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CA 2748980 C 2015/10/20

(11)(21) **2 748 980**

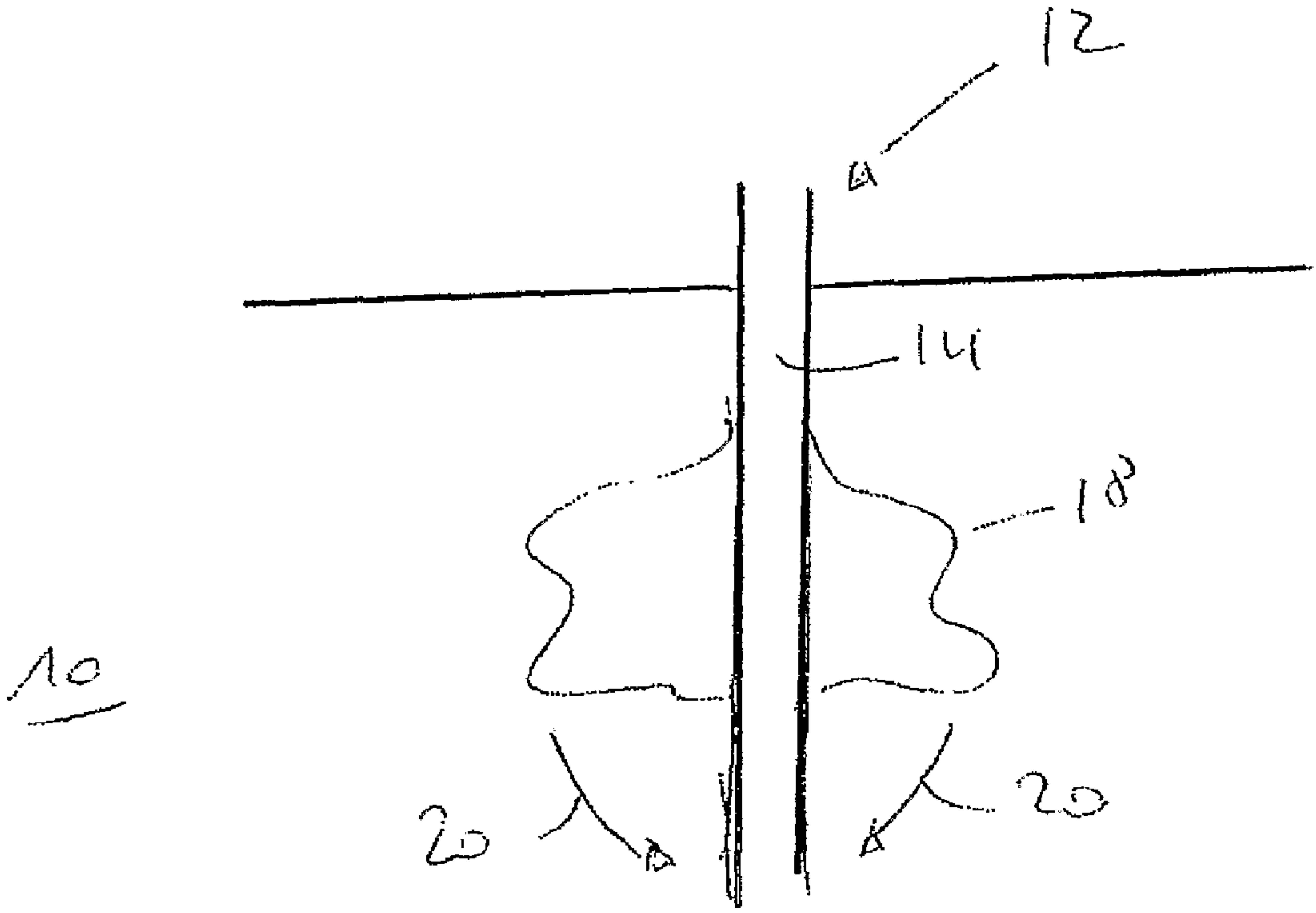
(12) **BREVET CANADIEN**
CANADIAN PATENT

(13) **C**

(86) **Date de dépôt PCT/PCT Filing Date:** 2009/01/20
(87) **Date publication PCT/PCT Publication Date:** 2010/07/29
(45) **Date de délivrance/Issue Date:** 2015/10/20
(85) **Entrée phase nationale/National Entry:** 2011/07/05
(86) **N° demande PCT/PCT Application No.:** IB 2009/000253
(87) **N° publication PCT/PCT Publication No.:** 2010/084369

(51) **Cl.Int./Int.Cl.** *E21B 43/24* (2006.01), *E21B 43/16* (2006.01), *E21B 43/30* (2006.01)
(72) **Inventeur/Inventor:**
ROCHON, JEAN, FR
(73) **Propriétaire/Owner:**
TOTAL S.A., FR
(74) **Agent:** ROBIC

(54) Titre : PROCEDE POUR EXTRAIRE DU PETROLE BRUT VISQUEUX A PARTIR D'UN RESERVOIR
(54) Title: METHOD FOR EXTRACTING VISCOUS PETROLEUM CRUDE FROM A RESERVOIR



(57) Abrégé/Abstract:
A method for extracting hydrocarbons from a reservoir comprises providing an installation including at least one wellbore extending into the reservoir, injecting steam into an injection region thereof, collecting hydrocarbons in a production region, the hydrocarbons production region being below the steam injection region, and injecting foam incorporating particles into the injection region. The method allows for better control of steam propagation within the reservoir and better exploitation of the reservoir.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

CORRECTED VERSION

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
29 July 2010 (29.07.2010)

PCT

(10) International Publication Number
WO 2010/084369 A9

(51) International Patent Classification:
E21B 33/138 (2006.01) *E21B 43/30* (2006.01)
E21B 43/24 (2006.01)

(21) International Application Number:
PCT/IB2009/000253

(22) International Filing Date:
20 January 2009 (20.01.2009)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant *(for all designated States except US)*: **TOTAL S.A.** [FR/FR]; 2, Place Jean Millier, La Défense 6, F-92400 Courbevoie (FR).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: **ROCHON, Jean** [FR/FR]; 6, Impasse Jean de La Fontaine, F-64000 Pau (FR).

