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(54) PLANT FOR UREA PRODUCTION

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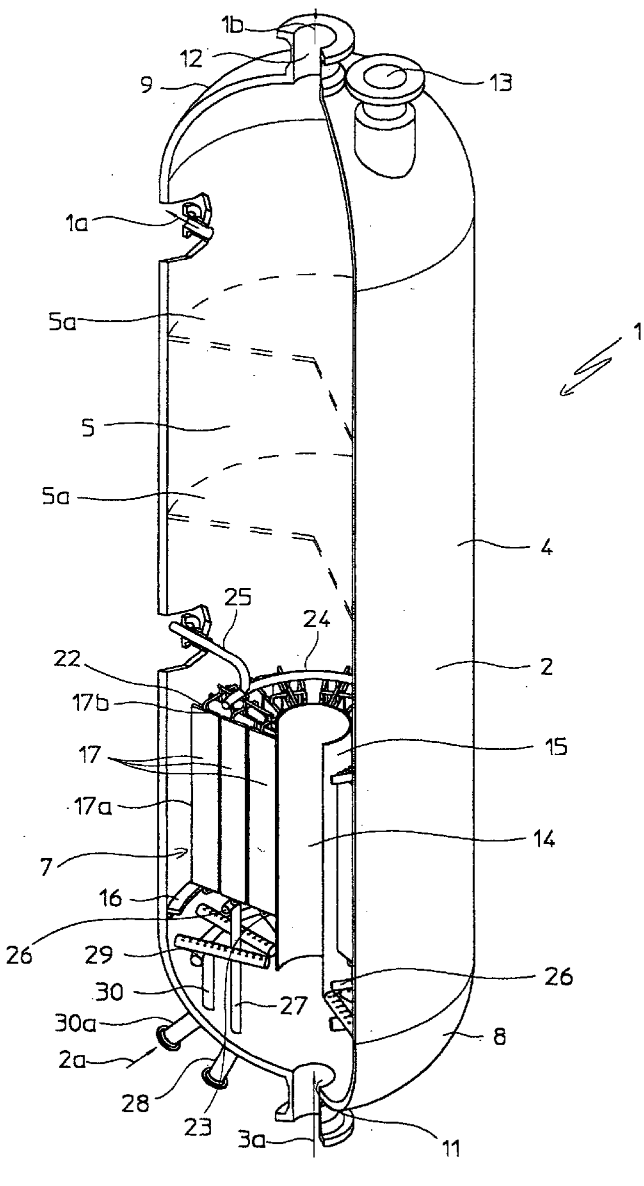
(57) **ABSTRACT**

Plant for urea production from ammonia and carbon dioxide having a