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(57) **Abrégé(suite)/Abstract(continued):**

overhead gravity drainage (COGD). The PIHC, by developing horizontal and vertical transmissive zones predispose a viscous oil reservoir to develop a conformable combustion chamber. Good conformance of the combustion chamber enhances recovery factor and improves well operations in the field for in-situ combustion applications.

ABSTRACT

A pre-ignition heat cycle (PIHC) using cyclic steam injection and steam flood techniques is described that improves the recovery of viscous hydrocarbons from a subterranean reservoir using an overhead in-situ combustion technique such as combustion overhead gravity drainage (COGD). The PIHC, by developing horizontal and vertical transmissive zones predispose a viscous oil reservoir to develop a conformable combustion chamber. Good conformance of the combustion chamber enhances recovery factor and improves well operations in the field for in-situ combustion applications.

SYSTEM AND METHOD FOR ENHANCED OIL RECOVERY FROM COMBUSTION OVERHEAD GRAVITY DRAINAGE PROCESSES

FIELD OF THE INVENTION

[0001] A pre-ignition heat cycle (PIHC) using cyclic steam injection and steam flood techniques is described that improves the recovery of viscous hydrocarbons from a subterranean reservoir using an overhead in-situ combustion technique herein referred to as combustion overhead gravity drainage (COGD). The PIHC, by developing horizontal and vertical transmissive zones predispose a viscous oil reservoir to develop a conformable combustion chamber. Good conformance of the combustion chamber enhances recovery factor and improves well operations in the field for in-situ combustion applications.

BACKGROUND OF THE INVENTION

[0002] In-situ overhead combustion methods are generally known as an enhanced recovery technique for the recovery of hydrocarbons from subterranean high viscosity/low mobility reservoirs. Such reservoirs are known to exist in the tar sand formations of Alberta, Canada and in Venezuela, with lesser deposits existing in the United States. In-situ overhead combustion methods are referred to in the literature as combustion overhead or split stream horizontal processes.

[0003] In-situ overhead combustion techniques typically utilize an array of vertical air injection wells and vertical gas vent wells positioned high in the reservoir with a horizontal oil production well or drain located lower in the reservoir (See Kisman & Lau, JCPT, March 1994, Volume 33, No. 3; Canadian Patent 2096034; Pebdani & Ostapovitch; U.S. Patent No. 5,211,230). With this technique, the hydrocarbons in the reservoir are ignited and an oxygen containing gas is supplied via the injection wells to sustain combustion in the reservoir such that the combustion front burns downwards towards the horizontal drain. The heat created increases the temperature of the reservoir such that various upgrading reactions occur, the viscosity of the hydrocarbons is reduced and reservoir water is vaporized to steam. The heated hydrocarbons having a

decreased viscosity, and any upgraded oils, then flow by means of gravity to one or more horizontal drains located low in the reservoir. Due to the arrangement of the drains, injection wells and vent wells, overhead combustion applications are generally described as gravity stable as the lighter components inherently separate from the heavier components and wherein the heavier components generally flow downward towards the drains.

[0004] Overhead combustion techniques typically address the problem of combustion front override that may occur with other in-situ combustion techniques by injecting oxygen containing gas high in the reservoir to support combustion and evacuating melted bitumen and condensed steam from a position low in the reservoir, thereby segregating the gas from the bitumen and water. Since the combustion chamber occupies the top portion of the reservoir and moves downward toward the horizontal drain, the combustion gases can be readily directed toward vent wells located high in the reservoir on the flank of the reservoir segment as the melted bitumen and condensed steam flow downwards under the effect of gravity. The interface between injected air and melted bitumen is maintained by the difference in density between the two substances and by gravity. In normal COGD operations, gases do not typically reach the horizontal drain in large quantities and liquids do not typically flow to the vent wells.

[0005] With in-situ combustion techniques, reaction kinetics are typically managed by controlling the volume of air injected into the reservoir via the injection wells and controlling the volume of air and combustion gas vented from the reservoir via the producing wells. As the evacuation of air and melted bitumen is segregated in overhead combustion processes, it is usually easier to manage the reaction kinetics of an overhead combustion process as the flux of injected gas can be maintained by adjusting the pressure of the reservoir at the injection wells and vent wells without impacting the draining of melted oil and condensed water at the horizontal drain. Similarly conformance of the combustion chamber can be optimized by adjusting pressure at the injection and vent wells. As known to those skilled in the art, the symmetry and/or shape of the combustion chamber is an important factor in improving the overall efficiency of the process. More specifically, in overhead combustion processes, it is desirable to have good conformance of the combustion chamber in order to maximize the displacement of melted bitumen and minimize cycling of injected gases. If cycling of injected gas can be minimized then residence time in the reservoir for combustion gases can be increased.

More specifically, residence time in the hot reservoir can provide for complete combustion of flammable gas by-products that would otherwise be produced to surface as contaminants. Typical flammable gas by-products of in-situ combustion include methane, carbon monoxide and hydrogen sulphide. In addition, it is desirable to minimize the cycling of injected gas due to impact of gas cycling on the operating costs.

[0006] In general, it has been found that developing transmissive pathways within a viscous oil reservoir prior to ignition of an overhead combustion process results in higher conformance for the combustion chamber, superior well operating conditions and better reaction kinetics than when no transmissive pathways are formed pre-ignition.

[0007] Accordingly, there has been a need for methods for predisposing a viscous oil reservoir to form a conformable gravity stable combustion chamber using cyclic steam injection and steam flood techniques specifically to develop lateral and vertical hot fluid transmissive zones.

SUMMARY OF THE INVENTION

[0008] In accordance with the invention, there is provided a method of preparing a viscous oil bearing reservoir for in-situ overhead combustion by developing transmissive pathways in the reservoir prior to igniting the reservoir, wherein the reservoir well network comprises one or more injection wells and one or more vent wells located in the top portion of the reservoir and a horizontal drain located in the bottom portion of the reservoir, wherein the method comprises the steps of:

injecting steam into one or more injection wells while imposing a pressure drawdown on the one or more vent wells;

injecting steam into the one or more vent wells while imposing a pressure drawdown on the one or more injection wells; and,

providing for cyclic reversal of steam injection and a pressure drawdown between the one or more vent wells and the one or more injection wells until a lateral transmissive zone is established in the top portion of the reservoir between the one or more injection wells and the one or more vent wells.

[0009] In a further embodiment, the invention further includes the steps of circulating steam into the horizontal drain to increase oil mobility in the region of the reservoir around the horizontal drain; and injecting steam into the one or more injection wells while shutting in the one or more vent wells and evacuating fluids from said horizontal drain until a vertical transmissive zone is established between the one or more injection wells and the horizontal drain.

[0010] In further embodiments, the steam is injected at a rate that yields a circulating pressure in the reservoir below fracture pressure or, depending on reservoir conditions, the steam is injected at a rate that yields a circulating pressure in the reservoir exceeding fracture pressure.

[0011] In another embodiment, the conformance of the transmissive zones is adjusted by control of injection and drawdown pressures during each step.

[0012] In yet another embodiment, after ignition, the lateral transmissive zones enable the combustion chamber to expand laterally through the lateral transmissive zones.

[0013] In yet another embodiment, the progression of the lateral transmissive zones is indirectly monitored from temperature data obtained from one or more observation wells in contact with the reservoir and/or from pressure communication data derived from pressure readings between the one or more injection wells and the one or more vent wells.

[0014] In one embodiment, steam is circulated between a heel tubing string and a toe tubing string in the horizontal drain to effect heating of the reservoir.

[0015] In another embodiment, progression of the vertical transmissive zone is monitored from pressure communication data derived from pressure readings between the one or more injection wells and the horizontal well.

[0016] In yet another embodiment, the invention includes the step of monitoring temperature data from the reservoir from one or more observation wells adjacent the one or more injection wells.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The invention is described with reference to the accompanying figures in which:

Figure 1 is a perspective schematic view of a typical overhead in-situ combustion well network as described in the prior art;

Figure 2 is a cross-sectional view of a well network representing a portion of the well network shown in Figure 1;

Figure 3 is a section view of a well network having horizontal and vertical transmissive paths after a pre-ignition heat cycle has been completed in accordance with the invention;

Figure 4 is a section view of a well network undergoing a pre-ignition heat cycle in accordance with a first phase of the invention;

Figure 5 is a section view of a well network undergoing a pre-ignition heat cycle in accordance with a second phase of the invention;

Figure 6 is a section view of a well network undergoing a pre-ignition heat cycle in accordance with a third phase of the invention.

Figure 7 is a section view of a well network undergoing a pre-ignition heat cycle in accordance with a fourth phase of the invention;

Figure 8 is a completion design of a vent well and injection well;

Figures 9A and 9B are representative simulation model outputs showing produced volumes for oil, gas and water during combustion operations for a process using a pre-ignition heat cycle in accordance with one embodiment of the invention (Figure 9A) as compared to an overhead combustion process as described in the prior art (Figure 9B); and,

Figure 10 is a simulation model output showing cumulative produced volumes of bitumen and oil recovery factors expressed as percent using a pre-ignition heat cycle in accordance with one embodiment of the invention and compared to an overhead combustion process as described in the prior art.

