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(54) METHOD FOR PUMPING FLUIDS

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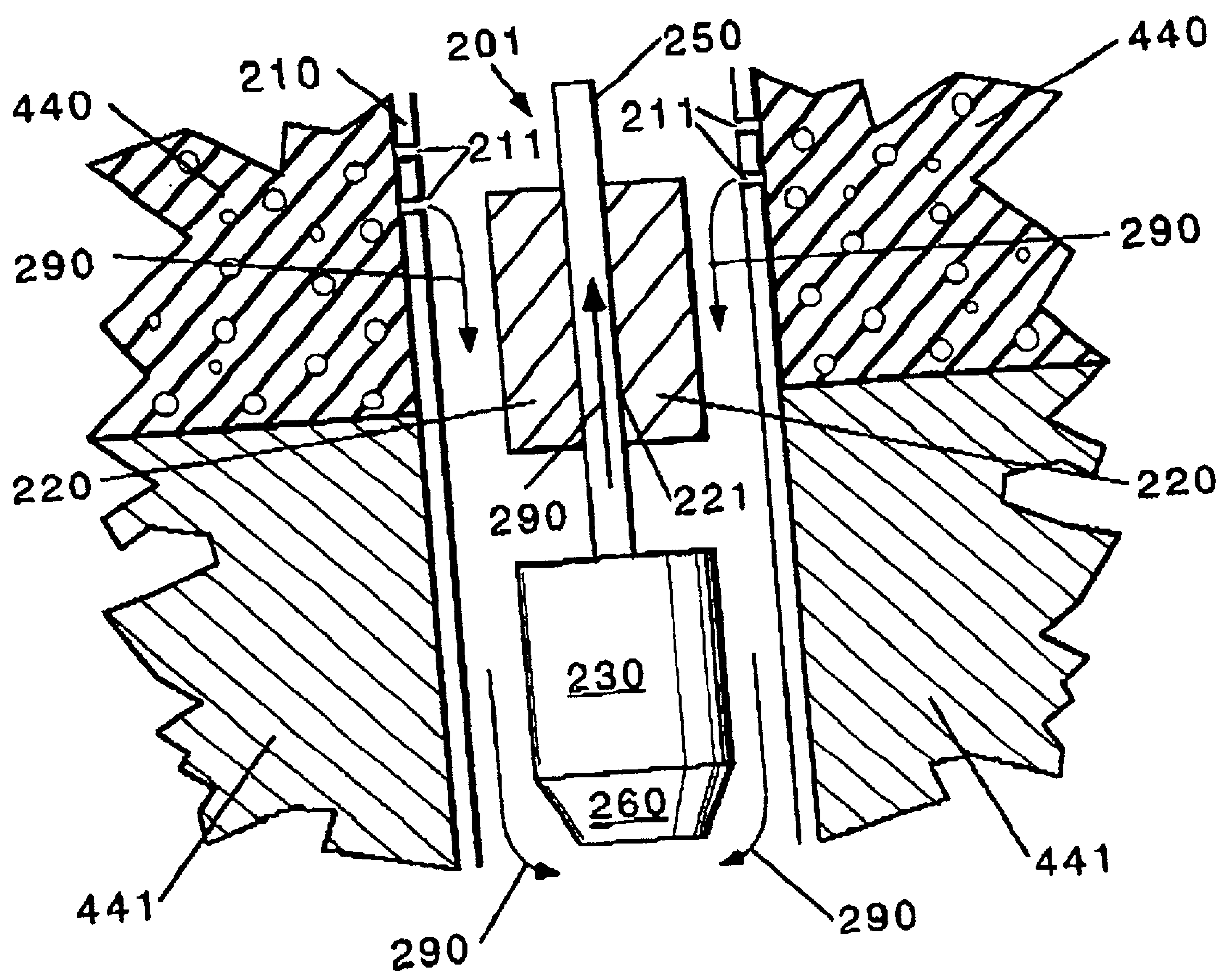
(57) **ABSTRACT**

The production rate, useful life and operating efficiency of electric submergible pumping systems (ESP) is improved by operating the system so that the motor is cooled by two passes of production. The two passes of production fluid are achieved by employing a shroud with the inlet at the opposite end of the production fluid intake or by installing the motor below the perforations that allow production fluids to enter a well. The motor is designed with an internal conduit through which the production fluids are pumped. Production fluids remove waste heat from the motor by passing in fluid contact with the exterior of the motor and again by passing through the internal conduit of the motor. The improved cooling permits the motor to be operated at a lower temperature improving life and efficiency, and/or to be operated at higher power at a similar temperature. Additionally, oversized and excess equipment is not required, further improving performance and economics for the user. In another aspect, the invention is a method of pumping fluids using a motor having vortex generators on its exterior surfaces or on the interior surfaces of a surrounding shroud, and a method for determining optimum well operating conditions.



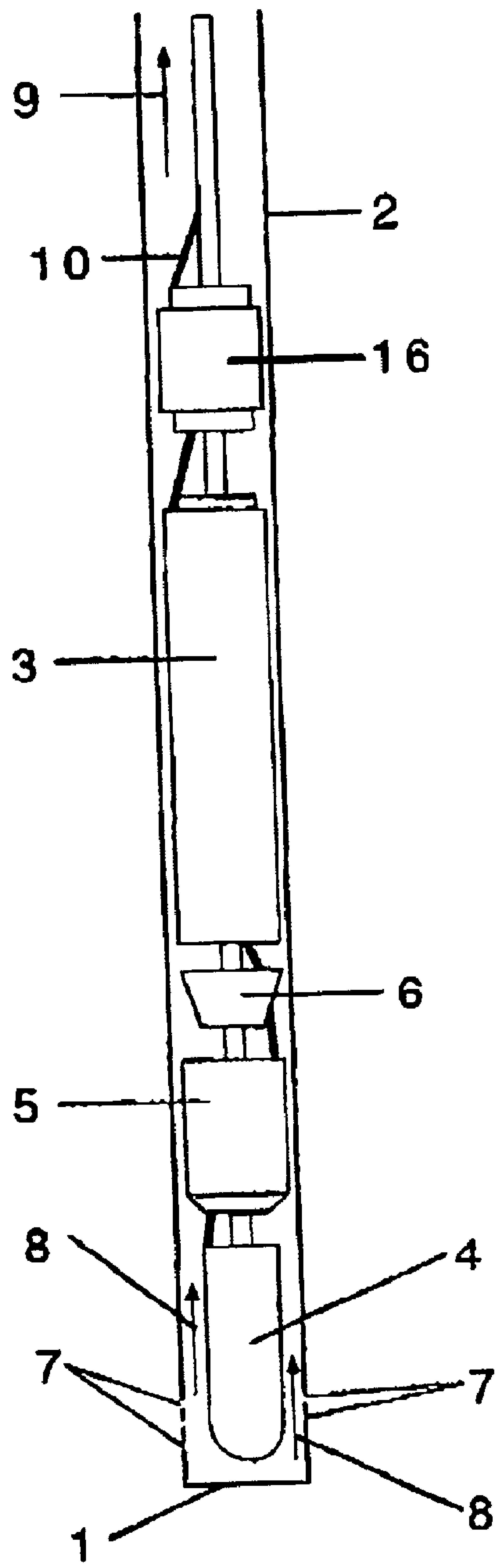


FIG. 1
(PRIOR ART)

