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AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,
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(54) Title: CATALYTIC CHEMICAL REACTOR WITH A LIQUID DISTRIBUTION TRAY AND -UNITS

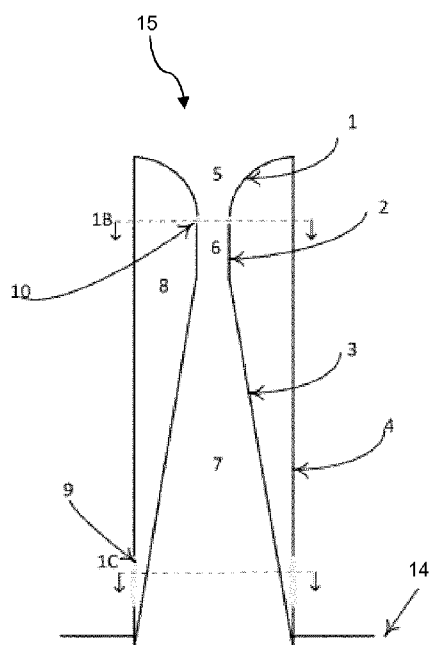


Fig.1A

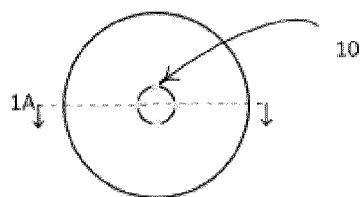


Fig.1B

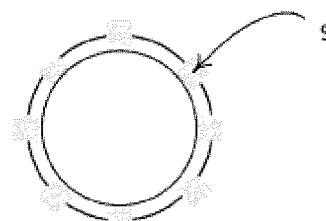


Fig.1C

(57) Abstract: A catalytic reactor comprises a distribution tray plate comprising a plurality of venturi distribution units adapted to suck liquid from the upper side of the distribution tray plate in an even amount of flow throughout the cross sectional area of the distribution tray plate despite variations in liquid height for an even liquid distribution to the cross sectional area of the part of the catalytic reactor beneath the distribution tray plate.

Declarations under Rule 4.17:

- *as to the identity of the inventor (Rule 4.17(i))*
- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*
- *of inventorship (Rule 4.17(iv))*

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Catalytic Chemical Reactor with a liquid distribution tray and –units

FIELD OF THE INVENTION

5 This invention relates to a catalytic chemical reactor comprising a liquid distribution tray device that improves liquid distribution over the cross sectional area of a vessel following the tray. The catalytic reactors liquid distribution tray also intimately contacts the fluid phases to achieve thermal and compositional equilibrium. The reactor can be a down-flow catalytic reactor which includes
10 vertically superimposed packed beds of particulate catalytic material. This type of reactor is used in the petroleum and chemical processing industries for carrying out various catalytic reactions, such as sulphur and nitrogen conversion (HDS/HDN); hydrogenation of: olefins (HYD) and aromatics (hydrodearomatisation - HDA), metals removal (hydrodemetallisation - HDM),
15 oxygen conversion (hydrodeoxygenation - HDO) and hydrocracking (HC).

BACKGROUND OF THE INVENTION

In catalytic chemical reactors it may be necessary to evenly distribute a liquid phase of the process fluid over the cross sectional area of a catalytic bed. Therefore, it is known to install a plate section, a liquid distribution tray, with evenly distributed apertures across its area above and process fluid upstream the catalytic bed. The tray then collects liquid which drips/flows through the apertures to the catalytic bed below. A problem may arise is the tray is not perfectly horizontal arranged, the liquid flow through the apertures then becomes uneven across the area of the tray. This has an impact on the chemical reactions and performance of the catalytic bed below, which is then also uneven and not optimal. In reality, it is very difficult to arrange the liquid distribution tray perfectly horizontal. Thus, a need exists for a catalytic chemical reactor comprising a liquid distribution tray which may distribute liquid evenly through the apertures across its area and thus distribute the liquid

evenly across the cross section of the catalytic bed below despite a slight deviation from horizontal of the liquid distribution tray. Also a need exists for a catalytic chemical reactor comprising a liquid distribution tray which intimately contacts the liquid and vapor phases of the process fluid, to achieve thermal and compositional equilibrium across the cross sectional area of the reactor volume below the liquid distribution tray and above the catalytic bed below the liquid distribution tray.

