(57) Abrégé/Abstract:
The present invention relates to a heat exchanger plate (1), to the manufacture thereof and to the use of the heat exchanger plate (1) according to the invention in a plate heat exchanger (100). A plate substrate (10) which is provided is formed at least on its top...
(57) **Abstract (continued)**:
side (10o) with a flow duct arrangement (20) which has a multiplicity of flow ducts (20k), wherein some or all of the flow ducts (20k) have, over the entire extent thereof or in sections, duct rods (20s) which form duct walls (20w) which delimit a duct channel (20w) of the respective flow duct (20k).
Abstract

The present invention relates to a heat exchanger plate (1), to the manufacture thereof and to the use of the heat exchanger plate (1) according to the invention in a plate heat exchanger (100). A plate substrate (10) which is provided is formed at least on its top side (10o) with a flow duct arrangement (20) which has a multiplicity of flow ducts (20k), wherein some or all of the flow ducts (20k) have, over the entire extent thereof or in sections, duct rods (20s) which form duct walls (20w) which delimit a duct channel (20w) of the respective flow duct (20k).
Heat Exchanger Plate, Plate Heat Exchanger Provided therewith, and Method for Manufacturing a Plate Heat Exchanger

AREA OF THE INVENTION

The present invention relates to a heat exchanger plate, a plate heat exchanger provided therewith, as well as a method for manufacturing a plate heat exchanger. The present invention also relates in particular to plate heat exchanger with ceramic plates.

BACKGROUND OF THE INVENTION

In heat exchangers or recuperators for exchanging a quantity of heat between two fluids or gaseous media that do not come into contact with each other and must not be blended together, so-called plate heat exchangers or plate recuperators are often used, in which the region for exchanging the heat between the two media is formed by stacking so-called heat exchanger plates or recuperator plates, which lie against or on top of each other like a packet, wherein directly adjacent heat exchanger plates establish a flow space between them, and directly adjacent flow spaces are separated from each other in terms of flow, and each allocated to one of the two media. Therefore, an odd number of consecutive flow spaces in the stack or packet here carry a first medium and an even number of consecutive flow spaces in the stack or packet carry a second medium, without there being any blending. The heat is here exchanged via the heat exchanger plates that respectively border and separate the flow spaces, so that they serve as boundary walls for the flow spaces, and are sealed relative to each other through the provision of corresponding gaskets.
Known heat exchanger plates are made out of metal, for example, so that a configuration thereof comprised of a plurality of heat exchanger plates can be welded or soldered, as a result of which the soldered or welded seam simultaneously acts as a gasket as well.

In light of their manufacturing costs, weight and physicochemical properties, metallic heat exchanger plates are sometimes not advantageous.

SUMMARY OF THE INVENTION

The object of the invention is to indicate a heat exchanger plate for a plate heat exchanger, a plate heat exchanger itself, as well as a method for manufacturing a heat exchanger plate, in which a heat exchange can be realized in a particularly effective way at an especially high level of reliability and mechanical stability.

The object underlying the invention is achieved according to the invention by way of the features in independent claim 1 with respect to a heat exchanger plate for a plate heat exchanger, according to the invention by way of the features in independent claim 17 with respect to the plate heat exchanger, and according to the invention by way of the features in independent claim 18 with respect to a method for manufacturing a heat exchanger plate for a plate heat exchanger. Advantageous further developments are the respective subject of the dependent claims.

Therefore, one aspect of the present invention involves providing a ceramic material, and in particular a SiC material or silicon carbide material, as the material for the heat exchanger plate for a plate heat exchanger instead of a conventionally provided metallic material.
Another aspect of the present invention involves ensuring the mechanical stability of the heat exchanger plate given the selection of this type of material by having part or all of the provided flow ducts of the flow duct arrangement partially or completely exhibit duct webs, which form channel walls that completely or sectionally border duct grooves. These duct webs mechanically stabilize the flow ducts of the flow duct arrangement, and hence the plate substrate as a whole, in particular in cases where they interact with other heat exchanger plates during use and when integrated in a plate heat exchanger, and allow a specific heat exchanger plate to abut against another directly adjacent heat exchange plate in essentially a flat manner, so that the pressures exerted by the flowing media cannot lead to plate fractures in the underlying ceramic material.

Let emphasis be placed on the following aspects that can be realized according to the invention:

- The plate substrate, and hence the heat exchanger plate, can exhibit any, i.e., even conventional, shapes and dimensions, so that in particular an overall height and overall width of the plate substrate, and hence of the heat exchanger plate according to the invention, are not limited.

