US 20080271996A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2008/0271996 A1

(43) Pub. Date: Nov. 6, 2008

Lamaze et al.

(54) ELECTROLYTIC CELL WITH A HEAT EXCHANGER

(75) Inventors: **Airy-Pierre Lamaze**, Reaumont (FR); **Richard Laucournet**, La Buisse (FR); **Christian Barthelemy**, Voiron (FR)

Correspondence Address:
BANNER & WITCOFF, LTD.
TEN SOUTH WACKER DRIVE, SUITE 3000
CHICAGO, IL 60606 (US)

(73) Assignee: **ALUMINUM PECHINEY**, Voreppe (FR)

(21) Appl. No.: **12/093,556**

(22) PCT Filed: **Nov. 6, 2006**

(86) PCT No.: **PCT/FR2006/002465**

§ 371 (c)(1), (2), (4) Date: **May 13, 2008**

(30) **Foreign Application Priority Data**

Nov. 14, 2005 (FR) 0511503
Nov. 6, 2006 (FR) PCT/FR06/02465

Publication Classification

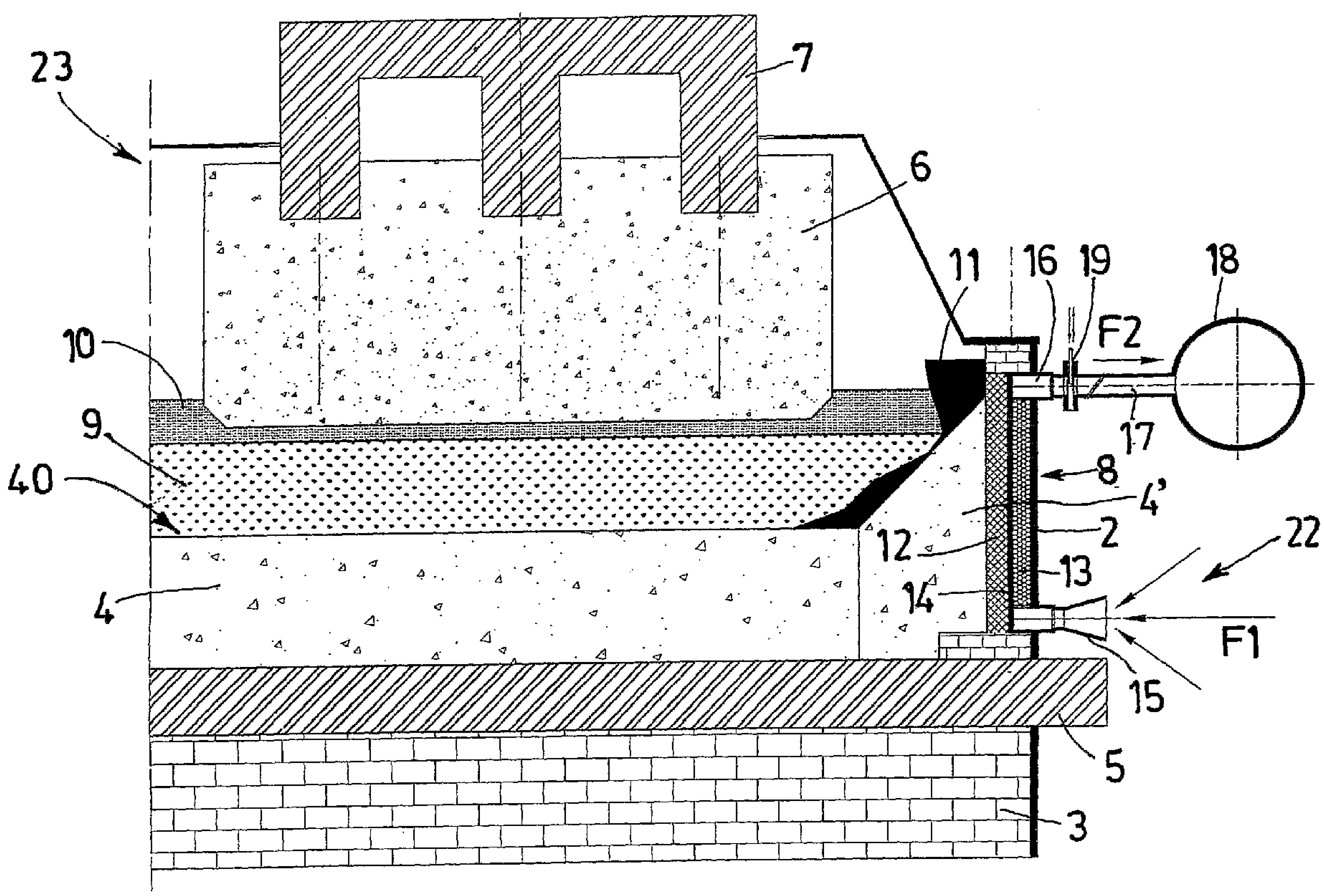
(51) **Int. Cl.**
C25C 7/00 (2006.01)

(52) **U.S. Cl.** **204/274**

(57) **ABSTRACT**

This invention relates to electrolytic cells used for production of aluminium.

The side walls (**8**) of the pot surrounding its crucible (**4**, **4'**) include a part (**13**) made of a porous material over at least one fraction of their height and/or their thickness, to enable a heat transfer gas to circulate, the part (**13**) made of a porous material being connected to heat transfer gas inlet means (**15**) and outlet means (**16**), so as to make a heat exchanger in order to recover heat energy lost through the sides of the pot.



