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(54) **DISTRIBUTOR FOR PLATE-FIN HEAT EXCHANGER**

(57) Plate-fin heat exchanger with mitered distributor design for improved fluid flow distribution through the plate-fin heat exchanger resulting in improved heat exchanger efficiency. Sections of the distributor have different fin types that provide improved distribution of the fluid through the heat exchanger. The fin types for the different sections of the distributor are selected based on a friction factor parameter ratio and a j-factor parameter ratio for the different fin types.

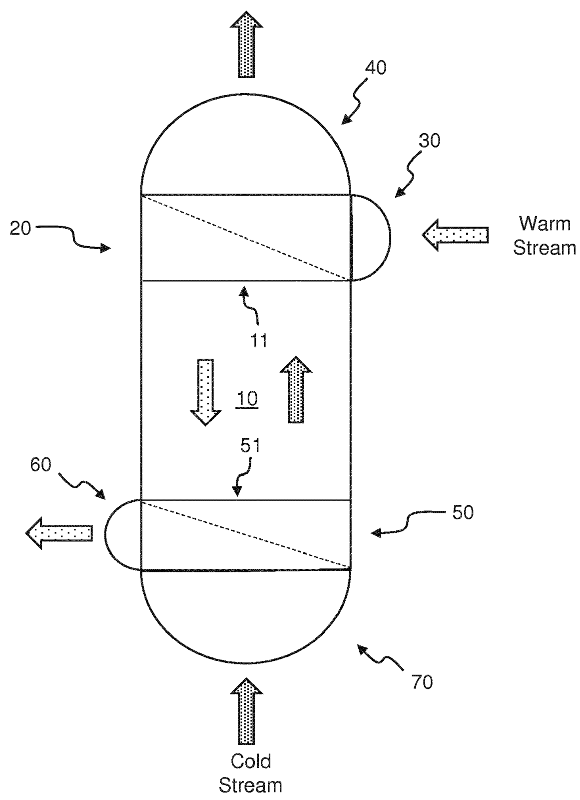

FIG. 1

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Description

BACKGROUND

[0001] Plate-fin heat exchangers are well-known in the chemical process industry including processes for air separation.

[0002] Uniform flow rate distribution of the process streams exchanging heat in plate-fin heat exchangers is important for heat exchanger efficiency.

[0003] Plate-fin heat exchangers with mitered distributors are prone to flow rate maldistribution because of flow resistance variations due to differences in the length of the flow paths in the distributor feeding the main heat exchanger core. In addition to the flow resistance variations in the distributor, changes in the density of the process fluid in the distributor can further worsen flow rate maldistribution. The density of the process fluid can vary in the distributor due to differences in the change in temperature of the process fluid in the distributor, which also depends on the flow path in the distributor.

[0004] Industry desires plate-fin heat exchangers with improved heat exchanger efficiency, i.e. smaller heat exchangers providing the same heat duty as larger heat exchangers.

[0005] Industry desires distributors for plate-fin heat exchangers that improve process fluid flow rate distribution in the heat exchanger core.

BRIEF SUMMARY

[0006] The present disclosure relates to plate-fin heat exchangers. The present disclosure more specifically relates to an improvement in the distributor for plate-fin heat exchangers.

[0007] There are several aspects of the plate-fin heat exchanger as outlined below. In the following, specific aspects of the invention are outlined below. The reference numbers and expressions set in parentheses are referring to an example embodiment explained further below with reference to the figures. The reference numbers and expressions are, however, only illustrative and do not limit the aspect to any specific component or feature of the example embodiment. The aspects can be formulated as claims in which the reference numbers and expressions set in parentheses are omitted or replaced by others as appropriate.

Aspect 1. A plate-fin heat exchanger comprising:

a main heat exchanger core section (10) comprising a first group of heat transfer passages (54) and a second group of heat transfer passages (56), each heat transfer passage of the first group of heat transfer passages (54) containing a respective fin section, and each heat transfer passage of the second group of heat transfer passages (56) containing a respective fin section;

a distributor section (20) abutting the main heat exchanger core section (10) along a face (11) of the main heat exchanger core section (10), the distributor section (20) comprising

> a plurality of parting sheet segments (22), the plurality of parting sheet segments (22) disposed in fixed, spaced relation, wherein the plurality of parting sheet segments (22) defines a first group of passages (24) and a second group of passages (26);

a first header (30) abutting and in fluid communication with the first group of passages (24) along a face (31) of the first header (30), wherein each passage of the first group of passages (24) is closed on a side opposite the first header (30) by a respective closing bar segment (32);

a second header (40) abutting and in fluid communication with the second group of passages (26) of the distributor section (20);

wherein the first group of passages (24) abuts the main heat exchanger core section (10) along the face (11) of the main heat exchanger core section (10), wherein each passage of the first group of passages (24) is in fluid communication with a respective heat transfer passage of the first group of heat transfer passages (54) of the main heat exchanger core section (10), and wherein each passage of the first group of passages (24) is closed on a side opposite the main heat exchanger core section (10) by a respective closing bar (12);

wherein each passage of the first group of passages (24) has a long flow path region (15) between the parting sheet segments of each passage of the first group of passages (24) defined by the union of a first cuboid and a second cuboid, the first cuboid extending normal to the respective closing bar (12) from the fin-side facing surface of the respective closing bar (12) to a position 50% of the distance along the face (31) of the first header (30) from the respective closing bar (12) towards the face (11) of the main heat exchanger core section (10), and the second cuboid extending normal to the respective closing bar segment (32) to a position 50% of the

distance along the face (11) of the main heat exchanger core section (10) from the respective closing bar segment (32) towards the face (31) of the first header (30);
wherein each passage of the first group of passages (24) has a short flow path region (25) between the parting sheet segments of each passage of the first group of passages (24) bounded by the long flow path region (15), a portion of the face (31) of the first header (30), and a portion of the face (11) of the main heat exchanger core section (10);
wherein the long flow path region of each passage of the first group of passages (24) contains at least a portion of two or more fin sections extending throughout the long flow path region including a first-type fin section (1) and a second-type fin section (2), at least a portion of the first-type fin section (1) and at least a portion of the second-type fin section (2) abutting at a junction (9), the first-type fin section (1) comprising a plurality of fins defining a plurality of channels in the first-type fin section (1), and the second-type fin section (2) comprising a plurality of fins defining a plurality of channels in the second-type fin section (2);
wherein the first-type fin section (1) of each passage of the first group of passages (24) abuts the face (31) of the first header (30) along a border (33) of each respective first-type fin section (1);
wherein the second-type fin section (2) of each passage of the first group of passages (24) abuts the face (11) of the main heat exchanger core section (10) along a border (13) of each respective second-type fin section (2), wherein there is a break in continuity between the second-type fin section (2) of each passage of the first group of passages (24) and the respective fin section of the respective heat transfer passage of the first group of heat transfer passages (54) in fluid communication with the respective passage of the first group of passages (24);
wherein the first-type fin section (1) and the second-type fin section (2) of each passage of the first group of passages (24) have a respective friction factor parameter ratio, $\frac{F_{1,Re=3000}}{F_{2,Re=3000}}$, where $0 < \frac{F_{1,Re=3000}}{F_{2,Re=3000}} \leq 0.8$, or $0 < \frac{F_{1,Re=3000}}{F_{2,Re=3000}} \leq 0.3$, where

$$\frac{F_{1,Re=3000}}{F_{2,Re=3000}} = \frac{f_1 A_{f,2}^2 D_{h,2}}{f_2 A_{f,1}^2 D_{h,1}},$$

wherein the first-type fin section (1) and the second-type fin section (2) of each passage of the first group of passages (24) have a respective j-factor parameter ratio, $\frac{J_{1,Re=3000}}{J_{2,Re=3000}}$, where $0 < \frac{J_{1,Re=3000}}{J_{2,Re=3000}} \leq 0.8$, or $< \frac{J_{1,Re=3000}}{J_{2,Re=3000}} \leq 0.3$ where

$$\frac{J_{1,Re=3000}}{J_{2,Re=3000}} = \frac{j_1 A_{s,1} A_{f,2}}{j_2 A_{s,2} A_{f,1}},$$

where

f_1 is the respective friction factor for the fins in the first-type fin section (1) of each passage of the first group of passages (24) evaluated at a Reynolds number of 3000,
f_2 is the respective friction factor for the fins in the second-type fin section (2) of each passage of the first group of passages (24) evaluated at a Reynolds number of 3000,
j_1 is the respective j-factor for the fins in the first-type fin section (1) of each passage of the first group of passages (24) evaluated at a Reynolds number of 3000,
j_2 is the respective j-factor for the fins in the second-type fin section (2) of each passage of the first group of passages (24) evaluated at a Reynolds number of 3000,
$D_{h,1}$ is the respective hydraulic diameter for the first-type fin section (1) of each passage of the first group of passages (24),
$D_{h,2}$ is the respective hydraulic diameter for the second-type fin section (2) of each passage of the first group of passages (24),
$A_{f,1}$ is the respective free flow area per unit width per passage for the first-type fin section (1) of each passage of the first group of passages (24),

$A_{f,2}$ is the respective free flow area per unit width per passage for the second-type fin section (2) of each passage of the first group of passages (24),
$A_{s,1}$ is the respective heat transfer area per unit width per unit length per passage for the first-type fin section (1) of each passage of the first group of passages (24),
$A_{s,2}$ is the respective heat transfer area per unit width per unit length per passage for the second-type fin section (2) of each passage of the first group of passages (24),

where consistent units are used for each of $D_{h,1}$, $D_{h,2}$, $A_{f,1}$, $A_{f,2}$, $A_{s,1}$, and $A_{s,2}$.

Aspect 2. The plate-fin heat exchanger according to aspect 1 wherein one or more fin section characteristics of the second-type fin section (2) of each passage of the first group of passages (24) is different than a corresponding fin section characteristic of the respective fin section of each heat transfer passage of the first group of heat transfer passages (54) for each passage of the first group of passages (24) in fluid communication with the respective heat transfer passage of the first group of heat transfer passages (54) of the main heat exchanger core section (10).

Aspect 3. The plate-fin heat exchanger according to aspect 2 wherein the one or more fin section characteristics are selected from the group consisting of fin style, free flow area, fin density, fin thickness, and hydraulic diameter.

Aspect 4. The plate-fin heat exchanger according to any one of aspects 1 to 3 wherein the plate-fin heat exchanger is configured to pass a first fluid through the first group of heat transfer passages (54) in countercurrent flow relationship to a second fluid passed through the second group of heat transfer passages (56).

Aspect 5. The plate-fin heat exchanger according to aspect 1 wherein a second border (7) of each respective first-type fin section (1) is parallel with the respective closing bar (12) of each respective passage of the first group of passages (24).

Aspect 6. The plate-fin heat exchanger according to any one of aspects 1 to 5 wherein the first-type fin section (1) of each passage of the first group of passages (24) has a longitudinal direction, wherein the longitudinal direction of each respective first-type fin section (1) is aligned parallel with the respective closing bar (12) of each respective passage of the first group of passages (24).

Aspect 7. The plate-fin heat exchanger according to any one of aspects 1 to 6 wherein a second border (8) of each respective second-type fin section (2) of each passage of the first group of passages (24) is aligned parallel with the respective closing bar (32) of each respective passage of the first group of passages (24).

Aspect 8. The plate-fin heat exchanger according to any one of aspects 1 to 7 wherein the second-type fin section (2) of each passage of the first group of passages (24) has a longitudinal direction, wherein the longitudinal direction of each respective second-type fin section (2) is aligned parallel with the respective closing bar segment (32) of each respective passage of the first group of passages (24).

Aspect 9. The plate-fin heat exchanger according to any one of aspects 1 to 8 wherein the short flow path region (25) of each respective passage of the first group of passages (24) contains a portion of the respective first-type fin section (1).

Aspect 10. The plate-fin heat exchanger according to any one of aspects 1 to 9 wherein the short flow path region (25) of each respective passage of the first group of passages (24) contains a portion of the respective second-type fin section (2).

Aspect 11. The plate-fin heat exchanger according to any one of aspects 1 to 10 wherein the short flow path region (25) of each passage of the first group of passages (24) contains two or more respective fin sections including a respective third-type fin section (3) comprising a plurality of fins defining a plurality of channels in the respective third-type fin section (3), wherein the respective third-type fin section (3) of each passage of the first group of passages (24) abuts the face (31) of the first header (30) along a border (34) of each respective third-type fin section (3);

wherein the first-type fin section (1) and the third-type fin section (3) of each passage of the first group of passages (24) have a respective friction factor parameter ratio, $\frac{F_{1,Re=3000}}{F_{3,Re=3000}}$, where $0 < \frac{F_{1,Re=3000}}{F_{3,Re=3000}} \leq 1$, or $0 < \frac{F_{1,Re=3000}}{F_{3,Re=3000}} \leq 0.95$, or $0 < \frac{F_{1,Re=3000}}{F_{3,Re=3000}} \leq 0.5$, where

$$\frac{F_{1,Re=3000}}{F_{3,Re=3000}} = \frac{f_1 A_{f,3}^2 D_{h,3}}{f_3 A_{f,1}^2 D_{h,1}},$$

where

f_3 is the respective friction factor for the fins in the third-type fin section (3) of each passage of the first group of passages (24) evaluated at a Reynolds number of 3000,
$D_{h,3}$ is the respective hydraulic diameter for the third-type fin section (3) of each passage of the first group of passages (24),
$A_{f,3}$ is the respective free flow area per unit width per passage for the third-type fin section (3) of each passage of the first group of passages (24),

where consistent units are used for each of $D_{h,1}$, $D_{h,3}$, $A_{f,1}$, and $A_{f,3}$.

Aspect 12. The plate-fin heat exchanger according to any one of aspects 1 to 11 wherein the short flow path region (25) of each respective passage of the first group of passages (24) contains two or more fin sections including a respective fourth-type fin section (4) comprising a plurality of fins defining a plurality of channels in each respective fourth-type fin section (4), wherein the respective fourth-type fin section (4) of each passage of the first group of passages (24) abuts the face (11) of the main heat exchanger section (10) along a border (14) of each respective fourth-type fin section (4), wherein there is a break in continuity between the fourth-type fin section (4) of each passage of the first group of passages (24) and the respective fin section of the respective heat transfer passage of the first group of heat transfer passages (54) in fluid communication with the respective passage of the first group of passages (24);

wherein the fourth-type fin section (4) and the second-type fin section (2) of each passage of the first group of passages (24) have a respective j-factor parameter ratio, $\frac{J_{4,Re=3000}}{J_{2,Re=3000}}$, where $0 < \frac{J_{4,Re=3000}}{J_{2,Re=3000}} \leq 1$, or $0 < \frac{J_{4,Re=3000}}{J_{2,Re=3000}} \leq 0.95$ or $0 < \frac{J_{4,Re=3000}}{J_{2,Re=3000}} \leq 0.5$ where

$$\frac{J_{4,Re=3000}}{J_{2,Re=3000}} = \frac{j_4 A_{s,4} A_{f,2}}{j_2 A_{s,2} A_{f,4}},$$

where

j_4 is the respective j-factor for the fins in the fourth-type fin section (4) of each passage of the first group of passages (24) evaluated at a Reynolds number of 3000,
$A_{f,4}$ is the respective free flow area per unit width per passage for the fourth-type fin section (4) of each passage of the first group of passages (24),
$A_{s,4}$ is the respective heat transfer area per unit width per unit length per passage for the fourth-type fin section (4) of each passage of the first group of passages (24),

where consistent units are used for each of $A_{f,2}$, $A_{f,4}$, $A_{s,2}$, and $A_{s,4}$.

Aspect 13. The plate-fin heat exchanger according to any one of the preceding aspects wherein one or more fin section characteristics of the first-type fin section (1) of each passage of the first group of passages (24) is different than a corresponding fin section characteristic of the second-type fin section (2) of each passage of the first group of passages (24), and wherein the one or more fin section characteristics are selected from the group consisting of fin style, free flow area, fin density, fin thickness, and hydraulic diameter.

Aspect 14. The plate-fin heat exchanger according to any one of the preceding aspects wherein the distributor section (20) is manufactured separately from the main heat exchanger core section (10) and jointed to the main heat exchanger core section (10) at the face (11) of the main heat exchanger core section (10).

Aspect 15. The plate-fin heat exchanger according to any one of the preceding aspects wherein the distributor section (20) is a mitered distributor, the first-type fin section (1) abutting at least a portion of the second-type fin section (2) at a junction (9) which follows a diagonal from an intersection of the closing bar (12) and closing bar segment (32) to an intersection of the face (31) of the first header (30) and the face (11) of the main heat exchanger core section (10).

Aspect 16. The plate-fin heat exchanger according to any one of the preceding aspects in combination with aspect 11 wherein each third-type fin section (3) of each passage (24) of the first group of passages (24) extends through at least 20%, or at least 40% of the volume of the short flow path region (25) of the respective passage (24).

Aspect 17. The plate-fin heat exchanger according to any one of the preceding aspects in combination with aspect 11 wherein each third-type fin section (3) of each passage of the first group of passages (24) extends from the border (34) of each respective third-type fin section (3) towards a junction (9) and abuts at the junction (9) at least a portion of a fin section (2; 2, 4) extending from the junction (9) towards the face (11) of the main heat exchanger core section (10).

Aspect 18. The plate-fin heat exchanger according to any one of the preceding aspects in combination with aspect 11 wherein each third-type fin section (3) of each passage of the first group of passages (24) extends from the border (34) of each respective third-type fin section (3) towards a junction (9) and abuts at the junction (9) at least a portion of at least one fin section (2; 2, 4) of a type different from the third type.

Aspect 19. The plate-fin heat exchanger according to any one of the preceding aspects in combination with aspect 12 wherein each fourth-type fin section (4) of each passage of the first group of passages (24) extends through at least 20%, or at least 40% of the volume of the short flow path region (25) of the respective passage (24).