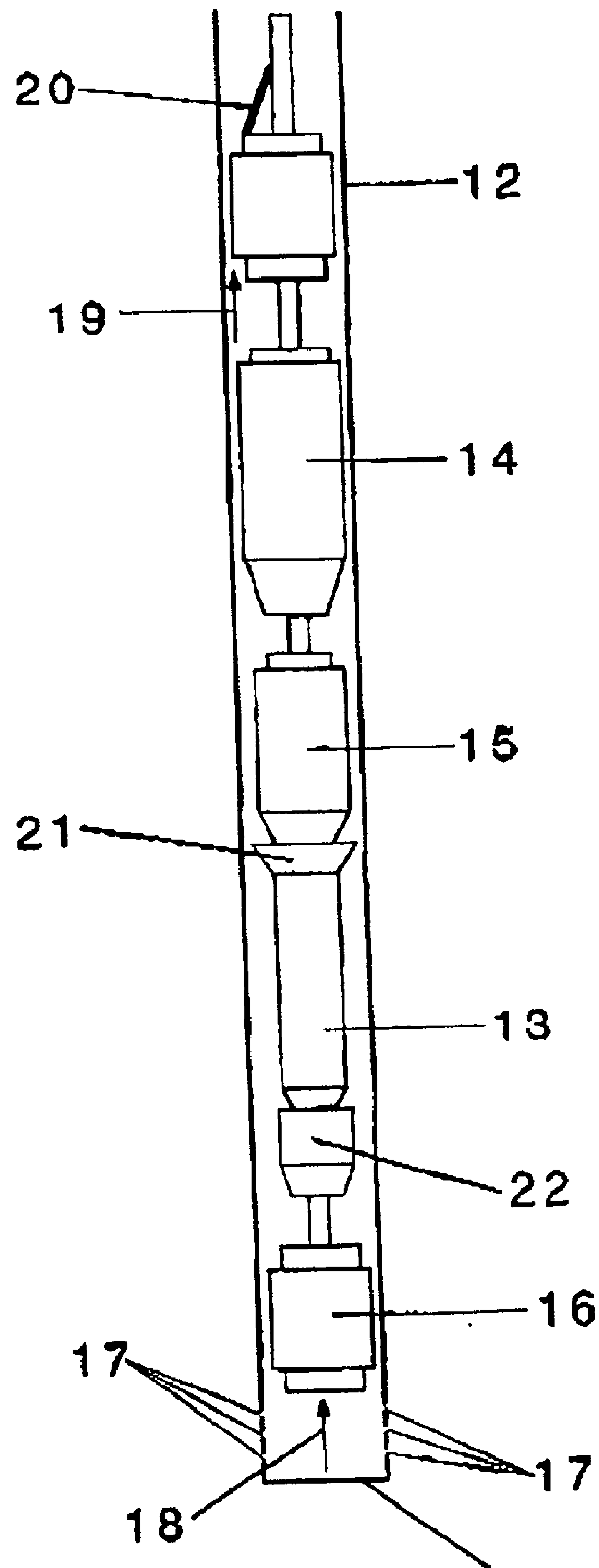


FIG. 1A
(PRIOR ART)