SUMMARY OF THE INVENTION

These problems are solved by the present invention, a catalytic chemical reactor with a liquid distribution tray and –units. The liquid distribution units 15 comprise a venturi which utilizes the gas or vapour flow to suck liquid from the liquid distribution tray through the apertures of the liquid distribution tray.

The liquid distribution tray is arranged as close to horizontal as possible in the catalytic reactor. It can be either a sectionalized or a solid plate 14. Whether sectionalized or solid, all liquid distribution tray edges are gasketed or otherwise sealed to provide an essentially leak free surface. The liquid distribution tray is perforated by evenly spaced apertures across its surface. The apertures may be round, square, rectangular or any other geometric shape. The apertures are optionally spaced on either a square, triangular, radial or other symmetrical pattern. If the horizontal liquid distribution tray is sectionalized, the apertures may be located optionally on each tray section. In all cases, an optimized pattern is used to provide proximately even spacing between all apertures and to provide an approximately even ratio of aperture area to horizontal tray area across the entire liquid distribution tray.

Each aperture is fitted with an venturi distribution unit 15. The venturi distribution units are attached to the liquid distribution tray plate 14 in such a way as to be leak tight. On the underside of the liquid distribution tray, a drip

edge may optionally be established for each aperture. This may be achieved by having the venturi distribution unit extend through the liquid distribution tray, by having a separate drip edge piece attached to the liquid distribution tray, by having the liquid distribution tray extruded down, or by some other equivalent means.

In an embodiment of the invention the venturi distribution units comprise at least one liquid conduit 8 which comprises one or more inlet holes 9 located on the outer side of the venturi distribution unit, above and near the upper surface of the distribution tray plate for the liquid on the distribution tray plate to be sucked in through. The liquid conduit leads up along the venturi distribution unit to one or more liquid holes 10, which are located in the upper part of the venturi distribution unit. The liquid holes are adapted to pass the liquid from the liquid conduit into the throat section 6 of the venturi distribution unit, where it mixes with the fluid streaming through the venturi distribution unit from the reactor volume above the distribution tray plate to the reactor volume below the distribution tray plate due to the pressure difference between the upper and below volume during reactor operation.

The venturi distribution unit further comprises a convergent inlet section 5 above (process fluid upstream of) the throat section and a divergent section 7 below (process fluid downstream of) the throat section.

In a further embodiment of the invention the outer side of the venturi distribution unit, the convergent inlet section, the throat section and the divergent section have a circular cross sectional shape. Thus, the venturi distribution unit may be made from tubular material, e.g. pipes, for instance metal pipe. In an embodiment, the liquid conduit is formed in the hollow space between an outer wall 4 of the venturi distribution unit and the inner wall formed by the convergent inlet section, the throat section and the divergent section. The liquid conduit may in one embodiment also be formed by a dedicated pipe, acting as a suction "straw".

In a further embodiment, the venturi distribution unit has a rectangular cross sectional shape, thus the outer side of the venturi distribution unit, the convergent inlet section, the throat section and the divergent section may be made of rectangular pipe material and/or plate material for instance of steel.

5 Whatever the shape of the cross section of the venturi distribution unit, the cross sectional area of the throat section may in an embodiment be smaller than the cross sectional area of the convergent inlet section and also in an embodiment smaller than the cross sectional area of the divergent section, to accomplish an efficient venturi effect. Furthermore, the venturi effect as well as
10 the pressure loss over the venturi distribution unit may be optimized by the convergent inlet section having a convex shape in a further embodiment as well as the divergent section having a conical shape.

In yet a further embodiment of the invention, the venturi distribution unit is
15 arranged above and around the apertures in the distribution tray plate, but a part of the venturi distribution unit also below the distribution tray plate, whereby the lower edge of the venturi distribution unit may act as a drip edge for the liquid to the catalytic bed arranged below the distribution tray plate.

20 In an embodiment of the invention, the catalytic reactor is a hydroprocessing reactor.

FEATURES OF THE INVENTION

- 25 1. Catalytic reactor for chemical reactions, comprising a distribution tray plate 14 within the catalytic reactor for even distribution of liquid, vapour and gas across a cross sectional area of the catalytic reactor, said distribution tray plate comprises a plurality of venturi distribution units 15 fixed to the upper side of the distribution tray plate above and around apertures in the distribution tray plate,
30 the venturi distribution units comprise
- a liquid conduit 8, with
 - one or more inlet holes 9 and

- one or more liquid holes 10 and a
- convergent inlet section 5, a
- throat section 6 and a
- divergent section 7,

5 wherein the inlet holes are arranged on the outer side of the venturi distribution units and below the liquid holes, the liquid holes are arranged in the throat section and the liquid conduit connects the inlet holes and the liquid holes, whereby the venturi distribution unit is adapted to suck liquid which is in contact with the inlet holes from the distribution tray plate, through the inlet holes, via
10 the liquid conduit, through the liquid holes and into the throat section when a fluid passes through the convergent inlet section, the throat section and the divergent section from above the distribution tray plate and out below the distribution tray plate.

