cuttings. Such regulations can require that the cuttings be mixed with sawdust or another oil-absorbent material to prevent the release of oil during shipment. This adds significantly to the expense of transportation and also increases the volume of material to be disposed of, thus compounding a problem.

[0007] It is common practice to truck cuttings to a storage area and to store the cuttings until such time as somebody finds a practical way to remediate the cuttings by removing or breaking down the oil which coats the particles of the cuttings. The existence of such storage areas is a significant potential liability.

[0008] Various methods for removing oils from soil or other similar materials have been proposed in the literature. Some such methods are economically impractical and others do not work.

[0009] There is a need for cost-effective, practical methods and apparatus able to remove oils from soils and other similar materials. There is a particular need for such methods and apparatus that are suitable for alleviating the problems described above.

<u>Brief Description of the Drawings</u>

[0010] The accompanying drawings illustrate non-limiting embodiments of the invention.

[0011] Figure 1 is a schematic illustration of a prior art drilling operation.

[0012] Figure 2 is a schematic diagram of a drilling operation implementing a method for remediating drilling cuttings according to the invention.

[0013] Figures 3 and 3A are flow diagrams illustrating methods according to example embodiments of the invention.

[0014] Figure 4 is a cross section through a horizontal decanter-type centrifuge adapted according to an embodiment of the invention.

[0015] Figure 5 is an alternate cross sectional view of the horizontal decanter-type centrifuge shown in Figure 4.

[0016] Figure 6 is a schematic illustration of a horizontal decanter-type centrifuge according to an embodiment of the invention equipped with a heating system.

[0017] Figure 7 shows an advantageous layout for apparatus according to an embbodiment of the invention.

Detailed Description

[0018] Throughout the following description specific details are set forth in order to provide a more thorough understanding to persons skilled in the art. However, well known elements may not have been shown or described in detail to avoid unnecessarily obscuring the disclosure. Accordingly, the description and drawings are to be regarded in an illustrative, rather than a restrictive, sense.

[0019] Figure 1 shows a typical prior art drill rig **10**. Drill rig **10** has a mud tank **12** containing drilling fluid **11**. The drilling fluid **11** is pumped through a pump **13** into a drill string **14** by way of swivel **15**. The drilling fluid passes downward through a bore **18** in drill string **14** to a drill bit **17**. As the drill bit **17** cuts away at rock or other material, drilling cuttings are carried upwardly by the drilling fluid though an annular space **19** surrounding drill string **14**.

[0020] After the drilling fluid reaches the surface, it is passed through a shale shaker **20**. Larger particles of cuttings do not pass through shale shaker **20** and are removed as solids **22** at a solids output **23**. Fluids and smaller particles which pass through shale shaker **20** are pumped by pump **24** to a centrifuge **25**. The centrifuge **25** separates some suspended solids **29** from the drilling fluid **11**. Drilling fluid **11** is then returned to mud tank **12** by way of conduit **27**.

[0021] The separated solids **22** and **29** are then mixed with a material such as sawdust **30** and loaded into a truck **32** for transportation to a storage and treatment location.

[0022] Figure 2 shows a drill rig **10A** modified according to an embodiment of the invention. Apparatus which is common to Figures 1 and 2 is identified by the same reference numerals in Figure 2 as in Figure 1. In the embodiment of Figure 2, solids output by shale shaker **20** and centrifuge **25** are collected. The collected solids **39** are passed to a second centrifuge **40** by way of a material conveyor **42**. It is convenient but not mandatory that the collected solids **39** be passed directly to second centrifuge **40** by a material conveyor. In some embodiments, collected solids **39** are conveyed to second centrifuge **40** by a loader or other material carrier. It is also possible to stockpile collected solids **39** and process the collected solids **39** in batches periodically.

[0023] Second centrifuge **40** removes further drilling fluid from the collected material **39**. In the illustrated embodiment, the drilling fluid removed by second centrifuge **40** is returned to mud tank **12** by way of conduit **44**. The drilling fluid could instead be collected and reused in some other manner. Solids **46** output by second centrifuge **40** have a significantly reduced oil content as compared to solids **39**. Solids **46** may, in many cases, be loaded directly into a truck **32** for transportation to a storage facility with reduced risk that any oil will escape during transportation to the storage facility. In some embodiments, solids **46** have a liquid content of 8% to 12% or less.

[0024] It can be seen from Figure 2 that second centrifuge **40** is connected in series with first centrifuge **25** in the sense that the solids output from first centrifuge **25** are passed through second centrifuge **40**. The material at the input of second centrifuge **40** may have a relatively high solids content. For example, the material at the input of second centrifuge **40** may have a solids content in excess of 50%, in some embodiments, 60%, or even 70%, or more (as much as 90% in some cases).

[0025] Figure 3 shows a method **50** according to one embodiment of the invention. At block **52**, method **50** receives drilling fluid containing cuttings. In optional block **54** larger particles are removed from the cuttings, for example by way of a shale shaker. In block **56** the drilling fluid is subjected to a first centrifuging step. In block **58** the solids separated from the drilling fluid in first centrifuging step **56** are passed to a second stage. In block **60** the second stage solids are subjected to a second centrifuging step. In block **62** the fluids from the second centrifuging step are collected. The collected fluids may be reused.

[0026] Collecting and reusing drilling fluid that would otherwise be disposed of with drilling cuttings can provide a significant cost savings because drilling fluids can be expensive. Collecting more of the drilling fluid permits both a higher recovery of costs and reduces the contamination of solid material that is removed from the drilling fluid in second centrifuging step **60**.

[0027] First centrifuging step **56** and second centrifuging step **60** may optionally be carried out by the same centrifuge (at different times). However, in a preferred embodiment, different centrifuges are used for steps **56** and **60**. In particular, it can be advantageous to adapt the centrifuge used for second centrifuging step **60** to treat materials high in solids content. In some embodiments the solids passed to the second stage in block **58** have a relatively high solids content compared to the solids content of material that is typically passed to a centrifuge for centrifugal separation. In some embodiments, the solids content of the solids passed to the second stage in block **58** is at least twice as great as the solids content of the material centrifuged in block **56**. In some embodiments the solids content of the solids passed to the second stage in block **58** is three or more, in some cases four or more times as great as the solids content of the material centrifuged in block **56**. This ratio can be even greater in some cases, especially where the material centrifuged in block **56** has a relatively low solids content.

[0028] Figure 3A shows a method **65** according to another embodiment of the invention. Method **65** begins at block **66** by collecting material that has a high solids content. In this context, high solids content means a solid content of at least 50% and, in some embodiments, 60%, or 70%, or more. The high solids content material is passed into a centrifuge in block **68**. In some embodiments, block **68** comprises carrying the high solids content material into a centrifuge by way of a mass conveyor, such as an auger. Where the centrifuge used in block **68** is an axially-fed centrifuge, such as a horizontal decanter-type centrifuge, then the mass conveyor may comprise an auger that extends axially relative to the centrifuge. In block **70**, fluids are removed from the high solids content material by centrifugation. Solids are expelled in block **72**. Fluids removed from the material of block **70** may be collected for reuse.

[0029] Figure 4 is a partially schematic view of a centrifuge **100** adapted for separating liquids, such as oil-based drilling fluid, from an in-feed material having a relatively high solids content (e.g. a solids content of 50% or more, or in some cases, 60% or more or 70% or more). Centrifuge **100** comprises a drum **102** which can be driven for rotation about its axis **103** by a motor **104** and a suitable transmission **106**. Drum **102** is housed inside drum housing **105**. An auger **108** comprising a hollow shaft **109** supporting auger flights **110** is disposed inside drum **102**. Auger **108** can be rotated about axis **103** at a rate that is slightly different from the rate of rotation of drum **102**. In the illustrated embodiment, auger **108** is driven by a separate motor **111** via a suitable transmission **112**.