- With respect to flow ducts to be provided, a minimal duct depth can be provide in the heat exchanger plates according to the invention depending on the area of application, e.g., also within a roughly 0.2 mm range in so-called micro-heat exchangers or micro-recuperators.

- When heat exchanger plates according to the invention are utilized in a plate heat exchanger, use can be made of an arrangement with gaskets. However, this is
not mandatory, since the reciprocal seal can also be established just by placing directly adjacent heat exchanger plates right on top of each other, wherein the heat exchanger plates support each other in the process, e.g., specifically in that the rear sides of plates consecutively touch the front sides of plates in the stack. Webs can also abut against webs, rear sides against webs, etc.

The geometric configuration of the heat exchanger plate according to the invention and its flow ducts in conjunction with the arrangement of a plurality of heat exchanger plates according to the invention in a plate heat exchanger makes it possible to realize a diversion of the heat exchange media or fluids, e.g., also in terms of a plate heat exchanger with multiple passages and/or multiple diversions of the heat exchange fluid(s).

A sintered silicon carbide material or SSiC material can be used in all or part of the plate substrate design. The special advantage to this material selection lies in the added mechanical stabilization and increase chemical inertness.

A minimal layer thickness Dmin and/or an average layer thickness Dm of the plate substrate can range between about 2 mm and about 4 mm, in particular measure about 3 mm or less, preferably about 2 mm. The formed duct webs make it possible to correspondingly reduce the layer thicknesses of the heat exchanger plates, without any resultant mechanical destabilization. In the absence of the mechanical stabilization provided by the corresponding webs of the flow ducts, far higher layer thicknesses would be needed to stabilize the heat exchanger plates, provided the latter were fabricated out of ceramic materials. This would lead to a rise in weight and volume, thus necessitating larger
equipment and higher costs at the same level of heat exchange.

The layer thickness $D_s$ of the plate substrate can be greater in the area of a duct web than the minimum layer thickness $D_{\text{min}}$ of the plate substrate and/or the average layer thickness $D_m$ of the plate substrate, thereby roughly satisfying the correlation

$$D_s \geq D_{\text{min}}$$

or roughly the correlation

$$D_s \geq D_m.$$

A local width $B_b$ of the floor of the duct groove of the flow duct and the local width $B_{sb}$ of a base of the duct web of the flow duct at the height of the floor of the duct groove of the flow duct—each measured perpendicular to the local direction of the flow duct—can exhibit a ratio $B_b : B_{sb}$ of about $1 : 4$, thereby roughly satisfying the correlation

$$B_b : B_{sb} = 10 : 4.$$

The local width $B_b$ of the floor of the duct grooves of the flow duct and the local width $B_{sp}$ of a plateau of a duct web of a flow duct on the side facing away from the floor of the duct groove of the flow duct—each measured perpendicular to the local direction of the flow duct—can exhibit a ratio $B_b : B_{sp}$ within a range of about $10 : 3$, thereby roughly satisfying the correlation

$$10 : 4 \leq B_b : B_{sp} \leq 10 : 2$$

or preferably roughly the correlation
Bb : Bsp = 10 : 3.

The local width Bsb of the base of the duct web of the flow duct at the height of the floor of the duct groove of the flow duct and the local width Bsp of the plateau of the duct web of the flow duct on the side facing away from the floor of the duct groove of the flow duct—each measured perpendicular to the local direction of the flow duct—can exhibit a ratio Bsb : Bsp ranging from about 1 : 1 to about 4 : 2, preferably of about 4 : 3, thereby roughly satisfying the correlation

\[ 4 : 2 \leq \text{Bsb} : \text{Bsp} \leq 1 : 1 \]

or preferably roughly the correlation

\[ \text{Bsb} : \text{Bsp} = 4 : 3. \]

The channel walls of a flow duct include an angle \( \alpha \) with the normal relative to the floor of the duct groove of the flow duct ranging from greater than 0° to less than 30°, preferably lying at about 15°, thereby roughly satisfying the correlation

\[ 0° < \alpha \leq 30° \]

or preferably roughly the correlation

\[ \alpha = 15°. \]

The local width Bb of the floor of the duct groove of the flow duct—measured perpendicular to the local direction of the flow duct—and the depth \( t \) of the duct groove of the flow duct—measured perpendicular to the floor of the duct groove of the flow duct—can exhibit a ratio Bb : t ranging from about 10 : 10 to about 10 : 4, preferably of about 10 : 4, thereby roughly satisfying the correlation
10 : 10 ≤ Bb : t ≤ 10 : 4

or preferably roughly the correlation

\[ Bb : t = 10 : 4. \]

The measures just described are realized by various geometric arrangements during the configuration of the heat exchanger plate according to the invention with regard to the duct geometry in relation to the plate thickness, as a result of which especially favorable mechanical properties are achieved at a comparatively low volume and/or weight.