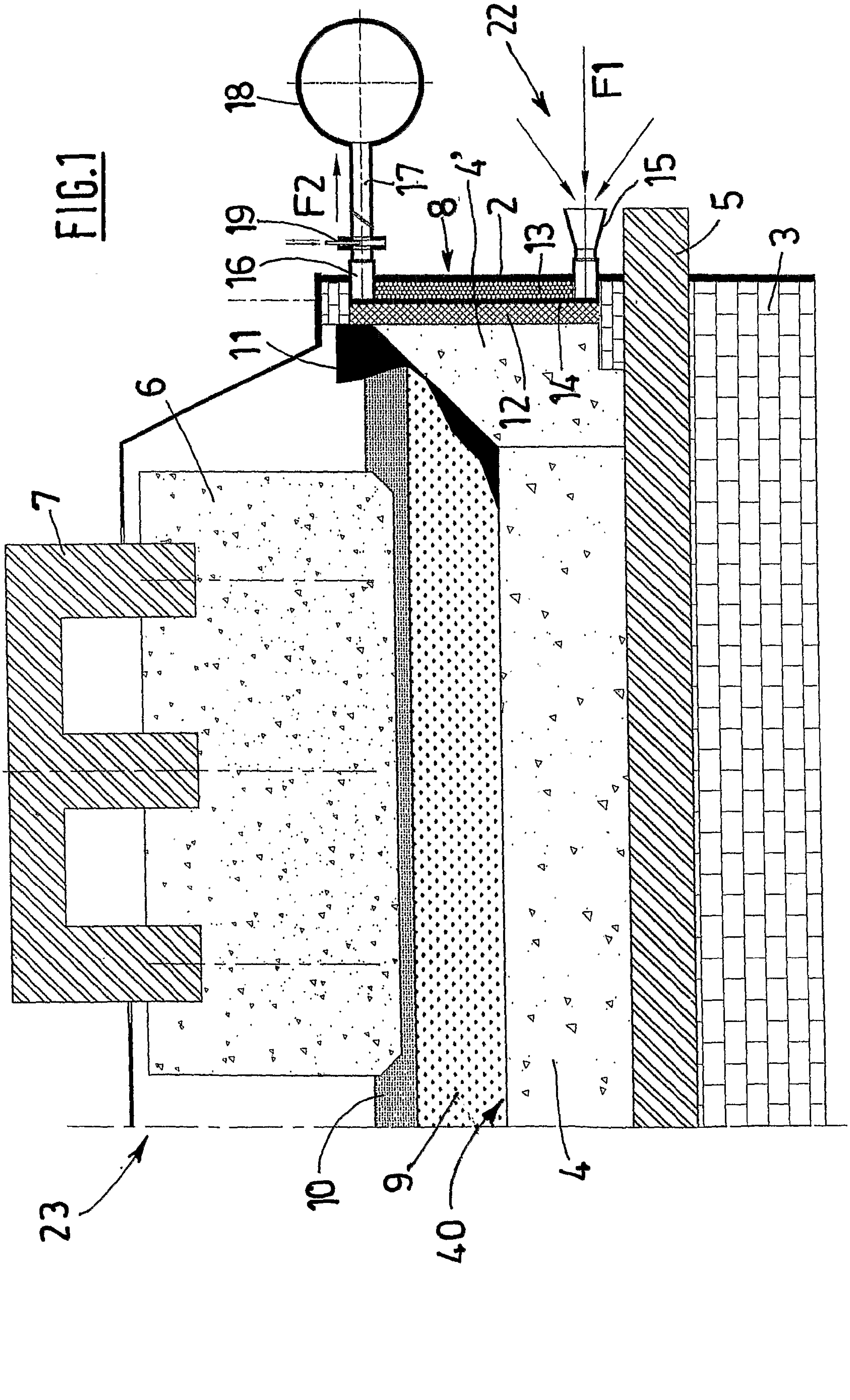


FIG.1

FIG.3

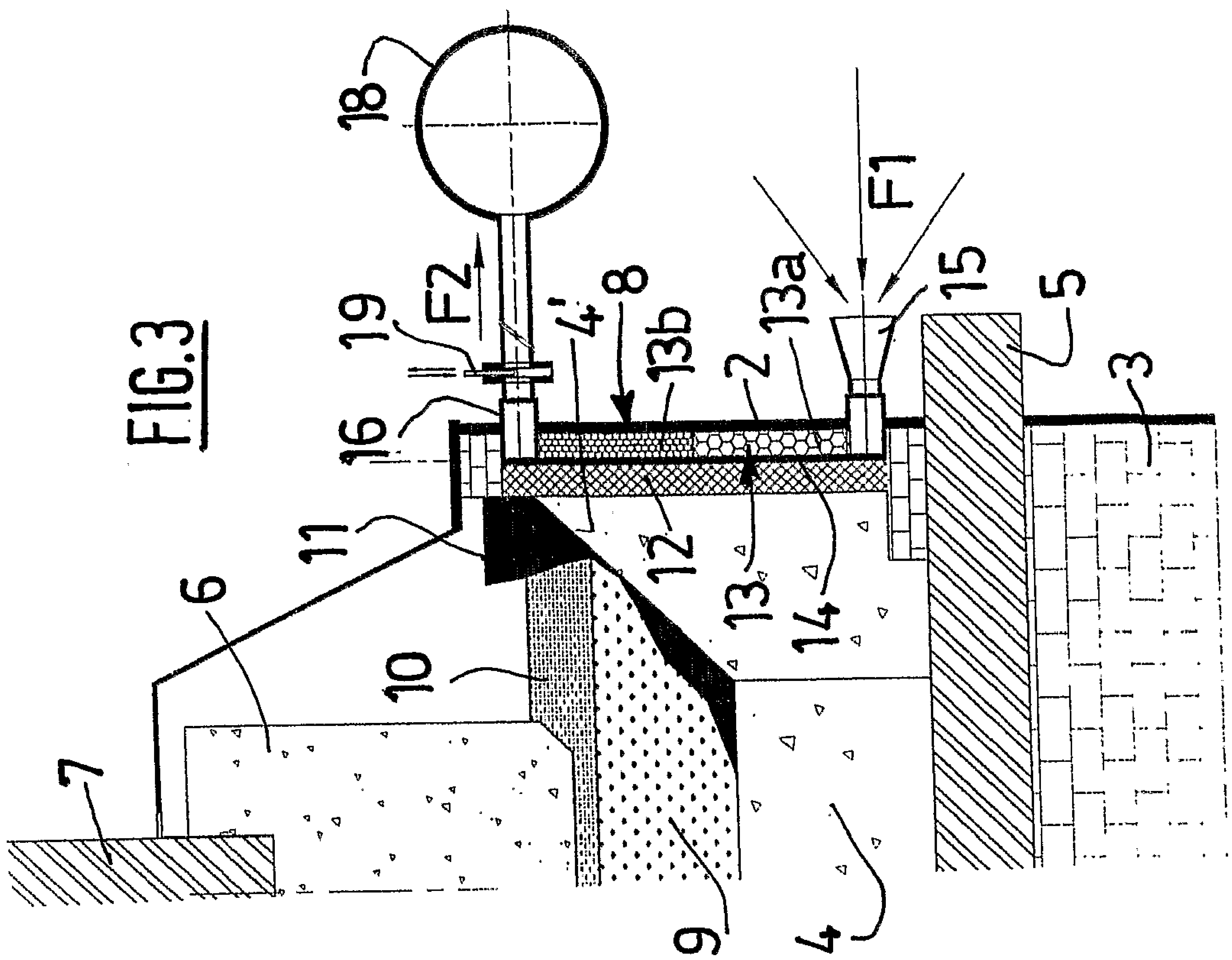

18
F1
15
5
3
F2
19
4'
8
13b
2
13a
16
11
12
13
14
6
10
7
9
4

FIG.2

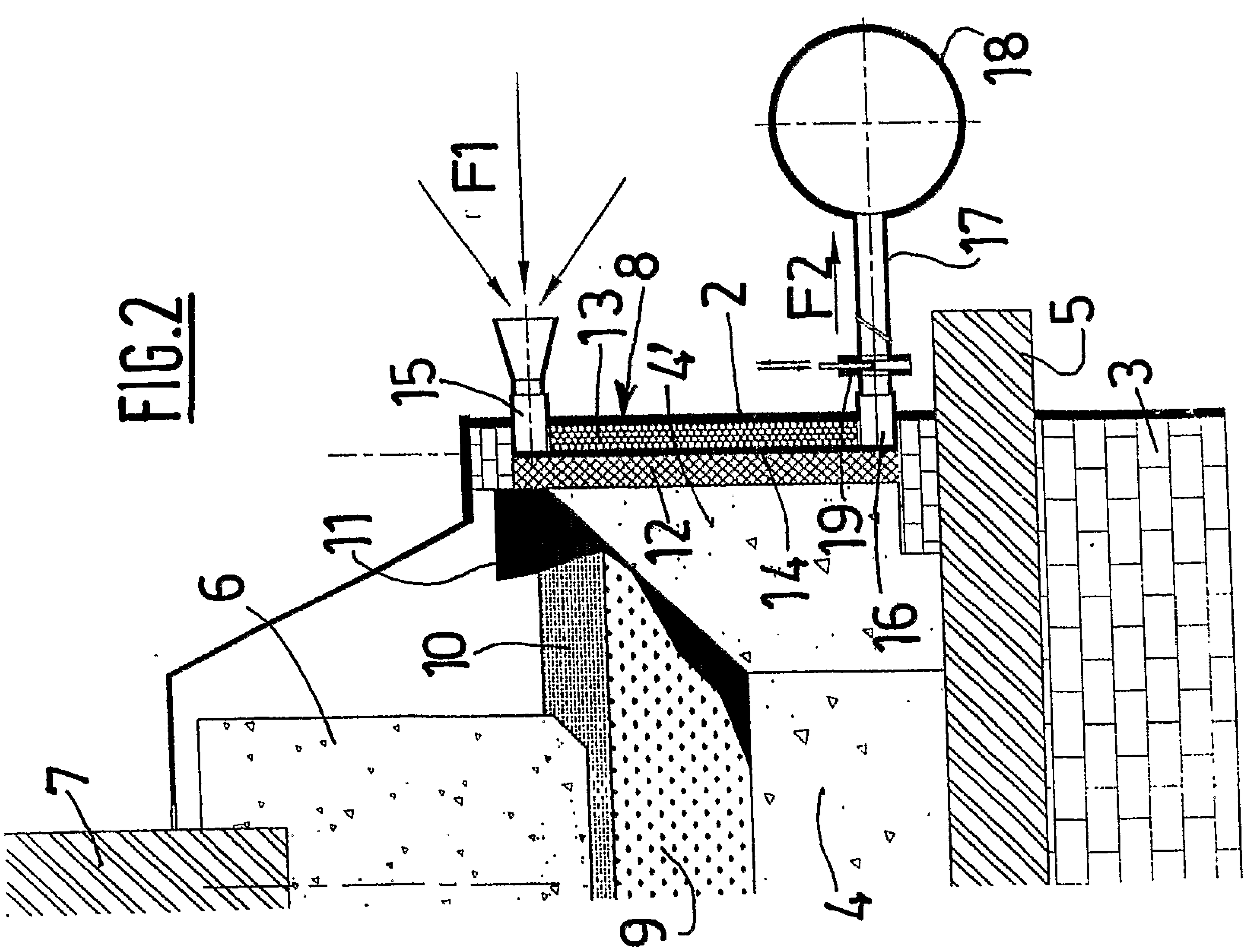

F1
18
17
F2
5
3
2
8
13
4'
15
11
12
14
19
16
6
10
7
9
4

FIG.5

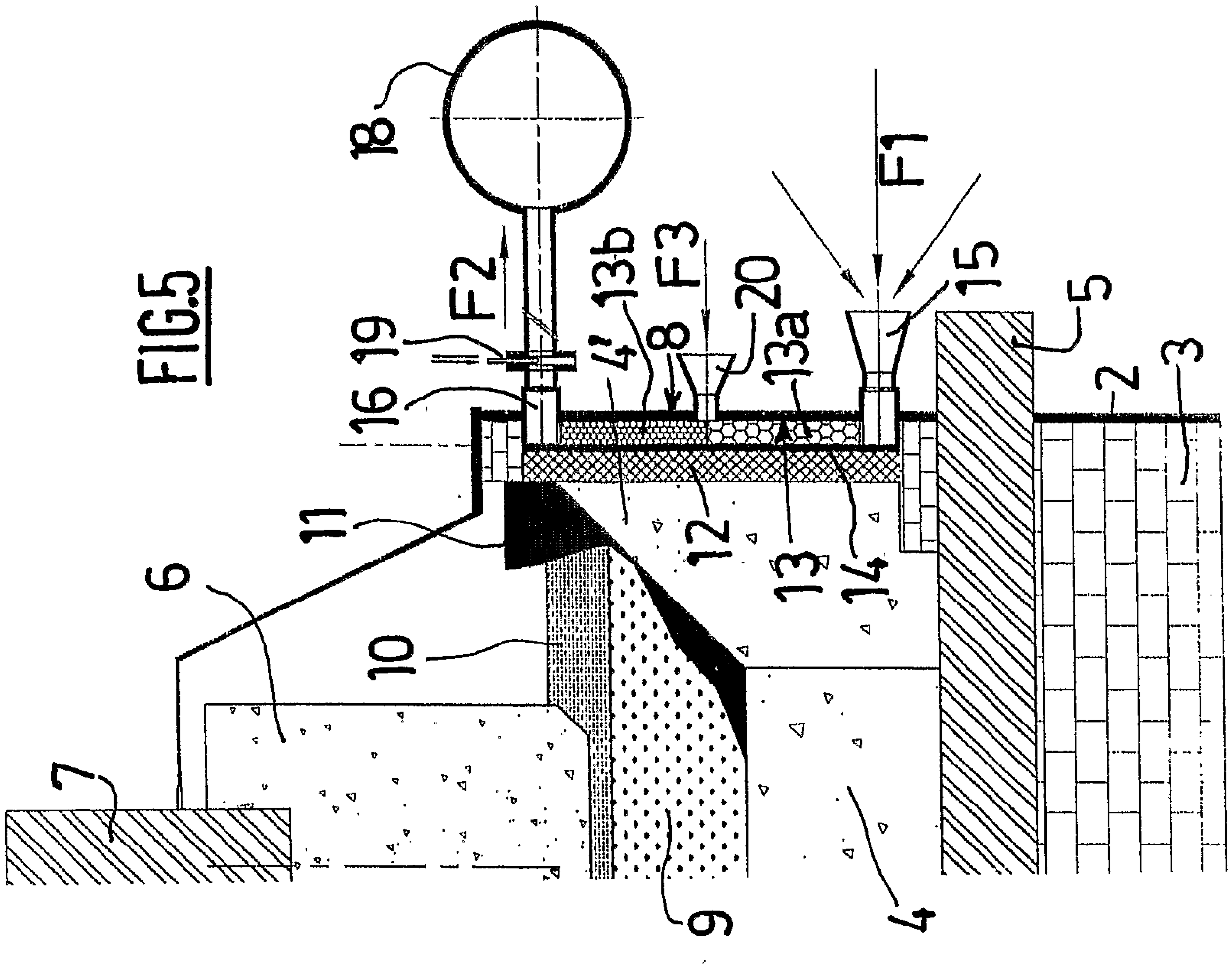

18
F2
19
16
13b
4'
8
F3
20
13a
F1
15
5
2
3
6
11
12
13
