Nov. 14, 1967 C. STILLEBROER 3,352,090

LIQUID-GAS SEPARATOR

Filed July 28, 1966 3 Sheets-Sheet 1

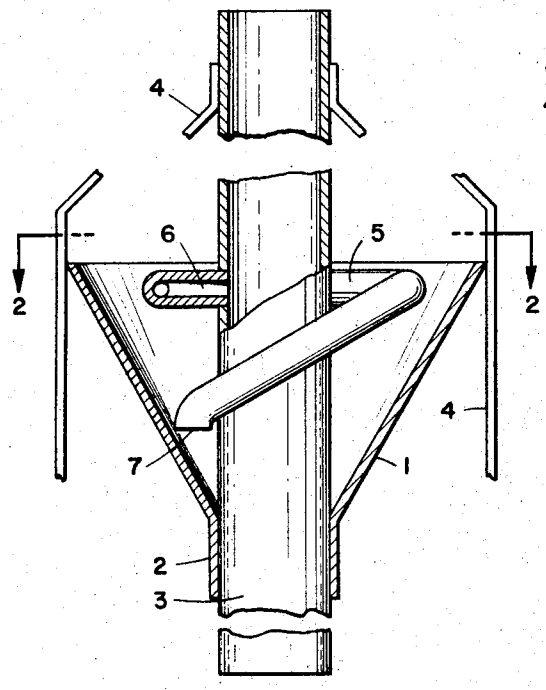

FIG. 1

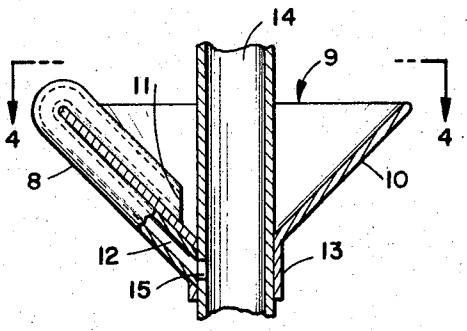

FIG. 3

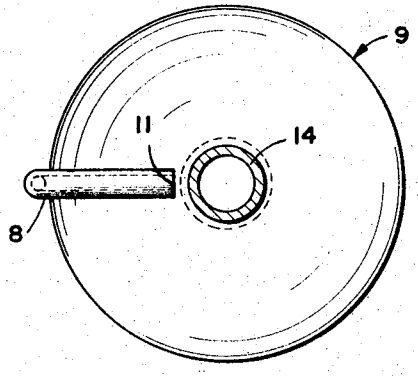

FIG. 4

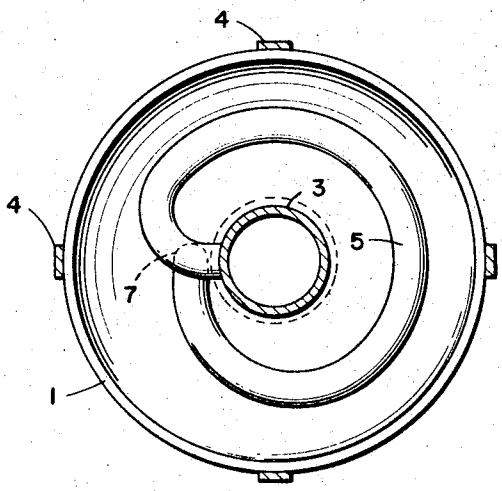

FIG. 2

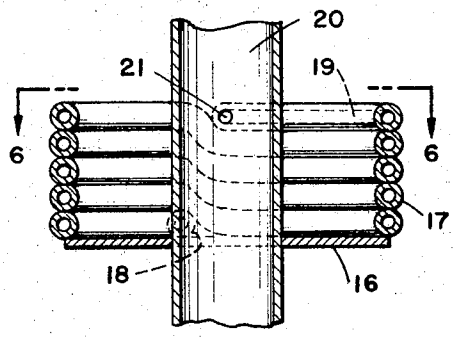

FIG. 5

INVENTOR:
CORNELIS STILLEBROER
BY: J. H. Mc Cartney
HIS AGENT

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Filed July 28, 1966 3 Sheets-Sheet 2