so-called high-pressure section which comprises a synthesis reactor and a condensation unit (**7, 107**) positioned inside the reactor, all substantially operating at the same pressure.



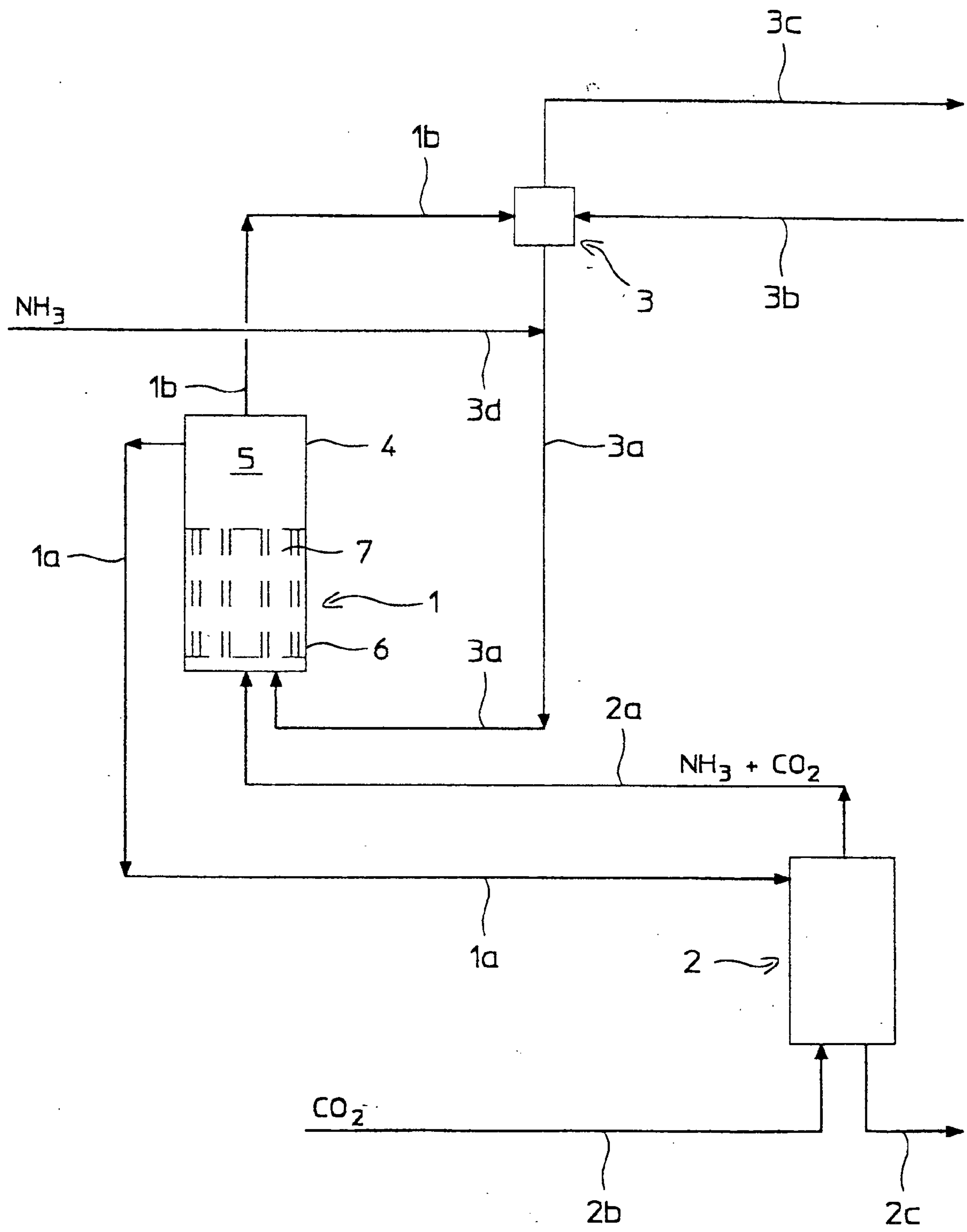
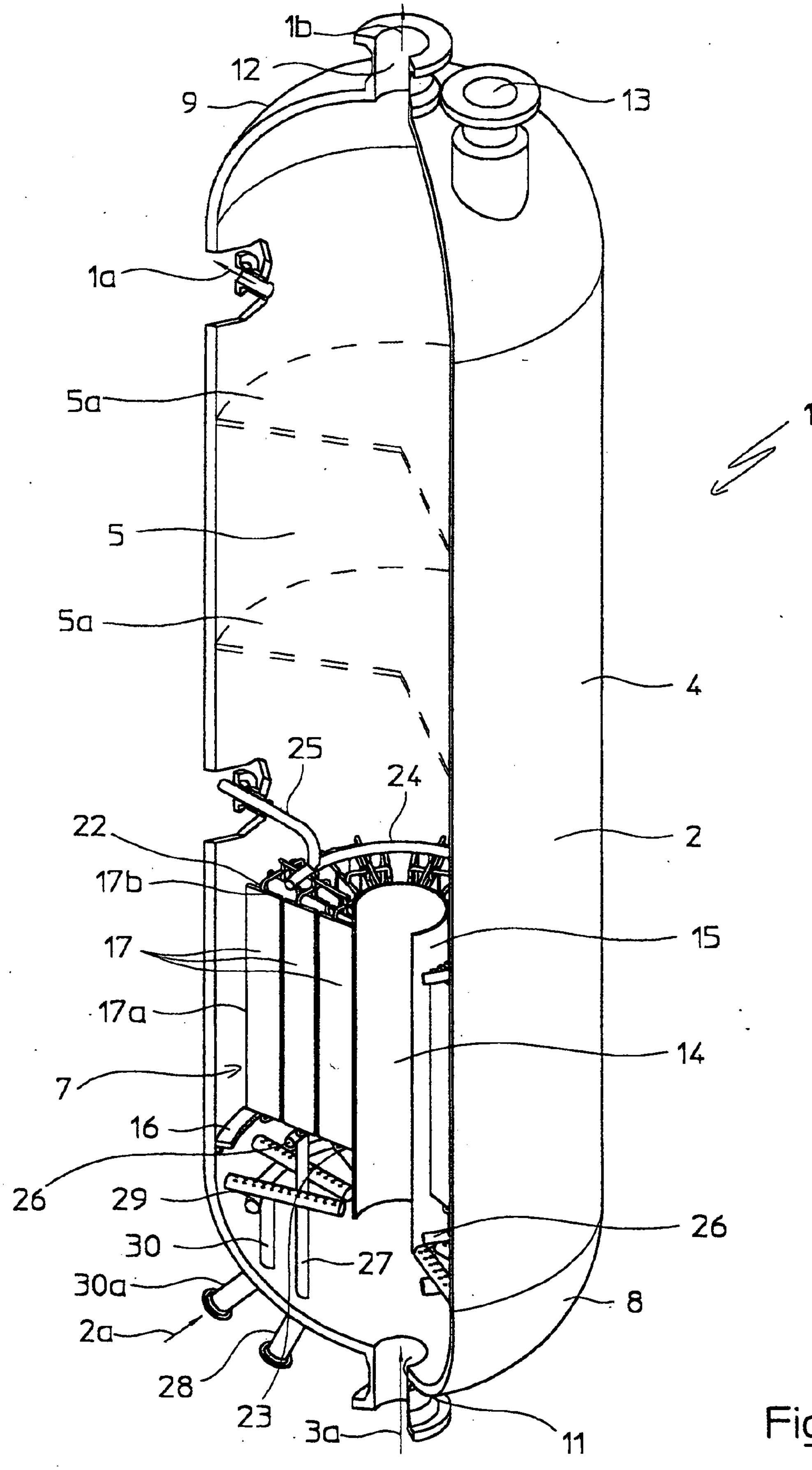


