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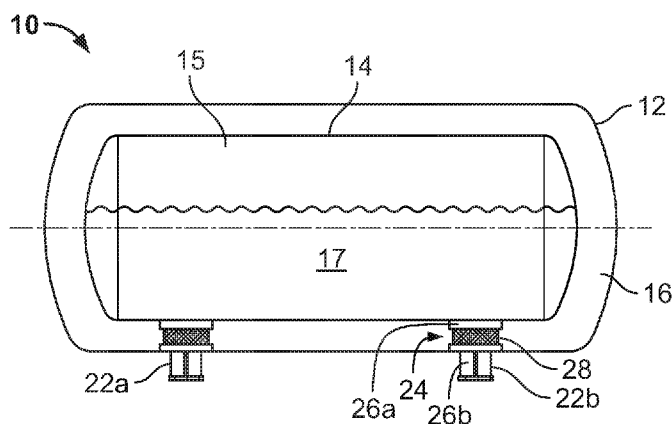


FIG. 1B

(57) Abstract: A liquid storage tank has inner and outer vessels with an inner vessel support configured to support the inner vessel within the outer vessel so that an insulation space is defined between the inner and outer vessels. The inner vessel support features a non-homogeneous structure that is formed using three-dimensional printing.



DOUBLE-WALLED TANK SUPPORT SYSTEM AND METHOD OF
CONSTRUCTION

CLAIM OF PRIORITY

[0001] This application claims priority to U.S. Provisional Patent Application No. 62/887,795, filed August 16, 2019, the contents of which are hereby incorporated by reference herein in their entirety.

FIELD OF THE INVENTION

[0002] The present disclosure relates generally to tanks featuring a double-wall construction with an insulation space between the inner and outer vessels of the tank and, in particular, to a system for supporting the inner vessel within the outer vessel of the tank and a method of constructing the supports for such a system.

BACKGROUND

[0003] Cryogenic fluids, that is, fluids having a boiling point generally below -150°C at atmospheric pressure, are used in a variety of applications, such as mobile and industrial applications. Cryogenic fluids typically are stored as liquids to reduce volume and thus permit containers of more practical and economical design to be used. The liquids are often stored in double-walled bulk tanks or containers with a vacuum between the walls of inner and outer vessels as insulation to reduce heat transfer from the ambient environment into the cryogenic liquid.

[0004] Proper positioning of the inner vessel within the outer vessel of the tank is ensured by an inner vessel support system. There are two competing major requirements for an inner vessel support system: (1) it must be robust enough to

safely secure the inner vessel within the outer vessel in a spaced relationship, and (2) it must be subtle enough to limit heat input into fluid stored in inner vessel. With regard to the latter, the inner vessel support system unavoidably will provide heat transfer pathways from the outer vessel, which is warmed by ambient temperature, to the inner vessel. This should be minimized, such as by using longer pathways or pathways with smaller cross sections, as such warming eventually causes liquid within the inner vessel to evaporate into vapor, which reduces the hold time of the tank.

[0005] There are two typical approaches in solving the contradictory requirements of the inner vessel support system. The first is use of a stainless steel inner vessel support system. Because of relatively high thermal conductivity of stainless steel (15 W/(m.K)), thin, long, narrow hanger straps are often used. Such structures are complicated, however, and cause local stress peaks at the support attachments. Alternative configurations of the support system include a skirt support or cone support which eliminate local stress concentrations but usually have higher thermal conductivity and then worse thermal performance.

[0006] The second common approach for addressing the contradictory requirements of an inner vessel support system is the use of fiberglass supports. Fiberglass is a common type of fiber-reinforced plastic using glass fiber. Typical thermal conductivity is 0.4 W/(m.K)). As thermal conductivity is approximately 40 times lower than thermal conductivity of stainless steel, the fiberglass supports can be shorter than metallic supports. Disadvantages of fiberglass supports include lack of tensile or shear strength, the lack of solid/welded connections and low mechanical properties at high temperature.

SUMMARY

[0007] There are several aspects of the present subject matter which may be embodied separately or together in the devices and systems described and claimed below. These aspects may be employed alone or in combination with other aspects of the subject matter described herein, and the description of these aspects together is not intended to preclude the use of these aspects separately or the claiming of such aspects separately or in different combinations as set forth in the claims appended hereto.

