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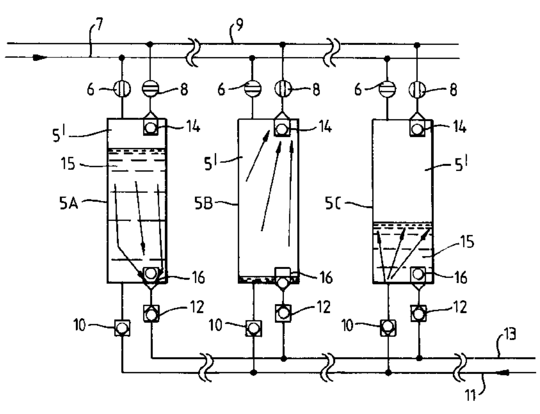
(54) **Method for boosting the transfer of production fluid from a well.**

(57) The flow of a liquid, such as a production fluid from an oil well, is boosted by allowing the fluid to enter a chamber (5A,B,C), from which it is subsequently displaced by gas supplied from a remote source under high pressure (7), the chamber also being connected to a vent line (9) through which the displacing gas, and any gas released from the production fluid, may be vented.

Fig.1.



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It is frequently necessary to boost the transfer of production fluid from an oil well. For example the well may be a very long way from an export point, such as the deck of a platform or landfall, in the case of a subsea well, and the pressure drop in the correspondingly long pipeline may reduce the flow rate to an unacceptable level or not at all. A similar problem arises when there is insufficient reservoir pressure to achieve an acceptable flow rate through a wellhead to an export point. Oil tapped from an oil well is invariably accompanied by a gaseous component which will increasingly come out of solution with reduced pressure. The result is that the production fluid, the transfer of which is to be boosted, conventionally incorporates liquid and gaseous components in indeterminate and widely varying proportions ranging from slugs of liquid oil through frothy mixtures to pockets of gas. Therefore the optimum position for a pump is below the hydrocarbon bubble point. Downhold pumps that have to be run inside the casing are necessarily small and have a short life.

Pumping such multiphase fluid is difficult because pumps that can pump liquids efficiently and ones that can pump gases efficiently have two different sets of characteristics and these have yet to be combined successfully in a single reliable pump. Even if multiphase pumping is achieved, energy is lost in recompressing the gaseous phase. The alternative is to allow gravitational or centrifugal separation of the different phases and then to pump or otherwise feed the liquid gaseous phases separately. The provision of large settling tanks is awkward and expensive, particularly for subsea operation, and two feeder lines have to be provided, one for the pumped gas and one for the pumped liquid, plus means for providing power.

In accordance with the present invention, a method of pumping a liquid from a source to a destination comprises providing at least one chamber connected via valving with a supply at a first pressure, from the source, of a fluid of which the liquid forms at least a part, the chamber having its lower part connected via valving with a feeder for at least the liquid component of the liquid to the destination, and the chamber having its upper part connected by a valving with both a high pressure gas supply line at a second pressure greater than the first pressure and with a low pressure gas vent line at a third pressure less than the first pressure; and alternately introducing gas from the gas supply line into the chamber to displace the liquid component of the fluid from the chamber into the feeder, and venting the chamber to the gas vent line whilst allowing the fluid to enter the chamber from the supply.

The new method has the advantage that liquid can be pumped at a relatively inaccessible location, for example adjacent to, or below, the mudline in the case of a subsea oil field, preferably below the bubble point, without the need for any local pumps and/or motors, using the energy provided through the gas supply line leading from a pumping station in an accessible position, such as on a platform or landfall in the case of a subsea oil field or a subsea pump at the well. The gas vent line will normally run alongside the gas supply line to the same station.

As gas has a low internal friction factor, and a low density compared with a liquid, the gas vent line can provide a low back pressure, which may be controlled at the pumping station to enable the chamber to act as a self filling pump at the appropriate part of the cycle during which the chamber is filled with fluid from the fluid supply.

The invention is applicable to the aquifier pumping of water from an upper aquifier zone into a lower oil reservoir to boost its pressure, in which case the fluid will be water and the destination an oil reservoir. In the case of a subsea oil field, the chamber will then normally be positioned below the aquifier and the water is pumped down and injected into the oil bearing reservoir.

The full advantages of the invention are achieved when the fluid is production fluid from an oil well and the destination is an export point. In addition to the advantages referred to above, in terms of controlling pumping from a remote station, there is the additional advantage that any gas released from the production fluid on entering the chamber may rise to the top of the chamber and be vented with the gas already in the gas chamber, up the gas vent line during the filling of the chamber. There is thus an automatic first stage separation of liquid and gas in the production fluid. The reduction in the quantity of gas in the production fluid liquid component also delays the onset of multiphase flow problems. Furthermore, by lowering the gas vent line pressure to cause a release of gas from the production fluid, gas can be removed so that a controlled single phase liquid can be achieved. The pressure in the gas supply line is then adjusted to ensure a single phase flow or stable multiphase flow through the feeder to the export point. The liquid phase is thus pumped by the supply of energy to the liquid phase only. The chamber can be deployed in any convenient location, e.g. downhole in a well, next to a subsea wellhead, or at an appropriate location along a pipeline. The gas supply should be compatible for hydrocarbon pumping, e.g. oxygen-free and may be, e.g. nitrogen on start-up. Usually however it will be recompressed gas from the production fluid, e.g. recycled from the vent line via the remote station. This is efficient as it is only necessary to provide enough energy to raise the gas pressure from that in the vent line to that necessary to pump the liquid.

The valving may be changed over from introducing gas into the chamber, to venting the chamber, by sensing the level of the liquid in the chamber. Essentially this will involve a high and/or low level sensor for the chamber. The sensors may be of any conventional type, such as distance or density sensors which are appropriately coupled to the chamber to detect the surface of the liquid or, possibly, a float which moves with the surface of the liquid. The sensors may operate the changeover valving either electrically, for example by solenoid operation, hydraulically or passively using pilot gas pressure. In order to increase throughput, and also to avoid discontinuous pumping of the liquid, a plurality of the chambers are preferably mounted in parallel between common source, feeder and gas supply and vent lines. Each chamber may operate independently, or in pairs, or as a train of the chambers or a set operating out of phase, i.e. some filling while others are emptying. This has the advantage that malfunction of one or one pair will not affect the other or others. However if their changeovers are all synchronized, a comparatively uniform flow along the feeder can be achieved.

The invention will now be described by way of example with reference to the accompanying drawings, in which:-

Figure 1 is a diagram illustrating the operation of the invention;

Figure 2 is a diagram showing a chamber with its circuit connections;

Figure 3 shows various possible uses of the invention in a subsea oil field;

Figure 4 is a diagrammatic vertical section through a well version of Figure 3;

Figure 5 is a diagram showing a development of the arrangement shown in Figure 2;

Figures 6a, 6b and 6c are to be read as connected in sequence (with slight overlap) one above the other with Figure 6a at the top, and together show in axial section a typical piece of equipment for putting the invention into effect downhole;

Figures 7a and 7b are axial sections through an inlet check valve shown in different operating positions;

Figures 8a and 8b are axial sections through an outlet check valve shown in different operating positions;

Figures 9a and 9b are axial sections through a low level float switch shown in different operating positions; and,

Figure 10 is an axial section through a high level shut off valve.

