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(71) Applicant: **BP EXPLORATION OPERATING COMPANY LIMITED**
Sunbury-on-Thames, Middlesex TW16 7BP (GB)

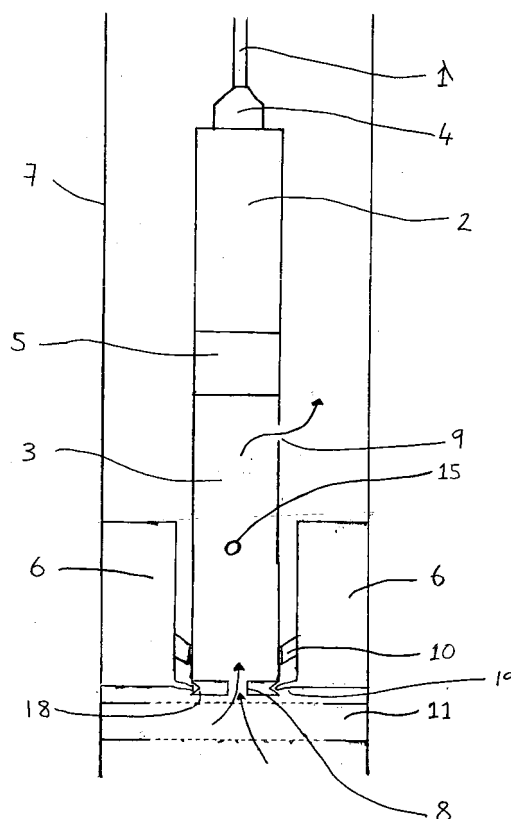
(72) Inventor: **The designation of the inventor has not yet been filed**

(74) Representative: **Ford, Louise Diane et al**
Global Patents & Technology Law (Central)
BP International Limited
1st Floor, Building 200
Chertsey Road
Sunbury-on-Thames, Middlesex TW16 7LN (GB)

(54) **Submersible pump assembly**

(57) An electric submersible pump assembly and method for artificially lifting fluid from a well bore to the surface. The assembly comprises a positive displacement pump (3), a motor (2) for driving the pump and an electro-mechanical cable (1), the electro-mechanical cable being capable of suspending the pump and motor in a well bore and of supplying electrical power to the motor. The motor is preferably a permanent magnet motor, and the pump is preferably a twin-screw pump.

Figure 1



Description

[0001] The present invention relates to a submersible pump assembly. Submersible pump assemblies are used widely to artificially lift fluids from well bores where the well bore pressure is insufficient to lift the fluids to the surface without assistance. Without such assistance, the production rate of a well will fall and ultimately the well will die.

[0002] A common submersible pump assembly includes a centrifugal pump powered by an induction motor, the assembly being attached to and carried on the lower end of the production tubing in the well bore. The motor is powered by way of an electrical cable extending along and attached to the external surface of the production tubing.

[0003] However, deployment of this system is cumbersome since the electrical cable must be fed out and clipped to the production tubing as the tubing is arranged for lowering into the well. Further, the motor and pump have a limited lifetime and must be replaced from time to time. To do this, the production tubing carrying the apparatus must be withdrawn in order to replace the broken piece of equipment. Not only is this very costly as a workover rig must be used, but this also takes a long time.

[0004] Other systems, such as that described in US 6415869, involve installing a production tubing in a well bore, the production tubing being provided near its lower end with an electrical connection (a wet connect). An electrical cable is coupled to the external surface of the production tubing during deployment of the tubing and extends from the electrical connection to the surface. A pump and motor assembly, which is provided with another electrical connection, is then lowered through the production tubing on a wire. When the motor and pump assembly reaches the desired position in the production tubing, the electrical connection on the production tubing engages the electrical connection on the motor and pump assembly. In this way, the motor can be powered from the surface. This system has the advantage that the motor and pump can be withdrawn from the well bore without having to withdraw the production tubing. However, the same problem mentioned above of clipping the electrical cable to the production tubing is also encountered in this system. Further, the electrical connections on the production tubing and motor and pump assembly are prone to failure and so can still necessitate the removal of the production tubing.

[0005] Accordingly, the current methods of deploying and maintaining an electrical submersible pump assembly are cumbersome and require the use of a workover rig, making the operation time consuming and costly.

[0006] Further, as mentioned above, typical submersible pump assemblies use induction motors. Induction motors tend to have a short, wide construction. This, however, cannot be accommodated in the narrow bore of the well casing, production tubing or well bore. Accordingly, the design of the induction motor has to be compromised

in order to fit the motor into the well casing or production tubing. This results in the motor being relatively long and thin. These design compromises make the induction motors less reliable and therefore more susceptible to failure, increasing the frequency of workovers needed to replace the failed equipment. Additionally, induction motors are inefficient since the generation of the magnetic flux in the rotor results in energy losses.

[0007] Another significant drawback of typical submersible pump assemblies is their inability to handle multiphase fluids, such as fluids with a high gas to liquid ratio. Impellers of a centrifugal pump preferentially accelerate liquids, leaving gas to accumulate around the impeller hub, thereby reducing its ability to pump further liquid. Accordingly, such pumps are unsuitable for use in environments where there is a high gas to liquid ratio. In addition, many pumping stages are required in order to generate high pressures using a centrifugal pump. This means that the pump must sometimes be exceptionally long, causing difficulties in handling the assembly and introducing/withdrawing the assembly into/from a well bore.

[0008] Some steps have been taken to try to improve submersible pump assemblies. For example, US 3411454 relates to a pump installation in which an electric pump is suspended in a well casing from a wire-line. The patent teaches a mechanical system for securing the pump in the well. The system is activated when the pump has built up sufficient pressure in the well above. Expandable slips engage the casing so that the casing can support the weight of the pump and the weight of the fluid column above the pump, thereby relieving longitudinal stress on the cable. However, this system has not been taken up in the industry. One problem with this system is that until the pressure required to activate the expandable slips is reached, the pump is not restrained and so the torque load is not resisted and the assembly will spin. As the pump is started and stopped periodically, the cable is torqued up and released which can wear/damage the cable and/or the seals between the pump and the well casing.

[0009] WO 2004/113670 describes a method of pumping well bore fluids comprising the steps of installing an electric submersible pump in a well bore and operating the pump at more than 4500 rpm to pump the well bore fluid. A permanent magnet motor can be used. However, high operation speeds such as this introduce problems such as increased frictional losses and mechanical wear, particularly since well fluids often contain small solid particles.

[0010] US 6413065 describes a modular downhole pump including a gear module for transferring power to the pump from a sucker rod or a downhole motor and a rotor module. The rotor module includes a pair of counter-rotating, interleaved rotors split into an upper pair and a lower pair which pump fluids in opposite directions within the rotor module. The rotor modules may be configured to increase the pressure capacity or the volume capacity

of the pump and may be connected in series to achieve a desired volume and pressure output.

[0011] Although some of these efforts to improve submersible pump assemblies may suggest some benefit, some of them have introduced different problems. Further, none of the proposals provide a system which could efficiently and reliably pump well fluids to the surface without any of the above-mentioned problems.

