

PLATE FOR HEAT EXCHANGER AND HEAT EXCHANGER WITH SUCH PLATE

The present invention relates to a plate for a heat exchanger.

The invention also relates to a heat exchanger with such a plate.

5 Heat exchangers are devices that are adapted to transfer heat between two different fluids that circulate at different temperatures.

Nowadays, for conditioning the air in enclosed environments, such as for example offices, machine rooms or data centers, various types of heat exchangers are employed.

10 Among these are plate heat exchangers.

Plate heat exchangers have a series of mutually parallel plates, which are normally made of metallic material.

These plates define, in pairs, alternating passage chambers for a hot fluid or for a cold fluid (hot air and cold air).

15 In the present description, the term “hot fluid” means a fluid with an enthalpy content higher than that of the fluid defined as a “cold fluid”.

Similarly, in the present description, the term “cold fluid” means a fluid with an enthalpy content lower than that of the fluid defined as a “hot fluid”.

20 As a consequence, each plate has one side in contact with the cold fluid and the other side in contact with the hot fluid.

Generally, the plates have corrugated surfaces.

The corrugation of the surfaces makes it possible to increase the area of heat exchange and the turbulence.

25 Such plates are then separated by spacers, which are adapted to keep them at a constant and preset distance.

These spacers can be:

- separate from the plates, and made for example of rubber or other plastic material,
- 30 - in a single piece with the plates, and constituted by protrusions

formed directly on them.

Plates that have spacers in a single piece are simpler, quicker and cheaper to make.

In fact, the spacers are made during the molding of the plate or, at most, with a subsequent molding and they do not have to be made separately and then associated with the plates.

For example, EP2645039B1 in the name of the company Heatex AB contains the teachings to provide plates that have a plurality of protrusions, which constitute the spacers, which are made in a single piece with the plates themselves, via molding.

This known art has a number of drawbacks if materials are used that have a low Young's modulus and there is a high pressure difference between the two faces of the surface.

The plates taught in EP2645039B1 are preferably made of aluminum, of stainless steel or plastic material, and have protrusions that form a series of channels.

On each side of the plate there are parallel channels and the channels of one side are arranged in a direction at right angles to that of the channels arranged on the other side of the plate.

During use of the plate, one of the two sides is in contact with the hot fluid, while the other side is in contact with the cold fluid.

To reduce the risk of contamination of the hot fluid with the cold fluid and to increase the enthalpy of the hot side, fans are placed on the hot fluid side, upstream of the hot side, and fans for the cold fluid are placed downstream of the cold side.

This creates a strong pressure difference on the two faces of the exchanger: the cold side is always in a partial vacuum, and the hot side is always under pressure.

As a consequence there is a deformation of the plate, and therefore a change in its geometry, thus compromising the regular outflow of cold fluid,

with an uncontrolled increase in flow resistances.

This drawback is most felt with plates made of plastic material or other materials with a low Young's modulus.

In the present description, the term "low Young's modulus" means of
5 the order of magnitude of thousands of MPa.

The aim of the present invention is to provide a plate for a heat exchanger and an exchanger with such plate that are capable of improving the known art in one or more of the above-mentioned aspects.

Within this aim, an object of the invention is to provide a plate for a
10 heat exchanger wherein the pressure difference between the hot side and the cold side does not result in a deformation thereof, and/or results in minor deformation, even if the plate is made of materials with a low Young's modulus.

Another object of the invention is to provide a plate for a heat
15 exchanger that is made of materials with a low Young's modulus, with optimization of the heat exchange characteristics and of the flow resistances.

Another object of the invention is to provide a heat exchanger with a plate that is capable of achieving the above-mentioned objects.

20 A further object of the present invention is to overcome the drawbacks of the background art in a manner that is alternative to any existing solutions.

Another object of the invention is to provide a plate for a heat exchanger and an exchanger with such a plate that are highly reliable, easy
25 to implement and low-cost.

This aim and these and other objects which will become more apparent hereinafter are achieved by a plate for a heat exchanger, which comprises a plurality of unit cells, each one of said unit cells comprising a first face and a second face which is opposite said first face, said first face
30 and said second face having a plurality of spacers which are arranged so as

to produce mutually perpendicular directions of flow between said first face and said second face, said plate being characterized in that said spacers differ between said first face and said second face in terms of number and/or shape and/or size.

5 This aim and these and other objects which will become more apparent hereinafter are also achieved by a heat exchanger of the plate type, characterized in that it comprises a plurality of plates, each one of them being a plate as previously described.