Figure 1 shows three pressure retaining vessels 5A, 5B and 5C, each having an internal chamber 5' and which may be considered either as the same vessel at a sequence of times in a pumping cycle, or as different vessels at different stages in the pumping cycle at the same time. The internal chamber 5' of each vessel is connected via an inlet valve 6 with a high pressure gas supply line 7, and via an outlet valve 8 with a low pressure gas vent line 9. At its lower end a chamber 5' of each vessel has an inlet, connected via a non-return inlet check valve 10 with a fluid supply line 11, and an outlet connected via a non return outlet check valve 12 with a feeder line 13. A float operated shut off valve 14 at the top of each vessel chamber 5' seals the chamber from the line 9 in the event of liquid 15 filling the chamber up to an unsafe upper level upon failure of a high level sensor to be described. Similarly, a float operated shut off valve 16 seals the outlet at the bottom of each chamber 5' from the feeder line 13, in the event of the liquid 15 in the chamber dropping to an unsafe lower level, in the event of failure of a low level sensor to be described.

As shown with respect to the vessel 5B in Figure 1, and to be described with reference to Figure 2, when the liquid in the chamber 5' has been almost completely displaced into the feeder line 13, the valve 6 is closed and the valve 8 is opened. The gas under pressure within the chamber 5' is therefore vented to the line 9, and, as the pressure drops below that in the supply line 11, fluid with a predominately liquid component 15 is free to enter the chamber 5' through the valve 10. This is shown with respect to the vessel 5C and continues until the liquid component 15 of the fluid substantially fills the chamber 5', whereupon the valves 6 and 8 are changed over again, the valve 6 being reopened and the valve 8 reclosed. Gas under pressure is then free to enter the chamber 5' from the line 7 to displace the liquid from the chamber 5' into the feeder line 13, and the cycle is repeated.

Figure 2 shows in more detail how the valves 6,8 in Figure 1 are changed over. Thus, as shown in Figure 2, the valves 6,8 for the vessel 5 are combined into a two position spool valve 68. In the upper position of the spool, as in Figure 2, the upper end of the chamber 5' is in communication with the high pressure gas supply line, while in the lower position, the upper end of the chamber 5' is in communication with the low pressure gas vent line 9. The spool is changed over between its upper and lower positions by pilot pressure applied to a piston and cylinder device 17. Both sides of the piston of which are connected via a duo-orifice bleed unit 18 and filter 19, to the line 7. The cylinder space of the device 17 above its piston is connected via a line 20 to a spool of a high level sensor in the form of an upper float operated pilot spool valve 21 and the cylinder of the device 17 below its piston is connected via a line 22 to a low level sensor in the form of a lower float operated pilot spool valve 23. The other side of each pilot valve 21 and 23 is connected by a line 24 to the gas vent line 9.

As shown in Figure 2, with the spool of the valve 68 in its upper position, high pressure gas from the line 7 will be applied to the top of the chamber 5' to pump the liquid 15 down out of the chamber. This corresponds to what is shown for the vessel 5A in Figure 1. During this operation, the float and spool of the valve 23 will remain in their upper position, thus isolating the line 22 from the line 24, and high pressure from the line 7 is then applied to the under side of the piston of the device 17, maintaining the spool of the valve 68 in its upper position. Only when the level of the liquid 15 drops to that of the valve 23 will its float and spool drop so that the pressure below the piston of the device 17 is vented via the lines 22 and 24 to the vent line 9. The spool of the valve 68 changes over as, with the spool of the pilot valve 21 in its lower position, the high pressure from the line 7 applied to above the piston of the device 17, will cause the piston and the spool of the valve 68 to move downwardly to the position in which the upper end of the chamber 5' is connected to the gas vent line 9. The events represented by the vessels 5B and 5C in Figure 1 will then take place, the chamber 5' filling with liquid from the supply line 11. As the liquid entering the chamber 5' rises to an upper level at which it passes the pilot valve 21, the float of that valve will cause its spool to rise so that the line 20 and upper side of the piston of the device 17 are vented to the gas vent line 9 via the line 24 and, with the spool of the pilot valve 23 in its upper position, the higher pressure applied to the underside of the piston of the device 17 will cause the piston of the device 17 to rise, together with the spool of the valve 68, so that the upper part of the chamber 5' is reconnected to the high pressure gas supply line 7 to restart the pumping cycle.

Figure 3 shows how the vessel of Figures 1 and 2 may be used in practice. The Figure suggests a subsea oil field with a subsea terrain 25, sea 26, and floating or fixed platforms 27 and 28. The compressor stations, at which the gas supply and vent lines 7 and 9 may terminate, may be provided at the platforms 27 and 28.

29 represents a water pump injection well through which water may be injected into the subsea oil reservoir 30. More usefully, for production, the pumping chambers will be mounted either within a subsea well 31, or in caissons 32, or in silos 33, which caissons and silos could be installed on the sea bed or on a template. In these latter cases, the chambers will be used for pumping, by means of the high pressure gas supply, production fluid liquid through an export line 34 to an export point, which may be at the platforms 27,28 or elsewhere.

When the chambers are used for pumping production fluid from downhole in a well 31, as shown schematically in Figure 4, there may be a number of the vessels 5 connected in a stacked formation one above the other in the well. They may be mounted within a production casing 35 so that production fluid from a reservoir 36, passing up through a tail pipe 37, sealed by a packer 38, may flow through ported tubing 39 to the annulus between the production casing 35 and vessels 5, exposed to inlets 40 of the individual vessel chambers. These chambers will have the appropriate valving, connecting them in parallel to the high pressure gas supply line 7, gas vent line 9, and production fluid export line 34.

The control principles described with reference to Figure 2 can be modified to control a unit of two vessels 5 operating out of phase in tandem, such that while one vessel is pumping, the other is filling. Such an arrangement is illustrated in Figure 5. It will be seen that the vessel 5A is connected in the liquid and gas circuits similarly to the vessel 5 in Figure 2, the only difference being that the upper spool valve 21 is now redundant. The second vessel 5C of the pair is similarly connected in the liquid and gas circuits, except that its spool valve 68A is a slave valve which responds to the outlet pressure from the master spool valve 68 of the vessel 5A. Thus when the valve 68 is transmitting the high pressure from the line 7, this is applied through a line 41 to the valve 68A, the spool of which rises against the action of a return spring 42. Conversely when the valve spool of the valve 68 is in its lower position, in which it is connected to the low pressure gas line 9, the pressure transmitted through the line 41 to the slave valve 68A results in the valve being pressure balanced which allows the spring 42 to move the spool downwards. It will therefore be appreciated that when the top of the vessel 5A is connected to the high pressure gas line 7, the vessel 5C is connected to the low pressure gas line 9, and vice versa.