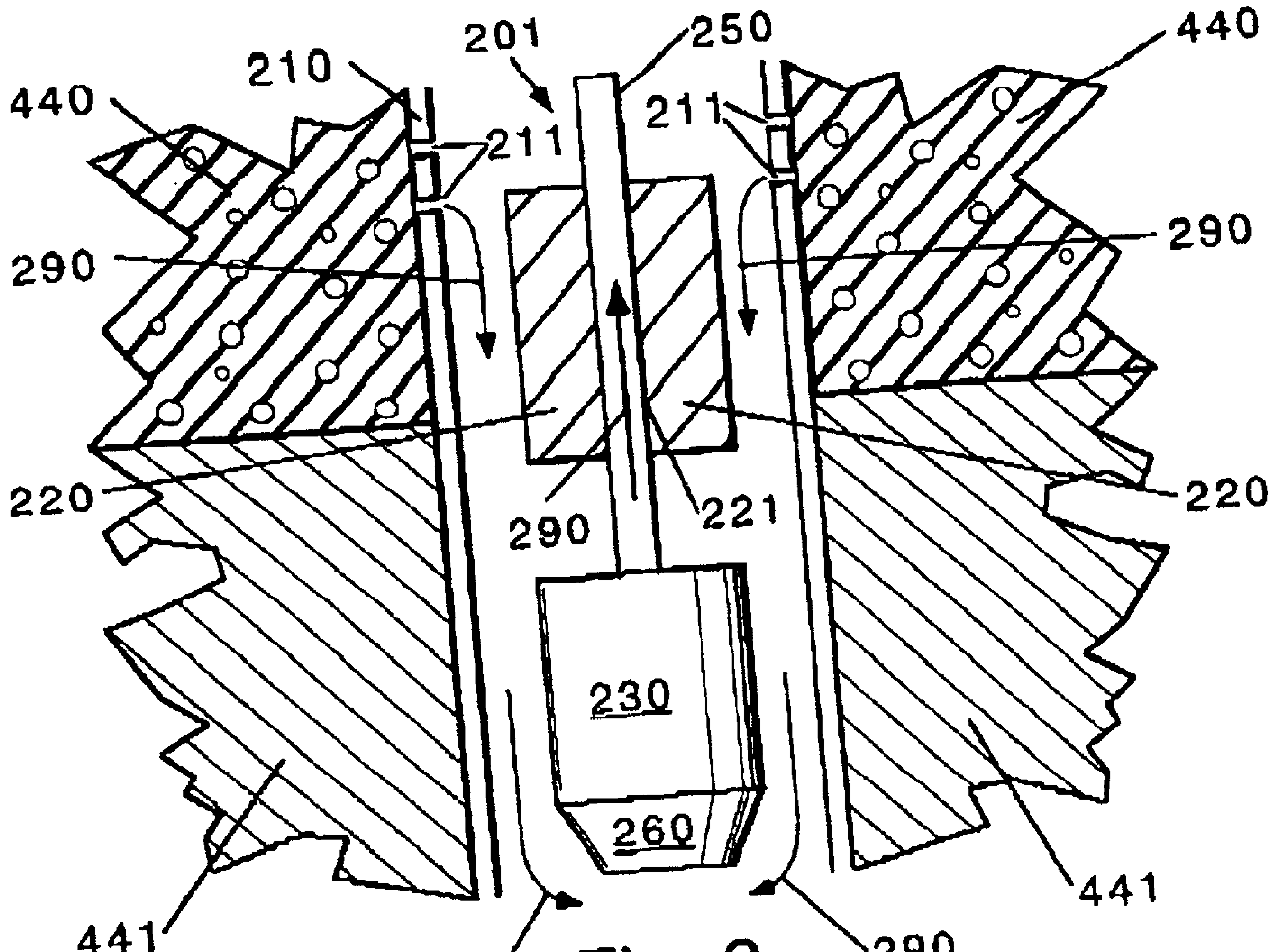

201
250
440
210
211
440
211
290
290
220
220
290
221
230
260
441
441
290
290

Fig. 2

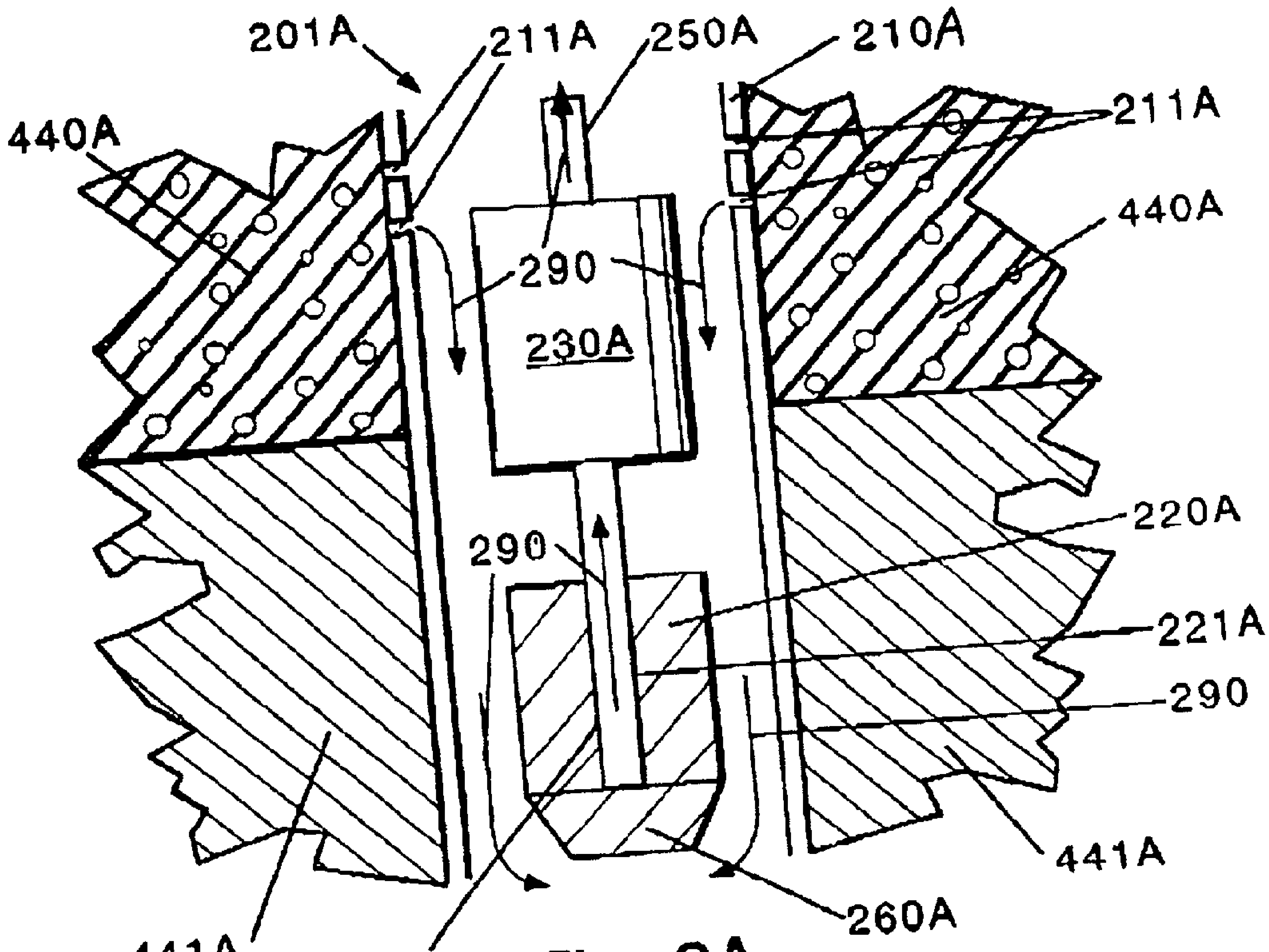

201A
211A
250A
210A
211A
440A
440A
290
230A
220A
290
221A
290
441A
260A
441A
221A

Fig. 2A

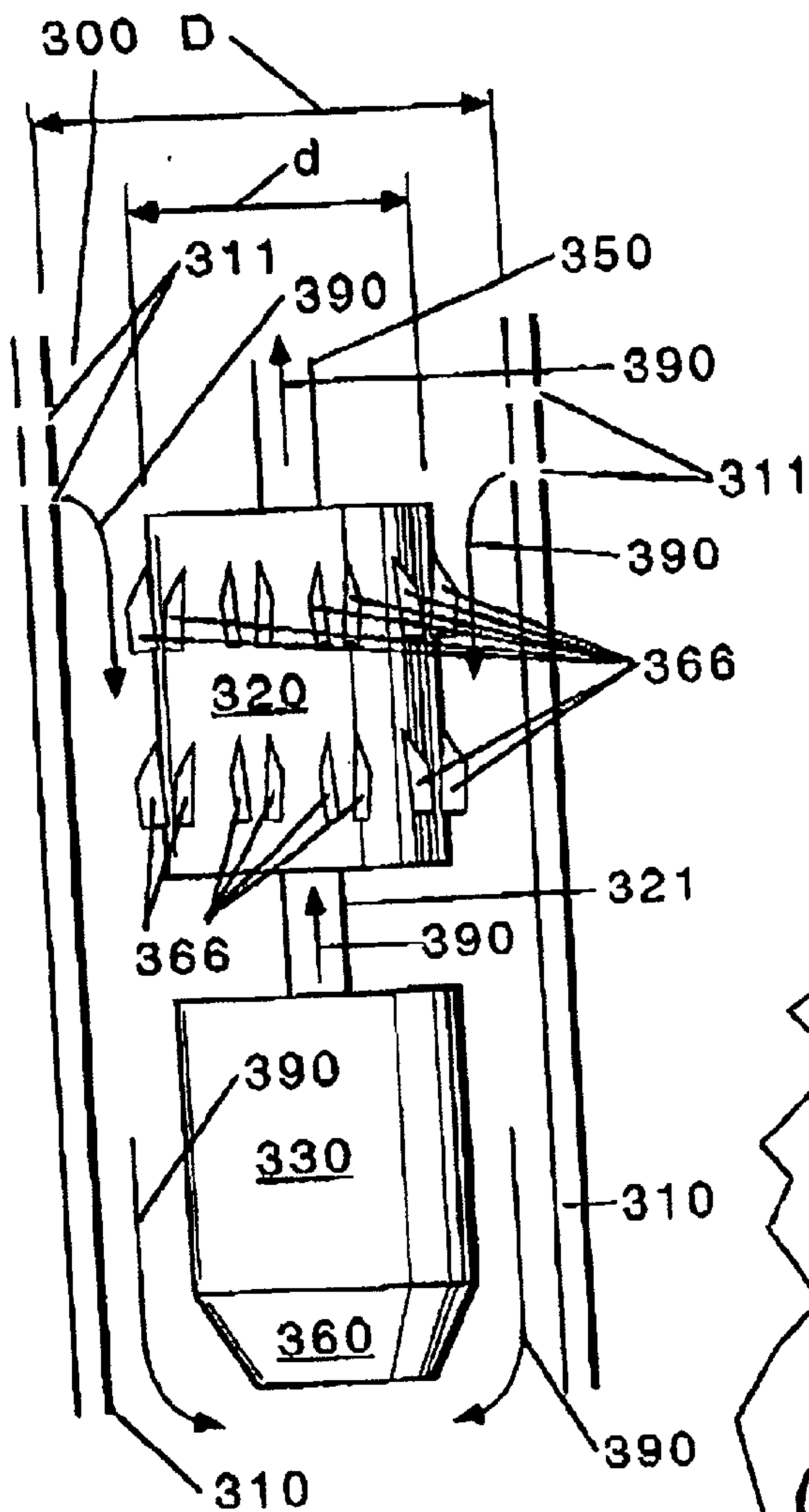

300
D
d
311
390
350
390
311
390
366
320
321
390
366
390
330
310
360
390
310

Fig. 3

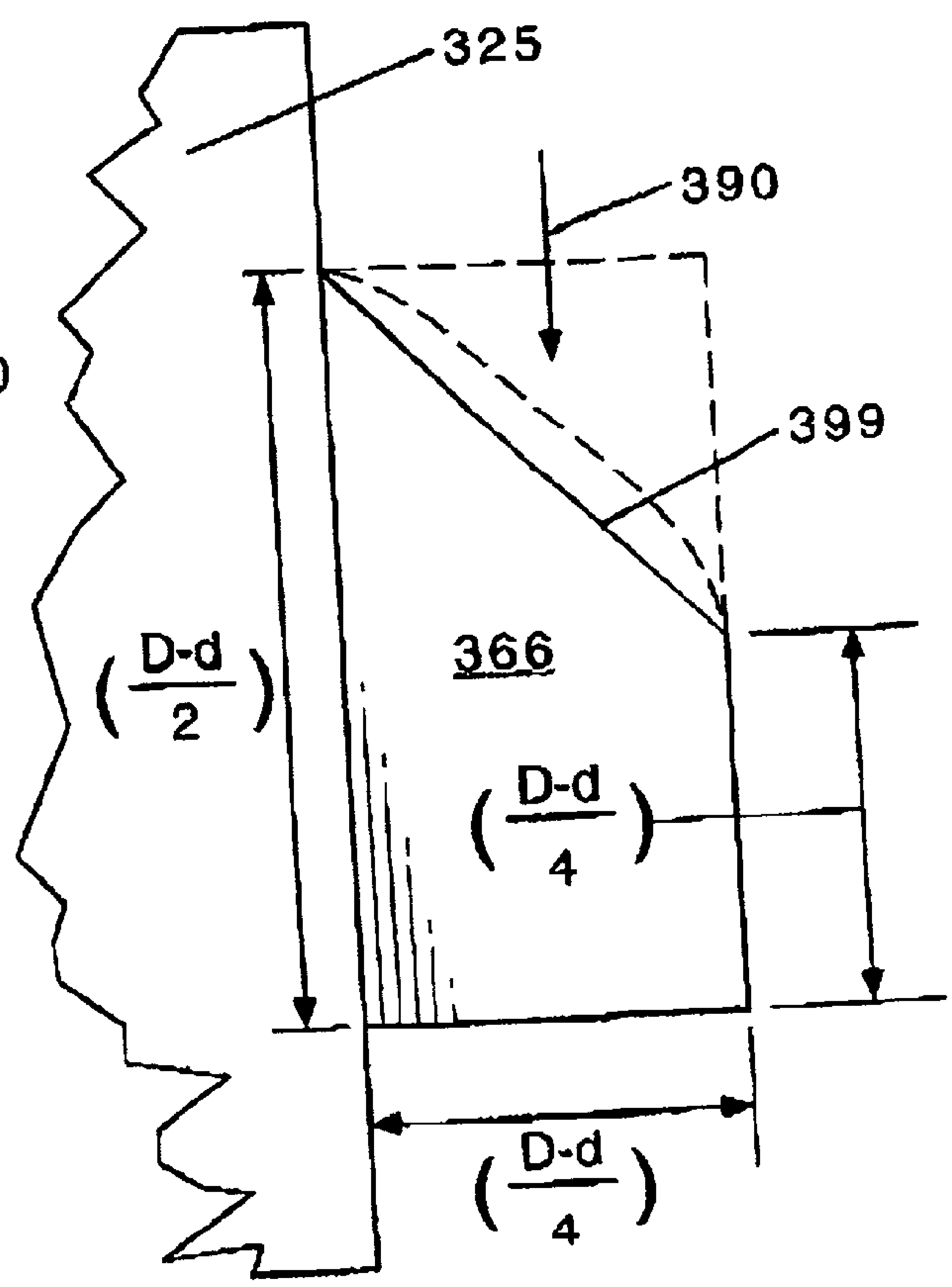

325
390
399
366
$\left(\frac{D-d}{2}\right)$
$\left(\frac{D-d}{4}\right)$
$\left(\frac{D-d}{4}\right)$

Fig. 3A

METHOD FOR PUMPING FLUIDS

BACKGROUND OF THE INVENTION

[0001] The present invention relates to methods for pumping fluids, primarily from wells.

[0002] Water, oil and natural gas are commonly produced in wells. The wells are formed by drilling a hole into a rock formation to the depth where the fluid reservoir lies. A well casing is inserted into the hole following the drilling. If natural gas is present in the well, it is readily recovered from the well due to its natural buoyancy, while in most cases water and oil must be pumped to the surface.

[0003] Various types of pumping systems are used to produce fluids from wells. Among these are sucker-rod/beam systems, plunger lift systems, continuous or intermittent gas lift systems, hydraulic reciprocating pumps, progressing cavity pumps and electrical submergible pumps (ESPs). An ESP includes an electric motor that drives a submergible pump that forces fluids from the reservoir to the surface.

[0004] ESPs are often remotely operated in wells commonly at great depths, in harsh environmental conditions. A challenge in using ESPs is effective heat removal. Resistance in the electric motor windings generates a significant amount of waste heat in operation, as do mechanical friction and fluid friction. If this waste heat is not sufficiently removed, the motor temperature can rise significantly. Increasing the motor temperature leads to a number of problems. Motor life becomes considerably shorter as temperatures increase. Motor winding insulation, bearings, seals, and lubrication are all adversely affected by high temperature. As a result, ESPs commonly are removed from wells more often than desired in