Alternative arrangements for driving drum **102** and auger **108** could be provided. For example, drum **102** and auger **108** could be driven by a single motor by way of suitable transmissions that cause drum **102** and auger **108** to rotate at different rates about axis **103**.

[0030] Material **101** is introduced into centrifuge **100** by way of an in-feed auger **118** which carries the material into centrifuge **100** through an axial conduit **119**. In an example embodiment, auger **118** has a diameter of 4 inches. In another example embodiment, auger **118** has a diameter in the range of about 4 inches to about 6 inches. In the illustrated embodiment, conduit **119** passes through the bore of bearings **120** that support drum **102** for rotation. The material is delivered to a bore **121** of hollow shaft **109**. From there, the material can exit through apertures **122** into a volume **124** between shaft **109** and housing **105**.

[0031] A feed mechanism **130** may be used to encourage the material to move from bore **121** to volume **124** without plugging. The feed mechanism may, for example, comprise a suitable cage-feed, spider-feed or bar-feed mechanism of types known in the art. Due to the high solids content of the material entering centrifuge **100**, it is preferable to provide a feed mechanism that has large passages (e.g. large apertures **122**) to make it unlikely that the feed mechanism will become plugged with material.

[0032] Figure 5 illustrates a cross section of centrifuge **100** through plane A-A in Figure 4. Feed mechanism **130** comprises apertures **122** cut through the walls of an axial portion of auger **108**. In the embodiment illustrated by Figures 4 and 5, apertures **122** are rectangular in shape. Edges **131** of segments **132** of the walls of auger **108** remaining between apertures **122** may have a slope which facilitates the exit of particles of material through apertures **122** into volume **124**. In the illustrated embodiment, edges **131** slope toward each other so that they meet and form a peak pointing toward the centre of auger **108**. Other shapes may be used to facilitate the exit of particles through apertures **122**. For example, segments **132** may have convex curved inner walls.

[0033] In a region **114**, the inner wall of housing **105** is substantially cylindrical. Drum **102** has a tapered portion **116** in which the radius of drum **102** decreases as one moves in direction **125**. Flights **110** of auger **108** are shaped to conform to the contours of drum **102**. There is a very small clearance between flights **110** and the inside of housing **105**. As a result, the rotation of auger **108** tends to sweep any particles of material along centrifuge **100** in direction **125**.

[0034] In the embodiment illustrated in Figure 4, the particles of material are carried by auger **118** through region **114** to a region in bore **121** of auger **108** which is intermediate the opposing ends of centrifuge **110**. Preferably the particles are delivered in bore **121** near a region in drum **102** where region **114** meets tapered portion **106**. In another embodiment, which is not illustrated, auger **118** may enter centrifuge **110** from tapered portion **116**. The particles of material first pass through region **116** as they are carried in auger **118** and delivered to a region in bore **121** which is near where tapered portion **116** meets region **114**. After the particles are delivered to bore **121**, the particles exit bore **121** through apertures **122** and move into volume **124**.

[0035] As particulate material in volume **124** is carried by auger **108** in a direction **125** it begins to move radially inwardly along the inside surface of housing **105** when it reaches region **116**. Any liquid that is coating or otherwise associated with the particles experiences a radially-outward force which, because of the inward slope of the walls of housing **102** in region **116** tends to cause the liquid to flow in a direction **126** which is opposite to direction **125**. Because auger **108** urges particles of solid material in direction **125** while the centrifugal forces acting on the liquids tend to cause the liquids, which can flow between flights **110** and housing **105,** to flow in direction **126**, a separation of the solids from the liquids occurs in region **116**. Solids are carried to the end of drum **102** where they exit through openings **128**. Liquids exit drum **102** at the other end of the centrifuge at openings **129**. The liquids can be captured for reuse. The solids can be collected for disposal.

[0036] In some embodiments, flights **110** are closer together in region **114** and are farther apart in region **116**. This can help to move fine particles out of the fluid that collects in region **114**. In an example embodiment, flights **110** are arranged to provide a double lead in region **114** and to provide a single lead in region **116**. The double lead may, for example, provide flights spaced apart by four inches while the single lead provides flights spaced apart by eight inches.

[0037] Many of the features of centrifuge **100** are conventional and may be varied in any suitable manner. One area in which centrifuge **100** differs from conventional horizontal decanter type centrifuges is the provisional of in-feed auger **118** which carries materials having a relatively high solids content into centrifuge **100**. Another area in which centrifuge **100** may differ from prior centrifuges is in the angle θ made by the outer wall of drum **102** to axis **103** in region **116** (this angle may be called the bowl angle). In most centrifuges, θ is at least 4° and may be 6° or more. In some embodiments of this invention, θ is significantly smaller. For example, in some embodiments of the invention θ is less than 4°. θ is in the range of ½° to 3.5° in some embodiments. In some embodiments θ is approximately 2°. In some embodiments θ is 2° ± ½°.

[0038] Another adaptation that centrifuge **100** may have to facilitate separation of liquids from high-solids-content infeed material is a shallow fluid depth. The fluid depth in region **114** is determined by the positions of openings **129**.

[0039] Having a low angle θ is thought by the inventor to assist in separating liquids from solids because, with a small angle θ, especially in combination with a shallow fluid depth, region **116** can be longer such that particles spend more time in region **116** before exiting centrifuge **100** than they would do if angle θ were steeper. In some embodiments, openings **129** are positioned to provide a fluid depth of 2 ½ inches or less. The fluid depth may be, 2 inches, 1 inch or 3/4 inches in example embodiments. In some embodiments, the fluid depth is in the range of 3/4 inches to 2 inches.

[0040] In some embodiments, region **116** has the length of at least 40 inches. In example embodiments, region **116** has a length of 45 to 80 inches. In some embodiments, region **114** is shorter than region **116** and region **116** may have a length of at least 70% of a length of drum **102**.

[0041] In some embodiments, the radius of drum **102** reduces by at least 15% between the point at which particles enter region **116** and the point at which particles exit region **116** (in the illustrated case, at exit openings **128**).

[0042] In the illustrated embodiment, centrifuge **100** is horizontal. Axis **103** is horizontal to within ± 5°. An auger **118** or other material conveyor may be provided in the context of a horizontal decanter-type centrifuge having features which are otherwise known in the art or may be provided in combination with a centrifuge having a small angle θ in region **116**, as described above.

[0043] In preferred embodiments of the invention, the solids content of material exiting centrifuge **100** at openings **128** is greater than 85%.In many areas, this solids content is high enough (or conversely, the liquids content is low enough) that it is permissible to ship the materials directly in a truck without mixing them first with sawdust or other liquid-absorbing materials. This reduces the volume of material that must be carried away to a storage and/or treatment location and also renders the material more environmentally benign by removing more liquids which would otherwise be considered to be pollutants. Ideally the fluid content of the solid material exiting centrifuge **100** is less than 10%.

[0044] Liquids which are removed from centrifuge **100** at openings **129** may include oils that can be reused in oil-based drilling fluids or used in the formulation of oil-based drilling fluids. Such recovered oils are a valuable by-product. Ideally the liquids removed at openings **129** have a solids content not exceeding about 5%.

[0045] The efficiency with which a centrifuge **100** can perform separation may be increased by increasing the temperature of the material being treated by centrifuge **100**. Centrifuge **100** may be operated in areas which could have explosive atmospheres. It is therefore desirable that any system provided to heat the materials being treated in centrifuge **100** be designed without open flames or other sources of ignition. In some embodiments, heating is provided by circulating hot air and/or hot fluids (e.g. hot water, glycol, or mixtures thereof). The air and/or fluids may be heated electrically, for example.