(74) Agents: **POCHART, François** et al.; Cabinet Hirsch-Pochart & Associés, 58, Avenue Marceau, F-75008 Paris (FR).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *of inventorship (Rule 4.17(iv))*

Published:
— *with international search report (Art. 21(3))*

[Continued on next page]

(54) **Title**: METHOD FOR EXTRACTING VISCOUS PETROLEUM CRUDE FROM A RESERVOIR

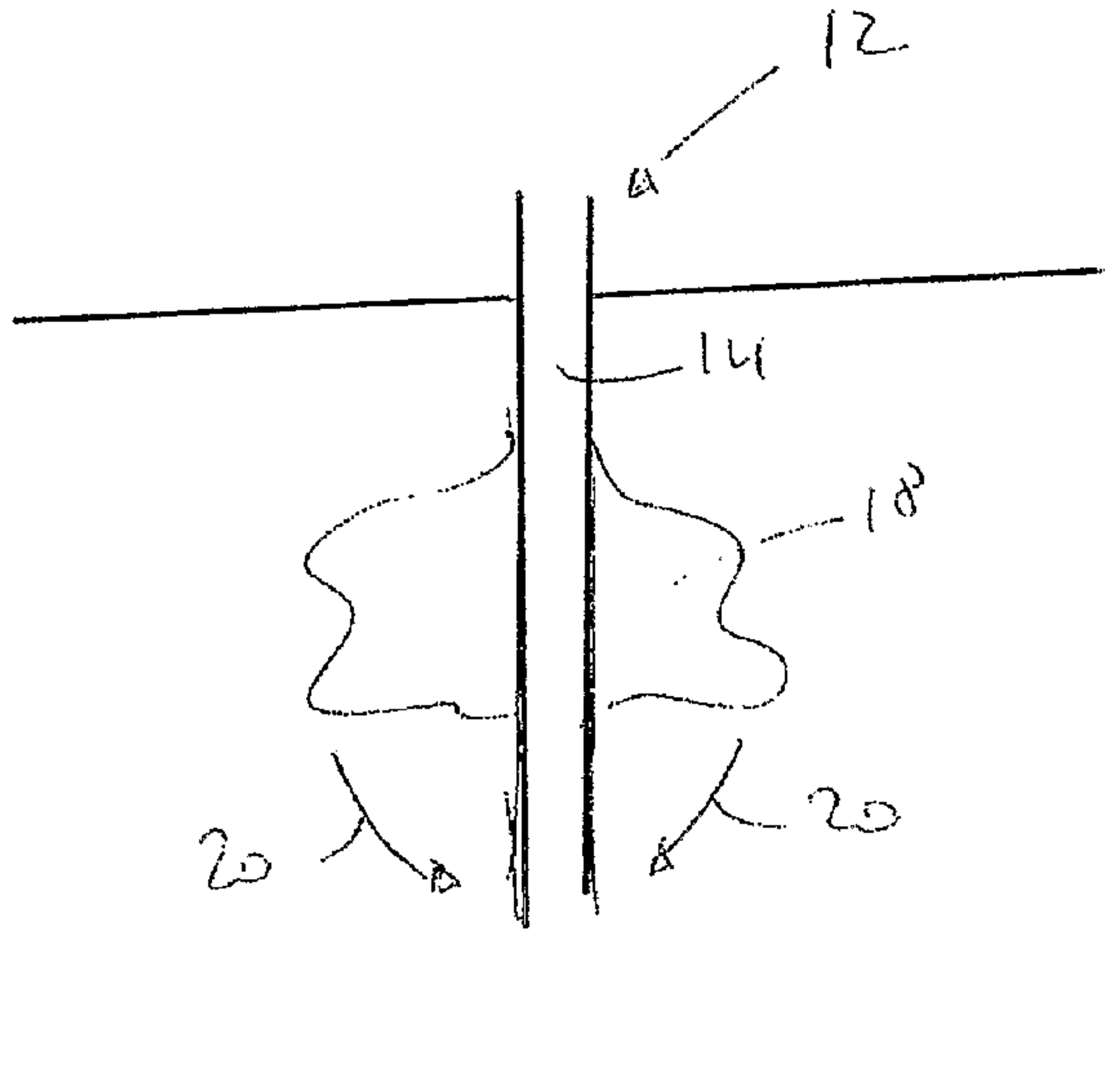


Fig 1

(57) **Abstract**: A method for extracting hydrocarbons from a reservoir comprises providing an installation including at least one wellbore extending into the reservoir, injecting steam into an injection region thereof, collecting hydrocarbons in a production region, the hydrocarbons production region being below the steam injection region, and injecting foam incorporating particles into the injection region. The method allows for better control of steam propagation within the reservoir and better exploitation of the reservoir.

WO 2010/084369 A9

WO 2010/084369 A9

— *with information concerning authorization of rectification of an obvious mistake under Rule 91.3 (b) (Rule 48.2(i))*

(48) Date of publication of this corrected version:
5 May 2011

(15) Information about Correction:
see Notice of 5 May 2011

METHOD FOR EXTRACTING VISCOUS PETROLEUM CRUDE FROM A RESERVOIR

The invention relates to the field of recovering viscous petroleum crude.

A major problem in heavy hydrocarbon production arises through the high viscosity of these hydrocarbons making them difficult to extract. To mobilize bitumen, the viscosity must be lowered significantly by using thermal recovery methods such as steam flooding.

Steam flooding of petroleum bearing formations has become one of the preferred methods of enhanced oil recovery. Heat reduces resistance of oil flow from a reservoir to a production well over a wide range of formation permeability by decreasing the oil viscosity. Further, steam injection enhances the natural reservoir pressure, and increases the differential pressure between oil in the reservoir and the producing well bore.

A petroleum reservoir is inherently inhomogeneous. Because of the differences of permeability in a reservoir, it is common practice to inject a foam forming surfactant in a reservoir with the injected steam, in order to block the higher permeability zones. The desired result is to divert steam from the oil depleted, high permeability channels into the less permeable zone having been not yet swept and then containing higher oil saturation. At the end, the sweep efficiency is highly improved.

Foam in porous media can be defined as a dispersion of gas phase in a liquid phase. The gas phase is broken into discrete bubbles, separated by liquid films called lamellae (Rossen 1996, Foams In Enhanced Oil Recovery, In *Foams : Theory Measurements and Application*, R.K. Prud'homme and S. Khan (eds.). New York : Marcel Dekker.). In porous medium, the lamellae between bubbles greatly restrict the mobility of gas. Thus the number and the size of these lamellae govern the mobility of gas.

Foam can be generated in-situ, by injection into a porous medium of a solution comprising steam (or water and gas mixture) and surfactant. Stable foam can also be generated at the surface, and then injected into the reservoir. "Foam Generation" is a transformation from a state of high gas mobility (weak foam or no foam) to one of low mobility (strong foam). Foam generation is a process where the rate of lamellae creation greatly exceeds the rate of lamellae destruction.

US 5 052 487 describes an improved method for enhanced oil recovery using steam and surfactant. An alpha olefin surfactant is injected with steam to form foam in areas of reduced oil concentration, and thereby divert steam to areas having higher oil concentration. At the end, the sweep efficiency is increased.

But the poor thermal stability of surfactant at high temperature limits its use in enhanced oil recovery. The choice of the surfactant is limited by two factors: chemical stability, and the ability to produce stable foam at steam injection conditions.

US 4 470 462 discloses an improved oil recovery process, where a stable foam containing particulate material is injected in the formation.

In this process, steam is injected into the formation for a sufficient period of time to cause the crude to become mobile and to move into the production well. When that event has occurred, stable foam containing particulate material is injected into the formation through the zone were the crude has been produced. Stable foam is used to convey the particles into the permeability paths within the formation. .The foam is then permitted to collapse, and the particulate material is retained in the formation.

In this process, particles are injected with foam into the formation in order to block the paths after steam breakthrough has occurred: Consequently, steam injection and foam injection are alternated. The above method relates to installations using sweep drainage in which the injection and production wells are vertical and may be separated by a considerable distance, for example some hundred metres.