Further characteristics and advantages of the invention will become
10 more apparent from the detailed description that follows of a preferred, but not exclusive, embodiment of the plate for an exchanger and of the exchanger, according to the invention, which are illustrated by way of non-limiting example in the accompanying drawings, wherein:

- Figure 1 is an overall perspective view of a plate according to the
15 invention;

- Figure 1a is a perspective view of a first side of a portion of the plate of Figure 1;

- Figure 1b is a perspective view of a second side, opposite the previous side, of the portion of Figure 1a;

20 - Figure 2 is an overall perspective view of an exchanger according to the invention;

- Figure 3 is an exploded view of a portion of the exchanger of Figure 2;

- Figure 4 is a cross-sectional side view of a portion of an exchanger
25 according to the invention;

- Figures 5 and 6 are two different perspective side views of a portion of a heat exchanger according to the invention;

- Figures 7, 8, and 9 schematically illustrate the distribution of the loads and the camber along a segment of a portion of the plate of Figure 1;

30 - Figures 10 and 11 show two beam cross-sections;

- Figure 12 graphically shows the results of a finite element simulation of the distribution of tensions on a plate according to the invention during operation;

- Figure 13 graphically shows the results of a finite element simulation of the deformations of a plate according to the invention during operation.

With reference to the figures, a plate for a heat exchanger, according to the invention, is generally designated by the reference numeral 1.

This plate 1 comprises a plurality of unit cells 10.

In particular, in order to make the details of the plate 1 clearly visible, Figures 1a and 1b show a unit cell 10 of the plate 1, which when replicated lengthwise and widthwise forms a plate 1 for a heat exchanger 30.

This unit cell 10 has a quadrangular profile, preferably square, and comprises:

- a first face 11, shown in Figure 1a, which is adapted to be in contact with the cold fluid,

- a second face 12, shown in Figure 1b, which is on the side opposite to the first face 11 and is adapted to be in contact with the hot fluid.

The unit cell 10 can have, for example, a side comprised between 50 and 100 mm, while the entire plate 1 can have, for example, a side comprised between 300 mm and 1300 mm.

Each face 11, 12 of the unit cell 10 has a corrugation.

The plate 1 is made of a material with a low Young's modulus, for example plastic material, PVC, polypropylene or PET.

Below is a table of possible materials of which the plate 1 is made, and the corresponding Young's modulus.

Material	Young's modulus (MPa)
Polypropylene (PP)	1300 – 1800
Polyethylene (PET)	2800 – 3100
Polyvinyl chloride (PVC)	1500 – 3000

Such plate 1 is made by molding, in a single molding operation.

In particular, the corrugation on the face 11 of the unit cell 10 is the reverse of the corrugation on the second face 12.

The above sentence means that a concavity on the first face 11
5 corresponds to a convexity on the second face 12, and vice versa.

This corrugation is adapted to increase the contact surface and the generation of turbulence in the fluid with which it is in contact, thus improving the heat exchange between the hot fluid and the cold fluid.

Each face 11, 12 has a plurality of spacers 14, 16, each one with an
10 elevation at right angles to the surface of the respective face 11, 12.

The spacers 14, 16, are arranged so as to produce mutually perpendicular directions of flow on the two faces 11, 12.

Such spacers 14, 16, are made in a single piece with the rest of the unit cell 10 and of the plate 1, during the molding of the latter.

15 At each spacer 14 of the first face 11, there is a complementary cavity/shaped portion 17 on the second face 12; while at each spacer 16 of the second face 12, there is a complementary cavity/shaped portion 18 on the first face 11.

One of the particularities of the invention consists in the fact that such
20 spacers 14, 16, differ between the first face 11 and the second face 12 in terms of number and/or shape and/or size.

In particular the spacers 14 on the first face 11 are more numerous and larger than the spacers 16 on the second face 12.

Considering a first axis X of the unit cell 10, substantially central and
25 perpendicular to the direction of the corrugation, such first face 11 comprises two portions:

- a first portion 13a,
- a second portion 13b.

Similarly, the second face 12 comprises two portions:

- 30 - a third portion 15a, which corresponds to and is opposite to the first

portion 13a,

- a fourth portion 15b, which corresponds to and is opposite to the second portion 13b.

The first face 11 has a longitudinal first protrusion 19 which extends
5 along the first axis X, from which two first spacers 20a, 20b rise.

The first protrusion 19 has an elevation of 2-4 mm, a length comparable to the size of the unit cell 10 along the first axis X, and a width of 8-12 mm.

In the present description:

10 - the term “elevation” means the dimension in the direction perpendicular to the plane of arrangement of the unit cell 10 and of the plate 1,

- the term “length” means the dimension along the axis of extension of the respective protrusion or spacer, perpendicular to the direction of the
15 elevation,

- the term “width” means the dimension in the direction perpendicular both to the elevation and to the length.

These two first spacers 20a, 20b have, for example, an elevation of 3-6 mm, a length of 15-30 mm and a width of 5-12 mm.