DETAILED DESCRIPTION

Overview

[0018] With reference to the figures, a pre-ignition heat cycle (PIHC) to prepare a viscous oil reservoir for a gravity stable overhead in-situ combustion process is described.

[0019] Figure 1 shows a well network pattern typically used in gravity-stable overhead in-situ combustion processes as described in the prior art. The overburden has not been shown for ease of reference. For the purposes of illustration, the reservoir 1 generally has dimensions of approximately 150 m width, 500 m length and 28 m thickness. The well network includes approximately four vertical injection wells 2, six vertical vent wells 3, a horizontal drain 4 and approximately four vertical observation wells 5. It is understood that the techniques described herein can be applied to overhead combustion systems having different dimensions and well networks as understood by one skilled in the art.

[0020] Figure 2 shows a section view of the well network from Figure 1. The injection well 2 and vent wells 3 are drilled and completed in the top section of the reservoir 1. The horizontal drain 4 is located in the bottom section of the reservoir and the observation well 5 is drilled and completed in the bottom section of the reservoir. Reference within this description to the injection well, vent well and observation well are understood to include all injection wells, vent wells and observation wells in the well network.

[0021] The PIHC prepares the low mobility reservoir for ignition in an in-situ overhead combustion process by developing a lateral hot fluid transmissive path 15 in the top section of the reservoir and a vertical hot fluid transmissive path 17 from the top section of the reservoir to the horizontal drain located in the bottom section of the reservoir as shown in Figure 3.

[0022] The purpose of the lateral hot fluid transmissive path is to provide communication between the injection wells 2 and vent wells 3. The development of a lateral hot fluid transmissive path facilitates the flow of combustion gases between the injection wells and vent wells such that the combustion gases do not flow preferentially to the horizontal

drain 4. This segregation allows for greater conformance for the combustion chamber by drawing the combustion front towards the vent wells 3. Operating conditions for the horizontal drain 4 are also improved by the segregation of combustion gas high in the reservoir. Specifically, good reservoir conformance of the combustion chamber enables the combustion front to mobilize the largest possible quantity of melted bitumen and minimize cycling of injected gas.

[0023] The purpose of the vertical hot fluid transmissive path is to provide communication between the injection well 2 located high in the reservoir and the horizontal drain 4 located low in the reservoir to facilitate the flow of melted bitumen and condensed steam toward the horizontal drain, by means of gravity, during combustion operations. Absent sufficient mobility between the injection well and the horizontal drain, a clear evacuation path is not available for melted bitumen. If melted bitumen cannot drain away from the combustion chamber, air flux may be insufficient to sustain combustion and development and conformance of the combustion chamber will be poor. Therefore the ready evacuation of melted bitumen by gravity drainage allows for the formation of a conformable combustion chamber such that efficient and effective combustion operations can occur.

[0024] The development of the lateral and vertical hot fluid transmissive paths during the PIHC involves several steps:

- a. Injecting a steam slug 14 into the injection well 2 and imposing a pressure drawdown on the vent wells 3, as shown in Figure 4;
- b. Injecting a steam slug 14 into the vent wells 3 and imposing a pressure drawdown on the injection well 2 as shown in Figure 5;
- c. Cyclic reversal of steam injection and pressure drawdown between the vent wells 3 and the injection well 2;
- d. Circulating steam 16 into the horizontal drain 4 to create mobility around the horizontal drain as shown in Figure 6; and
- e. Injecting a steam slug 14 into the injection well 2 while shutting in the vent wells 3, as shown in Figure 7.

Forming a Lateral Transmissive Pathway

[0025] The first phases of the PIHC are designed to form a lateral hot fluid transmissive path linking the injection well 2 and the vent wells 3 in the top of the reservoir 1 such that the lateral hot fluid transmissive path has saturations and temperatures that are conducive to the flow of combustion gases. As known to those skilled in the art, the quantity of steam required to form the desired saturations and temperatures will be determined on a case by case basis from field data records. For example, if the top of the reservoir is 100 % water saturated and has good porosity/permeability then combustion gas may flow within the reservoir without preheating and specifically forming a hot fluid transmissive zone. Alternatively, if the top of the reservoir is 100% bitumen saturated with poor porosity/permeability then the lateral transmissive path may not be successfully formed by steam injection. In most cases, steam heating will be required to enable efficient flow of combustion gases to the vent wells.

[0026] In the first phase of the pre-ignition heat cycle, as shown in Figure 4, steam slugs 14 are continually injected into the reservoir via the injection well 2 until the pressure in the reservoir becomes prohibitive (i.e. approaching fracture pressures). That is, generally maximum pressures will be utilized to accelerate the distribution of steam without damaging the formation. As steam is injected, the vent wells 3 are subject to a pressure drawdown in order to maximize the pressure differential across the reservoir. During this stage, reservoir fluids, including condensed steam and melted bitumen may be withdrawn from the vent wells during this period of steam injection. No fluids are recovered from the horizontal drain 4 in this phase.

[0027] In the second phase of the PIHC, as shown in Figure 5, the process is continued by reversing the flow and injecting steam slugs 14 into the vent wells 3 while imposing a pressure drawdown on the injection wells 2. Warm reservoir fluids are withdrawn from the injection wells. Steam slugs are injected at a rate such that the pressure in the reservoir does not exceed hydraulic fracture pressure.

[0028] As the PIHC continues, a cyclic steam injection/pressure drawdown process is maintained between the injection wells and the vent wells in accordance with good engineering/field practice. As steam is injected in the injection well, a pressure drawdown is imposed on the vent well, and vice versa in cyclical fashion until pressure

communication is observed between the injection wells 2 and vent wells 3. Once pressure communication is observed, the development of the lateral hot fluid transmissive zone 15 in the top section of the reservoir is complete, as shown in Figure 6.

[0029] As noted above, the amount of steam and time required to develop the hot fluid transmissive zone 15 is variable. Primarily, the amount of steam and time required will depend on reservoir quality and fluid saturation where the presence or absence of mobile water in the reservoir may provide a zone of naturally enhanced or decreased mobility in the top section of the reservoir which may minimize or maximize the amount of steam injection required to effect pressure communication.

[0030] Naturally enhanced mobility in reservoirs is commonly observed in the Athabasca Oil Sands region in Alberta, Canada and other fluvial estuarine depositional systems. Based on simulation analysis and geological modelling, a total steam injection of between 45,000 m³ and 106,000 m³ (cold water equivalent volumes) of 100 % quality steam at 5200 kPa may be required and/or utilized for applications in the Athabasca Oil Sands region when the horizontal separation between injection well and vent well is in the range of 75m and the reservoir depth is approximately 275 meters. In this situation, the time required to effect pressure communication may be in the order of 6-26 months.

Forming a Vertical Transmissive Path

[0031] As the development of the lateral hot fluid transmissive zone 15 is nearing completion, the development of the vertical hot fluid transmissive zone 17 commences. The steam cycling phase that develops the lateral hot fluid transmissive zone also initiates the development of the vertical hot fluid transmissive zone via conduction and convection processes.

[0032] In the development of the vertical hot fluid transmissive zone, a steam circulation process 16, as shown in Figure 6, is commenced to increase the mobility of the bitumen around the drain. Specifically, steam is circulated into a toe tubing string within the horizontal drain 4 and returned to surface through the heel tubing string of the horizontal drain so as to heat the formation in the region around the drain. Typically, a circulation

period of 1-2 months is needed to warm the region around the horizontal drain 4. Ideally, temperatures are monitored by a thermocouple string within the horizontal well and circulation is continued until a sustained well temperature of 150-200°C is achieved.

[0033] After the steam circulation process is complete, the next phase of the PIHC is initiated. As shown in Figure 7, a steam slug 14 is injected to the injection well 2 while the vent wells 3 are shut-in. In the preferred embodiment, a steam slug of approximately 6000 m³ (cold water equivalent) 100 % quality steam at 4000 kPa is used. Warm reservoir fluids, including melted bitumen and condensed steam, drain into and are recovered from the horizontal drain 4 during this phase. Steam injection continues until good pressure communication is established between the injection well and the horizontal drain. Pressure communication is monitored at each well by detecting significant pressure changes and/or responses at respective wells. Injection pressures are generally substantially below fracture pressure during this phase due to the increased mobility within the reservoir from the existence of the horizontal transmissive pathway and the preheating of the region between the injection wells 2 and the horizontal drain 4.

[0034] Once good pressure communication exists between the injection well and the horizontal drain, a vertical hot fluid transmissive zone 17, as shown in Figure 3, is present linking the injection wells 2 and the horizontal drain 4. The vertical hot fluid transmissive zone has saturations and temperatures that are conducive to the flow of melted bitumen and condensed steam toward the horizontal drain by gravity drainage.

[0035] Once the lateral hot fluid transmissive zone 15 and the vertical hot fluid transmissive zone 17 are developed, the PIHC is complete and the reservoir 1 is ready for ignition.

[0036] During PIHC and after ignition, the observation wells utilize data from thermocouples cemented within the observation wells. The thermocouples generally allow for indirect measurement of the growth of the transmissive zones in the reservoir, the temperature in the overburden as well as progression of the combustion front after ignition. The data obtained from the thermocouples allows the operator to adjust the pressures at the injection and vent wells to control the growth of the transmissive zones.