In Figure 5, the vessel 5A is pumping out and this continues until the liquid level drops sufficiently to change over the valve 23 and hence also the valves 68 and 68A. If the chamber 5C should fill before the valve 23 of the vessel 5A has been actuated, the shut off valve 14 will close to prevent further filling of the chamber 5C. Although Figure 5 shows a tandem system using a low float operation, the system could be adapted to use a high float operation or a high-low cascade system for a train of chambers.

The manner in which this automatically operating double vessel unit can be put into practice downhole is shown in Figures 6 to 10. Figure 6 shows lower parts of a 9 5/8 inch casing 45, containing, as shown exploded, sections each consisting of 7 inch casing 46 fitted between upper and lower housings 87 and 88. As shown in Figures 6a and 6c, each section is connected by a screw threaded sleeve 89 and sealed to the adjacent section above and below with the aid of orientation pins and sockets 49,50. Each section contains a length of 3½ inch tubing 34 which terminates in the end housings 87 and 88 such that when the string of sections is made up at the surface prior to running in, the tubing of adjacent sections are interconnected by mating spigots and sockets 90,91 of the end housings. The space of erescent-shaped cross section within each section of casing 46 not occupied by the tubing 34 defines a closed chamber forming one of the chambers 5'. As many of the sections as necessary to handle the production flow will be provided and adjacent sections will operate in pairs to provide multiple tandem units substantially as described with reference to Figure 5. The gas lines 7,9 and the interconnections between the valves 23, 68, 68A will be provided within the chambers 5' and will be inserted into the string when it is made up.

The casing 45 corresponds to the production casing shown schematically at 35 in Figure 4. Thus in operation production fluid flows up through an annulus 51 between the casings 45 and 46 to an inlet 40 and hence through an inlet valve 10 to one of the chambers 5'. The annulus thus corresponds to the line 11 in Figure 5. As shown in Figure 7, the inlet valve 10 comprises a valve body 53 which is sealed in a mounting 54 of the tool section with the aid of a seal 55; and a valve cap 56 having apertures 58 interconnecting the interior of the valve body with the respective chamber 5'. There is an orifice plate 57 at the bottom of the valve body. Within the valve body is a vertically sliding closure member 59 cooperating with a seating 60 in the valve body, and oriented by anti-rotation pins 61.

During a filling part of the cycle in which production fluid is flowing into the chamber 5', the valve closure member 59 will be raised to open the valve, as shown in Figure 7b. During the alternate pumping part of the cycle, when the pressure within the chamber 5' is greater than the production fluid supply pressure, the valve element 59 will be forced downwardly to close the valve as shown in Figure 7a.

As shown in Figure 6, above the valve 10 is to be found the outlet valve 12 which is shown in more detail in Figure 8. The valve 12 has a body 61 which is secured to the outside of the tubing 34 within the chamber 5' and has at its bottom an orifice plate 63, at its top a cap 64 and in its side wall an aperture 65 leading to within the tubing 34, which corresponds to the feeder line 13 in Figure 5. Within this valve body is another vertically slidable closure member 66 which cooperates with a valve seating 67. During the filling part of the cycle, the differential pressure across the valve 12 causes the valve closure member to move to its lower position and close the valve as shown in Figure 8a. Conversely, during the alternate part of the cycle, when the liquid is being pumped out of the chamber 5', the differential pressure across the valve closure member causes it to rise and open the valve as shown in Figure 8b.

Above the valve 12 in the tool string section is to be found the float operated pilot spool valve 23 which is shown in detail in Figure 9 and which consists of a cylinder housing 70 having a vent hole 74 at its upper end and to the lower end of which is secured a float guide 71 containing a float 72. The housing 70 is formed with upper and lower annular grooves 73 which lead at one annular position to respective ports effectively forming the ends of the control lines 22 and 24. A piston 75, which is raised and lowered by the float 72, controls the interconnection between the grooves 73 such that when the float and piston are in their lower position as shown in Figure 9a, the lines 22 and 24 are interconnected, and when the float and piston are in their raised position as shown in Figure 9b, the grooves 73 are isolated from one another and hence the lines 22 and 24 are isolated from one another. The valve is pressure balanced, so that it is only operated by float movement, because an auxiliary piston 92, connected to the main piston 75 by a stem 93, works in an upper part of the cylinder housing 70. The high pressure gas acts with equal face on the top of the main piston 75 and on the underside of the auxiliary piston 92.

Above the valve 23 the tool string section incorporates the high level shut off valve 14 which is shown in more detail in Figure 10. This is connected to the bottom of the changeover spool valve 68,68A and consists of a housing 76 forming a float tube, and containing a float 77 which operates via a push rod 78 on a valve closure member 79 having a lip seal 80 which cooperates with an annular seating 81 at the bottom of the spool valve 68. At the bottom of the housing 76 there is a travel stop 82, a spring 83 and a float orifice damper 84. A vent hole 85 is provided in the side of the housing. In the event of production fluid in the chamber 5 rising high enough to pass through the orifice 84 and raise the float 77, the closure element 79 will be raised to engage the seating 81 and close the connection to the gas lines. During reverse, high pressure gas flow through the valve and into the chamber 5', the closure member 79 is forced downwards and the gas flows out through apertures 85 and a knitmesh diffuser 86.

The high and low pressure gas lines are thus accommodated within the inner casing string 46 and these are the only external connections which are necessary in order for the production liquid to be pumped gently and substantially continually and alternately from the chambers of a tandem unit of two elements up through the tubing 34. No controls or signals therefore need to be sent downhole, other than those resulting from controlling above the well the high and low gas pressures. Control is otherwise entirely automatic as this is effected by the gas pilot system switched by the fluid level sensing.

It will be appreciated that the tubing sections provide an uninterrupted passage for wireline operations below the pumping chambers, for example for logging or zone isolation operations. The bottom of the bottom section of tubing would then be provided with a wireline set plug which could be removed and replaced by a seal such as a stuffing box to enable wireline operations during pumping.

Claims

1. A method of pumping a liquid from a source to a destination, the method comprising providing at least one chamber (5') connected via valving (10) with a supply (11) at a first pressure, from the source, of a fluid of which the liquid forms at least a part, the chamber having its lower part connected via valving (12) with a feeder (13) for at least the liquid component of the fluid to the destination, and the chamber having its upper part connected by a valving (6,8) with both a high pressure gas supply line (7) at a second pressure greater than the first pressure and with a low pressure gas vent line (9) at a third pressure less than the first pressure; and alternately introducing gas from the gas supply line into the chamber to displace the liquid component of the fluid from the chamber into the feeder, and venting the chamber to the gas vent line whilst allowing the fluid to enter the chamber from the supply.

2. A method according to claim 1, in which the fluid is water and the destination is an oil reservoir.

3. A method according to claim 1, in which the fluid is production fluid from an oil well and the destination is an export point.

4. A method according to claim 3, wherein a preliminary separation of gaseous and liquid components of the production fluid is achieved by allowing gas which is released from the production fluid to exit the chamber (5') into the gas vent line (9) during filling of the chamber from the supply (11).

5. A method according to any one of the preceding claims, in which the chamber is positioned adjacent to or below the mudline in a subsea oilfield and the gas supply and vent lines lead respectively from and to a station (27,28) at or adjacent to the surface.