Aspect 20. The plate-fin heat exchanger according to any one of the preceding aspects in combination with aspect 12 wherein each fourth-type fin section (4) of each passage of the first group of passages (24) extends from the border (14) of each respective fourth-type fin section (4) towards a junction (9) and abuts at the junction (9) at least a portion of a fin section extending from the junction (9) towards the face (31) of the distributor section (20).

Aspect 21. The plate-fin heat exchanger according to any one of the preceding aspects in combination with aspect 12 wherein each fourth-type fin section (4) of each passage of the first group of passages (24) extends from the border (14) of each respective fourth-type fin section (4) towards a junction (9) and abuts at the junction (9) at least a portion of at least one fin section (1, 3) of a type different from the fourth type.

Aspect 22. A process for exchanging heat between a first stream and a second stream, the process comprising:

providing the plate-fin heat exchanger according to any one of aspects 1 to 21;

passing the first stream through the first group of heat transfer passages (54) of the plate-fin heat exchanger in countercurrent flow relationship to the second stream being passed through the second group of heat transfer passages (56) of the plate-fin heat exchanger.

Aspect 23. The process of aspect 22 wherein the first stream is a first fluid having an oxygen concentration ranging from 20 vol.% oxygen to 22 vol. % oxygen and a nitrogen concentration ranging from 78 vol. % nitrogen to 80 vol. % nitrogen, and wherein the second stream is a nitrogen-rich waste gas stream from a distillation column.

BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

[0008]

FIG. 1 shows a cross-section of a plate-fin heat exchanger.

FIG. 2 shows fins of different styles.

FIG. 3 shows a cross-section of a distributor section of a plate fin heat exchanger.

FIG. 4 shows section A-A of the distributor section of FIG. 3 and FIG. 6.

FIG. 5 show section B-B of the distributor section of FIG. 3 and FIG. 6.

FIG. 6 shows a cross-section of a distributor section having two fin sections.

FIG. 7 shows a cross-section of a distributor section having three fin sections.

FIG. 8 shows a cross-section of a distributor section having three fin sections.

FIG. 9 shows a cross-section of a distributor section having four fin sections.

FIG. 10 shows a cross-section of a distributor section having five fin sections.

FIG. 11 shows a cross-section of a distributor section having a fin section having a longitudinal direction in the same direction as the longitudinal direction of the fins in the main heat exchanger core section.

FIG. 12 shows a cross-section of a distributor section having two fin sections.

FIG. 13. shows a cross-section of a distributor section of a plate fin heat exchanger.

FIG. 14 shows section C-C of the distributor section of FIG. 13.

FIG. 15 shows section D-D of the distributor section of FIG. 13.

FIG. 16 shows the heat exchanger and distributor discretized into a mesh and fluid flow path for the first (warm) stream.

FIG. 17 shows the heat exchanger and distributor discretized into a mesh and fluid flow path for the second (cold) stream.

DETAILED DESCRIPTION OF THE PREFFERED EMBODIMENTS

[0009] The ensuing detailed description provides preferred exemplary embodiments only, and is not intended to limit the scope, applicability, or configuration of the invention. Rather, the ensuing detailed description of the preferred exemplary embodiments will provide those skilled in the art with an enabling description for implementing the preferred exemplary embodiments of the invention, it being understood that various changes may be made in the function and arrangement of elements without departing from the scope of the invention as defined by the claims.

[0010] The articles "a" and "an" as used herein mean one or more when applied to any feature in embodiments of the present invention described in the specification and claims. The use of "a" and "an" does not limit the meaning to a single feature unless such a limit is specifically stated. The article "the" preceding singular or plural nouns or noun phrases denotes a particular specified feature or particular specified features and may have a singular or plural connotation depending upon the context in which it is used.

[0011] The adjective "any" means one, some, or all indiscriminately of whatever quantity.

[0012] The term "and/or" placed between a first entity and a second entity includes any of the meanings of (1) only the first entity, (2) only the second entity, and (3) the first entity and the second entity. The term "and/or" placed between the last two entities of a list of 3 or more entities means at least one of the entities in the list including any specific combination of entities in this list. For example, "A, B and/or C" has the same meaning as "A and/or B and/or C" and comprises the following combinations of A, B and C: (1) only A, (2) only B, (3) only C, (4) A and B and not C, (5) A and C and not B, (6) B and C and not A, and (7) A and B and C.

[0013] The phrase "at least one of" preceding a list of features or entities means one or more of the features or entities in the list of entities, but not necessarily including at least one of each and every entity specifically listed within the list of entities and not excluding any combinations of entities in the list of entities. For example, "at least one of A, B, or C" (or equivalently "at least one of A, B, and C" or equivalently "at least one of A, B, and/or C") has the same meaning as "A and/or B and/or C" and comprises the following combinations of A, B and C: (1) only A, (2) only B, (3) only C, (4) A and B and not C, (5) A and C and not B, (6) B and C and not A, and (7) A and B and C.

[0014] The term "plurality" means "two or more than two."

[0015] As used herein, "indirect heat transfer" is heat transfer from one stream to another stream where the streams are not mixed together. Indirect heat transfer includes, for example, transfer of heat from a first fluid to a second fluid in a heat exchanger where the fluids are separated by plates or tubes.

[0016] As used herein, "first," "second," "third," etc. are used to distinguish from among a plurality of steps and/or features, and is not indicative of the total number, or relative position in time and/or space unless expressly stated as such.

[0017] In order to aid in describing the invention, directional terms may be used in the specification and claims to describe portions of the present invention (e.g., upper, top, lower, bottom, left, right, etc.). These directional terms are merely intended to assist in describing and claiming the invention and are not intended to limit the invention in any way. In addition, reference numerals that are introduced in the specification in association with a drawing figure may be repeated in one or more subsequent figures without additional description in the specification in order to provide context for other features.

[0018] In the claims, letters may be used to identify claimed steps (e.g. (a), (b), and (c)). These letters are used to aid in referring to the method steps and are not intended to indicate the order in which claimed steps are performed, unless and only to the extent that such order is specifically recited in the claims.

[0019] The present disclosure relates to plate-fin heat exchangers. The plate-fin heat exchanger of the present disclosure will be described with reference to the figures.

[0020] FIG. 1 is a general representation of a plate-fin heat exchanger. As shown in FIG. 1, a first (warm) stream is passed from header 30 into distributor section 20, from distributor section 20 through main heat exchanger core section 10 to distributor section 50, and from distributor section 50 to header 60. A second (cold) stream is passed from header 70 into distributor section 50, from distributor section 50 through the main heat exchanger core section 10 to distributor section 20, from distributor section 20 to header 40. The first (warm) stream is shown to pass through the plate-fin heat exchanger in a flow direction countercurrent to the second (cold) stream.

[0021] The plate-fin heat exchanger comprises a main heat exchanger core section 10. The main heat exchanger core section 10 comprises parting sheet segments and fins. The parting sheet segments separate a first group of heat transfer passages 54 from a second group of heat transfer passages 56 illustrated in FIG. 5. Each heat transfer passage of the first group of heat transfer passages 54 contains a respective fin section. The respective fin section of each heat transfer passage of the first group of heat transfer passages 54 comprises a plurality of fins defining a plurality of channels in the respective fin section of each heat transfer passage 54 of the first group of heat transfer passages 54. Each heat transfer passage 56 of the second group of heat transfer passages 56 contains a respective fin section. The respective fin section of each heat transfer passage of the second group of heat transfer passages 56 comprises a plurality of fins defining a plurality of channels in the respective fin section of each heat transfer passage of the second group of heat transfer passages 56. Each of the first group of heat transfer passages 54 and the second group of heat transfer passages 56 of the main heat exchanger core section 10 may comprise any known fin style, for example, straight fins, perforated fins, serrated fins, and herringbone fins. The various fin styles are illustrated in FIG. 2.

[0022] The first group of heat transfer passages 54 may be configured to transport a first (warm) stream from distributor section 20 to distributor section 50 and give up heat to the second (cold) stream. The second group of heat transfer passages 56 may be configured to transport a second (cold) stream from distributor section 50 to distributor section 20 and receive heat from the first (warm) stream. The plate-fin heat exchanger may be configured to pass the first (warm) stream through the first group of heat transfer passages 54 in countercurrent flow relationship to the second (cold) stream passed through the second group of heat transfer passages 56.

[0023] For the case of air separation, the first (warm) stream may be air and the second (cold) stream may be a nitrogen-rich waste gas from a distillation column. The first group of heat transfer passages 54 and the second group of heat transfer passages 56 are configured to provide indirect heat transfer between the first (warm) stream and the second (cold) stream. Each heat transfer passage in the first group of heat transfer passages 54 may be adjacent to at least one heat transfer passage in the second group of heat transfer passages 56. Each heat transfer passage in the second group of heat transfer passages 56 may be adjacent to at least one heat transfer passage in the first group of heat transfer passages 54.

[0024] The plate-fin heat exchanger comprises a distributor section 20 abutting the main heat exchanger core section 10 along a face 11 of the main heat exchanger core section 10. With reference to FIGS. 3-6, showing several views of the distributor section 20, the distributor section 20 comprises a plurality of parting sheet segments 22. The plurality of parting sheet segments 22 are disposed in fixed, substantially parallel, spaced relation with each other. The plurality of parting sheet segments 22 define a first group of passages 24 and a second group of passages 26. Each passage 24 in the first group of passages 24 may be adjacent to at least one passage 26 of the second group of passages 26. Each passage in the second group of passages 26 may be adjacent to at least one passage of the first group of passages 24.

[0025] Each passage of the first group of passages 24 of the distributor section 20 is in fluid communication with a respective heat transfer passage of the first group of heat transfer passages 54 of the main heat exchanger core 10.

Each passage of the second group of passages 26 of the distributor section 20 is in fluid communication with a respective heat transfer passage of the second group of heat transfer passages 56 of the main heat exchanger core 10.

[0026] Referring to FIGS. 3-10, the plate-fin heat exchanger comprises a first header 30 abutting and in fluid communication with the first group of passages 24 of the distributor section 20 along a face 31 of the first header 30. Each passage of the first group of passages 24 is closed on a side opposite the first header 30 by a respective closing bar segment 32. Each respective closing bar segment 32 has a fin-side facing surface (i.e. the internal side) having a length, L_H.

[0027] The first group of passages 24 abuts the main heat exchanger core section 10 along a face 11 of the main heat exchanger core section 10. Each passage of the first group of passages 24 is in fluid communication with a respective heat transfer passage of the first group of heat transfer passages 54 of the main heat exchanger core section 10. Each passage of the first group of passages 24 is closed on a side opposite the main heat exchanger core section 10 by a respective closing bar 12. Each respective closing bar 12 has a fin-side facing surface having a length, L_W.

[0028] As shown in FIGS. 3, 4, and 7-10, each passage of the first group of passages 24 has a long flow path region 15 between the parting sheet segments 22 of each passage of the first group of passages 24 and a short flow path region 25 between the parting sheet segments 22 of each passage of the first group of passages 24, so-called because the distance traveled by the process fluid in the distributor section for the long flow path region 15 is greater than the distance traveled in the short flow path region 25. The distance that the process fluid needs to travel in the distributor section 20 from the header 30 to the main heat exchanger core 10 impacts the flow rate distribution of the process fluid in the main heat exchanger core 10.

[0029] The long flow path region 15 for each passage of the first group of passages 24 is defined by the union of a first cuboid and a second cuboid. A "cuboid" is a 3-dimensional shape that has six rectangular faces at substantially right angles to each other. The first cuboid extends normal to the respective closing bar 12 from the fin-side facing surface of the respective closing bar 12 to a position 50% of the distance along the face 31 of the first header 30 from the respective closing bar 12 towards the face 11 of the main heat exchanger core section 10. The second cuboid extends normal to the respective closing bar segment 32 to a position 50% of the distance along the face 11 of the main heat exchanger core section 10 from the respective closing bar segment 32 towards the face 31 of the first header 30.

[0030] The long flow path region 15 in FIG. 3 resembles an "L" rotated 90° clockwise.

[0031] The short flow path region 25 for each passage of the first group of passages 24 is bounded by the long flow path region 15, a portion of the face 31 of the first header 30, and a portion of the face 11 of the main heat exchanger core section 10.

[0032] The long flow path region 15 contains at least a portion of two or more fin sections extending throughout the long flow path region 15 including a first-type fin section 1 and a second-type fin section 2. As used herein, the term "type" is used to distinguish between fin sections composed of fins having one or more different characteristics, such as fin style and/or free flow area and/or fin density and/or hydraulic diameter, etc. For example, the first-type fin section 1 may have herringbone fins with a first fin density that is different from the second-type fin section 2 having herringbone fins with a second fin density that is different than the first fin density.

[0033] The long flow path region 15 of each passage of the first group of passages 24 may contain no additional fin sections other than a portion or all of the first-type fin section and a portion or all of the second-type fin section, such as shown in FIGS. 6, 7, and 9.

[0034] The long flow path region 15 of each passage of the first group of passages 24 may contain a portion or all of one or more other fin sections, for example, a third-type fin section, in addition to a portion or all of the first-type fin section 1 and a portion or all of the second-type fin section 2 as shown in FIGS. 8 and 10. For the case where each passage of the first group of passages 24 contains a portion or all of one or more other fin sections in addition to a portion or all of the respective first-type fin section 1 and a portion or all of the respective second-type fin section 2, the respective first-type fin section 1 and the respective second-type fin section 2 in combination may extend through at least 50%, or at least 75%, or at least 90% of the volume of the long flow path region 15 of the respective passage 24. FIG. 8 shows the first-type fin section 1 and the second-type fin section 2 in combination extending through greater than 90% of the volume of the long flow path region 15, with third-type fin section 3 extending through less than 10% of the volume of the long flow path region 15.

[0035] Fin sections of different types are designated as first-type fin section, second-type fin section, third-type fin section, etc. A fin section of a certain type, for example, the first-type fin section 1, is composed of an arrangement of fins having at least one structural characteristic effecting fluid flow and/or heat transfer which differs from the same structural characteristic of a fin section of another type, for example, the second-type fin section 2, and an optional fin section of another type. The at least one structural characteristic in which a fin section of one type, e.g. the first-type fin section 1, differs from a fin section of another type, e.g. the second-type fin section 2 or an optional third-type fin section, may be fin style, examples of which are illustrated in FIG. 2, free flow area, fin density, hydraulic diameter, etc. The respective fin sections of different types may differ one from the other in only one or in two or three or more characteristics.

[0036] As shown in FIGS. 6, 7, 9, and 10, the short flow path region 25 of each passage of the first group of passages

24 may contain a portion of the first-type fin section 1.

[0037] As shown in FIGS. 6, 7, 8, 9, and 10 the short flow path region 25 of each passage of the first group of passages 24 may contain a portion of the second-type fin section 2.

[0038] At least a portion of the first-type fin section 1 abuts at least a portion of the second-type fin section 2 at a junction 9. As shown in FIGS. 6, 7, 8, 9, 10, the junction 9 may follow a diagonal from the intersection of the closing bar 12 and closing bar segment 32 to the intersection of the face 31 of the first header 30 and the face 11 of the main heat exchanger core section 10. The distributor section 20 is a so-called mitered distributor.

[0039] The first-type fin section 1 comprises a plurality of fins defining a plurality of channels in the first-type fin section 1. The first-type fin section 1 of each passage of the first group of passages abuts the face 31 of the first header 30 along a border 33 of each respective first-type fin section 1. Each first-type fin section has as second border 7. The second border 7 of each respective first-type fin section may be parallel with the respective closing bar 12 of each passage of the first group of passages 24. A second border 7 of the first-type fin section 1 "parallel" with the closing bar 12 means that the spacing between the closing bar 12 and the border 7 of the first-type fin section 1 varies by less than 5% of L_W over the length, L_W, of the closing bar 12.

[0040] The first-type fin section 1 of each passage of the first group of passages 24 has a longitudinal direction.

[0041] The longitudinal direction of a fin section corresponds to the lengthwise direction of the fins. The longitudinal direction of a fin section is perpendicular to the fin density direction. The fin section forms channels where the path of least resistance for the process fluid is in the longitudinal direction. The longitudinal direction for each fin style is shown in FIG. 2.

[0042] The longitudinal direction of the first-type fin section 1 may be aligned parallel with the respective closing bar 12 of each passage of the first group of passages 24. A longitudinal direction aligned "parallel" with the closing bar 12 means that the distance between a planar segment perpendicular to the parting sheets in the longitudinal direction and the closing bar 12 varies by less than 5% of L_W over the length, L_W, of the closing bar 12.

[0043] Each second-type fin section 2 comprises a plurality of fins defining a plurality of channels in each respective second-type fin section 2. The second-type fin section 2 of each passage of the first group of passages 24 abuts the face 11 of the main heat exchanger core section 10 along a border 13 of each respective second-type fin section 2. The second-type fin section 2 of each passage of the first group of passages 24 and the respective fin section of the respective heat transfer passage of the first group of heat transfer passages 54 that are in fluid communication with the respective passage of the first group of passages 24 are separate pieces of fin section. Therefore, there is a break in continuity between the second-type fin section 2 of each passage of the first group of passages 24 and the respective fin section of the respective heat transfer passage of the first group of heat transfer passages 54 that are in fluid communication with the respective passage of the first group of passages 24. There may be a 0.5 mm to 5 mm gap between the second-type fin section 2 and the respective fin section of the main heat exchanger core section 10. One of the benefits of having separate pieces of fin section at the face 11 between the main heat exchanger core section 10 and the distributor section 20 is for ease of manufacturing.

[0044] One or more fin section characteristics of the second-type fin section 2 of each passage of the first group of passages 24 may be different than a corresponding fin section characteristic of the bordering fin section of heat transfer passage of the main heat exchanger core. The one or more fin section characteristics may be selected from the group consisting of fin style, free flow area, fin density, fin thickness, and hydraulic diameter. The overall efficiency of the plate-fin heat exchanger can be improved by using fin characteristics for the distributor section that are different than the fin characteristics of the main heat exchanger core. The criteria for selection of the fin characteristics of the distributor section may be tilted towards improved flow distribution and improved heat transfer while the criteria for selection of the fin characteristics for the main heat exchanger core section may be tilted towards improved heat transfer. The result is improved overall heat transfer performace of the plate-fin heat exchanger.