order to replace or repair the electric motor. In the oil market in particular, this results in high maintenance and repair costs as well as significant losses of revenue due to lost production. Alternatively, to keep motor temperatures within reasonable limits, sometimes the production is reduced to a rate lower than desired, equipment is oversized or excess equipment is used, compromising the efficiency and profitability of the well. Electrical efficiency also tends to decrease as the temperature rises and additional horsepower is necessary when excess equipment, like gas separators or additional seals, are used. This results in increased energy costs, as more electrical power is needed to perform a given amount of work.

[0005] Sometimes this problem is exacerbated because of particular well conditions or operator choices. Well conditions such as high gas content, high viscosity production fluids, the formation of emulsions, low flow rates, multiphase flows, steam flood production, deviated and horizontal wells, increasing well depth and other factors can contribute to high motor temperatures. Some of these conditions make it difficult for a well operator to properly size and operate an ESP.

[0006] The production fluid is often used to remove some of the waste heat and provide some temperature control. In conventional ESP installations, production fluids are drawn or pumped past the motor and remove some heat. This effect is illustrated in **FIGS. 1 and 1**A, which represents conventional ESP and so-called "inverted ESP" pumping systems. In **FIG. 1**, well **1** has casing **2** that has perforations **7** through which production fluids enter the well. The ESP system includes pump **3**, motor **4** and seal section **5**. Production fluids enter the well at a point below motor **4**, pass by motor **4** in the direction indicated by arrows **8**, and then enter pump **3** at pump intake **6**. The production fluids are forced upwardly by pump **3**, exiting at the top of pump **3** and traveling to the surface in the direction indicated by arrow **9**. Cable **10** provides electrical power to motor **4** from the surface. As shown, a packer **16** may be used in the assembly.