20 The two first spacers 20a, 20b, are substantially mirror-symmetrical with respect to a plane of symmetry that is perpendicular to the first axis X and passes through a second axis Y of the unit cell 10, which is substantially central and parallel to the direction of the corrugation.

The first face 11 has two longitudinal end protrusions 21a, 21b, which
25 extend in parallel to the first axis X, each one at a perimetric edge of the unit cell 10, respectively:

- a second protrusion 21a,

- a third protrusion 21b.

These two longitudinal end protrusions 21a, 21b have, for example, an
30 elevation of 2-4 mm, a length comparable to the size of the unit cell 10 and

a width of 8-12 mm.

Two second spacers 22a, 22b rise from this second protrusion 21a and are substantially mirror-symmetrical with respect to the plane of symmetry that is perpendicular to the first axis X and passes through the second axis Y.

5 These two second spacers 22a, 22b have, for example, an elevation of 3-6 mm, a length of 15-30 mm and a width of 5-12 mm.

Similarly, two third spacers 23a, 23b rise from this third protrusion 21b and are substantially mirror-symmetrical with respect to the plane of symmetry that is perpendicular to the first axis X and passes through the
10 second axis Y.

These two third spacers 23a, 23b have, for example, an elevation of 3-6 mm, a length of 15-30 mm and a width of 5-12 mm.

The first portion 13a has two fourth protrusions 24a, 24b, which extend along a substantially central axis thereof which is parallel to the first
15 axis X.

These two longitudinal fourth protrusions 24a, 24b have, for example, an elevation of 1-3 mm, a length of 20-30 mm and a width of 3-8 mm.

A fourth spacer 25a, 25b extends from each fourth protrusion 24a, 24b, at the respective perimetric edge of each unit cell 10 that is parallel to
20 the second axis Y.

Each fourth spacer 25a, 25b has, for example, an elevation of 3-6 mm, a length of 10-20 mm and a width of 5-15 mm.

The second portion 13b has a longitudinal fifth protrusion 26, which extends along a substantially central axis thereof that is parallel to the first
25 axis X.

This fifth protrusion 26 has, for example, an elevation of 1-3 mm, a length of 20-30 mm and a width of 3-8 mm.

A fifth spacer 27 rises from the fifth protrusion 26 in parallel to the first axis X and to the second axis Y.

30 This fifth spacer 27 has, for example, an elevation of 3-6 mm, a length

of 10-20 mm and a width of 5-15 mm.

The third portion 15a has a sixth spacer 28 which extends along the second axis Y.

This sixth spacer 28 has, for example, an elevation of 3-8 mm, a
5 length of 15-30 mm and a width of 5-15 mm.

The fourth portion 15b has two seventh spacers 29a, 29b, each one at a perimetric edge of the unit cell 10 that is parallel to the second axis Y.

These seventh spacers 29a, 29b have, for example, an elevation of 3-6 mm, a length of 15-30 mm and a width of 5-15 mm.

10 The protrusions 19, 21a, 21b, 24a, 24b, 26 are made in a single piece with the rest of the unit cell 10 and of the plate 1, during the molding of the latter and they define channels for the cold fluid to flow through, in the configuration for use.

These protrusions 19, 21a, 21b, 24a, 24b, 26 and these spacers 14, 16
15 are arranged so as to produce mutually perpendicular directions of flow on the two faces 11, 12.

At each protrusion 19, 21a, 21b, 24a, 24b, 26 of the first face 11 there is a complementary groove/shaped portion on the second face 12, not shown in the figures.

20 Each spacer that extends from a respective protrusion has an elevation that is higher than it, with respect to the corresponding face of the unit cell 10.

In particular:

- all the spacers 14 of the first face 11 have the same elevation with
25 respect thereto,
- all the spacers 16 of the second face 12 have the same elevation with respect to the latter.

The unit cell 10 has, furthermore, a surface shape that defines:

- in the first portion 13a and the corresponding third portion 15a, a
30 dome 100 with an elliptical profile,

- in the second portion 13b and the corresponding fourth portion 15b, two half-domes 100a and 100b with a semi-elliptical profile, which are mirror-symmetrical with respect to the second axis Y, respectively a first half-dome 100a and a second half-dome 100b.

5 In particular, the minor axis of the ellipse of the dome 100 is located at the sixth spacer 28 and the major axis of the ellipse extends between the fourth spacers 25a, 25b.

The dome 100 has a concavity directed toward the first face 11, a corresponding convexity directed toward the second face 12, with the peak
10 at the sixth spacer 28.

In practice, the dome 100 defines a protrusion toward the second face 12.

The first half-dome 100a has:

- the major half-axis at the fifth protrusion 26, extending between the
15 seventh spacer 29a and the fifth spacer 27,
- the minor axis at the seventh spacer 29a.

The first half-dome 100a has a concavity directed toward the first face 11, a corresponding convexity directed toward the second face 12, with the peak at the seventh spacer 29a.