But vertical well steaming processes are not technically or economically feasible in very viscous bitumen reservoirs. Steam Assisted Gravity Drainage is one of the most used thermal process to improve recovery from heavy oil reservoirs. This method is notably described in Canadian patent CA-A-1 304 287. In gravity drainage extraction process, steam is injected into a formation from a generally horizontal injection well and steam and/or water and oil are generally recovered from a lower parallel running horizontal production well. The vertical spacing between the upper well and the lower well is around 5 meters.

During the first stage of this process, steam is circulated in both wells. The region surroundings both wells is thus heated, mainly by conduction. When the thermal effects allow a flow communication to be established between the pair of wells, steam injection is stopped in the lower well, which is converted into a production well. The steam circulation in each well bore is often carried out for up to three months, or more.

During the second stage of the SAGD process, steam is continuously injected in the upper well. Around and above the injection well, a steam chamber grows. The injected steam flows into the steam chamber and eventually comes into contact with oil sand at its edge. As the steam condensates and changes phase to become water, the steam releases its latent heat to the oil sand. The oil heats up, its viscosity drops, and it flows with water condensate under gravity down the inclined chamber edge to the production well. Then newly liberated pore space of bitumen formation is continually filled with steam as the steam chamber expands.

In the SAGD process, gravity is the main driving force. However, the close spacing poses a challenge to avoid short-circuiting of the steam from the injector directly into the producer.

If steam breaks through at some point of the horizontal producer, the pressure gradient between the well bores vanishes and large amount of steam are produced from the lower well without delivering its heat to the formation. To ensure a good development of the steam chamber, it is essential to prevent steam breakthrough.

Various processes have been developed to avoid steam breakthrough. For instance, it is known from SPE publication 97921 to produce under sub-cool conditions, which means that the temperature of the fluid in the lower well is maintained below the saturated steam temperature at that location. This process involves monitoring very thoroughly the downhole pressure and the downhole temperature. High temperature resistant sensors are requires, but are not always available. Furthermore, due to the harsh conditions on site, they are subjected to failure.

The injection of foam during SAGD is known. For instance, US5215146 describes a SAGD process where a surfactant and a non-condensable gas (for instance nitrogen) are added while injecting steam into an upper horizontal well once steam breakthrough occurs in an interwell region. The increased pressure gradient adds to the gravity force thereby providing a greater interstitial oil velocity which increases oil drainage between well during start-up. In this process, foam is generated in situ.

There is a need to prevent steam breakthrough during the first stage of SAGD. More generally, there is a need during SAGD operations to control the development of the steam chamber.

The invention consequently provides a method for extracting hydrocarbons from a reservoir comprising:

- providing an installation including at least one wellbore extending into the reservoir,
- injecting steam into an injection region thereof,
- collecting hydrocarbons in a production region, the hydrocarbons production region being below the steam injection region,
- injecting a mixture comprising foam and particles into the injection region.

In an embodiment, the steam is injected through one or several vertical injection wellbores.

In an embodiment, the hydrocarbons are collected in one or several horizontal production wellbores in the production region.

In an embodiment, the steam is injected from one or several horizontal injection wellbores.

In an embodiment, the hydrocarbons are collected in one or several horizontal production wellbores in the production region.

In an embodiment, the production wellbores are parallel or perpendicular to the injection wellbores.

In an embodiment, the steam is injected from an upper portion of a wellbore and the hydrocarbons are collected in a lower portion of this same wellbore.

In an embodiment, the method further comprises the steps of:

- generating stable foam by mixing a surfactant solution with gas
- mixing particle and the stable foam.

In an embodiment, the method further comprises the steps of

- mixing particles to a surfactant solution
- adding gas to generate foam.

In an embodiment, the surfactant is a sulfonate.

In an embodiment, the surfactant is an alkylayl sulfonate.

In an embodiment, the mixture of foam and particles is injected continuously, sequentially or from time to time.

In an embodiment, the gas added to generate foam is a non condensable gas.

In an embodiment, the non condensable gas is methane.

In an embodiment, the non condensable gas is nitrogen.

In an embodiment, the particle size is comprised between 0.1 and 10 μm.

In an embodiment, the particles have a varying particle size.

In an embodiment, the particles are calcite.

In an embodiment, the particles are Fly Ashes.

In an embodiment, the injection of steam is continuous or discontinuous.

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

Figure 1 shows a hydrocarbon production installation, in accordance with a first exemplary embodiment in which the hydrocarbon production installation includes a single injection and production wellbore.

Figure 2 shows a hydrocarbon production installation, in accordance with a second exemplary embodiment in which the hydrocarbon production installation includes a plurality of substantially vertical injection wellbores and a substantially horizontal production wellbore.

Figure 3 shows a hydrocarbon production installation, in accordance with a third exemplary embodiment in which the hydrocarbon production installation includes a plurality of substantially vertical injection wellbores and a plurality of substantially horizontal production wellbores.

Figure 4 shows a hydrocarbon production installation, in accordance with a fourth exemplary embodiment in which the hydrocarbon production installation includes a substantially horizontal injection wellbore and a substantially vertical wellbore in a SAGD configuration.

Figure 5 shows a hydrocarbon production installation, in accordance with a fifth exemplary embodiment in which the hydrocarbon production installation includes mutually perpendicular substantially horizontal injection and production wellbores.

The invention provides a method for hydrocarbon production comprising injection of steam into an injection region of a reservoir and collection of hydrocarbons from a production region of the reservoir. The hydrocarbon production region is lower down in the reservoir than the steam injection region. The method further comprises injecting a mixture comprising foam and particles into the injection region. In a preferred embodiment, foam is generated by mixing a surfactant solution with gas. The foam is then mixed with particulate material. In another embodiment, a surfactant solution is mixed with particulate material, and then mixed with gas to generate foam.

The injection of foam containing particulate material makes possible to block off the paths with higher permeability. This results in the steam being diverted into low-permeability layers. The consequence is a better control of the steam propagation within the reservoir, and this consequently leads to a better development of the steam chamber. This improves reservoir exploitation.

Figures 1-5 illustrate installations in which the hydrocarbon production method can be implemented. Figures 1-5 show reservoirs 10 made up of strata which are inclined to a greater or lesser degree. The hydrocarbons are heavy oils, which, due to their high viscosity and low mobility, cannot be extracted simply by conventional manner. In particular, when a production well is drilled into a subterranean formation to recover oil residing therein, often little or no oil flows into the production well even if a natural or artificially induced pressure differential exists between the formation and the well. To mobilize bitumen, their viscosity must be lowered significantly by using thermal recovery methods such as Steam Assisted Gravity Drainage (SAGD). In gravity drainage extraction process, steam is injected into a formation from a generally horizontal injection well and is recovered from a lower parallel running generally horizontal production well.

In an alternate well pattern, a single vertical well is used for steam injection and hydrocarbon recovery.

In another alternate well pattern, steam is injected in a vertical well located in the upper, part of a formation and hydrocarbons are recovered in a lower horizontal well.