[0012] There are currently many hundreds, if not thousands of wells worldwide which are either no longer producing or producing at a less than optimum rate. There is therefore a great need for a system which is reliable, efficient, easy to install and maintain and which can be used in a wide variety of wells, thereby enabling the wells to be brought back into use or have their efficiency increased.

[0013] According to a first aspect of the present invention, an electric submersible pump assembly for artificially lifting fluid from a well bore to the surface comprises a positive displacement pump, a motor for driving the pump and an electro-mechanical cable, the electro-mechanical cable being capable of suspending the pump and motor in a well bore and of supplying electrical power to the motor. In a preferred embodiment, the motor can be a permanent magnet motor. The positive displacement pump can be a progressing cavity pump although it is preferred that a rotary positive displacement pump such as a screw type positive displacement pump is used, for example a twin screw pump.

[0014] The invention solves the problems encountered in using typical submersible pump assemblies. Suspending the pump and motor on an electro-mechanical cable allows the pump and motor to be deployed and raised to the surface as necessary without the need for a drilling or work over rig. This reduces the total repair time from weeks to days compared with assemblies which use rigid or coiled tubing to deploy the pump and motor, whilst simultaneously significantly reducing the cost.

[0015] There are particular advantages achieved by using the positive displacement pump and the permanent magnet motor together. For example, it is beneficial to be able to pump fluids which have a high proportion of gas as well as more viscous fluids, since only one type of assembly is required for any well type, resulting in economies in engineering effort and inventory holding etc. While positive displacement pumps are able to efficiently pump fluids with a high gas level, the fluid is less able to cool the pumping assembly than fluids with low gas levels. However, by using a permanent magnet motor together with the positive displacement pump, less waste heat is generated by the assembly and so the assembly can be used for high gas to liquid ratio fluids without significant risk of overheating.

[0016] Also, an assembly having a positive displacement pump and a permanent magnet motor is very much shorter than conventional assemblies using induction motors or centrifugal pumps. The permanent magnet motor can be significantly shorter than an induction motor,

whilst achieving the same power output. In contrast to centrifugal pumps, a positive displacement pump transports a fluid from the intake to the discharge at uniform velocity and the resulting pressure is determined by internal pump leakage, not by the number of pumping stages. Thus the pump can be much shorter. The ability to significantly reduce the length of the assembly allows low cost intervention into both dry tree and subsea wells. To date, intervention into live wells through the use of a lubricator and pressure control equipment has not been possible for electrical submersible pump assemblies due to the length of the assemblies. However, such interventions are now advantageously possible with the present invention.

[0017] The pump assembly of the present invention can pump a broad range of fluid types, from viscous heavy oils, to gas with traces of condensate and/or water. The use of a twin screw pump in particular enables the assembly to be used in environments where there is a high gas to liquid ratio since it does not suffer the same problems as centrifugal pumps. Although a twin screw pump does accelerate liquid to the extremities of each screw, the liquid then forms a viscous seal with the other screw or the housing, allowing gas to be efficiently transported to the discharge.

[0018] The use of a positive displacement pump in the invention can allow a sub-surface safety valve to be omitted from situations where one would otherwise be necessary. This is because there is no flow path through the pump when it is stationary.

[0019] The invention finds particular success in subsea wells. The requirement for regular interventions to repair or service conventional pumping assemblies renders use of such conventional electric submersible pumping assemblies unsuitable for subsea wells. Instead, subsea wells are often produced under gas lift, but this is inefficient and expensive to operate, and can result in considerable volumes of oil being left unrecovered. The present invention has improved reliability and also does not require large equipment such as semi-submersible drilling rigs to conduct servicing or repair of the assembly. The invention therefore opens up the use of electric submersible pumping assemblies to subsea wells.

[0020] The electro-mechanical cable can be provided with a connector for coupling the pump and motor to the cable. In a preferred embodiment, the motor is coupled between the electro-mechanical cable and the pump. The motor can be provided with a connector for this purpose. This has the advantage that the electrical conductor(s) in the electromechanical cable can be connected directly to the motor and need not be arranged to pass through or around the pump. Thus this arrangement is more reliable than known systems which arrange the pump between the motor and the coiled tubing or wire, and is also shorter than known systems which arrange the motor between the coiled tubing and the pump as those systems require a sealing unit between the motor

and pump as well as a thrust bearing unit below the pump, which is not required with the positive displacement pump.

[0021] The electro-mechanical cable preferably comprises a core, having at least one electrical conductor, and an outer sheath around the core capable of supporting the weight of the cable as well as the weight of the motor and the pump. The electrical conductor can be a copper wire or a group of copper wires. There can be a single conductor, for example for powering a single phase motor or there can be three conductors for powering a three-phase motor. One or more conductors/wires for transmitting data and/or control instructions can also be included in the core.

[0022] The outer sheath may include one or two layers of spiral wound wires, preferably steel armour wires. Where two layers are used, the layers are advantageously contra wound. This can balance torque under an applied tensile load. The wires of the outer layer may have a smaller diameter than the wires of the inner layer. This further balances the torque.

[0023] Optionally, the electro-mechanical cable further comprises a conduit for transmitting a fluid along the cable. The conduit can extend through the core of the cable. In use, the pump outlet can be in communication with the conduit for discharging fluid directly into the conduit. This can be advantageous when the assembly is used as a vertical separator as described below.

[0024] The motor is preferably a permanent magnet motor. It can be a DC motor or an AC motor, for example a single phase or three-phase AC motor. DC motors are beneficial since they can provide high starting torque which has been found to be useful for powering positive displacement pumps, particularly in a well that produces solids (e.g. sand particles). Although DC motors can require more servicing than AC motors, the invention allows for easy removal of the motor from the well for servicing, and the advantages of high starting torque outweigh the risk of possible increased servicing. DC motors and single phase AC motors have been found to be advantageous since the electro-mechanical cable can be narrower as only a single conductor is required. This is beneficial both because the cable can be lighter and also since sealing around a narrow cable is easier.

[0025] Preferably, the assembly further includes a packer which can be positioned in a well, for example it can be mountable on the casing or on the production tubing of a well. By providing the packer on the casing or production tubing, the motor and pump can be lowered or raised independently of the packer. The packer is engageable with the pump or the motor, or an element associated with the pump or motor, to hold the pump and motor at a desired location in the well. The packer may be sealingly engageable with the pump or motor, or an element associated with the pump or motor, so as to seal a region of the well below the packer from a region of the well above the packer.

[0026] Preferably, the pump, the motor and/or an ele-

ment associated with the pump or the motor, is provided with first engaging means for coupling to second engaging means provided on the packer.

[0027] The engaging means may comprise torque resisting means. The first engaging means can engage the second engaging means when the pump and motor are lowered to the desired position in the well. The torque resisting means prevent the pump and motor rotating with respect to the packer, for example when the pump and motor are activated. This prevents twisting of the electro-mechanical cable.