Fig. 1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12
13
9
1a
5a
1
5
5a
4
25
24
2
22
17b
15
17
17a
14
7
16
26
29
26
30
30a
27
8
2a
28
23
3a
11

Fig. 2

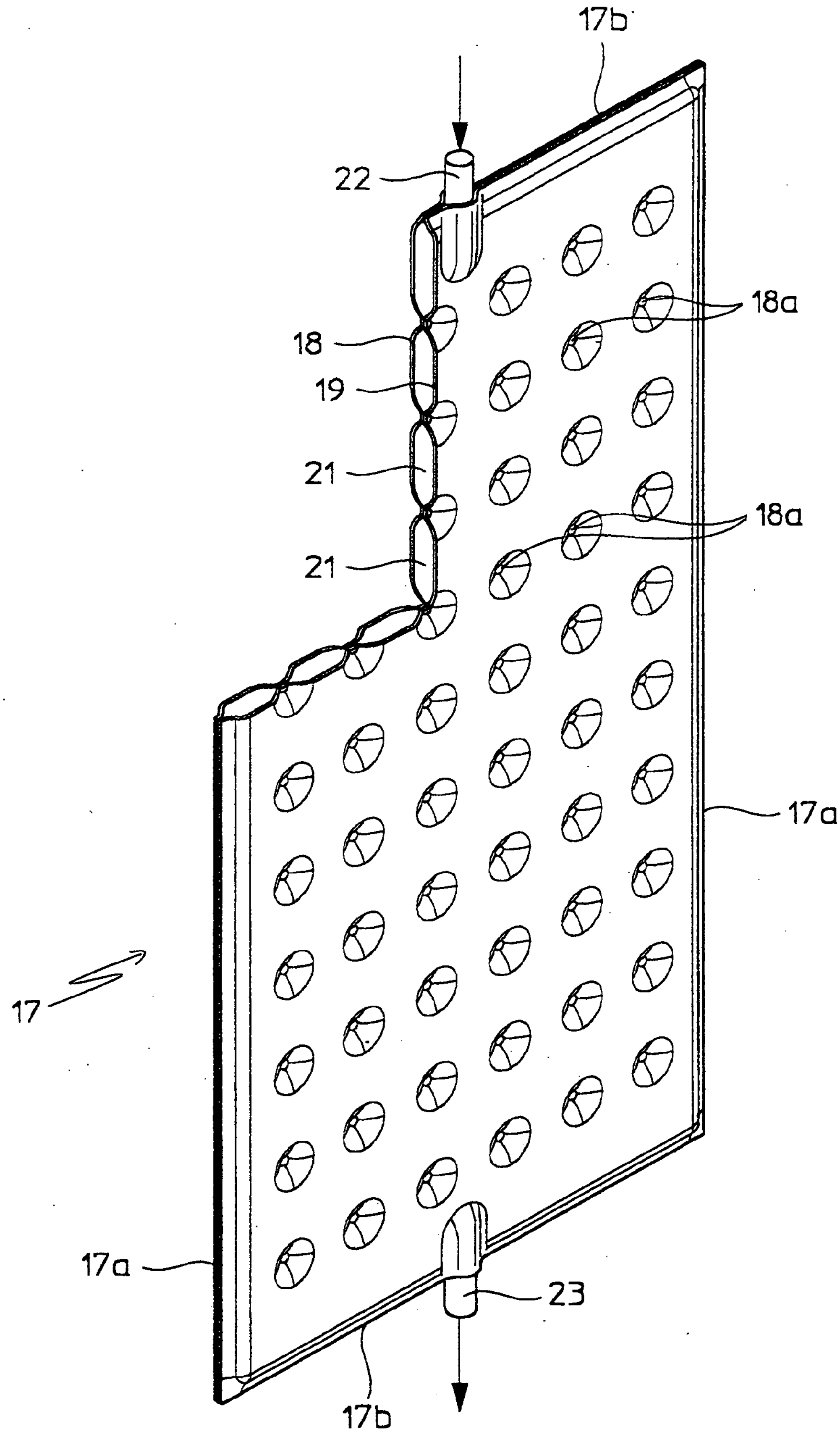


Fig. 3

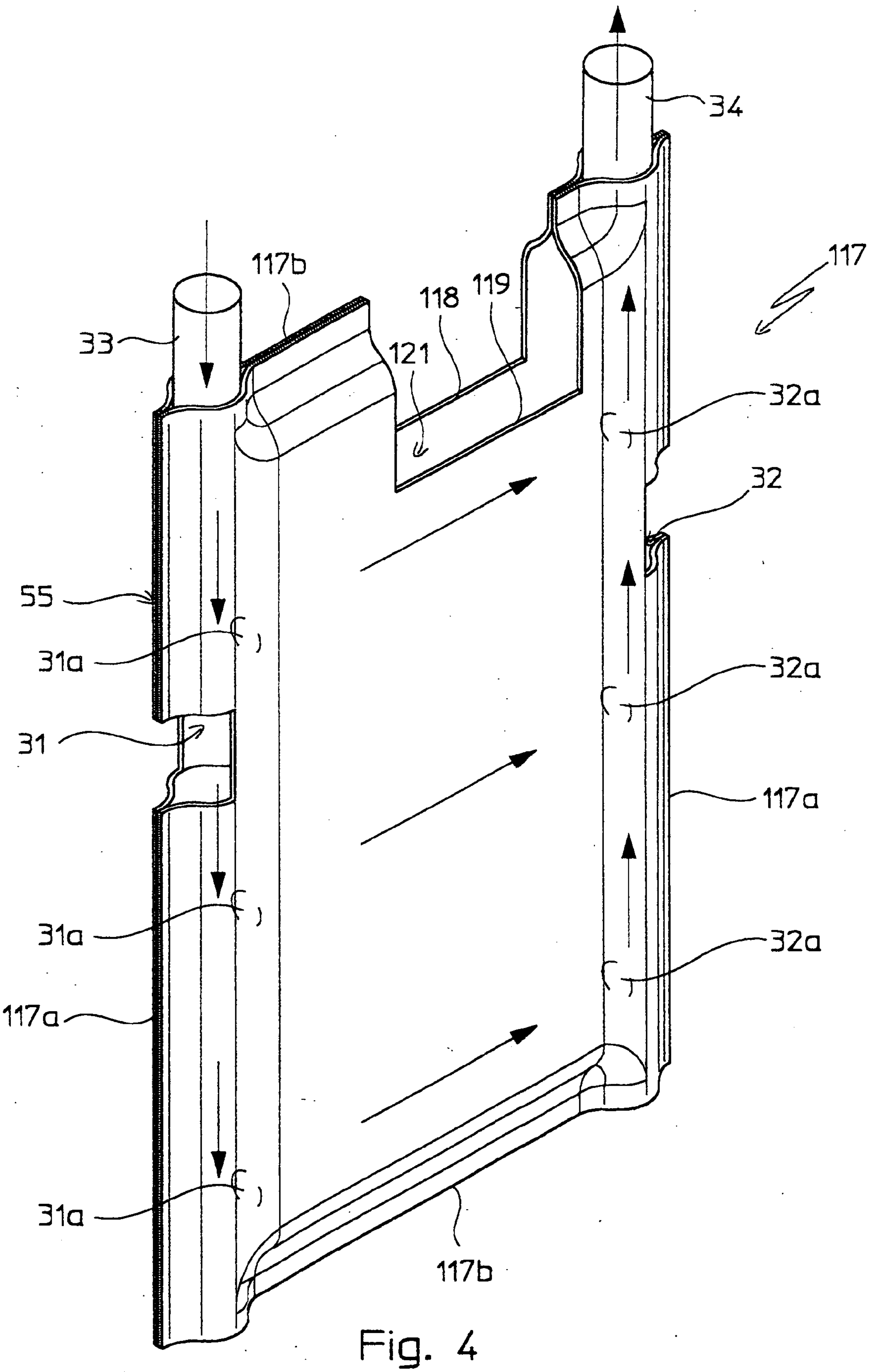

34
117
117b
118
119
33
121
32a
32
55
31a
32a
31
117a
31a
32a
117a
31a
117b

Fig. 4

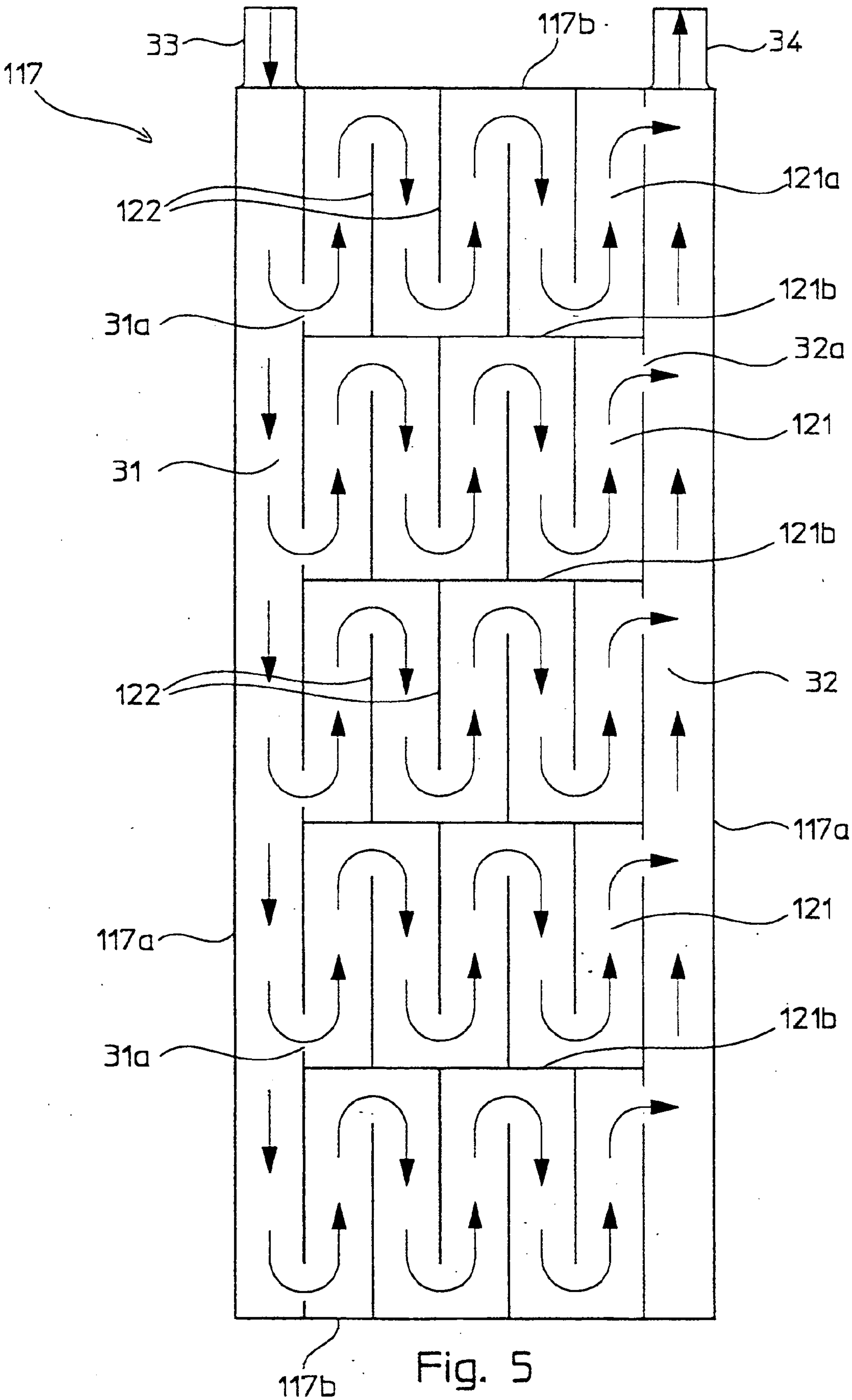