[0007] In the "inverted ESP" system shown in **FIG. 1**A, the relative positions of the pump and motor are reversed. Well **11** has casing **12** and perforations **17** as before. Production fluids enter pump intake **22** in the direction indicated by arrow **18**. The production fluids are pumped upwardly through pump **13**, exiting at point **21** and then flowing upwardly past seal section **15** and motor **14** in the direction indicated by arrow **19**. As before, cable **20** provides electrical power from the surface. A packer **16** is again illustrated in this assemblage.

[0008] In the systems shown in **FIGS. 1 and 1**A, the production fluids remove some heat as they flow past the motor. However, the amount of heat that is removed is often insufficient to optimize motor performance and life. As a result, well operators have attempted in various ways to improve motor performance and life. One way of accomplishing this is to use special high temperature windings in the motor so that it can better tolerate higher temperatures. Unfortunately, this does nothing to reduce heat in the bearings, seals, and lubrication, and significantly increases the cost of the motor. Additionally, running at higher temperatures makes the equipment more prone to scale and corrosion and lowers electrical efficiency. Another technique is to add a shroud around the motor to increase the fluid velocity. Except under conditions where fluid does not flow across the motor housing, shrouds will not significantly change the character of the flow (laminar or turbulent), are expensive and can be difficult or impossible to install in deviated and slim-hole wells.

[0009] Another attempt to improve production using ESPs is described in "Operating Electric Submersible Pumps Below Perforations, J. of Petrol. Techn., p. 742 (July 1997) and by Sison in "Use of A Motor Cooling By-Pass System in An Electric Submersible Pump to Increase the Economic Life of Gas Wells", Feb. 28, 2000. In these methods, an ESP system is installed in the well below the perforations. Production fluids enter the well and the pump intake without flowing past the motor. Without convective cooling, a portion of the production fluids must be drawn off from the pump and recirculated down to the base of the motor and released to remove heat. This typically requires that a second, recirculation pump be used together with special recirculation tubing, and thus is complex, expensive and less efficient than desired. It is also difficult to effectively recirculate enough fluid to provide adequate heat removal. Another approach is the so-called Framco ESP system, which also involves circulating a cooling fluid through the motor from the wellhead. This is described in "The Framco ESP System: A New Approach to Downhole Electric Submersible Pumping", presented by Jon A. Svaeren and Frank Mohn at the ESP Workshop, Houston, Tex., April 30-May 2, 1990. Again, the complexity and expense of such a system makes it undesirable.

[0010] Thus, an improved ESP system would be highly desirable, particularly one which enables more effective and efficient heat removal from the electrical motor particularly if this can be achieved without the expense of additional components or unnecessary features.

SUMMARY OF THE INVENTION

[0011] In one aspect, this invention is a method of pumping fluids with a submergible pumping system including a pump and an electrical motor, wherein

[0012] (a) the electrical motor has an internal conduit and said pumping system is adapted to pump said fluid through said internal conduit, and

[0013] (b) the pumping system is submerged in said fluid such that production fluids entering the pumping system pass in fluid contact with exterior portions of the electrical motor and remove heat therefrom before entering the production fluid intakes, and said production fluids then pass through the internal conduit of the electrical motor as the fluid is pumped, and remove additional heat from the motor.

[0014] In a second aspect, this invention is a method for pumping fluids from a well having a casing that contains perforations through which production fluids enter the well, comprising

[0015] (a) positioning an electrical submergible pumping system including an electric motor within said casing such that the electric motor is at or below at least some of said perforations, and

[0016] (b) pumping production fluids from the well with said pumping system,

[0017] wherein

[0018] (i) the pumping system includes a pump, an electrical motor having an internal conduit and production fluid intakes located below said electrical motor, said pumping system being adapted to pump said production fluids through said internal conduit of the electrical motor,

[0019] (ii) liquid production fluids entering the well through at least some of the perforations in the well casing come into fluid contact with exterior portions of the electrical motor and remove heat therefrom before entering the production fluid intakes, and

[0020] (iii) liquid production fluids pass through the internal conduit of the electrical motor as the fluid travels toward the wellhead, and remove additional heat from the motor.

[0021] The method of the invention provides several significant benefits. Production fluids in laminar or turbulent flow that come into fluid contact with the exterior of the electrical motor provide initial heat removal. In gassy wells, the increased flow rate made possible by operating the ESP below the perforations may foster turbulent flow in the annulus between the motor housing and the well casing contributing to a significant increase in heat transfer. An additional cooling effect is seen when the production fluids pass through the internal motor conduit; thus, the production fluids are used to remove heat twice in this invention, once before entering the pump and a second time as they pass through the internal motor conduit. The combined cooling effects help maintain the motor within optimal or desired temperature limits. This prolongs motor life and reduces maintenance costs and other expenses attributable to premature motor failure. It also allows an operator to increase the production by increasing the horsepower capability of existing equipment without raising the temperature. The cooling effect can be further facilitated if the pump and/or internal conduit are designed so that the production fluids experience turbulent flow as they pass through the internal motor conduit. The combined cooling from both passes past the motor provides advantages such as prolonged motor life, increased horsepower density and/or greater electrical efficiency. It often provides combinations of these benefits.

[0022] Surprisingly, these benefits are achieved despite the fact that the production fluids are forced through a reduced diameter area as they pass through the internal motor conduit. Additional energy is needed to accomplish this, which normally would be expected to increase operating costs and contribute to additional temperature rises. Unexpectedly, it has been found that this penalty is significantly offset by the benefits of additional heat removal that is achieved by flowing the production fluids past the motor twice.

[0023] In a third aspect, this invention is a method of pumping fluids with a submergible pumping system including a pump and an electrical motor, wherein the pumping system is submerged in said fluid such that production fluids entering the pumping system pass in fluid contact with exterior portions of the electrical motor and remove heat therefrom before entering the production fluid intakes, wherein the exterior portions of the electrical motor or the interior portions of a surrounding shroud include vortex generators adapted to impart streamwise vorticity to the production fluids as they pass in fluid contact with the exterior portions of the electrical motor. This aspect of the invention provides an economical means for substantially increasing the efficiency of heat removal from the motor. This aspect of the invention can be incorporated into the first and second aspects of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] **FIG. 1** is a schematic view of two conventional ESP systems

[0025] **FIG. 2** is a cross-sectional view of an embodiment of this invention.

[0026] **FIGS. 3 and 3**A represent a schematic view and detail of an embodiment of a motor having vortex generators for use in preferred aspects of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0027] In this invention, a submergible pumping system is used to pump a fluid. The system includes a pump and an electrical motor. The electrical motor has an internal conduit and said pumping system is adapted to pump said fluid through said internal conduit. The pumping system is submerged in the fluid such that production fluids entering the pumping system pass exterior portions of the electrical motor and remove heat therefrom before entering the production fluid intakes, and said production fluids then pass through the internal conduit of the electrical motor as the fluid is pumped, and remove additional heat from the motor. The conditions of the fluid flow are preferably such that the fluid flow is turbulent, has streamwise vortices, or both as the fluid passes the exterior portions of the electrical motor, and is turbulent as it passes through the internal conduit.

[**0028**] Typically, the pumping system is installed in a well, or else has a mechanical means for inducing the fluid to pass in fluid contact with exterior portions of the electrical motor. An example of such a mechanical means is a shroud which partially covers the pumping system, and has an opening to the fluid being pumped at the opposite end of the pumping system from where the production fluid intakes are located. This shroud permits the fluids to pass in fluid contact with the exterior portions of the electric motor and enter the production fluid intakes. The spacing between the shroud and the exterior portions of the electrical motor is preferably such that the fluids exhibit turbulent flow as they pass in fluid contact with the exterior of the motor and do not impair installation in the well or create excessive head loss. Alternatively, or in addition, vortex generators impart streamwise vortices to the production fluids as they flow through the spacing between the shroud and the exterior portions of the electrical motor.