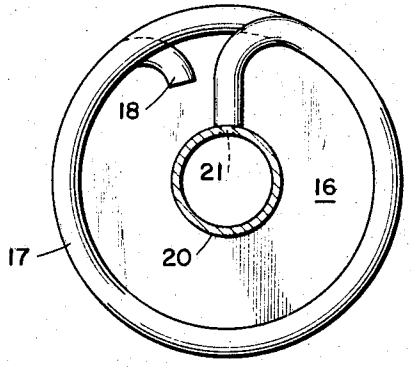

FIG. 6

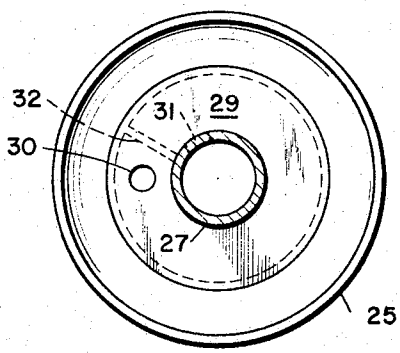

FIG. 9

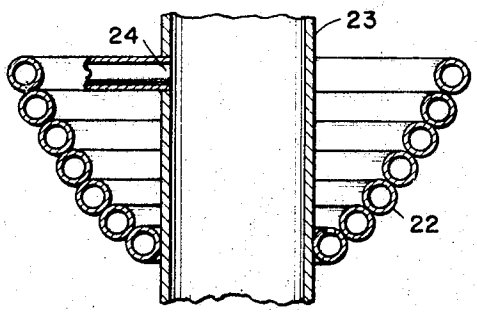

FIG. 7

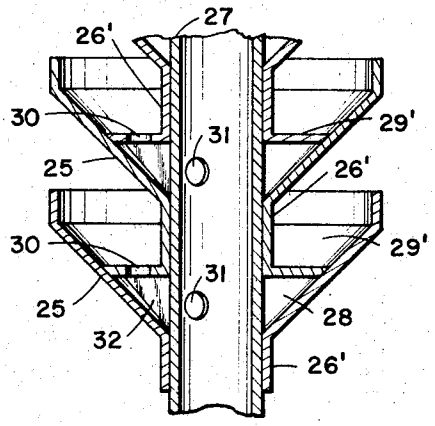

FIG. 10

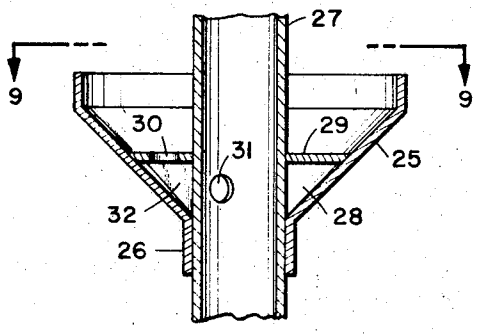

FIG. 8

INVENTOR:
CORNELIS STILLEBROER
BY: A. H. Th. & Cauthey
HIS AGENT

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Filed July 28, 1966 3 Sheets-Sheet 3

