

(19)



(11)

EP 2 597 412 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
29.05.2013 Bulletin 2013/22

(51) Int Cl.:
F28D 9/00 (2006.01) F28F 9/00 (2006.01)
F28F 19/02 (2006.01)

(21) Application number: **11190887.7**

(22) Date of filing: **28.11.2011**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

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(54) **Block-type plate heat exchanger with anti-fouling properties**

(57) An block-type plate that has a stack of heat transfer plates (30) which includes a first heat transfer plate (51) and a second heat transfer plate (52). At least a part of each of the first heat transfer plate (51) and the

second heat transfer plate (52) comprises a coating (701) that i) has a layer thickness of 1-30 μm , ii) is prepared by sol-gel processing, iii) comprises silicon oxide (SiO_x) having an atomic ratio of $\text{O/Si} > 1$, and iv) comprises ≥ 10 atomic percent carbon (C).

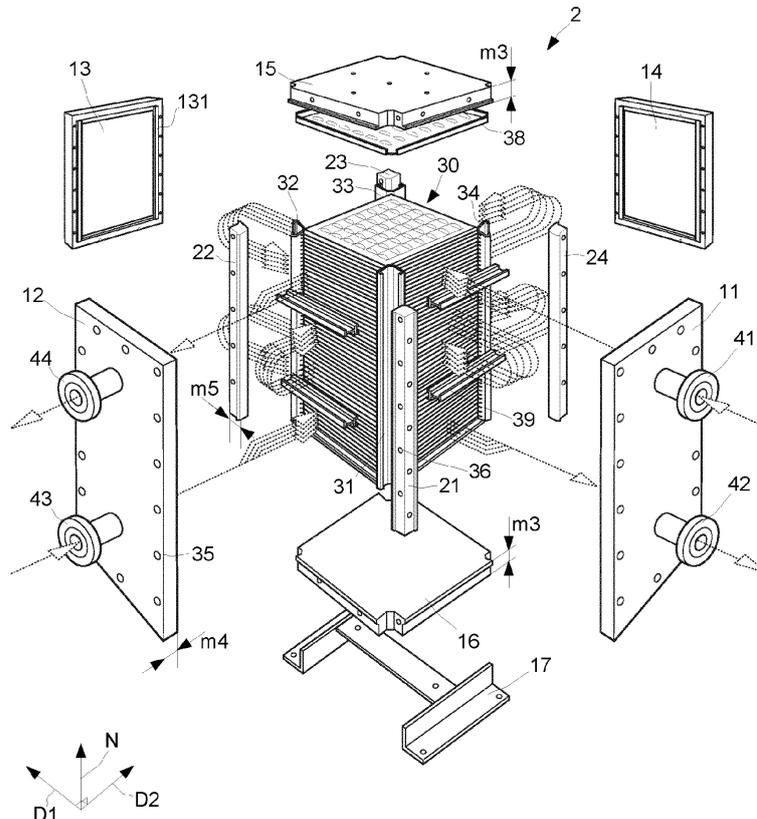


Fig. 1

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DescriptionTechnical Field

5 **[0001]** The invention relates to a block-type plate heat exchanger that comprises a top head, a bottom head and four side panels that are bolted together with a set of corner girders to form a sealed enclosure. A stack of heat transfer plates is arranged in the sealed enclosure. The block-type plate heat exchanger has properties that reduce fouling and facilitate cleaning the heat exchanger.

10 Background Art

[0002] Today several different types of plate heat exchangers exist and are employed in various applications depending on their type. One certain type of plate heat exchanger is assembled by bolting a top head, a bottom head and four side panels to a set of corner girders to form a box-like enclosure around a stack of heat transfer plates. This certain type of plate heat exchanger is referred to as a block-type heat exchanger. One example of a commercially available block-type heat exchanger is the heat exchanger offered by Alfa Laval AB under the product name Compabloc. Other block-type plate heat exchangers are disclosed in patent documents EP165179 and EP639258.

15 **[0003]** In the block-type plate heat exchanger fluid paths for two heat exchange fluids are formed between the heat transfer plates in the stack of heat transfer plates. During operation fouling of the heat transfer plates is of concern, for example due to deposits, microbial growth, dirt etc. that arise from the fluids that pass between the heat transfer plates. Fouling typically reduces a heat transfer capability and increases a pressure drop of the heat exchanger, which lead to an overall reduced performance. The problem of fouling is typically solved by removing one or more of the side panels such that the stack of heat transfer plates may be accessed and the plates may be cleaned.

20 **[0004]** For other types of heat exchangers it is known to coat areas of the heat exchanger that are susceptible to fouling. Examples of coating techniques may be found in a number of patent documents, such as in US20090123730, US20060196644, WO2008119751 and WO2009034359.

25 **[0005]** Even though these coating techniques may reduce fouling, it appears that they are not optimal for a block-type plate heat exchanger that typically is used in aggressive, high pressure applications where safety demands are high. For example, the coating would typically after some time be worn of its coating surface. Moreover, the unique design and structure of the block-type plate heat exchanger calls for a different coating that has been optimized in respect of the inherent design structure of the block-type plate heat exchanger.

Summary

35 **[0006]** It is an object of the invention to find a coating that reduces fouling of a block-type plate heat exchanger. Another object is to find embodiments of a block-type plate heat exchanger that ensure that the coating stays on the coated areas for a long operational time of the heat exchanger.

40 **[0007]** To fulfill these objects a block-type plate heat exchanger is provided. The block-type heat exchanger comprises a top head, a bottom head and four side panels that are bolted together with a set of corner girders to form a sealed enclosure, and a stack of heat transfer plates that is arranged in the sealed enclosure. The stack of heat transfer plates comprises pairs of heat transfer plates that are stacked such that a flow path for a first fluid is formed between the stacked pairs of heat transfer plates, wherein a pair of the stacked pairs of heat transfer plates comprises a first heat transfer plate and a second heat transfer plate that are joined such that a flow path for a second fluid is formed between the first and second heat transfer plates. At least a part of each of the first heat transfer plate and the second heat transfer plate comprises a coating that i) has a layer thickness of 1-30 μm , ii) is prepared by sol-gel processing, iii) comprises silicon oxide (SiO_x) having an atomic ratio of $\text{O/Si} > 1$, and iv) comprises ≥ 5 or ≥ 10 atomic percent carbon (C).

45 **[0008]** The block-type plate heat exchanger is advantageous in that fouling of the heat transfer plates is significantly reduced. As a consequence no or less cleaning is required. This reduces use of strong detergents and/or potentially abrasive, mechanical cleaning as well as reduces an operational downtime of the plate heat exchanger. Moreover, the coating is, comparison with prior art coatings, quite wear resistant and has a relatively resistance against formation of cracks in the coating which otherwise might form due to torque and tension forces that act on the heat transfer plates. Generally, each side or each both sides of the respective heat transfer plate may comprise the coating.

50 **[0009]** The plate heat exchanger may have predetermined measurements for a number of the components it comprises. For example, the first heat transfer plate and the second heat transfer plate may have a thickness of 0,6-1,4 mm or 0,8-1,2 mm. Each of the first heat transfer plate and the second heat transfer plate may have a heat transfer area of 0,05-0,30 m^2 or 0,6-1,8 m^2 . Any of the top head and the bottom head may have a thickness of 45-145 mm or 190-250 mm. Each of the four side panels may have a thickness of 35-85 mm or 65-175 mm. Each of the corner girders may comprise a cross-sectional side that measures 35-85 mm or 110-190 mm. Finally, the sealed enclosure may have a

volume of 0,02-0,40 m³ or 0,7-5,0 m³.