[0037] In further embodiments, the steam injected into the vent wells, and injection wells during the PIHC process may be injected at such a rate that the injection pressure exceeds hydraulic fracture pressure. This may be necessary to develop the lateral hot fluid transmissive pathways in a timely fashion in certain reservoirs.

[0038] Furthermore, while from a practical perspective it is preferred that the lateral transmissive pathways are established prior to the vertical pathways, the order of establishing the pathways could potentially be reversed.

[0039] More specifically, from an efficiency perspective, it is more important to develop the lateral pathways first as the development of lateral pathways will in effect partially and simultaneously develop the vertical pathways, such that the requirements for the active formation of the vertical pathways would be reduced. That is, the position of the injection well over the horizontal drain together with conduction and convection effects will cause the partial development of the vertical pathways as steam is injected into the injection wells during the creation of the lateral pathways.

Design of Facilities and Equipment

[0040] Referring to Figure 8, a completion design for the injection wells and the vent wells is shown. The completion design includes a casing string 20 set into the top of the reservoir and cemented in place; a cementing diverter tool 21 located in the casing string 20 to facilitate the cementing of the casing string; a tubing string 22 set into a pay section of the reservoir; a coil tubing string 23 set inside the tubing string 22; a thermal packer 24 set in the casing string 20 to isolate the casing annulus 25 (the space between the casing string 20 and the tubing string 22); a perforated joint 26 located below the thermal packer 24; base pipe wire wrap screen 27 for sand control over the liner 28 that comprises the bottom of the casing string 20; and a stab-in plug 29 to isolate the coil tubing string 23 from the tubing string 22. Liquids below the thermal packer 24 may be lifted by gas or steam lift through the coil tubing string 22. Typical dimensions of the completion design components in the preferred embodiment of the invention are shown in Table 1.

Table 1-Typical dimensions of the completion design components for the injection wells and vent wells

Reference Numeral	Completion Design Components	Typical Dimensions
20	Casing String	177.8 mm
22	Tubing String	88.9 mm
23	Coiled Tubing String	60.3 mm
24	Thermal Packer	177.8 mm
26	Perforated Joint	114.3 mm tubing
29	Stab-in Plug	88.9 mm x 60.3 mm

[0041] The principal objectives served by the completion design are:

- a) good communication of the vent well or injection well with the reservoir section;
- b) sand control for high temperature cycling operations;
- c) isolation of the casing annulus 25 from hot corrosive fluids; and
- d) capacity to lift liquids from below the thermal packer 24 using gas injection in the coil tubing string 23.

[0042] The completion design for the injection wells and vent wells are simple, with the option to produce reservoir fluids during the PIHC cycle made available using gas lift.

[0043] The surface facilities required for the PIHC cycle are consistent with current cyclic steam operations that can provide for multiphase flow to and from injection wells and vent wells.

[0044] To simplify operations, the horizontal drain is usually only equipped for production of reservoir fluids.

Simulation Models

[0045] In the preferred embodiment, the PIHC process is used to exploit a zone of naturally enhanced mobility such as is observed in the top of the reservoir section in the Athabasca Oil Sands Region and other fluvial estuarine depositional systems. A zone of enhanced mobility high in the reservoir is commonly observed due to:

- a fining upward depositional sequence that allows for higher observed water saturations providing for the presence of mobile water;
- a charge history that provides for the presence of mobile water high in the reservoir; and,
- an oil viscosity gradient that varies in order of magnitude from the bottom of the reservoir to the top of the reservoir.

[0046] The PIHC process has been numerically simulated to verify the physical principles of the PIHC and to evaluate the improvements relative to the prior art. In order to forecast production performance, a three dimensional (3-D) simulation was prepared to model the PIHC and subsequent in-situ combustion exploitation process. A geological model representative of an actual bitumen reservoir section based on full diameter core, well log and seismic data was used as the base earth model for the simulation (the Earth Model). The reservoir section modelled is characteristic of a well developed, bitumen saturated McMurray sand in the Athabasca Oil Sands Region. The Earth Model included the presence of silt and shale partings and inclined heterolithic strata characteristic of fluvio-estuarine depositional systems.

[0047] In the model the horizontal drain was positioned approximately 9 m above the base of the McMurray sand to avoid a shale parting that would serve as a baffle to vertical fluid movement in the reservoir. Bitumen saturated sands below the horizontal drain did not contribute to the reservoir exploitation cycle. All other dimensions of the model were consistent with the reservoir exploitation section shown in Table 2, Reservoir and Bitumen Properties used in the Simulation Model .

[0048] A commercial simulator (CMG STARS, Computer Modelling Group, Calgary, Alberta) was used as a platform for numerical modelling. CMG STARS simulation

routines handle many aspects of thermal and compositional reservoir modelling including: thermal, k value composition, chemical reactions, geo-mechanics, and combustion reaction kinetics.

[0049] The reservoir rock properties and bitumen properties used in the reservoir simulation are summarized in Table 2 as follows:

Table 2-Reservoir and Bitumen Properties used in the Simulation Model

Reservoir Property	Units	Value
Pay thickness	m	29
Porosity	%	30
Oil Saturation	%	62.5
Gas Saturation	%	0
Solution GOR	m ³ /m ³	4
Horizontal Permeability	mD	3747
Vertical Permeability	mD	2630
Reservoir Temperature	° C	8
Reservoir Pressure	kPa	2500
Rock Compressibility	1/kPa	1e-6
Petroleum Initially-in-place	10 ³ m ³	378.1
Conductivity	j/m.d.C	6.6e5
Heat Capacity	j/m ³ .C	1e6
Oil Properties		
Density	Kg/m ³	1012
Viscosity at 20 °C max	cp	1,103,304
Viscosity at 20 °C min	cp	306,300
Heat Capacity	j/gmole.C	1190
Combustion Enthalpy @ 25°C	j/gmole	483,460

[0050] Wells were controlled during simulation modelling using the constraints described in Table 3.

Table 3-Well constraints used in the Simulation Model

Constraint	Units	Value
Steam injection pressure (max)	kPa	5200
Air injection pressure (max)	kPa	4000
Production pressure (min)	kPa	125
Horizontal drain oxygen rate (max)	m ³ /day(sc)	2500
Vent well gas oxygen rate (min)	m ³ /day(sc)	2500

[0051] Operation of the model using the parameters described above provided a prediction of production performance of the PIHC and the COGD process over time. Generalized relative permeability curves published in the literature were used for oil water systems and gas liquid systems. Gas liquid systems were adjusted as a function of temperature to reduce gas relative permeability in the vicinity of high temperature fluid fronts. This adjustment was treated as a sensitivity in partial pattern 3-D models that were investigated prior to running a full pattern exploitation model.

[0052] In the model, ignition and air injection commenced in the 26th month, after injection of 106,000 m³ of steam. Steam injection for the purpose of developing the lateral hot fluid transmissive zone was injected into the top 3 meters of the reservoir section where reservoir conditions would permit. No optimization was undertaken with regard to PIHC steam volumes and the simulation volumes are viewed as maximum volumes.

[0053] As a base assumption, water saturations below 40% were deemed to be immobile in the simulation model. Should water saturations at the 25%-30% range prove to be mobile in the reservoir then steam injection can be accelerated and required injection volumes reduced. The range of injected steam volumes for the PIHC is expected to be 45,000 m³ to 106,000 m³ for a typical reservoir.

[0054] At termination of the PIHC, air injection commenced at a maximum rate of 200 10³m³/day (sc).

[0055] Referring to Figures 9A and 9B, simulation model outputs are presented for volumes of bitumen, water and gas expressed as rate time, produced from the horizontal drain, during combustion operations. Figure 9A shows the results of a simulation in accordance with the invention (base case) whereas Figure 9B shows the results of a simulation in accordance with the prior art (alternate case). The base case realization employs the pre-ignition heat cycle as described in the preferred embodiment. Oil rate, gas rate, gas rate oxygen, water rates and well bottom hole pressure for the horizontal drain are recorded for the base case. Figure 9B presents an alternative realization that employs a pre-ignition heat cycle as described in the prior art by Kisman and Lau, AOSTRA, (CA 2096034). More specifically, the Kisman process is described as cycling steam from the injection wells to the horizontal drain to form an initial hot fluid transmissive chamber prior to ignition of a combustion overhead process. Oil rate, gas rate, gas rate oxygen, water rates and well bottom hole pressure for the horizontal drain are recorded for the alternate model. All other input variables are maintained to provide a meaningful comparison between the base model and the alternate model.

[0056] As shown, about 12 months after initiation of combustion, oxygen is detected in the horizontal drain in both the base model and the alternate model. Oxygen is detected in small quantities at vent wells immediately after the initiation of combustion in both the base model and alternate model.

[0057] As shown in both Figures 9A and 9B, oil production from combustion operations commences shortly after ignition and rises to a maximum rate of 130 m³/day from the horizontal drain in both the base model and alternate model. In addition, a period of oxygen breakthrough is observed in both the base model and alternate model commencing in mid year 2012. Back pressure in the horizontal drain is increased as a result of the oxygen breakthrough and fluid off-take is reduced resulting in a decline in bitumen production in both the base model and alternate model. In year 2013 oxygen rates begin to stabilize in the base model and bitumen production is restored to 130 m³/day as horizontal drain back pressure is reduced. In the alternate model, oxygen breakthrough continues to impose higher back pressure at the horizontal drain and bitumen production is not restored to initial rates. The observed variance in production performance after year 2013 is attributed to the lateral transmissive path developed in the base model using the pre-ignition heat cycle as described in the preferred embodiment. That is, the absence of the lateral fluid transmissive path in the alternate

model has retarded the lateral development of the combustion chamber resulting in poorer production performance and increased cycling of injected gas.