Supply or removal openings that penetrate the plate substrate from the upper side to the bottom side and supply or remove a first heat exchange fluid F1 to or from the upper side of the plate substrate can be provided, wherein the flow duct arrangement is designed to transport the first heat exchange fluid F1 from the supply opening to the removal opening.

All or sections of the flow ducts in the flow duct arrangement can exhibit a multi-undulating progression.

The undulating direction U can run in a surface or plane defined by the plate substrate and/or perpendicular to the flowing direction defined by the respective flow duct locally and/or on average.

The shape of the undulation for a respective flow duct can be a shape from a group of shapes that includes sawtooth shapes, alternating echelon shapes, wave shapes, sinus shapes and combinations thereof.
The rear or bottom side of the plate substrate can exhibit a second flow duct arrangement for a second heat exchange fluid F2 with a plurality of corresponding flow ducts.

Second supply and removal openings that penetrate the plate substrate from the upper side to the bottom side can be provided to supply or remove the second heat exchange fluid F2 to or from the rear or bottom side of the plate substrate, wherein the second flow duct arrangement is designed to transport the second heat exchange fluid F2 from the second supply opening to the second removal opening.

The heat exchanger plate according to the invention can be designed to be rotationally symmetrical by 180° with respect to the front or upper side and rear or bottom side in relation to a symmetry axis S running in the plate substrate.

The plate substrate can essentially have a rectangular shape.

The supply and removal openings can here be formed in the area on opposing first—preferably shorter—sides of the rectangular shape, in particular in the corner areas.

The directions in which the first and/or second heat exchange fluids F1, F2 flow and/or the primary directions in which the flow ducts extend can essentially be formed along the directions in which opposing second—preferably longer—sides of the rectangular shape extend.

The measures described above make it possible to realize different flow geometries when a plurality of heat exchanger plates according to the invention interact, i.e., are rowed together in stacks or packets.
Another aspect of the present invention also provides for a plate heat exchanger as such, with a plurality of n heat exchanger plates according to the invention, wherein the heat exchanger plates are designed and arranged in such a way that the rear or bottom side of the plate substrate of a respective preceding heat exchanger plate \( j=1, \ldots, n-1 \) lies directly opposite the front or upper side of the plate substrate of a respective directly ensuing heat exchanger plate \( j+1 \) with \( j=1, \ldots, n-1 \) or abuts against the latter directly, or in particular with a sealing arrangement interspersed, that the sequence of heat exchanger plates \( j=1, \ldots, n \) and/or in particular the creation of the sealing arrangement cause directly sequential through-flow spaces \( R_1, \ldots, R_{n+1} \) separated from each other in terms of flow to form or be formed, that directly adjacent through-flow spaces \( R_j, R_j+1, j=1, \ldots, n \) are separated in pairs in terms of flow, and that respective next but one adjacent through-flow spaces \( R_j, R_j+2, j=1, \ldots, n-1 \) are joined together in pairs in terms of flow, are each allocated to a heat exchange fluid \( F_1, F_2 \) and designed to allow respectively allocated heat exchange fluid \( F_1, F_2 \) to flow from the respective supply opening to the respective removal opening.

Another aspect of the present invention also provides for a method of manufacturing a heat exchanger plate for a plate heat exchanger, which specifically involves the steps of providing or forming a plate substrate that contains or consists of a ceramic, SiC material or a silicon carbide material with a front or upper side and a rear or bottom side, forming a flow duct arrangement with a plurality of flow ducts on the front or upper side of the plate substrate, wherein some or all of the flow ducts of the flow duct arrangement are fabricated entirely or sectionally with duct webs that border duct grooves and form duct walls.
The plate substrate can contain or consist of a sintered silicon carbide material or SSiC material.

Flow ducts of the flow duct arrangement can be designed to exhibit a completely or sectionally multi-undulating progression.

The undulating direction U can be designed to run in a surface or plane defined by the plate substrate and/or perpendicular to the flowing direction defined by the flow duct locally or on average.

The shape of the undulation can be a shape from a group of shapes that includes sawtooth shapes, alternating echelon shapes, wave shapes, sinus shapes and combinations thereof.

These and other aspects will be explained based on the attached drawings.