[0010] Empirical tests as well as finite element-based analysis have shown that each of these measurements, either alone or one or more in combination, provide a structure of the heat exchanger that is particularly suitable for the coating. The underlying reasons for this is that the measurements provide a structure for the heat transfer plates that prevents extensive flexing of the heat transfer plates when the heat exchanger is operated. This is of great advantage since the coating then remains on the plates for a long period of time (flexing cause the coating to fall off or wear out faster). Thus, the coating together with one or more of the predetermined measurements provide a block-type heat exchanger that has been optimized in respect of resisting fouling for a longer period of time.

[0011] The layer thickness of the coating may be 1.5-25 μm, or 2-20 μm, or 2-15 μm, or 2-10 μm, or 3-10 μm. The silicon oxide, SiO_x, may have an atomic ratio of O/Si = 1.5-3, or may have an atomic ratio of O/Si = 2-2.5. The coating may have a content of carbon of 20-60 atomic% or 30-40 atomic%. The heat exchanger may comprise a gasket that is at least partially coated with the coating. The first heat transfer plate and the second heat transfer plate may be made of stainless steel.

[0012] Further features, objectives, aspects and advantages of the invention will appear from the following detailed description as well as from the drawings.

Brief Description of the Drawings

[0013] Embodiments of the invention will now be described, by way of example, with reference to the accompanying schematic drawings, in which

Fig. 1 is an exploded view of a block-type heat exchanger with a stack of heat transfer plates,
 Fig. 2 is a top view of pairs of heat transfer plates that are used for the stack of heat transfer plates of Fig. 1,
 Fig. 3 is a cross-sectional view along section A-A of Fig. 2,
 Fig. 4 is a cross-sectional view along section B-B of Fig. 2,
 Fig. 5 is an enlarged view of section C of Fig. 3, and
 Fig. 6 is a schematic, cross-sectional view of a coated heat transfer plate that is part of the stack of heat transfer plates of Fig. 1.

Detailed description

[0014] With reference to Fig. 1 a plate heat exchanger 2 of a block-type is shown. The plate heat exchanger 2 comprises a top head 15, a bottom head 16 and four side panels 11, 12, 13, 14 that are bolted together with a set of (typically four) corner girders 21-24 for assembling the plate heat exchanger 2. When assembled, the plate heat exchanger 2 has a box-like or block-like shape and an enclosure is formed by the top head 15, the bottom head 16 and the side panels 11-14. A stack of heat transfer plates 30 is arranged within the enclosure and comprises, as will be described in further detail, a number of pairs of heat transfer plates. The stack of heat transfer plates 30 also has a box-like or block-like shape, which shape corresponds to the shape of the enclosure formed by the heads 15, 16 and the side panels 11-14. The stack of heat transfer plates 30 has at its corners four linings 31-34 that are arranged to face the corner girders 21-24.

[0015] The assembly of the plate heat exchanger 2 is typically performed by using conventional methods and bolts (not shown) that attach the mentioned components to each other via bolt holes like holes 35 and 36. In brief, assembling the plate heat exchanger 2 includes arranging the stack of heat transfer plates 30 on the bottom head 16, sliding the corner girders 21-24 into the linings 31-34 and bolting them to the bottom head 16. A channel end plate 38 is arranged on top of the stack of heat transfer plates 30 and the top head 15 is bolted to the corner girders 21-24. Thereafter the side panels 11-14 are bolted to the corner girders 21-24 and to the heads 15, 16. Generally, the plate heat exchanger 2 also has a base 17 that facilitates attachment of the plate heat exchanger 2 to the ground.

[0016] Gaskets, such e.g. gasket 131, are arranged on the side panels 11-14 at sections that face the corner girders 21-24 and the heads 15, 16, such that the enclosure formed by the heads 15, 16 and side panels 11-14 is properly sealed for preventing leakage from the plate heat exchanger 2.

[0017] A first side panel 11 and a second side panel 12 of the side panels 11-14 comprise inlets and outlets for two fluids. In detail, the first side panel 11 has an inlet 41 and an outlet 42 for a first fluid. The inlet 41 and outlet 42 of the first panel 11 form a flow path for the first fluid in combination with the stack of heat transfer plates 30, where the flow path extends from the inlet 41, within the stack of heat transfer plates 30 and to the outlet 42. This flow path is illustrated by the broken arrows that extend in directions parallel to the direction D1. Conventional baffles, such as baffle 39, are connected to sides of the stack of heat transfer plates 30 for directing the flow of the first fluid in a number of passes within the stack 30 (four passes in the illustrated figure).

[0018] The second side panel 12 has an inlet 43 and an outlet 44 for a second fluid. The inlet 43 and outlet 44 of the second side panel 12 form a flow path for the second fluid in combination with the stack of heat transfer plates 30, where

the flow path extends from the inlet 43, within the stack of heat transfer plates 30 and to the outlet 44. This flow path is illustrated by the broken arrows that extend in directions parallel to the direction D2. Conventional baffles connected to sides of the stack of heat transfer plates 30 direct the flow of the second fluid in a number of passes within the stack 30 (here the same number of passes as for the first fluid).

[0019] The arrangement of baffles is per se accomplished by employing conventional techniques. However, the first flow path for the first fluid is between the pairs of heat transfer plates in the stack 30, while the second flow path for the second fluid is within the pairs of heat transfer plates in the stack 30. A pair of heat transfer plates comprises a first heat transfer plate and a second heat transfer plate, as will be described further on. This means that the flow of the first fluid is between heat transfer plates of different pairs of heat transfer plates, while the flow of the second fluid is between a first and a second heat transfer plate of the same pair, i.e. within a pair. The linings 31-34 seal the corners of the stack of heat transfer plates 30, which ensures that the two different fluids paths are separated.

[0020] With reference to Figs 2, 3 and 4 a first and a second pair 50, 60 of heat transfer plates are exemplified, where Fig. 3 is a cross-sectional view along section A-A of Fig. 2 and Fig. 4 is a cross-sectional view along section B-B of Fig. 2. The pairs 50, 60 of heat transfer plates are part of the stack of heat transfer plates 30 illustrated in Fig. 1. The stack 30 comprises a number of pairs of heat transfer plates that are similar to the pairs 50, 60, such as 4-200 pairs or even more.

[0021] For the pairs 50, 60 of heat transfer plates exemplified by Figs 2, 3 and 4, the first pair 50 of heat transfer plates comprises a first heat transfer plate 51 and a second heat transfer plate 52. The second pair 60 of heat transfer plates is typically similar to the first pair 50 of heat transfer plates, which means that it also comprises a first heat transfer plate 61 and a second heat transfer plate 62. Thus, the first heat transfer plate 61 of the second pair 60 of heat transfer plates is typically similar to the first heat transfer plate 51 of the first pair 50 of heat transfer plates, while the second heat transfer plate 62 of the second pair 60 of heat transfer plates may be similar to the second heat transfer plate 52 of the first pair 50 of heat transfer plates.

[0022] Also, the first heat transfer plate 51 and the second heat transfer plate 52 of the first pair 50 of heat transfer plates have similar shapes.