[**0029**] In preferred embodiments of the invention, the pumping system is installed in a well. The well may be vertical, horizontal, or a so-called “divert” type. The well has a casing that has perforations through which production fluids enter the well. The pumping system includes an electrical motor having an internal conduit. In preferred embodiments, the internal conduit functions as the drive shaft of the motor, rotating when the motor is operated to drive the pump. The pumping system has production fluid intakes through which the production fluids enter. These are located below (in the case of a horizontal well, downstream of) said electrical motor. The pumping system is adapted to pump said production fluids through the internal conduit of the electrical motor and then on to the wellhead.

[**0030**] By “production fluids”, it is meant any fluids which are desired to be withdrawn from the well. Examples of such fluids include water, oil, natural gas, and the like, with liquids being of particular interest and oil being of special interest.

[**0031**] By “perforations”, it is merely meant openings in a well casing through which the production fluids enter the well. No particular configuration or method of forming these openings is critical to the invention. The pumping system is located below at least some of the perforations in the casing. Thus, production fluids entering those perforations that are above the pumping system flow in fluid contact past the exterior portions of the electrical motor and into the production fluid intakes, by force of gravity and/or the action of the pumping system. In general, the pumping system should be below enough of the perforations that sufficient production fluids pass the exterior of the electrical motor to provide a cooling effect. Preferably, at least half of the production fluids will pass by the exterior of the motor before entering the production fluid intakes. More preferably, the pumping system is below substantially all of the perforations, and substantially the entire volume of production fluids passes in fluid contact with the exterior of the motor. This tends to maximize the desired cooling effect. Having the pumping system below substantially all of the perforations also facilitates separation of gaseous and liquid production fluids before the liquids enter the pumping system. This will increase the production rate when the well produces a mixture of gasses and liquids. Having the gasses circumvent the pump avoids various associated problems such as gas-lock or pumping inefficiencies that are attributable to entrained gasses. As gasses have lower heat capacities than liquids, having the gasses circumvent the motor in this manner further improves heat transfer and, thus, motor cooling. Additionally, without oversized equipment or a gas separator typically used in a system installed above the perforations, no significant additional power is consumed.

[**0032**] The pumping system includes an electrical motor and a submergible pump that is driven by the electrical motor. The motor and pump may have a unitary structure (i.e., share a common housing), but it is often preferred that they are separate units which are connected together directly or indirectly as they are installed in the well.

[**0033**] Two embodiments of the process of the invention are illustrated in **FIG. 2**. In **FIG. 2**, well casing **210** extends along the periphery of well **201**, which as shown has been bored through a producing subterranean rock stratum **440** and into a lower, non-producing subterranean rock stratum **441**. Producing stratum **440** contains production fluids that are to be pumped to the well head. Casing **210** includes perforations **211** through which the production fluids are admitted into the well for pumping to the surface.

[**0034**] Located within casing **210** is a pumping system that includes motor **220** and pump **230**. Both motor **220** and centrifugal pump **230** are located below perforations **211**. Motor **220** is affixed to production pipe **250**, which is shown in section. If desired, production pipe **250** can take the form of a coiled tube. Motor **220** is shown in section to reveal drive shaft **221**, which rotates when motor **220** is operated to provide motive force to operate pump **230**. Motor **220** contains an internal conduit through which the production fluids pass on their way to the wellhead. In **FIG. 2, a** preferred type of conduit is shown, in which drive shaft **221** is hollow to permit the production fluids to flow through it and then into production pipe **250**. Drive shaft **221** is mechanically connected, directly or indirectly, to pump **230** in a manner such that pump **230** is operated when drive shaft **221** is rotated. As shown, pump **230** is directly connected to drive shaft **221**, without intermediate apparatus. However, it may be desirable to include various types of intermediate apparatus such as a sealing section between motor **220** and pump **230**. The manner through which motor **220** is affixed to production pipe **250** and pump **230** is not critical; a variety of fasteners, interlocking devices and the like can be used. Power is provided to the motor from the wellhead through a cable or similar device, which is not shown.

[**0035**] Intake **260** is attached to pump **230**. When the pumping system is activated, drive shaft **221** rotates substantially along its longitudinal axis, driving the action of pump **230**. Production fluids enter the pumping system through intake **260** and enter pump **230**. Drive shaft **221** is in liquid communication with production pipe **250** and pump **230**, so that fluids pumped upwardly by pump **230** pass through hollow shaft **221** and then enter production pipe **250** through which they are delivered to the wellhead.

[**0036**] Because motor **220** is below perforations **211**, production fluids that enter well **201** flow in fluid contact past the exterior of motor **220** before entering intake **260**. This can be due to simple gravity, the pumping action of pump **230**, or some combination of these. Arrows **290** indicate the direction of flow of the production fluids. As the production fluids must flow between well casing **210** and motor **220**, the motor is somewhat smaller than the diameter of well casing **210**, creating an annulus through which the production fluids can move. As the production fluids move in fluid contact past the exterior portion of motor **220**, they remove waste heat and thus provide cooling.

[**0037**] As the production fluids then are pumped through the conduit in motor **220** (in the embodiment of **FIG. 2**, through drive shaft **221**), they remove additional waste heat and thus provide additional cooling. The embodiment of **FIG. 2** is a so-called "inverted" pumping system in which the motor is above the pump. Although this is preferred, it is not critical to the invention, and **FIG. 2A** illustrates an embodiment in which the motor is below the pump. In **FIG.** 2A, well **201**A has casing **210**A. The pumping system includes production pipe **250**A, pump **230**A, motor **220**A and intake **260**A. Motor **220**A includes drive shaft **221**A that is hollow and thus forms the internal conduit through which production fluids pass. As before, drive shaft **221**A is in mechanical communication with pump **230**A so that as motor **220**A operates, drive shaft **221**A causes pump **230**A to operate and pump the production fluids into production pipe **250**A and up to the wellhead. In the embodiment shown in **FIG.** 2A, production fluids enter the well through perforations **211**A, travel past the exterior of motor **220**A, enter intake **260**A, travel upwardly through the conduit in drive shaft **221**A through pump **230**A and then through production pipe **250**A to the wellhead. Motor **220**A is cooled twice by the production fluids; once as they pass in fluid contact with the exterior of motor **220**A and again as they pass through the internal conduit in motor **220**A (hollow drive shaft **221**A).

[**0038**] The pumping system may contain additional elements as may be necessary or desirable in any particular application. For example, seal chamber sections are often provided in pumping systems for deep hole wells. Such seal sections may also carry pump thrust and can perform additional functions as well, as described by Brookbank in "Inverted Pump Systems Design and Applications", ESP Workshop, Houston, Apr. 26-28, 2000. As described by Brookbank, the functions performed by the seal chamber section can be divided among several pieces of apparatus if desired. In this invention, a seal chamber section or other device for carrying pump thrust is preferably part of the pumping system. In so-called "inverted" embodiments, it is preferred that some means of carrying pump thrust is included in the pump or motor design or as a separate piece of apparatus above or below the pump. If desired, seal sections may be located above the pumping system, or between the motor and the pump. Any apparatus situated between the motor and pump must be adapted so that motive force is transmitted through the apparatus from the motor to the pump, and so that production fluids travel through internal conduits in the motor, as described above.