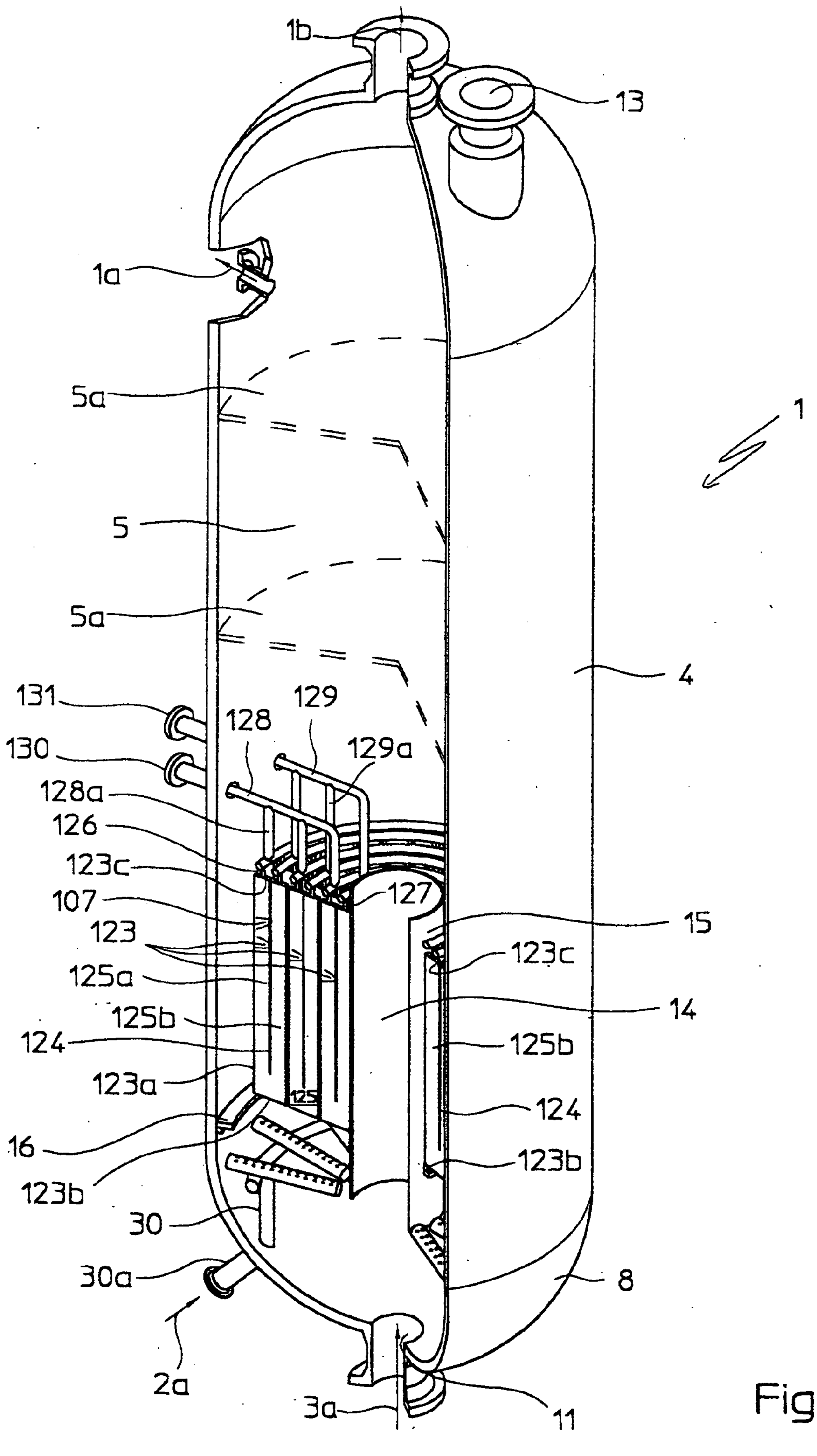

33
117b
34
117
121a
122
121b
31a
32a
121
31
121b
122
32
117a
121
117a
121b
31a
117b

Fig. 5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1a
5a
1
5
5a
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131
129
128
130
129a
128a
126
123c
127
107
15
123
123c
125a
14
125b
124
125b
123a
125
124
16
123b
123b
30
30a
8
2a
3a
11