20 In practice, the first half-dome 100a defines a protrusion toward the second face 12.

The second half-dome 100b has:

- the major half-axis at the fifth protrusion 26, extending between the
seventh spacer 29b and the fifth spacer 27,
- 25 - the minor axis at the seventh spacer 29b.

The second half-dome 100b has a concavity directed toward the first face 11, a corresponding convexity directed toward the second face 12, with the peak at the seventh spacer 29b.

In practice, the second half-dome 100b defines a protrusion toward
30 the second face 12.

This dome 100 and these half-domes 100a and 100b provide projections in the order of 0.05-0.3 mm toward the second face 12, in contact with the hot fluid, and are adapted to partially compensate the deformation owing to the depression effect that occurs on the first face 11 in
5 contact with the cold fluid.

Figure 2 shows a plate heat exchanger 30 according to the invention.

The exchanger 30 is of the air/air type.

Figures 3 and 4 show a portion of an exploded view and a cross-sectional side view of an internal area of the exchanger 30.

10 In the correct coupling of the plates, two plates 1 are arranged in the same direction, mutually directed towards the same face 11, 12.

The coupling of the plates is obtained by rotating one plate on the other by 180°, in such a way that only the spacers 14, 16 and the corresponding edges of two successive plates are in contact.

15 The results of the matching of the plates are shown in Figures 5 and 6.

Figure 5 schematically shows the arrangement of the plates in the exchanger 30 and the resultant conduits seen from the cold side, where the process fluid is, while Figure 6 schematically shows the arrangement of the plates in the exchanger 30 and the resultant conduits seen from the hot side,
20 where the data center is.

The exchanger 30 has conduits 81 for the hot fluid and conduits 80 for the cold fluid, which are arranged on mutually parallel planes, in directions at 90° with respect to each other.

In particular, as becomes clear from Figures 4, 5 and 6, the conduits
25 80, 81 are hexagonal in cross-section as a result of coupling two successive plates 1 by facing the same face 11, 12 of them.

The hexagonal cross-section of the conduits 80, 81 has two mutually opposite elongated sides, respectively 82a, 82b, 83a, 83b, and the other four sides, respectively 84a, 84b, 84c, 84d, 85a, 85b, 85c, 85d, are inclined with
30 respect to the preceding sides and are tapered toward the points 86, 87 of

mutual support/contact between the two successive plates 1.

The exchanger 30 has a plurality of plates 1, as described above.

In particular, the plates 1 are coupled so as to mutually face the same face, first 11 or second 12, of the respective unit cells 10, and so that each
5 spacer of the first face 11 of a unit cell 10 faces and is in contact with the corresponding spacer of the first face 11 of the next unit cell 10, and similarly with regard to the second face 12.

In practice, to assemble the exchanger 30 it is sufficient to arrange the plates 1 in series, rotating them mutually through 180° with respect to their
10 plane of arrangement.

Figure 3 shows:

- with the arrows C, substantially, the direction of travel of the cold fluid,
- with the arrows F, substantially, the direction of travel of the hot
15 fluid.

In Figure 4, the arrows P indicate the progression of the pressures on the various faces of the plates of the exchanger 30.

The first face 11, in contact with the cold side, is subjected to a negative pressure, while the second face 12, in contact with the hot side, is
20 subjected to a positive pressure.

The tensions balance out at the point of contact and the displacement is therefore substantially nil, thus reducing the deformation of the plate.

From experimental tests and finite element calculations it has emerged that the arrangement and the number of spacers on the two faces makes it
25 possible to reduce/eliminate the deformation of the plate owing to the pressure difference to which the two faces are subjected.

The spacers differ in terms of number, shape, size and functions between the cold side, where the process fluid is, and the hot side, where the data center is.

30 In particular, the cold side is the side in contact with the first faces 11

of the plates 1, while the hot side is the side in contact with the second faces 12 of the plates 1.

Such spacers are adapted mainly to:

- separate the plates 1 so as to create conduits for the cold fluid, the process fluid, and for the hot fluid, the fluid of the data center, at right angles to each other,
- increase the mechanical properties on the cold side, where the process fluid is.

The conduits of the hot side, where the data center is, are subjected to a positive pressure, while the conduits of the cold side, where the process fluid is, are subjected to a negative pressure.

Therefore a differential pressure is generated, given by the sum of the absolute values of the positive and negative pressures between the conduits of the data center side, which tend to expand, and the conduits of the process fluid side, which tend to collapse, and this determines the pressure load that the single plate has to withstand.

The spacers on the hot side (the data center side) withstand a small part of the pressure load because the pressure differential tends to pull the individual spacers away from the corresponding spacers (traction effect).

The spacers on the cold side, the process fluid side, have to withstand the greater part of the pressure load because the pressure differential tends to push the individual spacers against the corresponding spacers (compression effect).