[**0039**] Similarly, apparatus such as sand skirts, packers, various types of connectors and the like can be incorporated into the pumping system or used in conjunction with the pumping system. The pumping system may contain anti-cavitation devices like a primer pump to prevent cavitation of the fluid in the hollow rotor shaft or pump. These may be especially useful in configurations where the pump is above the motor.

[**0040**] In producing deep bore wells, it is common practice to use a pumping system that is made up of separate components of a relatively short length. This approach can be adopted in the process of this invention as well. The motor, pump, intakes, seal sections and other apparatus may be constructed as two or more separate sections that are connected together to form the overall pumping system.

[**0041**] A wide variety of electrical motor designs can be used in the pumping system of the invention, provided that the motor contains an internal conduit through which the production fluids can flow to provide cooling and/or vortex generators in the annulus between the motor and the well casing or shroud. Induction motors and brushless DC motors are useful, among others. The internal conduit is preferably a bore in a longitudinal drive shaft, as shown in **FIGS. 1 and** 2A. Suitable motors of that type are described in U.S. Pat. Nos. 5,951,262 and 6,000,915, both to Hartman, both incorporated herein by reference in their entirety. No special motor design is required, except that (1) it is adapted for submergible applications (2) it contains the internal conduit as described herein and (3) it is of a size and shape to fit within the well casing and allow production fluids to pass in fluid contact with the exterior of the motor. Conventional electric motors as are commonly used for downhole pumping applications can be used, if they are adapted to provide them with an internal conduit through which the production fluids can be pumped. In its simplest case, the motor can be any submergible electric motor having a longitudinal, rotating drive shaft, in which the drive shaft has a longitudinal bore. Conventional electric motors having a longitudinal bore in some cases can be retrofitted for use in this invention simply by boring out the drive shaft to form the internal conduit.

[**0042**] The motor may be a single piece or a tandem configuration. Multiple motors can be used and, if desired, pumps can be placed both above and below the motor. Seal sections and other components may be installed between the motor and pump.

[**0043**] As the motor will be submerged in the production fluids, it is preferably adapted to operate in those conditions: The motor preferably will contain a motor fluid that provides lubrication but more importantly retards the leakage of production fluids into the motor. The motor fluid may also contain various well-treating materials such as scale inhibitors, emulsifiers, anti-emulsion agents, surfactants, water, and the like. Various types of seals can be incorporated into the motor to retard the leakage of production fluids into it, and as mentioned above, seal chamber sections can be used to accommodate thermal expansion of the motor fluid and help equalize pressure between the inside and outside of the motor.

[**0044**] In a preferred type of motor, the motor fluid is at a positive pressure relative to the exterior of the motor and has leaking seals, so that motor fluid slowly leaks from the motor into the production fluid. A source of fresh motor fluid is provided, either from a reservoir in the pumping system or through a tube or capillary system from the wellhead. By maintaining a positive motor fluid pressure, displacement of the motor fluid by the production fluids can be reduced or eliminated, and motor life can be prolonged. A pressure independent modulating flow control valve, such as a Sko-Flo™ SubSea valve is suitable for maintaining a suitable positive pressure and flow of fresh lubrication fluid into the motor.

[**0045**] A particularly preferred motor has vortex generators on its exterior surface, or else is enclosed within a shroud that has vortex generators on its interior surface. The vortex generators operate to generate streamwise vortices in the production fluids as they pass the exterior of the motor. The vortex generators are preferably static devices having geometry and dimensions such that when the production fluids flow through and past the generators, a swirl in the flow is imparted. These streamwise vortices greatly improve heat transfer from the exterior of the motor to the production fluids, even further increasing the benefits of this invention.

[**0046**] An example of a motor containing vortex generators is schematically illustrated in **FIG. 3**. Well **300** has casing **310** and perforations **311**. The internal diameter of well **300** is D. Motor **320** and centrifugal pump **330**, each having a diameter d, are disposed in the well. Motor **320** is affixed to production pipe **350**, which extends to the wellhead. Shaft **321** connects motor **320** and pump **330**, in the same manner as described with respect to **FIG. 2**. Pump **330** includes intake **360**, where production fluids enter the pumping system. In the embodiment shown, production fluids enter the well at perforations **311**, flow past the exterior of motor **320**, into intake **360**, up shaft **321** through motor **320** and up through production pipe **350** to the well head, as indicated by arrows **390**.

[**0047**] In the embodiment shown in **FIG. 3**, the exterior surface of motor **320** has vortex generators. An alternative arrangement would be to surround motor **320** in a shroud that has vortex generators on its interior surface. In the embodiment in **FIGS. 3 and** 3A, the vortex generators take the form of a plurality of fins **366**. Fins **366** are slightly offset to the direction of flow of the production fluids, and adjacent fins **366** are offset in opposite directions. Thus, each pair of fins **366** define a gap which narrows in the direction of flow. The dimensions of fins **366** and the offset angle are sufficient to create streamwise vortices in the production fluids as they flow past the fins.

[**0048**] Suitable offset angles are typically +/− 10-30, preferably 10-20 degrees from the direction of flow of the production fluids. Suitable dimensions for fins **366** are illustrated in **FIG. 3A**. In **FIG. 3**, the gap between motor **320** and well casing **311** is defined by (D−d)/2, where D and d are as described before. A suitable fin **366** will extend outwardly from the exterior of motor **320** (or inwardly from the exterior surface of a surrounding shroud) approximately ⅓-¾ of the width of the gap between the motor and well casing or, when a shroud is used, between the motor and interior surface of the shroud; in **FIG. 3A** an especially preferred dimension of ½ the gap width is illustrated. In **FIG. 3**, numeral **325** designates either the exterior surface of the motor or the internal surface of a surrounding shroud. As shown in **FIG. 3**A, fin **366** is preferably beveled with increasing width in the direction of flow, reaching its maximum width at a point approximately ⅓-¾ down its length. However, if desired, leading edge **399** can take other shapes, including those shown in outline in **FIG. 3A**. Overall length is preferably about 1 to about 4, more preferably about 1.5 to about 3 times the width of the gap. In **FIG. 3**A, the length is shown as 2 times the gap width.

[**0049**] In the embodiment shown in **FIG. 3**, two rows of fins **366** are used. A single row can be used, or greater than two rows can be used. When multiple rows are used, a preferred spacing between the rows is about 10-30 times the gap distance. However, the spacing may be adjusted to trade off pressure loss with heat transfer.

[**0050**] Other suitable vortex generator designs can be used, such as are described, for example, by Paulie and Eaton, Report #MD51, August 1988, "The Fluid Dynamics and Heat Transfer Effect of Streamwise Vortices Embedded in a Turbulent Boundary Layer".

[**0051**] The pump itself has no special design requirements, other than it is adapted to pump production fluids through the internal conduit of the motor (in an inverted system) or from the internal conduit of the motor (in a conventional configuration). Generally, the particulars of the pump design will be selected to fit the particular application. The pump is typically in liquid communication with the internal conduit of the motor. This is accomplished by building the pump and motor as a single unit or incorporating the pump into the motor, as described in U. S. Pat. Nos. 5,951,262 and 6,000,915, by designing the pump to mate with the internal conduit of the motor, or in some other manner. Pumps of the type conventionally used in ESPs are entirely suitable, and can easily be adapted for use in this invention through the design of the connection between the pump outlet (or inlet) and the motor. Progressive cavity pumps are also preferred types. The pump may be one piece or in tandem sections. Multiple pumps may be used. If desired, separate pumps can be provided above and below the motor.