6. A method according to claim 5 when dependent on claim 3 or claim 4, in which the chamber is positioned down an oil well (31).

7. A method according to any one of the preceding claims, in which the valving may be changed over from introducing gas into the chamber to venting the chamber and vice versa by sensing the level of the liquid in the chamber.

8. A method according to claim 7, wherein upper and lower levels are sensed by floats which operated pilot valves (21,23) controlling the valving (6,8) between the upper part of the chamber (5') and the gas supply and vent lines (7,9).

9. A method according to any one of the preceding claims, in which a plurality of the chambers are mounted in parallel between common source, feeder and gas supply and vent lines.

10. A method according to claim 9, in which the changeovers at the chambers are synchronized with one another.

Fig.1.

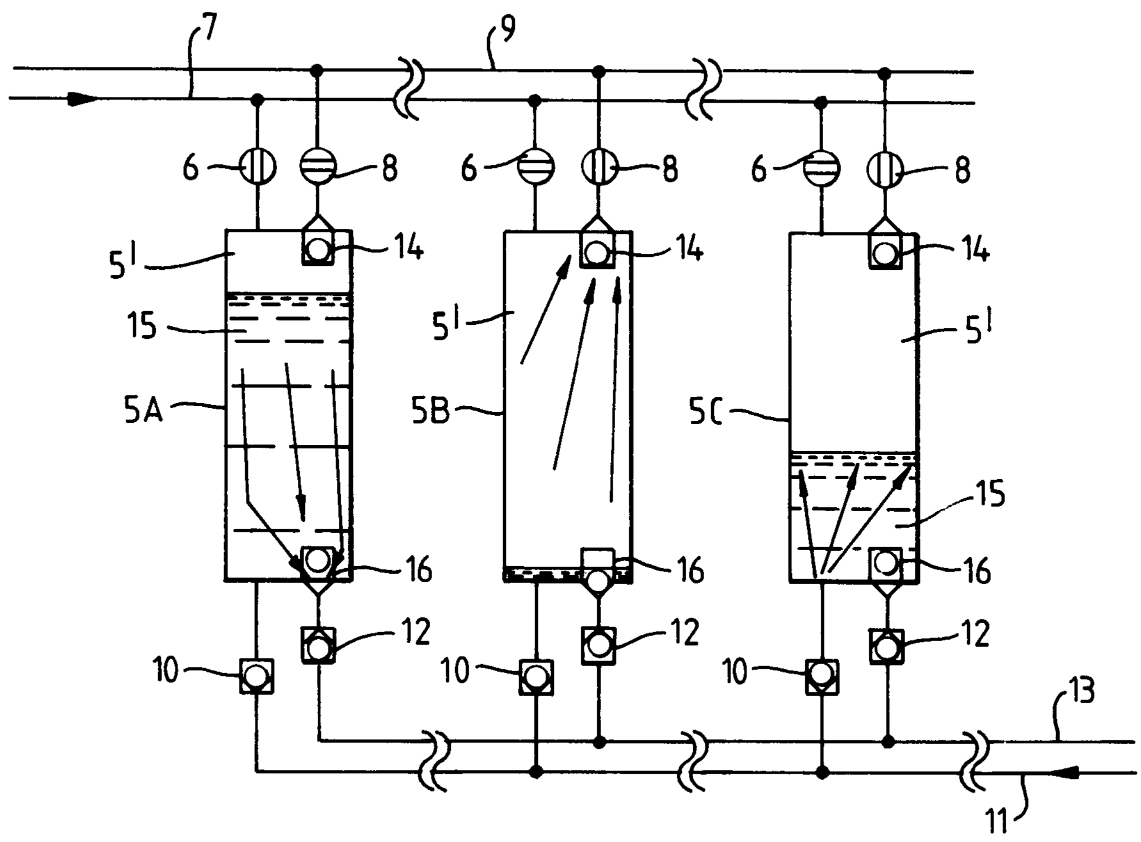
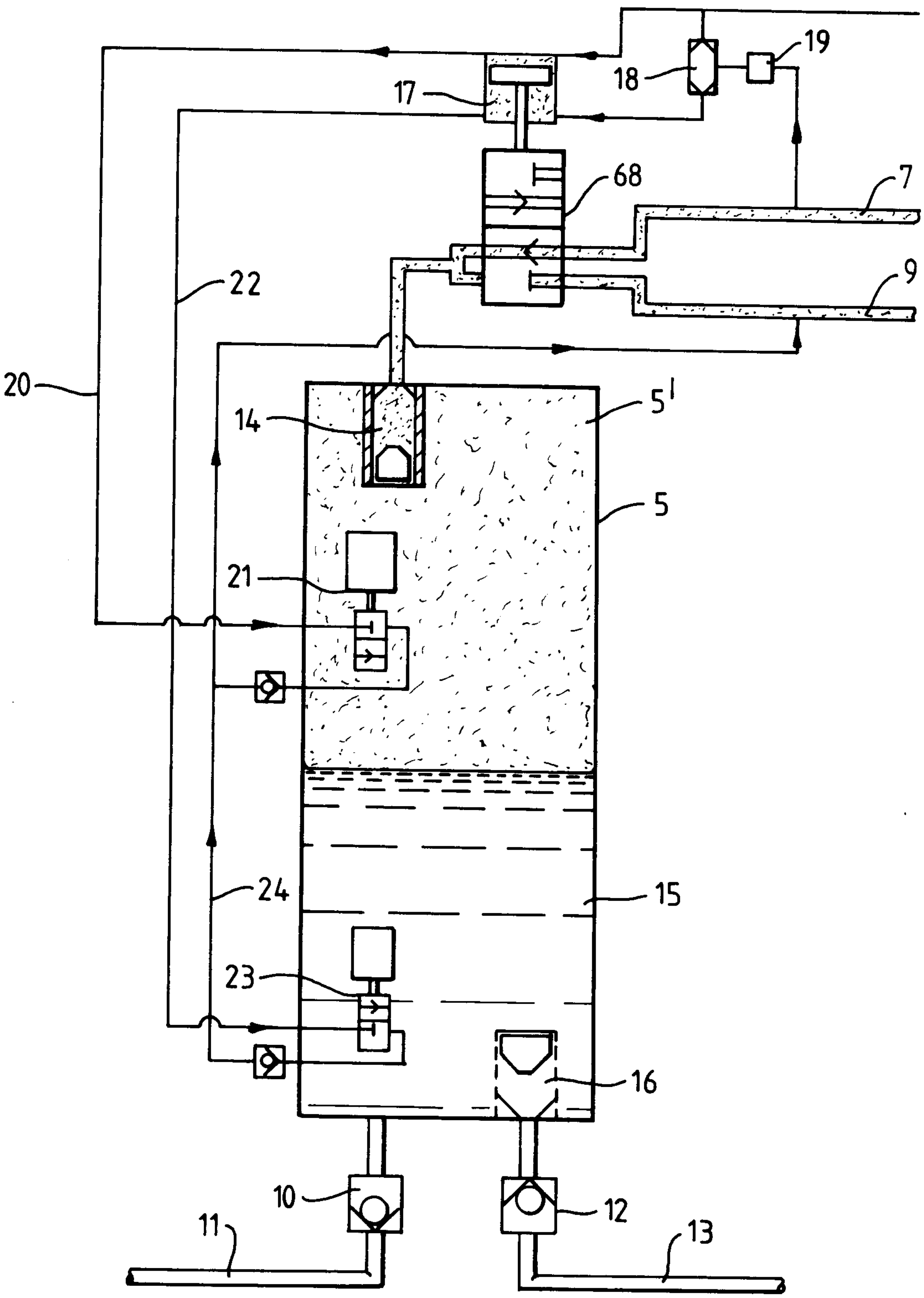


Fig. 2.