14
10
7
9
4

FIG.4

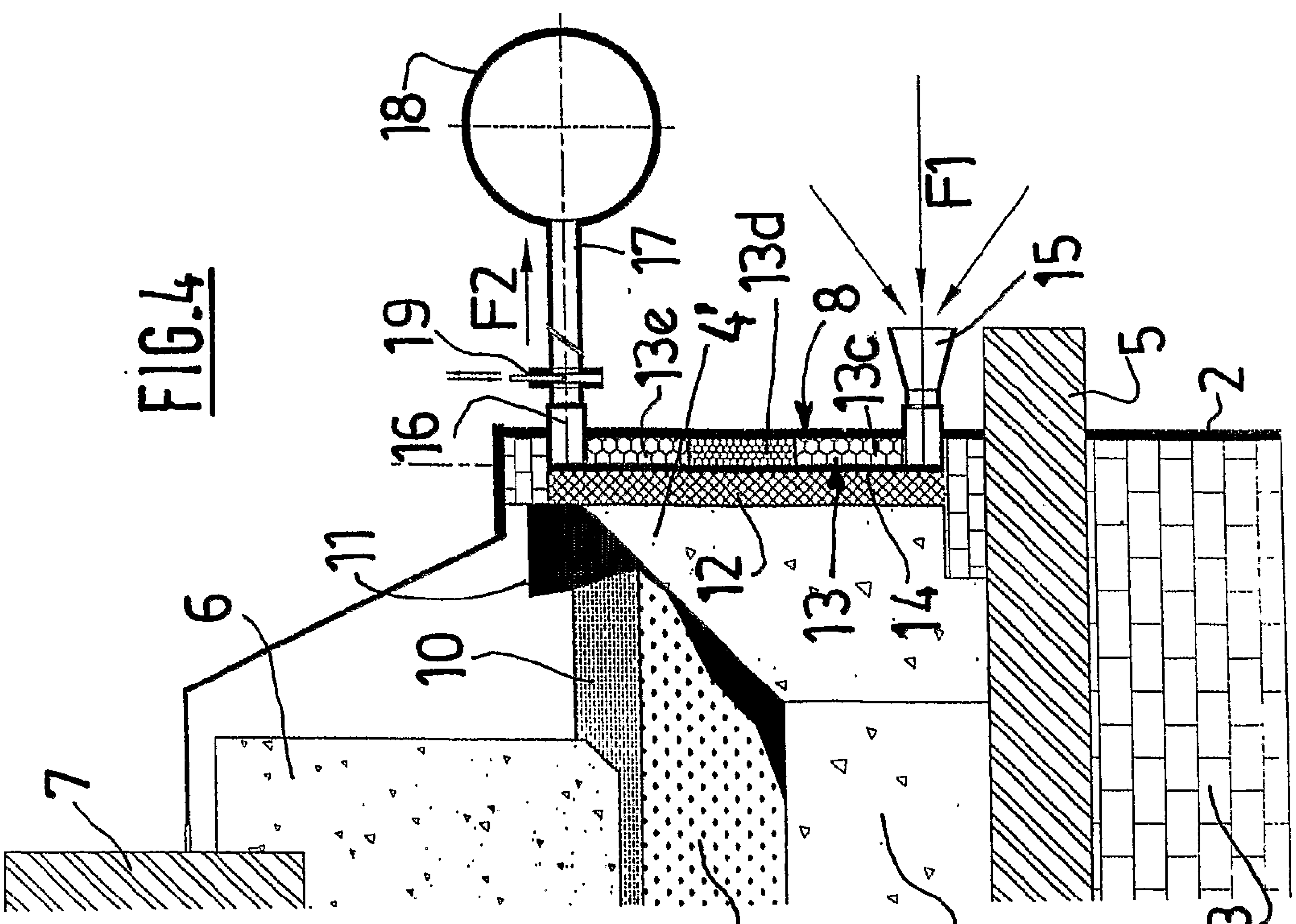

18
17
F2
19
16
13e
4'
13d
8
13c
F1
15
5
2
3
6
11
12
13
14
10
7
9
4

FIG. 7

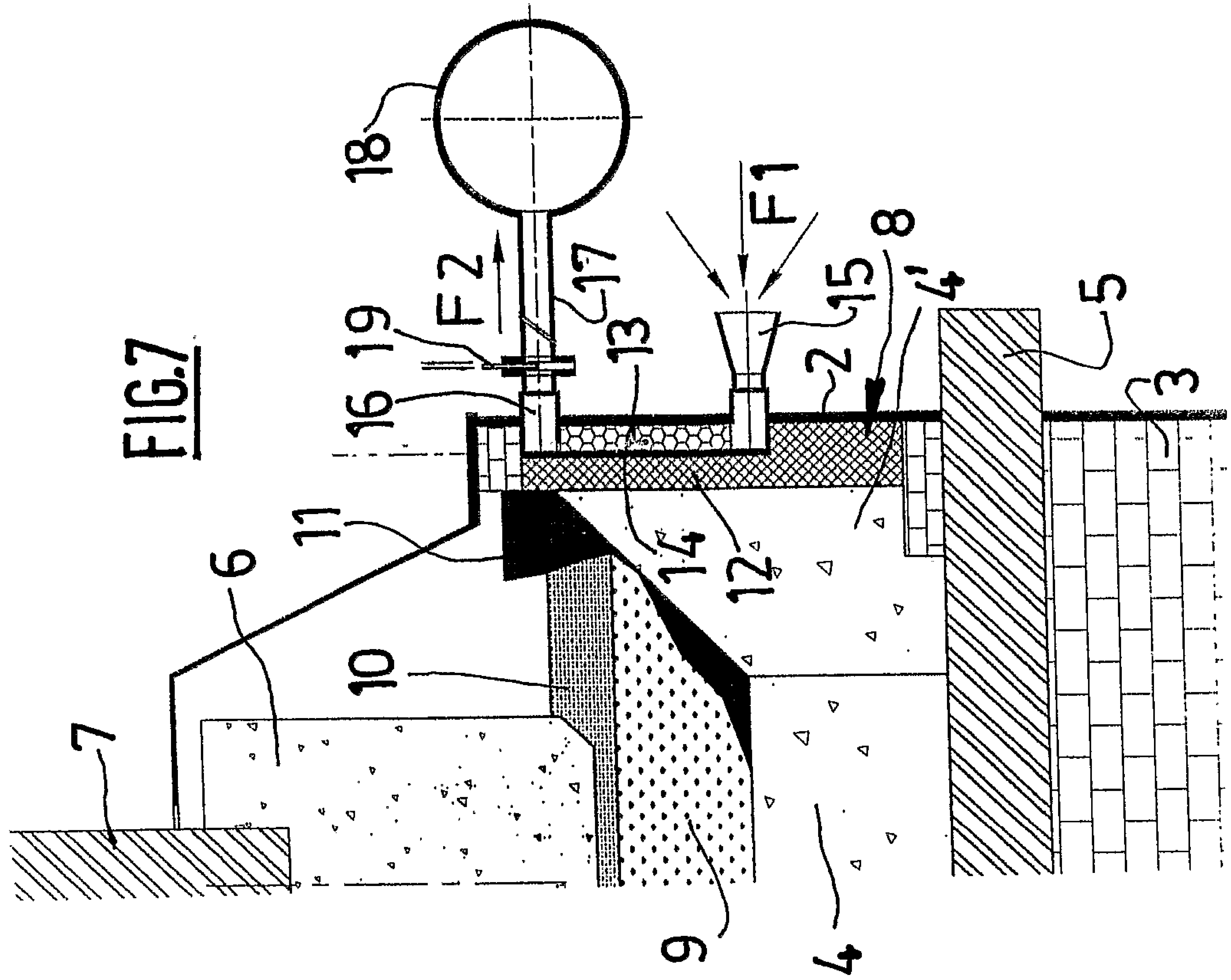

18
F2
19
17
16
13
F1
15
2
8
4'
5
3
11
14
12
6
10
7
9
4

FIG. 6

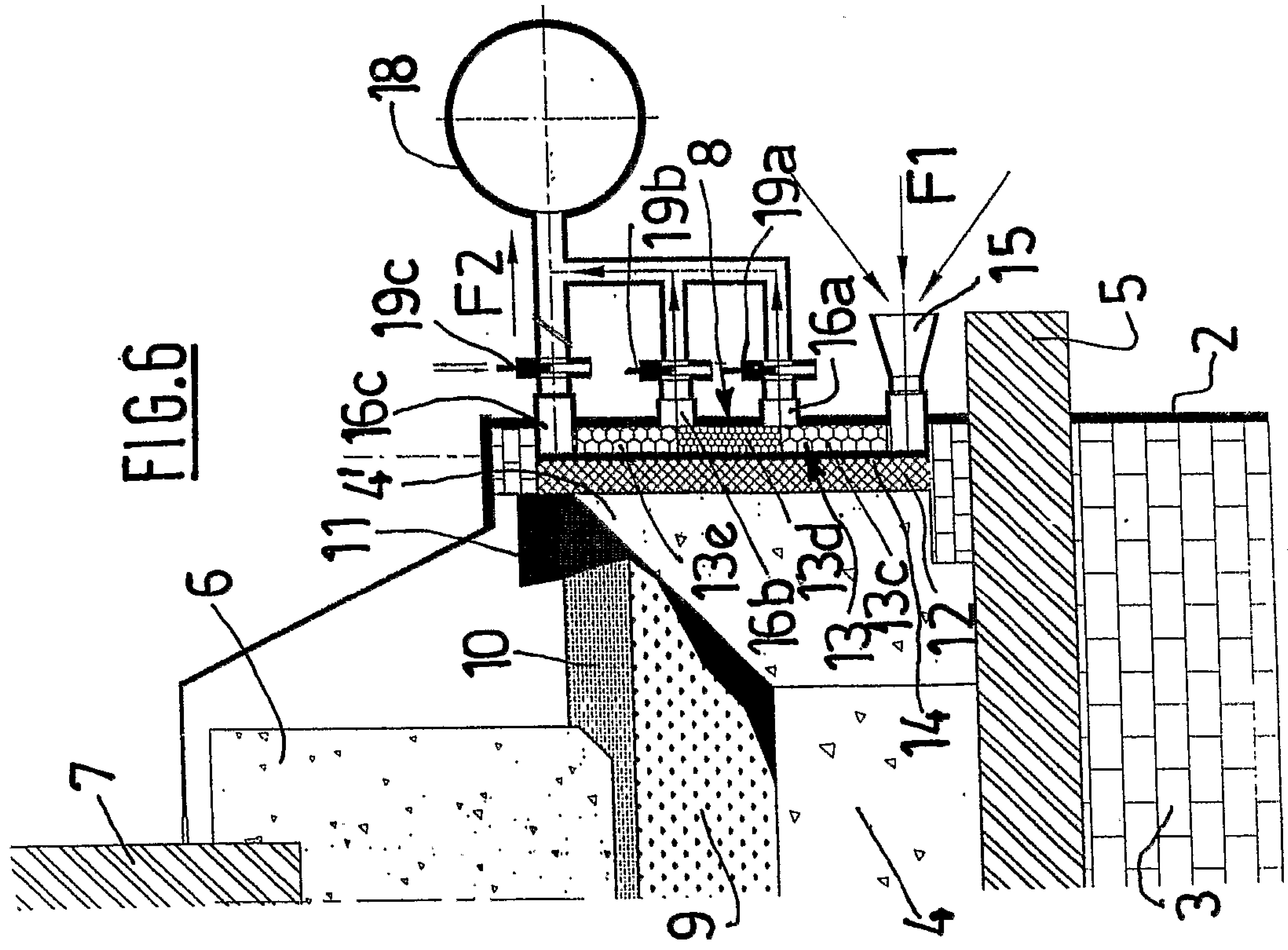

18
19b
8
19a
F1
F2
19c
16c
16a
15
5
2
4'
11
13e
16b
13d
13
13c
12
14
6
10
7
9
4
3