[**0052**] The method of this invention is useful in a variety of wells, including water, oil and natural gas wells. The pumping method is particularly adapted for wells where, using a conventional ESP, any flow of production fluids through the annulus between the motor housing and the well casing would be expected to be laminar. Wells of this type include those having well conditions such as high gas content, high viscosity production fluids, the formation of emulsions, low flow rates, multiphase flows, deviated and horizontal wells and increasing well depth, especially in the oil industry. The well operator can take advantage of the enhanced heat transfer and improved cooling of the motor in several ways. At equivalent power usage, the motor will be more efficiently cooled, and the operating temperature will be lower. The operator may choose to take advantage of this lower operating temperature to prolong the motor life. The lower temperature also tends to reduce electrical resistance, thus allowing equivalent work to be done with less power consumption. Conversely, the operator may elect to increase the power to the motor so that it runs at higher temperatures similar to those that would be experienced in prior art processes. In this case, the operator chooses to forego longer motor life in return for higher production rates that are achieved because of the additional power that is used.

[**0053**] In order to increase cooling efficiency as the production fluids flow through the motor, it is preferred to operate under conditions that produce turbulent flow within the internal conduit. More preferably, there is turbulent flow both inside the conduit, and turbulent flow or streamwise vortices in the annulus between the motor housing and the well casing where the production fluid passes in contact with the exterior of the motor. Turbulent flow can be expressed in terms of Reynolds number (a dimensionless parameter), which is a function of the average fluid velocity, kinematic viscosity of the fluid and diameter of the internal conduit. A Reynolds number of about 2300 or higher is typically indicative of turbulent flow. Preferably, flow conditions of the production fluids through the internal conduit of the motor is such that the Reynolds number is at least about 3000. A Reynolds number in excess of 5000 to 10000 is more preferred.

[0054] Another parameter, Nusselt number, is a dimensionless measure of heat transfer. The Nusselt number is a function of the Reynolds number, the Prantl number, and the absolute viscosity of the bulk fluid and fluid at the wall. With turbulent flow, a high Nusselt number (exceeding 10) represents a high heat transfer rate for a given temperature difference. The more turbulent the flow the higher the Reynolds and the Nusselt numbers. With laminar flow, low Nusselt numbers (below 5) are indicative of poor convective heat transfer. Enhanced heat transfer from the motor to the production fluid can be expected when the Nusselt number is at least 10, preferably at least 50, and the method of the invention is preferably operated under conditions that achieve such Nusselt numbers.

[0055] Operating conditions preferably are also chosen so as to provide a Brinkmann number (another dimensionless parameter) of less than 2, preferably less than 0.5. The Brinkmann number indicates the direction of heat transfer within a viscous fluid. It is a function of the average velocity of the fluid, its absolute viscosity, the thermal conductivity of the fluid and the temperature difference between the fluid and the inside wall of the internal conduit. When conditions are such that the Brinkmann number is less than 2, heat will travel from the hot motor to the cooler production fluid and fluid friction will not add additional heat to the motor. Viscous dissipation effects are negligible, when the Brinkmann number is less than 0.5.

[0056] When the internal conduit is the drive shaft of the motor, operating conditions can be further described with reference to a Rossby number (still another dimensionless parameter). The Rossby number provides an indication as to whether spinning flow will or will not dominate axial flow in the internal motor conduit. Conditions generating a Rossby number of at least about 0.5, preferably at least about 1.0 are preferred. The Rossby number is a function of average fluid velocity, fluid angular velocity and the diameter of the internal conduit.

[0057] Yet another advantage of this invention is that it permits gaseous production fluids to separate from liquids before entering the pumping system. Gasses entering the well through perforations above the pumping system will tend to travel directly upward to the wellhead without passing through the pumping system, due to the natural buoyancy of the gasses. Liquids will flow downwardly and enter the pumping system, without significant entrained gas, for delivery to the wellhead. Thus, a ready separation of production gasses and production liquids is made. Because the pumping system will process less gas, pumping problems and inefficiencies associated with pumping mixtures of gasses and liquids are largely mitigated. Moreover, by eliminating the need for oversized equipment or a gas separator in a typical system installed above the perforations, no additional failure modes or power losses are introduced.

What is claimed is:

1. A method of pumping a fluid with a submergible pumping system including a pump and an electrical motor, wherein

(a) the electrical motor has an internal conduit and said pumping system is adapted to pump said fluid through said internal conduit, and

(b) the pumping system is submerged in said fluid such that production fluids entering the pumping system pass in fluid contact with exterior portions of the electrical motor and remove heat therefrom before entering the pumping system, and said liquid production fluids then pass through the internal conduit of the electrical motor as the fluid is pumped, and remove additional heat from the motor.

2. A method for producing fluids from a well having a casing that contains perforations through which production fluids enter the well, comprising

(a) positioning an electrical submergible pumping system including an electric motor within said casing such that the electric motor is at or below or downstream of at least some of said perforations, and

(b) pumping production fluids from the well with said pumping system,

wherein

(1) the pumping system includes a pump, an electrical motor having an internal conduit and production fluid intakes located below said electrical motor, said pumping system being adapted to pump said production fluids through said internal conduit of the electrical motor,

(2) production fluids entering the well through at least some of the perforations in the casing pass in fluid contact with exterior portions of the electrical motor and remove heat therefrom before entering the production fluid intakes, and

(3) production fluids pass through the internal conduit of the electrical motor as the fluid travels to the wellhead, and remove additional heat from the motor.

3. The method of claim 2 wherein the production fluids pass through the internal conduit of the electrical motor under conditions of turbulent flow.

4. The method of claim 3 wherein the internal conduit takes the form of a hollow drive shaft.

5. The method of claim 4 wherein the electrical motor is located between the wellhead and the pump.

6. The method of claim 5 wherein production fluids entering the well through the perforations in the casing travel downward in fluid contact past exterior portions of the electrical motor to an intake, and the liquid production fluids are subsequently pumped upwardly through the internal conduit of the electrical motor and then to the wellhead.

7. The method of claim 6, wherein the flow of production fluid through the internal conduit is characterized by a Reynolds number of at least 2300.

8. The method of claim 7, wherein the motor contains a motor fluid at a positive pressure to the exterior of the motor, and has seals which allow motor fluid to leak into the production fluid.

9. The method of claim 7, wherein conditions are selected such that heat transfer from at least one of the internal conduit and the exterior surfaces of the motor to the production fluid is characterized by a Nusselt number of at least 10.

10. The method of claim 7 wherein the internal conduit is the drive shaft of the motor, and conditions are selected so as to generate a Brinkmann number of less than 2.

11. The method of claim 7 wherein the internal conduit is the drive shaft of the motor, and conditions are selected so as to generate a Rossby number of more than 0.5.

12. The method of claim 4 wherein the pump is located between the wellhead and the electric motor.

13. The method of claim 4 wherein electrical submergible pumping system contains two pumps, one of which is located above the electric motor and one of which is located below the electric motor.

14. A method of pumping fluids with a submergible pumping system including a pump and an electrical motor, wherein the pumping system is submerged in production fluids such that said fluids flow across vortex generators adapted to impart streamwise vorticity to the production fluids as the pass in fluid contact with the exterior portions of the electrical motor.

15. The method of claim 14 wherein the vortex generators are attached to the exterior portions of the electric motor.

16. The method of claim 14 wherein the vortex generators are attached to the interior surface of a motor shroud.

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