[0045] Each second-type fin section 2 has a second border 8. The second border 8 of each respective second-type fin section may be parallel with the respective closing bar segment 32 of each passage of the first group of passages 24. A second border 8 of the second-type fin section 2 "parallel" with the closing bar segment 32 means that the spacing between the closing bar segment 32 and the border 8 of the second-type fin section 2 varies by less than 5% of L_H over the length, L_H, of the closing bar segment 32.

[0046] The second-type fin section 2 of each passage of the first group of passages 24 has a longitudinal direction. The longitudinal direction of the second-type fin section 2 may be aligned parallel with the respective closing bar segment 32 of each passage of the first group of passages 24. A longitudinal direction aligned "parallel" with the closing bar segment 32 means that the distance between a planar segment perpendicular to the parting sheets in the longitudinal direction and the closing bar segment 32 varies by less than 5% of L_H over the length, L_H, of the closing bar segment 32.

[0047] According to the present disclosure, the second-type fin section 2 of each passage 24 is different than the first-type fin section 1 of each passage, meaning that the second-type fin section 2 has at least one different characteristic than the first-type fin section 1, such as fins of a different style, hydraulic diameter, free flow area per unit width per passage, or heat transfer area per unit width per unit length per passage. The first-type fin section 1 and the second-type fin section 2 of each passage of the first group of passages 24 are characterized by a respective friction factor parameter ratio, $\frac{F_{1,Re=3000}}{F_{2,Re=3000}}$, where $0 < \frac{F_{1,Re=3000}}{F_{2,Re=3000}} \leq 0.8$, or $0 < \frac{F_{1,Re=3000}}{F_{2,Re=3000}} \leq 0.3$, and a *j*-factor parameter ratio, $\frac{J_{1,Re=3000}}{J_{2,Re=3000}}$, where $0 < \frac{J_{1,Re=3000}}{J_{2,Re=3000}} \leq 0.8$, or $0 < \frac{J_{1,Re=3000}}{J_{2,Re=3000}} \leq 0.3$.

[0048] The friction factor parameter ratio, $\frac{F_{1,Re=3000}}{F_{2,Re=3000}}$, is $\frac{f_1 A_{f,2}^2 D_{h,2}}{f_2 A_{f,1}^2 D_{h,1}}$, where

f_1 is the friction factor for the fins in the first-type fin section 1 evaluated at a Reynolds number of 3000,

f_2 is the friction factor for the fins in the second-type fin section 2 evaluated at a Reynolds number of 3000,

$D_{h,1}$ is the hydraulic diameter for the first-type fin section 1,

$D_{h,2}$ is the hydraulic diameter for the second-type fin section 2,

$A_{f,1}$ is the free flow area per unit width per passage for the first-type fin section 1, and

$A_{f,2}$ is the free flow area per unit width per passage for the second-type fin section 2.

[0049] The *j*-factor parameter ratio, , $\frac{J_{1,Re=3000}}{J_{2,Re=3000}}$, is $\frac{j_1 A_{s,1} A_{f,2}}{j_2 A_{s,2} A_{f,1}}$, where

j_1 is the *j*-factor for the fins in the first-type fin section 1 evaluated at a Reynolds number of 3000,

j_2 is the *j*-factor for the fins in the second-type fin section 2 evaluated at a Reynolds number of 3000,

$A_{s,1}$ is the heat transfer area per unit width per unit length per passage for the first-type fin section 1,

$A_{s,2}$ is the heat transfer area per unit width per unit length per passage for the second-type fin section 2,

$A_{f,1}$ is the free flow area per unit width per passage for the first-type fin section 1, and

$A_{f,2}$ is the free flow area per unit width per passage for the second-type fin section 2.

[0050] Values for each of the parameters, f_1, f_2, j_1, j_2, $D_{h,1}$, $D_{h,2}$, $A_{f,1}$, $A_{f,2}$ $A_{s,1}$, and $A_{s,1}$ are available from vendors/manufacturers of commercially available fin types with these values preferred for designing the apparatus. In case values are not available from vendors/manufacturers, values may be determined from standard testing methods, such as described for example, in Kays, W.M., and London, A.L., Heat Transfer and Flow Friction Characteristics of Some Compact Heat Exchanger Surfaces - Part I: Test System and Procedure, Trans. ASME, Vol. 72, pp. 1075-1085, 1950, and London, A.L., and Ferguson, C.K., Test Results of High Performance Heat Exchanger Surfaces Used in Aircraft Intercoolers and Their Significance for Gas Turbine Regenerator Design, Trans. ASME, Vol. 71, P. 17, 1949.

[0051] In case of any difference between values obtained from Kays and London, 1950 and those obtained from London and Ferguson, 1949, the values from Kays and London, 1950 take precedence for the implementation of the present apparatus.

[0052] The friction factor, *f,* and *j*-factor are dimensionless numbers having values that are a function of Reynolds number. The Reynolds number, *Re,* is also a dimensionless number and is defined, $\frac{\rho v D_h}{\mu}$, where ρ is the density of the fluid, v is the velocity of the fluid in the fin channels, D_h is the hydraulic diameter of the fin section channels, and μ is the viscosity of the fluid.

[0053] The distributor section is generally operated with a Reynolds number ranging from 2000 to 30,000. Evaluating the friction factor and *j*-factor at a Reynolds number of 3000 has been found to be useful for characterizing the range of the friction factor parameter ratio and the *j*-factor parameter ratio that provides benefits according the present disclosure.

[0054] Consistent units are used for each of the parameters so that the friction factor parameter ratio and the j-factor parameter ratio are dimensionless. If $D_{h,1}$ has units of m, then $D_{h,2}$, has units of m. If $A_{f,1}$ has units of m^2/m, then $A_{f,2}$ has units of m^2/m. If $A_{s,1}$ has units of m^2/m/m, then $A_{s,2}$ has units of m^2/m/m.

[0055] The desirability to use a first-type fin section and second-type fin section as described can be understood from the following analysis.

[0056] The flow distribution among the fin channels is determined by the flow resistance, or the pressure drop in each fin channel. The pressure drop per unit length is given by

$$\frac{dP}{dL} = \frac{f}{\rho}\frac{2G^2}{D_h} = \frac{f}{\rho}\frac{2M^2}{A_f'^2 D_h}$$

where G is mass flux, M is mass flow rate through one passage, A'_f is the free flow area per passage, and the other parameters are as described above. When the density variation is neglected, the ratio of pressure drop per unit length in the first-type fin section and second-type fin section can be written as

$$\frac{\left(\frac{dP}{dL}\right)_1}{\left(\frac{dP}{dL}\right)_2} = \frac{f_1}{f_2}\frac{A_{f,2}'^2 D_{h,2}}{A_{f,1}'^2 D_{h,1}} = \frac{f_1}{f_2}\frac{A_{f,2}^2 L_w^2 D_{h,2}}{A_{f,1}^2 L_H^2 D_{h,1}} = F\frac{L_w^2}{L_H^2}$$

where $F = \frac{f_1}{f_2}\frac{A_{f,2}^2 D_{h,2}}{A_{f,1}^2 D_{h,1}}$, which is only a function of fin characteristics.

[0057] The first (warm) stream enters the heat exchanger from the header (30) and exits the heat exchanger from the header (60). Total flow path through the distributor (20) and distributor (50) is the same in different fin channels. However, the fluid density is much lower in the distributor (20) than the distributor (50). Therefore, the flow resistance in the fin channels which have long flow path in the distributor (20) is higher than the fin channels which have short flow path in the distributor (20). To reduce such flow resistance variation in the fin channels, the flow resistance in long flow path in the distributor (20) needs to be reduced.

[0058] The temperature of the fluid is higher in the first-type fin section than the second-type fin section. As a result, the density of the fluid is lower in the first-type fin section than the second-type fin section. The flow resistance is more pronounced in the first-type fin section than the second-type fin section. Therefore, low resistance fins should be used in the first-type fin section. F is adopted as a criterion for selecting fins in the first-type and second-type fin sections. When F is equal to 1, fin characteristics in the first-type fin section are the same as the fin characteristics in the second-type fin section. When F is less than 1, fin characteristics in the first-type fin section provide a lower flow resistance than the fin characteristics in the second-type fin section. In addition to the flow resistance variation due to differences in the flow path length and fin characteristics in the fin channels, heat transfer in the distributor section can also cause uneven fluid density in the different sections, which compounds the flow resistance variation in the fin channels.

[0059] The product, *UA,* of the overall heat transfer coefficient, *U,* and the heat transfer area, *A,* per unit width per unit length per passage is given by

$$\frac{1}{UA} = \frac{1}{hA_w} + \frac{1}{hA_c}$$

where h is the heat transfer coefficient, A_w is the heat transfer area per unit width per unit length per passage of first (warm) stream, A_c is the heat transfer area per unit width per unit length per passage of second (cold) stream.

[0060] The *hA* per unit width per unit length per passage for one stream is given by

$$hA_s = \frac{jC_pG}{Pr^{2/3}}A_s = \frac{jC_pM}{A_f'Pr^{2/3}}A_s$$

where $Pr = \frac{\mu C_p}{k}$, C_p is the heat capacity, k is the thermal conductivity, , and the other parameters are as described above.

[0061] When the difference in fluid physical properties is neglected, the ratio of *hA* per unit width per unit length per passage for one stream in the first-type fin section to the second-type fin section can be written as

$$\frac{(hA_s)_1}{(hA_s)_2} = \frac{j_1}{j_2}\frac{A_{s,1}}{A_{s,2}}\frac{A'_{f,2}}{A'_{f,1}} = \frac{j_1}{j_2}\frac{A_{s,1}}{A_{s,2}}\frac{A_{f,2}L_W}{A_{f,1}L_H} = J\frac{L_W}{L_H}$$

where $J = \frac{j_1}{j_2}\frac{A_{s,1}}{A_{s,2}}\frac{A_{f,2}}{A_{f,1}}$, which is only a function of fin characteristics.

[0062] The second (cold) stream enters the heat exchanger from the header (70) and exists the heat exchanger from the header (40). In the distributor (20) section, the second (cold) stream exchanges heat with the first (warm) stream. However, the first (warm) stream temperature in the first-type fin section is higher than the first (warm) stream temperature in the second-type fin section. Therefore, the driving force for exchanging heat between the first (warm) stream and the second (cold) stream in the first-type fin section is greater than the driving force for exchanging heat between the first (warm) stream and the second (cold) stream in the second fin-type section. Such uneven driving force results in uneven temperature and fluid density in fin channels of the second (cold) stream, and leads to flow maldistribution. To reduce such flow maldistribution due to uneven driving force, lower *hA* can be used in the first-type fin section. Therefore, *J* is adopted as another criterion for selecting fins in the first-type and second-type fin sections. When *J* is equal to 1, fin characteristics in the first-type fin section are the same as the fin characteristics in the second-type fin section. When J is less than 1, fins in the first-type fin section have a lower *hA* than in the second-type fin section.

[0063] As shown in FIGS. 7, 8, 9, and 10, the short flow path region 25 of each passage of the first group of passages 24 may contain at least a portion of a third-type fin section 3. Each third-type fin section 3 comprises a plurality of fins defining a plurality of channels in each respective third-type fin section 3. Each third-type fin section 3 of each passage of the first group of passages 24 abuts the face 31 of the first header 30 along a border 34 of each respective third-type fin section 3. Each third-type fin section 3 of each passage of the first group of passages 24 extends from the border 34 up to the junction 9 and abuts at the junction 9 at least a portion of a fin section extending from the junction 9 towards the face 11 of the main heat exchanger core section 10. Each third-type fin section 3 of each passage of the first group of passages 24 may abut at junction 9 at least a portion of at least one fin section of a type different from the third type such as, for example, a portion of the second-type fin section 2 in FIGS. 7 and 8 and a portion of a fourth-type fin section 4 in FIGS. 9 and 10.

[0064] For the case where the short flow path region 25 of each passage of the first group of passages 24 contains a portion or all of a third-type fin section 3, the respective third-type fin section 3 may extend through at least 20%, or at least 40% of the volume of the short flow path region 25 of the respective passage 24. FIGS. 7, 9 and 10 show the third-type fin section 3 extending through about 23% of the volume of the short flow path region 25. FIG. 8 shows the third-type fin section 3 extending through 50% of the volume of the short flow path region 25.

[0065] When a third-type fin section 3 is included in each passage of the first group of passages 24, preferred characteristics of each third-type fin section 3 relative to the characteristics of each first-type fin section 1 in each passage may be expressed in terms of a friction factor parameter ratio, $\frac{F_{1,Re=3000}}{F_{3,Re=3000}}$, where $0 < \frac{F_{1,Re=3000}}{F_{3,Re=3000}} \leq 1$, or $0 < \frac{F_{1,Re=3000}}{F_{3,Re=3000}} \leq 0.95$, or $0 < \frac{F_{1,Re=3000}}{F_{3,Re=3000}} \leq 0.5$. The friction factor parameter ratio, $\frac{F_{1,Re=3000}}{F_{3,Re=3000}}$ is $\frac{f_1 A_{f,3}^2 D_{h,3}}{f_3 A_{f,1}^2 D_{h,1}}$, where

f_1 is the friction factor for the fins in the first-type fin section 1 evaluated at a Reynolds number of 3000,

f_3 is the friction factor for the fins in the third-type fin section 3 evaluated at a Reynolds number of 3000,

$D_{h,1}$ is the hydraulic diameter for the first-type fin section 1,

$D_{h,3}$ is the hydraulic diameter for the third-type fin section 3,

$A_{f,1}$ is the free flow area per unit width per passage for the first-type fin section 1, and

$A_{f,3}$ is the free flow area per unit width per passage for the third-type fin section 3, where consistent units are used for each of $D_{h,1}$, $D_{h,3}$, $A_{f,1}$, and $A_{f,3}$,

[0066] Consistent units are used for each of the parameters so that the friction factor parameter ratio is dimensionless. If $D_{h,1}$ has units of m, then $D_{h,3}$, has units of m. If $A_{f,1}$ has units of m^2/m, then $A_{f,3}$ has units of m^2/m.

[0067] The desirability to use a third-type fin section as described can be understood from the following discussion.

[0068] The flow path in the first-type fin section is longer than the flow path in the third-type fin section. The flow resistance in the first-type fin section is more significant than the flow resistance in the third-type fin section. Therefore, lower resistance fins should be used in the first-type fin section than in the third-type fin section. The friction factor parameter ratio, , $\frac{F_{1,Re=3000}}{F_{3,Re=3000}}$, may be used as a criterion for selecting fins in the first-type fin section and the third-type fin section. When the friction factor parameter ratio, , $\frac{F_{1,Re=3000}}{F_{3,Re=3000}}$, is equal to 1, the fin characteristics in the first-type fin section are the same as the fin characteristics in the third-type fin section. When the friction factor parameter ratio, $\frac{F_{1,Re=3000}}{F_{3,Re=3000}}$, is less than 1, fin characteristics in the first-type fin section provide a lower flow resistance than the fin characteristics in the third-type fin section.

[0069] As shown in FIGS. 9 and 10, the short flow path region 25 of each passage of the first group of passages 24 may contain at least a portion of a fourth-type fin section 4. Each fourth-type fin section 4 comprises a plurality of fins defining a plurality of channels in each respective fourth-type fin section 4. Each fourth-type fin section 4 of each passage of the first group of passages 24 abuts the face 11 of the main heat exchanger core section 10 along a border 14 of each respective fourth-type fin section 4. Each fourth-type fin section 4 of each passage of the first group of passages 24 extends from the border 14 up to the junction 9 and abuts at the junction 9 at least a portion of a fin section extending from the junction 9 towards the face 31 of the distributor section 20. Each fourth-type fin section 4 of each passage of the first group of passages 24 may abut at junction 9 at least a portion of at least one fin section of a type different from the fourth type such as, for example, a portion of the first-type fin section 1 and all of the third-type fin section 3 in FIGS. 9 and 10.

[0070] For the case where the short flow path region 25 of each passage of the first group of passages 24 contains a portion or all of a fourth-type fin section 4, the respective fourth-type fin section 4 may extend through at least 20%, or at least 40% of the volume of the short flow path region 25 of the respective passage 24. FIG. 9 shows the fourth-type fin section 4 extending through about 26% of the volume of the short flow path region 25. FIG. 10 shows the fourth-type fin section 4 extending through 50% of the volume of the short flow path region 25.

[0071] Since , "first," "second," "third," "fourth," etc. are used to distinguish from among a plurality features, and not indicative of the total number of features, a fourth-type fin section may be present with or without the above-described third-type fin section.

[0072] The fourth-type fin section 4 of each passage of the first group of passages 24 and the respective fin section of the respective heat transfer passage of the first group of heat transfer passages 54 that are in fluid communication with the respective passage of the first group of passages 24 are separate pieces of fin section. Therefore, there is a break in continuity between the fourth-type fin section 4 of each passage of the first group of passages 24 and the respective fin section of the respective heat transfer passage of the first group of heat transfer passages 54 that are in fluid communication with the respective passage of the first group of passages 24. There may be a 0.5 mm to 5 mm gap between the fourth-type fin section 4 and the respective fin section of the main heat exchanger core section 10. The benefit of the having separate pieces of fin section is for ease of manufacturing. The benefit of the gap is to limit the flow restriction at the junction resulting from fin cross-sections overlapping the open area of the channels.