From a mechanical point of view, the total pressure load is symmetrical to the plane that lies on the contact surface of the spacers on the cold side (the process fluid side).

On this contact surface, the pressure load is completely discharged/balanced and the displacements are therefore equal to zero.

The spacers on the cold side (the process fluid side) therefore need to have a robust shape and structure and there needs to be a greater number of

them than of the spacers on the hot side, in order to ensure an adequate structural rigidity of the plate and prevent deformations that would obstruct the path of the process fluid, thus compromising the operation of the exchanger.

5 Differently, the spacers on the hot side (data center) have a tapered shape and there is a smaller number of them, in order to reduce as far as possible the flow resistances on the hot side and since they have little influence on the rigidity of the structure of the plate during use.

10 In particular, the tapered shape and the smaller number of spacers on the hot side (second face 12) create small obstacles (or concentrated resistances) in the path of the fluid originating from the data center.

For example, looking at Figure 1a, the tensional state that develops along the line R that passes through the spacers 14 of the cold side can be found in the following manner.

15 Consider the segment, along the line R, composed of: half-spacer 14, corresponding to the fourth spacer 25a, the fourth protrusion 24a, the sixth spacer 28 (hot side), the fourth protrusion 24b and half-spacer 14, corresponding to the fourth spacer 25b.

20 This segment repeats periodically up to the ends of the plate 1, the effects of which are negligible, and can be shown schematically as in Figure 7.

The fourth spacers 25a and 25b are shown schematically as coupled solidly, and they have the following boundary conditions:

- vertical displacement substantially nil, contact between
25 corresponding fourth spacers 25a, 25b of subsequent plates,
- horizontal displacement substantially nil, there being no load in that direction,
- angular displacement substantially nil, due to the periodicity with the preceding/next segment.

30 The sixth spacer 28 is shown schematically as coupled by resting

contact and able to yield, and it has the following boundary conditions:

- vertical movement allowed, yielding coupling,
- horizontal displacement substantially nil, there being no load in that direction,
- 5 - angular movement substantially nil, due to the symmetry of structure and load with respect to the midpoint of the plate.

The fourth protrusions 24a, 24b are overall shown schematically as a beam T having:

- static moment of inertia (I),
- 10 - Young's modulus (E),
- length (2L),
- which is subjected to:
- a distributed load (q), constituted by the pressure differential acting on the plate,
- 15 - a concentrated load (k), constituted by the constraining reaction of the yielding coupling determined by the sixth spacer 28.

The tensional diagram in Figure 7 can be broken down into two tensional sub-diagrams, shown in Figures 8 and 9, which when summed together give the overall tensional diagram.

- 20 The first sub-diagram, shown in Figure 8, shows a beam T1 supported at both ends with a distributed load q.

Looking at Figure 8, the beam T1 has:

- a bending moment: $M = \frac{q}{12} \cdot (12Lt - 6t^2 - 4L^2)$ which has its maximum at the midpoint ($t=L$), which is equal to: $M_{max} = \frac{qL^2}{6}$;
- 25 - camber: $f = \frac{-qt^2}{24EI} \cdot (2L-t)^2$, with $0 < t < 2L$, which has its maximum at the midpoint ($t=L$), which is equal to: $f_{max} = \frac{-q(2L)^4}{384EI}$.

The second sub-diagram, shown in Figure 9, shows a beam T2 supported at both ends with a concentrated load k at the midpoint.

Looking at Figure 9, the beam T2 has:

- a bending moment: $M = \frac{k}{8} \cdot (4t - 2L)$ which has its maximum at the midpoint ($t = L$), equal to: $M_{max} = \frac{k2L}{8}$;
 - camber: $f = \frac{kt^2}{48EI} \cdot (6L - 4t)$, with $0 < t < L$, which has its maximum at the
- 5 midpoint ($t = L$), which is equal to: $f_{max} = \frac{+k(2L)^3}{192EI} = \frac{+kL^3}{24EI}$.

The overall camber of the beam T of Figure 7 is therefore (with $0 < t < L$):

$$f_{sys} = \frac{kt^2}{48EI} \cdot (6L - 4t) - \frac{qt^2}{24EI} \cdot (2L - t)^2$$

The case $k = 0$ corresponds to the condition described in the first sub-diagram, shown in Figure 8.

The case $k = qL$ corresponds to the rigid resting support condition such that $f_{sys} = 0$.

The case $k < qL$ corresponds to the yielding coupling condition which schematically represents the sixth spacer 28 (hot side, the data center).