15 2. Catalytic reactor according to feature 1, wherein the outer side of the venturi distribution unit, the convergent inlet section, the throat section and the divergent section have a circular cross sectional shape.

20 3. Catalytic reactor according to feature 1, wherein the outer side of the venturi distribution unit, the convergent inlet section, the throat section and the divergent section have a rectangular cross sectional shape.

4. Catalytic reactor according to any of the preceding features, wherein the cross sectional area of the throat section is smaller than the cross sectional area of the convergent inlet section.

25 5. Catalytic reactor according to any of the preceding features, wherein the cross sectional area of the throat section is smaller than the cross sectional area of the divergent section.

30 6. Catalytic reactor according to any of the preceding features, wherein the liquid conduit is formed between an outer wall 4 of the venturi distribution unit

and a divergent wall 3 of the divergent section and a throat wall 2 of the throat section.

5 7. Catalytic reactor according to any of the features 1 - 5, wherein the liquid conduit is formed by a pipe.

8. Catalytic reactor according to any of the preceding features, wherein the convergent inlet section has a convex shape.

10 9. Catalytic reactor according to any of the preceding features, wherein the divergent section has a conical shape.

15 10. Catalytic reactor according to any of the preceding claims, wherein a part of the venturi distribution unit is arranged below the distribution tray plate, whereby a lower edge of the venturi distribution unit acts as a dripping edge for the liquid.

11. Catalytic reactor according to any of the preceding features, wherein the venturi distribution unit further comprises one or more fluid by-pass holes 16 arranged in the upper part of the outer wall.

20 12. Catalytic reactor according to any of the preceding features, wherein the venturi distribution unit further comprises one or more liquid by-pass holes 17 arranged in divergent wall.

25 13. Catalytic reactor according to any of the preceding features, wherein said catalytic reactor is a hydroprocessing reactor.

BRIEF DESCRIPTION OF THE DRAWINGS

30 The invention is further illustrated by the accompanying drawings showing examples of embodiments of the invention.

FIG. 1A I show a longitudinal sectional view of a first embodiment of the venturi tube of the present invention as seen along the lines 1A of FIG. 1B,

FIG. 1B shows liquid inlets to the throat along the lines 1B of FIG. 1A,

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FIG. 1C shows liquid inlets to the liquid conduit along the lines 1C of FIG. 1A,

Figs. 2A & 2B show another embodiment of the venturi tube of the present invention, where the liquid holes is located in the convergent section,

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Figs. 3A & 3B show another embodiment of the venturi tube of the present invention, where the liquid is fed to the center of venturi by a straw,

Figs. 4A & 4B show another embodiment of the venturi tube of the present invention, where the venturi tube is in square or rectangular form,

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Fig, 5 shows profile of a liquid hole with elevation edge,

Fig.6 shows another embodiment of the venturi tube of the present invention, with a fluid bypass hole on divergent section wall, and

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Fig. 7 shows another embodiment of the venturi tube of the present invention, with a liquid bypass hole on outer wall.

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POSITION NUMBERS

1. Wall profile.
2. Throat wall.
3. Divergent wall.
4. Outer wall.
5. Convergent inlet section.
6. Throat section.

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7. Divergent section.
8. Liquid conduit.
9. Inlet holes.
10. Liquid holes.
5 11. Liquid conduit exit.
12. Liquid conduit inlet.
13. Liquid conduit pipe.
14. Distribution tray plate.
15. Venturi distribution unit.
10 16. Fluid bypass hole.
17. Liquid bypass hole.

DESCRIPTION OF THE DRAWINGS

- 15 Some specific embodiments of the invention will be explained in more detail in the following with reference to the drawings as seen on Fig 1A to Fig 4B.

A catalytic reactor (not shown) comprises a liquid distribution tray with a distribution tray plate 14 with a plurality of apertures on a uniform square or
20 triangular pitch. One venturi distribution unit 15 is fitted down through or above and around each aperture.