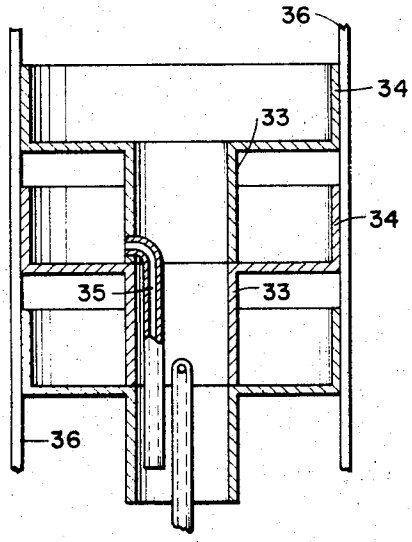

FIG. 11

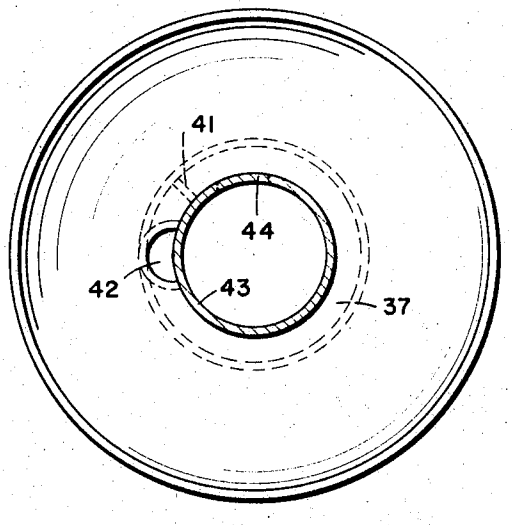

FIG. 13

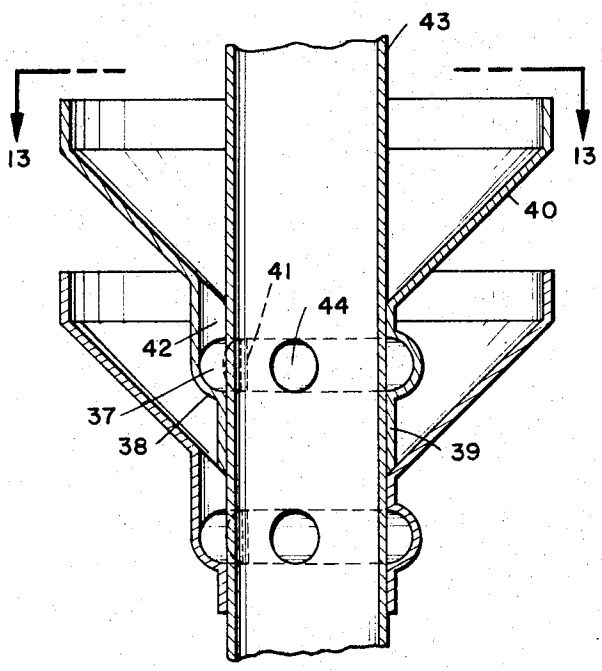

FIG. 12

INVENTOR:
CORNELIS STILLEBROER
BY: A. H. M. Corthy
HIS AGENT

United States Patent Office 3,352,090 Patented Nov. 14, 1967

3,352,090

LIQUID-GAS SEPARATOR

Cornelis Stillebroer, Rijswijk, Netherlands, assignor to Shell Oil Company, New York, N.Y., a corporation of Delaware

Filed July 28, 1966, Ser. No. 568,551
Claims priority, application Great Britain, Aug. 9, 1965, 34,096/65
7 Claims. (Cl. 55—201)

This invention relates to a gas anchor for separating liquid and gas from a liquid/gas mixture which is produced from a subsurface formation into a well penetrating into the formation. The principal aim of the present invention is to provide a gas anchor which has an extremely high separation effect.

In order to pass the produced liquid (such as oil) from the bottom of the well to the surface a pump is often employed near the bottom of the well, the pump having its outlet end in communication with a production tube extending to the surface. In order to obtain a high volumetric efficiency of the pump the liquid to be introduced into the pump should be as free as possible from gas bubbles. For this purpose it has been arranged that the inlet end of the pump communicates with a gas anchor which separates the gas and the liquid which are introduced into the well in the form of a mixture. The liquid separated by the gas anchor is guided to the pump inlet and hence to the top of the well and the gas separated from the mixture by the gas anchor flows directly through the annular space around the production tubing to the surface.