BRIEF DESCRIPTION OF THE FIGURES

Fig. 1A presents a schematic top view depicting the front side of an embodiment of the heat exchanger plate according to the invention.

Fig. 1B presents a schematic top view depicting the rear side of the embodiment of the heat exchanger plate according to the invention shown on Fig. 1.

Fig. 2A, 2B present another embodiment of the heat exchanger plate according to the invention analogous to Fig. 1 and 2, in which the primary flow ducts have a different geometry.
Fig. 3, 4 present schematic top views depicting the front side of two embodiments of heat exchanger plates according to the invention, which are designed similarly to those on Fig. 1A and 2A, but the duct webs of the supply ducts exhibit a different geometry relative thereto.

Fig. 5, 6 present cross sectional views depicting heat exchanger plates according to the invention to illustrate the cross sections of the duct geometries.

Fig. 7 presents an exploded view depicting a stack of heat exchanger plates according to the invention, of the kind that can be provided in a plate heat exchanger.

Fig. 8A-8D present schematic side views depicting the stacks or packets of heat exchanger plates shown on Fig. 7, wherein the flow conditions for two provided flow media are illustrated.

Fig. 9 presents a schematic side view depicting an embodiment of a plate heat exchanger according to the invention, which exhibits a stack or packet of heat exchanger plates according to the invention.

Fig. 10A, 10B present a top view and cross section that schematically depict another embodiment of a heat exchanger plate according to the invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS
Embodiments of the present invention will be described below. All embodiments of the invention along with their technical features and properties can be combined in isolation from each other or randomly compiled as desired and without limitation.

Structurally and/or functionally identical, similar or equally acting features or elements are marked with the same reference numbers below in conjunction with the figures. A detailed description of these features or elements is not repeated in each case.

Reference will first be made to the drawings in general.

The present invention also relates in particular to a plate heat exchanger 100 or plate recuperator 100 with a plurality of heat exchanger plates 1 according to the invention.

In particular monolithically designed, ceramic materials are here provided for configuring the heat exchanger plates 1 according to the invention.

Monolithic, ceramic materials are highly sensitive to flexural loads. This is why their use in configuring heat exchanger plates 1 in plate heat exchangers 100 has previously been largely ruled out, since various construction concepts for flow chambers in ceramic heat exchanger plates and in particular in SSiC heat exchanger plates 1 offer no support over large areas of the heat exchanger plates 1. This has previously resulted in plate fractures owing to flexural loads caused by the interior pressure loads during exposure of the respective flow chambers to liquid pressure.

This is countered according to the invention by designing the flow ducts 20k with so-called duct webs 20s, which form
duct walls 20w that on their part completely or sectionally border the duct grooves 20r of the flow ducts 20k of the flow duct arrangement 20.

It is precisely the duct webs 20s that inherently stabilize the structure of the heat exchanger plate 1 composed of a ceramic material, and especially of an SiC or SSiC material, in particular by virtue of the fact that they help support an arrangement of a plurality of heat exchanger plates 1 according to the invention relative to each other in a plate heat exchanger 100.

Detailed reference will now be made to the drawings.

Fig. 1 presents a schematic top view of a first embodiment of the heat exchanger plate 1 or heat recuperator 1.

The latter essentially consists of a plate substrate 10, which is also referred to simply as a substrate 10 for the heat exchanger plate 1, and contains or consists of at least one ceramic material 10’, preferably an SiC material or silicon carbide material 10’, and further preferably contains or consists of at least one sintered silicon carbide material 10’ or SSiC material 10’.

The substrate 10 for the heat exchanger plate 1 has a plate structure with a front side or upper side 10o and a rear side or bottom side 10u; however, these can in particular be on an equal footing, precisely with respect to a respective application, and can also be similarly or even identically structured.
The so-called front side or upper side 10o of the substrate of the heat exchanger plate 1 according to the invention will first be described below.

Initially provided are a supply opening 2 for a first fluid F1, a removal opening 3 for the first fluid F1, a supply
opening 2' for a second fluid F2 as well as a removal opening 3' for the second fluid F2. All openings 2, 2', 3, 3' are formed at the edge or corner regions of the plate substrate 10.

The supply opening 2 for the first fluid F1 is formed in the upper left corner in the view shown on Fig. 1A. The removal opening 3 for the first fluid F1 is formed in the lower left corner. However, the removal opening 3 for the first fluid F1 can be situated diagonally opposite the supply opening 2 for the first fluid F1, i.e., in the lower right corner in the view presented on Fig. 1A.