[0008] In one aspect, a liquid storage tank includes an outer vessel and an inner vessel positioned within the outer vessel. The inner vessel has an interior storage space configured to contain a liquid. An inner vessel support is configured to support the inner vessel within the outer vessel so that an insulation space is defined between the inner and outer vessels. The inner vessel support features a non-homogeneous structure that is formed using three-dimensional printing.

[0009] In another aspect, an inner vessel support for a double-walled liquid storage tank includes a non-homogeneous structure that is formed using three-dimensional printing.

[0010] In still another aspect, a method of constructing a double-walled liquid storage tank includes the steps of forming an inner vessel support having a non-homogeneous structure using three-dimensional printing, fastening the inner vessel support to an inner surface of an outer vessel, positioning an inner vessel within the outer vessel so that an outer surface of the inner vessel is supported by the inner vessel support and fastening the outer surface of the inner vessel to the inner vessel support.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] In describing the preferred example embodiments, references are made to the accompanying drawing figures wherein like parts have like reference numerals, and wherein:

[0012] Fig. 1A is an end elevational schematic view of a cryogenic fluid storage tank including an embodiment of the inner vessel support system of the disclosure;

[0013] Fig. 1B is a side elevational schematic view of the cryogenic fluid storage tank of Fig. 1A;

[0014] Fig. 2 is an enlarged partial perspective view of a portion of an inner vessel support in a first embodiment of the inner vessel support system of the disclosure;

[0015] Fig. 3 is an enlarged partial perspective view of a portion of an inner vessel support in a second embodiment of the inner vessel support system of the disclosure;

[0016] Fig. 4 is an enlarged partial perspective view of a portion of an inner vessel support in a third embodiment of the inner vessel support system of the disclosure.

DETAILED DESCRIPTION OF EMBODIMENTS

[0017] A cryogenic storage tank incorporating an embodiment of the inner vessel support system of the disclosure is indicated in general at 10 in Figs. 1A and 1B.

[0018] It should be understood that while the technology is described below with regard to a metallic inner vessel support system of a double-walled cryogenic fluid storage tank, the technology may be applied to alternative types of tanks or containers and may use supports constructed of non-metallic materials.

[0019] The tank 10 includes an outer vessel or jacket 12 within which is positioned an inner vessel 14. The inner vessel features an interior storage space

15 configured to receive and hold a supply of cryogenic liquid 17. As will be described in greater detail, the inner vessel is supported within the outer vessel so that an insulation space 16 is provided between the inner and outer vessels. The insulation space 16 may vacuum insulated or at least partially evacuated of air so that heat transfer from the ambient environment surrounding the outer vessel to the inner vessel and its contents is limited. In alternative embodiments, the insulation space 16 may be filled with insulation material.

[0020] As is known in the art, an outer vessel support system, including saddle supports 22a and 22b, may be used to support the tank 10 on a surface or otherwise mount the tank.

[0021] In an embodiment of the disclosure, an inner vessel support system includes a number of inner vessel supports, indicated in general at 24. While four supports are illustrated in Figs. 1A and 1B (with three being visible), the system may use an alternative number of inner vessel supports, and even a single inner vessel support positioned under the inner vessel 14. Furthermore, the positions and shapes of the inner vessel supports 24 are presented as examples only, with alternative shapes and positions being used.

[0022] In the embodiment illustrated in Figs. 1A and 1B, each inner vessel support 24 preferably includes an inner mounting plate 26a that is shaped so as to accommodate the shape of the outer surface of the inner vessel 14. Each inner vessel support also preferably includes an outer mounting plate 26b that is shaped so as to accommodate the shape of the inner surface of the outer vessel 12. Sandwiched between the inner and outer mounting plates 26a and 26b is one or more support layers 28. The inner and outer mounting plates 26a and 26b may be secured to the inner and outer vessels, respectively, and to the support layer(s) 28

using fastening arrangements known in the art, such as welding, adhesives, fasteners, etc. In alternative embodiments, the inner and outer mounting plates 26a and 26b of Fig. 1 may be omitted with the support layer(s) being directly fastened to the inner and outer vessels using the fastening arrangements known in the art.