[0046] In some embodiments, heat is applied to one or more of:

- housing **105**;
- conduit **119** and/or auger **118**; and
- a feed funnel or conveyor through which the material to be treated passes to infeed auger **118**.

[0047] The heat may be supplied, for example, by:

- passing a heated fluid or gas through coils, a suitable heating jacket or other passages such that the heated fluid comes into thermal contact with the material to be treated;
- providing electrical heating elements in thermal contact with the material to be treated; and/or
- the like.

Thermal contact may be made through a wall of centrifuge **100** or its associated apparatus or more directly with the material to be treated.

[0048] Advantageously, by the time it has reached apertures**122** or feed mechanism **130** the material to be treated is at a temperature in excess of 95 °F, preferably at least 120 °F and more preferable at least 150 °F. Where glycol is used as a heat transfer agent, the glycol may be heated, for example, to a temperature in the range of 200 °F to 300 °F and then circulated to warn the incoming material and centrifuge **100**. In some embodiments, the glycol or other heat exchange fluid is heated by an electrical heating element which may be an immersion-type heating element.

[0049] It can be beneficial to heat the incoming material at or near to the inlet of centrifuge **100**. If the incoming material is heated too early then some oil may separate from the material before the material reaches centrifuge **100**. In some cases this could result in leakage of oil or interfere with the operation of a material conveyor **42** or other apparatus for delivering material to centrifuge **100**. In an example embodiment, heating is provided both around housing **105** and around conduit **119** and/or auger **118**. In some embodiments, material to be treated is also heated at or in a first centrifuge **25**.

[0050] Figure 6 shows schematically a centrifuge **200** that includes a heating system. Centrifuge **200** includes a feed funnel **202** that receives material to be treated. Feed funnel **202** delivers the material to an infeed auger **204** that passes through a conduit **206**. Conduit **206** extends into the rotating drum **208** of centrifuge **200**. Centrifuge **200** may operate in the same or substantially the same way as centrifuge **100**, which is described above.

[0051] A heating jacket **214** surrounds drum **208**. Heating jacket **214** may comprise an insulated wall **215**. Heating elements **218** are provided within heating jacket **214**. The heating elements in the illustrated embodiment include coils of tubing. A heater **220** heats a heat exchange fluid. The heat exchange fluid is circulated though heating elements **218** by a circulation pump **222**. In the illustrated embodiment additional heating elements are provided. In particular:

- heating elements **224** are provided on the walls of feed funnel **202**;
- heating elements **225** are provided on the wall of conduit **206**; and,
- heating elements **226** are provided within a shaft **227** of infeed auger **204**.

[0052] In some embodiments, some or all of the heating is provided in other manners. For example, heating may be provided by electrical heating elements or by mechanical friction. In some embodiments, drum **208** is heated by mechanical friction between drum **208** or a member that rotates with drum **208** and a stationary member.

[0053] Figure 7 shows one advantageous arrangement for apparatus **230** according to an example embodiment of the invention. Apparatus **230** comprises a main centrifuge **234** and a shale shaker **236** arranged on either side of an input bin **238**. Solids **239A** from main centrifuge **234** and solids **239B** from shale shaker **236** are both delivered into input bin **238**.

[0054] A conveyor **242** carries the solids to a feed funnel **244** of a horizontal decanter-type centrifuge **246** that serves as a horizontal decanter oil cuttings drier to separate oils from the solids as described above. Oils may be returned to a drill rig or other collection point for reuse in drilling fluid by a fluid output line **247**. Solids having much reduced oil content are delivered by solids output **248** to a collection point from which the solids can be loaded for transport.

[0055] The arrangement illustrated in Figure 7 is advantageous because it permits operation with or without centrifuge **246**. When centrifuge **246** is not present or is not operational because it is being serviced or the like then operation can continue with solids **239A** and **239B** being collected in input bin **238**. The solids can be allowed to collect in bin **238** until centrifuge **246** is back online or can be handled in a manner known in the prior art while centrifuge **246** is not present or not operational.

[0056] In some embodiments, heaters **250** are provided to preheat material in input bin **238** and or material being delivered by conveyor **242**. For example, heaters **250** may be applied to heat the structures of input bin **238** and/or conveyor **242**. For example, the heaters may heat the walls and/or floor of input bin **238** and/or the structure of conveyor **242**. In some embodiments, input bin **238** and/or conveyor **242** may be located inside an insulated structure **251** to conserve heat.

[0057] Apparatus **230** can be conveniently located in close proximity to a drill rig.

[0058] The various aspects of the invention described herein may be used independently of one another. For example:

- The methods for processing drilling fluids which involve feeding the solids output by one centrifuge and/or a shale shaker into a second centrifuge may be practiced without using the specific centrifuge designs described herein.

- A centrifuge may be provided with a feed auger **118** or other material conveyor to bring high-solids-content material into the centrifuge without having a low bowl angle and vice versa.
- A centrifuge may be provided with a heating system as described herein while differing in other design features from the example centrifuges described herein.
- The methods for removing liquids from high-solids-content materials by passing the high-solids-content materials through a centrifuge may be practiced without using the specific centrifuge designs described herein.

Features of different disclosed embodiments may be combined in combinations and sub-combinations other than those expressly described and depicted herein.

[0059] Where a component (e.g. a material conveyor, bearing, assembly, device, etc.) is referred to above, unless otherwise indicated, reference to that component (including a reference to a "means") should be interpreted as including as equivalents of that component any component which performs the function of the described component (i.e., that is functionally equivalent), including components which are not structurally equivalent to the disclosed structure which performs the function in the illustrated exemplary embodiments of the invention.

[0060] While a number of exemplary aspects and embodiments have been discussed above, those of skill in the art will recognize certain modifications, permutations, additions and sub-combinations thereof. The invention may be applied to separate oils from oily materials other than drill cuttings. For example, the invention may be applied to separate oils or oily materials from dirt in the event of oil spills or leaks.

WHAT IS CLAIMED IS:

1. A centrifuge adapted for removing liquids from material high in solid content, the centrifuge comprising:

   a generally horizontal rotatable drum having a first tapered portion in which liquids are separated from the material, the tapered portion having a wide end and a narrow end;

   an infeed conveyor for delivering the material to a main auger inside the drum, the main auger comprising a hollow shaft which supports a plurality of flights for sweeping the delivered material toward a first set of openings near the narrow end, while permitting liquids which have separated from the material to flow toward a second set of openings at an end of the drum opposing the narrow end.

2. A centrifuge according to claim 1 wherein the drum is supported for rotation by a plurality of bearings and the infeed conveyor extends through a bore of at least one of the bearings.

3. A centrifuge according to claim 1 wherein the infeed conveyor comprises an auger.

4. A centrifuge according to claim 3, wherein the infeed conveyor extends into a bore of the hollow shaft of the main auger.

5. A centrifuge according to claim 4, wherein the main auger comprises a feed mechanism for delivering material from the bore into a space between the shaft and the inner wall of the drum.

6. A centrifuge according to claim 5, wherein the feed mechanism comprises apertures in the wall of the shaft, and segments of the wall of the shaft between the apertures have radially inward-facing peaks.

7. A centrifuge according to claim 1, wherein an angle between a central axis of the drum and an inside wall of the tapered portion is 4 degrees or less.

8. A centrifuge according to claim 1 wherein the second openings are spaced radially inwardly from the inner wall of the drum by an amount such that a fluid depth of 2 inches or less is maintained.

9. A centrifuge according to claim 1, wherein the drum comprises a second generally cylindrical portion joined to the tapered portion at the wide end.

10. A centrifuge according to claim 9 wherein the material is delivered by the infeed conveyor to a location inside the second portion of the drum.