In the embodiment on Fig. 1A, the supply opening 2' for the second fluid F2 is formed in the area of the upper right corner, while the removal opening 3' for the second fluid F2 is formed in the area of the lower right corner. However, the removal opening 3' for the second fluid can also be situated diagonally opposite the supply opening 2' for the second fluid, i.e., in the area of the lower left corner in the view depicted on Fig. 1A.

The respective supply openings and removal openings for a respective fluid each lie opposite each other in relation to the longitudinal alignment of the plate substrate 10. In the arrangement shown on Fig. 1A, they are additionally both arranged on the respective left side or right side of the plate substrate 10 in relation to the short edge k. In addition, the two supply openings 2, 2' on the one hand and the two removal openings 3, 3' on the other hand lie opposite each other in relation to the longitudinal edge 1 or long edge 1 of the plate substrate 10, so that a countercurrent process is realized in particular when combining a plurality of heat exchanger plates 10 according to the invention in a plate heat exchanger 100; this will be elucidated in even more detail below.
The supply opening 2 and removal opening 3 for the first fluid are encompassed or bordered on the upper side 10a of the plate substrate 10 by a primary gasket 6 for the front side 10o and for the first fluid F1, so that the supply opening 2' and removal opening 3' for the second fluid F2 lie outside the primary gasket 6 for the upper side 10o.

Provided inside the primary gasket 6 for the front side 10o in addition to the supply opening 2 and removal opening 3 for the first fluid F1 is an arrangement 20 for flow ducts 20k, which is also referred to as a duct arrangement 20 or flow duct arrangement 20. The plurality of flow ducts 20k provided in this channel arrangement 20 extends on the surface or upper side 10o of the substrate 10, specifically in that a plurality of the individual ducts 20k form a kind of relief on the upper side 10o of the plate substrate 10 inside the primary gasket 6 for the upper side 10o. The ducts 20k essentially extend between the supply opening 2 and removal opening 3 for the first fluid F1.

The entire duct arrangement 20 is divided into a primary duct arrangement or primary heat exchange duct arrangement 21, which is located in the middle between the supply opening 2 and removal opening 3 for the first fluid and spaced a little apart from the latter, and is formed by primary ducts 21k or primary heat exchange ducts 21k. A supply or distribution duct arrangement 22 with distribution ducts 22k or distribution ducts 22k or a bundling, merging or removal duct arrangement 23 with a plurality of bundling, merging or removal ducts 23k is directly adjacent to the supply opening 2 and removal opening 3 for the first fluid F1 and directly connected with the primary duct arrangement 21 and/or adjacent thereto.

During operation, the first fluid F1 is supplied via the supply opening 2, and introduced on the upper side 10o of
the plate substrate in a practical manner and distributed there. The distribution is handled by the distribution ducts 22k of the supply and distribution duct arrangement 22 that adjoins the supply opening 2 for the first fluid F1.

The distribution ducts 22k of the supply and distribution duct arrangement 22 carry the first fluid F1 over into the primary ducts 21k or primary heat exchange ducts 21k of the primary duct arrangement 21 or primary heat exchange duct arrangement 21. The primary ducts 21k and primary duct arrangement 21 are comparatively longer in design than the supply and distribution duct arrangement 22, resulting in a longer retention time there for the first fluid F1 streaming in the ducts 20k, so that a strong heat transfer to the plate substrate 10 comes about.

The primary ducts 21k then transition into the so-called bundling ducts 23k, which can also be referred to as removal ducts 23k or merging ducts 23k, and which accommodate the first fluid F1 from the primary ducts 21k and route it to the removal opening 3 for the first fluid F1, through which the first fluid F1 then once again exits the duct arrangement 20, and thus the upper side 10o of the substrate of the heat exchanger plate 1 according to the invention, after streaming through the ducts 20k of the entire duct arrangement 20, starting from the supply opening 2 for the first fluid F1.

Due to the primary gasket 6 for the first fluid F1 and for the upper side 10o, the first fluid F1 does not reach the outer region outside of the primary gasket 6, and hence the regions of the supply opening 2' and removal opening 3' for the second fluid F2, while flowing from the supply opening 2 to the removal opening 3. In addition, the supply opening 2' and removal opening 3' for the second fluid exhibit first and second secondary gaskets 4-1 or 4-2, which once
again seal off the supply opening 2' or removal opening 3' for the second fluid F2 by outwardly enveloping the supply opening 2' and removal opening 3' for the second fluid F2 in its edge region. As a consequence, the supply opening 2 and removal opening 3 for the first fluid F1 and the supply opening 2' and removal opening 3' for the second fluid F2 are separated or isolated from each other overall in terms of flow, so that the first and second fluid F1 or F2 do not mix together on the upper side 10o of the plate substrate.