One of the simplest forms of gas anchor is of the cup-type, which comprises a plurality of generally cup-shaped members or cups each arranged around a central tube and spaced substantially equidistant from each other along this tube. The mixture of gas and liquid is supplied to the cups. The inside of each cup communicates with the interior of the central tube via openings arranged in the wall of this tube for passing liquid which is as free as possible from gas bubbles from the cups into the tube and thence to the inlet of the pump.

An improved cup-type gas anchor has been described in British Patent No. 1,006,739. This gas anchor comprising a central tube around which a plurality of cups are arranged at substantially equal distances between each other, has the inside of each cup adjacent the lower part thereof in communication with the inside of the central tube via one or more openings arranged in the wall of the tube. The total area of the passage through said opening(s) is at most 100 square millimeters per cup. Compared with cup-type gas anchors having openings between the cups and the interior of the tube of which the total area per cup is greater than 100 square millimeters, the gas anchors according to this patent show a remarkable increase of the separation efficiency. Problems may, however, be encountered if the gas/oil mixture which is to be treated by this gas anchor is laden with foreign material such as dirt or rust, which may have fallen down to the bottom of the casing or liner during the lowering of the pump and gas anchor in the well.

When such foreign material is present in the well, the openings in the wall of the central tube of the gas anchor will soon be plugged when the pump is put into operation, with the result that no liquid will enter the tube. Enlarging the area of the openings does not form a solution for the problem since this lowers the separation efficiency to an undesirable extent.

An object of the present invention is to provide a gas anchor for separating gas and liquid out of a gas-liquid mixture.

A further object is to provide a gas anchor capable of handling a gas-liquid mixture, which may contain foreign particles, without clogging the anchor.

A still further object is to provide a gas anchor capable of handling a gas-liquid mixture containing particles while maintaining a high separation efficiency.

These and other objects will become apparent in the course of the following detailed description, taken in connection with the accompanying drawings.

According to the present invention a gas anchor for separating gas and liquid comprises a central tube around which a plurality of cups are arranged at substantially equal distances between each other, each cup being provided with pressure drop control means in the form of at least one flow resistant conduit, one end of which is positioned within the cup near the lower part thereof, and the end of which is in communication with the interior of the central tube.

Since the location of both ends of each conduit is more important than the location of the rest of each conduit, it will be clear that the invention may be carried into practice in a great number of ways. Only several specific embodiments will now be described by way of example with reference to the accompanying drawing, in which:

FIGURE 1 is a longitudinal section of part of a gas anchor according to the invention;

FIGURE 2 is a cross-section thereof taken along section II—II;

FIGURE 3 is a longitudinal section of part of an alternative construction of a gas anchor according to the invention;

FIGURE 4 is a cross section taken along section IV—IV;

FIGURE 5 is a longitudinal section of another modified construction of the gas anchor;

FIGURE 6 is a cross section taken along section VI—VI;

FIGURE 7 is a cross section of an alternative of the construction according to FIGURE 5;

FIGURE 8 is a longitudinal cross section of a further alternative construction of the gas anchor;

FIGURE 9 is a cross section taken along section IX—IX;

FIGURE 10 is a longitudinal section of an alternative construction of the gas anchor according to FIGURE 8;

FIGURE 11 is a longitudinal section of part of a gas anchor according to the invention, wherein the wall of the central tube is formed by parts of the cups;

FIGURE 12 is a longitudinal section of part of a gas anchor according to the invention wherein the wall of the conduit of each cup is formed by the wall of the central tube and by the cylindrical extension of the cup; and,

FIGURE 13 is a cross section taken along section XIII—XIII in FIGURE 12.

The cup **1** as shown in FIGURE 1 is of the frusto-conical type and is provided at its lower end with a cylindrical extension **2** fitting around the central tube **3**. The cup **1** is supported by the central tube **3** by connecting the extension **2** to the tube in a suitable manner, e.g., by brazing or welding. A further reinforcement is obtained by strips **4** which are connected to the outer rim of the cup **1** and to the rims of the other (not shown) cups which are arranged below cup **1** at substantially equal distances between each other. These connections between the strips **4** and the cups **1** may be obtained, e.g., by welding. Any number of strips **4** may be used, provided that the passage for the liquid so as to enter the cup **1** is not seriously hampered.