11. A centrifuge according to claim 9 wherein flights of the main auger are closer together in a second part of the main auger that extends through the second portion than are the flights of the main auger in a first part of the main auger that extends through the first tapered portion of the drum.

12. A centrifuge according to claim 11 wherein the flights of the main auger are arranged in a single lead configuration in the first part of the main auger and in a double lead configuration in the second part of the main auger.

13. A centrifuge according to claim 1 comprising a heating jacket adjacent to the drum, the heating jacket disposed to heat a wall of the drum.

14. A centrifuge according to claim 1 comprising a heating element located within a shaft of the infeed auger.

15. A centrifuge according to claim 1 wherein the infeed conveyor comprises a conduit having a bore for carrying the material into the drum and the centrifuge comprises one or more heating elements in thermal contact with the conduit.

16. A centrifuge according to claim 1 wherein the infeed conveyor comprises an axial conduit that is substantially concentric with the drum.

17. A centrifuge according to claim 1 wherein an axis of rotation of the drum is within $\pm 5^\circ$ of horizontal.

18. A system for treating drilling fluid, the system comprising:

a shale shaker comprising a vibrating screen located to receive drilling fluid containing cuttings retrieved from a well bore and to separate solids that do not pass through the vibrating screen; and,

a horizontal decanter-type centrifuge connected to take in the separated solids from the shale shaker and to separate liquids from the separated solids.

19. A system according to claim 18 wherein the centrifuge comprises:

a generally horizontal rotatable drum having a first tapered portion in which liquids are separated from the material, the tapered portion having a wide end and a narrow end; and

an infeed conveyor for delivering the material to a main auger inside the drum, the main auger comprising a hollow shaft which supports a plurality of flights for sweeping the delivered material toward a first set of openings near the narrow end, while permitting liquids which have separated from the material to flow toward a second set of openings at an end of the drum opposing the narrow end.

20. A system according to claim 19 wherein the drum is supported for rotation by a plurality of bearings and the infeed conveyor extends through a bore of at least one of the bearings.

21. A system according to claim 20 wherein the infeed conveyor comprises an auger.

22. A system according to claim 21 wherein an angle between an axis of rotation of the drum and an inside wall of the tapered portion is 4 degrees or less.

23. A system according to claim 22 wherein the second openings are spaced radially inwardly from the inner wall of the drum by an amount such that a fluid depth of 2 inches or less is maintained.

24. A system according to claim 21 comprising a heating means for heating the material being treated in the centrifuge.

25. A system according to claim 24 wherein the heating means comprises a heating element located within a shaft of the infeed auger.

26. A system according to claim 19 further comprising a main centrifuge having an inlet connected to receive fluids that do pass through the vibrating screen of the shale shaker and a solids outlet wherein the solids outlet of the main centrifuge is connected to deliver solids to the inlet of the horizontal decanter-type centrifuge.

27. A system according to claim 26 comprising a bin located to receive the solids outlet of the main centrifuge and the solids that do not pass through the vibrating screen of the shale shaker and a material conveyor connected to carry material from the bin to the input of the horizontal decanter-type centrifuge.

28. A method for removing liquids from material high in solids content, the method comprising:

passing material having a solids content of at least 50% into a horizontal decanter-type centrifuge; and

expelling liquids and solids at different outlets of the centrifuge.

29. A method according to claim 28, wherein the solids expelled from the centrifuge has a solids content of at least 85%.

30. A method according to claim 28 comprising heating the material to a temperature of at least 100 °F.

31. A method for removing liquids from drilling fluid containing cuttings, the method comprising:

passing the drilling fluid and cuttings to an input of a first centrifuge;

processing the drilling fluid and cuttings in the first centrifuge to provide a first output enriched in solids and a second output enriched in fluids;

passing the first output of the first centrifuge to an input of a second centrifuge; and,

processing the first output in the second centrifuge to provide a third output enriched in solids and a fourth output enriched in liquids.

32. A method according to claim 31 comprising collecting the second and fourth outputs and recycling the second and fourth outputs as drilling fluid.

33. A method according to claim 31 comprising heating the first output to a temperature of at least 100 °F before completing processing the first output in the second centrifuge.

34. A method according to claim 31 wherein the first output has a solids content of 50% or more and the third output has a solids content of 85% or more.

35. A method according to claim 31 wherein passing the first output of the first centrifuge to the input of a second centrifuge comprises carrying the first output along an infeed auger that is concentric with an axis of rotation of a drum of the second centrifuge.

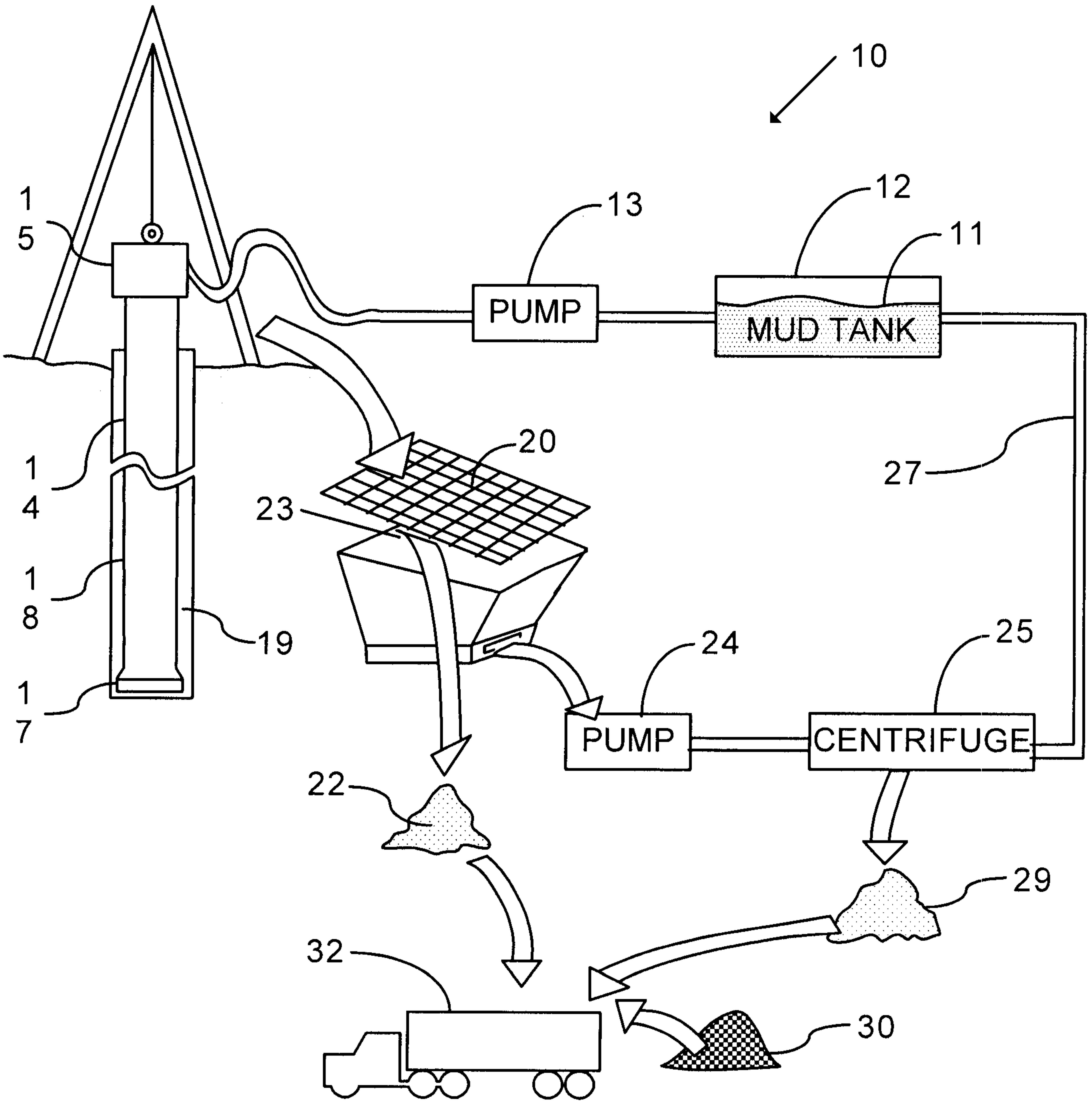


FIGURE 1 (PRIOR ART)