[0023] In an embodiment of the disclosure, stainless steel (or another metal) is used to create an inner vessel support having a non-homogenous structure which combines the beneficial properties of stainless steel and the beneficial properties of fiberglass. The non-homogeneous structure features cells or is porous so that the structure material doesn't fill the entire volume of the inner vessel support structure. As a result, the effective cross sectional area of the inner vessel support is very low, which significantly decreases heat flow through support. Nevertheless, the material distribution in the structure is designed to ensure that the total stiffness and rigidity of the inner vessel support meet the requirements necessary to securely position the inner vessel within the outer vessel. As will now be described, there are several structures for the inner vessel support that may accomplish this.

[0024] In a first embodiment, the inner vessel support includes a metallic honeycomb structure, indicated in general in Fig. 2 at 32. The structure includes a number of walls 34 that form cells 36 that are open at the top and bottom. While each cell 36 in Fig. 2 features a hexagonal cross sectional shape, the honeycomb structure may feature cells having alternative cross sectional shapes including, but not limited to, round, square, triangular, pentagonal, etc. In addition, while flat or planar walls 34 are illustrated in Fig. 2, the walls may alternatively be curved or feature other shapes and contours.

[0025] The honeycomb structure 32 of Fig. 2 may form the support layers 28 of the inner vessel supports 24 of Figs. 1A and 1B, with the walls 34 extending

generally perpendicular, and mounted, to the inner and outer mounting plates 26a and 26b. Alternatively, the honeycomb structure of Fig. 2 may form the entire inner vessel support, with the walls 34 extending generally perpendicular, and mounted directly, to the outer and inner vessels 12 and 14.

[0026] In a second embodiment, the inner vessel support includes a metallic lattice structure, indicated in general in Fig. 3 at 42. The structure includes a number of struts 44 that form cells 46 that are open at the top, bottom and sides. While each cell 46 in Fig. 3 features a cubic cross sectional shape, the lattice structure may feature cells having alternative cross sectional shapes. In addition, while straight struts 44 are illustrated in Fig. 3, the struts may alternatively be curved or feature other shapes and contours.

[0027] The lattice structure 42 of Fig. 3 may form the support layers 28 of the inner vessel supports 24 of Figs. 1A and 1B, with the ends of perpendicular struts, and the sides of parallel struts, mounted to the inner and outer mounting plates 26a and 26b. Alternatively, the lattice structure of Fig. 3 may form the entire inner vessel support, with the ends of perpendicular struts, and the sides of parallel struts, mounted directly to the outer and inner vessels 12 and 14.

[0028] In a third embodiment, the inner vessel support includes a metallic porous structure, indicated in general in Fig. 4 at 52. The pores may be open or some of the pores may be sealed within the structure material. The porous structure 52 of Fig. 4 may form the support layers 28 of the inner vessel supports 24 of Figs. 1A and 1B, with the porous structure mounted to the inner and outer mounting plates 26a and 26b. Alternatively, the porous structure of Fig. 4 may form the entire inner vessel support, with the porous structure mounted directly to the outer and inner vessels 12 and 14.

[0029] Non-homogeneous structures other than those illustrated in Figs. 2-4 may be used in alternative embodiments of the inner vessel supports.

[0030] Use of traditional manufacturing technologies to produce the structures of Figs. 2-4, and other non-homogeneous structures, is impractical. In accordance with the disclosure, metal three-dimensional (3D) printing technology is used for manufacturing the desired non-homogeneous structures.

[0031] As noted previously, the technology of the disclosure is not limited to use in cryogenic tanks or containers, but instead it can also be used in other fields where high stiffness and low thermal conductivity at the same time are required for the inner vessel support system of a double-walled tank or container.

[0032] While the preferred embodiments of the disclosure have been shown and described, it will be apparent to those skilled in the art that changes and modifications may be made therein without departing from the spirit of the disclosure, the scope of which is defined by the following claims.