Steam is injected into a wellbore to heat an adjacent subterranean formation. After a start-up phase for which steam is circulated in both upper well and lower well in order to heat mainly by conduction the interwell region, steam is continuously injected into the upper well. Around and above the injection well, a steam chamber grows. The injected steam flows into the steam chamber and eventually comes into contact with oil sand at its edge. The steam then releases its latent heat to the oil sand, the oil heats up, its viscosity drops, and it flows with water condensate under gravity down the inclined chamber edge to the production well. As the mobilized bitumen drains downwards, the freed pore space is continually filled with steam. The steam chamber expands.

In particular, on figures 1-5, the hydrocarbons are collected at least in part by gravity. In effect, the hydrocarbon production region is lower down in the reservoir than the steam injection region. Thus, once they have been heated up and are less viscous, the hydrocarbons have a tendency to flow at the periphery of the steam chamber. The hydrocarbons are collected then at least in part under gravity in the production region which is lower down in the reservoir.

Figures 1-5 also show that the injection and production regions are remote from each other within the reservoir. The reservoir may be made up of strata having various permeability values. When steam is injected, this will have a tendency to preferentially go into the most permeable areas of the reservoir. The least permeable regions are not readily accessible to the steam. This leads to the development of a heterogeneous steam chamber, which tends to enlarge. The least permeable regions are consequently exploited less effectively. It then becomes extremely difficult to subsequently be able to recover hydrocarbons from these regions. Further, during the first stage of the SAGD process, while steam is circulated in both well in order to heat up mainly by conduction the interwell region, there is a risk of setting up preferential or breakthrough paths between the upper well and the lower well. In effect, if there are strata of greater permeability between the injection region and production region, the steam will have a tendency to pass preferentially through these strata. The steam chamber cannot be set up and is now the danger of making the drilling unusable.

In order to allow the steam to distribute uniformly within the reservoir, it has been proposed to inject foam into the injection region. The foam incorporates particles. The particles are carried by the foam and will migrate into the reservoir through the pores. The pores will then get filled by particles until the pore entrances get blocked off, with a consequent decrease in permeability. Thus, the steam will be forced into regions or strata that are less permeable. The use of foam as the carrier makes it possible to carry the particles into the deep regions of the reservoir.

The foam mixed with particulate material (or particles) can be injected continuously with steam into the reservoir. In other words the mixture can be constantly injected. Alternatively, the injection of foam with particles can be discontinuous, that is, the injection can be stayed. For example, the injection can cyclic: during a first stage, steam will be injected alone in the injection well and then, a slug of foam mixed with particles will be injected. The mixture may also be injected from time to time, i.e., injected irregularly. The discontinuous injection may be predetermined.

Which mode of injection is used depends on the type of heterogeneity to a be dealt with (far and diffuse or near and local) and on processing cost optimization.

In a preferred embodiment, foam is generated by mixing a surfactant solution with gas. The foam is then mixed with particulate material. In another embodiment, a surfactant solution is mixed with particulate material, and then mixed with gas to generate foam.

A thermally stable foam forming surfactant is required. Such surfactant is described in the publication SPE 13 572 "Thermal Stability of Surfactants for Steamflood Applications" presented at the *International Symposium on Oilfield and Geothermal Chemistry* held in Phoenix , Arizona, April 9-11 1985. .Examples of sulfonates surfactants are disclosed in European patent application EP-A-1,604,094 can be chosen, as well as surfactant as disclosed in EP –A-0, 681, 460.

The method makes it possible to directly modify permeability of the reservoir. To reduce permeability, particle size is smaller than the size of the reservoir pores, in order to fill the pores. In general a size around one micrometer will be chosen Preferably the particle size is comprised between 0.1 and 10μm depending on reservoir permeability.

One such material is silica floor. Calcite particles can also be chosen, as well as fly ashes.

In a particular embodiment, it can be arranged to sequentially inject particles of differing particle size. This makes it possible to adapt to steam chamber creation status, and how the reservoir is reacting to steam and foam.

Preferably, the injected steam has a high water content, in order to generate foam with a sufficient water content. Because the particles are trapped in the liquid phase of the foam, it is preferable to provide a foam composition with a sufficient liquid content to ensure a better penetration of the foam and particles into the reservoir. In a particular embodiment, a non condensable gas is injected along with steam and surfactant. The non condensable gas can be nitrogen, or methane.

Figures 1-5 illustrate some examples of hydrocarbon production installations. These installations notably comprise equipment, which is not shown, for injecting particle-bearing foam and steam, as well as equipment for hydrocarbon extraction.

Figure 1 shows one example of a hydrocarbon production installation. In Figure 1, the installation 12 comprises a wellbore 14 that penetrates into reservoir 10. Wellbore 14 is substantially vertical. Wellbore 14 extends over several hundreds of meters in a reservoir, passing through strata of differing permeability. The installation 12 of Figure 1 has the particular feature of having one single injection and production wellbore. In other words, the steam and foam injection region is in the upper portion of wellbore 14 and the production region is in the lower portion of wellbore 14. The hydrocarbon production region is at a lower level than the steam injection region.

Figure 1 further shows a steam chamber 18 in the process of formation. Steam chamber 18 causes the hydrocarbons at the outer regions of the chamber to heat up. The hydrocarbons move in a direction of arrows 20 towards the production region at the lower portion of wellbore 14. The hydrocarbons are drained by gravity towards the production region. As indicated above, foam incorporating particles is injected along with the steam as a way of forcing the steam towards the less permeable regions. This has an effect of enlarging the steam chamber thereby increasing the volume of hydrocarbons extracted at this site. The value of this type of installation is its simplicity of implementation.

Figure 2 shows another example of a hydrocarbon production installation. In figure 2, installation 12 has a plurality of wellbores 14 penetrating into reservoir 10. The wellbores 14 are substantially vertical. They extend over several hundreds of meters into the reservoir and pass through strata of differing permeability. The installation 12 in Figure 2 has the particular feature of having one single production wellbore 22. This wellbore 22 is horizontal and extends below each one of the injection wellbores 14. The wellbores are substantially in the same plane. Production wellbore 22 is in a lower region than injection wellbores 14.

Figure 2 further shows a steam chamber 18 in the course of formation for each one of the injecting wellbores 14. Steam chamber 18 causes the hydrocarbons in the outer regions of the chamber to heat up. The hydrocarbons follow the path shown by arrows 20 towards the collection regions where production wellbore 22 is located. The hydrocarbons drain under gravity towards the production region. As indicated above, foam incorporating particles is injected with the steam as a way of forcing the steam towards less permeable regions. This makes it possible to extend the steam chambers thereby increasing the volumes of hydrocarbon extracted at this site. Further, the use of foam incorporating particles makes it possible to reduce the risk of the formation of breakthrough paths between the injection wellbores 14 and production wellbore 22. The value of such an installation is that of being able to cover a larger field area while limiting the number of production wellbores.

Figure 3 shows another example of an installation for producing hydrocarbons. Installation 12 in Figure 3 is similar to the installation in Figure 1 as regards the injection wellbores 14 but differs as regards its production bores. Installation 12 in figure 3 comprises a plurality of production wellbores 22. These production wellbores 22 are in a lower region than the injection wellbores 14. The production wellbores 22 are additionally offset with respect to injection wellbores 14. The production wellbores 22 are substantially perpendicular to the plane of Figure 3 and are shown in cross section. The production wellbores 22 are horizontal. In Figure 3, only one plane containing injection wellbores 14 is shown; additional wellbores 14 on planes parallel to the plane of Figure 3 are arranged along the production bores 22.