[0028] In one embodiment, one of the first and second engaging means may comprise one or more projections such as pins or ribs. The other engaging means may comprise one or more recesses such as slots into which said projection can extend to prevent rotational movement of the pump and motor with respect to the packer.

[0029] Optionally, said recess may further be provided with a cammed surface for guiding said projection into said recess. In this way, the motor and pump can be circumferentially aligned with the packer as it is lowered.

[0030] Alternatively or in addition, the first engaging means may comprise axial movement resisting means which can engage the packer so as to resist axial separation of the pump and motor from the packer. The axial direction is taken to be along the length of the local well bore. The second engaging means of the packer may include means which co-operate with the axial movement resisting means of the first engaging means. For example, one of the first or second engaging means may include one or more projections such as fingers, clips or flanges for engaging one or more corresponding recesses on the other of the pump and the packer, such that axial movement of the projection out of the recess is resisted.

[0031] In preferred embodiments, the first and second engaging means include torque resisting means and axial movement resisting means. This allows the pump and motor to be accurately and securely held in a desired position in the well.

[0032] In a preferred embodiment, the assembly further comprises a valve having an open condition and a closed condition, the valve being in the open condition when the pump is coupled to the packer or when the pump is in operation and the valve moving from the open condition to the closed condition when the pump stops operating or is separated from the packer. Accordingly, turning the pump off or removing the pump from the packer automatically closes the valve. Not only does this reduce the need for well kill when the pump assembly is removed from the well, but the valve moves between open and closed positions only as necessary and is not, therefore, subjected to unnecessary usage and wear. The valve may be a one way valve. The valve can be removable so that it could be replaced if it leaks.

[0033] According to a second aspect of the invention, a method of pumping fluids from a well to a surface comprises the steps of:

providing an electro-mechanical cable capable of suspending a positive displacement pump and a motor in a well bore and of supplying electrical power to such a motor;

coupling a positive displacement pump and a motor to the electro-mechanical cable; deploying the electro-mechanical cable with the motor and pump suspended therefrom into a well bore and lowering the motor and pump to a desired location;

activating the motor and therefore the pump so as to pump a fluid up the well bore.

[0034] Accordingly, the method of the invention does not require a drilling or work over rig to deploy or retrieve the motor and pump.

[0035] The method can further comprise positioning a packer in the desired location in the well bore before the electro-mechanical cable, motor and pump are deployed. The motor and pump are lowered until the pump is located in the packer.

[0036] The cable, motor and pump can form an electrical submersible pump assembly having any of the features of the assembly described above in connection with the first aspect of the invention.

[0037] In one embodiment, the cable, motor and pump are deployed and lowered into a production tubing located in the well bore, the production tubing carrying on its lower end a submersible pump assembly which has failed. In this way, the invention can be used to put wells back into operation after a conventional pump assembly already located at the end of the production tubing has failed, without requiring the withdrawal of the production tubing. Where the failed submersible pump assembly allows fluid to flow there-through, such as one comprising a centrifugal pump, the assembly of the invention can simply be lowered down the production tubing. Where the failed pump assembly does not allow the passage of fluid unless it is turned on, a fluid passage can be created to allow fluid to flow despite the failed pump. For example, a hole can be punched in the production tubing above the failed pump.

[0038] In another embodiment, the well is a gas well and the cable, motor and pump are deployed and lowered into a production tubing located in the gas well until the inlet of the pump is located below the end of the production tubing. Liquid is allowed to collect at the base of the gas well in the region of the pump inlet, and the pump is activated so as to pump the liquid out of the well. The liquid may be pumped up the production tubing, as described above, while the gas is allowed to flow between the production tubing and a casing lining the well bore. Alternatively, the cable may be provided with a conduit extending there-through which is suitable for conducting fluids, especially liquids. When the motor and pump are suspended on the cable, the discharge of the pump is in communication with the conduit for discharging fluids directly into the conduit. Accordingly, liquid can be pumped out of the well through the fluid conduit of the electro-

mechanical cable, while gas flows up the production tubing.

[0039] Thus the invention can advantageously avoid reduced production or killing of gas wells by water accumulation. Liquid, such as water, can be pumped up through the cable or the production tubing and out of the well, whilst not restricting the gas flowing respectively up the production tubing or the annulus between the production tubing and the casing.

[0040] It is to be understood that some gas may also be drawn into the pump in this embodiment along with the liquid. However, the invention has been found to be particularly advantageous in this embodiment since the positive displacement pump can transmit fluids having a high gas to liquid ratio through the pump and up the conduit in the cable. In contrast, earlier attempts have failed since centrifugal pumps tend to 'gas lock' at the high gas to liquid ratios encountered in a gas de-liquification application.

[0041] The pump may be operated continuously, for example in gas wells which continuously produce liquid. Alternatively, the pump could be controlled to operate on demand when a predetermined level of liquid has accumulated or at the start of production.

[0042] In this embodiment, a packer may be provided generally as described above, so as to prevent the pump assembly rotating. Where gas is allowed to flow up the production tubing, the pump does not form a seal with the packer. Instead, the engagement between the pump and the packer allows gas to flow between the pump and the packer and up the production tubing. Where gas is allowed to flow up the annulus between the production tubing and the casing, the pump can form a seal with the packer.

[0043] In an alternative to using a packer, when making a new well a nipple profile can be provided at the lower end of the production tubing such that, at some point in the future if de-liquification becomes necessary, the assembly may be connected to the nipple profile by way of a connector on the assembly. The connection between the assembly and the nipple profile can form a seal if the gas is to flow up the annulus between the production tubing and the casing, or can allow gas to flow into the production tubing if liquid is to be passed directly into the conduit in the cable.

[0044] In still a further embodiment, the method can be a method of cleaning up an injection well. In other words, the well into which the cable, motor and pump is deployed can be an injection well. The invention can be used to pump a fluid up the injection well bore. In this way, an injection well can periodically undergo a clean up operation in which accumulated drilling fluids, debris etc are removed. After the clean up operation, the well is operated as an injection well again i.e. fluids are injected down the well bore again. Accordingly, the invention can be used to quickly and cheaply clean up an injection well, thereby restoring and maximising the performance of the injection well.

[0045] The pump can be a bidirectional positive displacement pump. For example, the pump may be a rotary positive displacement pump such as a screw pump. A bidirectional pump can be selectively operated to pump fluid in either direction through the pump i.e. in a forwards direction and in a reverse direction which is opposite to the forwards direction. The invention can therefore be used to pump a fluid up an injection well bore for a first period of time, and then used to pump a fluid down an injection well for a second period of time, thereby assisting injection. The first and second periods can form a cycle which can be repeated.

[0046] According to a third aspect of the present invention, an electric submersible pump assembly for artificially lifting fluid from a well bore to the surface comprises a pump, a permanent magnet motor for driving the pump and an electro-mechanical cable, the electro-mechanical cable being capable of suspending the pump and motor in a well bore and of supplying electrical power to the motor. The pump may be a positive displacement pump, in which case the assembly may include any of the features described above in connection with the first aspect of the invention.