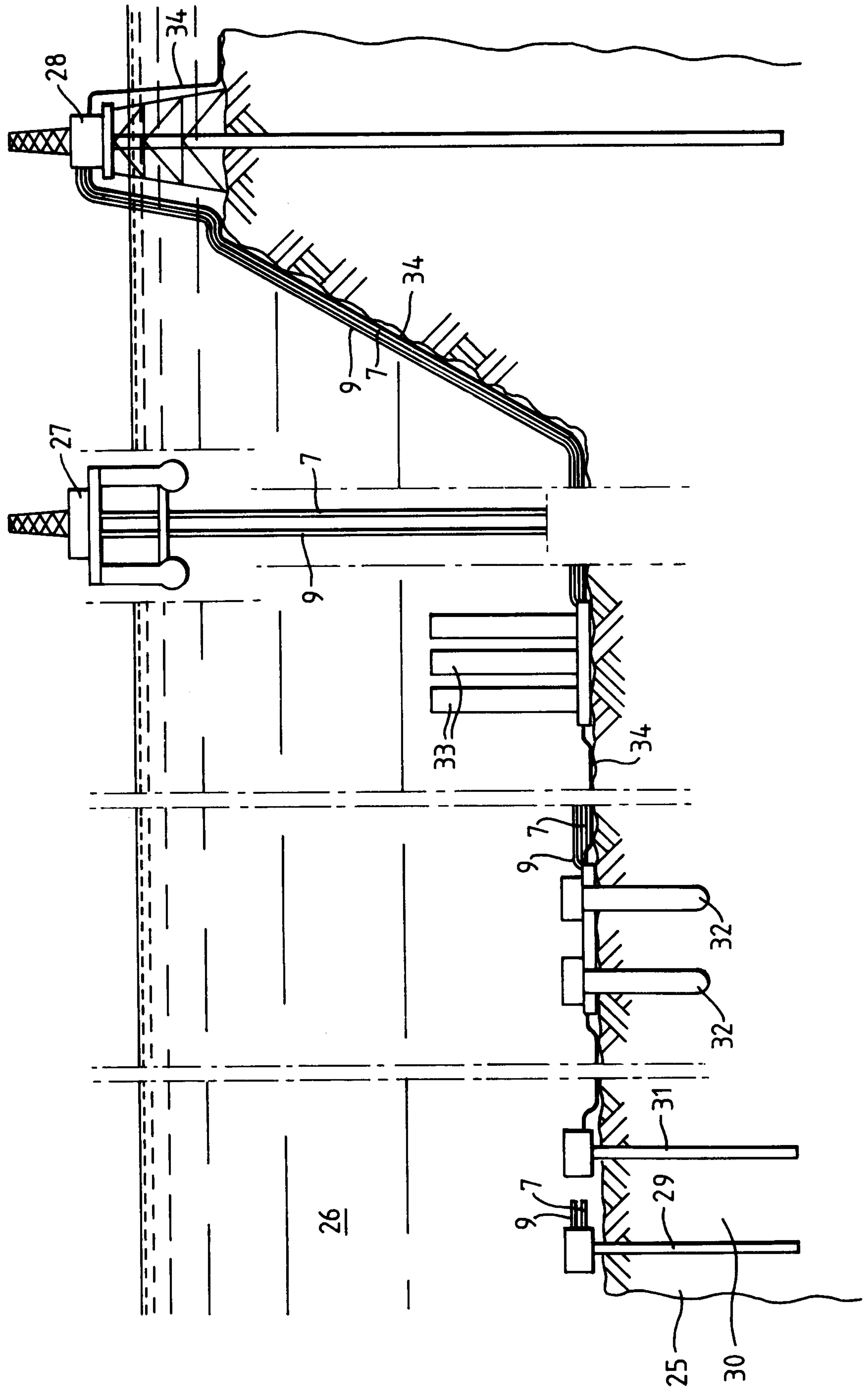


Fig.3.

Fig. 4.