[0058] Figure 10 shows the results of simulations in which cumulative volumes of bitumen and bitumen recovery factor expressed as percentage are shown for the base model and alternate model. The base model recovers 244,100 m³ of bitumen in 10 years representing 65% recovery of the petroleum-initially-in-place. The alternate model recovers 146,000 m³ of bitumen in 10 years representing 39% recovery of the petroleum-initially-in-place. The higher recovery factor observed in the base model is attributed to the enhanced lateral conformance of the combustion chamber developed as a result of the pre-ignition heat cycle, as described in the preferred embodiment. The absence of the lateral fluid transmissive path in the alternate model has retarded the lateral development of the combustion chamber resulting in poorer recovery performance and increased cycling of injected gas.

[0059] Relative to the pre-ignition heat cycle described in this application the process outlined in the prior art recovers only 39% of the petroleum-initially-in-place. The incremental recovery factor secured by the PIHC is evidence of improved bitumen exploitation using overhead combustion gravity drainage processes.

CLAIMS

1. A method of preparing an oil bearing reservoir for in-situ overhead combustion by developing transmissive pathways in the reservoir prior to igniting the reservoir, wherein the reservoir includes a reservoir well network having one or more injection wells and one or more vent wells located in the top portion of the reservoir and a horizontal drain located in the bottom portion of the reservoir, wherein the method comprises the steps of:

injecting steam into one or more injection wells while imposing a pressure drawdown on the one or more vent wells;

injecting steam into the one or more vent wells while imposing a pressure drawdown on the one or more injection wells; and,

providing for cyclic reversal of steam injection and a pressure drawdown between the one or more vent wells and the one or more injection wells until a lateral transmissive zone is established in the top portion of the reservoir between the one or more injection wells and the one or more vent wells.

2. The method as in claim 1 further comprising the steps of:

circulating steam into the horizontal drain to increase oil mobility in the region of the reservoir around the horizontal drain; and

injecting steam into the one or more injection wells while shutting in the one or more vent wells and evacuating fluids from said horizontal drain until a vertical transmissive zone is established between the one or injection wells and the horizontal drain.

3. The method as in any one of claims 1 or 2 wherein the steam is injected at a rate that yields a circulating pressure in the reservoir below fracture pressure.

4. The method as in any one of claims 1 or 2 wherein steam is injected at a rate that yields a circulating pressure in the reservoir exceeding fracture pressure.

5. The method as in any one of claims 1-4 wherein the conformance of the transmissive zones is adjusted by control of injection and drawdown pressures during each step.
6. The method as in any one of claims 1-5 wherein the reservoir is configured with two or more injection wells over the horizontal drain and two or more laterally displaced vent wells.
7. The method as in any one of claims 1-6 wherein after ignition, the lateral transmissive zones enable the combustion chamber to expand laterally through the lateral transmissive zones.
8. The method as in any one claims 1-7 wherein progression of the lateral transmissive zones is indirectly monitored from temperature data obtained from one or more observation wells in contact with the reservoir.
9. The method as in any one of claims 1-8 wherein progression of the lateral transmissive zones is monitored from pressure communication data derived from pressure readings between the one or more injection wells and the one or more vent wells.
10. The method as in any one of claims 2-9 wherein progression of the vertical transmissive zone is monitored from pressure communication data derived from pressure readings between the one or more injection wells and the horizontal well.
11. The method as in any one of claims 1-10 further comprising the step of monitoring temperature data from the reservoir from one or more observation wells adjacent the one or more injection wells.

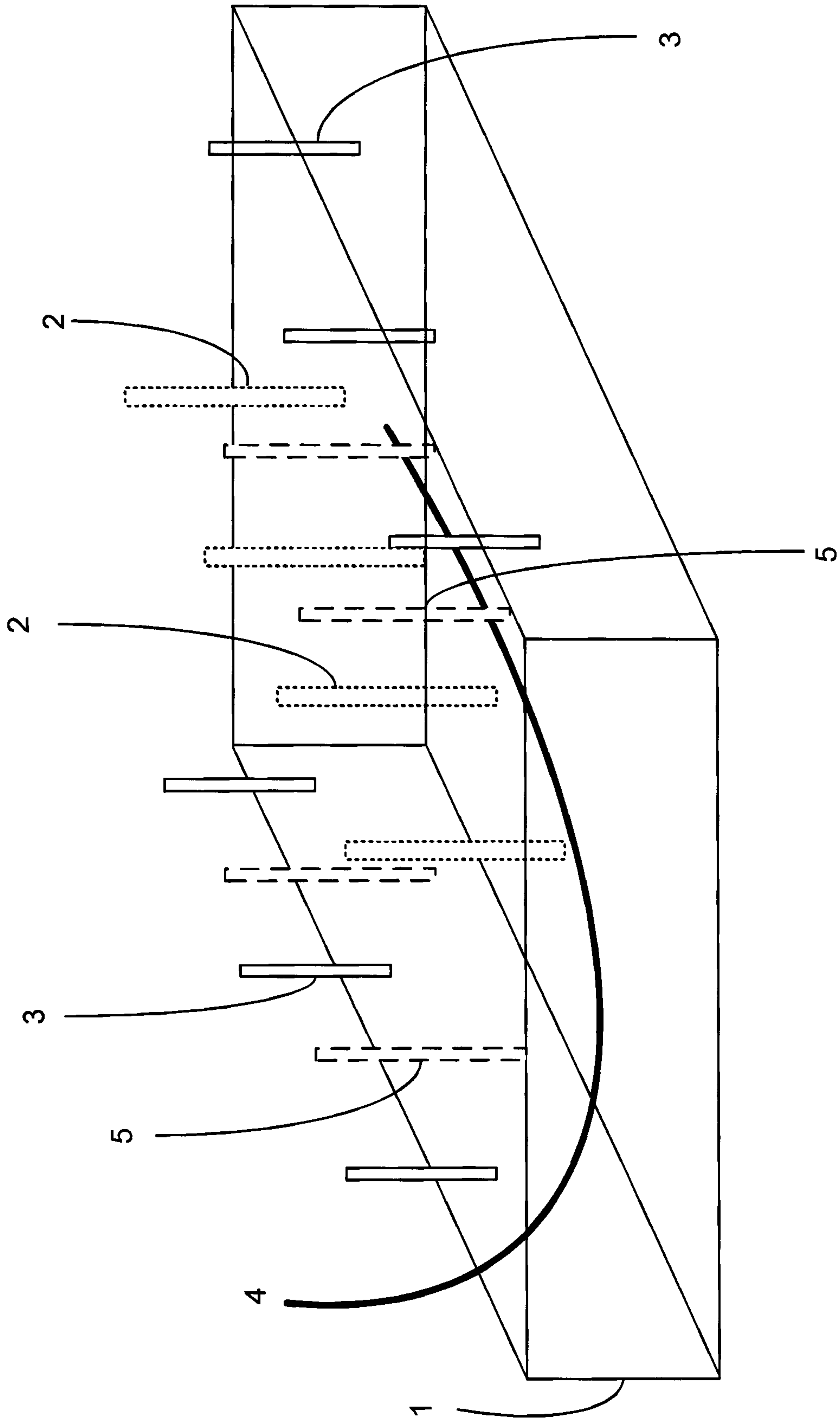


Figure 1 (Prior Art)