[0047] According to a fourth aspect of the present invention, a method of pumping fluids from a well to a surface comprises the steps of:

- providing an electro-mechanical cable capable of suspending a pump and a permanent magnet motor in a well bore and of supplying electrical power to such a motor;
- coupling a pump and a permanent magnet motor to the electro-mechanical cable;
- deploying the electro-mechanical cable with the motor and pump suspended therefrom into a well bore and lowering the motor and pump to a desired location;
- activating the motor and therefore the pump so as to pump a fluid up the well bore.

[0048] The pump may be a positive displacement pump, in which case the method may include any of the features described above with respect to the second aspect of the invention.

[0049] The invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 shows a schematic diagram of an electric submersible pump assembly according to the invention;

Figure 2 shows a cross-section through the electro-mechanical cable of the assembly shown in Figure 1; Figure 3 shows part of the inner surface of the bore through the packer;

Figure 4 shows a schematic diagram of a further embodiment of the present invention;

Figure 5 shows a schematic diagram of yet a further

embodiment of the present invention;

Figure 6 shows a cross-section through the electro-mechanical cable of the assembly shown in Figure 5.

[0050] An embodiment of the electric submersible pump assembly of the present invention can be seen in Figure 1. The assembly includes an electro-mechanical cable (1) supporting a permanent magnet motor (2) and a positive displacement pump (3) in a well casing (7). The cable (1) is connected to the motor (2) through a sealed connection (4). There is a seal unit (5) coupled between the motor (2) and pump (3) which prevents leakage of fluid between the pump and the motor.

[0051] A packer (6) is positioned within the well casing (7), though it could equally be positioned within a production tube in the same way. The pump (3) is located within and extends through a seal bore of the packer such that the pump's inlet (8) is below the packer (6) and the pump's outlet (9) is above the packer. The pump is held within the seal bore by engaging means which will be described in more detail below. A seal (10) in the seal bore seals off the region of the well below the packer from the region above the packer.

[0052] An automatic isolation valve (11) is located in the well casing (7) below the packer (6). The valve (11) is adapted to be in its open position when the pump is located in the packer and in its closed position when the pump is not located in the packer. In this way, the valve operates automatically to isolate the region of the well below the valve when the electric submersible pump assembly is not in position in the packer, for example when the assembly is lifted from the packer and subsequently from the well for servicing or the like. The valve is mechanically actuated, though it could alternatively be differential pressure/flow actuated upon starting the pump. Valves of this type are known in the field.

[0053] Figure 2 shows the electro-mechanical cable (1) in more detail. The cable has an outer armoured sheath and a core. Three copper conductors (13), each of which can be either a single strand wire or can comprise a plurality of smaller copper wires, are arranged in the core for supplying electrical power to the three-phase motor (2). Each conductor (13) is covered by one or more layers of insulating material. A filler material (14) such as EPDM, PTFE etc surrounds the conductors (13) and fills the internal region of the outer sheath. The outer armoured sheath comprises two layers (12a, 12b) of spiral wound steel armour wires. The two armour layers (12a, 12b) are contra wound to torque balance the cable under an applied tensile load. To further balance the torque, the wires of the external layer (12b) are of a smaller diameter than the wires of the inner layer (12a).

[0054] The cable can be mounted on a reel at ground level and unwound from the reel for deployment, as is known in other applications which use cables or wires.

[0055] The spiral wound steel sheath ensures that the cable (1) is strong enough to support its own weight as well as the weight of the motor (2) and pump (3), and

ensures that the cable is torque balanced.

[0056] The motor (2) is a three-phase permanent magnet AC motor and so it results in a higher degree of efficiency compared with induction motors as no rotor magnetising current is required and there are reduced copper losses. The permanent magnet motor can also be significantly shorter than an induction motor whilst achieving the same power.

[0057] The positive displacement pump (3) of this embodiment is a twin screw pump. The twin screw pump may be of the type described in US 6413065 of Can-K Artificial Lift Systems, Inc. of Alberta, Canada.

[0058] The permanent magnet motor and the positive displacement pump work efficiently together compared with known assemblies using induction motors and centrifugal pumps. The power developed by a motor increases linearly with rotational speed of the motor, whereas the power to drive a centrifugal pump increases as the cube of the rotational speed. Accordingly, a centrifugal pump only truly matches its motor at one speed. A slight change in the motor speed has a much larger effect on the centrifugal pump and so the motor can easily be underloaded or overloaded. The power of a permanent magnet motor is matched to the power of a positive displacement pump across a wider speed range because the power to drive a positive displacement pump also increases almost linearly with speed.

[0059] Also, the permanent magnet motor and the positive displacement pump are shorter than their typical counterparts (i.e. an induction motor and a centrifugal pump). This results in a relatively light load on the electro-mechanical cable compared with the load that would result with known assemblies. The light assembly weight and lower motor current mean that the required cross sectional area of steel armour and copper conductor is reduced. The cable can therefore be narrow, which is beneficial for deployment into a live well where the cable must pass through a pressure seal. The pressure difference across the seal acts to force the cable back out of the well, the force being proportional to the cross-sectional area of the cable. The invention therefore minimises the magnitude of the force acting to push the cable out of the well.

[0060] Further details of the means for engaging the pump in the packer will now be described with reference to Figures 1 and 3. The pump (3) is provided with means for engaging the packer (6) so as to hold the pump both axially and circumferentially in place with respect to the packer. To prevent rotation of the pump in the well when the pump is in operation, two pins (15) (only one of which is seen in Figure 1) extend away from the pump and engage the packer. The packer is formed with two slots (16) in the seal bore (only one slot shown in Figure 3) such that each pin (15) slides into one of the slots (16) as the pump (3) is lowered into the packer (6). The pins (15) therefore sit in the slots (16) when the pump is in operation and the side walls of the slots prevent the pins, and therefore the pump, rotating. Other numbers of pins

and slots could be used.

[0061] In this embodiment, the mouth of each slot diverges so as to have a funnel-like configuration. In this way, the side walls can act as cam surfaces (17) which guide the pins (15) as the pump (3) is lowered, so as to bring the pump into the correct orientation to allow the pins to enter the slots (16).

[0062] The pump (3) and packer (6) are also provided with a latch mechanism to hold the pump in the packer against the pressure of the formation fluids below the pump. In this example, as can be seen in Figure 1, there are recesses (18) on the underside of the pump. The packer is provided with a latch (19) that projects below the pump and into the recesses (18) when the pump is in the correct position with respect to the packer. For example, the latch (19) may be a snap ring or, as shown in Figure 1, fingers which have ends which project into the recesses. The fingers engage the recesses and act to hold the pump in the packer against the pressure of the formation fluids below. However, the latch has some resilience which allows it to release the pump when a predetermined upward force is applied on the cable (1), enabling withdrawal of the pump from the packer.