The supply opening 2 for the first fluid F1 and the supply and distribution duct arrangement 22 with the distribution ducts 22k or supply ducts 22k together form the supply or distribution region 7 for the front side 10o of the substrate or for the first fluid F1.

The primary duct arrangement 21 or primary heat exchange duct arrangement 21 with its primary ducts 21k or primary heat exchange ducts 21k forms the primary heat exchange region or primary heat transfer region 9 on the upper side 10o of the plate substrate 10 or the first fluid F1 of the heat exchanger plate 1 according to the invention.

Accordingly, the removal opening 3 for the first fluid F1 and the bundling and removal duct arrangement with their bundling ducts 23k, merging ducts 23k or removal ducts 23k form the so-called bundling and removal region 8 for the front side 10o of the plate substrate 10 of the heat exchanger plate 1 according to the invention or the first fluid.

The arrangement shown in a top view on Fig. 1A is strictly axially symmetrical in relation to the recorded symmetry axis x. With respect to the also recorded symmetry axis y, at least the supply opening 2 for the first fluid F1 and the removal opening 3' for the second fluid F2 on the one hand and the removal opening 3 for the first fluid F1 and
the supply opening 2' for the second fluid F2 are arranged in a strictly axially symmetrical manner. The outer shape of the substrate 10 is arranged in a strictly axially symmetrical manner in relation to both axes x and y, and essentially is shaped like an elongated rectangle with rounded corners, and a height-width ratio for the long edge I and short edge k within a range of about 2 : 1.

In the arrangement depicted on Fig. 1A, the supply ducts 22k or distribution ducts 22k transition directly into the primary ducts 21k in a 1-to-1 arrangement or allocation, and the latter in turn transition into the bundling ducts 23k or removal ducts 23k in a 1-to-1 arrangement. The duct hollow spaces 20r or duct grooves 20r on the figure are depicted as white or bright, while the duct webs 20s comprising the duct walls are shown as black or dark.

Therefore, the ducts 20k as a whole in the arrangement on Fig. 1A are formed by a respective supply duct 22k, a directly allocated primary duct 21k and a removal duct 23k directly allocated thereto. The primary ducts 21k here are shaped like a sawtooth or zigzag line with a triangular basic pattern. However, other embodiments are also conceivable.

The crucial factor with respect to the arrangement from Fig. 1A is that the duct arrangement 20 as a whole and the ducts 20k in particular are comprised of so-called duct webs 20s, which form the duct walls 20w of the duct groove 20r. These duct webs 20s yield the special mechanical stability, precisely from a hydrodynamic or fluidodynamic standpoint in the area of the supply openings 2 for the first fluid F1.

On the one hand, the mechanical stability of the inherently flatly designed plate substrate 10 is inherently stabilized by the recessed sequence of the groove 20r and web 20s.
However, the interaction between a plurality of plate substrates 10 of stacked heat exchanger plates 1 according to the invention in a plate heat exchanger 100 additionally has an effect in which directly adjacent substrates 10 are mutually supported on the areas of the duct webs 20s. This double mechanical stabilization or reinforcement makes it possible to use the ceramic substrate material 10' of the plate substrate 10 that is inherently not able to withstand strong loads in terms of flexural stress according to the invention, in particular in the form of so-called silicon carbide materials or SiC materials, and in particular in the form of sintered silicon carbide materials or S3SiC materials, without it being necessary to increase the plate thickness or layer thickness DS of the plate substrate 10 of the heat exchanger plate 1 according to the invention, since the web structure, i.e., the recessed sequence of the grooves 20f of the ducts and the webs 20s of the ducts 20k, along with the reciprocal support by abutting the webs 20s of the ducts 20k directly in the plate stack of adjacent heat exchanger plates 1 yields a higher stiffness and stabilization relative to each other, so that the flexural stress on the plate substrate 10 of the heat exchanger plate 1 according to the invention does not exceed the possible maximum, even when the first fluid F1 is introduced through the supply opening 2 for the first fluid F1 at the accompanying high pressures.

Viewed from the direction of the upper side 10o of the substrate 10 from the arrangement on Fig. 1A, Fig. 1B presents a kind of phantom view showing the structure of the rear side 10u or bottom side 10u of the same substrate 10. For this reason, all structures are depicted with dots or dashes.