Figure 3 also shows a steam chamber 18 in the process of formation for each of the injection wellbores 14. Steam chamber 18 causes the hydrocarbons in the outer regions of the chamber to heat up. The hydrocarbons follow the path indicated by the arrows 20 down towards the production region in which the production bores 22 are located. Hydrocarbons not only drain by gravity towards the production region which is lower than the injection region, but are also drained by sweeping towards the production region which is not in line with the injection region. As indicated above, foam incorporating particles is injected with the steam as a way of forcing the steam towards the less permeable regions. This makes it possible to extend the steam chambers thereby increasing the volume of hydrocarbon extracted at this site. Further, the use of foam incorporating particles reduces the risk of breakthrough paths being set up between the injection wellbores 14 and production wellbores 22. The value of such an installation is that of being able to space the injection wellbores 14 when compared to the injection wellbores 14 shown in figure 2. This allows a larger area to be covered by an installation while limiting the number of injection wellbores.

Figure 4 shows another example of an installation for producing hydrocarbons. In figure 4, the installation 12 comprises a wellbore 14 penetrating into reservoir 10. Wellbore 14 is substantially horizontal. It extends over several hundreds of metres in the reservoir and passes through strata of differing permeability. This installation 12 in Figure 4 has the particular feature of including a production wellbore 22 which is also horizontal. Production wellbore 22 is in a region which is lower than injection wellbore 14. This is a steam-assisted gravity drainage (SAGD) configuration. The injection 14 and production 22 wellbores are substantially parallel and are separated by several metres.

Figure 4 further shows a steam chamber 18 in the process of being formed. Steam chamber 18 causes the hydrocarbons at the outer regions of the chamber to heat up. The hydrocarbons follow paths shown by the arrows 20 towards the production region which is lower down than wellbore 14. The hydrocarbons drain under gravity towards the production region. As indicated above, foam incorporating particles is injected with the steam as a way of forcing the steam towards the less permeable regions. This makes it possible to extend the steam chamber thereby increasing hydrocarbon volumes extracted at this site. The value of this particular installation is its simplicity of implementation.

In figure 5, it can also be envisaged to provide injection wellbores 14 and production wellbores 22 which are horizontal, but not parallel to each other but rather mutually perpendicular. One then has a first plane containing a plurality of injection wellbores 14 which are mutually parallel and a second plane, parallel thereto, and at a lower level than the first plane, containing a plurality of mutually parallel production wellbores 22. The injection wellbores 14 are however perpendicular to the production wellbores 22. The same remarks made in connection with figure 4 apply here too.

In the description, the injection 14 and production 22 wellbores may be substantially horizontal in the injection and production regions. Nevertheless, the wellbores are also provided with a non-horizontal portion linking these regions with the surface of the reservoir.

Further, the production wellbores may be at least partially horizontal in that at least a portion of the wellbore is horizontal. Nevertheless, another portion (as shown in figures 4 and 5) of the wellbore is not horizontal to link the horizontal portion to the surface of the reservoir.

WHAT IS CLAIMED IS:

1. A method for extracting hydrocarbons from a reservoir comprising:

- providing an installation including at least one wellbore extending into the reservoir,
- injecting steam into an injection region thereof,
- collecting hydrocarbons in a production region, the hydrocarbons production region being below the steam injection region,
- injecting a mixture comprising foam and particles into the injection region.

2. The method according to claim 1, in which the steam is injected through one or several vertical injection wellbores.

3. The method according to claim 1 or 2, in which the hydrocarbons are collected in one or several horizontal production wellbores in the production region.

4. The method according to claim 1, in which the steam is injected from one or several horizontal injection wellbores.

5. The method according to claim 4, in which the hydrocarbons are collected in one or several horizontal production wellbores in the production region.

6. The method according to claim 5, in which the production wellbores are parallel or perpendicular to the injection wellbores.

7. The method according to claim 1 or 2, in which the steam is injected from an upper portion of a wellbore and the hydrocarbons are collected in a lower portion of this same wellbore.

8. The method according to any one of claims 1 to 7, comprising the steps of:

- generating stable foam by mixing a surfactant solution with gas;
- mixing particles and the stable foam.

9. The method according to any one of claims 1 to 7 comprising the steps of:
- mixing particles to a surfactant solution;
- adding gas to generate foam.

10. The method according to claim 8 or 9, in which the surfactant is a sulfonate.

11. The method according to any one of claims 8 to 10, in which the surfactant is an alkylayl sulfonate.

12. The method according to any one of claims 1 to 11, in which the mixture of foam and particles is injected continuously, sequentially or from time to time.

13. The method according to claim 9, in which the gas added to generate foam is a non condensable gas.

14. The method according to claim 13, in which the non condensable gas is methane.

15. The method according to claim 13, in which the non condensable gas is nitrogen.

16. The method according to any one of claims 1 to 15, in which the particles have a size comprised between 0.1 and 10 μm.