FIG.9

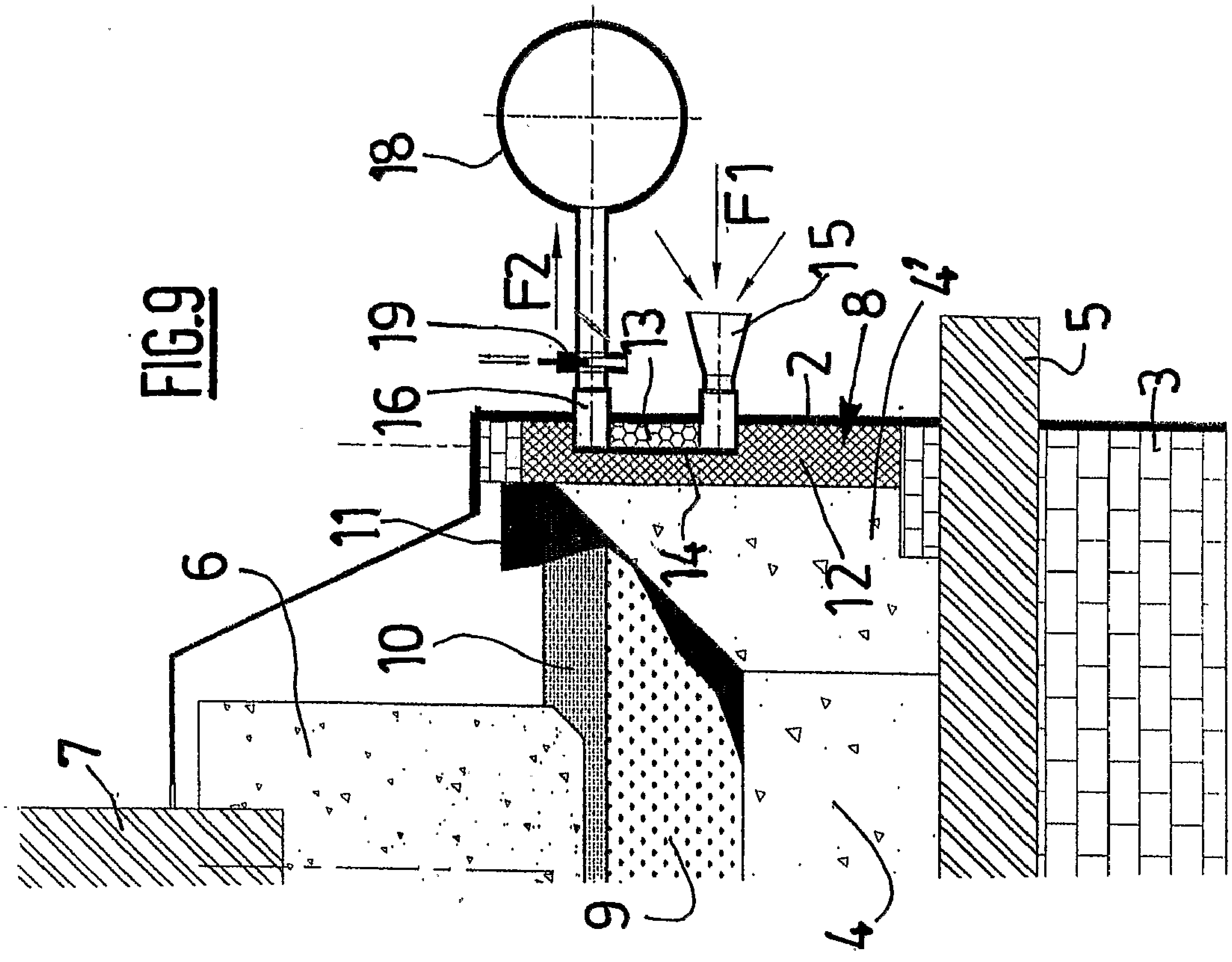
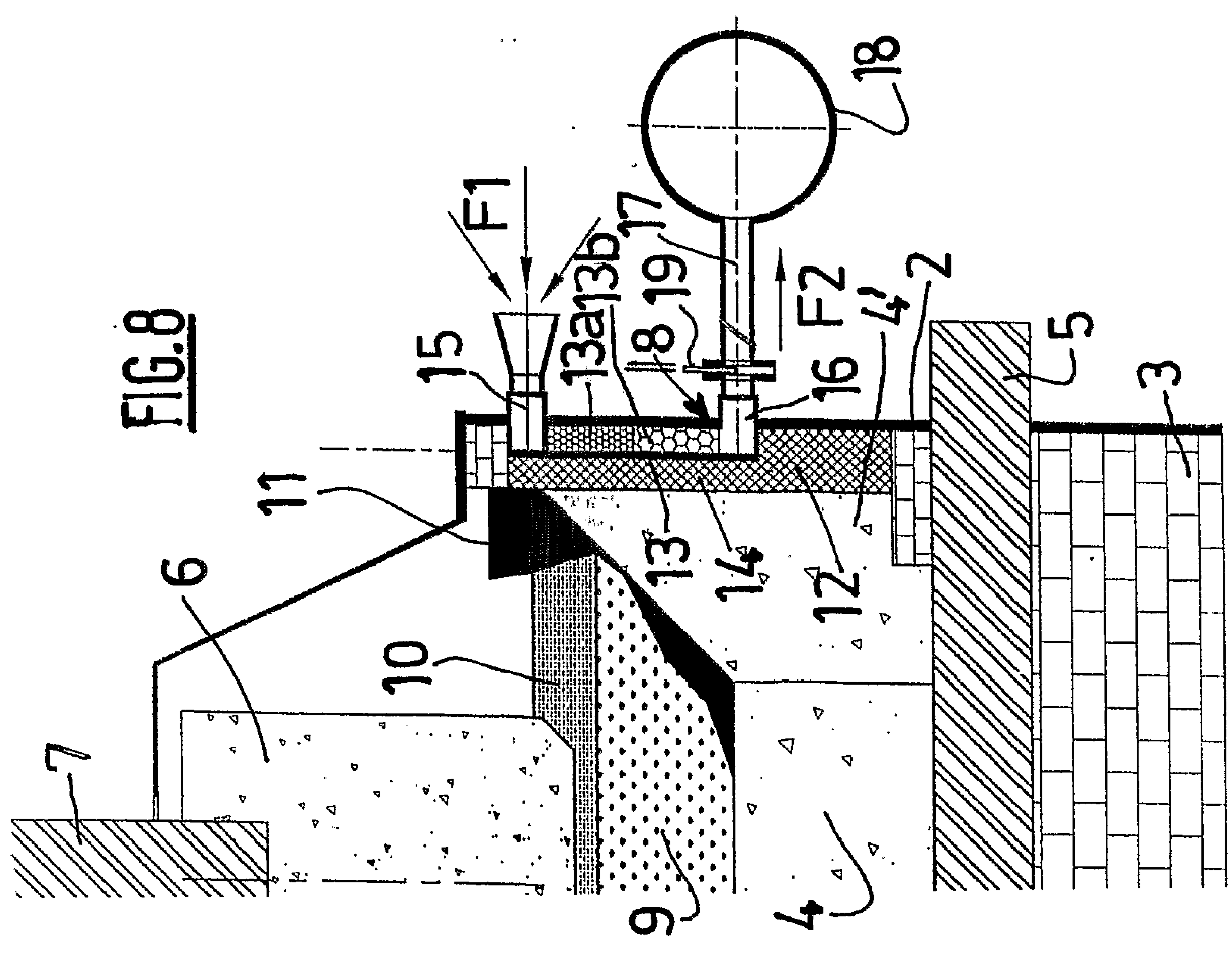