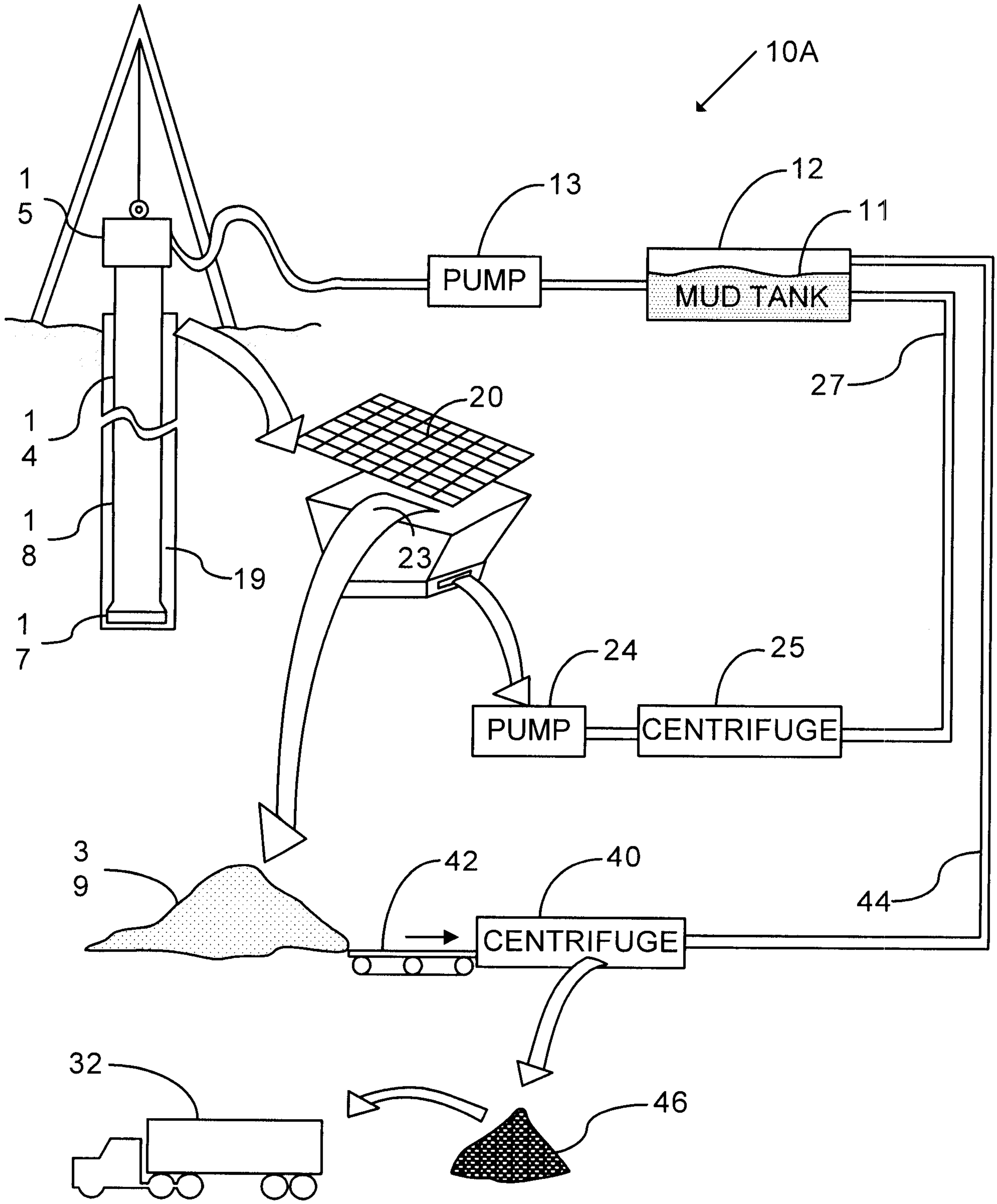

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FIGURE 2

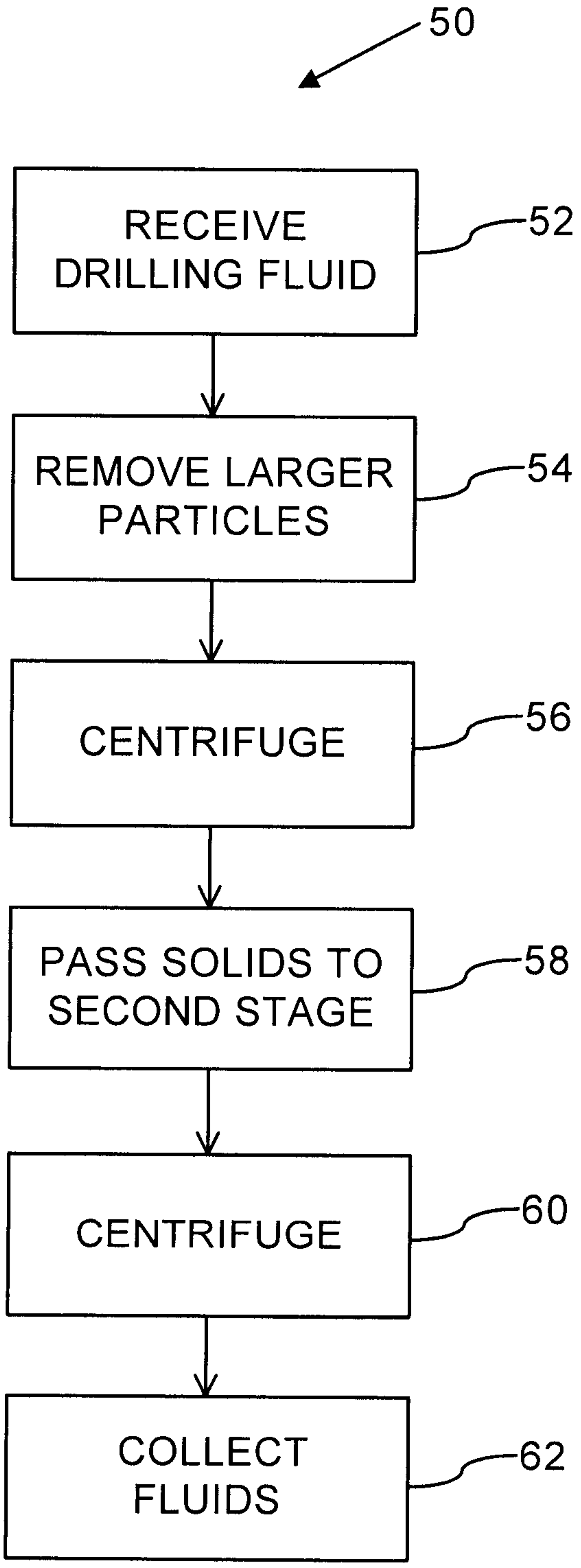

FIGURE 3