[0063] As can be seen in this embodiment, the engaging means (i.e. the pins (15) and the recesses (18)) are provided on the pump and so the pump is located in the packer. In alternative embodiments, rather than providing the engaging means on the pump, they may be provided on the motor or on an element associated with the pump or the motor, such as a collar or frame above or below the motor or the pump. In this way, the assembly can be arranged so that the pump is instead held above or below the packer.

[0064] The packer (6) is positioned in the well casing (20) in a manner well known to the skilled artisan so as to prevent circumferential or axial movement of the packer within the casing.

[0065] Compared with earlier assemblies, the electric submersible pump assembly described above allows for much easier deployment into, and withdrawal from, a well, and is also efficient and effective in operation. In use, a short amount of cable (1) is spooled off a reel carrying a length of the cable. The connector (4) on the free end of the cable is used to connect the cable (1) to the motor (2). The pump (3) is connected to the other side of the motor so that the motor is above the pump when the assembly is suspended in the well casing. Using a winch or the like, the pump (3) and motor (2) are lowered down the well, suspended from the cable (1). The cable is spooled off the reel until the pump and motor reach the desired location in the well, at which point the pump (3) moves into engagement with the packer (6). The pins (15) on the pump (3) slide along the cam surfaces (17) to bring the pump into the correct angular alignment to allow the pins to slide into the slots (16) on the packer. The resilient fingers of the latch (19) on the packer (6) slip into the recesses (18) on the pump. At the same time, since the pump has moved into engagement with

the packer, the isolation valve (11) automatically opens.

[0066] The pump is activated by sending current down the copper conductors (13) in the electro-mechanical cable (1) so as to operate the motor. Liquid is drawn into the pump inlet (8) and is pumped out the pump outlet (9), so as to assist the production of well fluids from the well. Fluids of up to and above 70% gas to liquid ratio can be pumped successfully and efficiently using the assembly.

[0067] If the pump, the motor or indeed the electro-mechanical cable develop problems or fail, operation of the pump is stopped and the cable is retracted from the well. This withdrawal causes the resilient fingers of the latch (19) on the packer to release the pump, and the pins (15) on the pump are pulled from the slots (16). As the pump lifts out of the packer, the automatic isolation valve (11) closes, thereby closing off the well. The cable is withdrawn until the pump and motor are pulled out of the well for servicing.

[0068] One of the benefits of the present invention is that the combined use of a twin screw positive displacement pump with a permanent magnet motor results in a short assembly compared with prior pumping assemblies. With the present invention, it is possible to introduce the cable carrying the pump and motor into a live, pressurised well using a lubricator.

[0069] An adaptation of the above method can be used in injection wells. The twin screw pump can be operated in reverse so as to pump fluid in the opposite direction i.e. downwards. In this way, if the performance of an injection well decreases, the electric submersible pump of the invention can be deployed into the injection well and operated for a period of time to remove accumulated drilling fluids and debris from the well. After sufficient drilling fluids and debris etc have been removed, operation of the pump is reversed so as to aid injection of fluids down the cleaned well.

[0070] In another embodiment of the invention, as shown in Figure 4, an electric submersible pump assembly as described above is used to bring a well back into production after a conventional pumping assembly (21) comprising a centrifugal pump carried on the lower end of a production tubing (22) has failed. The conventional assembly is powered via an electric cable (26) running along the outside of the production tubing and terminating into the side of the motor using a pothead (27). Rather than lowering the pump assembly of the invention directly into a well casing (20) as described above, the assembly is lowered into the production tubing (22). A packer (6) as described above is positioned near the lower end of the production tubing before the pump (3) and motor (2) are lowered.

[0071] Since the failed centrifugal pump allows the passage of fluid despite it not being operational, fluid is drawn through the old pump by the new pump. If the failed assembly comprises a pump which does not allow the passage of fluid unless the pump is operating, a hole can be punched in the production tubing above the failed pump, thereby providing a fluid by-pass.

[0072] In all other respects, the assembly of this embodiment is the same as that described above in connection with Figures 1 to 3.

[0073] Accordingly, once installed, the assembly of the invention can draw fluids through the failed pumping assembly (21) into the production tubing (22) and through the pump (3) of the present invention so as to pump the fluid to the surface. This has particular advantage for many existing wells in which the pumping system already in place is of poor efficiency, is towards the end of its useful life, or has already failed.

[0074] Referring now to Figures 5 and 6, a further embodiment of the invention is shown. The electric submersible pump assembly of this embodiment comprises similar components described above with respect to Figures 1 to 3 and so like reference numerals have been used.

[0075] In this embodiment, the electric submersible pump assembly is used as a vertical separator to deliquify a gas well. A production tubing (22) in a gas well carries gas from the bottom of the well to the surface. A packer (29) prevents the gas flowing between the production tubing and the well casing. Liquid (28) accumulates at the bottom of the well if the gas flow is insufficient to carry the liquid up the production tubing. If liquid builds up, gas production can be reduced and the well can eventually be killed.

[0076] In accordance with this embodiment of the invention, a twin screw pump (3) and permanent magnet motor (2) are suspended from an electro-mechanical cable (1) as described above as shown in Figure 5. However, the cable, shown in Figure 6, additionally comprises a fluid conduit (23) extending there-through for carrying a fluid to the surface, and the pump outlet pumps fluid directly into the fluid conduit (23) rather than out into the production tubing (22). Also, the pump inlet (8) is found at the end of an inlet conduit (24) extending down from the pump.

[0077] In this embodiment, a packer (25) is provided in the production tubing (22) of an existing well to engage the pump (3) and hold it against axial and rotational movement as described above. However, there is no seal between the pump and the packer so that gas can flow from the bottom of the well, between the pump and the packer and up the production tubing.

[0078] In use, the motor (2) and pump (3) are lowered through the production tube (22) in the gas well until the motor and pump are near the bottom of the well, and specifically until the inlet conduit (24) reaches a region where liquid (28) collects. Activation of the pump causes liquid from the bottom of the well to be drawn through the inlet (8) and up into the pump (3) and consequently up through the fluid conduit (23) extending through the electro-mechanical cable (1). In this way, accumulation of liquid in the bottom of the well, which could otherwise kill or severely restrict production from the gas well, is prevented. Gas flowing from the formation is able to pass into the production tubing (22), flowing between the pump and the packer and passed the motor.

[0079] The liquid carried up the cable's conduit (23) can also have gas entrained therein, though this does not cause a problem for the twin screw pump as the pump can handle fluids having up to and above 70% gas to liquid ratio.

[0080] The pump is operated continuously so as to maintain a minimum level of liquid in the bottom of the well.