18
F1
F2
15
19
13
16
8
2
4'
5
3
11
6
14
12
10
7
9
4

FIG.8


F1
18
17
15
13a
13b
19
8
F2
16
4'
2
5
3
11
6
13
14
12
10
7
9
4

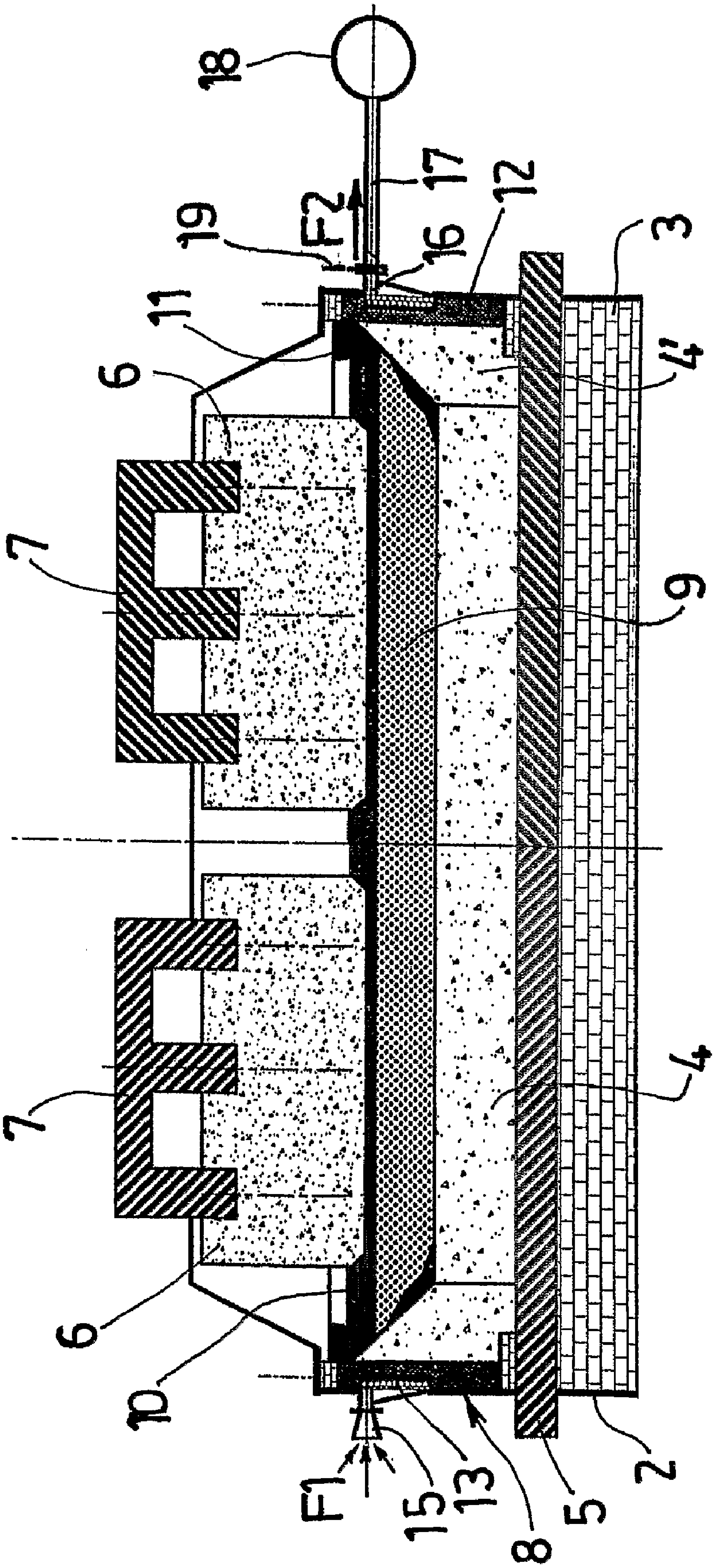


FIG.10

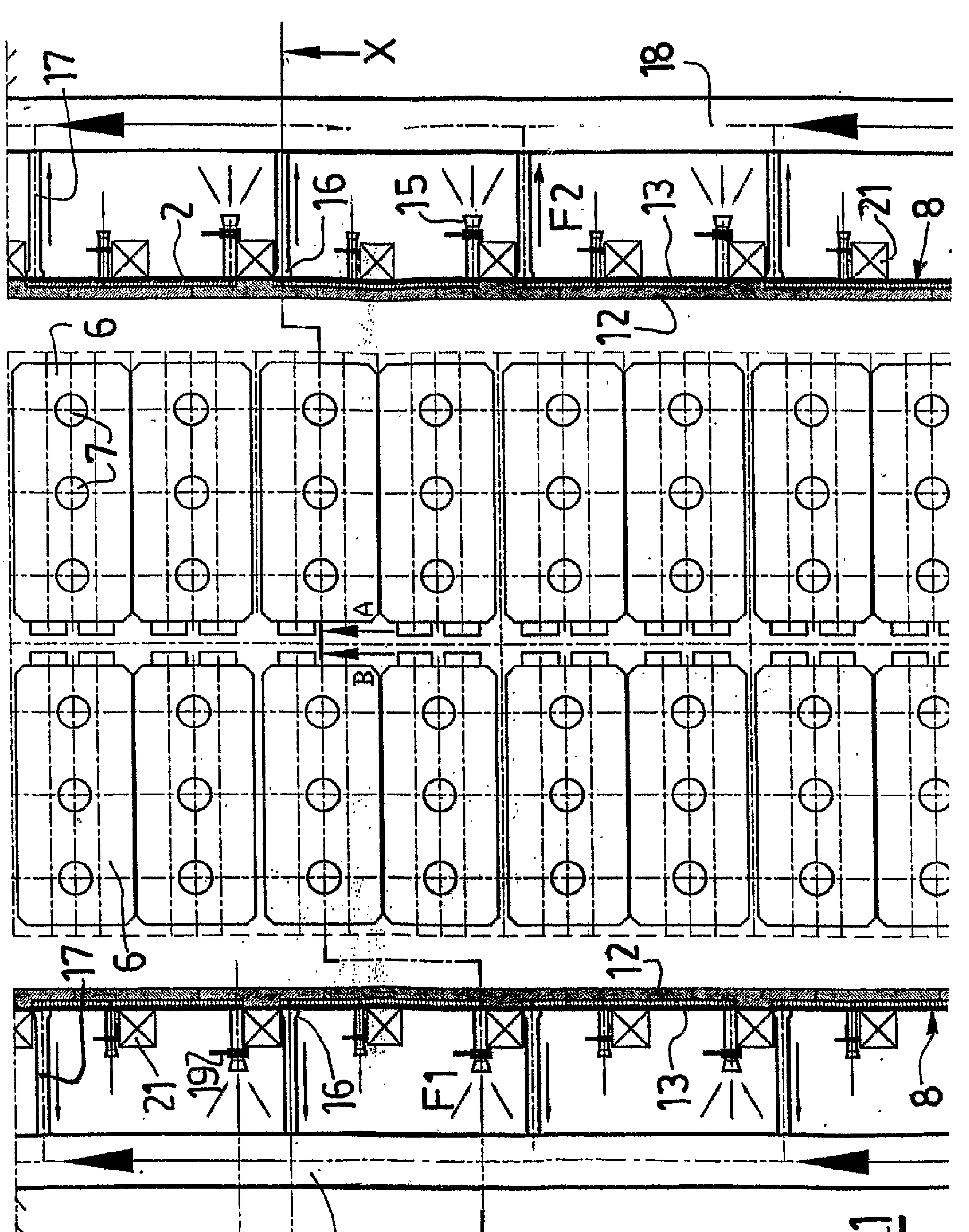


FIG.11

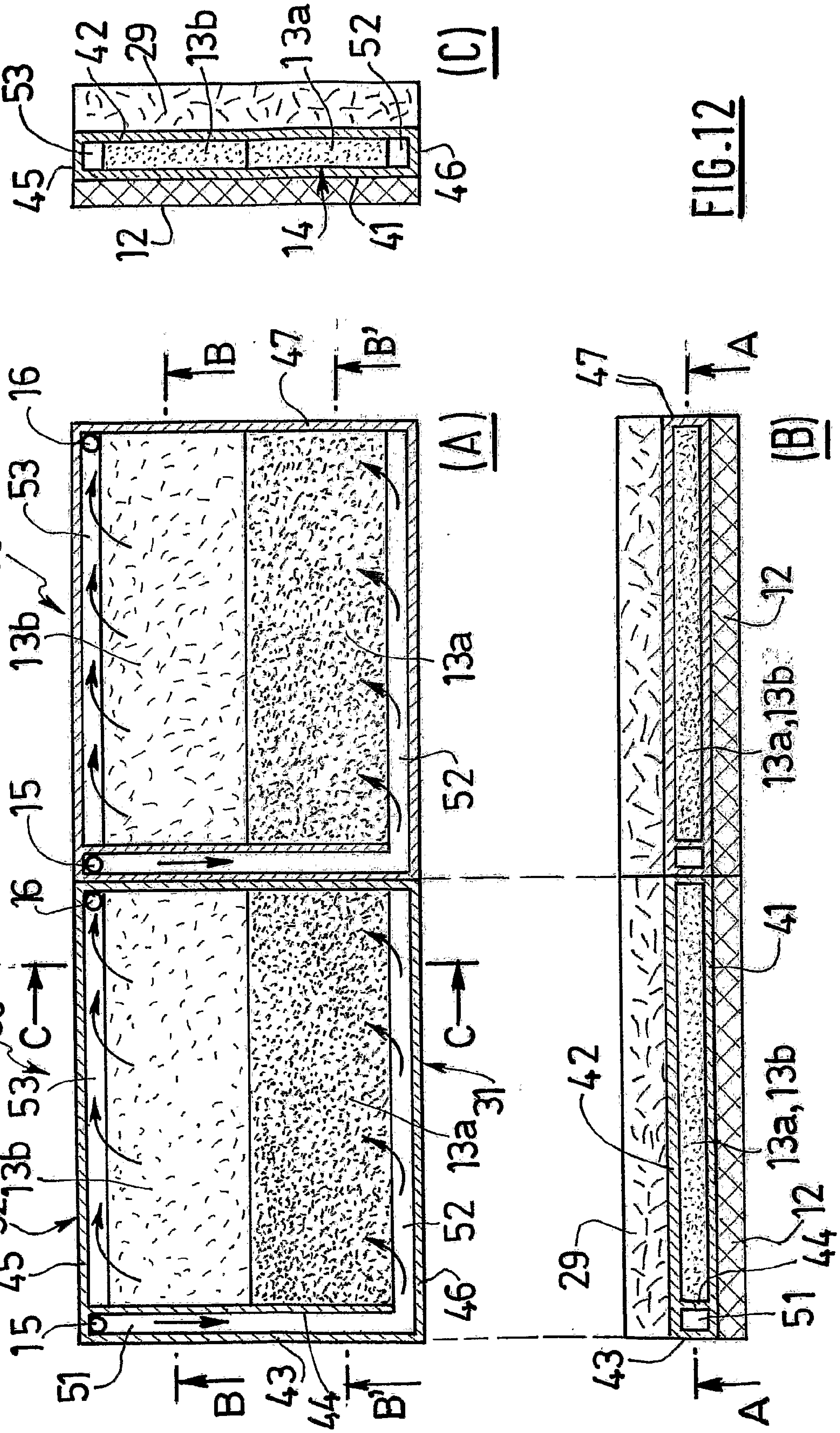

(A)
(B)
(C)
A
B
B'
C
12
13a
13b
13a,13b
14
15
16
29
30
31
32
41
42
43
44
45
46
47
51
52
53

FIG.12

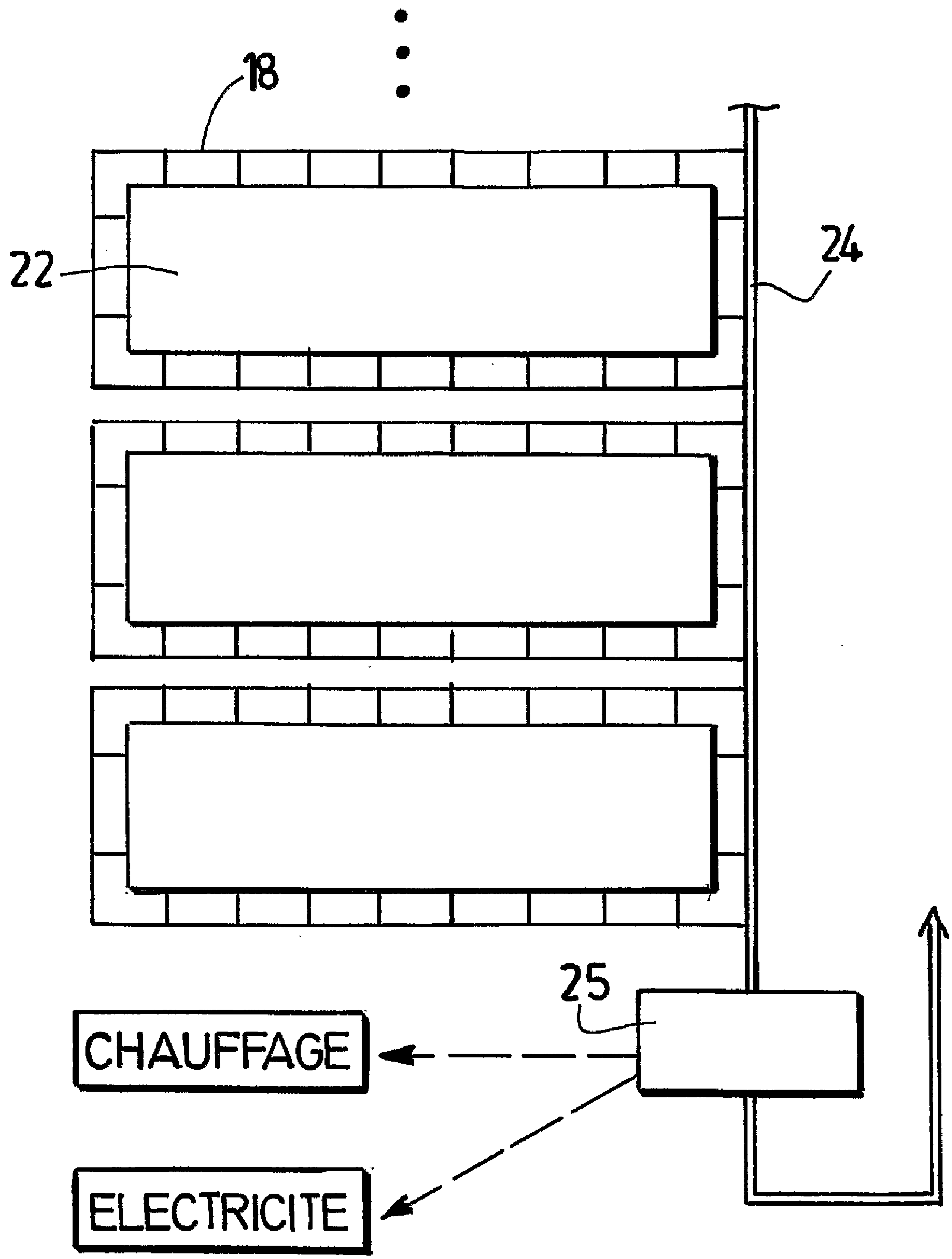


FIG.13

ELECTROLYTIC CELL WITH A HEAT EXCHANGER

[0001] This invention relates to the technical domain of electrolytic cells, and particularly cells used in the electrolysis process used for industrial production of aluminium.

[0002] More particularly, this invention relates to equipment of the side walls of an electrolytic cell pot, designed to recover heat energy lost through the sides of the pot by heat exchange with a heat transfer fluid, while protecting and preserving the sides of the pot and improving operating conditions of this pot.

[0003] International patent application WO 2004/083489 A1 describes an electrolytic cell for aluminium production in which the pot is provided with a kerb slab equipped for recovery of heat energy, by circulation of a gas or liquid heat transfer fluid. The heat transfer fluid is circulated through internal channels, arranged in a "coil" type path within the body of the kerb slab, gas tight cavities being obtained by various means at the time of production and assembly of side panels, with internal profiles obtained by casting and carbonaceous resin elements that are eliminated during sintering. The heat transfer fluid is added and extracted through ceramic pipes or connectors, glued to the material of the side panels.

[0004] Leak tightness of the heat transfer fluid circuit thus made up is complex and difficult to achieve using the means described, either for cavities formed in the bulk of the material making up the panels, or at the junction between the slab supply pipes, particularly because sintering of the parts is accompanied by large shrinkage of the material, and the residual porosity of the material close to the cavities can induce leaks.

[0005] Document WO 87/00211 that also relates to electrolytic cells for aluminium production is based on the control of the electrolysis bath temperature by a complex system of gas circuits provided in cooling chambers arranged not only in the side walls of the pot, but also in the anode and in the refractory material at the bottom of the pot, the heat transfer gas preferably being helium. The controlled cooling system is designed to minimise the thickness of insulating refractory materials and to recover heat energy. This system appears very expensive, both in implementation and in operation.

[0006] U.S. Pat. No. 4,222,841 describes a tubular heat exchanger above the electrolysis bath, due to the use of thermal insulation by refractory or carbonaceous panels separating the bath and the heat exchanger to prevent the formation of crusts. No information is given about the nature of the materials from which the heat exchanger is made, which is particularly subject to fluoride corrosion at high temperature. This document also describes a tubular heat exchanger at the sidewalls and the bottom of the pot containing the bath, once again without giving any further information about the structure and materials from which the exchanger is made.

[0007] Finally, document WO 01/94667 describes placement of cooling side panels that are insulated from the outside shell by a thick refractory material, inside an electrolytic pot for the production of aluminium, as a substitute for conventional kerb slabs. Each side panel is cooled by evaporation of a metal or alloy such as zinc, sodium or a sodium—lithium alloy in the liquid state. The panel evaporation chamber is covered by a condensation chamber cooled by circulation of a heat transfer gas. Such a device is complex and introduces obvious safety problems. Furthermore, the refractory material may be attacked by metals or alloys in the liquid or vapour phase with which it is in contact.

[0008] Faced with this state of the art, the purpose of this invention is to provide a new and advantageous technique for the side wall of an electrolytic pot, with the function, in addition to the function of surrounding the kerb of the crucible, of making a heat exchanger in order to recover heat energy lost through the sides of the pot, with a large exchange surface area, and to control the thickness of the frozen bath ridge that protects the side lining materials of the pot from chemical attack by the liquid aluminium and the molten salts bath, the proposed solution being intended to be simple and therefore economic, while remaining safe, and having a high heat energy recovery efficiency, and possibly with modulation of this energy recovery.

[0009] To achieve this, the purpose of the invention is an electrolytic pot that can be used for the production of aluminium, comprising sidewalls provided with a heat exchanger through which a heat transfer gas can pass, characterised in that the sidewalls of the pot are at least partly made of a porous material over at least a fraction of their height and their thickness, to enable circulation of the heat transfer gas, the part or each part made of a porous material being connected to heat transfer gas inlet and outlet means.

[0010] Thus according to the invention, the sidewalls of the electrolytic pot include porous parts in which the required heat exchange takes place. These porous parts, with open pores, have a high porosity such that the number of pores and the size distribution of these pores can enable circulation of the heat transfer gas without any excessive head loss, between an entry point and an exit or extraction point, gas circulation preferably being controlled by suction from the extraction side.