15 To minimize the overall camber f_{sys} it is necessary to act on at least one of the parameters on which it depends: E, q, L or I:

- it is not possible to act on the Young's modulus (E), to increase it, since the material and its Young's modulus are a design parameter,
 - it is not possible to reduce the extent of the distributed load q
- 20 because that would limit the thermodynamic performance,
- it is possible to reduce the length L of the beam, but there must be an adequate compromise between thermodynamic performance and mechanical strength, since an excessive reduction of the length L produces a greater density per unit of surface area of the spacers 14, and therefore consequent
- 25 localized flow resistances which impair the thermodynamic performance;
- it is possible to increase the static moment of inertia I, but there must be an adequate compromise between thermodynamic performance and mechanical strength, since an excessive variation of the cross-section would

produce both a criticality at the technological/production level, due to the difficulty of implementation, and also an impairment in terms of thermodynamic performance.

A distribution of protrusions and spacers, as illustrated previously, makes it possible to obtain satisfactory thermodynamic performance, by optimizing the geometry and in particular the profile of the plate 1, thus increasing the static moment of inertia I, while at the same time ensuring sufficient mechanical strength.

Considering the cross-section of the plate taken along the segment Q, with reference to Figures 10 and 11, below the contribution of the static moment of inertia I is shown and the difference is analyzed between the typical profile of a flat plate, represented as a flat beam in Figure 10, and the optimized profile, represented as a beam with an omega-shaped cross-section in Figure 11, as in the case of the segment Q of the plate according to the present invention.

The objective is to highlight the benefits introduced by the optimized profile on the geometry of a plate according to the invention.

For convenience, the effect of the corrugation is ignored.

Taking, for the purposes of example, the beam with flat cross-section shown in Figure 10, with:

- width $w=30\text{ mm}$,
- thickness $h=0.3\text{ mm}$,

the static moment of inertia I of the flat cross-section with respect to its center of gravity G is:

$$I = \frac{1}{12} w h^3 = 0.0675 \text{ mm}^4, \text{ considering the center of gravity G at a height } s_G = \frac{h}{2} \text{ with respect to the lower side of the cross-section.}$$

To increase the static moment of inertia I, we can act on the parameters w and h.

However, an increase of the width w would result in an increase of the

surface of the plate with consequent increase of the distributed load that acts on it, while a reduction of the width would result in a decrease of the static moment of inertia, a reduction of the surface of the plate, and therefore a reduction of the distributed load that acts on the plate.

5 As a consequence, the choice of the width w must be a compromise in order to obtain sufficient thermodynamic performance.

An increase in the thickness h on the other hand would result in using more plastic material to make the plate, and as a consequence it would result in an increase in cost.

10 The thickness h is furthermore an essential parameter from the point of view of production for the manufacture of the plate.

The minimum thickness h that allows a successful process of thermoforming the plate must therefore be chosen.

15 Taking instead, again for the purposes of example, the beam with an omega-shaped cross-section shown in Figure 11, with:

- width $w=30\text{ mm}$,
- thickness $h=0.3\text{ mm}$,
- first characteristic dimension $a=2\text{ mm}$,
- second characteristic dimension $b=14\text{ mm}$,

20 the static moment of inertia I of the omega-shaped cross-section with respect to its center of gravity G is:

$$I = a^2 \left[\frac{a^2}{12} + \left(\frac{a}{2} - s_G \right)^2 \right] - (a-2h)(a-h) \left[\frac{(a-h)^2}{12} + \left(\frac{a-h}{2} - s_G \right)^2 \right] + 2bh \left[\frac{h^2}{12} + \left(s_G - \frac{h}{2} \right)^2 \right] = 2.6568\text{ mm}^4$$

considering the center of gravity G at a height approximately equal to $s_G = \frac{2a^2}{3a+2b}$ with respect to the lower side of the cross-section.

25 As can be seen, the introduction of the omega-shaped cross-section in place of the flat cross-section produces an appreciable increase in the static moment of inertia I , for the same width w and thickness h .

Using CFD (Computational Fluid Dynamics) simulations, it has been verified that the geometry thus proposed enables satisfactory heat exchange

conditions.

Furthermore, the particular arrangement of the spacers, the dimensions, the shape and the number of them makes it possible to limit the deformation of the unit cell 10 and its warping toward the cold side.

5 Figures 12 and 13 graphically show, for the purposes of example, the results of two finite element simulations on a portion of plate 1, with a thickness of 0.3 mm, on the side of the second faces 12, subjected under operating conditions to a pressure of 3000 Pa.

10 In the simulations, a Young's modulus of the material was set as $E=2250$ MPa and a Poisson's ratio was set as $\nu=0.34$.

Figure 12 graphically shows the distribution of the tensions according to the Von Mises yield criterion on a portion of plate, where:

- the zones indicated with 65 are zones where the tension is nil,
- the zones indicated with 64 are zones with a tension of 1 MPa,
- 15 - the zones indicated with 62 are zones with a tension of 2 MPa,
- the zones indicated with 63 are zones with a tension of 3.1 MPa,
- the zones indicated with 61 are the zones where the tension is maximum and is equal to 4.7 MPa, at the longitudinal ends of the spacers, which in turn are surrounded by zones 63.