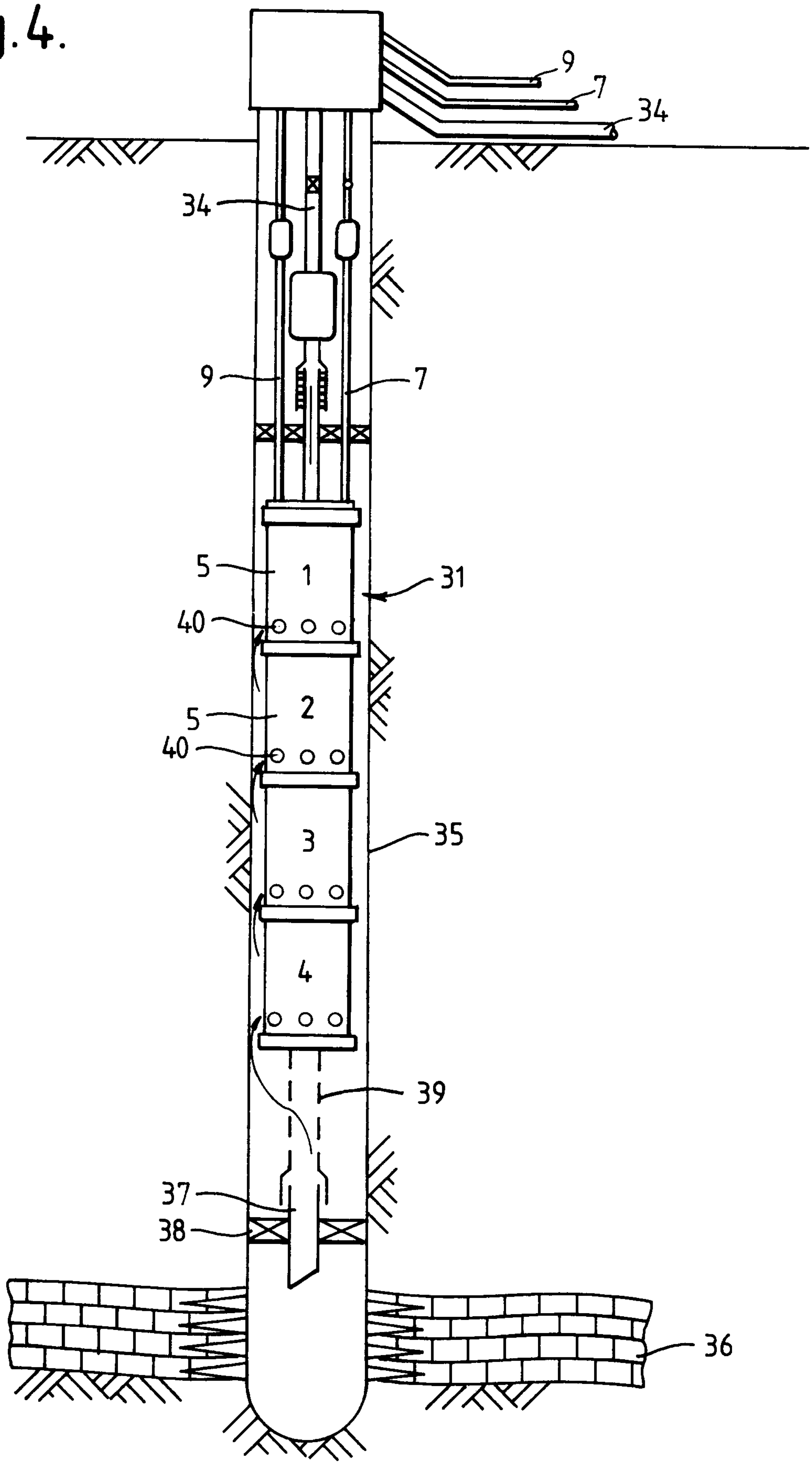


Fig.5.

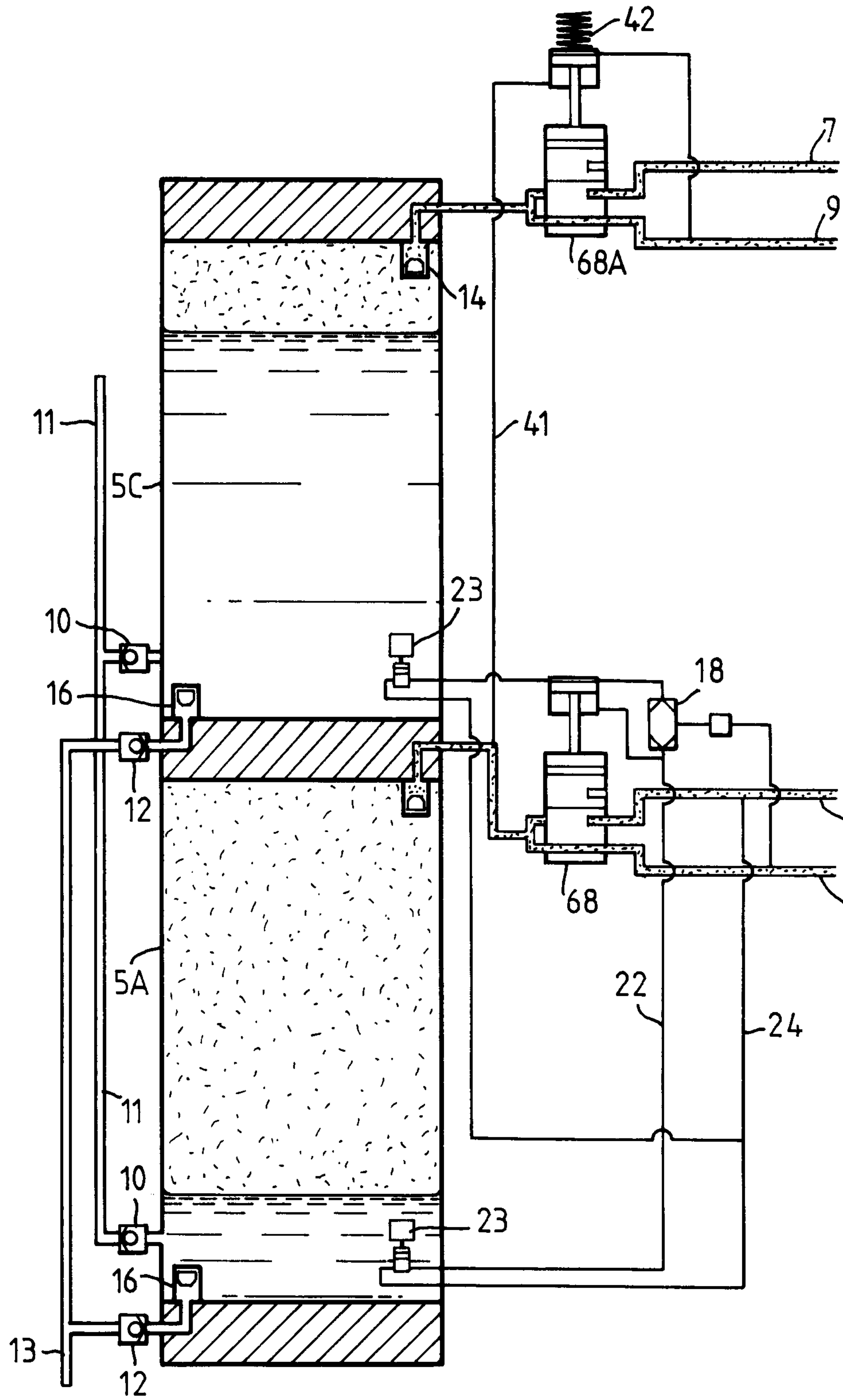


Fig.6a.

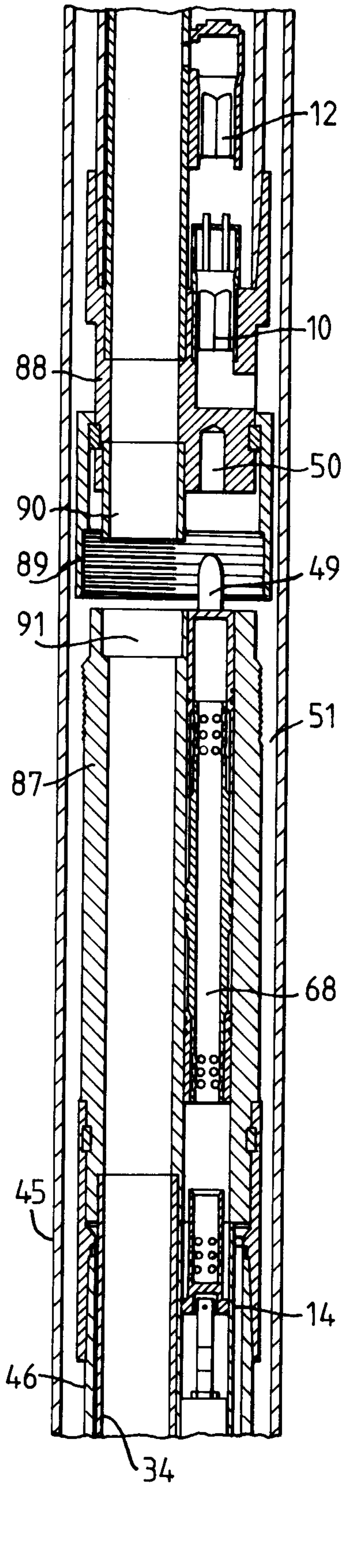


Fig.6b.