The cup **1** in FIGURE 1 is provided with pressure drop control means in the form of flow resistant conduit formed by a pipe **5** having a circular cross-section. One end of this pipe communicates with the interior of the central tube **3**. The end **6** of this pipe **5** is preferably seal-

ingly passed through an opening arranged in the wall of this tube, and connected thereto, e.g., by welding or brazing. The other end **7** of the pipe **5** is positioned near the lower part of the interior of the cup **1**. If desired, this end **7** or any other part of the pipe **5** may be connected to the cup **1**. As can be seen from section II—II as shown in FIGURE 2, the pipe **5** makes nearly a full turn around the central tube **3**. The invention, however, is limited neither to the number of turns nor to the shape of the pipe **5** as shown in FIGURE 2 and in FIGURE 1 as will be seen from the other constructions as shown in FIGURES 3–13. The flow resistant conduit must have a sufficient length to insure a dynamic pressure drop between the cup **1** and the central discharge tube **3**. This length may vary with each application but in any event the conduit has a length greater than the diameter of the tube **3**. In addition, the cross-sectional area of the conduit must be great enough to permit passage of foreign particles carried by the liquid as will be described later.

The upper and lower ends of each central tube **3** are preferably provided with connecting means (not shown), such as screwthreads arranged on the outer surface of the tube. By means of these screwthreads and suitable coupling sleeves (not shown), provided with cooperating screwthreads, several similar tubes also provided with cups, can be combined together to form a single elongated gas anchor. The upper screwthread of the upper tube may then be coupled to the lower end of a well pump, while the lower end of the lowest tube will be closed by a suitable closing cap screwed to the lower screwthread of this tube.

The inlet of the well pump does not necessarily need to be connected to the top of the central tube, or to the top of the uppermost of the string of central tubes of the gas anchor according to the invention. In an alternative arrangement a suction tube which at the top communicates with the suction side of the well pump, may be arranged within the central tube **3**, in such a way that the lower open end of the suction tube is preferably located below the lowermost conduit. It will be clear that the annulus between the suction tube and the central tube is sealed near the top of the central tube.

FIGURE 3 shows part of a gas anchor in which a pipe **8** is folded over the rim **9** of the cup **10**. End **11** of pipe **8** is positioned near the lowest part of the interior of the cup **10**, while the end **12** thereof passes through an opening provided in the cylindrical extension **13** arranged at the lower end of the frusto-conical cup **10**. During assembly, the cup-pipe combination can be slid over the central tube **14** until the open end **12** of the pipe coincides with the opening **15** arranged in the wall of the central tube **14**. In this position the cup **10** is connected to the tube **14**, e.g., by brazing or welding the extension **13** to the tube **14**. The connection of the extension **13** to the central tube **14** need not be absolutely liquid tight, since any liquid passing through a short circuit formed between the interior of the cup **10** and the opening **15** will promptly be plugged by dirt or other foreign matter which is drawn thereinto. It will be appreciated that the pipe **8** may be connected at any desired spot to the wall of the cup **10** such as by welding or brazing, and that the legs of the folded pipe **8** need not be arranged in a common plane.

The bend in the pipe **8** does not need to extend beyond the rim **9** of the cup **10**. If desired, this rim **9** may be provided with a recess (not shown) in which the bend of pipe **8** is arranged.

Still another construction is shown in FIGURES 5 and 6. Herein the cup comprises an annular plate **16** forming the bottom part of the cup, and a spirally wound tube **17** forming the side wall thereof. The lower end **18** of this tube is bent inwardly and opens into the interior of the cup, while the upper end **19**, which is also bent inwardly, communicates with the interior of the central tube **20** through an opening **21** provided in the wall of the tube **20**. The tube **17** and the plate **16** preferably form a single unit, e.g., by welding or brazing the turns of the tube **17** together and welding or brazing the lowest turn of the tube **17** to the plate **16**. On mounting the cup to the tube **20**, the plate **16** is preferably welded or brazed to the tube **20** at their contact area, and the end **19** of the pipe **17** is sealingly connected to the wall of the tube **20** around the opening **21**.