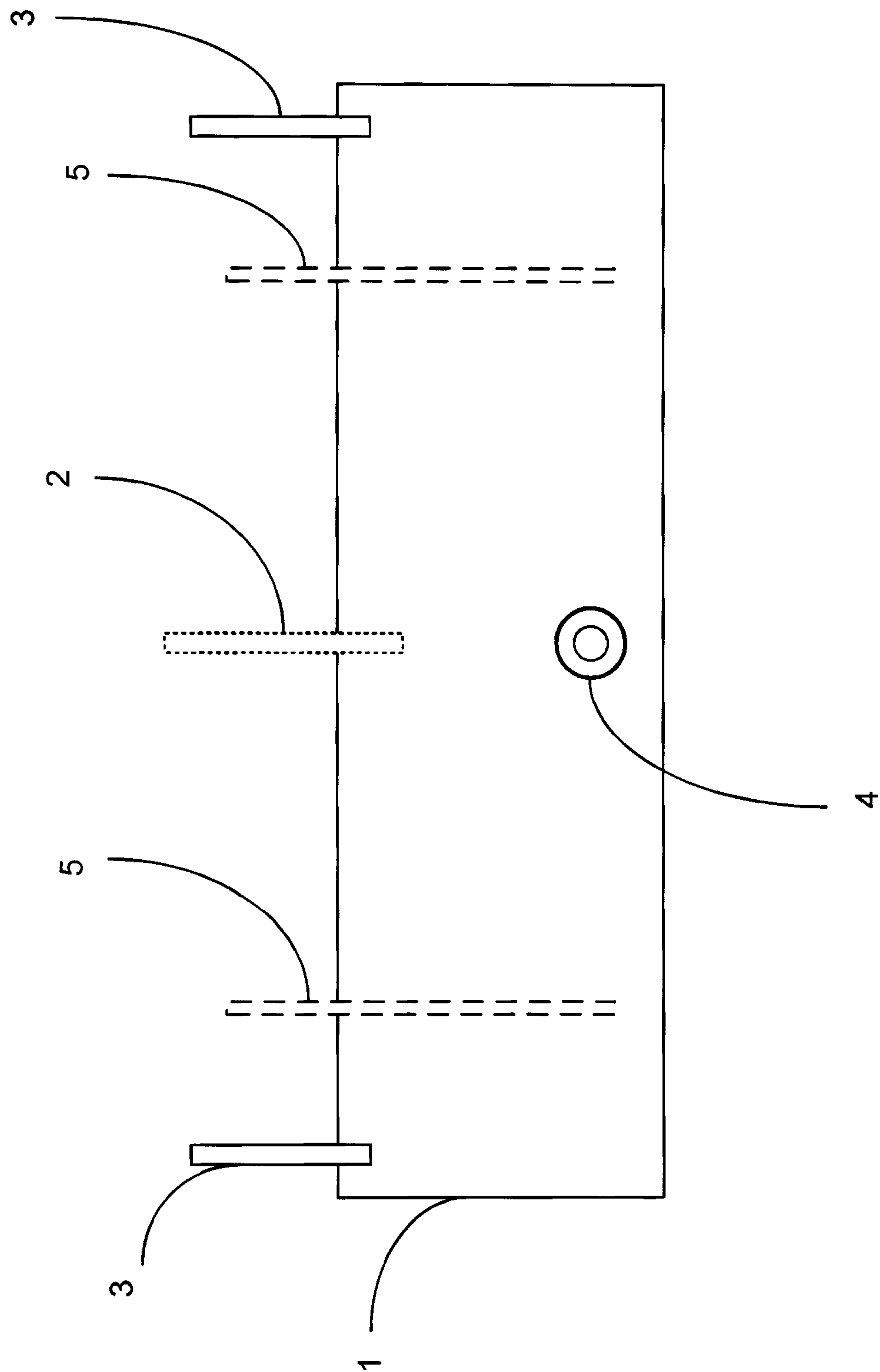


Figure 2 (Prior Art)