17. The method according to any one of claims 1 to 16, in which the particles vary in particle size.

18. The method according to any one of claims 1 to 17, in which the particles are calcite.

19. The method according to any one of claims 1 to 17, in which the particles are Fly Ashes.

20. The method according to any one of claims 1 to 19, in which the injection of steam is continuous or discontinuous.

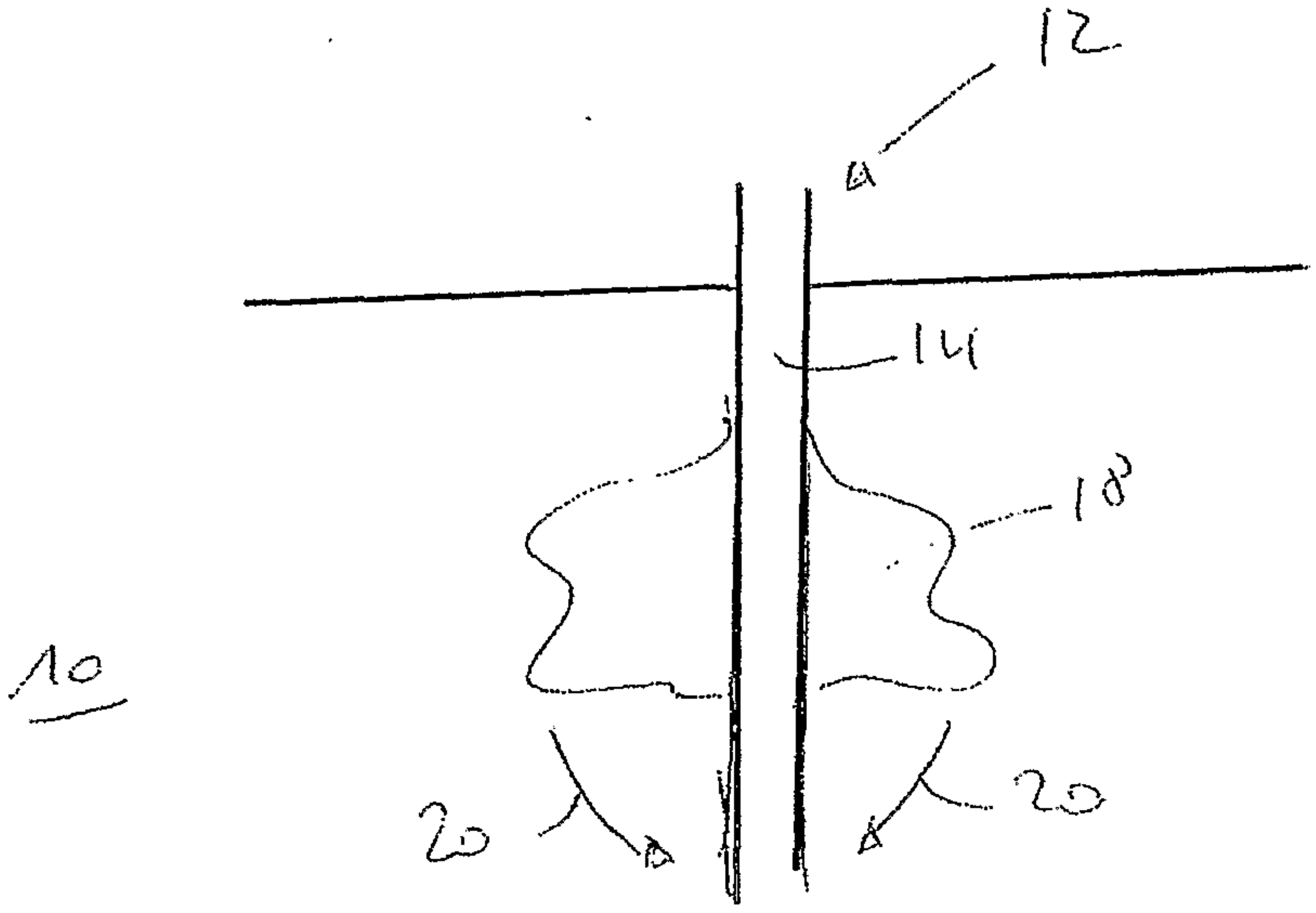


Fig 1

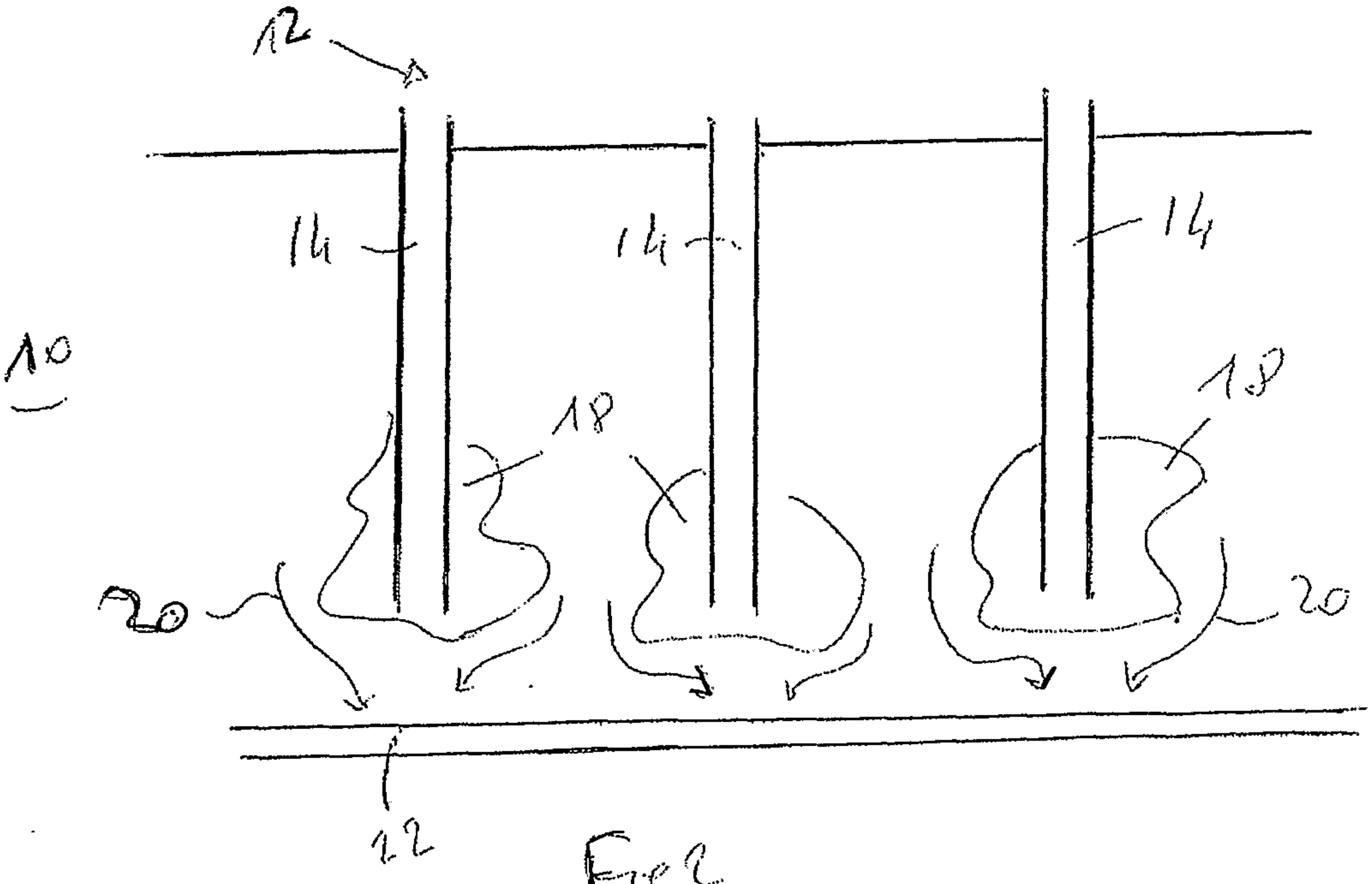