[0011] In one simple embodiment, the porous material may have homogenous characteristics over the entire height and width of the porous part. However according to an advantageous variant, the porous material has variable characteristics, and particularly porosity, thickness and/or thermal conductivity characteristics, over the height of the porous part, so as to obtain successive zones in the direction of the height with different heat exchange characteristics. The porous part can thus be optimised either by a progressively varying gradient, or by a sub-division in the direction of the height into successive zones with distinct characteristics (such as porosity and/or thickness) chosen to achieve the required power for a corresponding heat transfer gas flow. The sidewalls of the pot may also comprise at least one pipe through which the heat transfer gas can be circulated along a preferred path, particularly towards the bottom of the porous part and/or from the top of the porous part.

[0012] The porous part may be formed from one or several porous slabs, each slab having a monolithic structure made of a porous material.

[0013] According to one embodiment of the invention, the sidewalls of the electrolytic pot comprise at least a first part made of a dense material located on the inner side of these walls, and at least a second part made at least partially of a porous material, located between the first part and the outside shell of the pot, in other words the outer side of these walls facing the outside shell of the pot.

[0014] The first part made of a dense material is typically in contact with a kerb with an inclined edge which, together with the cathode blocks, form the cathode crucible. A contact material may be inserted between said first part and the kerb so as to reduce the thermal resistance at this interface. During operation, said first part may possibly be in contact with the upper part of the ridge of the frozen electrolytic bath. The heat exchange in this case is done in the part made of a porous material, on the outer side of the sidewalls.

[0015] The part made of a dense material may also be formed by one or several slabs with a monolithic structure. According to one variant, the part made of a dense material may be joined to the part made of a porous material by assembly. The two parts of these walls, namely the inner part made of a dense material and the outer part made of a porous material, can be assembled using a refractory material such as concrete, typically in the form of a refractory grout, or by a standard glue for the materials concerned, or by a special glue for this application.

[0016] Instead of deciding to assemble two distinct materials, one after the other through the thickness of the sidewalls of the pot, in one variant of the invention, the sidewalls of the electrolytic pot include a structure formed from monolithic slabs made from a material with variable porosity in the direction of the thickness of said sidewalls.

[0017] The slabs may form individual heat exchanger devices.

[0018] A porous part may be obtained by a process comprising the production of a porous polymer body comprising one or several polymer foams with open porosity, preparation of a suspension of a ceramic precursor, impregnation of the porous body with this suspension, drying of the impregnated suspension, baking of the porous body in order to burn organic components and sintering of the porous body. American patent U.S. Pat. No. 5,039,340 describes such a process. A material with variable porosity can be obtained by forming an initial body comprising a foam with variable porosity or superposition of two or more distinct porous foams with different porosities. A slab comprising a part made of a dense material and a part made of a porous material may be obtained by forming the dense part by casting, vibrocompaction and pressing of a ceramic precursor, and by combining the dense body thus obtained with one or several porous bodies as described above, typically after impregnating them with a ceramic precursor, baking and sintering preferably being done after bringing the dense body and the porous body together.

[0019] The porous material used may be formed from a metal or a metal alloy, a heat conducting ceramic or a mix or combination of these materials, and is typically in the form of a foam. Preferably, the metal or metal alloy has a melting point exceeding 800° C. and is resistant to oxidation at temperatures of above 250° C., like nickel-based alloys (in other words containing more than 50% by weight of nickel). Said metal or metallic alloy preferably has a coefficient of thermal expansion less than 25×10^{-6} K^{-1}, such as Inconel® 686 containing nickel, chromium, molybdenum and tungsten. The intrinsic thermal conductivity of ceramic is preferably greater than 5 W/m.K, and preferably even greater than 20 W/m.K. In order to increase the compatibility of thermal expansion between the dense material and the porous material, the porous material is preferably made from a foam containing a majority of silicon carbide (SiC), silicon nitride and/or aluminium nitride, that are heat exchanging materials according to the meaning of this invention (a majority meaning more than 50% by weight). In this case, the porous material preferably contains at least 70% by weight of heat conducting ceramic, and preferably 85% by weight of heat conducting ceramic, for example the remainder may be oxide type mineral binders such as silicates or oxinitrides.

[0020] The porous material has a porosity of more than 70%, preferably more than 80% (the porosity being defined in this case as being the void ratio).

[0021] Considering more particularly the case of sidewalls comprising a first part made of a dense material and a second part made of a porous material, it is preferable for the part made of a dense material to have a porosity of less than 20%. The dense material is preferably a ceramic material containing at least 70% by weight of silicon carbide (SiC) and more preferably 85% by weight of silicon carbide (SiC).

[0022] In combination with the distribution in the direction of the thickness of the sidewalls of the pot, the part made of a porous material that is the source of the heat exchange may be present around all or part of the height of these walls.

[0023] According to a first possibility, the part made of a porous material extends substantially over the entire height of the sidewalls of the pot, so that a controlled quantity of heat energy produced by electrolysis can be drawn out over an extended surface area.

[0024] According to another possibility, the part made of a porous material extends over a limited portion of the total height of the sidewalls of the pot, particularly over a fraction of the order of one third to one half of the height of this pot, so as to concentrate the heat exchange and therefore the drawn off thermal flux, facing limited and judiciously selected areas, for example at the interface between the liquid aluminium layer and the molten salts bath, known as being a critical area with regard to stability of the ridge.

[0025] The heat transfer gas inlet and outlet means may in particular be located at the top and at the bottom of the (each) part made of a porous material, therefore near the top part and bottom part of the sidewalls of the pot, particularly in the case of a porous area extending substantially over the entire height of the sidewalls.

[0026] However, particularly in the case of a part made of a porous material divided in the direction of the height into successive zones having different heat exchange characteristics, it is advantageously planned to use at least one additional inlet or one additional outlet of the heat transfer gas located at an intermediate height, particularly at the transition between two successive zones, as a function of heat exchange needs in these different zones.

[0027] The heat transfer gas inlet and outlet means may also be distributed along the horizontal dimension of a part of the sidewalls of the pot made of a porous material, particularly by arranging the inlet and outlet at the two horizontally opposite ends of a part made of a porous material. This is particularly applicable to the case of a long part made of a porous material in order to achieve the most uniform possible heat exchange over the entire length of said part made of a porous material.

[0028] In that respect, it can be noted that a part made of a porous material may extend over a zone very much longer than a slab (for example when the porous part is formed by the assembly of two or more slabs made of a porous material). In these cases, the junction between slabs is made so as to enable the heat transfer gas to flow between the porous zones in each adjacent slab. The junction cement may be concrete, refractory grout or appropriate glue. The number of heat transfer gas inlets and outlets can thus be limited.

[0029] Preferably, the heat transfer gas inlet(s) have orifices located at a level higher than the liquid level in the pot, in other words the inlet orifices are near the top of the sides of the shell or are around the periphery of the top of the shell, or if the actual inlets are located near the bottom of the pot for technical reasons, these inlets are extended by tubes oriented upwards and with their orifices at a level higher than the liquid level in the pot, in order to avoid a flow of hot liquids outside the outside shell of the pot, particularly when the porous zone extends substantially over the entire height of the sidewalls of the pot, and therefore the shell, in the case of a local failure of the different heat exchanger devices.

[0030] For the heat transfer gas outlet, and more particularly for extraction of this gas by suction, at least one side manifold is advantageously provided connected to several heat transfer gas outlets. Preferably, each side of the electrolytic pot is equipped with at least one manifold, all manifolds being connected to a common suction unit. The two long sides of the pot may each be equipped with two parallel manifolds.

[0031] Regardless of the position of the heat transfer gas inlet and outlet orifices, the through cross-section of these orifices or of some of these orifices is advantageously made adjustable using flaps. These flaps may be pre-set when cold, before the electrolytic pot is put into operation, as a function of local specificities and the pot design. The design and manufacture of the manifold(s) through which the heat transfer gas is extracted, is preferably such that before the above mentioned flaps are adjusted, an equivalent head loss at the suction is obtained in all individual heat exchanger devices in the pot connected to these flaps, so as to obtain constant heat flows per unit volume.

[0032] The heat transfer gas may be air or an inert gas, typically nitrogen, helium or argon, or a mix of air and inert gas.

[0033] If air is used as the heat transfer gas, air inlets may be open to the surrounding atmosphere, more particularly into the space located between adjacent pots, and in this case only the air outlets are connected to suction manifolds. Air inlets are thus composed of single orifices with an appropriate shape and size, that operate by depression to supply a heat exchanger device, in other words a part made of a porous material.

[0034] However, in another preferred embodiment in which air is used as the heat transfer gas, this air is recycled to increase its inlet temperature into the porous zone, and consequently its outlet temperature from this zone so as to increase the usage efficiency of the recovered energy, for example through an external heat exchanger. In this case, a distribution network is provided to bring air drawn off at the outlet orifices to the inlet orifices. The design of this distribution network assures an identical head loss at all air inlet orifices to the pot, in order to obtain uniform operation.

[0035] Similarly, if the heat transfer gas contains an inert gas, it is advantageous to recycle it due to its value.

[0036] Finally, if a distribution network is provided, the embodiment without recycling the heat transfer gas, and therefore with air intake in the space located between the pots, can be combined with the production mode with air recycling using direct air inlet valves into the distribution network, these valves possibly being located at different points in the distribution network, preferably in combination with isolating valves that can isolate the different portions of the distribution network from each other. This "combined" mode has the advantage that it enables work to be done on the distribution network, or can temporarily overcome a failure in the "upstream" part of the gas recycling system, or compensate for air losses in the circuit.

[0037] Advantageously, a thermal insulation is also provided between the part made of a porous material and the shell of the pot, and more precisely between firstly the outer face of the part made of a porous material, and secondly the inner face of the pot shell. The layer of insulating material limits thermal losses, which makes it possible to improve energy recovery. The thermal insulation is advantageously made of a fibrous material that can act as a deformable buffer to protect kerb slabs, by absorbing any thermal expansions of the pot, particularly during its temperature rise when the cell is brought into service. The insulation typically forms a substantially vertical layer with a thickness of between 10 and 100 mm, and preferably between 15 and 50 mm.

[0038] The heat transfer gas preferably travels by suction and therefore by depression, through the heat exchanger device so that if the device fails, it will not blow heat transfer gas into the structure of the pot, kerb blocks, the bottom of the pot or liquid phases. This variant of the invention may be used by connecting the electrolytic cell to a suction system that can circulate a heat transfer gas by depression in the part or each part made of a porous material.

[0039] Finally, another purpose of the invention is an industrial aluminium production plant comprising a plurality of electrolytic pots like those mentioned above, that are connected through manifolds to a heat transfer gas circuit directed towards energy recovery means, comprising at least one external heat exchanger and/or at least one electricity generator.

[0040] The heat exchanger system as a whole proposed by the invention has the following advantages:

[0041] This heat exchanger system is very simple to make, which makes it economic and reliable,

[0042] Since it is located as close as possible to the thermal energy source, the system enables optimum recovery of this energy; reuse of this energy is optimised because it is done at high temperature;

[0043] Application of the invention does not require any redesign to the structure of the electrolytic pot, which contributes to simplicity and enables retrofitting of existing pots;

[0044] Energy recovery is easily modulable as a function of the inlet temperature of the heat transfer gas and its flow, so that this enables participation in regulation of the service intensity of electrolytic pots as a function of production needs or the availability of electrical energy. The heat exchanger system is used to evacuate all or some excess energy beyond a defined operating point;

[0045] The invention makes it possible to increase the control precision of the thickness of the ridge of frozen electrolytic bath that protects materials from which the sidewalls of pots are made from chemical attack by liquid aluminium and the molten salts bath. This, together with the previous points, makes it possible to develop new electrolytic pots with a significantly improved unit power, and with exactly the same or a better energy balance, with the possibility of modulating the pot intensity without disturbing the thermal equilibrium of the pot.