The arrangement of the primary gasket 6' provided here for the second fluid F2 for the rear side 10u as well as of the first and second secondary gaskets 4-1' and 4-2' for the
supply opening 2 or for the removal opening 3 for the first fluid F1 in relation to the rear side 10u is strictly axially or mirror symmetrical to the symmetry axis x, and by comparison to the corresponding arrangement shown on Fig. 1A in relation to the primary gasket 6 for the first fluid F1 and the secondary gaskets 4-1 and 4-2 for the second fluid in relation to the front side 10o is strictly axially or mirror symmetrical to the symmetry axis y.

The primary gasket 6' here envelops the supply opening 2' and the removal opening 3' for the second fluid F2, outwardly separates the supply opening 2 and removal opening 3 for the first fluid F1 in terms of flow with the corresponding first and second secondary gaskets 4-1' and 4-2', and its interior exhibits the duct arrangement 20' or flow duct arrangement 20' for the second fluid F2 on the rear side 10u of the plate substrate 10 of the heat exchanger plate 1 according to the invention.

As a consequence, the arrangement for the rear side 10u or bottom side 10u of the plate substrate 10 essentially corresponds to that for the front side 10o of the plate substrate 10, which is depicted o Fig. 1A.

Accordingly, a supply area 7' or distribution area 7', a bundling area 8' or removal area 8', and a primary heat exchange area 9' or primary heat transfer area 9' between them are formed for the rear side 10u or second fluid F2, specifically through the interaction of the supply opening 2' for the second fluid F2 and the supply duct arrangement 22' or distribution duct arrangement 22' with the supply ducts 22k' or distribution ducts 22k' for the second fluid F2, through the primary duct arrangement 21' or primary heat exchange duct arrangement 21' with the primary ducts 21k' or primary heat exchange ducts 21k' for the second fluid F2, or through the interaction of the removal opening 3' for the second fluid F2 with the bundling duct
arrangement 23', merging duct arrangement 22' or removal duct arrangement 24' with the bundling, merging or removal ducts 23k' for the second fluid F2 on the rear side 10u of the plate substrate 10 of the heat exchanger plate 1 according to the invention.

Otherwise, that which was stated for the front side 10o according to Fig. 1A applies accordingly.

The arrangements shown on Fig. 2A and 2B correspond to those from Fig. 1A and 1B, except that the primary ducts 21k for the first fluid 1 and 21k' for the second fluid F2 and the corresponding webs 20s, 20s' on Fig. 1A and 1B exhibit a sawtooth or zigzag shape, while a wave shape is present in the embodiment according to Fig. 2A and 2B, in particular a type of sinusoidal progression.

All duct shapes are basically conceivable, i.e., for example with any lateral undulation, i.e., running in the plane of the upper side 10o or bottom side 10u of the substrate 10, with an undulating direction U in the XY plane of the front side 10o and/or the rear side 10u of the plate substrate 10 of the heat exchanger plate 1 according to the invention.

The undulation itself results in a longer retention time of the fluid F1, F2 flowing or streaming in the duct 20k, 20k', and hence in a more intimate exchange of heat with the material 10' of the substrate 10.

Fig. 3 and 4 present top views depicting the upper sides 10o of substrates 10 for two other embodiments of the heat exchanger plate 1 according to the invention. In terms of their structure, the primary ducts 21k, 21k' of ducts 20k, 20k' here essentially correspond to the ducts in the arrangements on Fig. 1A, B on the one hand and Fig. 2A, B on the other, i.e., they exhibit a sawtooth or wave shape.
As opposed to the arrangements on Fig. 1A to 2B, the arrangements on Fig. 3 and 4 exhibit supply ducts 22k, 22k' and removal ducts 23k, 23k', which are no longer in a 1-to-1 correspondence with the primary ducts 21k, 21k'. Rather, the duct webs 20s, 20s'—in particular 22s, 22s', 23s, 23s'—are here greatly extended in design, so that the overall number of supply ducts 22k, 22k' and removal ducts is lower than the number of primary ducts 21k, 21k'. However, given the extension of webs 20s, 20s', 22s, 22s', 23s, 23s', the mechanical stability is here further increased in the area of the supply opening 2 and removal opening 3 for the first medium, and correspondingly for the supply opening 2' and 3' for the second medium on the rear side 10u.

Fig. 5 and 6 present cut partial views through a substrate 10 of two embodiments of the heat exchanger plate 1 according to the invention, specifically as viewed in direction Y taking the arrangements on Fig. 1A to 4 as the basis.