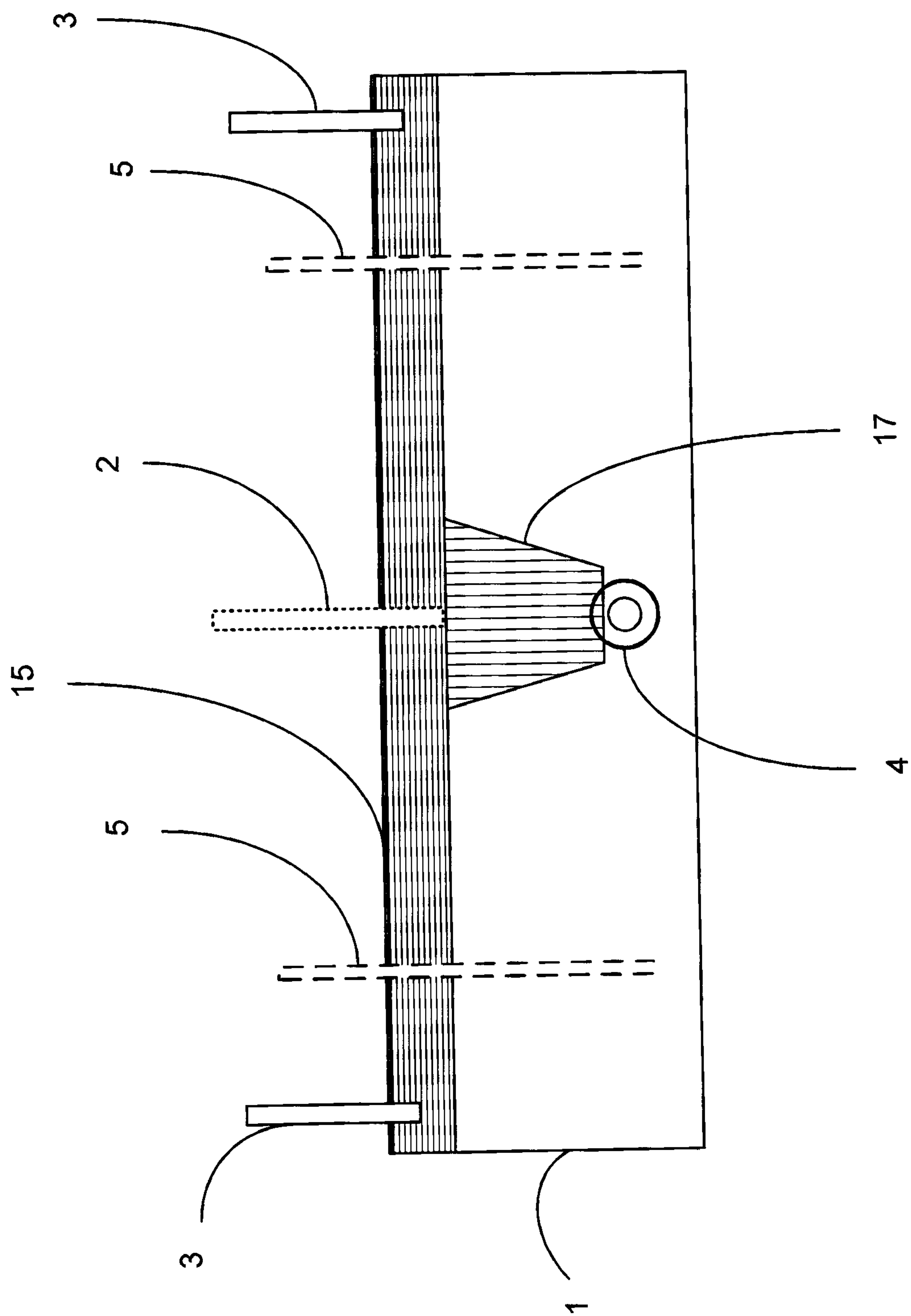


Figure 3

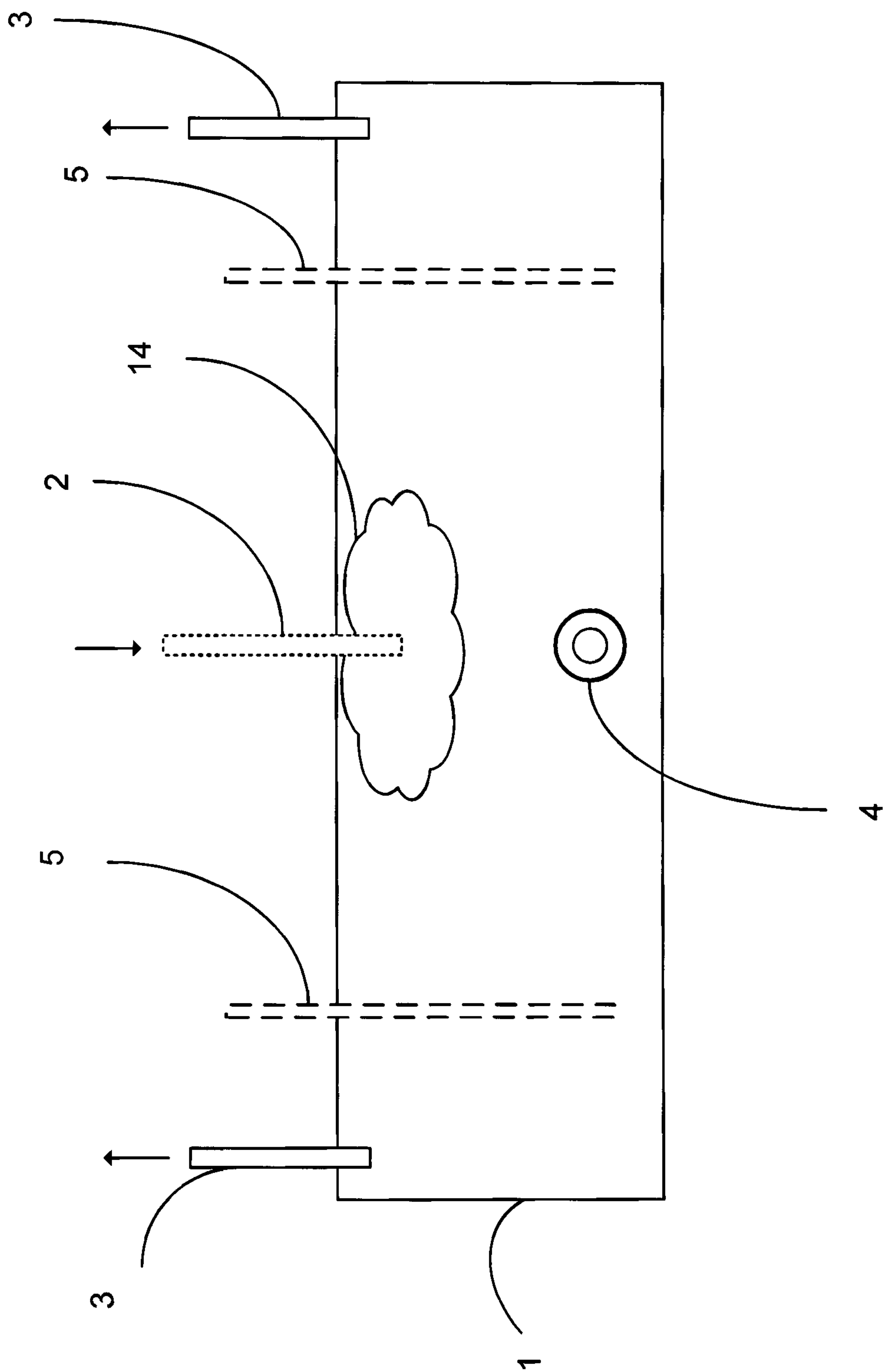


Figure 4

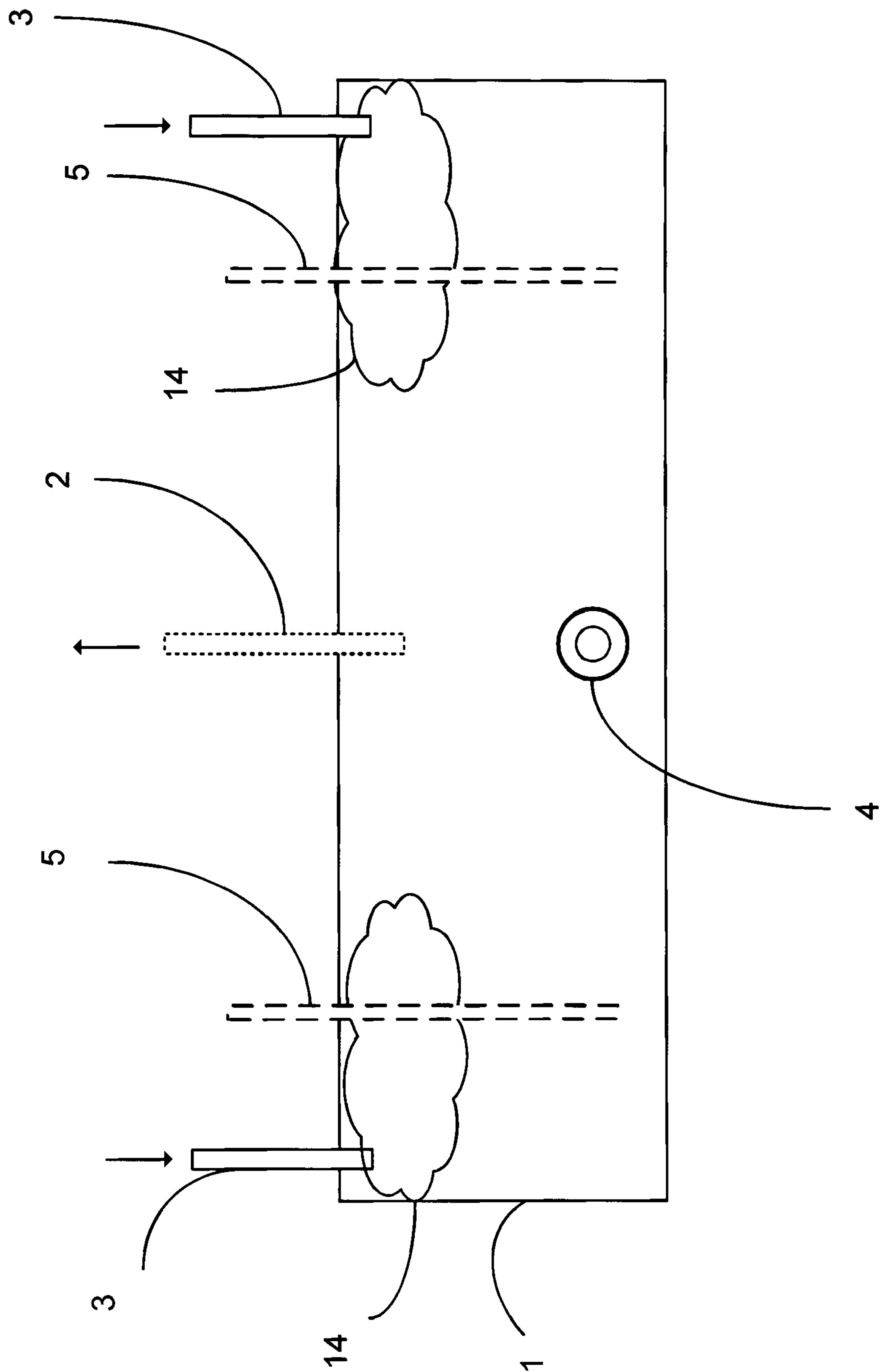


Figure 5