20 Figure 13 graphically shows the results of a finite element simulation of the deformations of a plate according to the invention during operation, on a portion of plate, where:

- the zones indicated with 71 are zones where the displacement is maximum and is equal to 0.11 mm,
- 25 - the zones indicated with 72 are zones where the displacement is equal to 0.07 mm,
- the zones indicated with 73 are zones where the displacement is equal to 0.04 mm,
- the zones indicated with 74 are zones where the displacement is
- 30 equal to 0.009 mm,

- the zones indicated with 75 are zones with negative displacement, equal to -0.0025 mm.

It should be noted that a plate according to the invention favors low flow resistances on the hot side in overpressure over plates in a partial vacuum, in order to obtain an improvement in energy consumption.

Also, by virtue of the symmetry of the points of contact of the side in a partial vacuum between the plates, the tensions balance out at the point of contact. This results in a displacement and therefore a reduction in the deformation of the plate.

In practice it has been found that the invention fully achieves the intended aim and objects by providing a plate for a heat exchanger wherein the pressure difference between the hot side and the cold side does not result in a deformation thereof, and/or results in a minor deformation, even if the plate is made of materials with a low Young's modulus.

With the invention a plate for a heat exchanger has been devised that is made of materials with a low Young's modulus, which makes it possible to obtain better yields by way of containment of flow resistances compared to similar, conventional plates.

Furthermore, with the invention a heat exchanger has been provided with a plate that is capable of achieving the above-mentioned objects.

The invention thus conceived is susceptible of numerous modifications and variations, all of which are within the scope of the appended claims. Moreover, all the details may be substituted by other, technically equivalent elements.

In practice the materials employed, provided they are compatible with the specific use, and the contingent dimensions and shapes, may be any according to requirements and to the state of the art.

The disclosures in Italian Patent Applications No. 102020000023473 and No. 102021000023270 from which this application claims priority are incorporated herein by reference.

Where technical features mentioned in any claim are followed by reference signs, those reference signs have been included for the sole purpose of increasing the intelligibility of the claims and accordingly, such reference signs do not have any limiting effect on the interpretation of each
5 element identified by way of example by such reference signs.

CLAIMS

1. A plate (1) for a heat exchanger (30), which comprises a plurality of unit cells (10), each one of said unit cells (10) comprising a first face (11) and a second face (12) which is opposite said first face (11), said first face
5 (11) and said second face (12) having a plurality of spacers (14, 16) which are arranged so as to produce mutually perpendicular directions of flow between said first face (11) and said second face (12), said plate (1) being characterized in that said spacers (14, 16) differ between said first face (11) and said second face (12) in terms of number and/or shape and/or size.
- 10 2. The plate (1) according to claim 1, characterized in that each one of said unit cells (10) has a quadrangular profile and in that said first face (11) and said second face (12) have a corrugation.
3. The plate (1) according to one or more of the preceding claims, characterized in that it is made of a material with a low Young's modulus.
- 15 4. The plate (1) according to one or more of the preceding claims, characterized in that it is made of plastic material such as PVC and/or PP and/or PET.
5. The plate (1) according to one or more of the preceding claims, characterized in that it is made of a material with a Young's modulus
20 substantially comprised between 1000 MPa and 3000 MPa.
6. The plate (1) according to one or more of the preceding claims, characterized in that each one of said spacers (14, 16) has an elevation at right angles to the plane of the respective face (11, 12) and is made in a single piece with the rest of said plate (1).
- 25 7. The plate (1) according to one or more of the preceding claims, characterized in that:
- at each one of said spacers (14) of said first face (11) there is a complementary cavity/shaped portion (17) on said second face (12),
 - at each one of said spacers (16) of said second face (12) there is a
30 complementary cavity/shaped portion (18) on said first face (11).

8. The plate (1) according to one or more of the preceding claims, characterized in that, considering a first axis (X) of each one of said unit cells (10), which is substantially central and perpendicular to the direction of said corrugation:

- 5 - said first face (11) comprises two portions:
- a first portion (13a),
 - a second portion (13b),
- said second face (12) comprises two portions:
- a third portion (15a), which corresponds to and is opposite said first
 - 10 portion (13a),
 - a fourth portion (15b), which corresponds to and is opposite said second portion (13b).

9. The plate (1) according to one or more of the preceding claims, characterized in that said first face (11) has a longitudinal first protrusion

15 (19) which extends along said first axis (X), two first spacers (20a, 20b) rising from said first protrusion (19), said two first spacers (20a, 20b) being substantially mirror-symmetrical with respect to a plane of symmetry that is perpendicular to said first axis (X) and which passes through a second axis (Y) of each one of said unit cells (10), which is substantially central and

20 parallel to the direction of said corrugation.