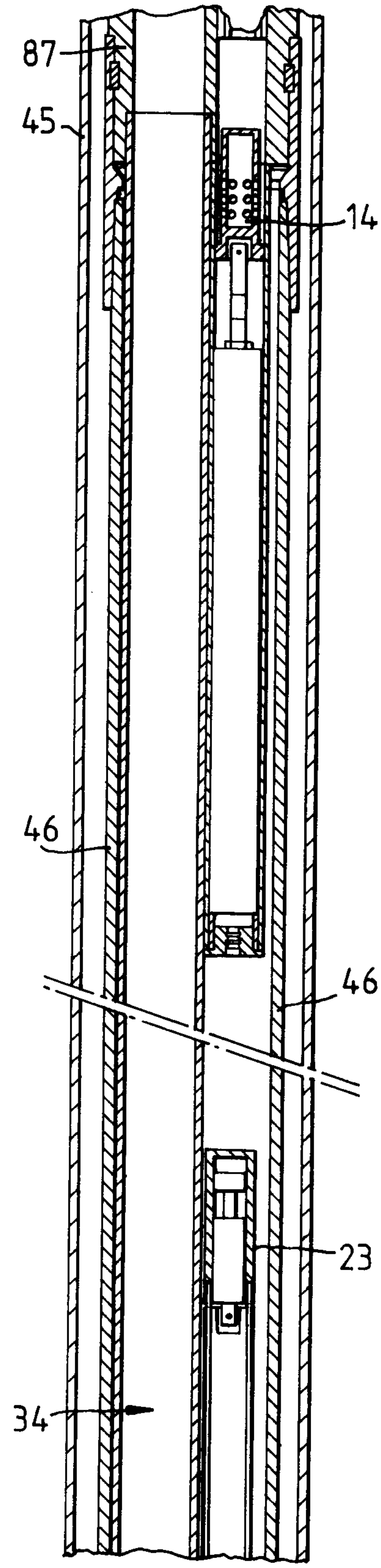


Fig. 6c.

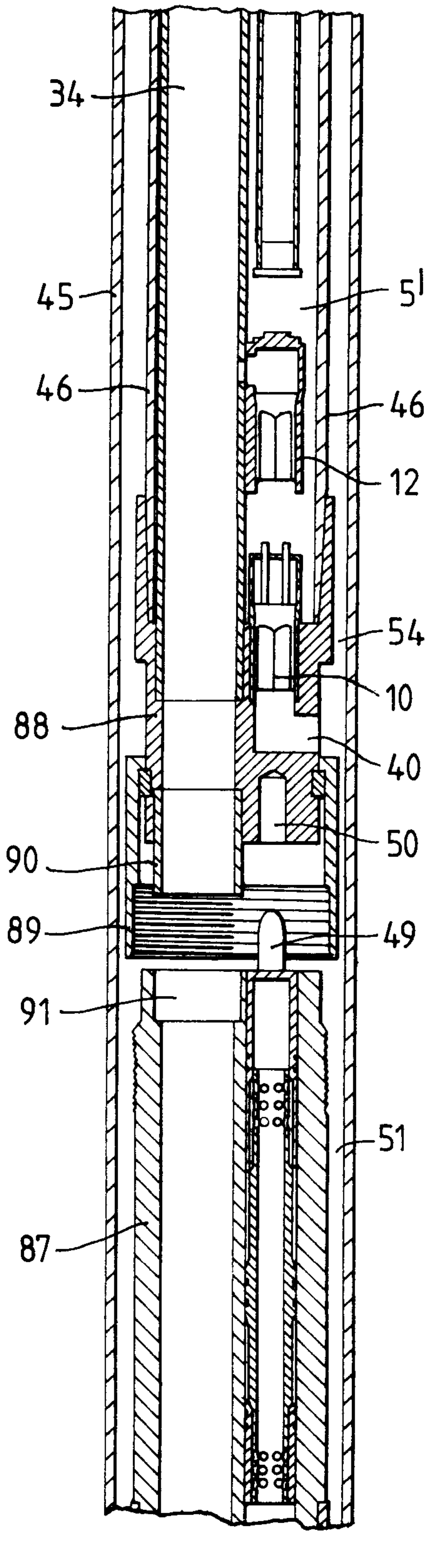


Fig. 7a.

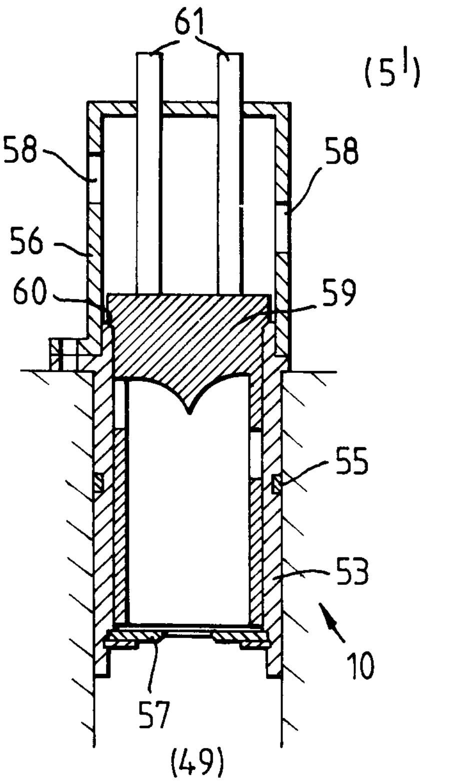


Fig. 7b.

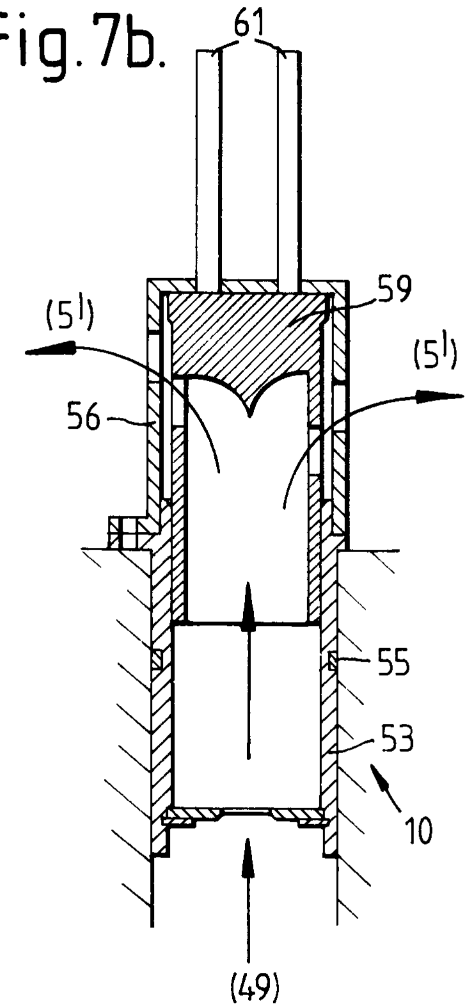


Fig. 8a.