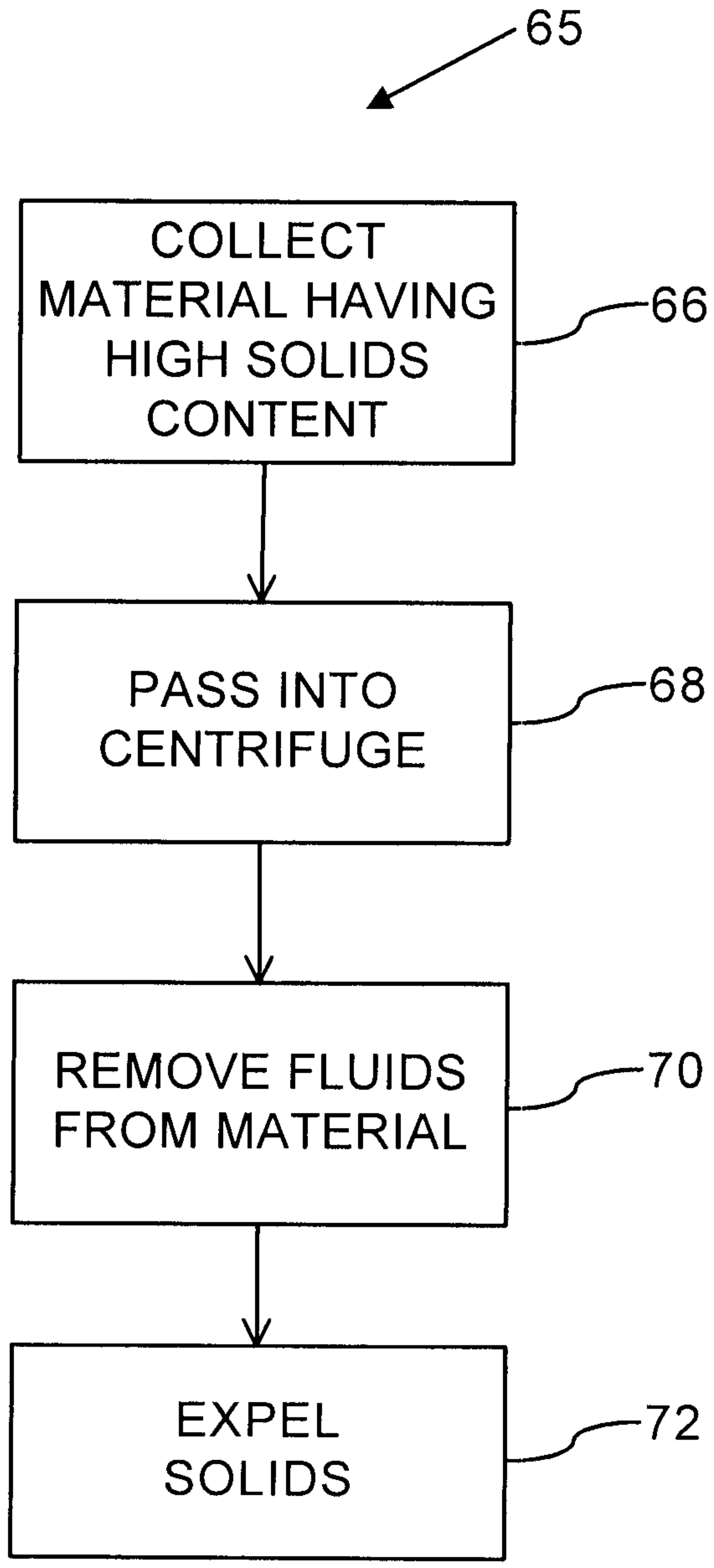

FIGURE 3A

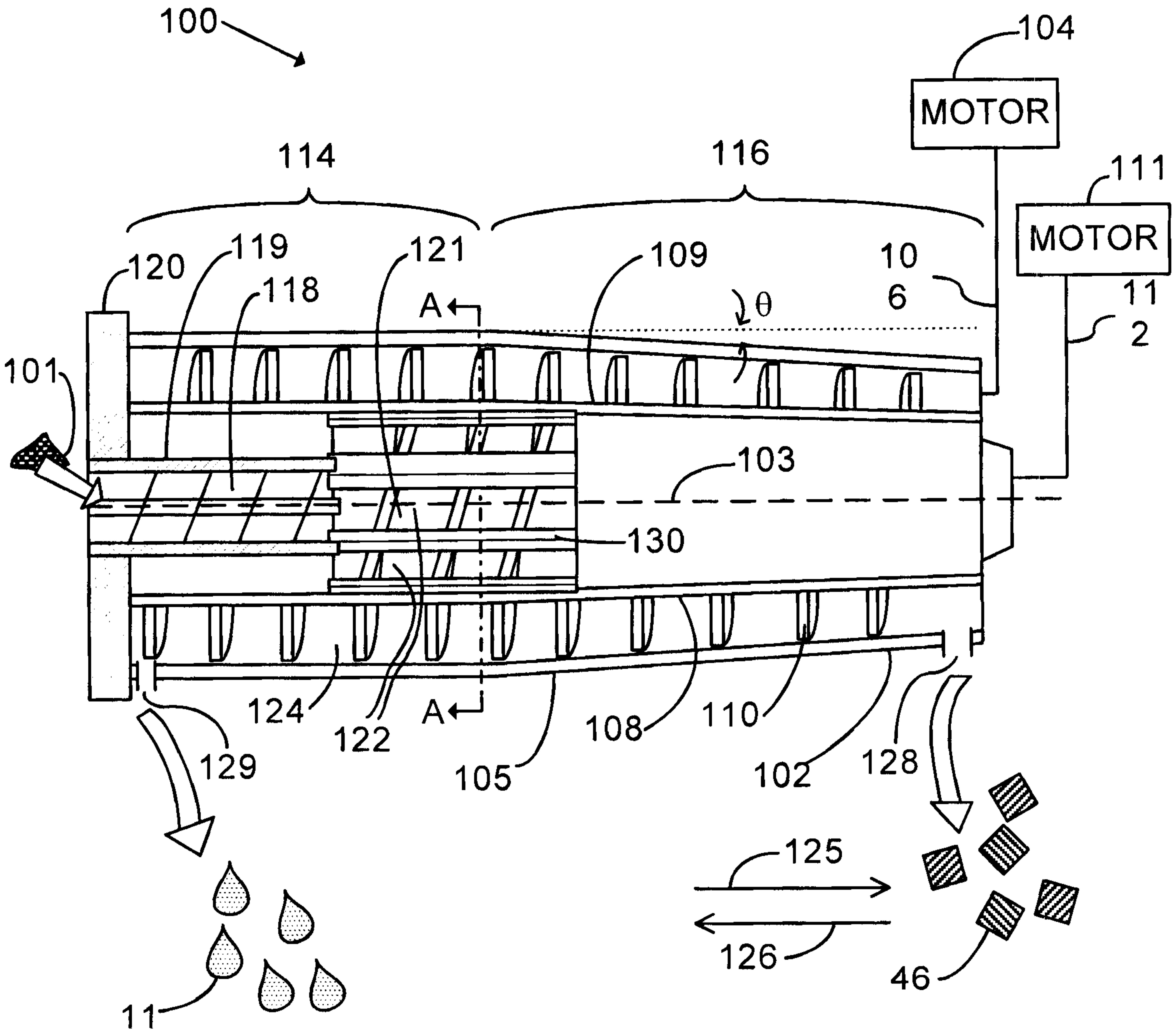
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FIGURE 4