10. The plate (1) according to one or more of the preceding claims, characterized in that said first face (11) has two longitudinal end protrusions (21a, 21b), which extend parallel to said first axis (X), each one at a perimetric edge of each one of said unit cells (10), respectively:

- 25 - a second protrusion (21a), two second spacers (22a, 22b) rising from said second protrusion (21a) and being substantially mirror-symmetrical with respect to said plane of symmetry that is perpendicular to said first axis (X) and passes through said second axis (Y),
- a third protrusion (21b), two third spacers (23a, 23b) rising from said
 - 30 third protrusion (21b) and being substantially mirror-symmetrical with

respect to said plane of symmetry that is perpendicular to said first axis (X) and passes through said second axis (Y).

11. The plate (1) according to one or more of the preceding claims, characterized in that said first portion (13a) has two fourth protrusions (24a, 24b), each one of which extends along a substantially central axis thereof, which is parallel to said first axis (X), a fourth spacer (25a, 25b) extending from each one of said fourth protrusions (24a, 24b) at the respective perimetric edge of each one of said unit cells (10) that is parallel to said second axis (Y).

12. The plate (1) according to one or more of the preceding claims, characterized in that said second portion (13b) has a longitudinal fifth protrusion (26), which extends along a substantially central axis thereof that is parallel to said first axis (X), a fifth spacer (27) rising from said fifth protrusion (26) at said second axis (Y).

13. The plate (1) according to one or more of the preceding claims, characterized in that said third portion (15a) has a sixth spacer (28) which extends along said second axis (Y).

14. The plate (1) according to one or more of the preceding claims, characterized in that said fourth portion (15b) has two seventh spacers (29a, 29b), each one at a perimetric edge of each one of said unit cells (10) that is parallel to said second axis (Y).

15. The plate (1) according to one or more of the preceding claims, characterized in that said protrusions (19, 21a, 21b, 24a, 24b, 26) are provided in a single piece with the rest of said plate (1).

16. The plate (1) according to one or more of the preceding claims, characterized in that at each protrusion (19, 21a, 21b, 24a, 24b, 26) of said first face (11) there is a complementary groove/shaped portion on said second face (12).

17. The plate (1) according to one or more of the preceding claims, characterized in that:

- all the spacers (14) of said first face (11) have the same elevation with respect to said first face,

- all the spacers (16) of said second face (12) have the same elevation with respect to said second face.

5 18. The plate (1) according to one or more of the preceding claims, characterized in that each one of said unit cells (10) has a surface shape that defines:

- in said first portion (13a) and said corresponding third portion (15a), a dome (100) with an elliptical profile,

10 - in said second portion (13b) and said corresponding fourth portion (15b), two half-domes (100a, 100b) with a semi-elliptical profile, which are mirror-symmetrical with respect to said second axis (Y), said dome (100) and said half-domes (100a, 100b) providing projections toward said second face (12).

15 19. A heat exchanger (30) of the plate type, characterized in that it comprises a plurality of plates (1), each one of them being a plate (1) according to one or more of the preceding claims.

20 20. The exchanger (30) according to claim 19, characterized in that said plates (1) are coupled so as to mutually face the same first (11) or second (12) face of the respective unit cells (10), and so that:

- each spacer (14) of said first face (11) of a unit cell (10) faces and is in contact with the corresponding spacer (14) of said first face (11) of the next unit cell (10),

25 - and/or each spacer (16) of said second face (12) of a unit cell (10) faces and is in contact with the corresponding spacer (16) of said second face (12) of the next unit cell (10).

21. The exchanger (30) according to claim 19 or 20, characterized in that said plates (1) are arranged mutually rotated by 180° with respect to their own plane of arrangement.

30 22. The exchanger (30) according to claim 21, characterized in that

the coupling between said plates (1) is obtained in such a way that only said spacers (14, 16) and the corresponding edges of two successive plates (1) are in contact.

23. The exchanger (30) according to one or more of claims 20 to 22,
5 characterized in that it has conduits (81) for a hot fluid and conduits (80) for a cold fluid, which are arranged on mutually parallel planes, in directions at 90° with respect to each other.

24. The exchanger (30) according to claim 23, characterized in that
10 said conduits (80, 81) are hexagonal in cross-section as a result of coupling two successive plates (1) by being directed toward the same face (11, 12) of them.

25. The exchanger (30) according to claim 24, characterized in that
said hexagonal cross-section of said conduits (80, 81) has two mutually
opposite elongated sides (82a, 82b, 83a, 83b) and the other four sides (84a,
15 84b, 84c, 84d, 85a, 85b, 85c, 85d) are inclined with respect to the preceding
sides and are tapered toward the points (86, 87) of mutual support/contact
between two successive ones of said plates (1).