[0073] One or more fin section characteristics of the fourth-type fin section 4 of each passage of the first group of passages 24 may be different than a corresponding fin section characteristic of the bordering fin section of heat transfer passage of the main heat exchanger core. The one or more fin section characteristics may be selected from the group consisting of fin style, free flow area, fin density, fin thickness, and hydraulic diameter. The overall efficiency of the plate-fin heat exchanger can be improved by using fin characteristics for the distributor section that are different than the fin characteristics of the main heat exchanger core.

[0074] When a fourth-type fin section 4 is included in each passage of the first group of passages 24, preferred characteristics of each fourth-type fin section 4 relative to the characteristics of each second-type fin section 2 in each passage may be expressed in terms of a j-factor parameter ratio, $\frac{J_{4,Re=3000}}{J_{2,Re=3000}}$, where $0 < \frac{J_{4,Re=3000}}{J_{2,Re=3000}} \leq 1$, or

$0 < \frac{J_{4,Re=3000}}{J_{2,Re=3000}} \leq$ 0.95, or $0 < \frac{J_{4,Re=3000}}{J_{2,Re=3000}} \leq 0.5.$ The j-factor parameter ratio, $\frac{J_{4,Re=3000}}{J_{2,Re=3000}}$, is $\frac{j_4 A_{s,1} A_{f,3}}{j_2 A_{s,3} A_{f,1}}$, where

j_2 is the *j*-factor for the fins in the second-type fin section 2 evaluated at a Reynolds number of 3000,

j_4 is the j-factor for the fins in the fourth-type fin section 4 evaluated at a Reynolds number of 3000,

$A_{f,2}$ is the free flow area per unit width per passage for the second-type fin section 2, and

$A_{f,4}$ is the free flow area per unit width per passage for the fourth-type fin section 4,

$A_{s,2}$ is the heat transfer area per unit width per unit length per passage for the second-type fin section 2, and

$A_{s,4}$ is the heat transfer area per unit width per unit length per passage for the fourth-type fin section 4,

where consistent units are used for each of $A_{f,2}$, $A_{f,4}$, $A_{s,2}$, and $A_{s,4}$.

[0075] Consistent units are used for each of the parameters so that the j-factor parameter ratio is dimensionless. If $A_{f,2}$ has units of m^2/m, then $A_{f,4}$ has units of m^2/m. If $A_{s,2}$ has units of $m^2/m/m$, then $A_{s,4}$ has units of $m^2/m/m$.

[0076] The desirability to use a fourth-type fin section as described can be understood from the following discussion.

[0077] The second (cold) stream enters the heat exchanger from header 70 and exits the heat exchanger from header 40. In the distributor 20 section, the second (cold) stream exchanges heat with the first (warm) stream. However, the first (warm) stream temperature in the fourth-type fin section is higher than the first (warm) stream temperature in the second-type fin section. Therefore, the driving force for exchanging heat between the first (warm) stream and the second (cold) stream in the fourth-type fin section is higher than the driving force for exchanging heat between the first (warm) stream and the second (cold) stream in the second-type fin section. Such uneven driving force results in uneven temperature and fluid density in the fin channels of the second (cold) stream, and leads to flow maldistribution. To reduce such flow maldistribution due to uneven driving force, lower *hA* can be used in the fourth-type fin section. The j-factor parameter ratio, $\frac{J_{4,Re=3000}}{J_{2,Re=3000}}$, may be used as a criterion for selecting fins in the second-type fin section and the fourth-type fin section. When the j-factor parameter ratio, $\frac{J_{4,Re=3000}}{J_{2,Re=3000}}$, is equal to 1, fin characteristics in the second-type fin section are the same as the fin characteristics in the fourth-type fin section. When the j-factor parameter ratio, $\frac{J_{4,Re=3000}}{J_{2,Re=3000}}$, is less than 1, fins in the fourth-type fin section have a lower *hA* than the fins in the second-type fin section.

[0078] The plate-fin heat exchanger also comprises a second header 40 abutting and in fluid communication with the second group of passages 26 of the distributor section 20.

[0079] In the design shown in FIG. 11, the second group of passages 26 of the distributor section 20 abut along face 41 of the second header 40. Each passage of the second group of passages 26 abuts the main heat exchanger core section 10 along face 11 of the main heat exchanger core section 10. Each passage of the second group of passages 26 is closed on one side by a respective closing bar segment 38 on the side adjacent the first header 30 and a respective closing bar segment 36 on the side opposite the first header 30.

[0080] The specific design of the fin sections in the passages of the second group of passages 26 of the distributor section 20 has been determined to be less important than the design of the fin sections in the passages for the first group of passages 24.

[0081] As shown in FIG. 11, the longitudinal direction of the fin sections in the second group of passages 26 may be oriented substantially parallel to respective closing bar segments 36 and having the same longitudinal direction as the fin sections in the corresponding heat transfer passages 56 (FIG. 5) in the main heat exchanger core section 10.

[0082] The fins in the second group of passages 26 of the distributor section 20 may be the same type of fins, having the same fin characteristics as the fins in the corresponding heat transfer passages of the main heat exchanger core 10. Alternatively, the fins in the second group of passages 26 of the distributor section 20 may have different fin characteristics than the fins in the heat transfer passages of the main heat exchanger core 10.

[0083] In an alternative design for the second group of passages 26 of the distributor section 20, a side header 40b may be used as shown in FIG. 12, requiring a mitered design.

[0084] In a plate-fin heat exchanger design with the side header 40b, the fin sections 42 and 43 in the passages of the second group of passages 26 can have the same type of fins, having the same characteristics such that the friction factor parameter ratio is equal to 1 and the j-factor parameter ratio is equal to 1. In case the fin sections 42 and 43 in the second group of passages 26 have different fin characteristics, it may be desirable to implement similar criteria for respective friction factor parameter ratio and j-factor parameter ratio as used for the first-type fin section and second-type fin section of the first group of passages 24. The description provided for the first-type fin section and the second-type fin section applies mutatis mutandis to fin section 43 and fin section 42, respectively.

[0085] The plate-fin heat exchanger comprises a distributor section 50 abutting the main heat exchanger core section 10 along a face 51 of the main heat exchanger core section 10. With reference to FIGS. 13-15, showing several views of the distributor section 50, the distributor section 50 comprises a plurality of parting sheet segments 72. The plurality of parting sheet segments 72 are disposed in fixed, substantially parallel, spaced relation with each other. The plurality of parting sheet segments 72 define a first group of passages 74 of the distributor section 50 and a second group of passages 76 of the distributor section 50. Each passage 74 in the first group of passages 74 may be adjacent to at least one passage of the second group of passages 76. Each passage 76 in the second group of passages 76 may be adjacent to at least one passage of the first group of passages 74.

[0086] Each passage of the first group of passages 74 of the distributor section 50 is in fluid communication with a respective heat transfer passage of the first group of heat transfer passages of the main heat exchanger core 10. Each passage of the second group of passages 76 of the distributor section 50 is in fluid communication with a respective heat transfer passage of the second group of heat transfer passages of the main heat exchanger core 10.

[0087] Referring to FIGS. 13-15, the plate-fin heat exchanger comprises a header 60 abutting and in fluid communication with the first group of passages 74 of the distributor section 50 along a face 81 of the header 60. Each passage of the first group of passages 74 is closed on a side opposite the header 60 by a respective closing bar segment 82.

[0088] The first group of passages 74 of distributor section 50 abuts the main heat exchanger core section 10 along a face 51 of the main heat exchanger core section 10. Each passage of the first group of passages 74 is closed on a side opposite the main heat exchanger core section 10 by a respective closing bar 62.

[0089] The second group of passages 76 of distributor section 50 abut along face 61 of header 70. Each passage of the second group of passages 76 of distributor section 50 abuts the main heat exchanger core section 10 along face 51 of the main heat exchanger core section 10. Each passage of the second group of passages 76 is closed on one side by a respective closing bar segment on the side adjacent the header 60 and a respective closing bar segment 86 on the side opposite the header 60.

[0090] The distributor section 50 may be constructed with fin sections according to known conventional design methods or according to the design method described herein for the distributor section 20.

Examples

[0091] A two-dimensional numerical model was developed to calculate coupled heat transfer and fluid flow distribution in a two-passage heat exchanger with distributors. The outlet temperature of the two streams are solved with a prescribed inlet temperature for each of the two streams. The heat exchanger and distributors are discretized into a mesh comprising a number of cells as shown schematically in FIGS. 16 and 17. The number of cells is chosen such that a further increase in the number of cells results in no significant change in the resulting solution. FIG. 16 shows the prescribed fluid flow path for the first (warm) stream. FIG. 17 shows the prescribed fluid flow path for the second (cold) stream. A cell within the mesh may normally contain more than one fin channel.

[0092] A heat balance is calculated for each cell from:

$$UA\left[\frac{(T_{warm\ in}+T_{warm\ out})}{2}-\frac{(T_{cold\ in}+T_{cold\ out})}{2}\right]=C_{p,cold}M_{cold}(T_{cold\ out}-T_{cold\ in}),$$

and

$$UA\left[\frac{(T_{warm\ in}+T_{warm\ out})}{2}-\frac{(T_{cold\ in}+T_{cold\ out})}{2}\right]=C_{p,warm}M_{warm}(T_{warm\ in}-T_{warm\ out}).$$

[0093] The pressure drop is calculated for each cell. The pressure drop includes the pressure drop at the fin junctions and the pressure drop in the fin channels. The pressure drop at the fin junction of flow path *i* is given by:

$$\Delta P_i = \frac{\rho_q v_{iq}^2}{2} = \frac{M_i^2}{2A_q^2 \rho_q}$$

where v_i is the upstream velocity of the fin junction q in path i, ρ_q is the corresponding density of the fluid in the cell upstream of the fin junction, q, A_q is the corresponding free flow area in the cell upstream of the fin junction, q.

[0094] The pressure drop through a fin section along flow path i in cell j is given by:

$$\Delta P_{i,j} = \frac{2f_{i,j}L_{i,j}\rho_{i,j}v_{i,j}^2}{D_{h,i,j}} = \frac{2f_{i,j}L_{i,j}M_i^2}{D_{h,i,j}A_{i,j}^2\rho_{i,j}}$$

where $L_{i,j}$ is the flow path length along flow path i in cell j.

[0095] The total pressure drop along flow path i is given by:

$$\Delta P_i = \sum_{q=1}^{q=N1} \frac{M_i^2}{2A_q^2\rho_q} + \sum_{j=1}^{j=N2} \frac{2f_{i,j}L_{i,j}M_i^2}{D_{h,i,j}A_{i,j}^2\rho_{i,j}}$$

where N1 is the total number of fin junctions, and N2 is the total number of cells in a flow path.

[0096] At steady state, the pressure drop along each flow path is the same. In other words, ΔP_i is a constant. Then the mass flow M_i in flow path i is proportional to

$$\frac{1}{\sqrt{\sum_{q=1}^{q=N1}\frac{1}{2A_q^2\rho q}+\sum_{j=1}^{j=N2}\frac{2f_{i,j}L_{i,j}}{D_{h,i,j}A_{i,j}^2\rho_{i,j}}}}.$$

Therefore,

$$M_i = \frac{\dfrac{1}{\sqrt{\sum_{q=1}^{q=N1}\frac{1}{2A_q^2\rho_q}+\sum_{j=1}^{j=N2}\frac{2f_{i,j}L_{i,j}}{D_{h,i,j}A_{i,j}^2\rho_{i,j}}}}}{\sum_{i=1}^{i=N3}\dfrac{1}{\sqrt{\sum_{q=1}^{q=N1}\frac{1}{2A_q^2\rho_q}+\sum_{j=1}^{j=N2}\frac{2f_{i,j}L_{i,j}}{D_{h,i,j}A_{i,j}^2\rho_{i,j}}}}} \times M$$

where N3 is the number of flow paths used in the model.

[0097] The total mass flow rate of each stream, and the temperature and pressure at the inlet to the distributor are specified and input values in the model. The physical properties of the fluid in each cell are a function of the calculated temperature and pressure in each cell. A solution is calculated iteratively, solving for the temperature of the first (warm) stream and the second (cold) stream at the outlet of the opposite distributor for each respective stream. The mass flow rate of each flow path, the temperature, and the pressure of each cell are updated for each iteration based on the equations described above.

[0098] Three cases are summarized in Table 1 and demonstrate the effect of the present plate-fin heat exchanger design. T_{b1} is the bulk outlet temperature of the first stream and T_{b2} is the bulk outlet temperature of the second stream. L_{HX} is the length of the heat exchanger required to provide the bulk outlet temperature of the first stream and the bulk outlet temperature of the second stream.

[0099] The total mass flow rate of the first (warm) stream and the total mass flow rate of the second (cold) stream are both set at 0.3 kg/s. The temperature of the first (warm) stream entering header 30 is set at 24.14°C. The temperature of the second (cold) stream entering header 70 is -179.11 °C. The pressure of the first (warm) stream entering header 30 is 5.3 bar and the pressure of the second (cold) stream entering header 70 is 5.01 bar. Physical properties for air are used for the first (warm) stream and physical properties for nitrogen are used for the second (cold) stream for these model results.

[0100] In case 1, the fin characteristics in the first-type fin section are the same as the fin characteristics in the second-type fin section, representative of prior art designs. In this case, the friction factor parameter ratio, $\frac{F_{1,Re=3000}}{F_{2,Re=3000}}=1$, and the j-factor parameter ratio, $\frac{J_{1,Re=3000}}{J_{2,Re=3000}}=1$. The heat exchanger length is set at 3.3 m. The resulting bulk temperature for the first (warm) stream discharged to header 60 is -174.59°C. The resulting bulk temperature for the second (cold) stream discharged to the header 40 is 20.62°C. The bulk temperature is calculated in the normal way using the mass flow rate to provide the mass averaged bulk value.

[0101] In case 2, the fin characteristics in the first-type fin section are the same as for case 1 and the fin characteristics in the second-type fin section are changed to provide a friction factor parameter ratio, $\frac{F_{1,Re=3000}}{F_{2,Re=3000}}=0.3$, and a j-factor parameter ratio, $\frac{J_{1,Re=3000}}{J_{2,Re=3000}}=0.5$. All of the other conditions are maintained the same as for case 1. The heat exchanger length is adjusted until the same bulk temperature is obtained for the first (warm) stream discharged to header 60 and the same bulk temperature is obtained for the second (cold) stream discharge to header 40. The results from the model show that the heat exchanger length required to obtain the same bulk outlet temperatures for the first and second streams is 3.25 m, which is less than the heat exchanger length in case 1. This means that the heat exchanger design in case 2 provides improved heat transfer efficiency than the heat exchanger design in case 1.

[0102] In case 3, the fin characteristics in the first-type fin section are the same as for case 1 and the fin characteristics in the second-type fin section are changed to provide a friction factor parameter ratio, $\frac{F_{1,Re=3000}}{F_{2,Re=3000}}=0.03$, and a j-factor parameter ratio, $\frac{J_{1,Re=3000}}{J_{2,Re=3000}}=0.08$. All of the other conditions are maintained the same as for case 1. The heat exchanger length is adjusted until the same bulk temperature is obtained for the first (warm) stream discharged to header 60 and the same bulk temperature is obtained for the second (cold) stream discharge to header 40. The results from the model show that the heat exchanger length required to obtain the same bulk outlet temperatures for the first and second streams is 3.15 m, which is less than the heat exchanger length in case 1. This means that the heat exchanger design in case 3 provides improved heat transfer efficiency than the heat exchanger design in case 1.

[0103] In case 4, the fin characteristics of the first-type fin section and the second-type fin section are the same as in case 3. A third-type fin section is added like shown in FIG. 7. The fin characteristics of the third-type fin section are selected to provide a friction factor parameter ratio, $\frac{F_{1,Re=3000}}{F_{3,Re=3000}}=0.23$. All of the other conditions are maintained the same as in case 3. The third-type fin section extends for a length of 20% of L_H from the face 11 of the heat exchanger core section 10 towards the closing bar 12. The heat exchanger length, L_{HX}, is adjusted until the same bulk temperature is obtained for the first (warm) stream discharged to header 60 and the same bulk temperature is obtained for the second (cold) stream discharged to header 40. The results from the model show that the heat exchanger length required to obtain the same bulk outlet temperatures for the first and second streams is 3.13 m, which is less than the heat exchanger length in each of cases 1, 2, and 3. This means that the heat exchanger design in case 4 provides improved heat transfer efficiency than the heat exchanger designs in each of cases 1, 2, and 3.

Table 1.