[0023] Each heat transfer plate has, as exemplified by the first heat transfer plate 51 of the first pair 50 of heat transfer plates, a rectangular shape with a first 511, a second 512, a third 513 and a fourth elongated side 514. When the stack of heat transfer plates 30 is arranged within the enclosure of the plate heat exchanger 2, the first elongated side 511 is facing the first side panel 11 while the third side 513 is facing the third side panel 13. The first heat transfer plate 51 is joined with the second heat transfer plate 52 via a joint 78 at the first elongated side 511 and via a joint 79 at the third elongated side 513, as may be seen in Fig. 3.

[0024] The first heat transfer plate 51 comprises sets of corrugations 101-106 that are arranged on respective sides of elongated joints 72-76 that join the first and second heat transfer plates 51, 52. It may also be said that the corrugations 101-106 are separated by the elongated joints 72-76. The sets of corrugations 101-106 extend a direction that is parallel to the joints 72-76, which direction in the exemplified embodiment is parallel to the direction D2. The sets of corrugations 101-106 have two outermost sets of corrugations 101, 106, and further joints 71, 77 may be arranged intermediate the outer sets of corrugations 101, 106 and the corresponding, closest elongated side 513, 511. As previously indicated, since all heat transfer plates may be similar, all or some of the heat transfer plates of the stack of heat transfer plates 30, such as plates 52, 61 and 62, may have the same properties and structural shape as plate 51.

[0025] The corrugations 101-106 comprise ridges and grooves that extend in a direction D1 that is 45°-90° transverse a direction D2 along which the elongated joints 71-77 extend. The directions D1, D2 are here the same directions as previously discussed in respect of the flow of the first and second fluid. Corrugations 101, 102 on the first heat transfer plate 51 and corresponding corrugations 201, 202 on the second heat transfer plate 52 each comprise ridges and grooves, such as ridge 92 and groove 93 of the first heat transfer plate 51 and ridge 192 and groove 193 of the second heat transfer plate 52.

[0026] The first pair 50 of heat transfer plates comprises elongated joint grooves, as exemplified by joint grooves 81-87 of the first heat transfer plate 51, along which the elongated joints 71-77 are arranged. Each corrugation of the set of corrugations 101-106 comprising ridges and grooves that extend in a direction D1 that is transverse a direction D2 along which the elongated joint grooves 81-87 extend.

[0027] The ridges of the first heat transfer plate 51 may be aligned with the ridges of the second heat transfer plate 52, as seen in a direction parallel to a normal direction N of the first pair 50 of heat transfer plates. This is advantageous in that efficient heat transfer and flow of fluid may be accomplished.

[0028] As shown, the joints 71-77 are arranged in a respective joint groove 81-87. Since the second heat transfer plate 52 is similar to the first heat transfer plate 51 it also comprises elongated joint grooves along which the elongated joints 71-77 are arranged.

[0029] With reference to Fig. 3 and to Fig. 5 illustrating the enlarged section C of Fig. 3, it is shown that e.g. joint groove 82 of the first heat transfer plate 51 abut a corresponding joint groove 182 of the second heat transfer plate 52. The heat transfer plates 51, 52 are then joined at the joint grooves 82, 182 by virtue of the joint 72. In this context, a backside surface 515 of the joint groove 82 of the first heat transfer plate 51 is in contact with a backside surface 525

of the joint groove 182 of the second heat transfer plate 52.

[0030] The joints are typically formed by welding but may also be formed by brazing or by some other, suitable means of joining. The heat transfer plates 51, 52, 61, 62 are typically made of metal, such as stainless steel. When welding is used for forming the joints, i.e. when the joint are welds, laser welding may be used as well as other welding techniques, such as resistance welding.

[0031] Each of the joints 71-77 may comprise two at least partially overlapping joint sections, as exemplified by a first section 721 and a second section 722 of the joint 72. The joint sections 721, 722 may be overlapping by a predetermined distance, such as 5-30 mm. The two joint sections 721, 722, or welding sections when the joints are formed by welding, may begin at a respective end section of the joint groove, as illustrated by the two end sections 821, 822 of joint groove 82.

[0032] As indicated, the joining of the first heat transfer plate 51 with the second heat transfer plate 52 at the first and third elongated sides 511, 513 may be accomplished by a first set of opposite, elongated side joints 78, 79, such that a flow path 57 for the second fluid is formed between the first set of opposite, elongated side joints 78, 79, i.e. within the first pair 50 of heat transfer plates. The flow path 57 is then parallel to the direction D2 discussed in connection with Fig. 1.

[0033] For facilitating joining of the plates in a pair 50, the first and second heat transfer plates 51, 52 have peripheral sections like sections 53, 54 that are folded towards each other. The peripheral sections 53, 54 are folded towards each other since the second heat transfer plate 52 is arranged as an inverted mirror-image of the first heat transfer plate 51, having in mind that the plates 51, 52 are similar. The related weld 79 is applied at a contact surface formed between the folded sections 53, 54.

[0034] The joint grooves 81-87 may extend unbroken along the flow path 57 that is formed between the first and second heat transfer plates 51, 52. Also since the first heat transfer plate 51 and the second heat transfer plate 52 are typically joined by multiple elongated joints 71-77, the flow path 57 for the second fluid formed between the first and second heat transfer plates 51, 52 comprises multiple parallel flow channels 571-576.

[0035] To form the stack of heat transfer plates 30, pairs of heat transfer plates like the first pair 50 of heat transfer plates and the second pair 60 of heat transfer plates are joined via opposite, elongated side joints. Such joints are exemplified by a set of opposite, elongated side joints 781, 782 arranged between the first pair 50 of heat transfer plates and the second pair 60 of heat transfer plates. Such elongated side joints 781, 782 are transverse the first set of elongated side joints 78, 79 and joins a pair of heat transfer plates (exemplified by pair 50) with an adjacent pair of heat transfer plates (exemplified by pair 60). For facilitating joining, the plates 51, 52, 61, 62 have respective peripheral sections that are folded towards a heat transfer plate that belongs to another pair of heat transfer plates, such as folded sections 56 and 65. The related weld 781 is applied at a contact surface formed between the folded sections 56, 65.

[0036] When the pairs 50, 60 of heat transfer plates are joined, a flow path 67 for the first fluid is formed between the pairs 50, 60 of heat transfer plates. Since the pairs 50, 60 are joined only at the second set of side joints 781, 782 a so called free-flow path is formed between the joints 781, 782, i.e. a free-flow path is formed between the pairs 50, 60 of heat transfer plates. A free-flow path may in this context be defined as a flow path without any contact points intermediate the side joints 781, 782. Generally, free-flow has been observed to be advantageous since occurrence of e.g. deposits from the fluid or the presence of bacteria may be reduced or, in practice, even eliminated.

[0037] To form the complete stack of heat transfer plates 30, a number of pairs of heat transfer plates are stacked adjacent each other and joined to each other in a manner like the joining of the first and the second pairs 50, 60 of heat transfer plates. The joining of the pairs may be accomplished by using the same methods (welding, brazing etc.) as when joining the plates of one pair.

[0038] For efficiently joining the heat transfer plates to the linings 31-34 each heat transfer plate has four protrusions at its corners, such as protrusions 515-518 of the first heat transfer plate 51. The protrusions are then joined to the linings 31-34 by e.g. welding, brazing or by some other suitable means of joining. The linings 31-34 partially surround the set of corner girders 21-24 when the plate heat exchanger 2 is assembled, such that the stack of heat transfer plates 30 is firmly fixed within the enclosure that is formed by the heads 15, 16 and the side panels 11-14.