Fig. 6

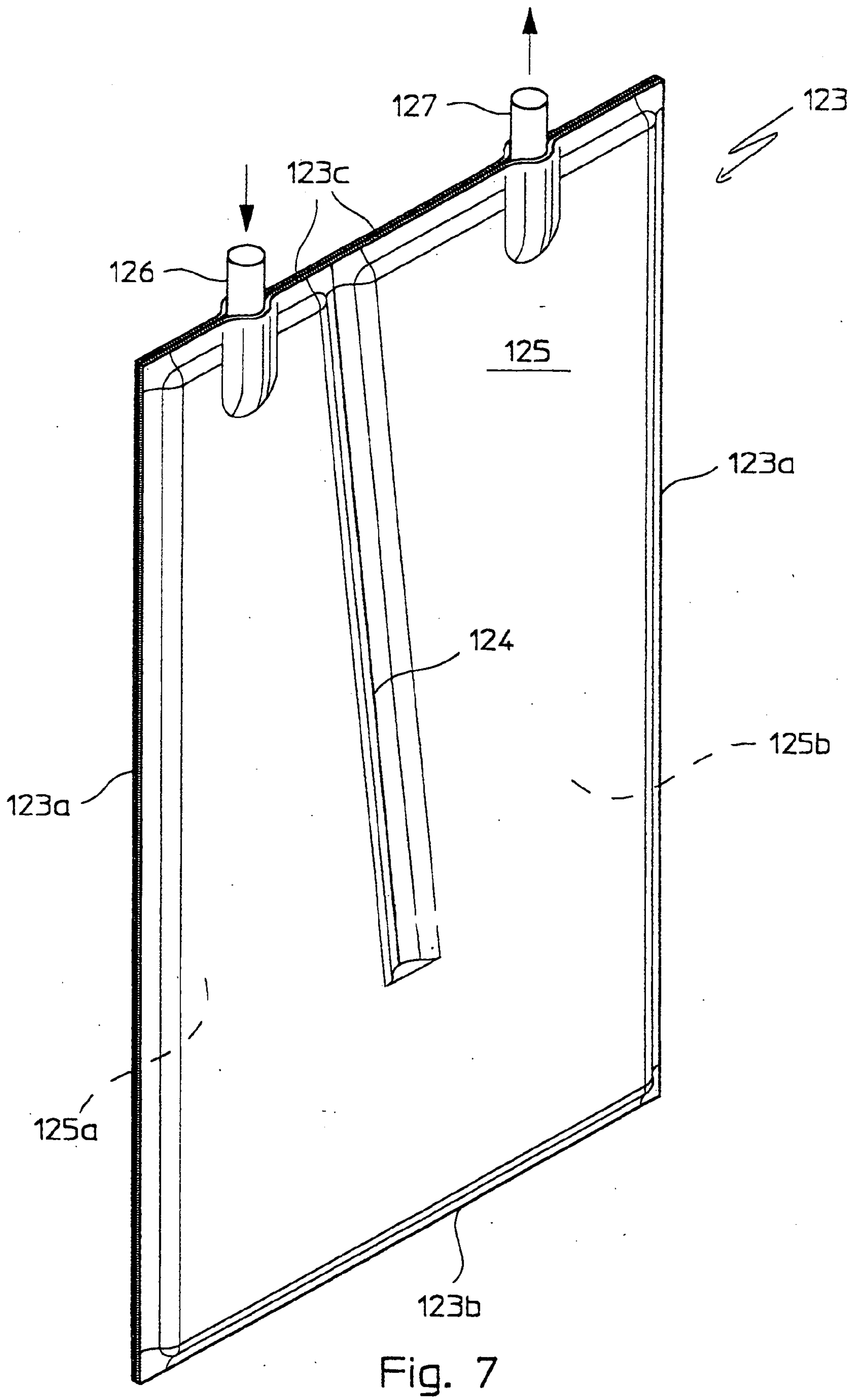

Fig. 7

PLANT FOR UREA PRODUCTION

FIELD OF APPLICATION

[0001] In its most general aspect the present invention refers to a so-called "urea stripping plant" for producing urea from ammonia and carbon dioxide.

[0002] More specifically, this invention concerns the high-pressure section of a plant of the aforementioned type comprising a urea synthesis reactor and a condenser or else a urea synthesis reactor, a stripper and a condenser.

PRIOR ART

[0003] From the main reaction between ammonia and carbon dioxide, carried out in certain well-known pressure and temperature conditions, an aqueous solution comprising urea, ammonium carbamate and free ammonia (i.e. not bound with the carbamate) and a gaseous mixture comprising ammonia, carbon dioxide, water (in steam phase), plus possible inert gases are obtained.

[0004] In processes that use so-called stripping technology, the aqueous solution containing urea (product of the reaction) that comes out of the synthesis reactor is subjected, in an appropriate stripper, to a heat treatment for the decomposition of the carbamate in ammonia and carbon dioxide and simultaneously to stripping (for example through the same flow of carbon dioxide fed to the urea plant) to separate a flow of gas comprising most of the unreacted ammonia and carbon dioxide from said solution.

[0005] These gases, to which one adds the carbon dioxide used for stripping, are recondensed to carbamate in an appropriate condenser (known as high-pressure carbamate condenser) and the carbamate is recycled in the synthesis reactor.

[0006] Also the ammonia and carbon dioxide present in gas phase in the reaction mixture coming out from the reactor, are generally transformed into ammonium carbamate, in particular through absorption in an appropriate condenser (known as a scrubber) with the help of a flow of carbamate coming from the urea recovery section. The flow of carbamate coming out from said scrubber is recycled, via the high-pressure carbamate condenser, to the synthesis reactor.

[0007] In the plants for urea production considered here (Urea Stripping Plant—USP), synthesis reactor, stripper, condenser and scrubber all operate substantially at the same pressure (high-pressure) and constitute the most important elements of the so-called "high-pressure section" of such plants.

[0008] In the prior art of the sector, it has advantageously been proposed to comprise in the same shell (high-pressure vessel) of the synthesis reactor also one or both of the other functions of (high-pressure) carbamate condenser and scrubber. For example in WO 00/43358 (PCT/NL/00044), included here for reference, a synthesis reactor is described in the vertical shell of which a reactor section is defined between a condenser section lying below it, and a scrubber section lying above it; the scrubber and condenser sections are in fluid communication through a vertical duct which crosses the entire reactor section and which is used to feed said condenser with the entire flow of carbamate formed in the scrubber itself.

[0009] Although advantageous under different aspects, the aforementioned plants for urea production of the prior art have some drawbacks as yet not overcome.

[0010] A first and most substantial drawback consists of a recognised upper limit of productive capacity, which is practically not overcome, to the point that, to obtain substantial productions, it is necessary to install one or more other similar plants (many lines, double apparatuses).

[0011] Indeed, in the plants of the prior art, and with particular reference to their high-pressure section, the condenser and the stripper essentially consist of respective heat exchange units exclusively formed from tube bundles, in which the tubes, in general, connect to opposite tubular support plates, said tubes being internally crossed, respectively, by the gases to be condensed and by the aqueous solution comprising carbamate to decompose and to subject to stripping.

[0012] The tubular plates are designed directly according to the number of tubes to be supported. The degree of the heat exchange that can be obtained in the condenser and in the stripper and, therefore, the "productive capacity" of both the condenser and of the stripper depends upon the number of tubes and upon their size. Consequently, it can be said that the productive capacity that one intends to obtain from a plant of the type considered, or rather from its high-pressure section, depends also upon the number and the size of the tubes of the tube bundles (and therefore upon the size of the relative tubular plates) used in the condenser and in the stripper of such section. Therefore, it can be said that said tubular plates must be realised with a size (diameter), thickness and weight which gradually increase as the productive capacity of said high-pressure section increases.