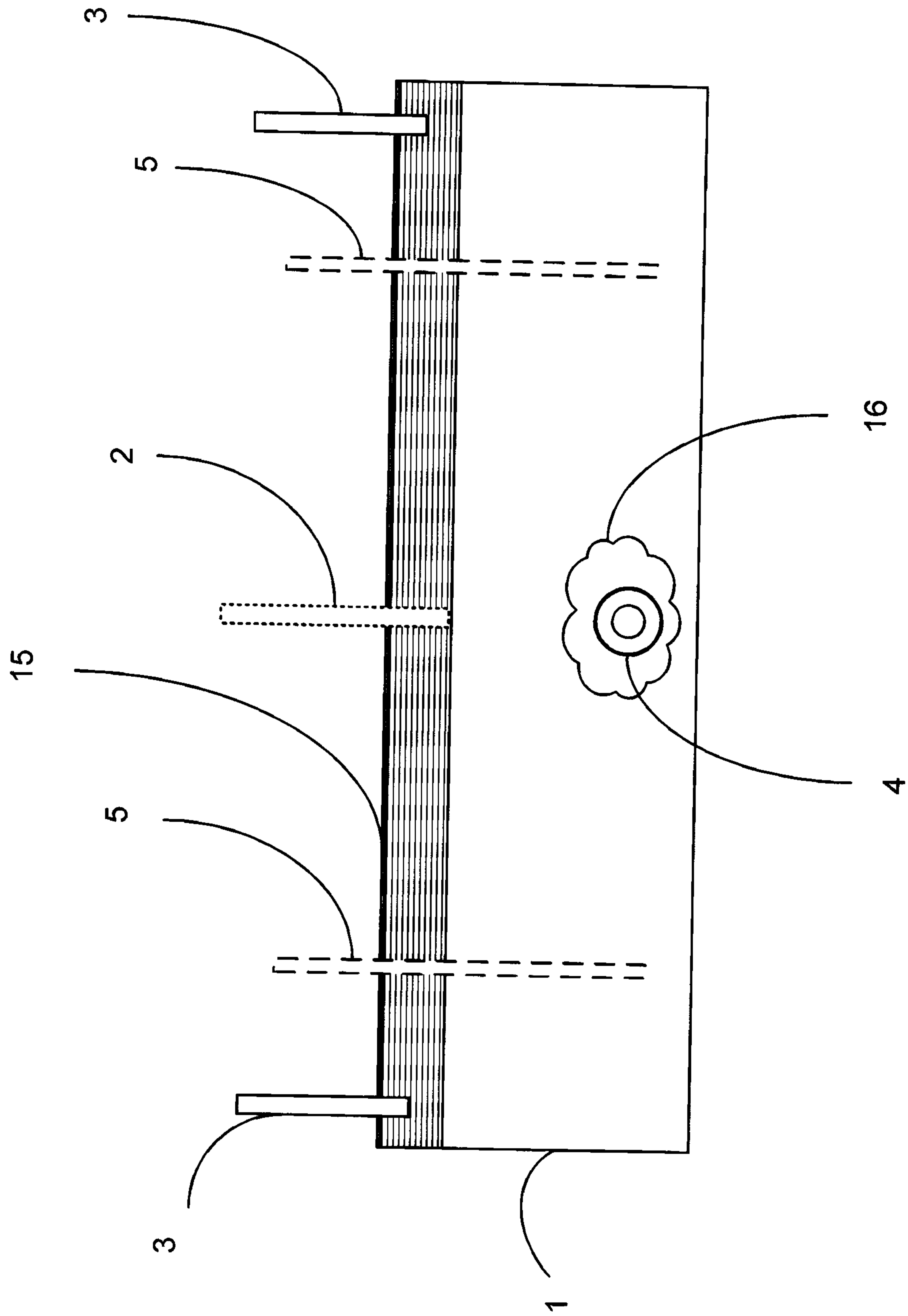


Figure 6

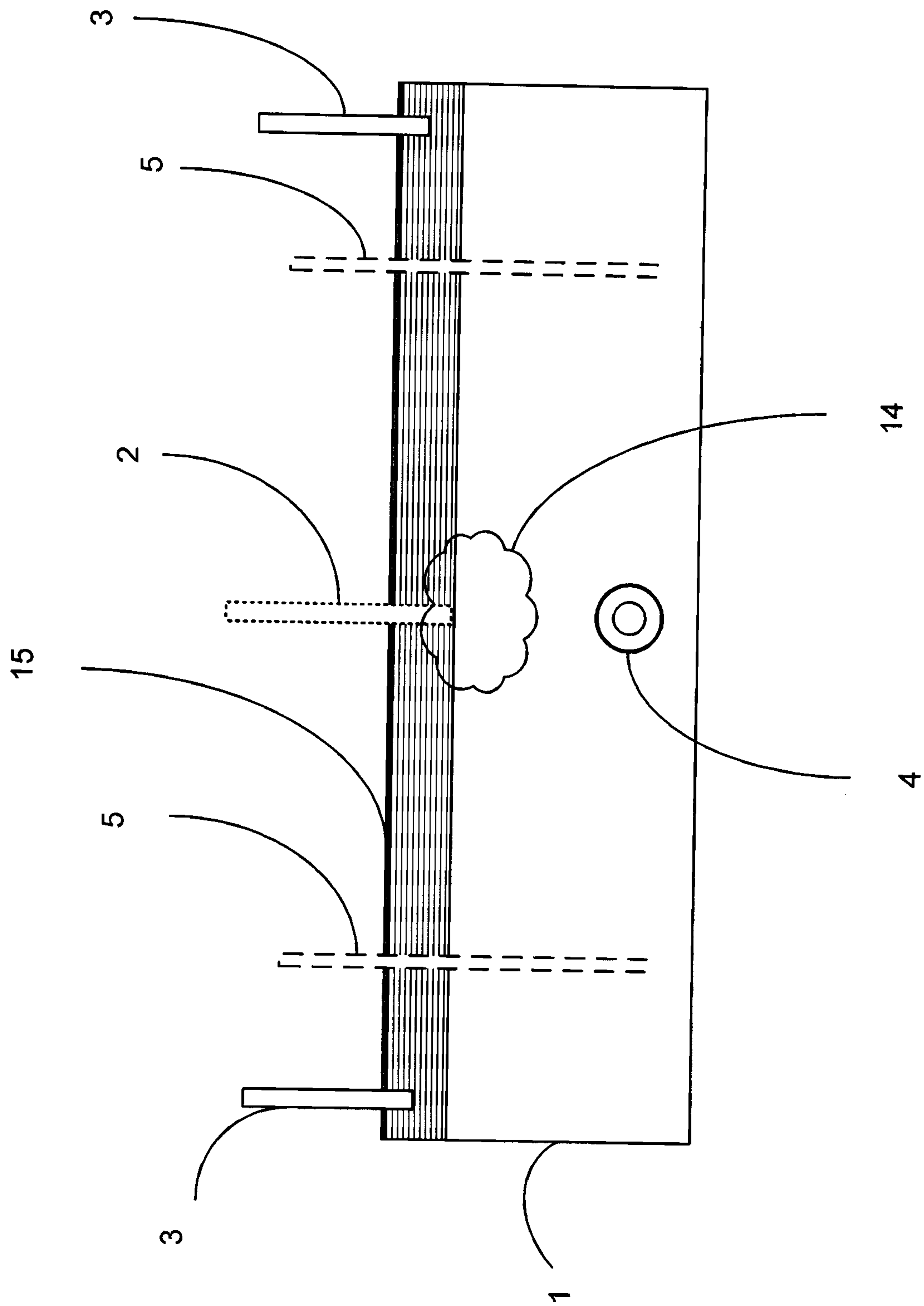


Figure 7

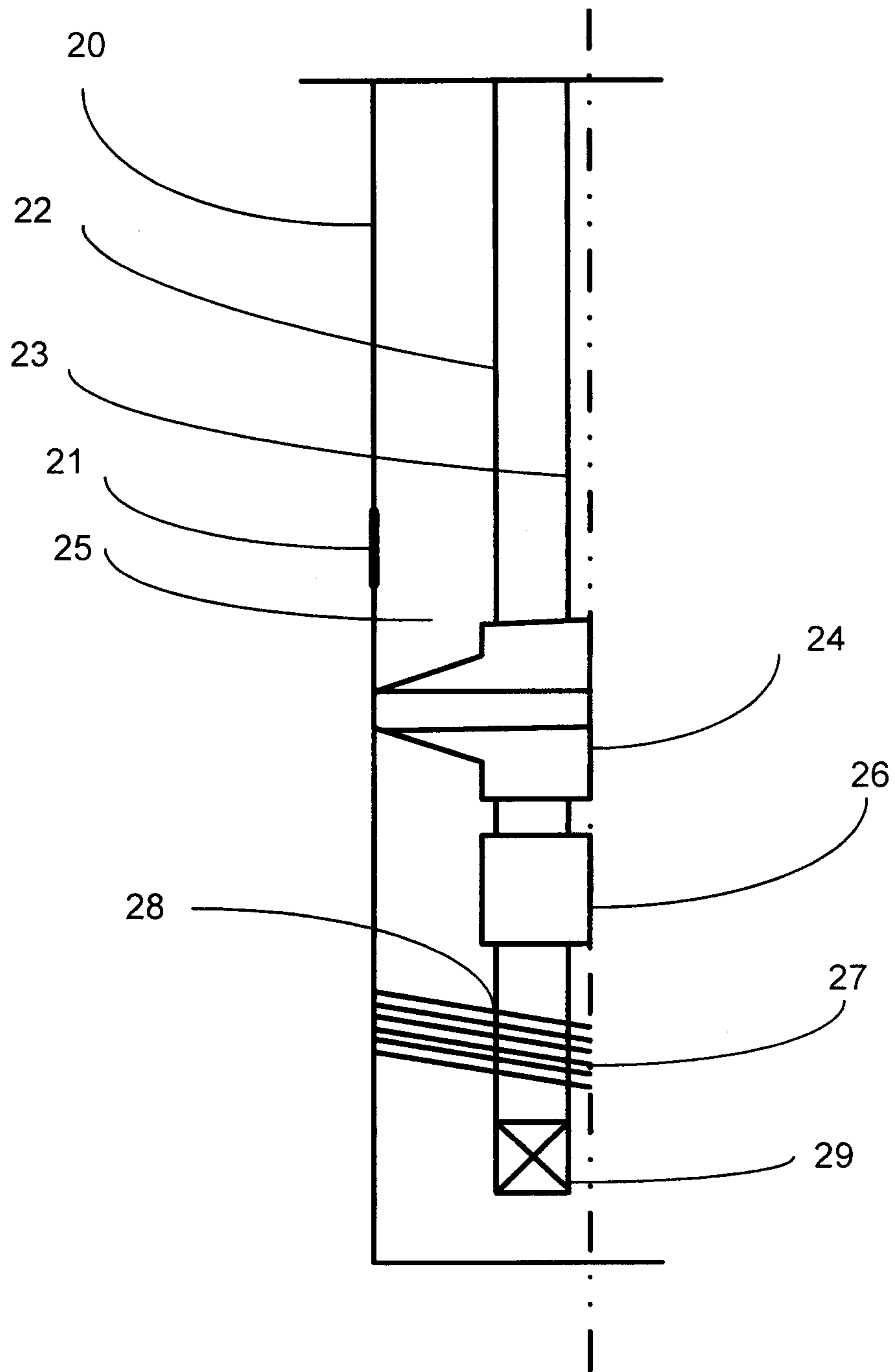


Figure 8