[0039] The heat transfer plates 51, 52, 61, 62 may per se be manufactured from steel sheets that are pressed with a press tool that forms the corrugations and the weld grooves. A cutting machine thereafter cuts the pressed plates along their periphery and the edges of the cut plates are folded in a machine that forms the folded, peripheral sections.

[0040] The heat transfer plates in the stack of heat transfer plates 30 comprises a coating. The coating may be referred to as a non-stick coating and makes it easy to clean the plates. The coated plates provide improved heat transfer over time compared to conventional heat transfer plates since the latter gets fouled much quicker, which decreases the heat transfer performance to a larger extent. The coating also results in a much more even surface on the plates, which gives better flow characteristics. Also, a pressure drop over the plates is reduced over time for the plate heat exchanger 2 in comparison with conventional block-type plate heat exchangers, since the buildup of impurities, microorganisms and other substances is reduced.

[0041] The coated plates may easily be cleaned by using high pressure washing with water. Moreover, there is no need for extensive, time consuming mechanical cleaning or cleaning using strong acids, bases or detergents, such as e.g. NaOH and HNO₃.

[0042] The heat transfer plates in the stack 30 are in a sol-gel process coated with a coating that comprises organosilicon compounds. The organosilicon compounds are starting materials that are used in the sol-gel process and are preferably silicon alkoxy compounds. In the sol-gel process a sol is converted into a gel to produce nano-materials. Through hydrolysis and condensation reactions a three-dimensional network of interlayered molecules is produced in a liquid. Thermal processing stages are then used to process the gel further into nano-materials or nanostructures, which results in a final coating. The coating comprising said nano-materials or nanostructures mainly comprise silicon oxide, SiO_x , having an atomic ratio of $\text{O/Si} > 1$, alternatively an atomic ratio within the range of $\text{O/Si} = 1.5-3$, or alternatively within the range of $\text{O/Si} = 2-2.5$. By an "atomic ratio of $\text{O/Si} > 1$ " is meant that the number of Oxygen atoms (O) of the silicon oxide (SiO_x) divided by the number of Silicon atoms (Si) of the silicon oxide (SiO_x) is larger than one. Correspondingly, for the alternatives the number of Oxygen atoms (O) divided by the number of Silicon atoms is within the range of 1.5-3, or within the range of 2-2.5.

[0043] A preferred silicon oxide is silica, SiO_2 . The siliconoxide forms a three dimensional network having excellent adhesion to the plates. All heat transfer plates of the stack 30, such as the first heat transfer plate 51 and the second heat transfer plate 52, may be coated. Typically the plates are coated on the sides that face either one or both of the flow path for the first fluid and the flow path for the second fluid.

[0044] The coating has a content of carbon originating from hydrocarbon chains. The hydrocarbons chains may have functional groups such as those found in hydrocarbon chains or aromatic groups, e.g. $\text{C}=\text{O}$, $\text{C}-\text{O}$, $\text{C}-\text{O}-\text{C}$, $\text{C}-\text{N}$, $\text{N}-\text{C}-\text{O}$, $\text{N}-\text{C}=\text{O}$, etc. Preferably the content of the carbon is ≥ 10 atomic%, or in the range of 20-60 atomic%, or in the range of 30-40 atomic%. The carbon impart flexibility and resilience to the coating which is important if the plates during operation flex due to high pressures exerted on the plates in the stack 30. The hydrocarbon chains are hydrophobic and oleophobic, which results in the non-stick properties of the coating.

[0045] With reference to Fig. 6 a schematic view is shown where the first heat transfer plate 51 is provided with a siliconoxide sol gel coating 701 as described above. The coating is also referred to as siliconoxide layer 701. Closest to the plate 51 the siliconoxide layer 701 forms an interface 702 between the coating siloxane and a metal oxide film of the plate 51. A bulk of the coating 701 is the siloxane network 703 that has organic linker chains and voids that impart flexibility to the coating 701. The siloxane network 703 is "on top" of the interface 702. The siliconoxide layer 701 forms an outermost layer in front of a functional surface 704 that has hydrophobic and oleophobic properties that reduce fouling. There are no sharp boundaries between the interface 702 and the siloxane network 703 respectively the siloxane network 703 and the functional surface 704, but rather gradual transitions

[0046] All plates in the stack 30 that are coated may have the coating described in connection with Fig. 6. The coating is both durable and flexible and provides a plate for a block-type plate heat exchanger that has excellent non-stick properties and wear-and crack-resistance.

[0047] In one embodiment at least one sol comprising organosilicon compounds is applied to the surface of the heat transfer plates that are coated. The surface may be wetted/coated with the sol in any suitable way. The surface coating may e.g. be applied by spraying, dipping or flooding. Typically, all surfaces of a heat transfer plate that is in contact with a fluid that may cause fouling are coated. Also, the gaskets like gasket 131 arranged on the side panels 11-14 may be coated, typically with the same type of coating that is used for the heat transfer plates. The coating is then typically applied at least on the surfaces of the gaskets that are in contact with the fluid that may cause fouling.

[0048] A method of coating the heat transfer plates of the stack 30 comprises pretreatment of at least the surfaces on the heat transfer plates to be coated. This pretreatment may be carried out by means of dipping, flooding or spraying. The pretreatment is used to clean the surfaces to be coated in order to obtain increased adhesion of the coating. Examples of pretreatments are treatment with acetone and/or alkaline solutions, e.g. caustic solution.

[0049] The method of coating the heat transfer plates may comprise thermal processing stages, e.g. a drying operation may be carried out after a pretreatment and a drying and/or curing operation may be used after the coating of the plate has taken place. The coating may be subjected to heat by using conventional heating apparatuses, such as ovens.

[0050] The coating, which as indicated comprises SiO_x , is applied to the plates of the stack 30. The application of the coating is done by means of sol-gel processing. The coating is preferably between 1 and 30 μm thick. A coating thickness below 1 μm is considered being not enough wear resistant since the plates in the plate heat exchanger 2 are able to flex slightly during operation. Flexing of the plates causes wear on the coating and with time the coating wear down. Still, the thickness of the coating has an upper limit since the application of substances on the heat transfer plates influences their heat transfer capability and thus the overall performance of the plate heat exchanger. The upper limit for the thickness of the coating is preferably 30 μm . Thus, the coating thickness of the silicon oxide sol containing coating is 1-30 μm , and in alternatives preferably 1.5-25 μm , preferably 2-20 μm , preferably 2-15 μm , preferably 2-10 μm or preferably 3-10 μm .

[0051] The material of which the heat transfer plates in the stack 30 are made of may be chosen from several metals and metal alloys. Preferably, the material is stainless steel or titanium. The material may also be chosen from nickel, copper, any alloys of the mentioned metals and/or carbon steel.

[0052] In an attempt to find more a foul resistant block-type plate heat exchanger, tests were conducted on two low

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surface energy glass ceramic coatings of which both are of the type of coating described above. The tested coatings are referred to as Coat 1 and Coat 2. The tests, the analysis and the results are presented below. Coat 1 is a silan terminated polymer in butyl acetate and Coat 2 is a polysiloxan-urethan resin in solvent naphtha/butylacetate. The test were performed on coated heat transfer plates in the stack 30. In the following a plate for which tests is performed is also referred to as "substrate".

[0053] The tests shows properties of the coatings in respect of substrate wetting, substrate adhesion, contact angle, coating thickness and stability against 1.2 % HNO₃ in H₂O, 1 % NaOH in H₂O and crude oil. The results are summarized below in Table 1.