Claims

1. An electric submersible pump assembly for artificially lifting fluid from a well bore to the surface comprising a positive displacement pump (3), a motor (2) for driving the pump and an electro-mechanical cable (1), the electro-mechanical cable being capable of suspending the pump and motor in a well bore and of supplying electrical power to the motor.
2. An assembly as claimed in claim 1, in which the motor (2) is a permanent magnet motor.
3. An assembly as claimed in claim 1 or claim 2, in which the motor (2) is an AC motor or a DC motor.
4. An assembly as claimed in claim 3, in which the AC motor (2) is a single phase or three phase motor.
5. An assembly as claimed in any one of the preceding claims, in which the positive displacement pump (3) is a twin screw pump.
6. An assembly as claimed in any one of the preceding claims, in which the motor (2) is located between the cable (1) and the pump (3).
7. An assembly as claimed in any one of the preceding claims, in which the electro-mechanical cable (1) comprises a core having at least one electrical conductor (13) and an outer sheath around the core capable of supporting the weight of the cable (1) as well as the weight of the motor (2) and the pump (3).
8. An assembly as claimed in claim 7, in which the outer sheath comprises two layers (12a,12b) of spiral wound steel wires, the wires of the outer layer (12b) having a smaller diameter than the wires of the inner layer (12a).
9. An assembly as claimed in claim 7 or claim 8, in which the core additionally comprises at least one conduit (23) for transmitting fluid along the cable.
10. An assembly as claimed in any preceding claim, further including a packer (6) having engaging means (16,19) for engaging co-operating engaging means (15,18) on the pump (3).

11. An assembly as claimed in claim 10, wherein the engaging means comprise torque resisting means (15,16) for preventing rotation of the pump during operation.

12. An assembly as claimed in claim 10 or claim 11, wherein the engaging means comprise axial movement resisting means (18,19) for resisting axial separation of the pump from the packer.

13. An assembly as claimed in any one of claims 10 to 12, further comprising an automatic isolation valve (11) which automatically moves from its open position to its closed position when the pump is turned off or is removed from the packer.

14. An assembly as claimed in any one of the preceding claims, in which the positive displacement pump is selectively operable in a forwards direction and in a reverse direction.

15. A method of pumping fluids from a well to a surface comprising the steps of:

providing an electro-mechanical cable (1) capable of suspending a positive displacement pump and a motor in a well bore and of supplying electrical power to such a motor; coupling a positive displacement pump (3) and a motor (2) to the electro-mechanical cable (1);
deploying the electro-mechanical cable with the motor and pump suspended therefrom into a well bore and lowering the motor and pump to a desired location;
activating the motor and therefore the pump and thereby pumping a fluid up the well bore.

16. A method as claimed in claim 15, wherein the cable (1), motor (2) and pump (3) are deployed into a production tubing (22) in the well bore (7), the production tubing carrying on its end a submersible pump assembly (21) which has failed, such that activating the motor (2) and therefore the pump (3) draws fluid up the production tubing (22) above the failed pump assembly (21).

17. A method as claimed in claim 15, wherein the well is a gas well and the cable (1), motor (2) and pump (3) are deployed and lowered into a production tubing located in the gas well until an inlet (8) of the pump is located in a region of the gas well where liquid (28) collects, and wherein the cable (1) comprises a conduit (23) for transmitting fluids along the cable, an outlet of the pump being in communication with the conduit (23), the method including pumping liquid up the conduit (23) and allowing gas to flow up the production tubing.

18. A method as claimed in claim 15, wherein the well is a gas well and the cable (1), motor (2) and pump (3) are deployed and lowered into a production tubing located in the gas well until an inlet (8) of the pump is located in a region of the gas well where liquid (28) collects, the method including pumping liquid up the production tubing and allowing gas to flow up an annulus formed between the production tubing and a casing which lines the well bore. 5
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19. A method as claimed in claim 15, wherein the well into which the cable (1), motor (2) and pump (3) are deployed is an injection well.
20. A method as claimed in claim 19, wherein the pump is a rotary positive displacement pump which operates in a first direction during a first period of time to pump the fluid up the injection well bore, the method comprising the further step of operating the pump in a second, reverse direction for a second period of time to pump fluid down the injection well bore. 15
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21. A method as claimed in any one of claims 15 to 20, using the electric submersible pump assembly of any one of claims 1 to 13. 25
22. An electric submersible pump assembly for artificially lifting fluid from a well bore to the surface comprising a pump (3), a permanent magnet motor (2) for driving the pump and an electro-mechanical cable (1), the electro-mechanical cable being capable of suspending the pump and motor in a well bore and of supplying electrical power to the motor. 30
23. A method of pumping fluids from a well to a surface comprising the steps of: 35
providing an electro-mechanical cable (1) capable of suspending a pump and a permanent magnet motor in a well bore and of supplying electrical power to such a motor; 40
coupling a pump (3) and a permanent magnet motor (2) to the electro-mechanical cable (1);
deploying the electro-mechanical cable with the motor and pump suspended therefrom into a well bore and lowering the motor and pump to a desired location; 45
activating the motor and therefore the pump so as to pump a fluid up the well bore. 50