Case	$\frac{F_{1,Re=3000}}{F_{2,Re=3000}}$	$\frac{J_{1,Re=3000}}{J_{2,Re=3000}}$	$\frac{F_{1,Re=3000}}{F_{3,Re=3000}}$	T_{b1} (°C)	T_{b2} (°C)	L_{HX} (m)
1	1	1	-	-174.59	20.62	3.3

(continued)

Case	$\frac{F_{1,Re=3000}}{F_{2,Re=3000}}$	$\frac{J_{1,Re=3000}}{J_{2,Re=3000}}$	$\frac{F_{1,Re=3000}}{F_{3,Re=3000}}$	T_{b1} (°C)	T_{b2} (°C)	L_{HX} (m)
2	0.3	0.5	-	-174.59	20.62	3.25
3	0.03	0.08	-	-174.58	20.62	3.15
4	0.03	0.08	0.28	-174.58	20.62	3.13

Claims

1. A plate-fin heat exchanger comprising:

a main heat exchanger core section (10) comprising a first group of heat transfer passages (54) and a second group of heat transfer passages (56), each heat transfer passage of the first group of heat transfer passages (54) containing a respective fin section, and each heat transfer passage of the second group of heat transfer passages (56) containing a respective fin section;
a distributor section (20) abutting the main heat exchanger core section (10) along a face (11) of the main heat exchanger core section (10), the distributor section (20) comprising

a plurality of parting sheet segments (22), the plurality of parting sheet segments (22) disposed in fixed, spaced relation, wherein the plurality of parting sheet segments (22) defines a first group of passages (24) and a second group of passages (26);

a first header (30) abutting and in fluid communication with the first group of passages (24) along a face (31) of the first header (30), wherein each passage of the first group of passages (24) is closed on a side opposite the first header (30) by a respective closing bar segment (32);
a second header (40) abutting and in fluid communication with the second group of passages (26) of the distributor section (20);
wherein the first group of passages (24) abuts the main heat exchanger core section (10) along the face (11) of the main heat exchanger core section (10), wherein each passage of the first group of passages (24) is in fluid communication with a respective heat transfer passage of the first group of heat transfer passages (54) of the main heat exchanger core section (10), and wherein each passage of the first group of passages (24) is closed on a side opposite the main heat exchanger core section (10) by a respective closing bar (12);
wherein each passage of the first group of passages (24) has a long flow path region (15) between the parting sheet segments of each passage of the first group of passages (24) defined by the union of a first cuboid and a second cuboid, the first cuboid extending normal to the respective closing bar (12) from the fin-side facing surface of the respective closing bar (12) to a position 50% of the distance along the face (31) of the first header (30) from the respective closing bar (12) towards the face (11) of the main heat exchanger core section (10), and the second cuboid extending normal to the respective closing bar segment (32) to a position 50% of the distance along the face (11) of the main heat exchanger core section (10) from the respective closing bar segment (32) towards the face (31) of the first header (30);
wherein each passage of the first group of passages (24) has a short flow path region (25) between the parting sheet segments of each passage of the first group of passages (24) bounded by the long flow path region (15), a portion of the face (31) of the first header (30), and a portion of the face (11) of the main heat exchanger core section (10);
wherein the long flow path region of each passage of the first group of passages (24) contains at least a portion of two or more fin sections extending throughout the long flow path region including a first-type fin section (1) and a second-type fin section (2), at least a portion of the first-type fin section (1) and at least a portion of the second-type fin section (2) abutting at a junction (9), the first-type fin section (1) comprising a plurality of fins defining a plurality of channels in the first-type fin section (1), and the second-type fin section (2) comprising a plurality of fins defining a plurality of channels in the second-type fin section (2);
wherein the first-type fin section (1) of each passage of the first group of passages (24) abuts the face (31) of the first header (30) along a border (33) of each respective first-type fin section (1);
wherein the second-type fin section (2) of each passage of the first group of passages (24) abuts the face (11) of the main heat exchanger core section (10) along a border (13) of each respective second-type fin section

(2), wherein there is a break in continuity between the second-type fin section (2) of each passage of the first group of passages (24) and the respective fin section of the respective heat transfer passage of the first group of heat transfer passages (54) in fluid communication with the respective passage of the first group of passages (24);

wherein the first-type fin section (1) and the second-type fin section (2) of each passage of the first group of passages (24) have a respective friction factor parameter ratio, $\frac{F_{1,Re=3000}}{F_{2,Re=3000}}$, where $0<\frac{F_{1,Re=3000}}{F_{2,Re=3000}}\leq 0.8$, where

$$\frac{F_{1,Re=3000}}{F_{2,Re=3000}}=\frac{f_1 A_{f,2}^2 D_{h,2}}{f_2 A_{f,1}^2 D_{h,1}},$$

wherein the first-type fin section (1) and the second-type fin section (2) of each passage of the first group of passages (24) have a respective j-factor parameter ratio, $\frac{J_{1,Re=3000}}{J_{2,Re=3000}}$, where $0<\frac{J_{1,Re=3000}}{J_{2,Re=3000}}\leq 0.8$, where

$$\frac{J_{1,Re=3000}}{J_{2,Re=3000}}=\frac{j_1 A_{s,1} A_{f,2}}{j_2 A_{s,2} A_{f,1}},$$

where

f_1 is the respective friction factor for the fins in the first-type fin section (1) of each passage of the first group of passages (24) evaluated at a Reynolds number of 3000,
f_2 is the respective friction factor for the fins in the second-type fin section (2) of each passage of the first group of passages (24) evaluated at a Reynolds number of 3000,
j_1 is the respective j-factor for the fins in the first-type fin section (1) of each passage of the first group of passages (24) evaluated at a Reynolds number of 3000,
j_2 is the respective j-factor for the fins in the second-type fin section (2) of each passage of the first group of passages (24) evaluated at a Reynolds number of 3000,
$D_{h,1}$ is the respective hydraulic diameter for the first-type fin section (1) of each passage of the first group of passages (24),
$D_{h,2}$ is the respective hydraulic diameter for the second-type fin section (2) of each passage of the first group of passages (24),
$A_{f,1}$ is the respective free flow area per unit width per passage for the first-type fin section (1) of each passage of the first group of passages (24),
$A_{f,2}$ is the respective free flow area per unit width per passage for the second-type fin section (2) of each passage of the first group of passages (24),
$A_{s,1}$ is the respective heat transfer area per unit width per unit length per passage for the first-type fin section (1) of each passage of the first group of passages (24),
$A_{s,2}$ is the respective heat transfer area per unit width per unit length per passage for the second-type fin section (2) of each passage of the first group of passages (24),

where consistent units are used for each of $D_{h,1}$, $D_{h,2}$, $A_{f,1}$, $A_{f,2}$, $A_{s,1}$, and $A_{s,2}$.

2. The plate-fin heat exchanger according to claim 1 wherein one or more fin section characteristics of the second-type fin section (2) of each passage of the first group of passages (24) is different than a corresponding fin section characteristic of the respective fin section of each heat transfer passage of the first group of heat transfer passages (54) for each passage of the first group of passages (24) in fluid communication with the respective heat transfer passage of the first group of heat transfer passages (54) of the main heat exchanger core section (10).

3. The plate-fin heat exchanger according to claim 2 wherein the one or more fin section characteristics are selected from the group consisting of fin style, free flow area, fin density, fin thickness, and hydraulic diameter.

4. The plate-fin heat exchanger according to any one of claims 1 to 3 wherein the plate-fin heat exchanger is configured to pass a first stream through the first group of heat transfer passages (54) in countercurrent flow relationship to a second stream passed through the second group of heat transfer passages (56).

5. The plate-fin heat exchanger according to any one of claims 1 to 4 wherein a second border (7) of each respective first-type fin section (1) is parallel with the respective closing bar (12) of each respective passage of the first group of passages (24).

6. The plate-fin heat exchanger according to any one of claims 1 to 5 wherein the first-type fin section (1) of each passage of the first group of passages (24) has a longitudinal direction, wherein the longitudinal direction of each respective first-type fin section (1) is aligned parallel with the respective closing bar (12) of each respective passage of the first group of passages (24).

7. The plate-fin heat exchanger according to any one of claims 1 to 6 wherein a second border (8) of each respective second-type fin section (2) of each passage of the first group of passages (24) is aligned parallel with the respective closing bar (32) of each respective passage of the first group of passages (24).

8. The plate-fin heat exchanger according to any one of claims 1 to 7 wherein the second-type fin section (2) of each passage of the first group of passages (24) has a longitudinal direction, wherein the longitudinal direction of each respective second-type fin section (2) is aligned parallel with the respective closing bar segment (32) of each respective passage of the first group of passages (24).

9. The plate-fin heat exchanger according to any one of claims 1 to 8 wherein the short flow path region (25) of each respective passage of the first group of passages (24) contains a portion of the respective first-type fin section (1).

10. The plate-fin heat exchanger according to any one of claims 1 to 9 wherein the short flow path region (25) of each respective passage of the first group of passages (24) contains a portion of the respective second-type fin section (2).

11. The plate-fin heat exchanger according to any one of claims 1 to 10 wherein the short flow path region (25) of each passage of the first group of passages (24) contains two or more respective fin sections including a respective third-type fin section (3) comprising a plurality of fins defining a plurality of channels in the respective third-type fin section (3), wherein the respective third-type fin section (3) of each passage of the first group of passages (24) abuts the face (31) of the first header (30) along a border (34) of each respective third-type fin section (3);
wherein the first-type fin section (1) and the third-type fin section (3) of each passage of the first group of passages (24) have a respective friction factor parameter ratio, $\frac{F_{1,Re=3000}}{F_{3,Re=3000}}$, where $0 < \frac{F_{1,Re=3000}}{F_{3,Re=3000}} \leq 1$, where

$$\frac{F_{1,Re=3000}}{F_{3,Re=3000}} = \frac{f_1 A_{f,3}^2 D_{h,3}}{f_3 A_{f,1}^2 D_{h,1}},$$

where

f_3 is the respective friction factor for the fins in the third-type fin section (3) of each passage of the first group of passages (24) evaluated at a Reynolds number of 3000,
$D_{h,3}$ is the respective hydraulic diameter for the third-type fin section (3) of each passage of the first group of passages (24),
$A_{f,3}$ is the respective free flow area per unit width per passage for the third-type fin section (3) of each passage of the first group of passages (24),

where consistent units are used for each of $D_{h,1}$, $D_{h,3}$, $A_{f,1}$, and $A_{f,3}$.

12. The plate-fin heat exchanger according to claim 11 wherein each third-type fin section of each passage of the first group of passages extends through at least 20% of the volume of the short flow path region of the respective passage.

13. The plate-fin heat exchanger according to any one of claims 1 to 12 wherein the short flow path region (25) of each respective passage of the first group of passages (24) contains two or more fin sections including a respective fourth-type fin section (4) comprising a plurality of fins defining a plurality of channels in each respective fourth-type fin section (4), wherein the respective fourth-type fin section (4) of each passage of the first group of passages (24) abuts the face (11) of the main heat exchanger section (10) along a border (14) of each respective fourth-type fin section (4), wherein there is a break in continuity between the fourth-type fin section (4) of each passage of the first group of passages (24) and the respective fin section of the respective heat transfer passage of the first group of heat transfer passages (54) in fluid communication with the respective passage of the first group of passages (24); wherein the fourth-type fin section (4) and the second-type fin section (2) of each passage of the first group of passages (24) have a respective j-factor parameter ratio, $\frac{J_{4,Re=3000}}{J_{2,Re=3000}}$, $0<\frac{J_{4,Re=3000}}{J_{2,Re=3000}}\leq 1$, where

$$\frac{J_{4,Re=3000}}{J_{2,Re=3000}}=\frac{j_4 A_{s,4} A_{f,2}}{j_2 A_{s,2} A_{f,4}},$$

where

j_4 is the respective j-factor for the fins in the fourth-type fin section (4) of each passage of the first group of passages (24) evaluated at a Reynolds number of 3000,
$A_{f,4}$ is the respective free flow area per unit width per passage for the fourth-type fin section (4) of each passage of the first group of passages (24),
$A_{s,4}$ is the respective heat transfer area per unit width per unit length per passage for the fourth-type fin section (4) of each passage of the first group of passages (24),

where consistent units are used for each of $A_{f,2}$, $A_{f,4}$, $A_{s,2}$, and $A_{s,4}$.

14. A process for exchanging heat between a first stream and a second stream, the process comprising:

providing the plate-fin heat exchanger according to any one of claims 1 to 12;
passing the first stream through the first group of heat transfer passages (54) of the plate-fin heat exchanger in countercurrent flow relationship to the second stream being passed through the second group of heat transfer passages (56) of the plate-fin heat exchanger.

15. The process according to claim 14 wherein the first stream is a first fluid having an oxygen concentration ranging from 20 vol.% oxygen to 22 vol. % oxygen and a nitrogen concentration ranging from 78 vol. % nitrogen to 80 vol. % nitrogen, and wherein the second stream is a nitrogen-rich waste gas stream from a distillation column.

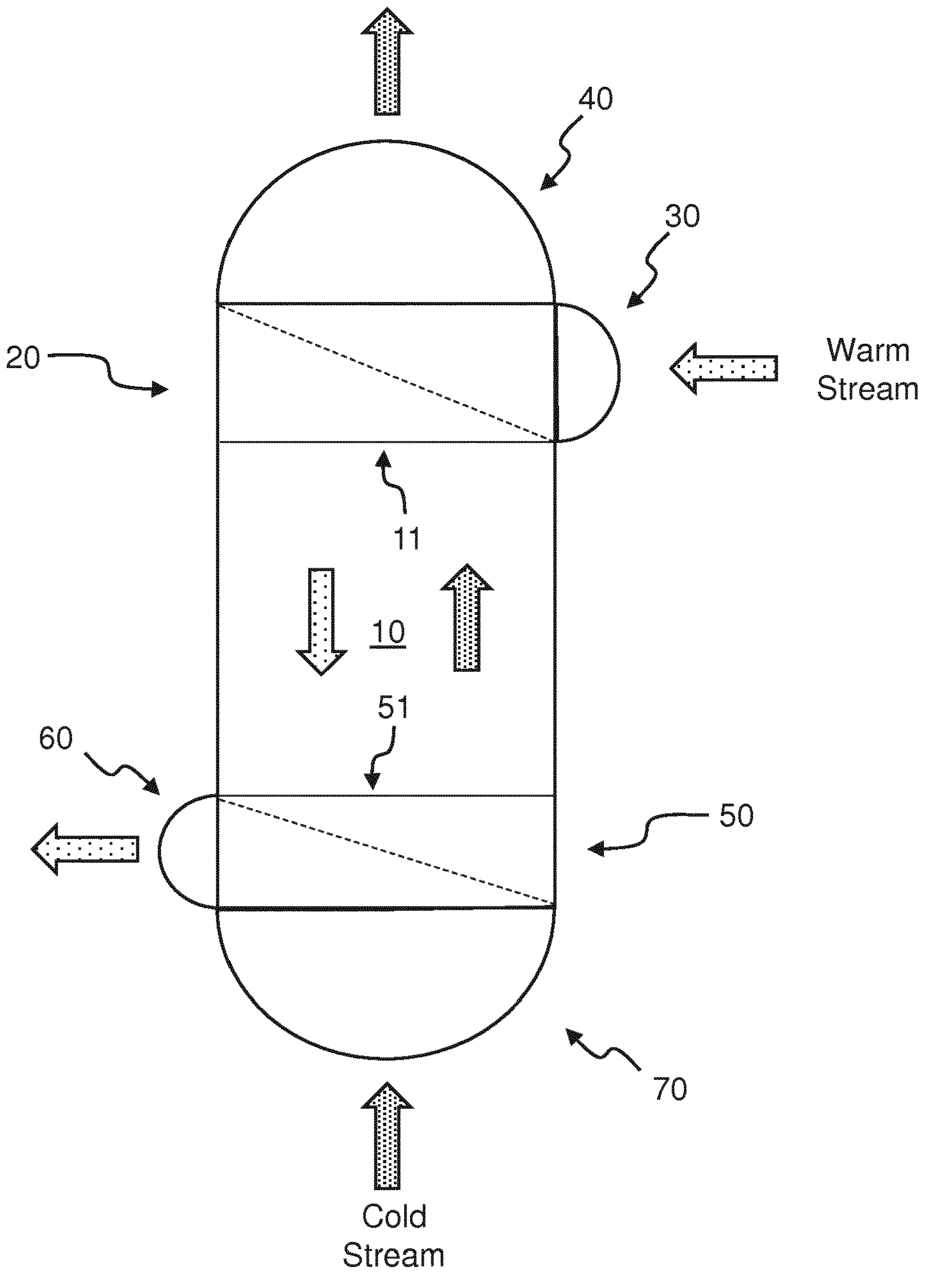


FIG. 1

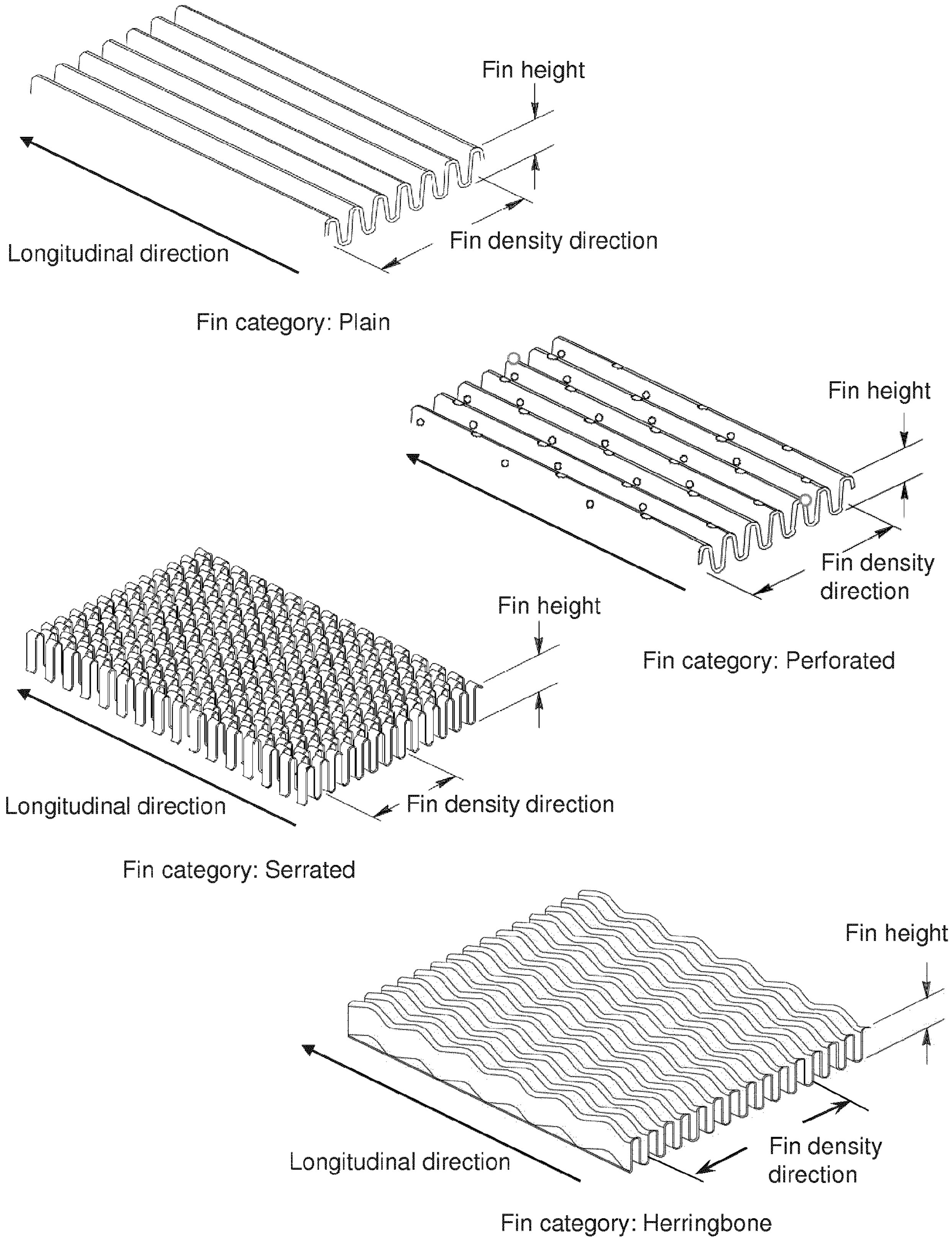

Fin height
Longitudinal direction
Fin density direction
Fin category: Plain
Fin height
Fin density direction
Fin category: Perforated
Fin height
Longitudinal direction
Fin density direction
Fin category: Serrated
Fin height
Longitudinal direction
Fin density direction
Fin category: Herringbone