Table 1

	Coat 1	Coat 2
Substrate wetting	Excellent	Excellent
Substrate adhesion	Al: 0/0 Stainless steel: 0/0 Ti: 0/0 (see below)	Al: 0/0 Stainless steel: 0/0 Ti: 0/0 (see below)
Contact angle measurements	H ₂ O: 102-103°	H ₂ O:102-103°
Coating thickness	4-10 μm	2-4 μm
Stability	1.2 % HNO ₃ in H ₂ O: 1½ h at 75 °C 1% NaOH in H ₂ O: 3 h at 85 °C Crude oil: 6 months at 20 °C	1.2 % HNO ₃ in H ₂ O: 1½ h at 75 °C 1 % NaOH in H ₂ O: 2 h at 85 °C Crude oil: 6 months at 20 °C

[0054] Both coatings showed excellent wetting when spray coated onto either stainless steel or titanium substrates.

[0055] Adhesion was determined by cross-cut/tape test according to the standard DIN EN ISO 2409. Rating is from 0 (excellent) to 5 (terrible). 0 or 1 is acceptable while 2 to 5 is not. First digit indicates rating after cross cut (1 mm grid) and the second digit gives rating after tape has been applied and taken off again.

[0056] To obtain proper adhesion for Coat 1 and Coat 2 the substrates were subjected to pre-treatment. To obtain a proper adhesion of Coat 1 on stainless steel the substrate was pre-treated by submerging it in an alkaline cleaning detergent for 30 minutes. Next the substrate was washed with water and demineralized water and dried before Coat 1 was applied (applied within half an hour to achieve optimal adhesion). Tests have shown that the adhesion is reduced if cleaning of the substrate is only carried out with acetone. Pre-treatment was also used for stainless steel substrates that are coated with Coat 2. This coating displayed unaffected adhesion whether an alkaline detergent or acetone was used as pre-treatment or not. If the pre-treatment step is neglected or not properly made the coating adhesion will be effected.

[0057] Both coatings showed good stability under acidic condition. The coatings were stable for 1 ½ hours at 75 °C and more than 24 hours at room temperature.

[0058] Under alkaline conditions Coat 1 showed a better result than Coat 2. Coat 1 could withstand the alkaline conditions for 3 hours at 85 °C and Coat 2 for 2 hours at 85 °C. Both coatings showed no decomposition or reduction in oleophobic properties after being subjected to crude oil for 6 months at a temperature of 20 °C.

[0059] Heat transfer plates in the stack 30 were then coated with Coat 1 and Coat 2. The heat exchanger plates were in this test made of titanium and the heat exchanger 2 was used in a crude oil application. All coated heat transfer plates underwent pre-treatment, which comprised treatment with acidic and alkaline solutions to remove fouling and high pressure washing of the plates with water. The plates were left to dry before application of coating.

[0060] The pre-treatment was completed a day before Coat 1 and Coat 2 were applied to the plates. As the plates have been left to dry at ambient temperature (approximately cover 20 °C), some plates were still wet. More precisely, a third of the plates were coated with Coat 1 and a third of the plates were coated with Coat 2, while a remaining third of the plates were kept uncoated. The coating is accomplished by spraying the respective coat into the flow paths 57, 67 that are formed by the plats in the stack 30, such that the sides of the that faces the flow paths are coated. The thickness of the coating was measured to be 2-4 μm. Curing/drying for the two coatings was performed for 1 ½ hours in an oven at elevated temperatures of 200 °C respectively 160 °C.

[0061] The stack 30 with the coated heat transfer plates were then arranged in the heat exchanger of Fig. 1 and an evaluation of the coated plates was performed after about seven months of operation of the plate heat exchanger 2.

[0062] The plates were analyzed after the seven months. In detail, three different silicon oxide-coated heat transfer plates were analyzed by means of XPS (X-ray Photoelectron Spectroscopy), also known as ESCA (Electron Spectroscopy for Chemical Analysis). The XPS method provides quantitative chemical information, including a chemical composition

expressed in atomic% for the outermost 2-10 nm of a surface.

[0063] A measuring principle of the XPS method comprises that a sample (i.e. a heat transfer plate coated with Coat 1, a heat transfer plate coated with Coat 2 and an uncoated plate) is placed in high vacuum and is irradiated with well defined x-ray energy, which results in an emission of photoelectrons from the sample. Only photoelectrons from the outermost surface of the sample reach the detector. By analyzing the kinetic energy of the photoelectrons, their binding energy can be calculated, thus giving their origin in relation to a chemical element (including the electron shell) of the sample.

[0064] XPS provided quantitative data on both the elemental composition and different chemical states of a chemical element of the sample (such as different functional groups, chemical bonding, oxidation state, etc). All chemical elements except hydrogen and helium are detected and the obtained chemical composition of the sample is expressed in atomic%.

[0065] XPS spectra were recorded using a Kratos AXIS Ultra^{DLD} x-ray photoelectron spectrometer. The samples were analyzed using a monochromatic Al x-ray source. The analysis area was below 1mm². In the analysis so a called wide spectra run was performed to detect chemical elements present in the surface of the sample. The relative surface compositions were obtained from quantification of each chemical element.

[0066] When heat transfer plates with different types (in respect of a content of C, O and Si) of the silicon oxide coating described herein are analyzed, or more precisely when the chemical elements of the coating is analyzed, a relative surface composition in atomic% and an atomic ratio O/Si may be found. It has then been observed that mainly C, O and Si may be detected on the outermost surfaces of the coating. A content of C is typically 41.9-68.0 atomic%, a content of O is 19.5-34.3 atomic% while a content of Si is 8.6-23.4 atomic%. The atomic ratio O/Si is 1.46-2.30. Note that for the atomic ratio O/Si, the total amount of oxygen is used. This means that also oxygen in functional groups with carbon is included. Otherwise, for silica a theoretical ratio O/Si of 2.0 is expected (i.e. SiO_x in form of SiO₂).

[0067] After four months of operation a pre-inspection by thermo-imaging was performed. A thermo-image was taken of a mid region of the heat exchanger 2 when the heat exchanger was operated. From the image it was obvious that some heat transfer plates show increased heat transfer compared to other heat transfer plates in the heat exchanger.

[0068] The inspection showed an elevated temperature at the coated plates. The non-coated plates showed a lower operating temperature. The difference in temperature is an effect of different fouling, where coated plates has elevated temperatures.

[0069] A visual inspection revealed that the plates with the coating designated Coat 1 was covered with the least amount of fouling on the crude oil facing plate side. Also, Coat 2 had a reduced amount of fouling on the crude oil facing plate side compared to the bare titanium surface, but to a lesser extent than Coat 1. The bare titanium plates were completely covered in a thick layer of crude oil that "fouled" the plates. The term "fouling" is here used to describe deposits formed on the heat transfer plates during operation. The fouling is residues and deposits formed by the crude oil and consists of a waxy, organic part and a mineral/inorganic part.

[0070] By subtracting the average weight of a clean plate from the weight recorded for the individual fouled plates the average amount of fouling per surface type was calculated (table 2). The weight of the coating was not compensated for and so the real fouling reduction is slightly higher. For the heat transfer plates used in the test the heat transfer surface is 0.85 m², so for a plate with a 4 μm thick coating on both sides the total volume of coating material is around 6.8 cm³. If the coating is estimated to be pure SiO₂ (density 2.6 g/cm³) then the amount of coating per plate is about 20 g.