The venturi distribution unit design concept is shown in FIG. 1. The center wall is formed as a venturi with three main sections, a convergent inlet section 5, a
25 throat section 6 and divergent section 7. The venturi distribution unit provides a flow path for vapor across the liquid distribution tray — inlet through the convergent section, down flow through the throat section and divergent section and discharge through the open end of the divergent section to below the distribution tray plate. The wall profile 1 of the convergent section could be
30 straight or any convex curve form as shown in Fig 1A. An outer wall 4 is attached leak-tight to the inner wall at the top of the venturi distribution unit, to form an annular liquid conduit 8 between the two walls. At the bottom of the

outer wall, a number of inlet holes 9 are cut to allow liquid from the pool on the distribution tray plate to enter the liquid conduit. At the top of the throat section on the inner wall, a number of liquid holes 10 are cut to allow liquid from the liquid conduit to enter the throat. The flow path for the liquid is via inlet holes, the liquid conduit and liquid holes, before it is mixed with fluid (e.g. vapor) in the venturi channel.

The liquid holes could be located in the convergent section as shown in Fig. 2A & 2B. The total cross sectional area of the inlet holes is much larger than the total cross sectional area of the liquid holes, such as flow restriction for liquid is dependent on the size of the liquid holes alone. The inlet holes and the liquid holes can be any geometric form, egg, circular, rectangular, etc.

Optionally, for some operating conditions, one or more fluid bypass holes are cut in the top of outer wall 4 as shown in Fig. 6.

Optionally, for operation with high liquid flow, one or more liquid bypass holes are cut in divergent section wall as shown in Fig. 7.

During operation, process fluid of the catalytic reactor is entered to the inlet convergent section. Fluid flow velocity is increasing until it reaches the inlet of the throat section. The high fluid velocity creates a low pressure at the liquid holes, which sucks the liquid from the pool on the distribution tray plate via the inlet holes, the liquid conduit and the liquid holes. At the outlet of the liquid holes, a large portion of liquid is atomized to small droplets due to the shear of high fluid velocity in the convergent section or in the throat section. The formed liquid droplets are accelerated by the drag force of fluid at high velocity. Energy to increase the kinetic energy of liquid droplets is provided by the fluid, which results in a certain pressure drop of the fluid. Another fraction of fluid pressure drop is caused by the frictional pressure drop in the flow channel. In the divergent section, a part of static pressure is recovered by reducing fluid velocity. The dimensions of the venturi are selected so that liquid level on the

tray is between the upper edge of the inlet holes and the lower edge of the liquid holes for all operating conditions. The dimensions, which are adjusted to achieve this are the diameter of the throat section, as well as the position and dimension of liquid holes.

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A high fraction of liquid atomized is preferred to get high dependency of pressure drop to amount of liquid. Fig 3A & 3B show an embodiment with a separate liquid conduit 13 (the straw). The high fluid velocity at the liquid conduit exit 11 of the straw creates a low pressure that suck the liquid from the liquid pool on the distribution tray plate via the liquid conduit inlet 12. The liquid is fed to the center space of the throat section, thereby maximizing the fraction of liquid to be atomized. Optional, the liquid holes for embodiments shown in Fig. 1, Fig. 2 and Fig. 4 could have an elevation edge as shown in Fig.5 in order to reduce the fraction of liquid film on the wall surface.

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The principle to achieve low sensitivity to levelness is explained below. Consider a distribution tube that is located at lower elevation than another tube on the same tray. The liquid level will be higher relative to that tube. Therefore, more liquid will be sucked to that tube. The higher liquid flow causes extra pressure drop in the tube because more energy is required to accelerate a higher amount of liquid. On the other hand, all tubes on the tray should have the same total pressure drop. In order to compensate for the high pressure drop by the increasing liquid, less fluid flow will pass to the low elevated tube so that its total pressure drop will equal to the other tubes pressure drop. The low fluid flow rate results in low suction pressure, thereby less liquid going to that tube. That is the compensation mechanism to counteract the effect of low elevation. That mechanism reduces the liquid mal-distribution due to out of level of the distribution tray plate.

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A hydraulic test proves that sensitivity to 10 mm out of level can be reduced to below 10-15%.