[0046] The invention will be better understood with the help of the following description made with reference to the appended diagram showing various embodiments of this electrolytic cell with a pot with sidewalls provided with a heat exchanger, for use as examples:

[0047] FIG. 1 shows a partial vertical sectional view of an electrolytic cell according to this invention;

[0048] FIG. 2 shows a partial sectional view corresponding to the right part of FIG. 1 showing a first variant of this cell;

[0049] FIG. 3 is a view similar to that in FIG. 2, illustrating a second variant;

[0050] FIGS. 4 to 9 are views similar to the above, illustrating other embodiments of the cell according to the invention;

[0051] FIG. 10 shows a vertical sectional view along X-X in FIG. 11, of another embodiment of the electrolytic cell according to the invention;

[0052] FIG. 11 shows an overhead partial plan view of the cell in FIG. 10;

[0053] FIG. 12 represents a modular assembly according to an advantageous variant of the invention.

[0054] FIG. 13 is a diagram illustrating a method of recovering thermal energy from cells according to the invention.

[0055] As can be seen on FIG. 1, an electrolytic pot 22 used for the production of aluminium from alumina, usually comprises:

- [0056] an external shell 2 made of steel,
- [0057] floor lining 3 made of a refractory material,
  - [0058] a crucible 40 designed to be cathodically polarised, formed entirely or partly from cathode blocks 4 and a kerb 4' that is typically formed from kerb blocks made of carbonaceous materials,
  - [0059] current inlet into the cathode, through horizontal steel bars 5 that pass through the shell 2 and are sealed to the cathode blocks 4,
- [0060] pot side walls 8, described in detail below.

[0061] An electrolytic cell 23 is formed by the assembly of a pot 22 and one or several carbonaceous anodes 6 in the upper part above the crucible, and connected to a current inlet through anode multipodes 7.

[0062] In service, the crucible 40 contains a layer of liquid aluminium 9 above which there is a molten electrolyte bath 10 based on cryolite into which each anode 6 dips. The assembly formed by the liquid aluminium layer 9 and by the electrolyte bath 10 is surrounded by a solidified bath zone called the "ridge" 11 close to the sidewalls 8 and in contact with kerb blocks 4' of the crucible 40.

[0063] Seen from above, the electrolytic pot has a generally rectangular shape, with two long sides and two short sides.

[0064] An electrolytic cell is usually associated with other similar cells arranged in line with free spacings (therefore filled by air) between the pots of these cells.

[0065] As illustrated in the right part of FIG. 1, the sidewalls 8 of the electrolytic pot are divided along the direction of their thickness into at least two adjacent parts, in accordance with this invention. A first part 12 located on the inner side and thus at the contact of the kerb blocks 4' (and possibly the ridge 11) is made from a dense refractory material as leak tight to gases as possible and particularly in the form of a plurality of silicon carbide (SiC) based slabs.

[0066] In this case, a second part closer to the outer side and therefore facing the inner face of the shell 2, is composed of a porous material 13 over almost its entire height. The porous material, that is typically a foam (preferably a silicon carbide foam) has an appropriate porosity, typically between 10 and 90 ppi (namely between about 4 and 36 pores/cm) and preferably between 20 and 70 ppi (namely approximately between 8 and 28 pores/cm) so as to offer a low head loss while maintaining a high heat exchange capacity.

[0067] The thickness of the dense part 12 may be between 10 and 100 mm and preferably between 30 and 50 mm, while the thickness of the part made of a porous material 13 is between 5 and 50 mm, and preferably between 10 and 25 mm, and typically between 15 and 25 mm. These two parts 12 and 13 can be assembled at their interface 14 using special glue in the form of a suspension or a paste, containing a mix of a mineral filler with an average size grading of less than 250 μm, and a silicone resin. In the case of a suspension, the mix may possibly contain a solvent to solubilise the resin and form a fluid suspension. International patent applications WO 03/033435 and WO 03/033436 describe possible glues.

[0068] A heat insulating fibrous material (not shown) may be inserted between the shell and the porous part so as to reduce heat losses to the shell, for recovery of this heat. This insulation may also be put into compression between the outer wall of the part 13 made of a porous material, and the inner face of the shell 2.

[0069] The part made of a porous material 13 is designed to allow air to enter through an air inlet orifice 15 near the bottom of the sidewall 8 and then pass through the part from bottom to top in FIG. 1, to be extracted through an air outlet orifice 16 near the top part of the sidewall 8.

[0070] Air, that is not recycled in the case illustrated in FIG. 1, is drawn off outside the pot, and particularly in a free space between pots, and enters the air inlet orifice 15 under the effect of depression along the direction of arrows F1. This air, extracted through the air outlet orifice 16, passes along the direction of arrow F2 through a tube 17 connected to this orifice 16 and reaches a lateral manifold 18 that extends horizontally along one side of the pot and is itself connected to a suction unit (not shown). The same manifold 18 may thus contain air flows extracted from several similar heat exchangers following each other along a sidewall 8 of the pot.

[0071] Air passing through the heat exchangers thus formed recovers heat energy released within the pot and transfers this energy to outside the pot. The range of heat flux thus evacuated through the walls 8 of the pot typically varies between 1 and 35 kW/m^2.

[0072] The air outlet orifice 16 is advantageously provided with a flap 19 for varying the air outlet cross section.

[0073] According to an inverse arrangement illustrated in FIG. 2 (on which the corresponding elements are shown with the same references), the air inlet orifice 15 is located near the top part while the air outlet orifice 16 is located near the bottom part of the sidewall 8.

[0074] FIG. 3 shows an embodiment similar to that in FIG. 1, but in which the part made of a porous material 13 is subdivided along the direction of the height into two partial successive porous zones 13*a* and 13*b*. More particularly, the lower partial zone 13*a* has higher porosity, and the upper partial zone 13*b* has lower porosity conducive to more intense heat exchange, this partial zone 13*b* being preferably located at substantially the same height as the layer of liquid aluminium 9 and the electrolyte bath 10. In this case air passes in sequence through the lower partial zone 13*a* and then the upper partial zone 13*b*. In one variant not shown, the air inlet is located near the top of the sidewall, in this case air passes firstly through the upper partial zone 13*b* then the lower partial zone 13*a*.

[0075] FIG. 4 shows another variant in which the part made of a porous material 13 is subdivided in the direction of its height into three successive partial porous zones, namely a lower partial zone **13***c*, an intermediate partial zone **13***d* and an upper partial zone **13***e*.

[0076] FIG. **5** shows yet another variant, similar to the embodiment shown in FIG. **3** but including an additional air inlet orifice **20** located at the transition between the lower porous partial zone **13***a* and the upper porous partial zone **13***b*. As shown by the arrow F**3**, an additional air flow is allowed to enter due to depression into the additional inlet orifice **20**, and this flow is added inside the upper partial zone **13***b*, to the airflow inlet through the lower inlet orifice **15**.

[0077] Conversely, it is also possible to keep a single air inlet orifice **15** and to multiply air outlets as illustrated in FIG. **6**; in this case, the different air outlet orifices **16***a*, **16***b* and **16***c* located at distinct heights on the sidewall **8**, each have their flap **19***a*, **19***b* or **19***c* and are all connected to the same side manifold **18**, itself connected to the suction unit.

[0078] Other combinations of air inlets and outlets distributed over the height of the sidewalls **8** of the pot are also possible, the embodiments described in detail above only being examples.

[0079] FIG. **7**, on which the elements corresponding to the elements described above are once again shown with the same references, shows another embodiment in which the part made of a porous material **13** from which the heat exchanger is made extends only over a fraction of the total height of the sidewalls **8** of the electrolytic pot, for example over about half the height of these walls. In particular, in this case the part made of a porous material **3** is present in the upper half of this height of walls, so that it is also located at the same height as the liquid aluminium layer **9** and the electrolyte bath **10**. The air inlet orifice **15** is thus at about mid-height of the sidewall **8**, while the air outlet orifice **16** is near the top part. Obviously, as in the previous examples, it is possible to invert the position of the air inlet and the air outlet.

[0080] As can be seen in FIG. **8**, also for the case of a part made of a porous material **13** that only extends over a fraction of the height of the sidewalls **8**, this part made of a porous material can still be divided into two or several partial zones, in this example an upper partial zone **13***a* and a lower partial zone **13***b* with different porosities. An additional air inlet or outlet may be provided at the junction between the two partial porous zones **13***a* and **13***b*.

[0081] The height of the part made of a porous material **13** may be further reduced and for example only represent about one third of the total height of the sidewalls **8** of the pot, as illustrated in FIG. **9**.

[0082] In all embodiments described above with reference to FIGS. **1** to **9**, the air inlet and outlet orifices are distributed over the height of the sidewalls **8** of the pot, regardless of their number.

[0083] In another type of embodiment illustrated in FIGS. **10** and **11**, the inlet orifices **15** and the outlet orifices **16** are located at the same height, at the two horizontally opposite ends of the successive parts **13** made of a porous material, with a horizontal extension. As shown particularly in FIG. **11**, each part made of a porous material **13** extends horizontally along several adjacent slabs **12** making up the sidewalls **8**. Each part made of a porous material **13** is thus very much longer than the slabs **12** and the spaces between the cradles **21** of the shell **2**. As described above, the outlet orifices **16** are connected to manifolds **18** that extend along the sides of the electrolytic pot.

[0084] In one variant not illustrated related to the previous embodiment, the parts made of a porous material are joined together to form a continuous strip with alternating inlet and outlet orifices around the perimeter of the electrolytic pot.

[0085] In all cases, in order to force circulation of air or another heat transfer gas into the parts **13** made of a porous material, the side or end surfaces of these parts made of a porous material can be made leak tight by impregnation or sealing, thus preventing any leaks or losses of air or gas.

[0086] FIG. **12** illustrates a modular assembly of porous sections according to a particularly advantageous embodiment of the invention. The drawing shows two adjacent modules **30**, seen in (A) along section A-A in FIG. **12** (B), in (B) along sections B-B and B'-B' in FIG. **12** (A) and in (C) along section C—C in FIG. **12** (A). In this embodiment, the modules **30** are composite and have a first side **31** designed to be at the bottom of the heat exchanger and a second side **32** designed to be at the top of the heat exchanger.

[0087] The modules comprise at least a first porous section **13***a* and a second porous section **13***b* and internal conduits **51**, **52**, **53** through which the heat transfer gas can be circulated along preferred paths. The inlet points **15** and outlet points **16** are preferably in a part of the modules **30** that will be in the upper part of the heat exchanger. The said first and second porous sections **13***a*, **13***b* may be distinct slabs placed adjacent to each other or parts of the same porous slab.

[0088] In the example illustrated, the modules **30** are provided with a down conduit **51** through which the heat transfer gas flows towards the bottom part of the first porous section **13***a*, a first horizontal conduit **52** through which the heat transfer gas flow can be distributed along the first porous section **13***a* and a second horizontal conduit **53** to collect the heat transfer gas from the second porous section **13***b*. The walls **43**, **44**, **45**, **46** of said conduits **51**, **52**, **53** may be formed using metallic or ceramic elements such as tubes, by moulding and/or sealing of porous surfaces using glues or refractory cements.

[0089] The first porous section **13***a* has a first porosity, and particularly a first number of pores per unit length. The second porous section **13***b* has a second porosity, and particularly a second number of pores per unit length. The number of pores per unit length is typically expressed in ppi or pores per cm.

[0090] These composite modules have the advantage that they enable a uniform and substantially vertical circulation velocity of the heat transfer gas, to avoid the formation of a thermal gradient along the walls of a pot that could be harmful to the shape of the solidified bath ridge.

[0091] These composite modules **30** advantageously comprise a support slab **12** made of a heat conducting material, typically a dense ceramic material like that defined above, that will be located on the inner side of the pot, typically in contact with the kerb **4'**. These composite modules **30** may also comprise a layer **29** of a heat insulating material, typically a fibre, designed to be located on the outer side, typically in contact with the inside face of the shell **2**.

[0092] These composite modules may be placed adjacent to each other so that an inlet **15**, usually colder, can be placed close to an outlet **16**, usually warmer, which is conducive to better uniformity of the temperature by mutual compensation, particularly by the possible use of a heat conducting support slab **12**.