Table 2

Surface	Average fouling (g)	Fouling reduction (%)
Titanium	585	-
Coat 1	203	65
Coat 2	427	27

[0071] For both Coat 1 and Coat 2 the fouling of the plates were more easily removed compared to the fouling on bare titanium plates, see Table 3. The difference in cleaning requirements was tested by manually wiping of the plates with a tissue and by high pressure water cleaning. Just wiping the plates with a tissue showed that the fouling was very easily removed from the coated plates, contrary to the uncoated plates. By using high pressure water cleaning all fouling except for one or two small patches could be removed from the Coat 1 coated surface. On the Coat 2 coated surface somewhat more fouling was present after water jet cleaning. This fouling had the form of slightly burnt oil. The coating was in a good condition. The crude oil has passed through the first flow path of the heat exchanger 2, while sea water has passed through the second flow path. On plate surfaces that face the seawater both coatings had deteriorated.

Table 3

	Coat 1	Coat 2	Uncoated
View	very little fouling	reduced fouling	fouling significant and widespread
Wipe with tissue	very easy to remove fouling	very easy to remove fouling	fouling was not removed
High pressure water washing	the plates appeared as new	most of the fouling was removed	even after attempts of manual removal of fouling, still a considerable layer remains

[0072] The coatings resistance to cold conditions was tested submerging the plates in liquid nitrogen having a temperature of -196 °C. Next the plates were washed by high pressure water, which removed almost all fouling. No coating failure was observed for either Coat 1 or Coat 2.

[0073] Turning back to Fig. 1, 2 and 4, the plate heat exchanger 2 has predetermined measurements for a number of the components it comprises. For example, the first heat transfer plate and the second heat transfer plate may have a thickness m1 of 0,6-1,4 mm or 0,8-1,2. Each of the first heat transfer plate and the second heat transfer plate may have a heat transfer area m2 of 0,05-0,30 m² or 0,6-1,8 m². Any of the top head and the bottom head may have a thickness m3 of 45-145 mm or 190-250 mm. Each of the four side panels may have a thickness m4 of 35-85 mm or 65-175 mm. Each of the corner girders may comprise a cross-sectional side m5 that measures 35-85 mm or 110-190 mm. Finally, the sealed enclosure may have a volume of maximum 0,02-0,40 m³ or 0,7-5,0 m³. As explained, these measurements provides, each alone or in combination, conditions where the heat transfer plates in the stack 30 flex less which allows the coating to remain on the heat transfer plates for a longer period of time. Still, the components are not unnecessarily over-dimensioned but the measurements has been optimized in respect of allowing the coating to remain for a longer period of time while still assuring that reasonable amounts of materials are used for the heat exchanger 2.

[0074] In detail, the measurements m1-m5 may be optimized in respect of each other. For example, in one embodiment the first heat transfer plate and the second heat transfer plate have a thickness of 0,7-0,9 mm and a heat transfer area of 0,02-0,035 m², while any of the top head and the bottom head has a thickness of 35-45 mm, each of the four side panels may has a thickness of 35-45 mm, each of the corner girders comprises a cross-sectional side that measures 35-45 mm, and the sealed enclosure has a volume of 0,005-0,020 m³.

[0075] In another embodiment the first heat transfer plate and the second heat transfer plate have a thickness of 0,7-0,9 mm and a heat transfer area of 0,05-0,07 m², while any of the top head and the bottom head has a thickness of 45-55 mm, each of the four side panels may has a thickness of 35-65 mm, each of the corner girders comprises a cross-sectional side that measures 45-55 mm, and the sealed enclosure has a volume of 0,02-0,06 m³.

[0076] In another embodiment the first heat transfer plate and the second heat transfer plate have a thickness of 0,7-0,9 mm and a heat transfer area of 0,09-0,11 m², while any of the top head and the bottom head has a thickness of 45-55 mm, each of the four side panels may has a thickness of 35-65 mm, each of the corner girders comprises a cross-sectional side that measures 45-55 mm, and the sealed enclosure has a volume of 0,04-0,22 m³.

[0077] In another embodiment the first heat transfer plate and the second heat transfer plate have a thickness of 0,9-1,1 mm and a heat transfer area of 0,13-0,19 m², while any of the top head and the bottom head has a thickness of 60-80 mm, each of the four side panels may has a thickness of 45-85 mm, each of the corner girders comprises a cross-sectional side that measures 55-65 mm, and the sealed enclosure has a volume of 0,12-0,26 m³.

[0078] In another embodiment the first heat transfer plate and the second heat transfer plate have a thickness of 0,9-1,1 mm and a heat transfer area of 0,24-0,30 m², while any of the top head and the bottom head has a thickness of 120-160 mm, each of the four side panels may has a thickness of 45-85 mm, each of the corner girders comprises a cross-sectional side that measures 65-105 mm, and the sealed enclosure has a volume of 0,2-0,6 m³.

[0079] In another embodiment the first heat transfer plate and the second heat transfer plate have a thickness of 0,9-1,1 mm and a heat transfer area of 0,50-0,80 m², while any of the top head and the bottom head has a thickness of 170-230 mm, each of the four side panels may has a thickness of 90-160 mm, each of the corner girders comprises a cross-sectional side that measures 100-140 mm, and the sealed enclosure has a volume of 1,0-2,4 m³.

[0080] In another embodiment the first heat transfer plate and the second heat transfer plate have a thickness of 1,1-1,3 mm and a heat transfer area of 1,4-2,0 m², while any of the top head and the bottom head has a thickness of 120-400 mm, each of the four side panels may has a thickness of 110-250 mm, each of the corner girders comprises a cross-sectional side that measures 120-240 mm, and the sealed enclosure has a volume of 2,4-5,9 m³.

[0081] From the description above follows that, although various embodiments of the invention have been described

and shown, the invention is not restricted thereto, but may also be embodied in other ways within the scope of the subject-matter defined in the following claims. For example, optimization calculations may show that other measurements for components of the heat exchanger may provide a structure that allows the coating to remain on the coated surface for long period of time. Also, the heat transfer plates may have another pattern of corrugation than the shown one. In other embodiments the elongated joints and their associated joint grooves on the heat transfer plates may be omitted such that e.g. corrugations cover the heat transfer areas of the plates.