An alternative of the construction according to FIGURE 5 is shown in FIGURE 7. The pipe **22** is spirally wound so as to form a cup, which is connected to the central tube **23** by brazing or welding the innermost winding thereof to the wall of this tube. The one end of this tube opens into the bottom of the cup formed thereby, whereas the other end is bent inwardly and welded or brazed to the central tube **23** at the part of the wall surrounding an opening **24**. If desired, the windings of the pipe **22** may be mutually sealed, e.g., by brazing them together. The innermost winding of the pipe **22** is preferably connected to the central tube, such as by brazing or welding.

The cup **25** as shown in FIGURE 8 is conically shaped and provided at its lower end with a cylindrical extension **26** which may slide over the central tube **27** so as to bring the cup **25** in the desired position. A conduit **28** arranged to communicate between the interior of the cup **25** and the interior of the central tube **27**, is formed between the lower part of the inner wall of the cup **25**, an annular plate **29** and part of the outer wall of the tube **27**. One side of the conduit **28** communicates with the lower part of the cup **25** via the opening **30** provided in the annular plate **29**, while the other side communicates with the interior of the central tube **27** via the opening **31** provided in the wall of this tube **27**. A short circuit between the two openings **30** and **31** is prevented by a closure plate **32**. Welds and/or brazings are arranged at suitable places, firstly so as to form a unit comprising the cup **25**, the annular plate **29** and the closure plate **32**, and secondly to connect this unit to the tube **27** such that the plate **32** is arranged between the openings **30** and **31**.

An alternative of the construction according to FIGURE 8 is shown in FIGURE 10. Herein the extension **26'** is further extended and forms at the lower end an annular cover **29'** which closes the upper side of the conduit **28** of a lower arranged cup. Openings **30**, **31** and closure plate **32** are arranged in the same manner as indicated in the FIGURES 8 and 9. In this construction the cups can be stacked together and do not need to be welded to the central tube **27**. Preferably suitable markings and/or locking means (not shown) are arranged on the cups so as to align the closure plates **32**. A locking means or marker (not shown) may be arranged on the lowermost cup and the central tube **27** so as to locate the closure plates **32** correctly with respect to the openings **31** in the tube **27**. The cups may be mutually welded or brazed at their contact areas. In another manner, the cups may be held together by strips **4** in the manner as indicated in FIGURE 1.

In the construction as shown in FIGURE 11 the central tube is formed by the tubular extensions **33** of the cups **34**. The pipes **35** are arranged within the central tube and are each at one end thereof connected to the lowest part of a tubular extension **33**. The cups are formed to a common unit by welding or brazing (or connecting them in another manner known per se) to strips **36**. It will be appreciated, that although in the embodiment shown the pipes **35** are arranged in a downward direction with respect to the end thereof communicating with the interior of the cups, they may also, without departing from the scope of the invention, be arranged in an upward direction, or any other direction (e.g., in a horizontal plane).

In the construction according to FIGURE 12, each conduit **37** is partly formed by a channel **38** arranged in an extension **39** of a cup **40**. This channel **38** is preferably pressed or rolled into the extension **39**. A separation plate **41** is arranged in the channel **38** in a suitable manner,

at one side of a cross channel **42** which is arranged between the channel **38** and the interior of the cup **40**. Cross channel **42** may be of semi-cylindrical shape and welded or brazed to the cup **40**, the extension **39** and the channel **38** after the required parts thereof have been removed, e.g., by milling.