Fig 2

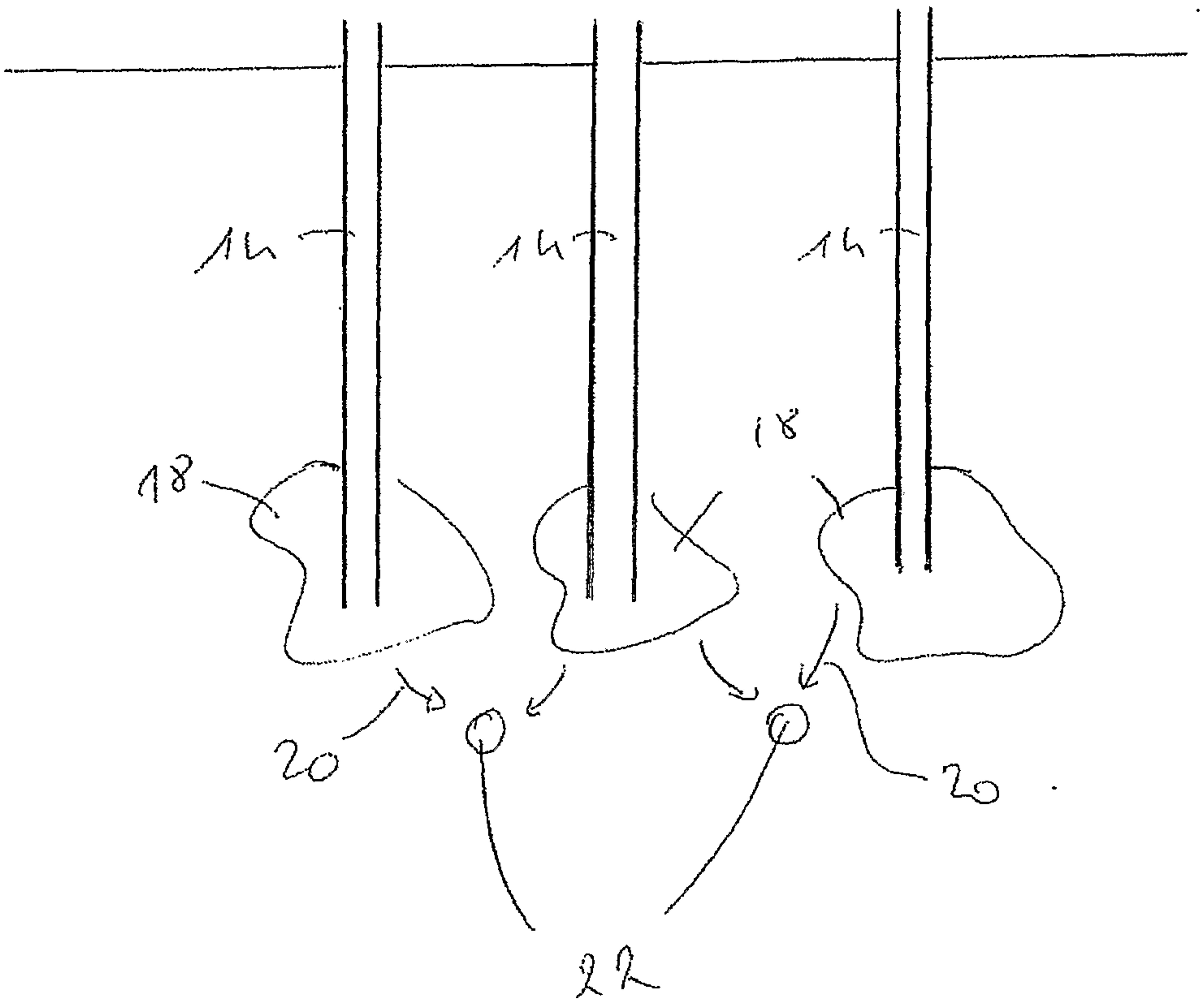


fig 3

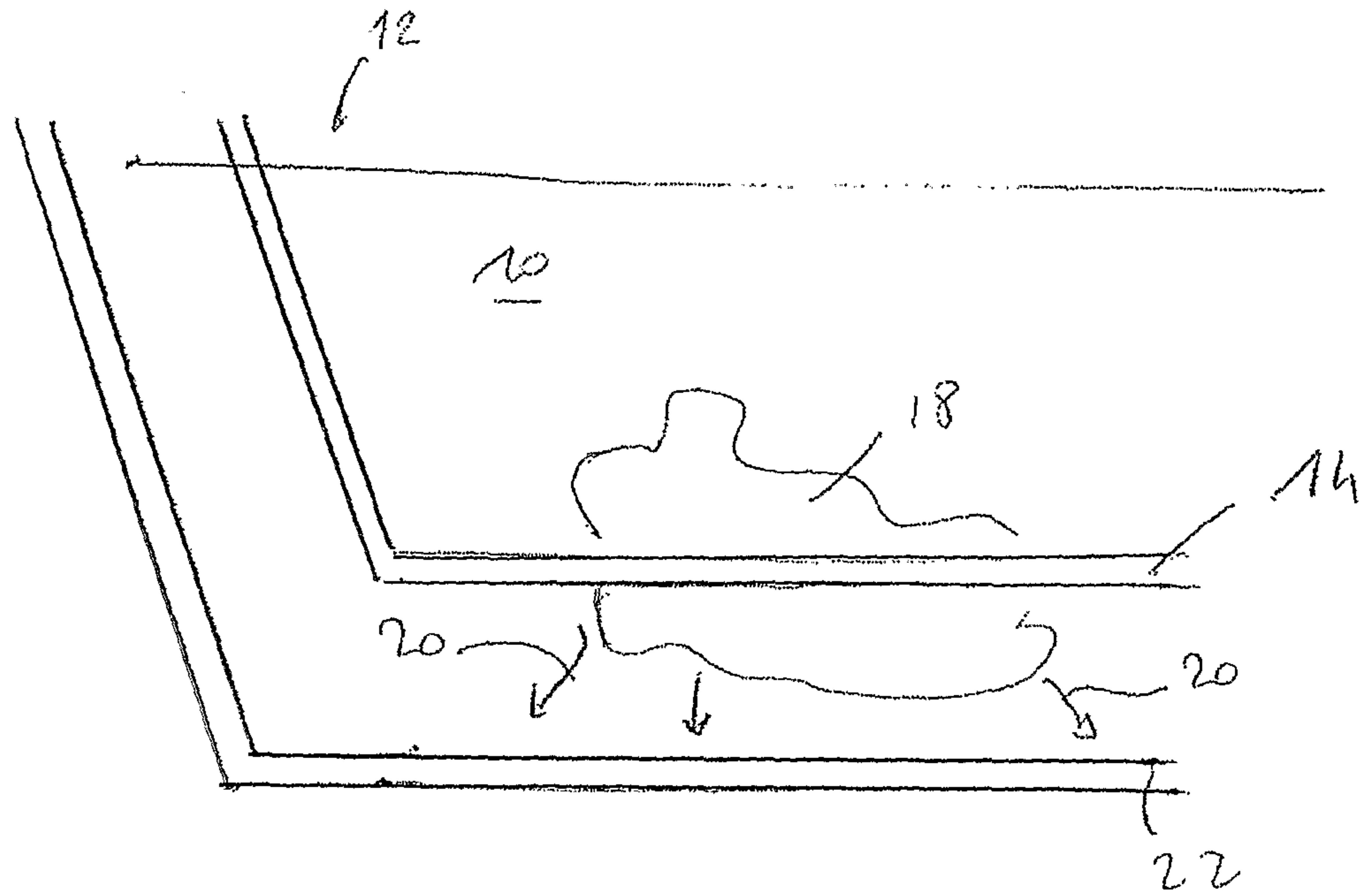


fig 4

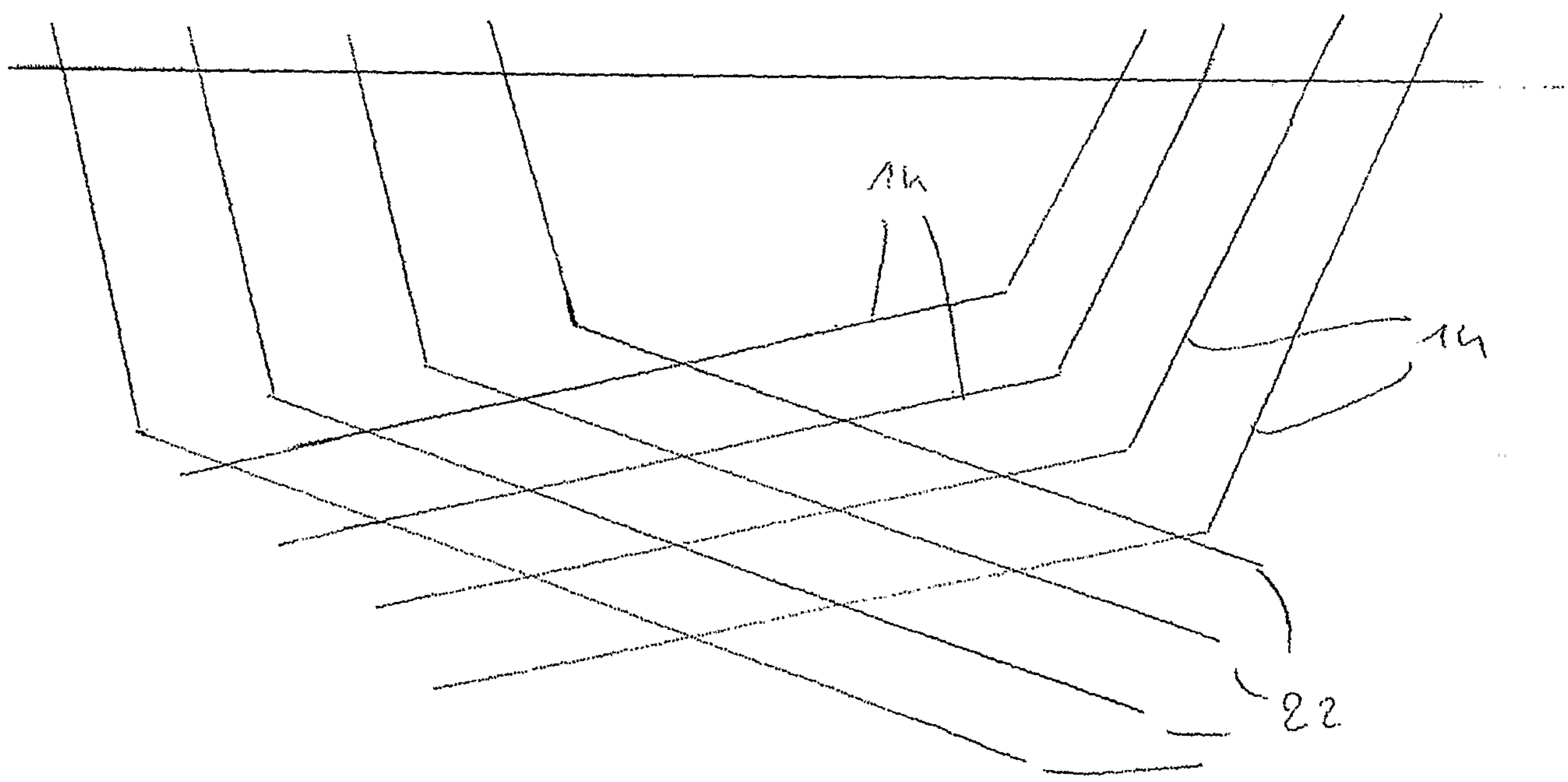
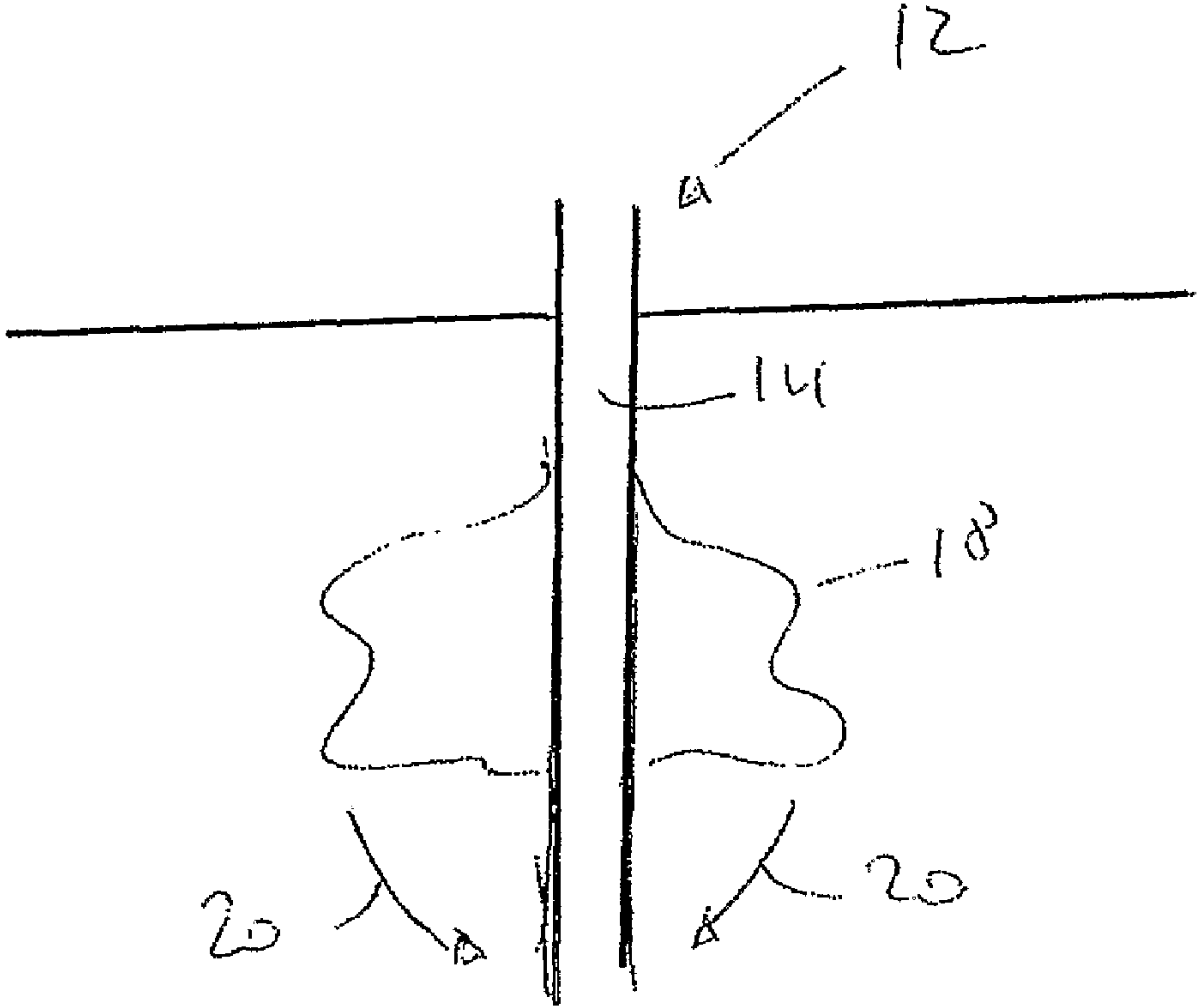


fig 5



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