Other advantages of the venturi distribution unit are:

- Less dependency to the flow of liquid, thus can be operated with wide range of liquid turndown.
- 5 - Small dimension: both diameter and height is low. Density of tubes can be up to 150 drip point /m². The height can be reduced to 200 mm, thus save space in the catalytic reactor.
- The upward flow direction in the liquid conduit helps to separate scales before the liquid reach the liquid holes. The risk of fouling or plugging the liquid holes is therefore low.
- 10 - Intimate contact between liquid and vapor.
- The liquid discharges in a conic spray pattern from the divergent section.

CLAIMS

1. Catalytic reactor for chemical reactions, comprising a distribution tray plate 14 within the catalytic reactor for even distribution of liquid, vapour and gas across a cross sectional area of the catalytic reactor, said distribution tray plate comprises a plurality of venturi distribution units 15 fixed to the upper side of the distribution tray plate above and around apertures in the distribution tray plate, the venturi distribution units comprise
- a liquid conduit 8, with
 - one or more inlet holes 9 and
 - one or more liquid holes 10 and a
 - convergent inlet section 5, a
 - throat section 6 and a
 - divergent section 7,
- wherein the inlet holes are arranged on the outer side of the venturi distribution units and below the liquid holes, the liquid holes are arranged in the throat section or the convergent inlet section and the liquid conduit connects the inlet holes and the liquid holes, whereby the venturi distribution unit is adapted to suck liquid which is in contact with the inlet holes from the distribution tray plate, through the inlet holes, via the liquid conduit, through the liquid holes and into the throat section when a fluid passes through the convergent inlet section, the throat section and the divergent section from above the distribution tray plate and out below the distribution tray plate.
2. Catalytic reactor according to claim 1, wherein the outer side of the venturi distribution unit, the convergent inlet section, the throat section and the divergent section have a circular cross sectional shape.
3. Catalytic reactor according to claim 1, wherein the outer side of the venturi distribution unit, the convergent inlet section, the throat section and the divergent section have a rectangular cross sectional shape.

4. Catalytic reactor according to any of the preceding claims, wherein the cross sectional area of the throat section is smaller than the cross sectional area of the convergent inlet section.
- 5 5. Catalytic reactor according to any of the preceding claims, wherein the cross sectional area of the throat section is smaller than the cross sectional area of the divergent section.
- 10 6. Catalytic reactor according to any of the preceding claims, wherein the liquid conduit is formed between an outer wall 4 of the venturi distribution unit and a divergent wall 3 of the divergent section and a throat wall 2 of the throat section.
- 15 7. Catalytic reactor according to any of the claims 1 - 5, wherein the liquid conduit is formed by a pipe.
8. Catalytic reactor according to any of the preceding claims, wherein the convergent inlet section has a convex shape.
- 20 9. Catalytic reactor according to any of the preceding claims, wherein the divergent section has a conical shape.
- 25 10. Catalytic reactor according to any of the preceding claims, wherein a part of the venturi distribution unit is arranged below the distribution tray plate, whereby a lower edge of the venturi distribution unit acts as a dripping edge for the liquid.
11. Catalytic reactor according to any of the preceding claims, wherein the venturi distribution unit further comprises one or more fluid by-pass holes 16 arranged in the upper part of the outer wall.
- 30 12. Catalytic reactor according to any of the preceding claims, wherein the venturi distribution unit further comprises one or more liquid by-pass holes 17 arranged in divergent wall.

13. Catalytic reactor according to any of the preceding claims, wherein said catalytic reactor is a hydroprocessing reactor.