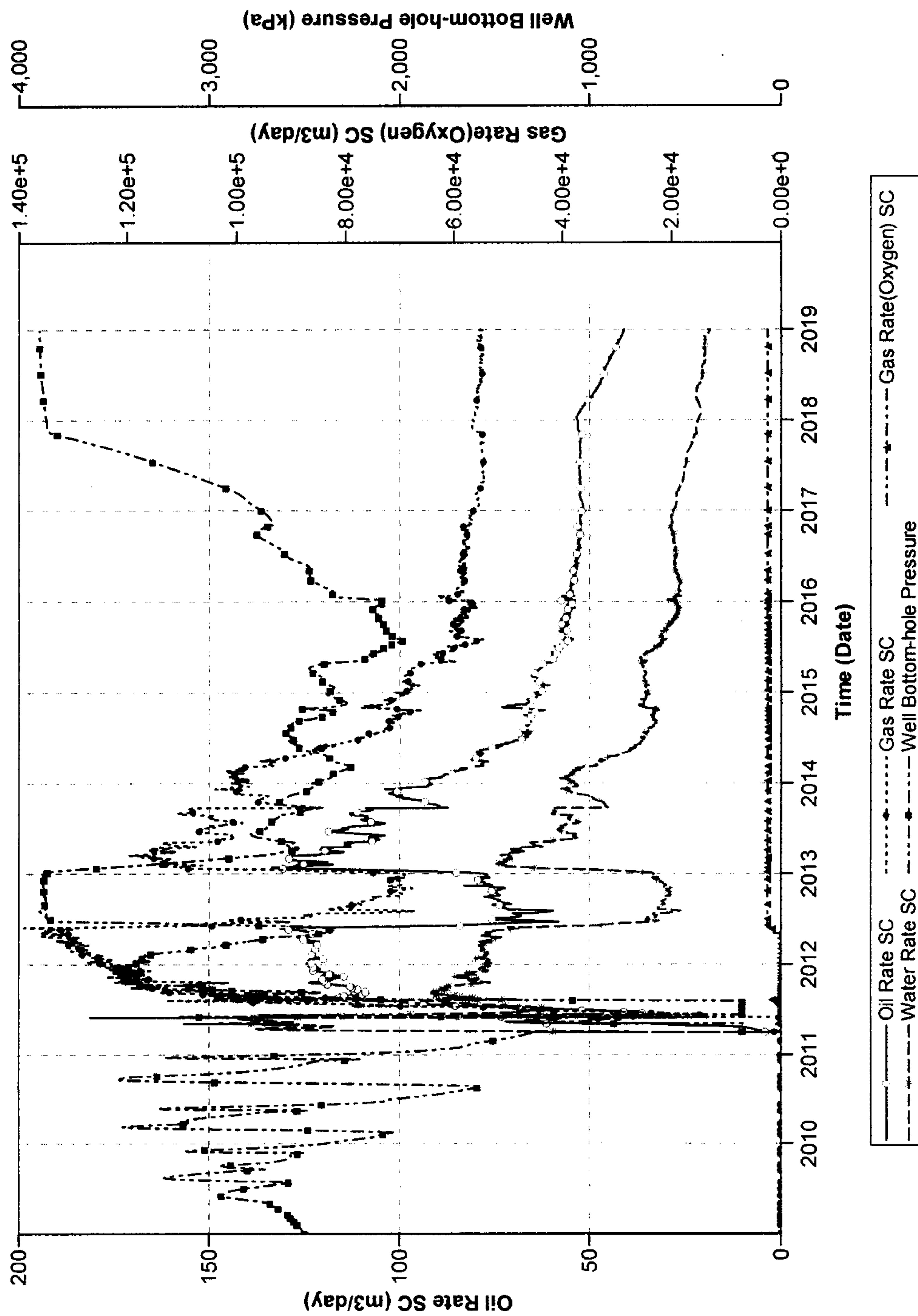


FIGURE 9A

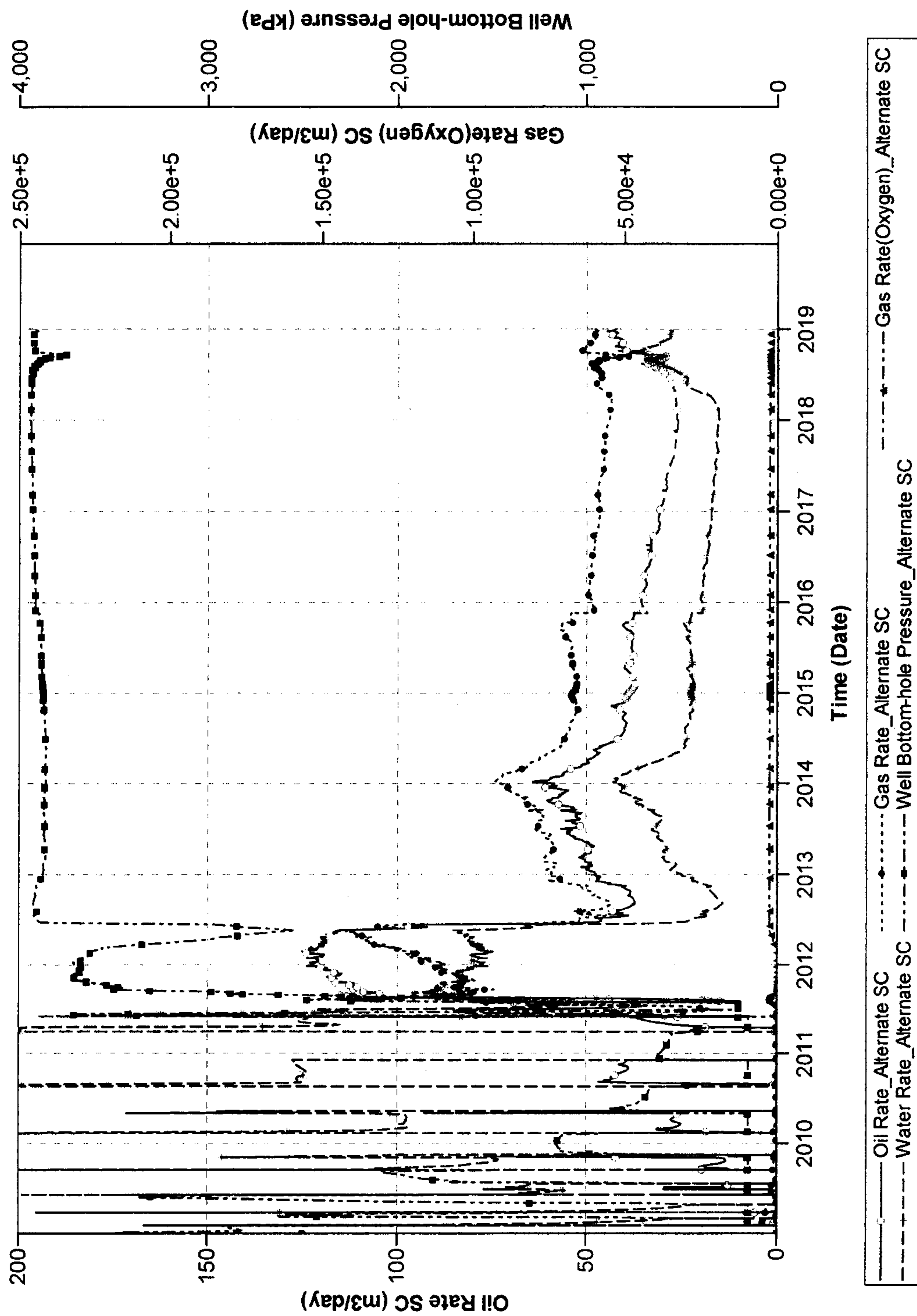


FIGURE 9B

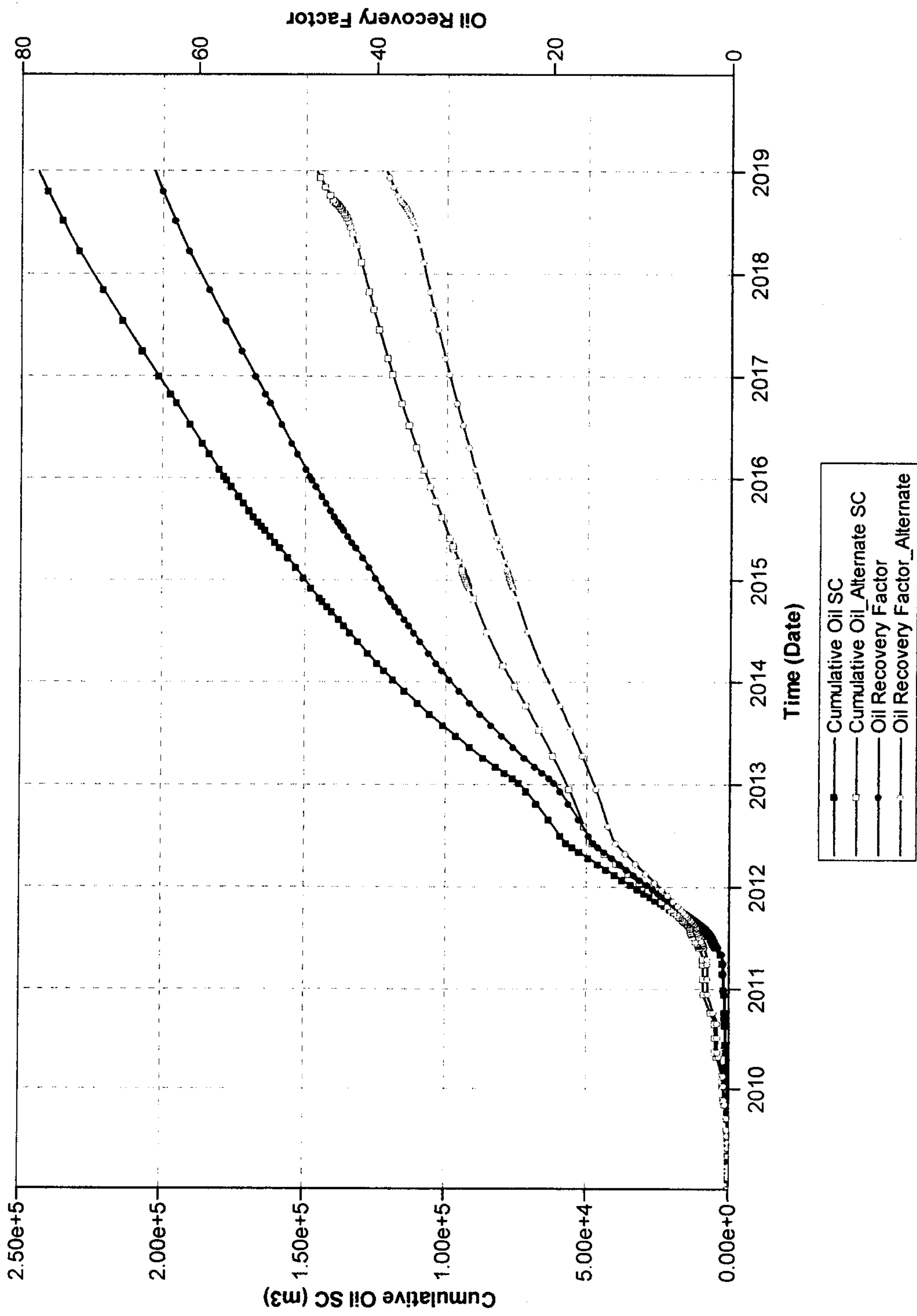


FIGURE 10