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Figure 1

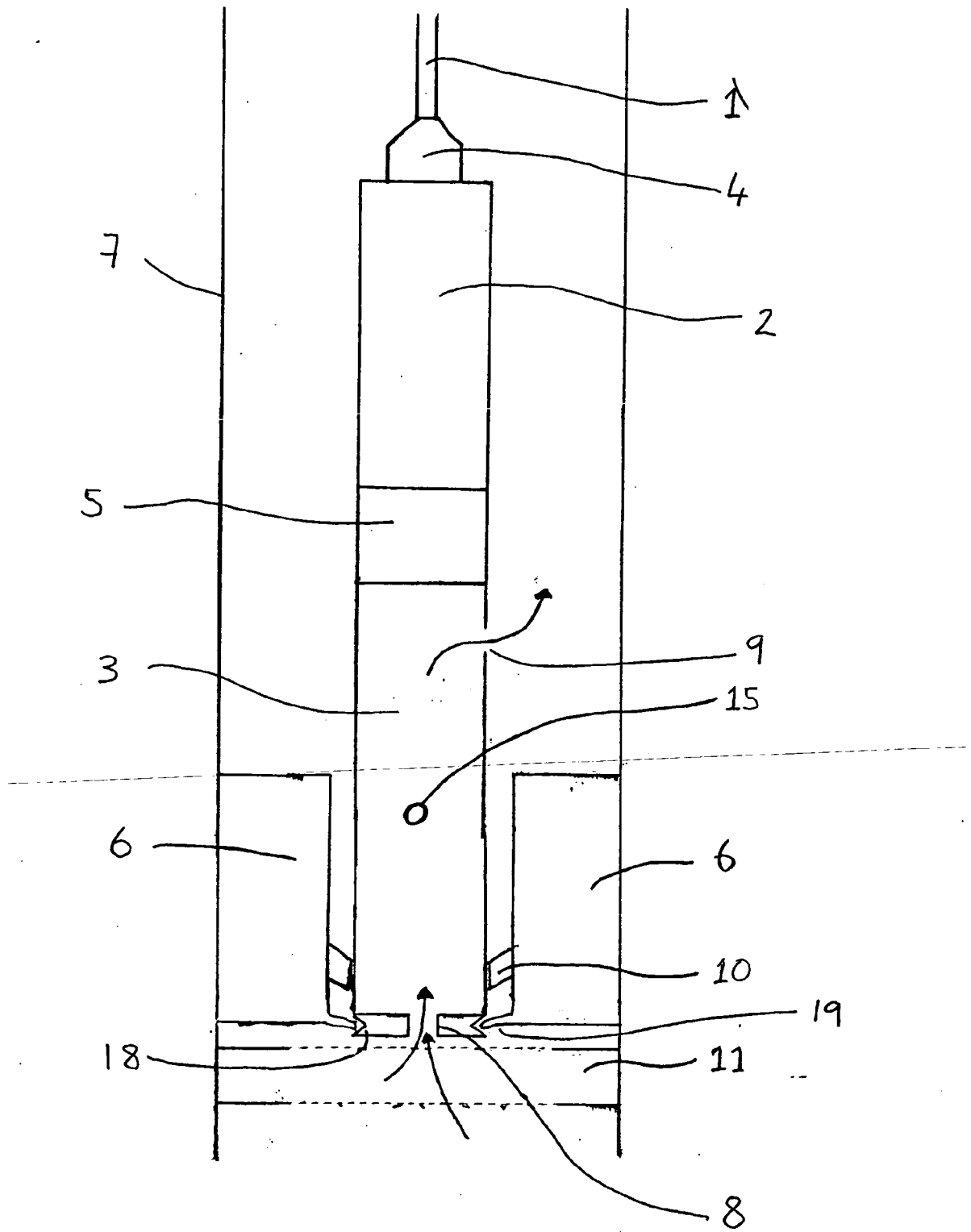


Figure 2

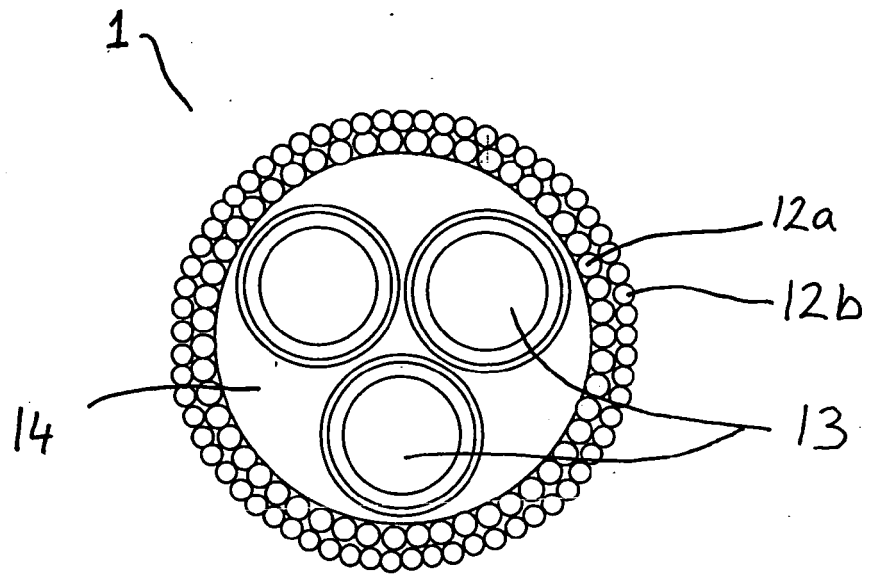
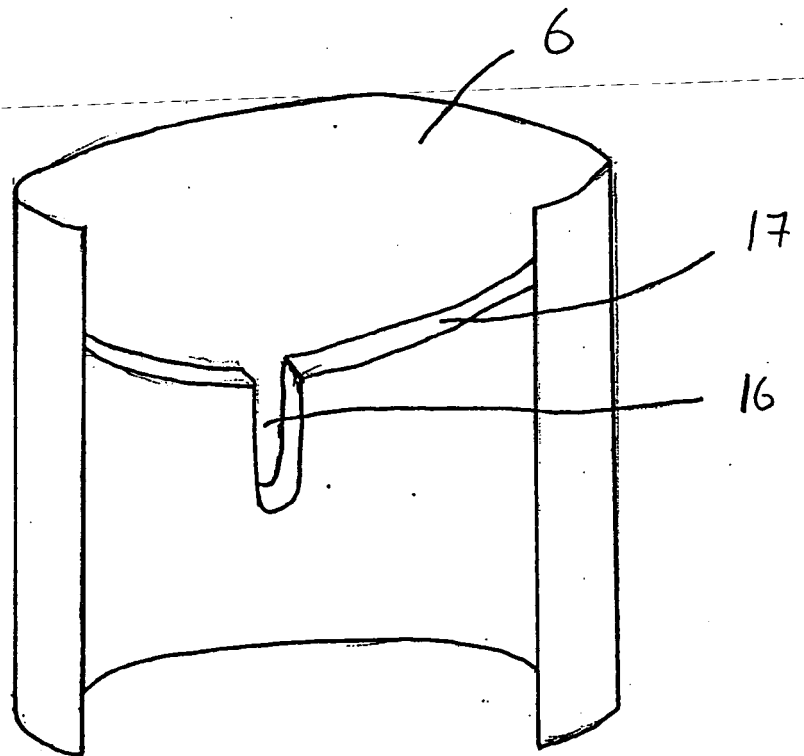