FIG. 2

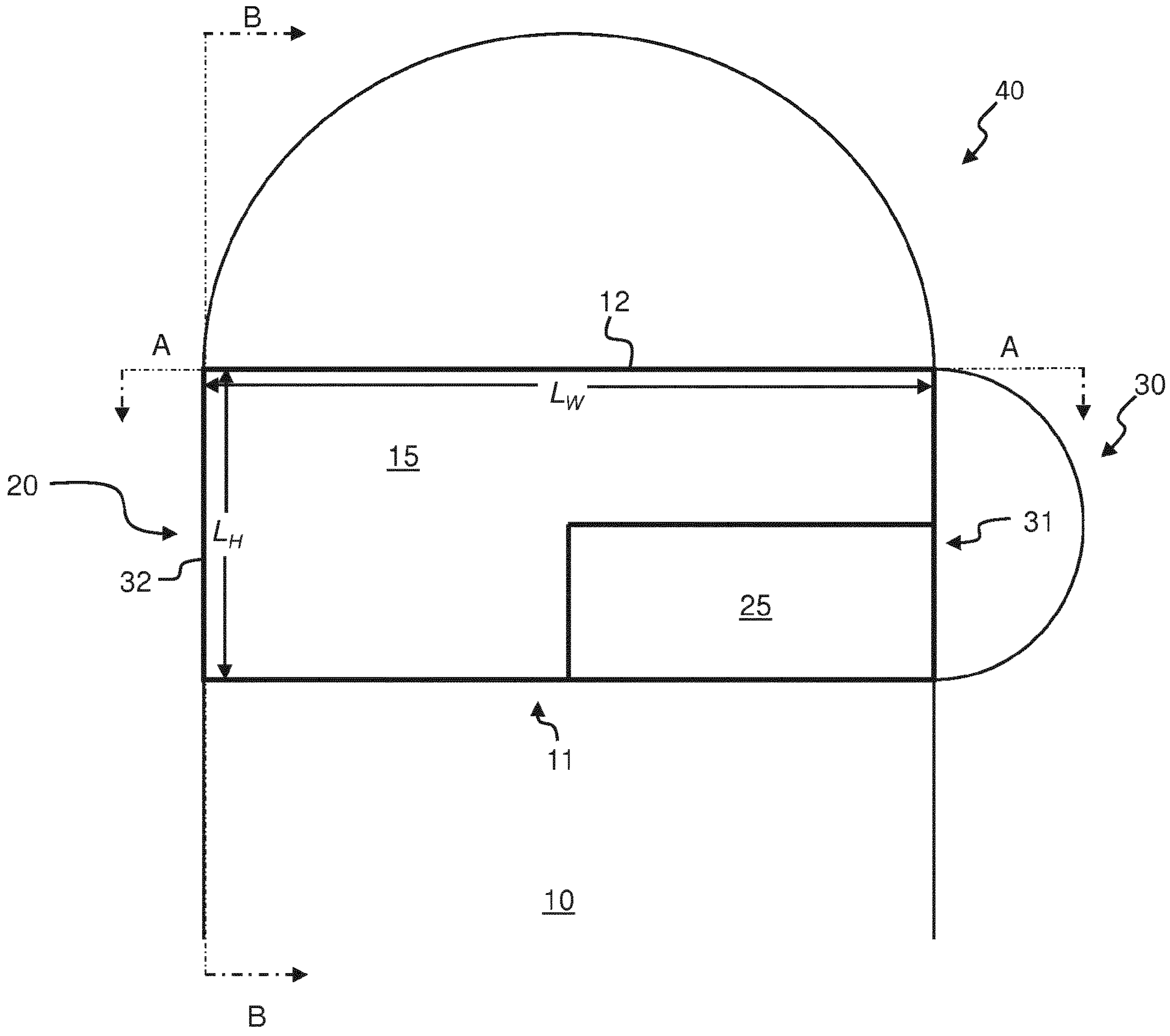
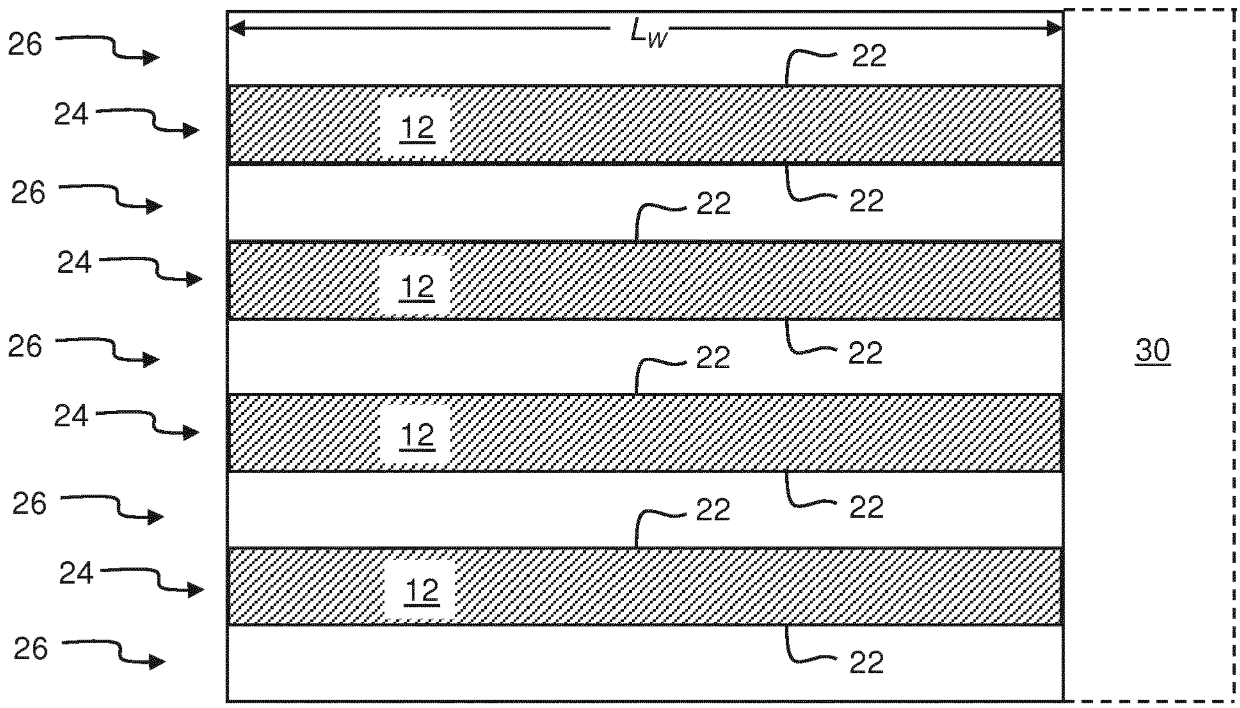
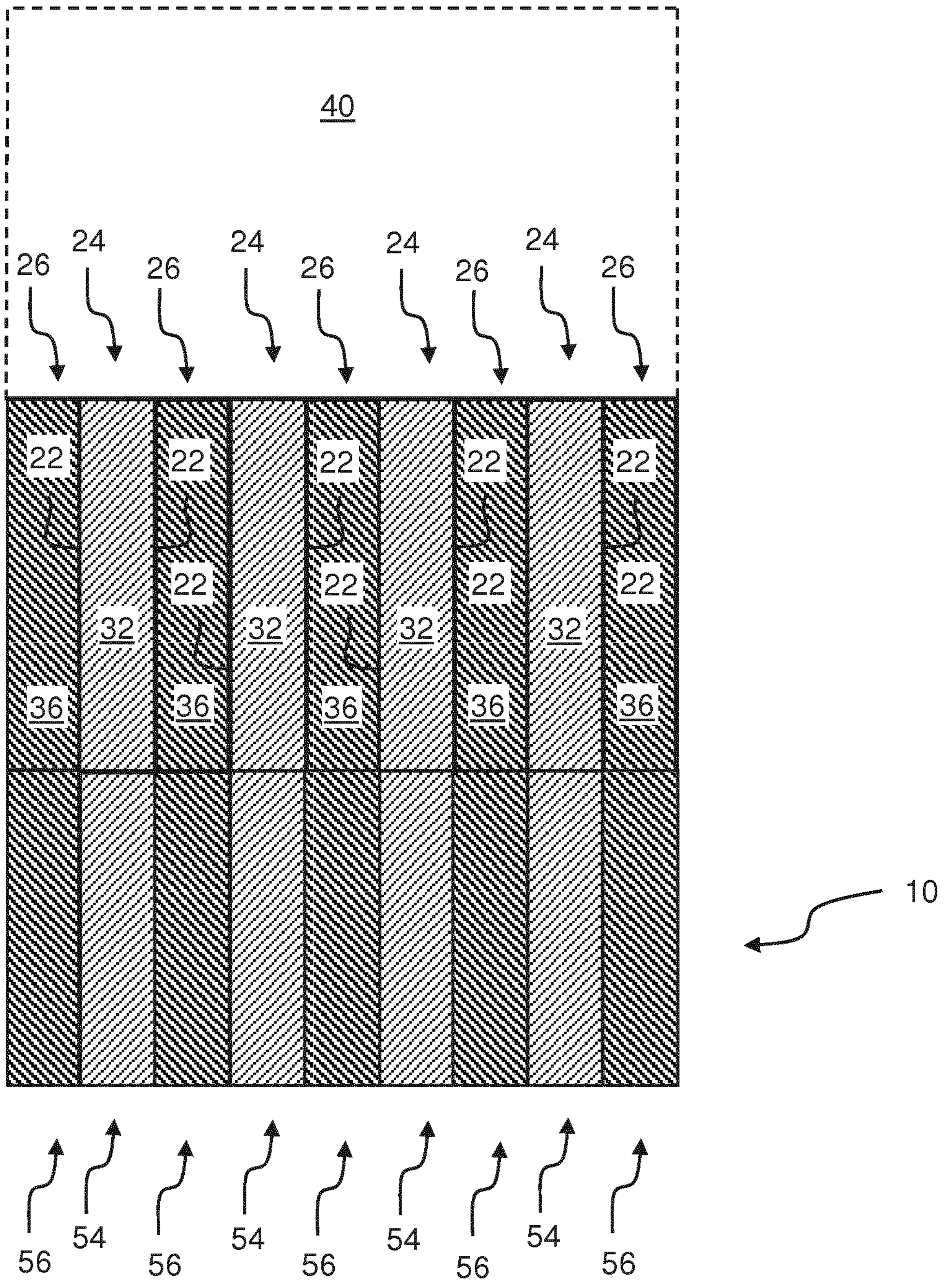