[0013] There are recognisedly sizes and weight of the tubular plates beyond which it is no longer economically viable nor technically possible to position them inside a pressure vessel of, for example, a conventional urea synthesis reactor, or of a condenser or of a stripper. This gives the upper limit of the productive capacity of the plants of the prior art.

[0014] Another drawback of the use of tube bundles consists of the difficulty of distributing the fluid inside each tube and of guaranteeing that each tube be appropriately cooled or heated by the operating fluid which acts outside of it.

[0015] The last but not least drawback consists of the long times in which the plant is inoperative required to identify and replace tubes which may be damaged, for example by corrosion, as well the drawbacks of the constructive difficulties and the high costs for realising such reactors.

SUMMARY OF THE INVENTION

[0016] The problem forming the basis of the present invention is that of providing a plant for urea production, of the type known as a "urea stripping plant" in which the functional components of its high-pressure section have structural and functional characteristics such as to overcome the aforementioned drawbacks with reference to the prior art, with particular reference to the limitation in productive capacity.

[0017] This problem is solved according to the present invention by a plant of the aforementioned type the high-pressure section of which comprises a synthesis reactor, a condensation unit positioned inside said reactor, a stripper and a scrubber, all operating substantially at the same pressure, having the structural characteristics specified in the subsequent claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] **FIG. 1** represents a schematic view of the high-pressure section of a plant for urea production according to the present invention;

[0019] **FIG. 2** represents an enlarged schematic view of the urea synthesis reactor of the plant of **FIG. 1**;

[0020] **FIG. 3** represents a further enlarged perspective view of a detail of the synthesis reactor of **FIG. 2**;

[0021] **FIGS. 4 and 5** represent enlarged perspective and schematic views, respectively, of variant embodiments of the detail of **FIG. 3**;

[0022] **FIG. 6** represents a perspective partial section view of the reactor of **FIG. 2** according to a further variant embodiment;

[0023] **FIG. 7** represents an enlarged perspective view of a detail of the synthesis reactor of **FIG. 6**.

DETAILED DESCRIPTION

[0024] With reference to **FIG. 1**, the high-pressure section of a plant for urea production from ammonia and carbon dioxide, of the type known as a "urea stripping plant", essentially comprises a synthesis reactor **1**, a stripper **2** and a scrubber **3**, all operating at the same pressure.

[0025] In the vertical shell **4** of said synthesis reactor **1**, an actual reactor zone **5** and a condensation zone **6** are defined, in which a condensation unit **7**, which shall be described in detail hereafter, is supported.

[0026] In the reactor zone **5** suitable perforated plates, which are per se known since they are conventional, can be provided for, represented with a broken line in **FIG. 1** with reference numeral **5***a*.

[0027] In accordance with a non-limiting example of urea production through the aforementioned plant, the aqueous solution produced in the reactor **1**, essentially comprising urea, ammonium carbamate and free ammonia, is sent, through duct **1***a*, to the stripper **2**, fed, at the same time, from below, through duct **2***b*, with a current of carbon dioxide (corresponding to the carbon dioxide fed to the plant or to part of it).

[0028] The gases coming out from the stripper **2**, essentially carbon dioxide and ammonia, are sent, through the duct **2***a,* to the reactor **1**, entering below the condensation unit **7**.

[0029] The solution coming out from the stripper **2**, essentially a urea, ammonium carbamate and free ammonia solution, is sent, through duct **2***c*, to the urea recovery section (not represented).

[0030] The gases coming out from the synthesis reactor **1**, essentially unreacted ammonia and carbon dioxide and possible inert gases, are fed through duct **1***b*, to the scrubber **3** where, freed from the inert gases (duct **3***c*) they are condensed with the help of a flow of carbamate coming, through duct **3***b*, from the urea recovery section.

[0031] Coming out from the scrubber **3**, the carbamate solution, with the ammonia necessary for the reaction added (duct **3***d*), is sent, through duct **3***a*, to the synthesis reactor **1**, below said condensation unit **7**.

[0032] With reference to **FIG. 2**, the cylindrical shell **4** of said reactor **1** is closed at the opposite ends by respective base plates, lower **8** and upper **9**; the base plate **8** is equipped with a connector or inlet port **3***a*, for the entry of the gases coming from the stripper **2** (as described hereafter) and with an axial passage **11**, for the entry of the ammonia-carbamate mixture, coming from the scrubber **3**, through the duct **3***a*. The base plate **9** is equipped with an axial passage **12** for discharging the gases produced by the reaction and with a manhole **13**.

[0033] Said condensation unit **7** has an overall cylindrical annular configuration, coaxial with the shell **4**. It has an outer diameter of a little less than the inner diameter of the shell **4** and is axially crossed by a passage **14**, in which an axial duct **15** is removably mounted. Said duct **15** has preferably an axial length greater than that of said condensation unit **7**, so as to protrude from both sides of it.

[0034] In a totally schematic way, the condensation unit **7** is supported by an annular bracket **16**, fixed to the inner wall of the shell **4**, at a predetermined distance from its base plate **8**.

[0035] In accordance with the present invention, said condensation unit **7** comprises a plurality of plate-shaped heat exchange elements (or exchangers) **17**, regularly distributed in many coaxial and concentric rows (three in the example); each exchanger **17** (**FIG. 3**) is substantially flattened box-shaped with an essentially elongated rectangle configuration, in which two opposite long sides **17***a*, **17***a* and two opposite short sides **17***b*, **17***b* are emphasized.

[0036] In the aforementioned condensation unit **7**, the exchangers **17** are substantially arranged radially, with long sides **17***a* parallel to the axis of said unit **7** (and therefore to the axis of the shell **4**), and short sides **17***b*, extending radially; they are also arranged to form pluralities of radial coplanar exchangers **17** in groups of three.

[0037] Obviously, according to different technical-applicational requirements, each radial group of three exchangers **17** can be replaced by a pair of coplanar plate-shaped exchangers, or by a single plate-shaped exchanger which substantially occupies the entire (annular) space between the axial duct **15** and the shell **4**.

[0038] Yet more specifically (**FIG. 3**) each exchanger **17** consists of a pair of juxtaposed metallic plates **18**, **19**, reciprocally joined, in a predetermined spaced relationship, of perimetric welded joints so that a chamber **21** is defined between them, intended to be crossed by an operating heat exchange fluid.

[0039] Each exchanger **17** is equipped on opposite connector sides **22**, **23** for the entry and exit, respectively, of said operating heat exchange fluid, into and from said chamber **21**.