Figure 3



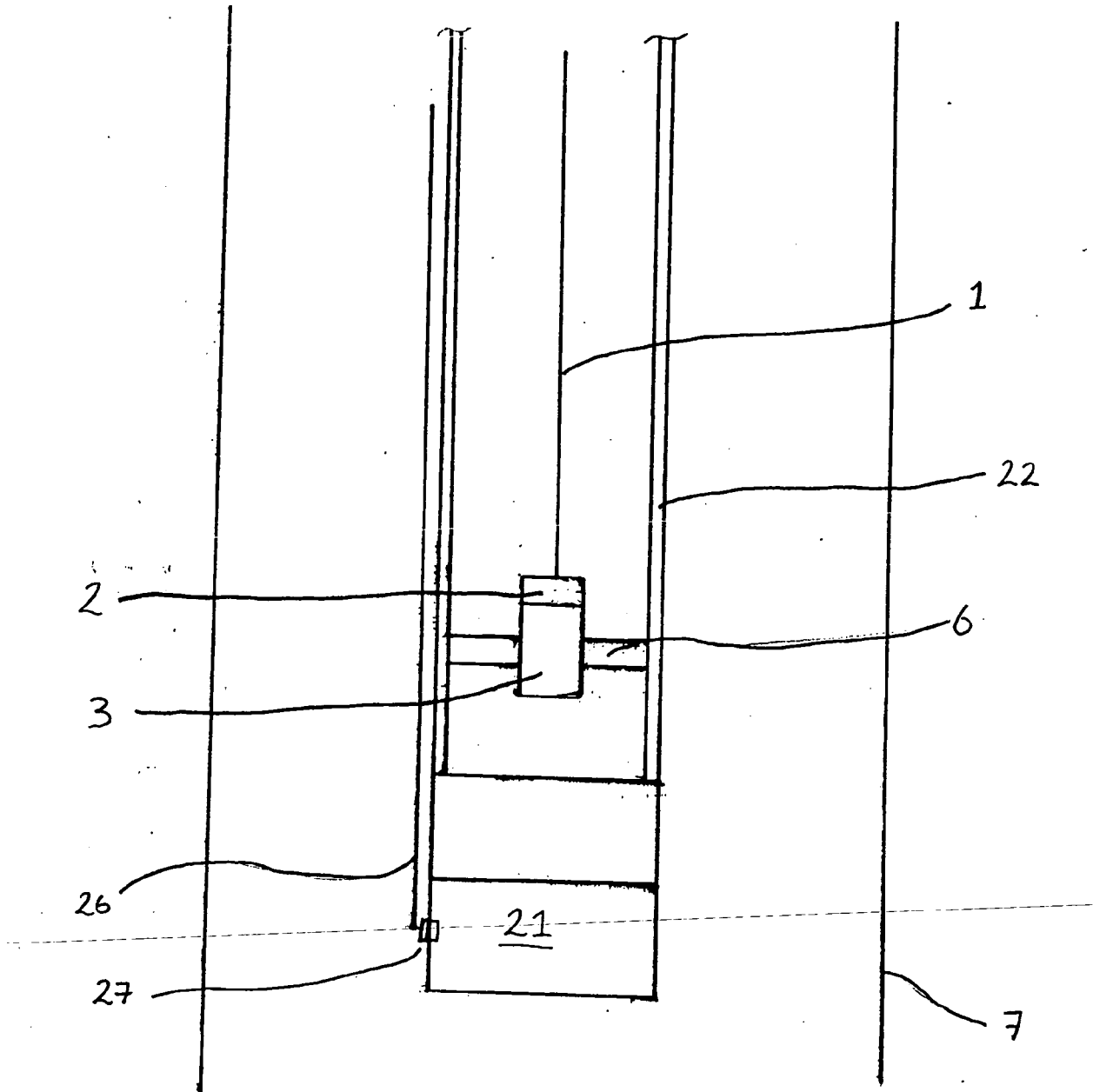


Figure 4

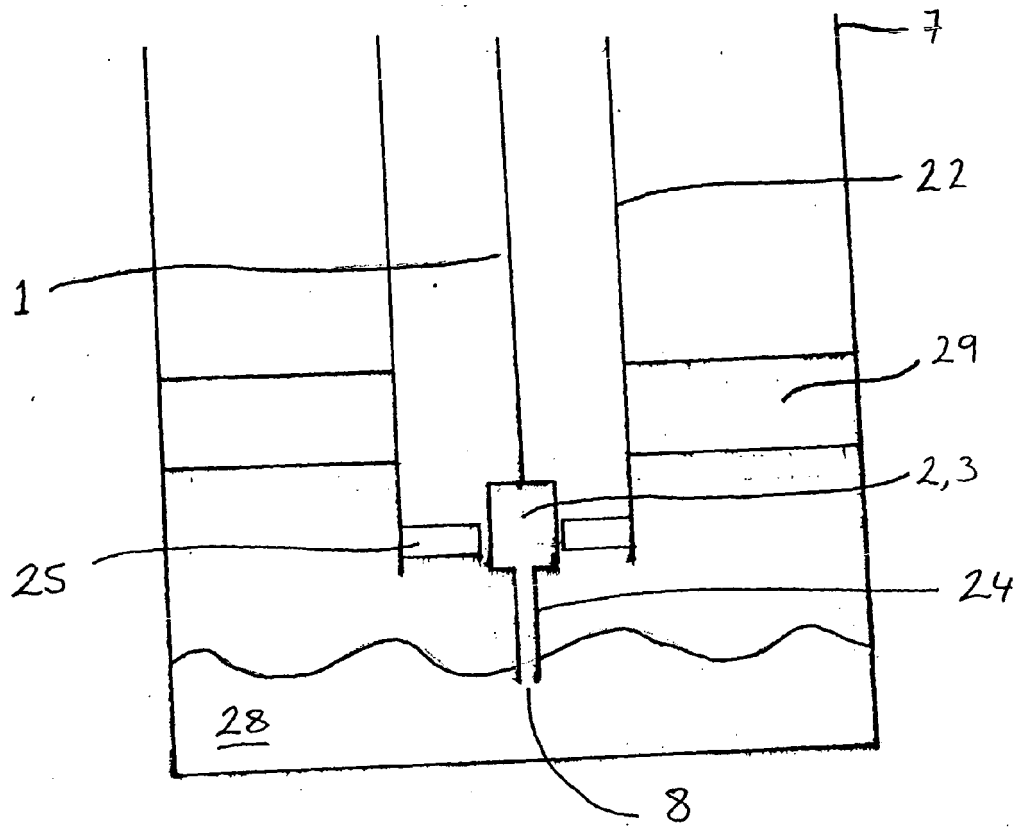


Figure 5

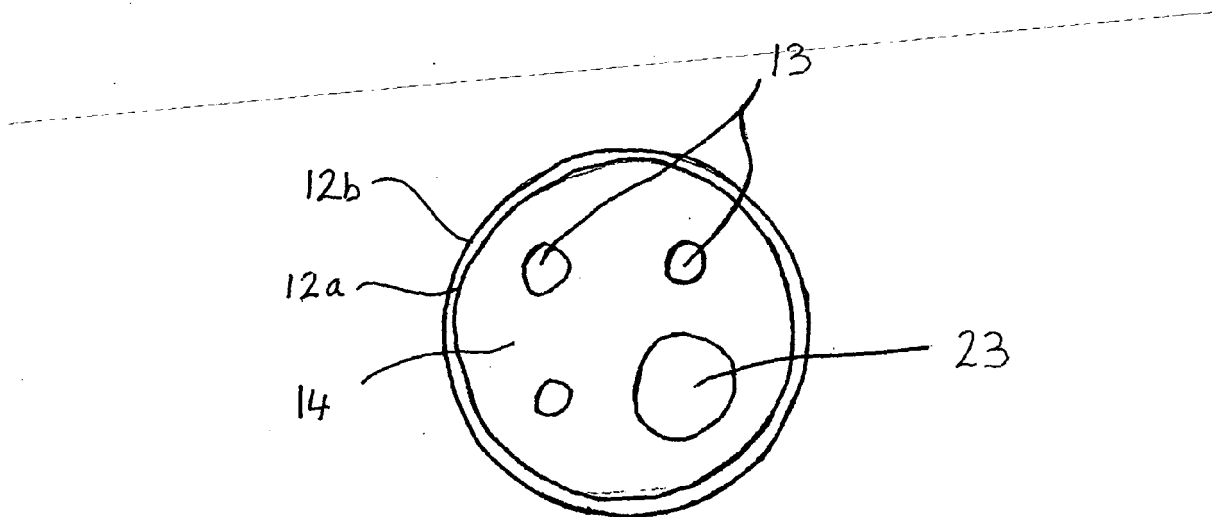


Figure 6



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EUROPEAN SEARCH REPORT

Application Number
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Place of search The Hague		Date of completion of the search 8 July 2008	Examiner Dantine, Patrick
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