CLAIMS

What is claimed is:

1. A liquid storage tank comprising:
 - a. an outer vessel;
 - a. an inner vessel positioned within the outer vessel, said inner vessel having an interior storage space configured to contain a liquid;
 - c. an inner vessel support configured to support the inner vessel within the outer vessel so that an insulation space is defined between the inner and outer vessels;
 - d. said inner vessel support featuring a non-homogeneous structure that is formed using three-dimensional printing.

2. The liquid storage tank of claim 1 wherein the insulation space contains a vacuum.

3. The liquid storage tank of either claim 1 or 2 wherein the non-homogeneous structure includes a metallic material.

4. The liquid storage tank of claim 3 wherein the metallic material is stainless steel.

5. The liquid storage tank of any one of claims 1 through 4 wherein the inner vessel support includes an inner mounting plate fastened to the inner vessel, and outer mounting plate fastened to the outer vessel and a support layer including the

non-homogeneous structure positioned between and fastened to the inner and outer mounting plates.

6. The liquid storage tank of any one of claims 1 through 5 wherein the non-homogeneous structure includes a honeycomb structure.

7. The liquid storage tank of any one of claims 1 through 5 wherein the non-homogeneous structure includes a lattice structure.

8. The liquid storage tank of any one of claims 1 through 5 wherein the non-homogeneous structure includes a porous structure.

9. The liquid storage tank of claim 1 wherein the non-homogeneous structure is mounted directly to the inner and outer vessels.

10. An inner vessel support for a double-walled liquid storage tank comprising a non-homogeneous structure that is formed using three-dimensional printing.

11. The inner vessel support of claim 10 wherein the non-homogeneous structure includes a metallic material.

12. The inner vessel support of claim 11 wherein the metallic material is stainless steel.

13. The inner vessel support of any one of claims 10 through 12 further comprising an inner mounting plate configured to be fastened to the inner vessel, and outer mounting plate configured to be fastened to the outer vessel and a support layer including the non-homogeneous structure positioned between and fastened to the inner and outer mounting plates.

14. The inner vessel support of any one of claims 10 through 13 wherein the non-homogeneous structure includes a honeycomb structure.

15. The inner vessel support of any one of claims 10 through 14 wherein the non-homogeneous structure includes a lattice structure.

16. The inner vessel support of any one of claims 10 through 15 wherein the non-homogenous structure includes a porous structure.

17. A method of constructing a double-walled liquid storage tank comprising the steps of:

- a. forming an inner vessel support having a non-homogeneous structure using three-dimensional printing;
- b. fastening the inner vessel support to an inner surface of an outer vessel;
- c. positioning an inner vessel within the outer vessel so that an outer surface of the inner vessel is supported by the inner vessel support;
- d. fastening the outer surface of the inner vessel to the inner vessel support.

18. The method of claim 17 wherein the non-homogeneous structure is formed from metal.

19. The method of either one of claims 17 or 18 wherein the non-homogenous structure is selected from the group consisting of a honeycomb structure, a lattice structure and a porous structure.

20. The method of any one of claims 17 through 19 further comprising the step of evacuating air from an insulation space formed between the inner and outer vessels.