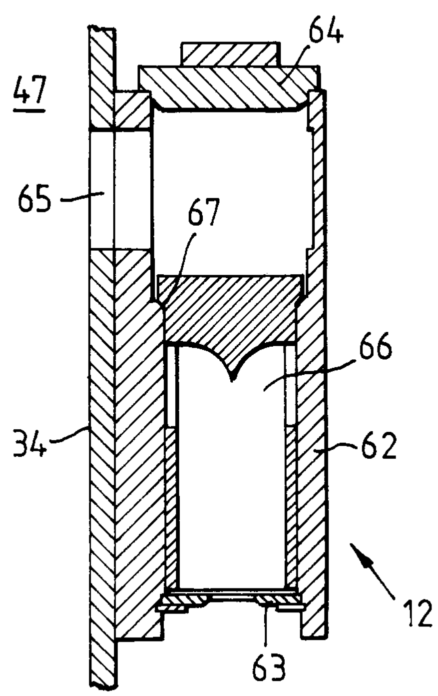


Fig. 8b.

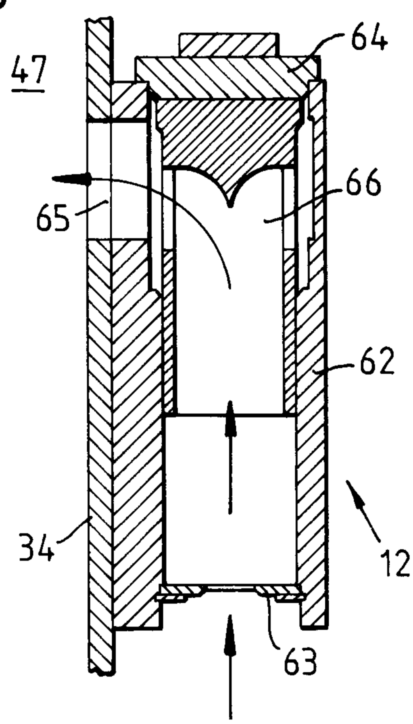


Fig. 9a.

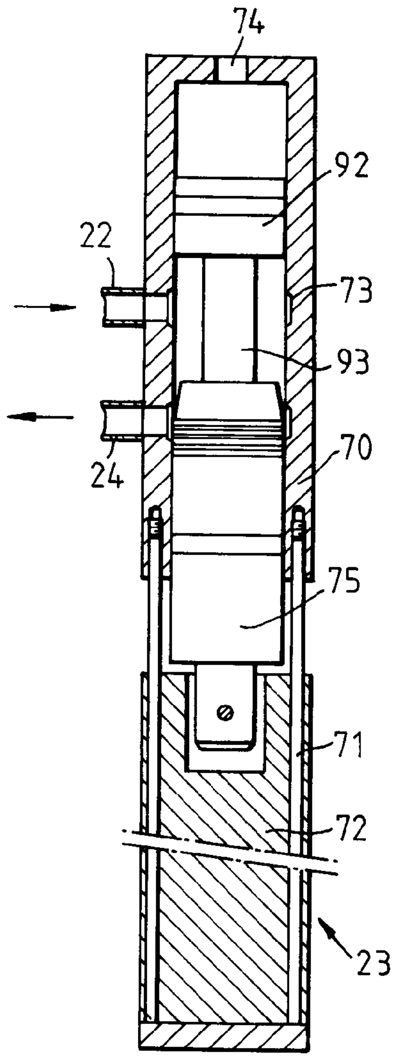


Fig. 9b.

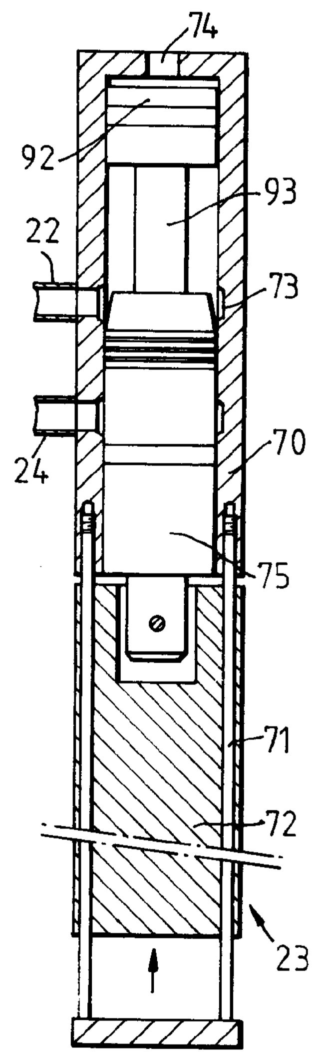
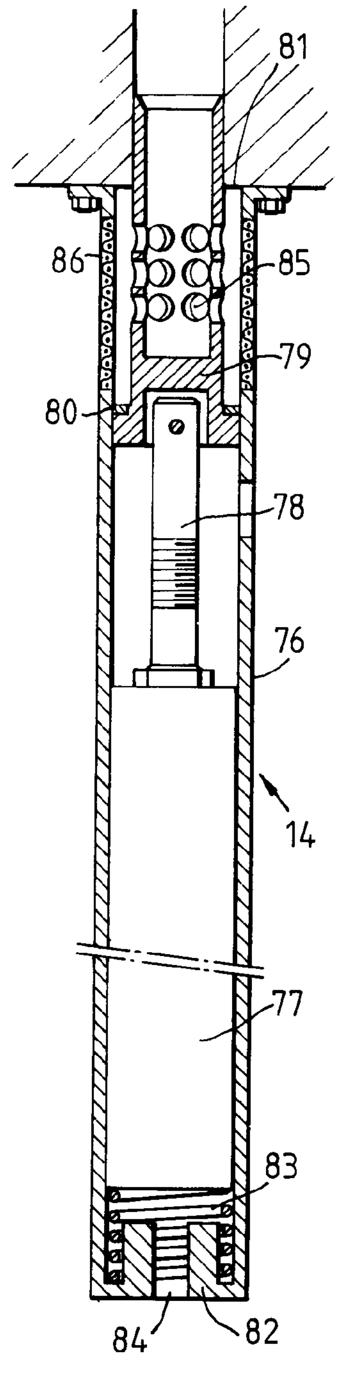


Fig. 10.



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 93 30 5563

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	US-A-3 486 297 (S.EISINGA ET AL.)	1,3,4, 7-10	E21B43/36 E21B43/38 E21B43/00 F17D1/12
	* column 3, line 1 - line 33 *		
A		2	
X	US-A-3 221 816 (H.L.SHATTO ET AL.)	1,3,7,9, 10	
	* column 5, line 15 - line 73; figure 8 *		
A		2	
A	GB-A-2 224 220 (AKER ENGINEERING A/S) * the whole document *	1,4,5	
A	US-A-4 761 225 (M.K.BRESLIN) * abstract *	1	
A	US-A-2 261 100 (R.W.ERWIN) * page 1, left column, line 13 - line 19 *	2	
A	GB-A-2 242 373 (BRITISH OFFSHORE ENG.TECHN.LTD.) * page 3, line 12 - line 28 *	4,5	TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			E21B F17D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	21 OCTOBER 1993	RAMPELMANN K.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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