FIG. 3



Section A-A

FIG. 4



Section B-B

FIG. 5

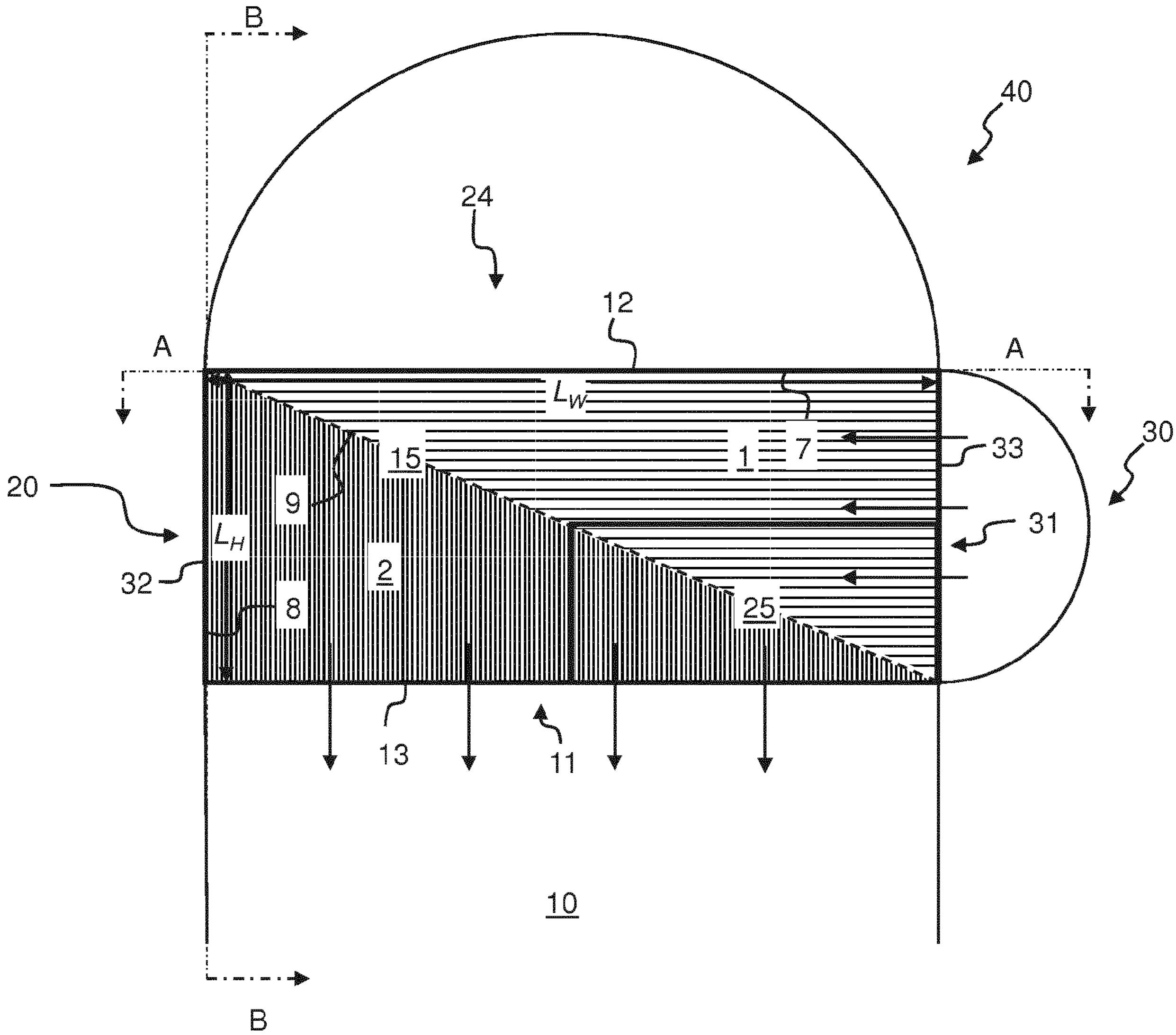


FIG. 6

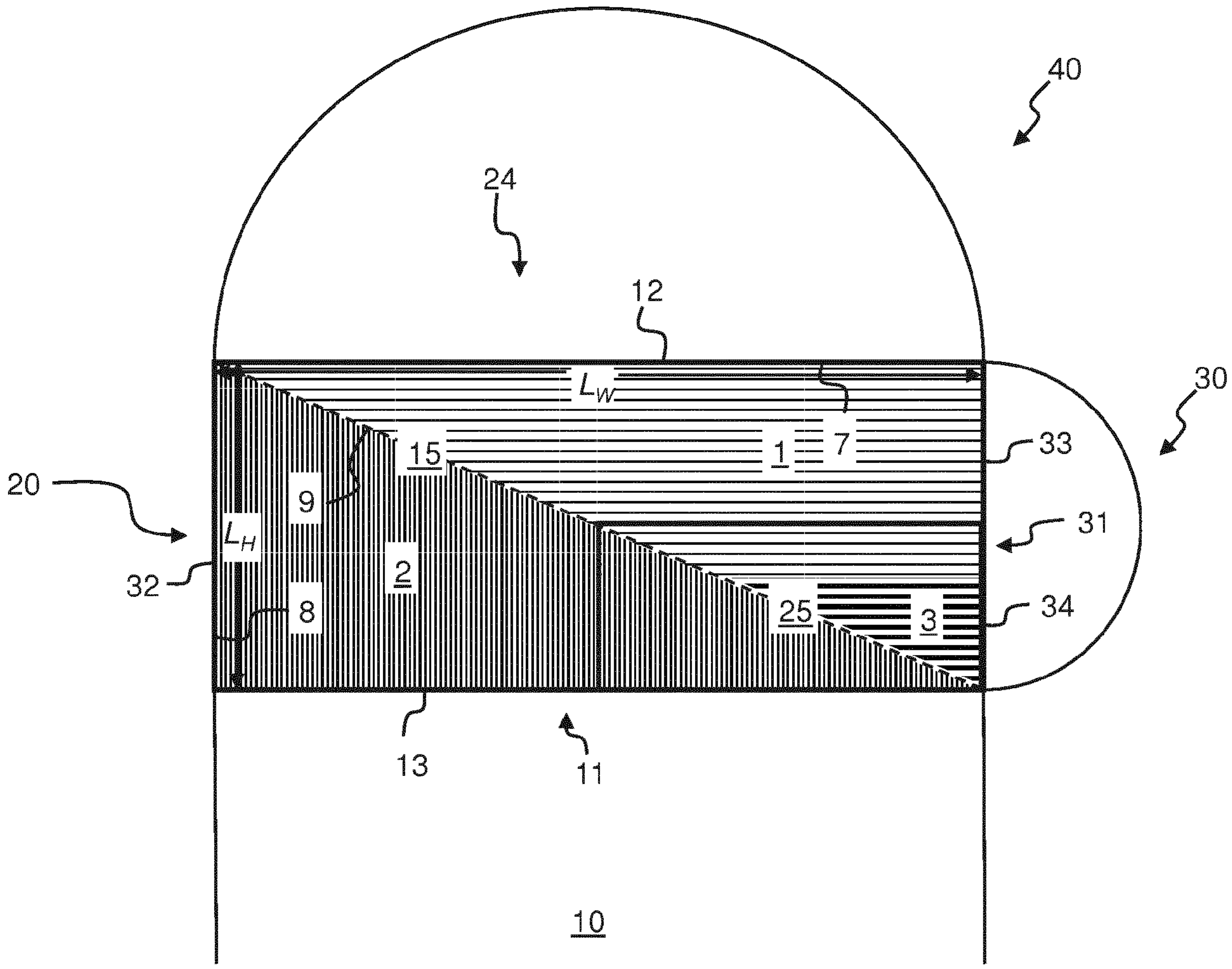


FIG. 7

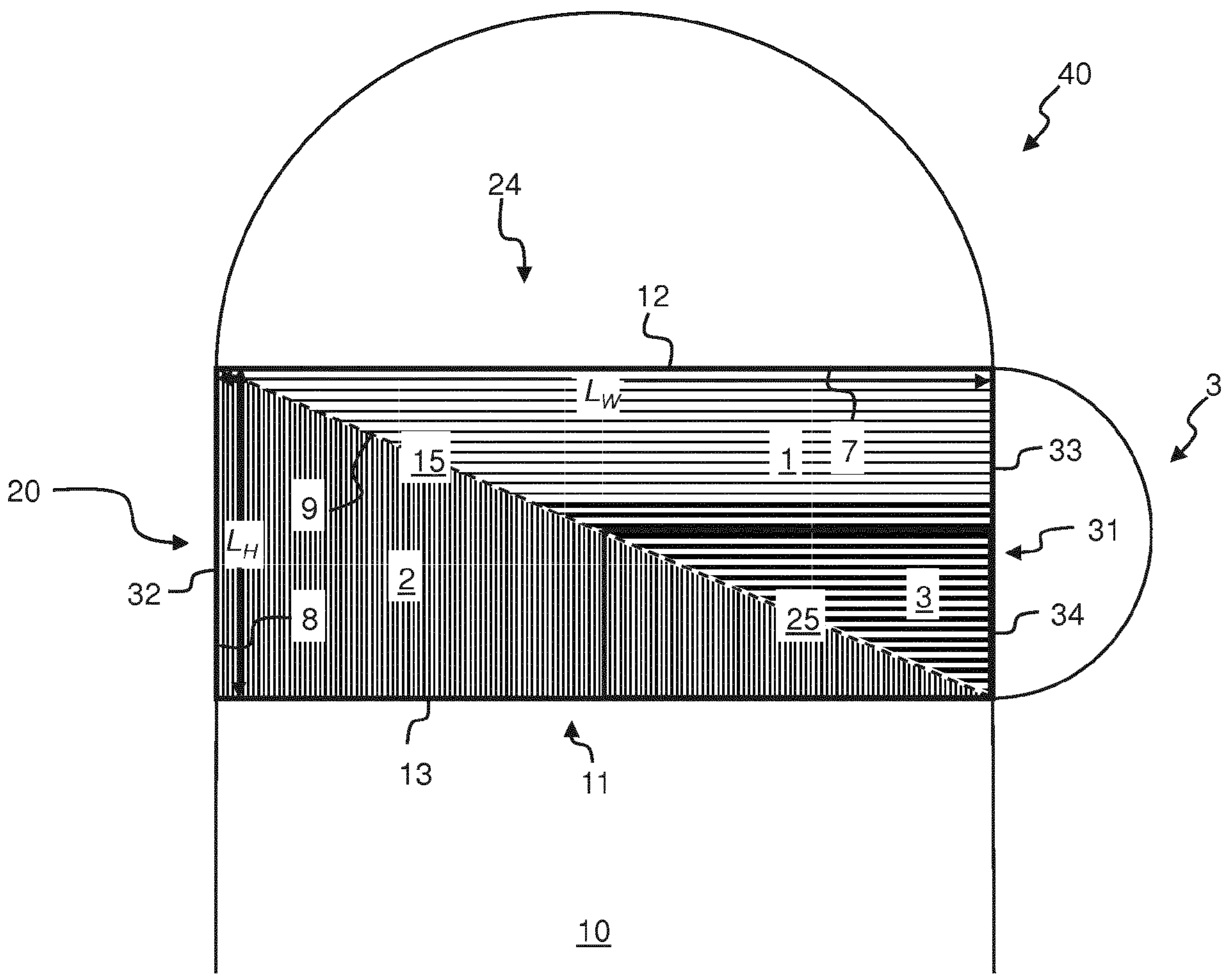


FIG. 8

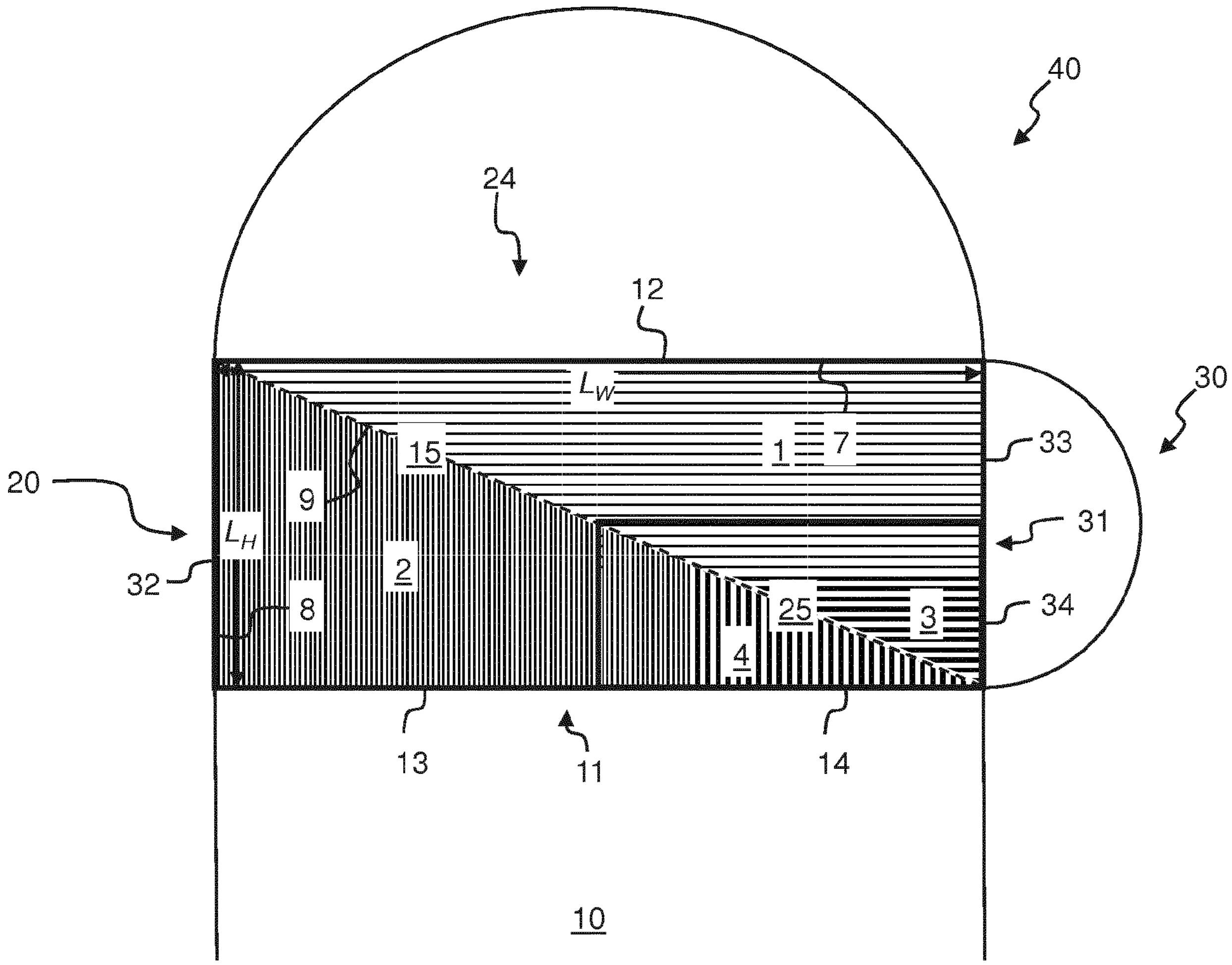


FIG. 9

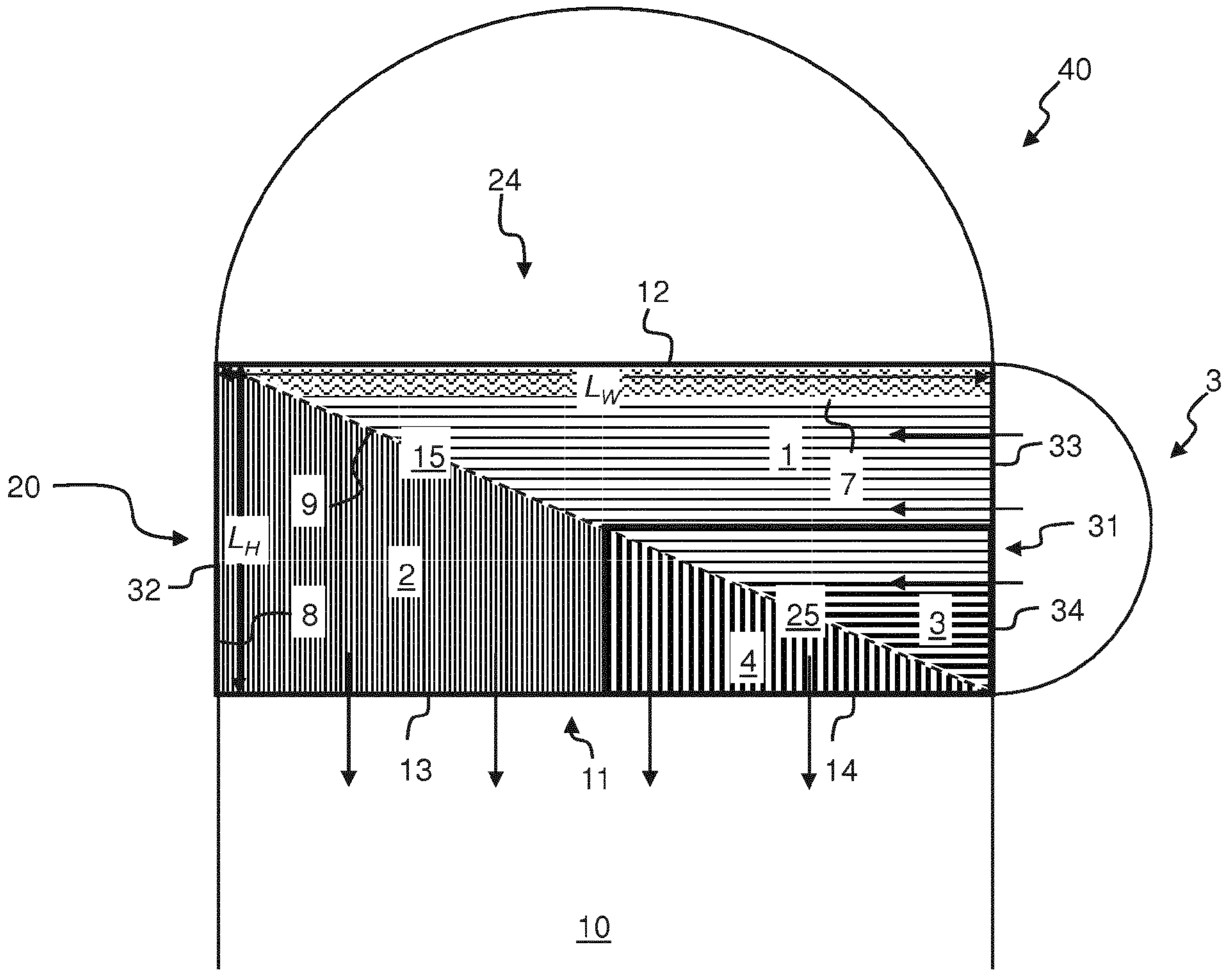


FIG. 10

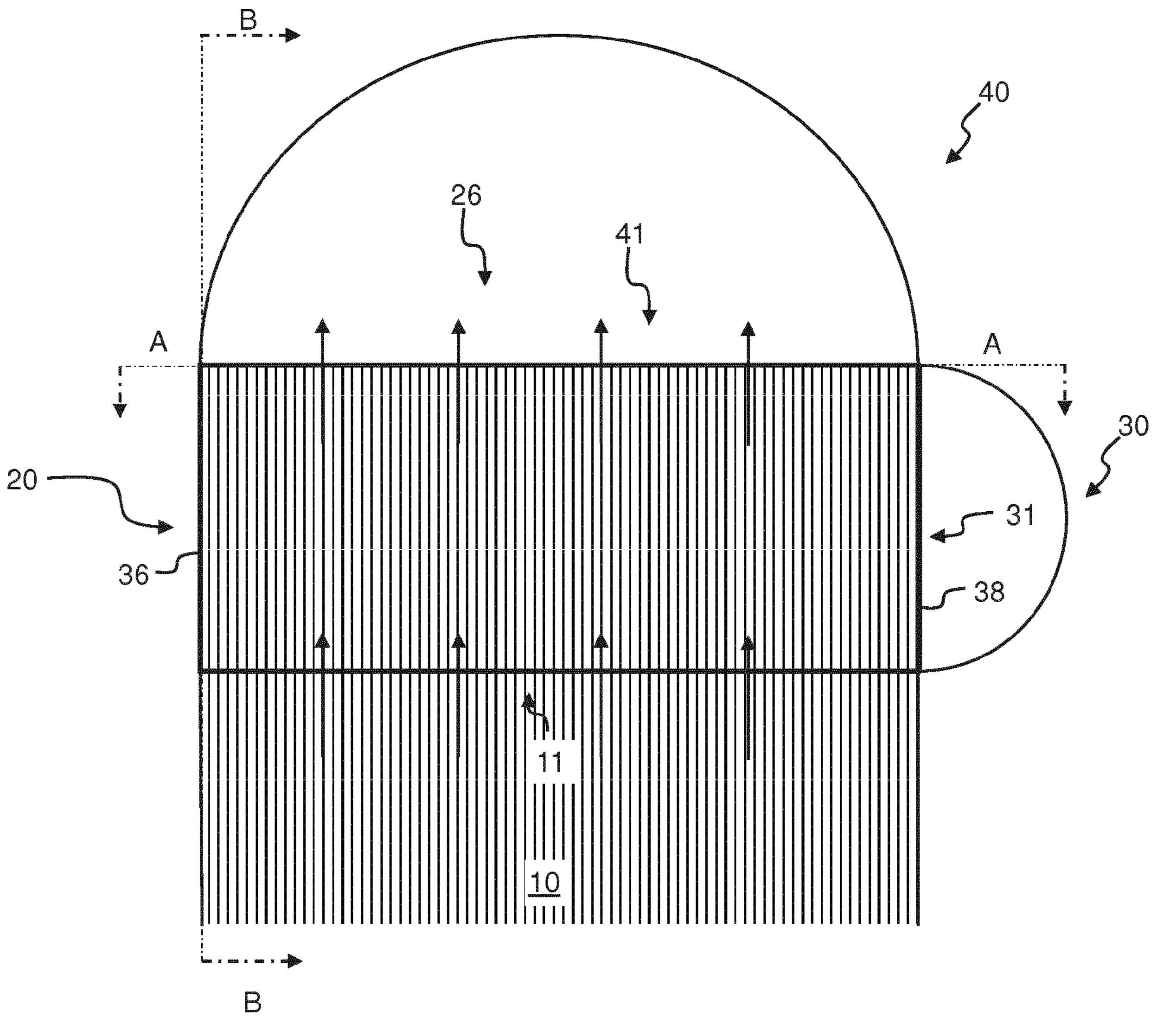


FIG. 11

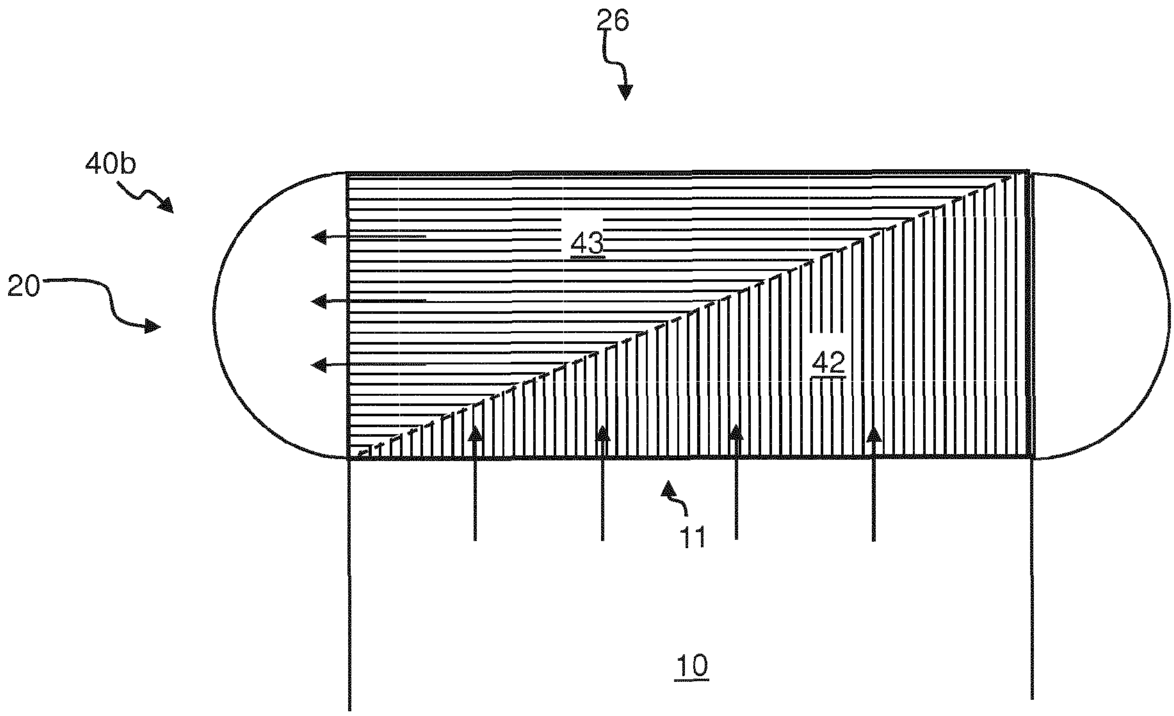


FIG. 12

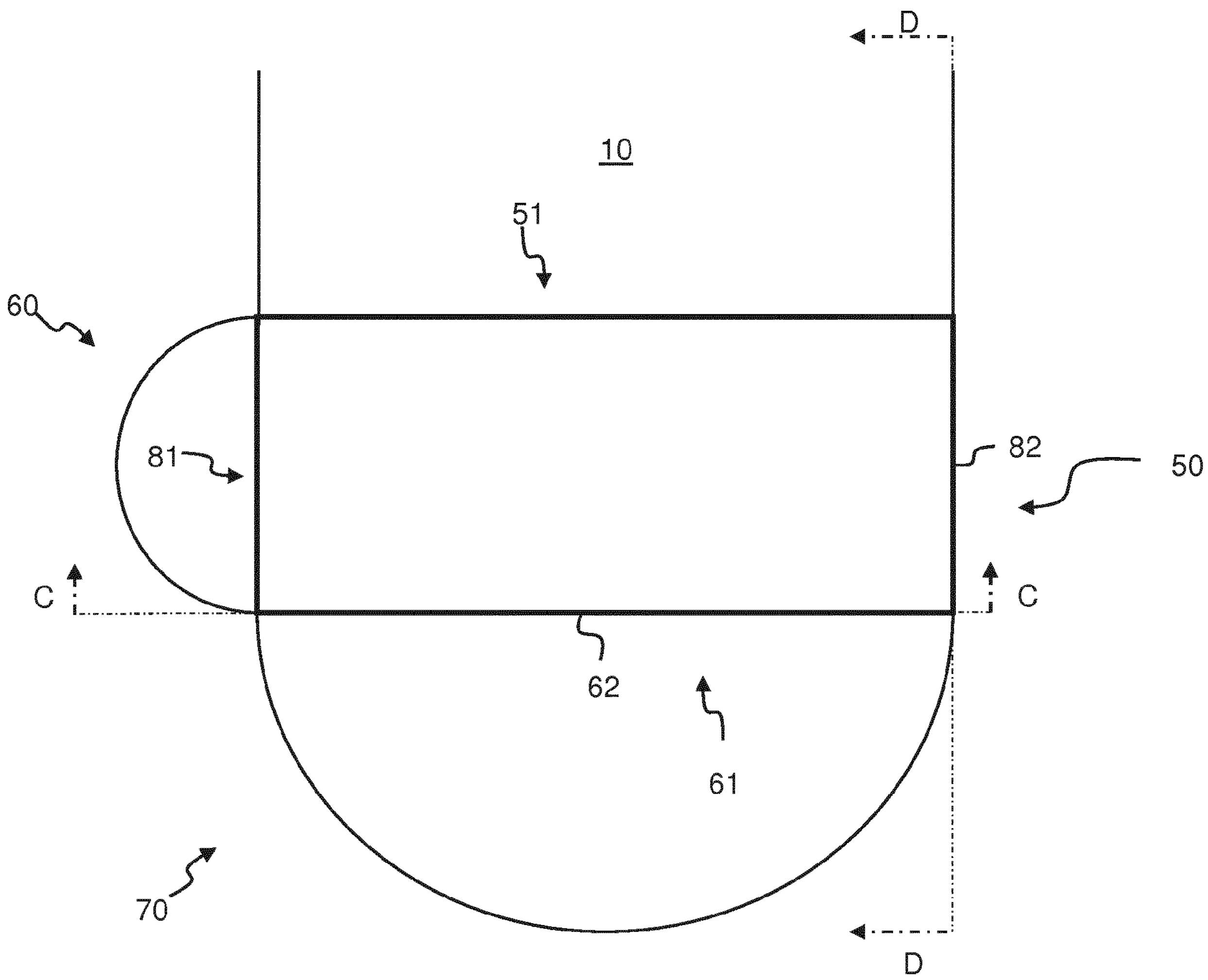