[0093] The first porous section **13***a* is advantageously located at the average height of the interface between liquid aluminium **9** and the liquid electrolyte bath **10** in the pot during operation, so as to enable better heat exchange due to higher porosity and due to the conduit to the first porous section **13***a* of all or part of the heat transfer gas originating directly from the inlet **15**.

[0094] In the case in which the level of the interface between the liquid aluminium **9** and the liquid electrolyte bath **10** is at the first porous section **13***a*, the first porosity is preferably greater than the second porosity. For example, in this case the first number of pores per unit length is typically between 50 and 70 ppi and the second number of pores per unit length is typically between 30 and 50 ppi.

[0095] The composite modules **30** illustrated in FIG. **12** may be obtained by a process including:

- **[0096]** supplying a support slab **12** made of a heat conducting ceramic;
- **[0097]** supplying a first porous slab **13***a* and a second porous slab **13***b* or the supply of a porous slab with a first porous part **13***a* and a second porous part **13***b;*
- **[0098]** optionally, supplying a heat insulating material **29**;
- **[0099]** gluing said porous slab(s) on the support slab **12**, so as to seal the pores and to form a sealed surface **41** and make an efficient thermal contact at their interface **14**, in other words between a determined surface of the support slab and a determined surface of said porous slab(s);
- **[0100]** gluing the insulating material **29**, if required, onto an opposite surface of said porous slab(s), so as to seal the pores and to form a sealed surface **42**;
- **[0101]** sealing the sides **44**, **47** of the said porous slab(s) in order to partly or fully seal them;
- **[0102]** forming of conduits **51**, **52**, **53**.

[0103] Said gluing and sealing operations may be done using refractory glue like that described above.

[0104] Finally, FIG. **13** very diagrammatically illustrates an example means of recovering thermal energy recovered from several electrolytic pots, like those described above. The heat transfer air or gas output from the different cells **23** in an industrial aluminium production plant, and particularly recovered in the side manifolds **18**, is directed to the suction unit and then into a circuit **24** conveying it to an external heat exchanger **25** for heating applications, or for generation of electricity that can be used directly in pots in the plant, that inherently consume electricity. This arrangement may also be used to reduce the ambient temperature of electrolysis rooms by evacuation of the heat produced by the pots outside the electrolysis room.

[0105] Tests have been carried out with a board made of ceramic porous material so as to evaluate heat exchange capacities possible with the materials according to the invention. A heat exchanger was made by gluing a 25 mm thick board of porous ceramic foam made of silicon carbide with a porosity of 20 ppi (8 pores/cm) with a porous volume of 88%, onto a 40 mm thick board of dense material based on silicon carbide bonded with silicon nitride. The effective thermal conductivity of the porous board was between 0.50 and 1 $W.m^{-1}.K^{-1}$. The glue was a refractory grout. The heat exchanger was placed at the entrance to a furnace to replace the door by using a metal frame. The heat exchanger device was isolated using fibrous materials around the frame. Thermocouples located at different locations, particularly at the inlet and outlet of the heat transfer fluid, were used to quantify heat exchange in the porous zone. The exposed surface area facing the furnace was 400 cm^2.

[0106] The furnace was heated to a fixed temperature and was then kept at this temperature during the series of tests, the air flow circulating in the exchanger being controlled using a flow meter.

[0107] Table I shows the heated air outlet temperature and the heat flux recovered by the exchanger, as a function of the flow of heat transfer fluid, namely air. These tests show that when the cooling airflow increases, the air temperature at the outlet reduces and the recovered heat flow increases.

TABLE I

Air flow (Nm^3/H)	Inlet air temperature (° C.)	Outlet air temperature (° C.)	Recovered heat flux (kW/m^2)
2.6	20	555	9.1
5	20	467	14.0
8	20	387	24.9
10	20	328	26.2
13	20	264	26.9
15	20	237	27.6
18	20	215	29.8

[0108] The inventors reckoned that, for a comparable density, the increase in the number of pores does not significantly increase the head loss in the porous medium up to about 60 ppi, but it does increase the heat exchange surface area with the heat transfer gas.

[0109] Obviously, the invention is not limited to the embodiments of this electrolytic pot described above as examples; on the contrary, it includes all variants that respect the same principle. Thus, in particular, changing the nature of materials, in particular the porous materials from which the heat exchanger is made can be changed without departing from the scope of the invention, and these materials may also be metallic or hybrid (such as a combination of silicon carbide and metal). Similarly, the number and positions of air or heat transfer gas inlet and outlet orifices related to porous parts or zones can be varied without departing from the scope of the invention. Finally, there is a wide variety of methods of using and/or converting the recovered thermal energy.

1. Electrolytic pot for production of aluminium, comprising side walls having a heat exchanger through which a heat transfer gas can circulate, wherein the side walls of the pot comprise at least one part made of a porous material over at least a fraction of a height and a thickness of the side walls, to enable circulation of the heat transfer gas, each part made of a porous material being connected to heat transfer gas inlet means and outlet means.

2. Electrolytic pot according to claim **1**, wherein the porous material is in the form of a foam.

3. Electrolytic pot according to claim **1**, wherein the porous material is formed from a material chosen from metals, metal alloys and ceramics, with an intrinsic thermal conductivity greater than 5 W/m.K, and a mix or a combination of these materials.

4. Electrolytic pot according to claim **3**, wherein said ceramic contains a majority of at least one component selected from the group consisting of: silicon carbide, silicon nitride and aluminium nitride.

5. Electrolytic pot according to claim **3**, wherein the porous material is a ceramic foam containing at least 70% by weight of heat conducting ceramic.

6. Electrolytic pot according to claim **3**, wherein said metal or metal alloy has a thermal expansion coefficient of less than $25\times10^{-6}\ K^{-1}$.

7. Electrolytic pot according to claim **1**, wherein the part made of a porous material has a porosity greater than 70%.

8. Electrolytic pot according to claim **1**, wherein the part made of a porous material is formed from one or more porous slabs.

9. Electrolytic pot according to claim **1**, wherein the part made of a porous material is between 5 and 50 mm thick.

10. Electrolytic pot according to claim **1**, wherein the side walls of the pot comprise at least one first part made of a dense material located on an inner side of the side walls, and at least one second part at least partly made of a porous material located between the first part and an outside shell of the pot.

11. Electrolytic pot according to claim **10**, wherein the dense material is a ceramic material containing at least 70% by weight of silicon carbide.

12. Electrolytic pot according to claim **10**, wherein the part made of dense material has a porosity of less than 20%.

13. Electrolytic pot according to claim **10**, wherein the first part made of dense material and the second part made of porous material are assembled using a refractory material.

14. Electrolytic pot according to claim **13**, the first and second parts of the side walls are assembled using glue, in the form of a suspension, comprising a mix of a mineral filler with an average size grading of less than 250 μm, a silicone resin and an organic solvent to solubilise the resin and control the rheology of the suspension.

15. Electrolytic pot according to claim **10**, wherein first part made of dense material is formed from several slabs with a monolithic structure.

16. Electrolytic pot according to claim **10**, wherein the side walls of the pot comprise a structure formed from monolithic slabs, made from a material with variable porosity in the direction of the thickness of said side walls.

17. Electrolytic pot according to claim **10**, wherein the dense part is between 10 and 100 mm thick.

18. Electrolytic pot according to claim **1**, wherein said part made of porous material extends substantially over the entire height of the side walls of the pot.

19. Electrolytic pot according to claim **1**, wherein said part made of porous material extends over a limited portion of the total height of the side walls of the pot.

20. Electrolytic pot according to claim **19**, wherein said part made of a porous material extends over a fraction of the order of one third to one half of the height of the side walls of the pot.

21. Electrolyte pot according to claim **19**, wherein said part made of a porous material overlaps an interface between a liquid aluminium layer and a molten salts bath.

22. Electrolytic pot according to claim **1**, wherein the porous material has at least one variable characteristic selected from the group consisting of: porosity, thickness and thermal conductivity characteristics, over the height of the porous part, so as to obtain successive zones in the direction of the height with different heat exchange characteristics.

23. Electrolyte pot according to claim **1**, wherein the heat transfer gas inlet means and outlet means are located at the top and at the bottom of each part made of a porous material.

24. Electrolytic pot according to claim **23**, wherein the heat transfer gas inlet means and outlet means are located near the top portion and bottom portion of the side walls of the pot.

25. Electrolytic pot according to claim **22**, wherein the pot further includes at least one additional inlet and one additional outlet for the heat transfer gas located at an intermediate height.

26. Electrolytic pot according to claim **25**, wherein at least one of the additional inlet and the additional outlet for the heat transfer gas is located at the transition between two successive zones.

27. Electrolytic pot according to claim **1**, wherein heat transfer gas inlet and outlet means are distributed over the horizontal dimension of a part made of a porous material of the side walls of the pot.

28. Electrolytic pot according to claim **27**, wherein the inlet and the outlet are arranged at the two horizontally opposite ends of the part made of a porous material.

29. Electrolytic pot according to claim **1**, wherein the heat transfer gas inlet has orifices located above the liquid level in the pot, near the top of the shell.

30. Electrolytic pot according to claim **1**, wherein at least one side manifold is connected to a plurality of heat transfer gas outlets.

31. Electrolytic pot according to claim **30**, wherein each side of the pot is equipped with at least one side manifold, all manifolds being connected to a common suction unit.

32. Electrolytic pot according to claim **1**, wherein the through cross-section of at least one of the heat transfer gas inlet and outlet orifices is made adjustable using flaps.

33. Electrolytic pot according to claim **1**, wherein the heat transfer gas used is air, and wherein the air inlets are open to the surrounding atmosphere.

34. Electrolytic pot according to claim **1**, wherein the heat transfer gas used is selected from the group consisting of:

air, an inert gas, and a mix of air and inert gas, and wherein the heat transfer gas is recycled through a distribution network bringing air or gas drawn off at the outlet orifices to the inlet orifices.

35. Electrolytic pot according to claim **34**, wherein the pot combines embodiments without air recycling and with air recycling, using direct air inlet valves located at different points in the distribution network.

36. Electrolytic pot according to claim **35**, wherein the pot further comprises isolating valves configured to isolate the different portions of the distribution network from each other.

37. Electrolytic pot according to claim **1**, wherein thermal insulation is provided between the part made of a porous material and the shell of the pot.

38. Electrolytic pot according to claim **37**, wherein the thermal insulation is a fibrous material.

39. Electrolytic pot according to claim **37**, wherein the insulation forms a substantially vertical layer, with a thickness of between 10 and 100 mm.

40. Electrolytic pot according to claim **1**, wherein the pot is connected to a suction system that can circulate a heat transfer gas by depression in each part made of a porous material.

41. Electrolytic pot according to claim **1**, wherein the side walls of the pot also comprise at least one conduit through which the heat transfer gas can be circulated along a preferred path towards the bottom of the porous part or from the top of the porous part, to enable a uniform and substantially vertical circulation velocity of the heat transfer gas.

42. Electrolytic pot according to claim **1**, wherein each porous part is assembled in the form of a module.

43. Electrolytic pot according to claim **42**, wherein said module comprises at least one first porous section with a first porosity and a second porous section with a second porosity arranged so as to be located above the first porous section in said side walls of the pot, the first porosity being greater than the second porosity, a first horizontal conduit through which the heat transfer gas flow can be distributed along the first porous section and a second horizontal conduit to collect the heat transfer gas from the second porous section.

44. Electrolytic pot according to claim **43**, wherein said module comprises an inlet to allow heat transfer gas to enter and an outlet for extraction of the heat transfer gas, and in that the inlet and the outlet are located in a portion of the module configured to be in the top part of said heat exchanger.

45. Electrolytic cell comprising a pot according to claim **1**.

46. Industrial aluminium production plant comprising a plurality of electrolytic pots according to claim **1**, connected through manifolds to a heat transfer gas circuit directed towards energy recovery means, comprising at least one of a heat exchanger and an electricity generator.

* * * * *