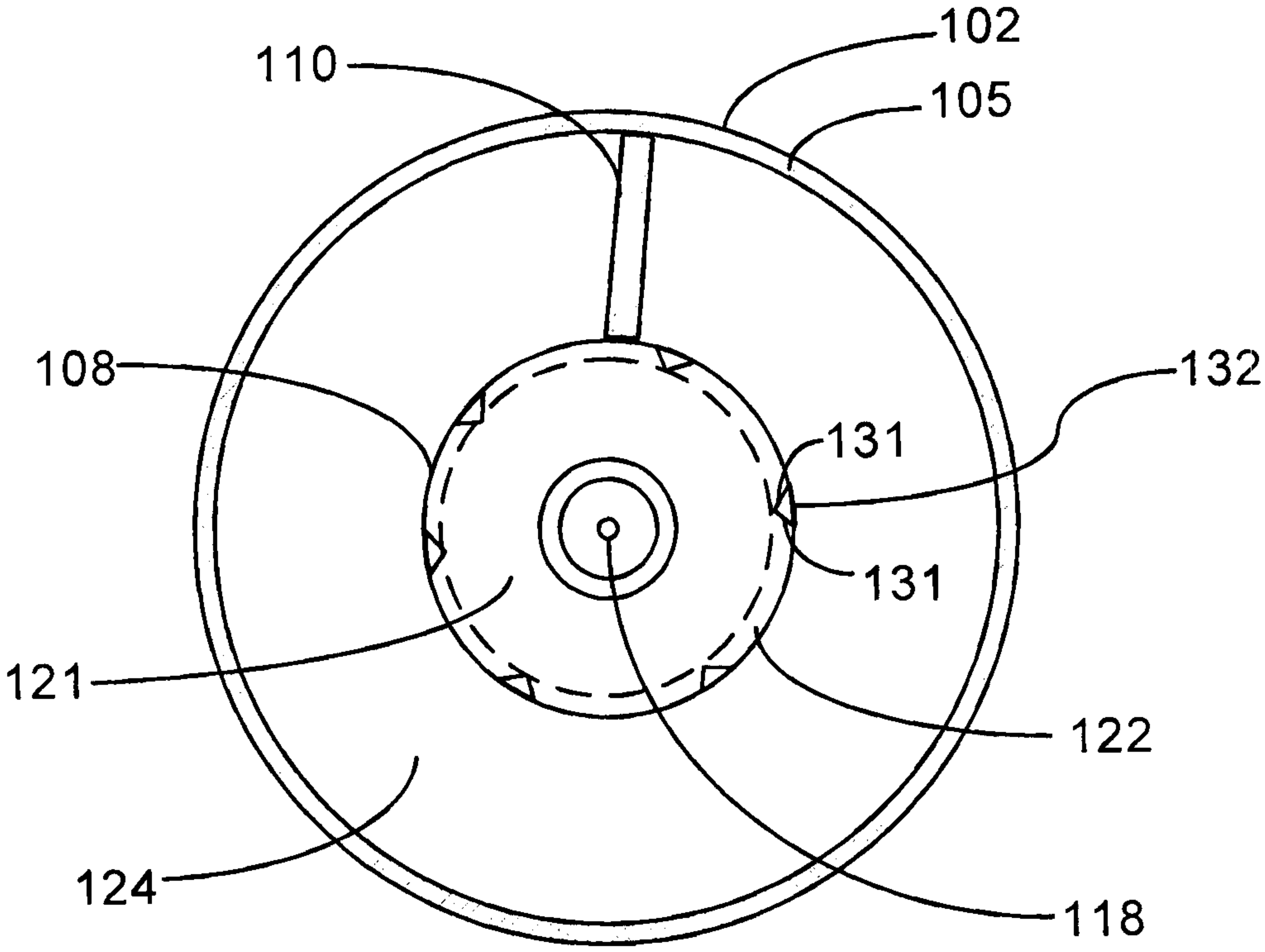


FIGURE 5

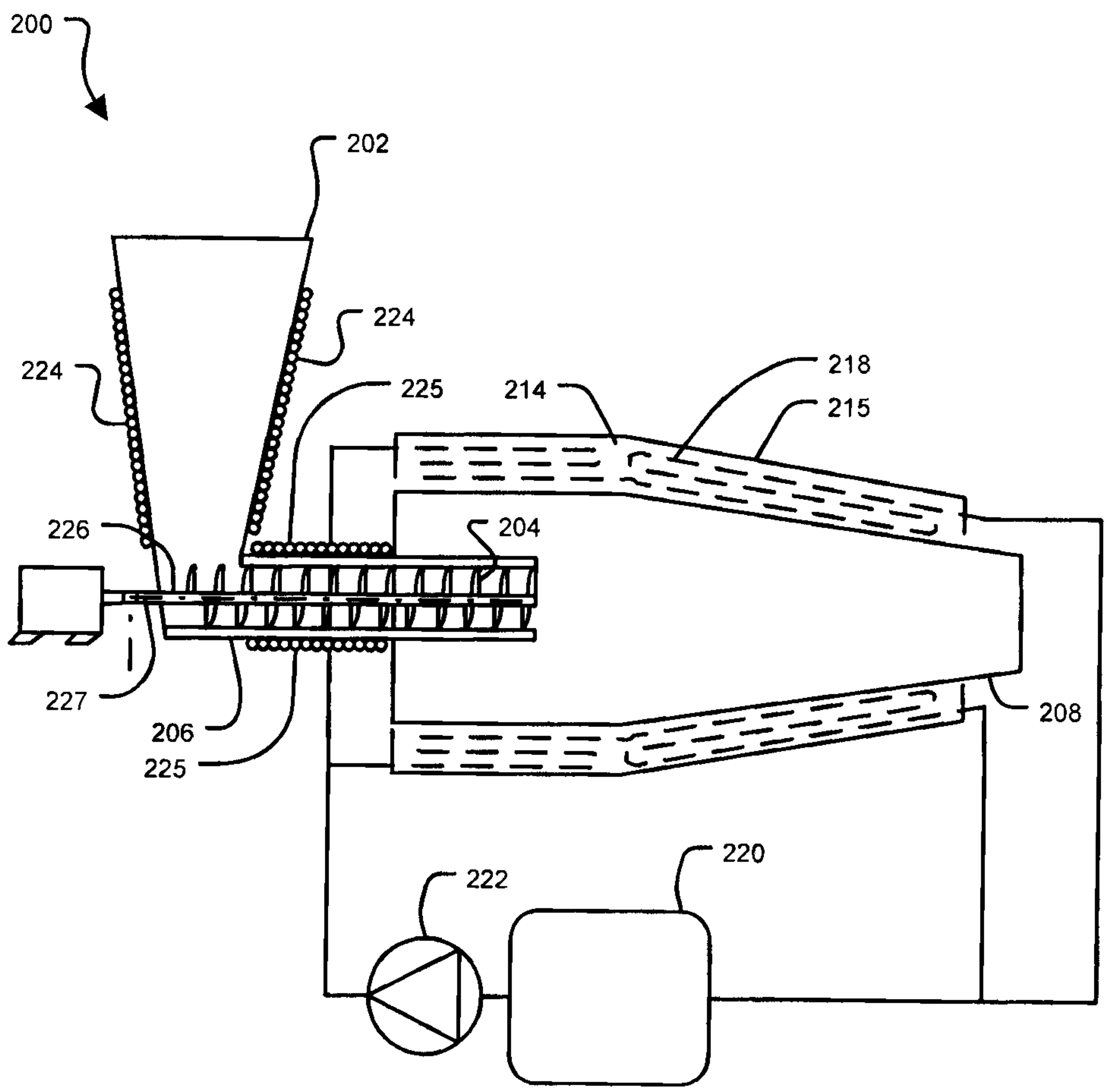


FIGURE 6

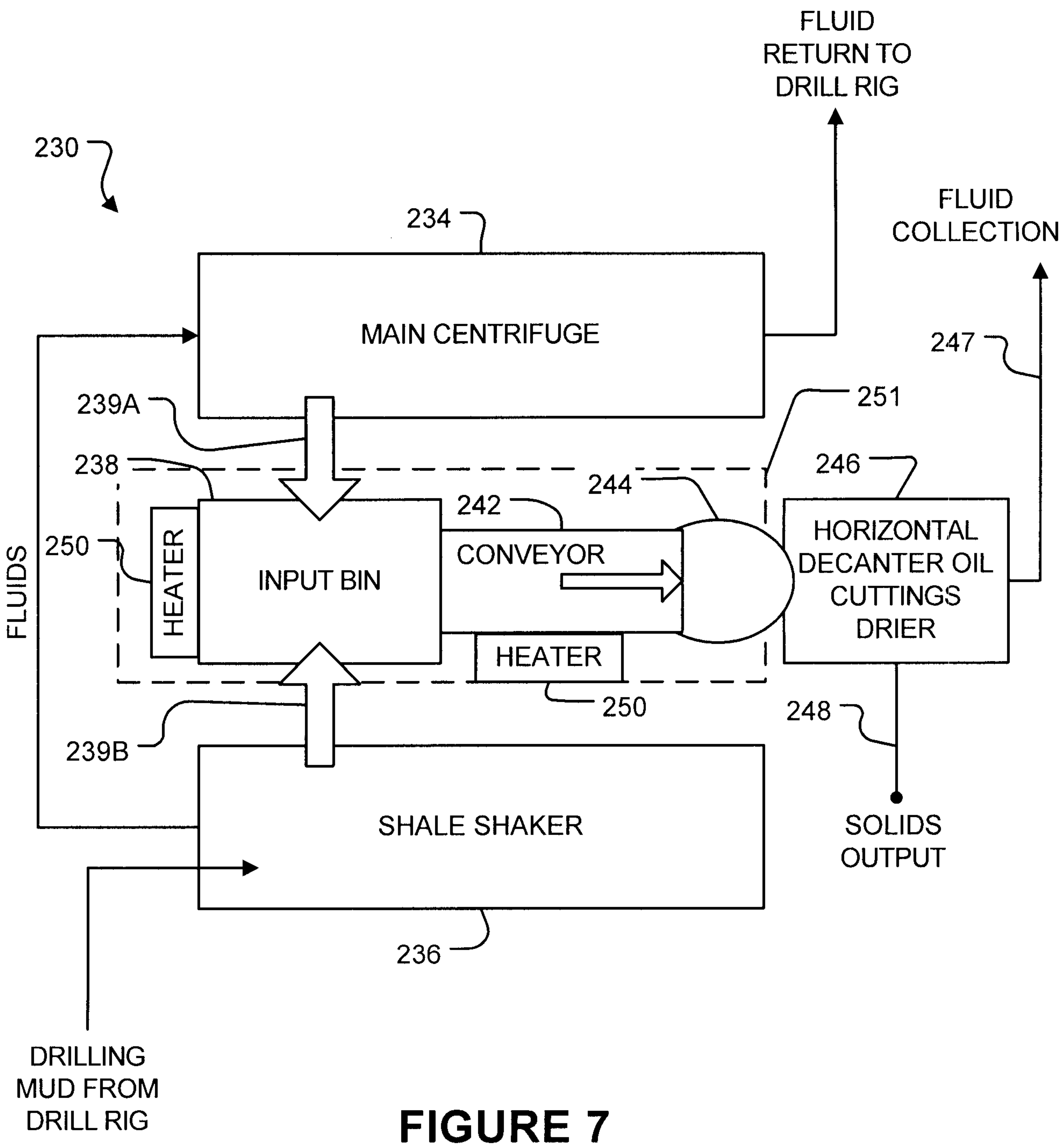
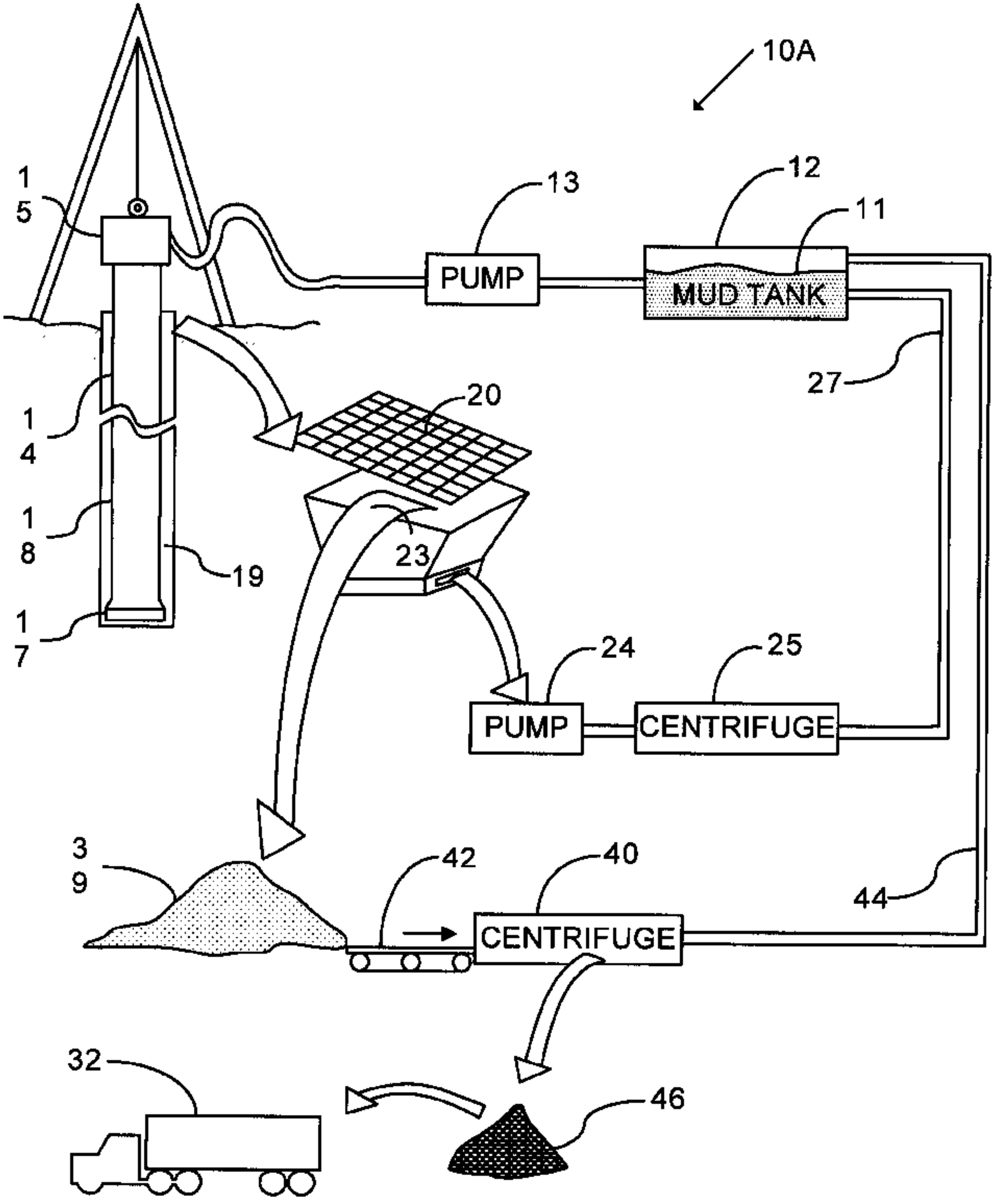

FLUID RETURN TO DRILL RIG
230
234
FLUID COLLECTION
MAIN CENTRIFUGE
247
239A
251
238
246
244
242
250
HEATER
INPUT BIN
CONVEYOR
HORIZONTAL DECANTER OIL CUTTINGS DRIER
FLUIDS
HEATER
250
248
239B
SHALE SHAKER
SOLIDS OUTPUT
236
DRILLING MUD FROM DRILL RIG

FIGURE 7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