Each integral unit comprising the channel **38**, the extension **39**, the cup **40**, the separation plate **41** and the cross channel **42** is thereafter slid over the central tube **43**, into such a position that an opening **44** provided in the wall of the central tube **43** is at the opposite side of the cross channel **42** with respect to the separation plate **41**. Locking means and/or markers may be used to assemble the central tube **43** with all the units such that the separation plates **41** of all these units are in the correct position with respect to the cooperating openings **44**. In the assembled position, the parts of the gas anchor thus formed are clamped or welded together in a suitable manner.

It will be appreciated that in all the embodiments of the invention as shown in the FIGURES 3–13, the central tubes thereof are at the upper and lower ends provided with connecting means suitable to connect such central tube either to another central tube, or to connect the top of a central tube to the lower end of a well pump, or to connect the lower end of a central tube to a closing cap. In this connection reference is made to the description of FIGURES 1 and 2.

The operation of the gas anchors according to the invention is as follows. At least one length of a central tube provided with cups and conduits according to the invention is coupled to the lower end of a well pump, and the lower end of the central tube or string of central tubes is closed by a suitable closing cap. The gas anchor together with the well pump is then introduced into the well and consequently lowered therein in a manner known per se through the casing which is cemented in the well. After the pump has arrived on its seat near the bottom of the well, it can be actuated and a liquid/gas mixture will flow out of the formation, and enter into the annular space between the casing and the gas anchor. When the mixture flows upward, the direction of the mixture is reversed when passing into a cup. At this reversal of direction the greatest gas bubbles are separated from the mixture and continue their travel in upward direction. A further separation of gas from the mixture takes place within the cups. The mixture which has passed over the rim of a cup, flows in a downward direction and radially with respect to the central tube to the entrance of the conduit. During this travel, the remaining gas bubbles have the opportunity to escape from the mixture and are led away to the annular space around the gas anchor, via the openings existing between the cups. In the annular space, the gas bubbles coalesce to greater bubbles, which are withdrawn alongside the well pump and travel upwardly through the space between the casing and the oil production tubing which is arranged in the well to provide a communication between the surface of the earth and the outlet end of the well pump. The gas leaving the well at the surface is either flared or transported.

Any foreign material, such as dirt, sludge or rust which is present in the gas-liquid mixture entering the gas anchor, remains in the liquid phase of the mixture and enters the conduits leading to the central tube together with the liquid. Since the area of the cross-section of each tube is sufficiently great, no clogging or plugging of these conduits will occur, and the liquid will flow unhampered into the central tube from which it is sucked into the well pump and consequently transported via the oil production tubing towards the surface of the earth.

Without limiting the present invention to a special theory, it is considered that the excellent separating action of the gas anchor according to the invention results from the fact that due to the high resistance to flow through the conduits arranged between the interior of the central tube and the cups, the pressure drop along these conduits, during operation of the anchor, will always be in the direction of the interior of the central tube. As the gas contents of the fluid columns inside and outside the tube are not the same, the hydrostatic pressure difference would at low dynamic pressure drops along the conduits between the cups and the tube (which may occur when the cross-sectional area of the conduits is too great and/or the length of the conduits is too small to create the required flow resistance to the fluid passing through the tubes), result in a flow of fluid out of the tube and into the cups at the lower part of the gas anchor. This flow of fluid out of the central tube at the lower part of the gas anchor would automatically be compensated by an increase in the flow of fluid into the tube at the upper part of the gas anchor, and the increased flow would decrease the separation efficiency.

A sufficiently high dynamic pressure drop along the conduits (obtained by suitably choosing the amount of liquid to pass through each conduit, and the cross section as well as the length of each conduit), results in a pressure drop which will always be in the direction of the tube, notwithstanding the differences in hydrostatic pressure occurring between the fluid columns inside and outside the central tube.

It will be appreciated that the invention is not limited to conduits having a particular cross-sectional shape provided that the distance between the walls of the conduit is sufficiently great to allow the foreign material present in the well to pass therethrough without clogging or plugging the passage.