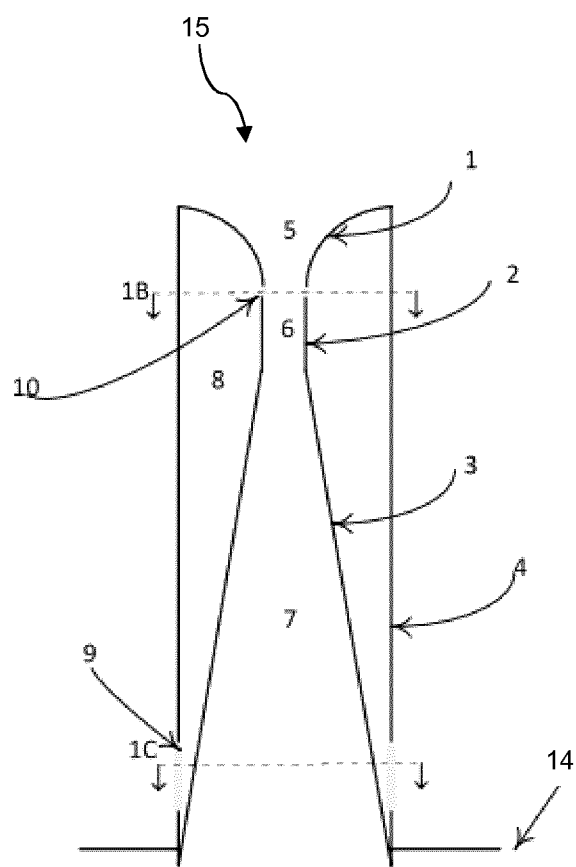


Fig.1A

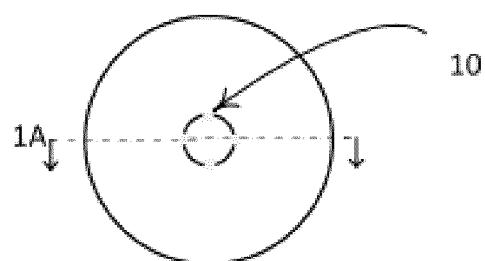


Fig. 1B

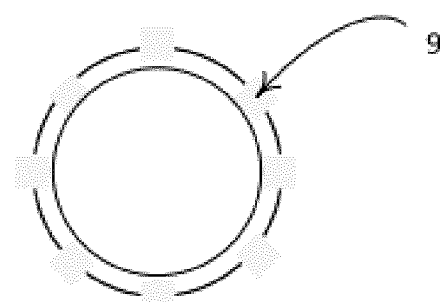


Fig.1C

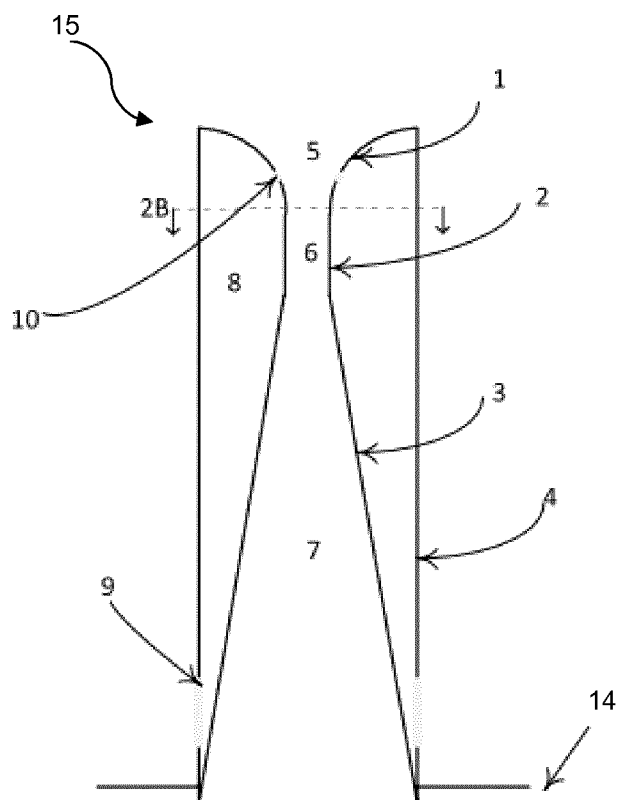


Fig.2A

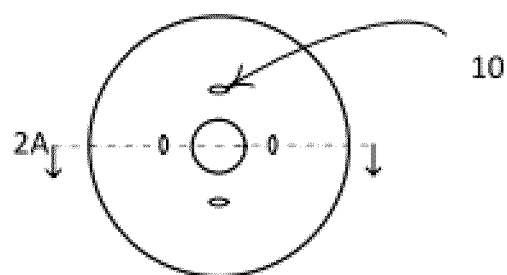


Fig.2B

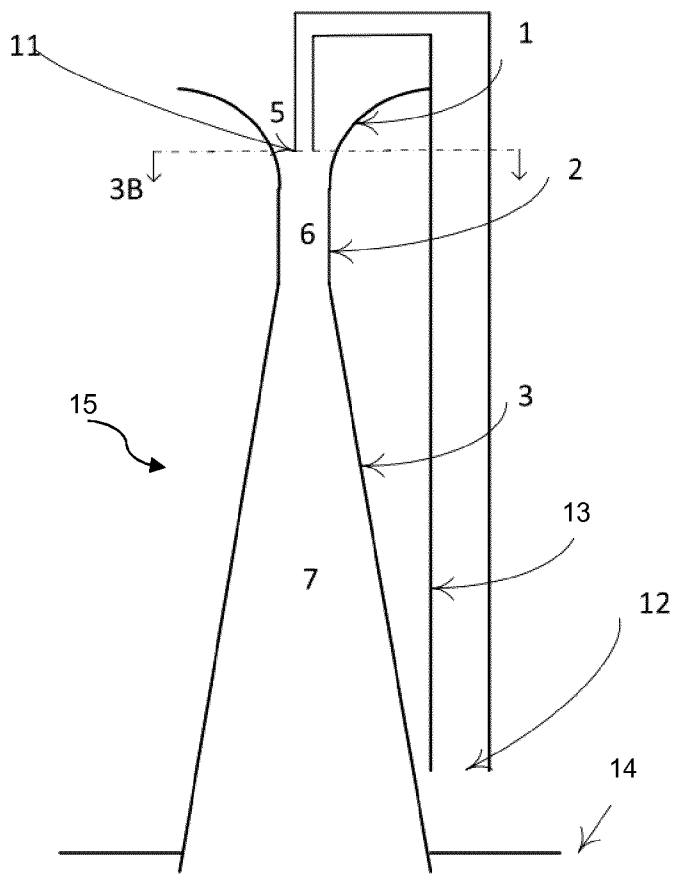


Fig.3A

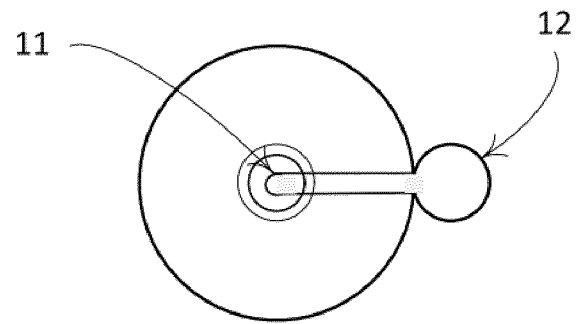


Fig.3B

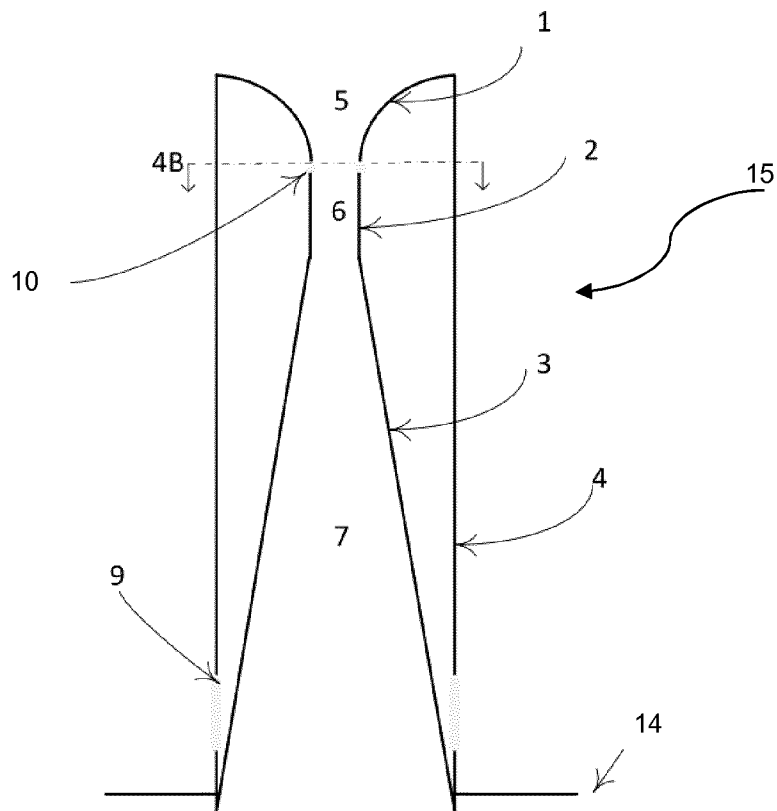


Fig.4A

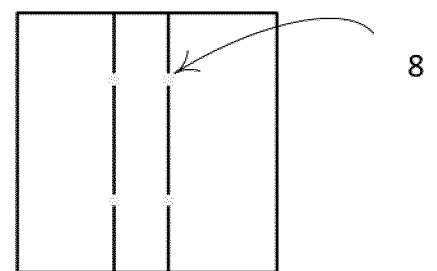


Fig.4B

3/3

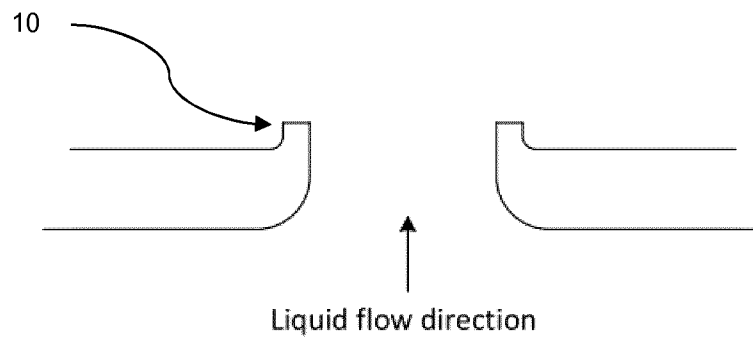