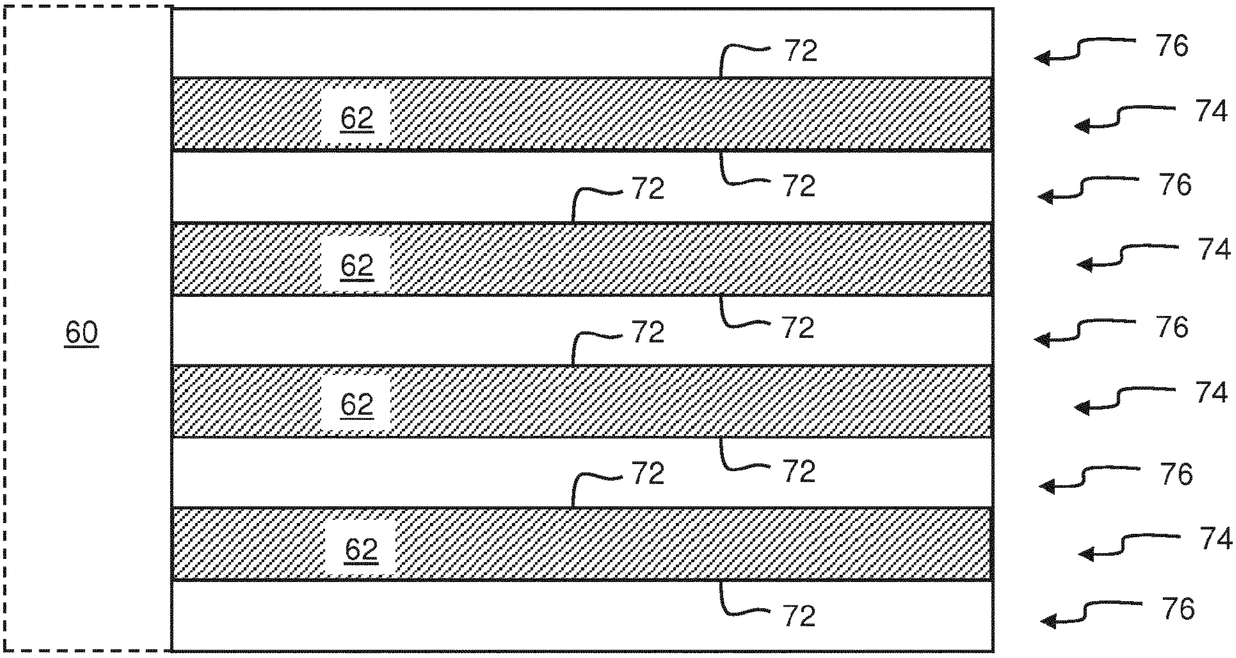
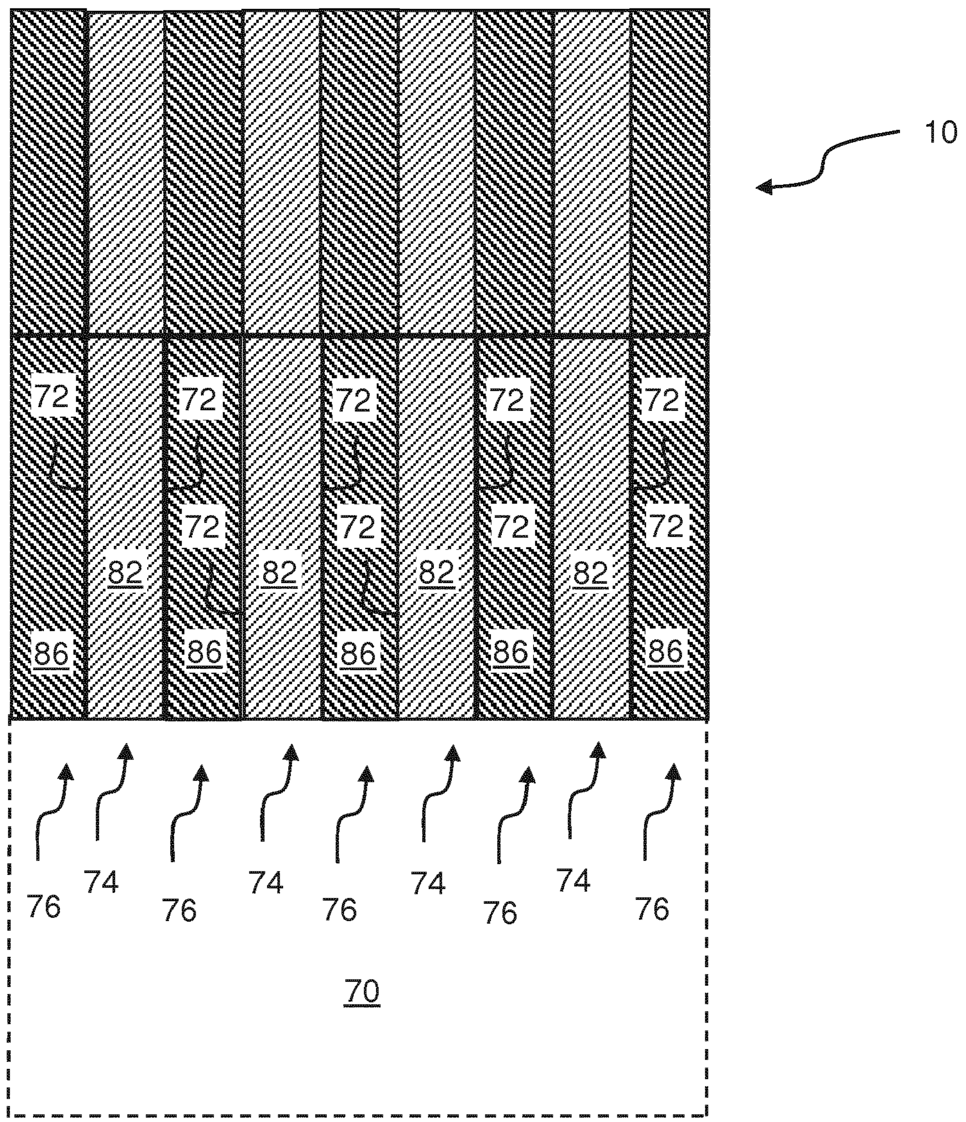


FIG. 13



Section C-C

FIG. 14



Section D-D

FIG. 15

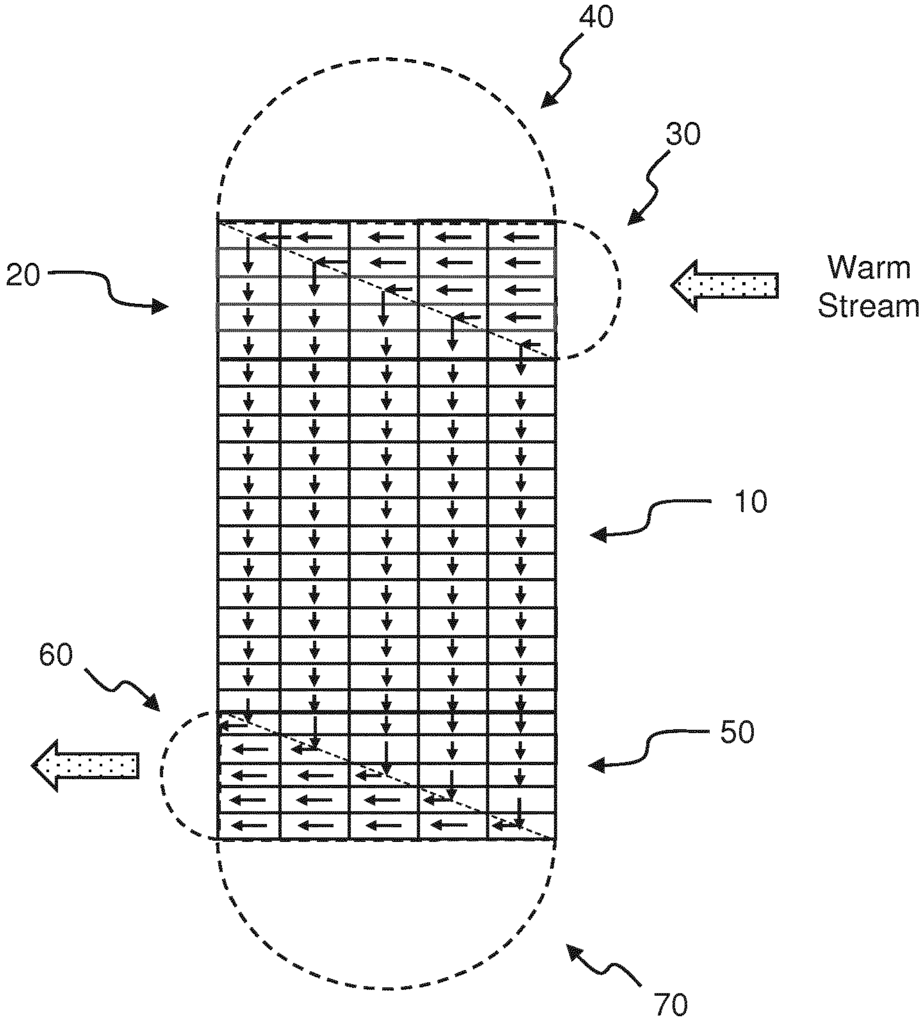


FIG. 16

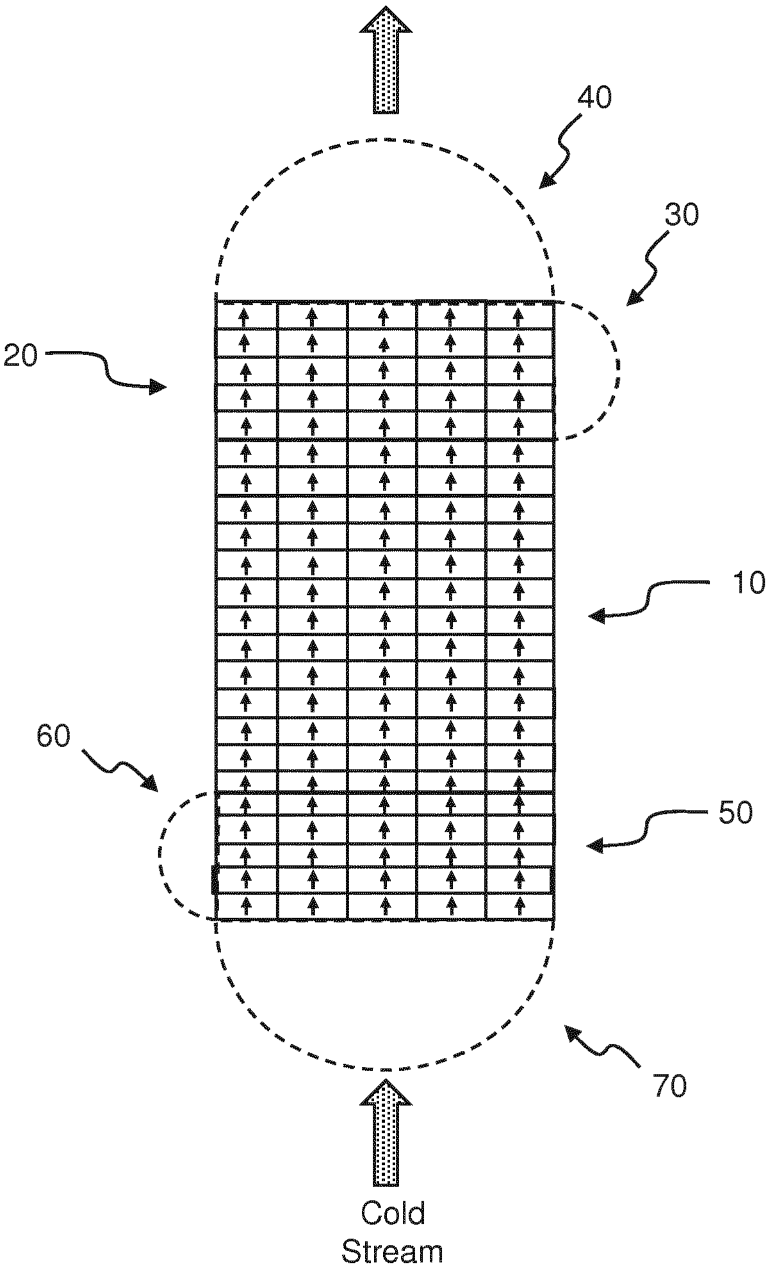


FIG. 17

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EUROPEAN SEARCH REPORT

Application Number
EP 18 15 3523

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	6 July 2018	Vassoille, Bruno

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