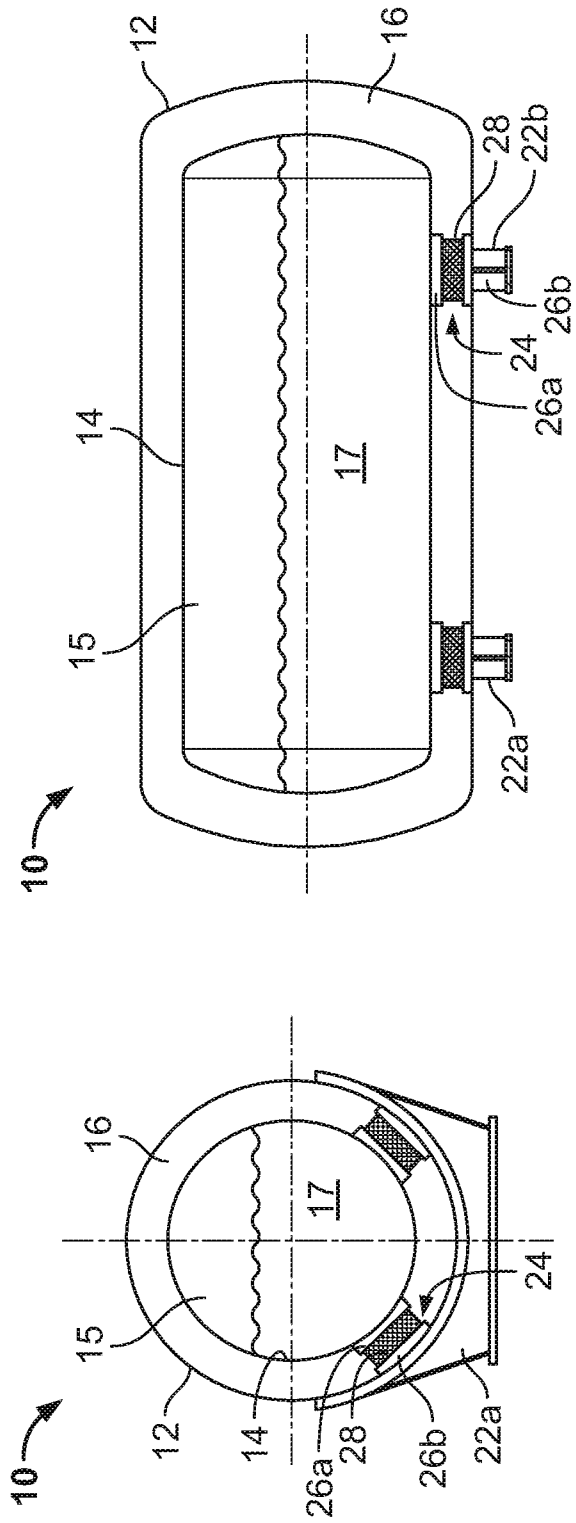


FIG. 1B

FIG. 1A

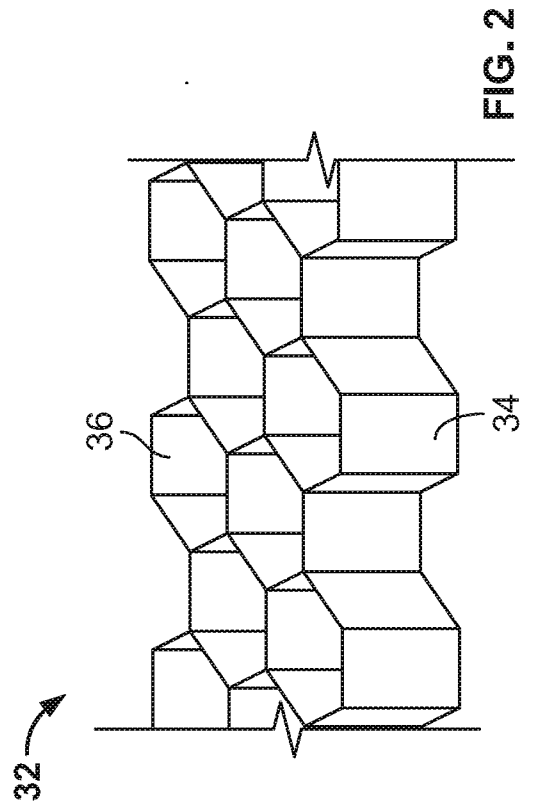


FIG. 2

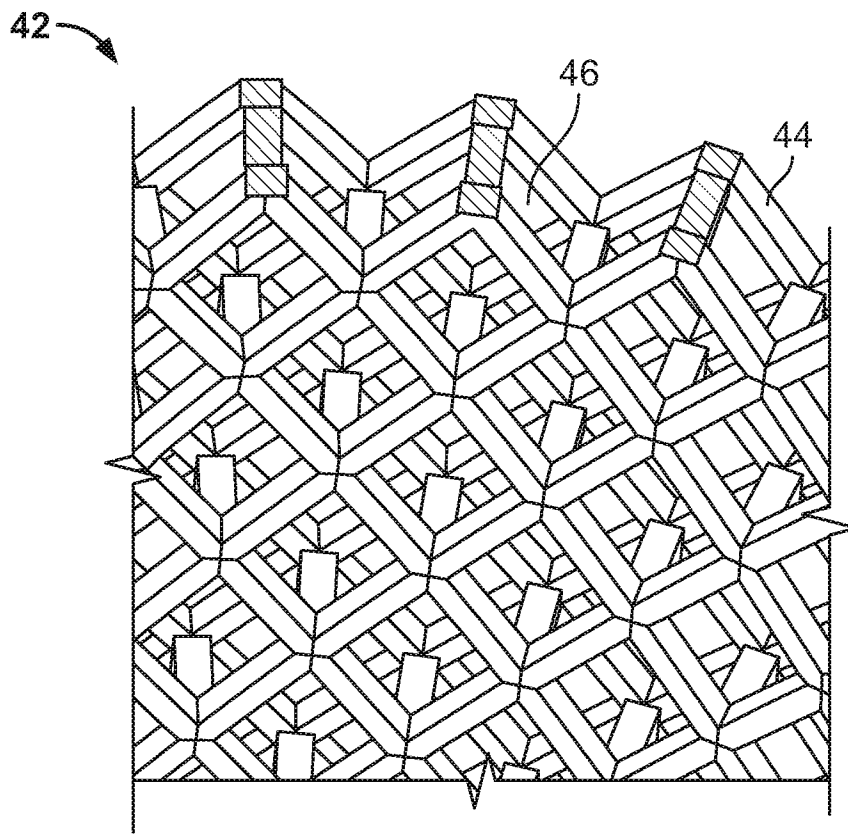


FIG. 3

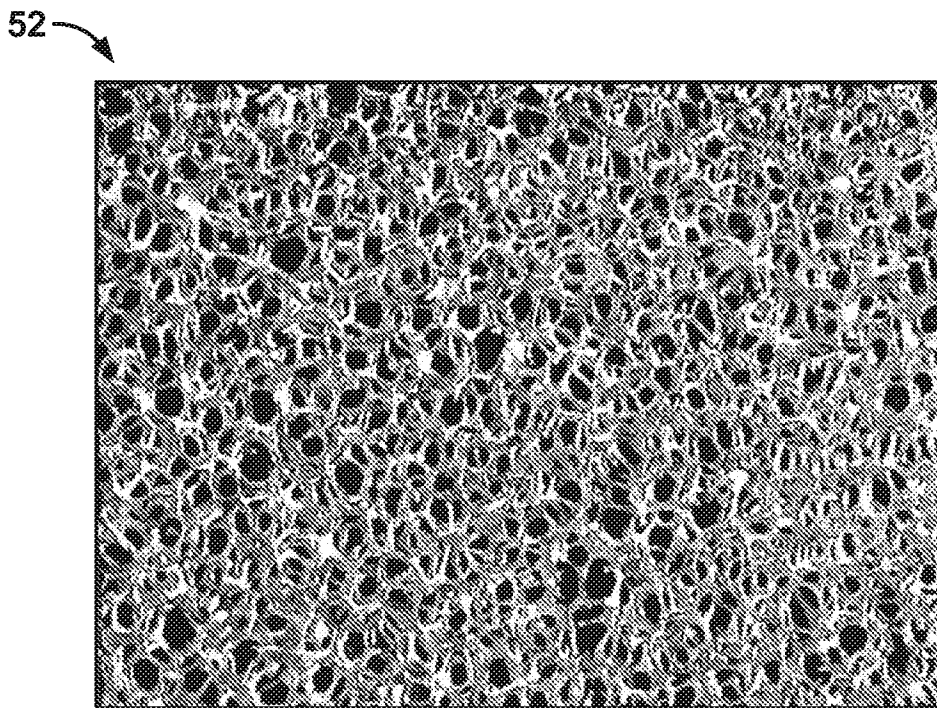


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2020/046448

A. CLASSIFICATION OF SUBJECT MATTER
INV. F17C13/08
ADD.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
F17C

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

<p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p>
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Date of the actual completion of the international search 6 November 2020	Date of mailing of the international search report 20/11/2020
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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2020/046448

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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X A	US 2018/229863 A1 (VETO CHRISTOPHER C [US] ET AL) 16 August 2018 (2018-08-16) figures 1,10	1-4,6, 9-14 5,7,8, 15-20
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Information on patent family members

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