[0040] According to a first embodiment, the plates **18**, **19** are mutually joined also through a plurality of welding points **18**_a_, regularly distributed, for example, and preferably according to an arrangement in groups of five, which give the exchanger **17** a substantially "quilted" aspect. The presence of the welding points **18**_a_ is such that the crossing of the exchanger **17** by the operating heat exchange fluid takes place according to winding paths, with improve heat exchange efficiency.

[**0041**] The entry connectors **22** of the exchangers **17**, are hydraulically connected to an annular distributor duct **24**, supported in position lying over the condensation unit **7** and in turn in fluid communication with the outside of the reactor **1**, through a duct **25**, for feeding (or discharging) the predetermined heat exchange fluid.

[**0042**] The exit connectors **23**, of the same exchangers **17** are hydraulically connected to an annular collector duct **26**, supported below said unit **7** and in turn in fluid communication with the outside of the reactor **1**, through a duct **27** and relative port **28**, for discharging (or feeding) the operating heat exchange fluid.

[**0043**] Below the condensation unit **7**, an annular tubular gas distributor **29** is supported in a conventional and non-represented manner, in fluid communication, through a duct **30** and relative port **30**_a_, with the duct **2**_a_ in which the gases arrive from the stripper **2**.

[**0044**] In **FIGS. 4 and 5** a variant embodiment of the exchanger **17**, intended to optimise the heat exchange efficiency, is represented.

[**0045**] According to this variant, each exchanger **117**, still comprising a pair of juxtaposed plates **118**, **119**, mutually welded only perimetrically (thus without the "quilting" described above with reference to **FIG. 3**) , is internally equipped, in correspondence with the opposite long sides **117**_a_, with a distributor duct **31** and a duct **32** for collecting said heat exchange fluid, respectively. The ducts **31** and **32** are, on one side, in fluid communication with said chamber **121**, through at least one, but preferably a plurality of openings or holes **31**_a_ and **32**_a_, with which they are equipped along one or more generatrices and, on the other side, with the outside of the exchanger **117**, through respective connectors **33** and **34**, for the entry and exit of said operating fluid.

[**0046**] Said ducts **31** and **32** can be formed directly in the long sides **117**_a_ of the exchanger **117**, at the time of the drawing and perimetric welding of the metallic plates **118** and **119**, which constitute it, or else they can consist of respective tubes, fixed in said chamber **121**, in correspondence with the long sides **117**_a_, **117**_a_ of the exchanger and parallel to them. In this case, said tubes extend outside of the exchanger **117**, to form a single piece with the respective connectors **33**, **34**, mentioned above.

[**0047**] In accordance with another characteristic of the aforementioned variant, the connectors **33**, and **34** for entry and exit into and from each exchanger **117** are positioned in correspondence with the same short side **117**_b_ thereof.

[**0048**] When adapted to form a condensation unit having the arrangement described in **FIG. 2**, the short side **117**_b_, with relative connectors **33** and **34**, constitutes the upper side of each exchanger **117**.

[**0049**] Advantageously, at least part of the exchangers **117**, of the respective condensation unit, is realised according to the variant schematically illustrated in **FIG. 5**.

[**0050**] In this alternative embodiment, the inner chamber of each exchanger **117** is subdivided into a plurality of chambers **121**_a_, not directly communicating with each other and obtained, for example, through a corresponding plurality of welding lines **121**_b_ of the metallic plates **118**, **119**, extending parallel to the short sides **117**_b_ of the exchanger **117**, in other words perpendicular to its distributor and collector ducts **31**, **32**. Said chambers **121**_a_, which can all have the same width or have different widths according to the requirements, are internally equipped with a plurality of deflector plates **122**, extending parallel to said ducts **31**, **32** and which define in each chamber **121**_a_, a substantially coiled fluid path.

[**0051**] Each chamber **121**_a_ is in fluid communication with said distributor duct **31**, through at least one opening **31**_a_ thereof and with said collector duct **32**, through at least one opening **32**_a_ thereof.

[**0052**] It should be noted that, for an improved control of the pressure drops, and therefore of the distribution of the operating fluid inside the chambers **121**_a_, the openings **31**_a_ of the distributor duct **31** are realised with a different width or diameter, in particular an increasing width in the flow direction of the operating fluid inside said duct **31**.

[**0053**] In **FIG. 6** an enlarged view of a urea synthesis reactor **1** according to the finding is represented, equipped with a condensation unit **107**, totally similar to the condensation unit **7** of the reactor of **FIG. 2**, but comprising heat exchange elements (or heat exchangers) **123** according to a further variant embodiment described hereafter.

[**0054**] In such a figure, the details of reactor **1**, structurally and functionally equivalent to those described with reference to the reactor of **FIG. 2**, will be described with the same reference numeral and will not be further described.

[**0055**] In particular, according to this preferred but not limiting embodiment, schematised in **FIG. 6**, said condensation unit **107** comprises a plurality of heat exchangers **123**, regularly distributed in three coaxial and concentric rows; each exchanger **123** has a substantially flattened box-shaped structure, with an essentially elongated rectangle configuration. According to the arrangement of **FIG. 6**, in the condensation unit **107**, all of the exchangers **123** are arranged with long sides **123**_a_ parallel to the axis of the shell **4** and short sides **123**_b_, **123**_c_ extending radially with respect to it.

[**0056**] Yet more precisely the exchangers **123** are of the type represented in **FIG. 3**, i.e. consisting of a pair of juxtaposed metallic plates, mutually joined, in a predetermined distanced relationship, through perimetric welding, so that between them a chamber **125** is defined, intended to be crossed by an operating heat exchange fluid.

[**0057**] In accordance with one characteristic of the present invention, inside each exchanger **123** a separator plate **124** is provided, extending from a short side **123**_c_ thereof and having a predetermined length which is shorter than that of the long sides **123**_a_, extending in the same direction as these long sides **123**_a_.

[**0058**] Preferably, the separator plate **124** is obtained through mutual welding of the two plates which form said exchanger **123**, from a mid-point position of one of their short sides **123**c and extending towards the opposite short side **123**b, with respect to which it is in a predetermined spaced relationship.

[**0059**] Due to the presence of said separator plate **124**, the aforementioned chamber **125** of each exchanger **123** is subdivided into two contiguous parts **125**a, **125**b, communicating with each other only near to the short side **123**b, opposite short side **123**c, from which the plate itself extends.

[**0060**] In accordance with another characteristic of the present invention, each of the two sides **125**a, **125**b of the inner chamber **125**, of each exchanger, is in communication with the outside through respective tubular connectors **126**, **127** provided in said exchanger **123**, in correspondence with the short side **123**c thereof, from which the separator plate **124** projects.

[**0061**] As shall be better seen from the rest of the description, in each exchanger **123**, the aforementioned sides **125**a, **125**b of the chamber **125**, respectively constitute the descending portion and the ascending portion of a substantially U-shaped path, for a predetermined heat exchange fluid.