Fig.5 liquid hole with elevation edge

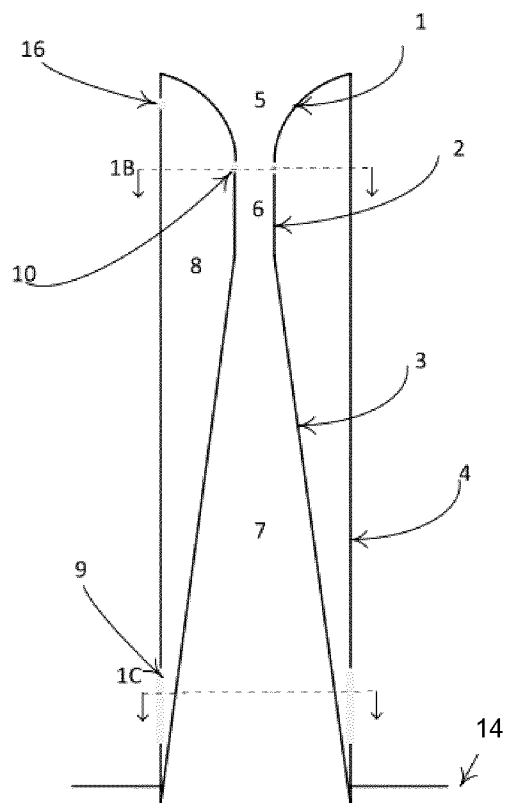


Fig.6

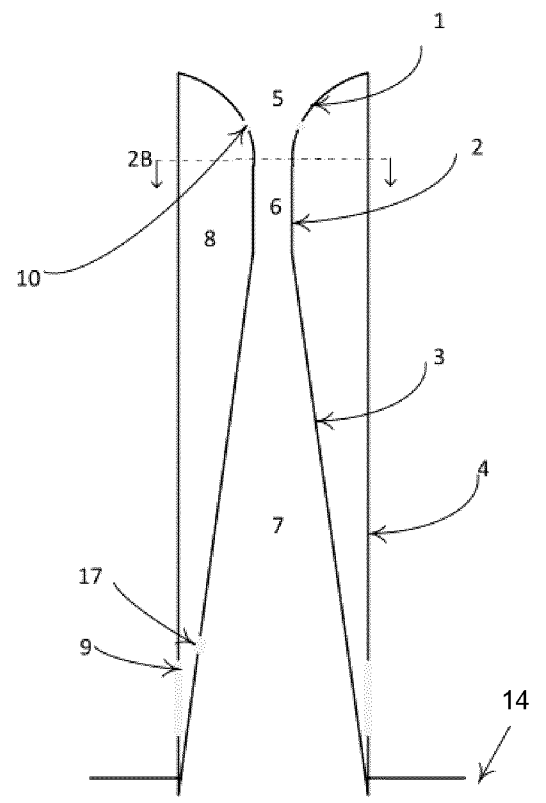


Fig.7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/069633

A. CLASSIFICATION OF SUBJECT MATTER
INV. B01J8/02 B01J8/04 B01J4/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/138175 A1 (XU ZHANPING [US] ET AL) 7 June 2012 (2012-06-07) figure 6 paragraphs [0026] - [0040] -----	1-13
A	US 2006/078483 A1 (KEMOUN ABDENOUR [US] ET AL) 13 April 2006 (2006-04-13) figures 2-3 -----	1-13



Further documents are listed in the continuation of Box C.



See patent family annex.

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"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search

18 September 2019

Date of mailing of the international search report

04/10/2019

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Borello, Ettore

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2019/069633

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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