Claims

1. A plate heat exchanger comprising a top head (15), a bottom head (16) and four side panels (11-14) that are bolted together with a set of corner girders (21-24) to form a sealed enclosure, and a stack of heat transfer plates (30) that is arranged in the sealed enclosure, the stack of heat transfer plates (30) comprising pairs (50, 60) of heat transfer plates that are stacked such that a flow path (67) for a first fluid is formed between the stacked pairs (50, 60) of heat transfer plates, wherein a pair (50) of the stacked pairs (50, 60) of heat transfer plates comprises a first heat transfer plate (51) and a second heat transfer plate (52) that are joined such that a flow path (57) for a second fluid is formed between the first and second heat transfer plates (51, 52), **characterized in that** first heat transfer plate (51) and the second heat transfer plate (52) comprise a coating (701) that has a layer thickness of 1-30 μm , is prepared by sol-gel processing, comprises silicon oxide (SiO_x) having an atomic ratio of $\text{O/Si} > 1$, and comprises ≥ 5 atomic percent carbon (C).
2. A heat exchanger according to claim 1, wherein the first heat transfer plate (51) and the second heat transfer plate (52) has a thickness (m_1) of 0,6-1,4 mm or 0,8-1,2 mm.
3. A heat exchanger according to any one of claims 1 - 2, wherein each of the first heat transfer plate (51) and the second heat transfer plate (52) has a heat transfer area (m_2) of 0,05-0,30 m^2 or 0,6-1,8 m^2 .
4. A heat exchanger according to any one of claims 1 - 3, wherein any of the top head (15) and the bottom head (16) has a thickness (m_3) of 45-145 mm or 190-250 mm.
5. A heat exchanger according to any one of claims 1 - 4, wherein each of the four side panels (11-14) has a thickness (m_4) of 35-85 mm or 65-175 mm.
6. A heat exchanger according to any one of claims 1 - 5, wherein each of the corner girders (21-24) comprises a cross-sectional side (m_5) that measures 35-85 mm or 110-190 mm.
7. A heat exchanger according to any one of claims 1 - 6, wherein the sealed enclosure has a volume of 0,02-0,40 m^3 or 0,7-5,0 m^3 .
8. A heat exchanger according to any one of claims 1 - 7, wherein the layer thickness of the coating is 1.5-25 μm , or 2-20 μm , or 2-15 μm , or 2-10 μm , or 3-10 μm .
9. A heat exchanger according to any one of claims 1 - 8, wherein the silicon oxide, SiO_x , has an atomic ratio of $\text{O/Si} = 1.5-3$, or has an atomic ratio of $\text{O/Si} = 2-2.5$.
10. A heat exchanger according to any one of claims 1 - 9, wherein the coating has a content of carbon of 20-60 atomic% or 30-40 atomic%.
11. A heat exchanger according to any one of claims 1 - 10, comprising a gasket (131) that is at least partially coated with the coating.
12. A heat exchanger according to any one of claims 1 - 11, wherein the first heat transfer plate (51) and the second heat transfer plate (52) are made of stainless steel.