[**0062**] When adapted to form said heat exchange unit **107**, in the arrangement described above (**FIG. 6**), the exchangers **123** have vertical long sides **123**a and horizontal short sides **123**b, **123**c, extending radially in the shell **4**; in particular, the side **123**c, connected to the relative connectors **126** and **127**, constitutes the upper side of each exchanger **123**, whereas the side **123**b constitutes the lower side in correspondence with which said exchanger is supported inside the shell **4**, through the bracket **16** as described above.

[**0063**] For each group of three radially aligned exchangers **123**, a duct **128** for feeding-distributing an operating heat exchange fluid, and a collector duct **129**, for collecting and discharging said fluid is provided. The duct **128** is connected to the tubular connectors **126** of said exchangers **123** through ducts **128**a, whereas the duct **129** is connected to the tubular connectors **127** thereof through ducts **129**a.

[**0064**] The feeding duct **128** crosses the shell **4**, to be connected, outside of it, to a non-represented source of said operating fluid (for example consisting of boiling water).

[**0065**] The collector duct **129**, in the same way as the feeding duct **128**, is engaged through the shell **4**, to be connected to different applications outside of the reactor **1**.

[**0066**] The engagement of the ducts **128** and **129** through the shell **4** is realised using suitable connectors **130** and **131**, respectively, provided in the shell at a height close to or coinciding with that of the upper sides **123**c of the individual exchangers **123**.

[**0067**] With the arrangement described above it is possible to achieve a further important advantage. Indeed, the exchangers **123** can freely expand upwards, where there is no obstacle between them and other parts of the reactor **1**, in particular the shell **4**.

[**0068**] In this way, it is possible to avoid possible drawbacks of a mechanical type, due to the different thermal expansions of the exchangers and of the shell. These being drawbacks which typically crop up when in the exchangers operating fluids different to the fluids flowing outside of them are used.

[**0069**] In **FIG. 7 a** variant embodiment of the exchanger **123** is represented which is particularly, even if not exclusively, recommended when the operating heat exchange fluid to be used is water. According to this variant, the separator plate **124** extends, inside the chamber **125**, in a direction forming a corner with said side **123**c of the exchanger **123** (i.e. in an inclined direction with respect to the long sides of the exchanger itself), so as to define in said chamber **125** a U-shaped fluid path, having both a descending portion and an ascending portion with a gradually growing cross-section.

[**0070**] Advantageously, the exchangers **17**, **117** and **123** have transversal dimensions such that one can easily, pass through the manhole **13**, with which the reactor **1** is equipped.

[**0071**] The advantages achieved by the present invention can be summed up as follows:

[**0072**] it is possible to realise plants for urea production with a much higher capacity than that which has been realised up to now, thanks to the fact that one of the most critical apparatuses from this point of view, the condenser, no longer has the "obstacles" consisting of the presence of the tubular plates;

[**0073**] there is no longer the problem of distributing the urea-carbamate solution in each tube of the tube bundles, nor of guaranteeing that each tube be sufficiently heated or cooled by the fluid outside of it;

[**0074**] the possibility of avoiding possible drawbacks of the mechanical type, due to the different heat expansions of the exchangers and of the shell;

[**0075**] the possibility of easily and quickly defining and replacing the damaged plates or groups of exchangers;

[**0076**] the ease and speed of installation of the condensation units inside the respective shells due to the size of the exchangers: indeed, they easily pass through the manholes normally provided in said shells;

[**0077**] a reduction in the investment costs and simplicity of realisation with respect to the prior art.

[**0078**] The invention thus conceived is susceptible to further variants and modifications all within the reach of the man skilled in the art and, as such, falling within the extent of protection of the invention itself, as defined by the following claims.

1. Plant for urea production from ammonia and carbon dioxide having a so-called high-pressure section which comprises a synthesis reactor and a condensation unit positioned inside said reactor, all substantially operating at the same pressure, characterised in that said condensation unit comprises a plurality of flated plate-shaped essentially rectangular heat exchangers, arranged with long sides parallel to the axis of said reactor.

2. Plant according to claim 1, wherein each of said exchangers comprises a pair of juxtaposed metallic plates, joined together byperimetric weldings so as to define a chamber of predetermined width between them.

3. Plant according to claim 2, wherein said plates are also joined together trough a plurality of welding points defining in said chamber a plurality of winding paths in fluid communication with each other and with connectors for the entry and exit, respectively, of a heat exchange fluid into and from the respective heat exchanger, said connectors being provided for on opposite sides of said exchangers.

4. Plant according to claim 3, wherein said welding points are distributed in groups of five.

5. Plant according to claim 3, wherein the entry and exit connectors of all of the exchangers are connected to respective ducts for distributing and collecting the heat exchange fluid entering and respectively exiting from said exchangers, respectively.

6. Plant according to claim 2, wherein each of said exchangers comprises at least one distributor duct and at least one collector duct of an operating beat exchange fluid, associated with two respective opposite sides of said exchanger and extending along theme said ducts being in fluid communication on one side with said chamber through at least one opening formed in them and, on the other side, with the outside of said exchangers, through respective connectors for the entry and exit of said operating fluid, positioned on a same short side of the exchanger.

7. Plant according to claim 6, wherein said ducts consist of respective tubes, positioned in said chamber and fixed to said opposite long sides of the exchanger.

8. Plant according to claim 7, wherein said ducts are directly formed in correspondence with said long sides at the time of the forming of the exchanger.

9. Plant according to claim 2, wherein said chamber is subdivided into a plurality of chambers not directly communicating with each other, each of which is in fluid communication with said distributor duct and with said collector duct, through respective openings formed in them.

10. Plant according to claim 9, wherein said chambers are obtained through welding lines of said metallic plates, extending perpendicularly to said ducts.

11. Plant according to claim 10, wherein each of said chambers is internally equipped with a plurality of deflector plates, extending parallel to said ducts and defining a substantially winding path for said operating fluid.

12. Plant according to claim 1 wherein said condensation unit has a substantially annular cylindrical configuration, crossed axially by a passage with a predetermined diameter, in which said plurality of beat exchangers are distributed in many coaxial and concentric rows, in a substantially radial arrangement.

13. Plant according to claim 2, wherein at least one of said exchangers is internally equipped wit a separator plate, extending from one side of said exchanger, towards a side opposite it and from which said plate is in a predetermined distanced relationship, said plate defining in said chamber a substantially U-shaped fluid path having descending and ascending portions respectively, in communication with the outside of the exchanger through respective connectors.

14. Plant according to claim 13, wherein said separator plate extends in said chamber in a direction forming an angle with said side, for which reason the portions of said fluid path inside the exchanger have a gradually increasing cross-section.

15. Plant according to claim 14, wherein said exchangers have predetermined cross sections of less than the cross sections of a manhole opening arranged in correspondence with a base plate of said reactor.

16. (canceled)

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