The length of the conduits will be chosen so as to obtain a required pressure drop along the conduit for a given cross section of the conduit and a given throughput of liquid. The conduits need not necessarily be of the same length. The pressure difference in the fluid columns inside and outside the central tube varies over the height thereof due to the difference in specific gravity of the fluid (which is a function of the amount of gas present in the fluid). If it is desired to obtain an equal throughput of fluid through all the conduits, the upper conduits will have to be longer than the lower conduits of the gas anchor. Applying different cross sectional areas in the conduits for the same purpose is not advised, since this increases the possibility of plugging of the conduits.

The number of cups applied per gas anchor depends on the required fluid flow through each conduit to reach the required pressure drop across the length thereof, and on the capacity of the well pump cooperating with the gas anchor. Adding more cups will decrease the efficiency of a gas anchor/pump combination since then the fluid velocity and consequently the pressure drop in each conduit will decrease, which would increase the pressure inside the central tube such, that the pressure inside the lower part of this tube would become greater than the pressure outside the tube at the same level, which would result in a flow of fluid out of the central tube.

The material used for the various components of the gas anchor according to the invention is preferably metal. The components are preferably connected together, where required, by brazing or welding. Instead of using metal pipes as conduits between the cups and the central tube, use may also be made in the constructions according to FIGURES 1, 2, 3, 4 and 11 of flexible pipes (e.g., rubber or plastic pipes), which are coupled to the cups and central tube by short metal coupling pipes welded to the cups and the central tube.

The highest separation efficiency of the gas anchors according to the invention will be obtained if the end of the conduits communicating with the interior of the cups is arranged as low as possible within the cups. The level at which the other end of the conduits communicates with the central tube can be chosen at will.

It will be appreciated, that the shape of the cup does not form part of the invention. Any shape may be used,

but it will be clear that the best separation efficiencies will be reached if the cups are not too shallow.

It will be understood that the present invention is not limited to the examples given, but that without departing from the spirit of the invention, various types of cups, central tubes, conduits and materials can be used by those skilled in the art. If desired, more than one conduit may be applied per cup for communication between the cup and the central tube.

I claim as my invention:

1. A gas anchor for separating gas and liquid, comprising a central liquid discharge tube, a plurality of substantially cup-shaped members arranged about said tube at substantially equal distances between each other, each cup being provided with pressure-drop control means in the form of at least one flow resistant conduit, said conduit having a length greater than the diameter of said discharge tube to assure a dynamic pressure drop between said cup and the interior of said tube and a cross-sectional area of a sufficient size to permit passage of foreign particles entrapped in said liquid, one end of said conduit terminating within the cup near the lower part thereof, and the other end of said conduit in communication with the interior of said central tube.

2. A gas anchor according to claim **1**, wherein the conduits are substantially arranged within the cups.

3. A gas anchor according to claim **1**, wherein the conduits are substantially arranged within the central tube.

4. A gas anchor according to claim **3**, wherein said cups are formed with co-axial tubular extensions which form the central tube, and the lower end of each extension is provided with an opening which communicates with one end of said conduit.

5. A gas anchor according to claim **1**, in which the conduit is defined by the inner wall of the cup, the outer wall of the central tube and an annular plate arranged within the cup, and said anchor further includes a separation plate mounted within said conduit, an opening in the annular plate at one side of said separation plate, and a second opening in the wall of the central tube at the other side of the separation plate.

6. A gas anchor according to claim **1**, wherein said cup is formed with a co-axial depending cylindrical portion, said conduit is defined by the outer wall of the central tube and the inner wall of the cylindrical portion of said cup, and said anchor further includes a separation plate mounted within said conduit, a second conduit communicating between the first conduit at one side of the separation plate and the lower part of the cup, and an opening in the wall of the central tube at the other side of the separation plate.

7. A gas anchor according to claim **1**, wherein said conduit is spirally wound and the wall of each cup is at least partly formed by the wall of said conduit.

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REUBEN FRIEDMAN, *Primary Examiner.*

R. BURKS, *Assistant Examiner.*