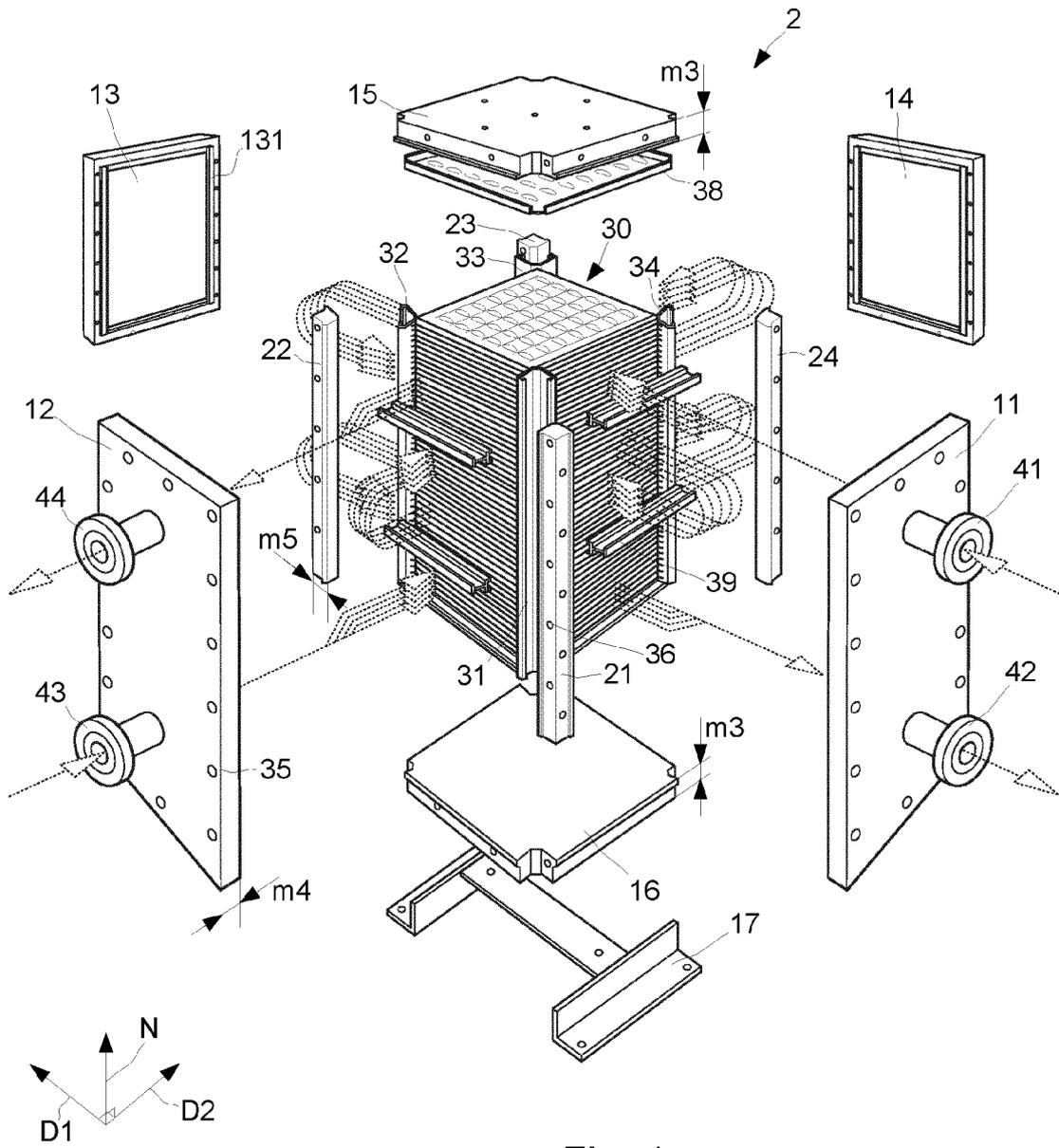


Fig. 1

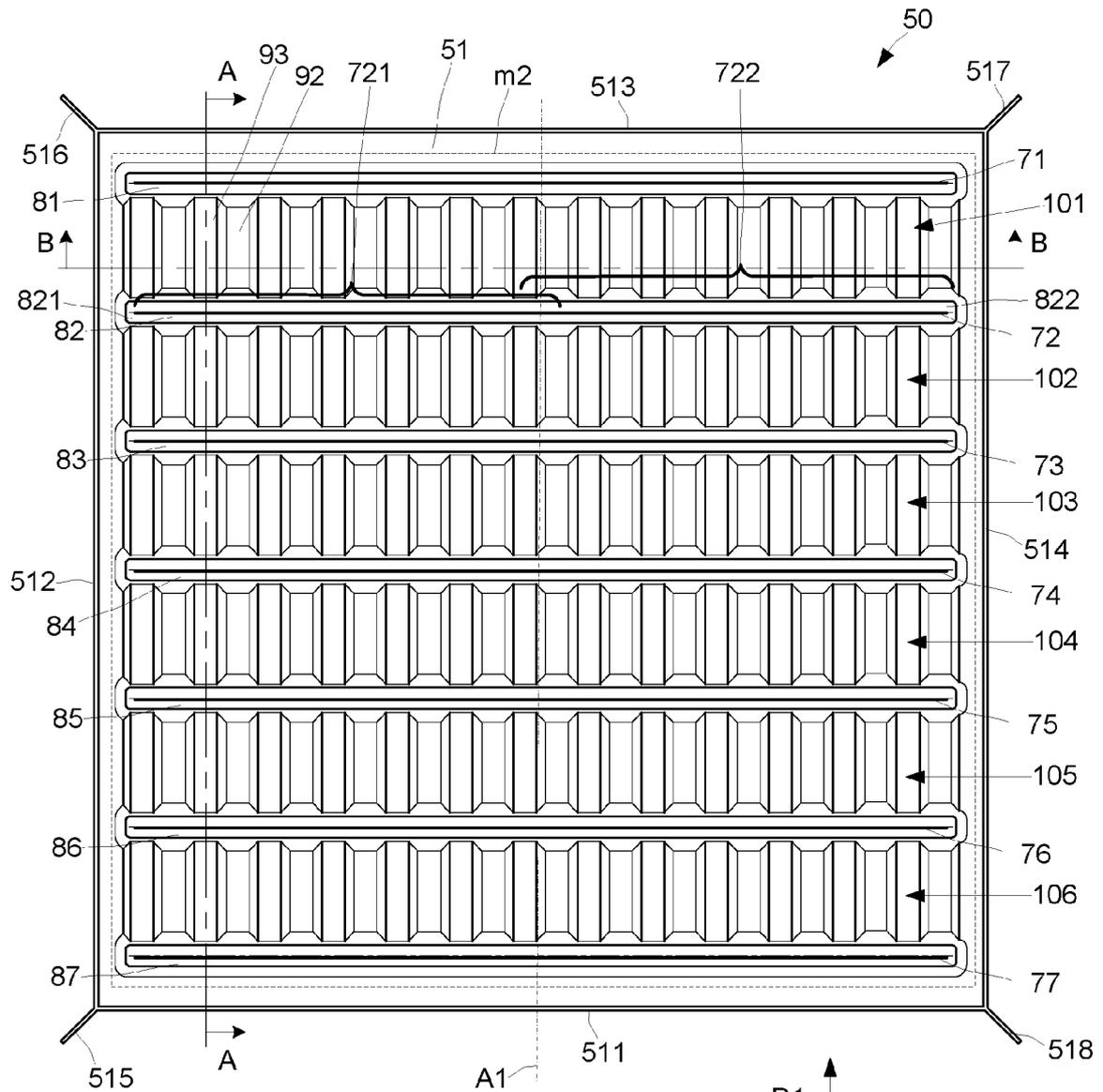


Fig. 2

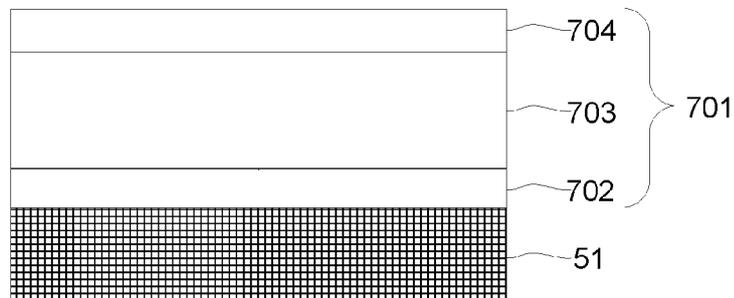


Fig. 6

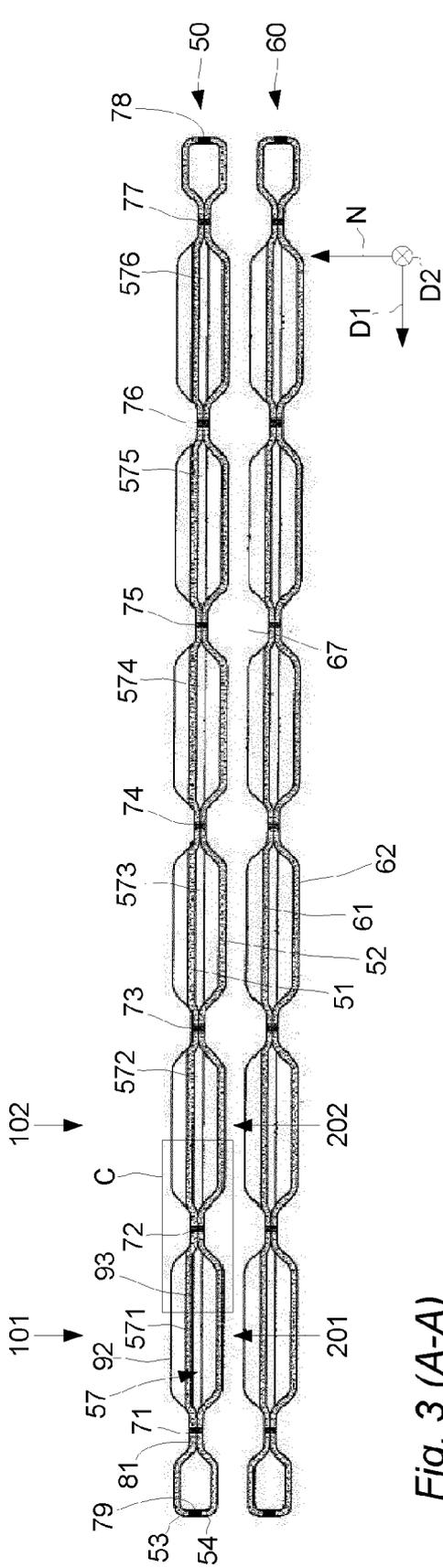


Fig. 3 (A-A)

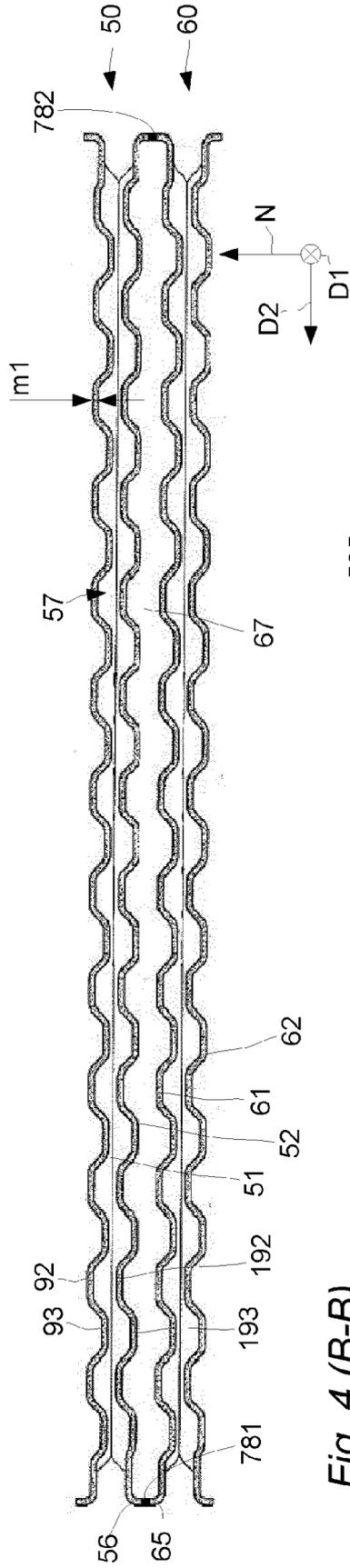


Fig. 4 (B-B)

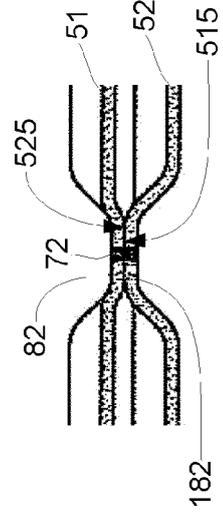


Fig. 5



EUROPEAN SEARCH REPORT

Application Number
EP 11 19 0887

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Munich		5 April 2012	Mellado Ramirez, J
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