The arrangement shown on Fig. 5 and 6 reveals the various possible embodiments for the cross section of ducts 20k, 20k', in particular the primary heat exchange duct arrangement 21, 21', i.e., primary ducts 21k, 21k'.

In the arrangement depicted on Fig. 5, the respective duct grooves 20r, 20r' and respective duct web 20s, 20s' of the respective duct 20k, 20k' have roughly a rectangular or quadratic shape, and exhibit essentially the same configuration relative to each other. For example, the respective duct floor 20b, 20b' here forms the level of minimum layer thickness Dmin for the underlying substrate 10. The webs or duct webs 20s, 20s' are placed hereupon with a height that forms the depth t of the duct groove 20r, 20r', which corresponds to the width Bb of the floor 20b, 20b' of the duct groove 20r of the flow duct 20k,
20k', but also to the width Bsb of the duct web 20s, 20s' at the height of the floor 20b, 20b', and also the local width Bsp of the plateau 20sp, 20sp' of the web 20s, 20s'.

The geometry of the ducts 20l, 20k' gives the duct walls 20w, 20w' a perpendicular design. An identical width is selected for the base of the respective duct web 20s, 20s' and the plateau 20sp, 20sp' of the duct web 20s, 20s', wherein Bsp = Bsb.

By contrast, the base of the duct web 20s, 20s' and the plateaus 20sp, 20sp' of the duct webs 20s, 20s' in the embodiment on Fig. 6 are selected in such a way as to yield a tapering progression for the duct webs 20s, 20s' toward the side facing away from the duct floor 20b, 20b', wherein the angle of inclination α for the respective duct wall 20w, 20w' is different than 0°, so that Bsb > Bsp.

Fig. 7 presents a schematic and perspective exploded view of an arrangement 100' for a plate heat exchanger 100 with a plurality of heat exchanger plates 1 or 1j, j=1, ..., n according to the invention, which are arranged so as to cover or be congruent with each other to resemble a stack 110, and alternately generate flow spaces R1, R3, R5, ... for the first fluid F1 or R2, R4, R6, ... for the second fluid F2. Also denoted is the allocation of the gaps or flow spaces R1, R2, R3, ... of directly adjacent heat exchanger plates 1 or 1j, j=1, ..., n according to the invention, relative to the corresponding first and second fluids F1, F2. The arrows denote the flow conditions with respect to forward and return flow, i.e., inflow and outflow. The respective gaskets 6, 4-1, 4-2 and various duct arrangements 20, 20' are not indicated in this depiction.

Fig. 8A to 8D schematically present cut side and top views of the flow conditions present in the arrangement 100' on Fig. 7 with respect to the first and second fluids F1 and
F2. Exclusively the first and second secondary gaskets 4-1, 4-2, 4-1', 4-2' for the first and second fluids F1, F2 are here shown.

As evident from the information provided for Fig. 7 to 8D, stringing together and interconnecting a plurality of heat exchanger plates 1 or 1j, j=1, ..., n according to the invention yields a sequence of alternating flow spaces for the first and second fluids F1 and F2, wherein consecutive, odd numbered gaps R1, R3, R5, ... between directly consecutive heat exchanger plates 1 or 1j, j=1, ..., n form flow spaces R1, R3, R5, ... for the first fluid F1, while even numbered gaps R2, R4, R6, ... between consecutive heat exchanger plates 1 or 1j, j=1, ..., n form flow spaces R2, R4, R4, ... for the second fluid F2.

The depictions on Fig. 8A to 8D are here not to scale, since the primary gaskets 6, 6' and secondary gaskets 4-1, 4-2, 4-1', 4-2' have too thick a configuration; however, this serves to illustrate the geometric and flow conditions.

Fig. 9 presents a schematic and partially cut side view of a more realistic depiction of the arrangement 100' of a plate heat exchanger 100 according to the invention with a plurality of heat exchanger plates 1 or 1j, j=1, ..., n according to the invention combined into a stack 110.

The stack 110 comprised of a plurality of heat exchanger plates 1 or 1j, j=1, ..., n according to the invention is here clamped between two clamping plates 120 or clamping devices 120 via a corresponding screw joint 130, so that the conditions described in the preceding figures come about as a whole during the interaction between the individual heat exchanger plates 1 or 1j, j=1, ..., n according to the invention.
Fig. 10A and 10B describe another embodiment of the heat exchanger plate 1 according to the invention that contains or consists of a ceramic substrate 10.

The heat exchanger plate 1 according to the invention here also has an essentially rectangular configuration, but with an edge ratio between the long and short edges 1 or k measuring about 4 : 1. Otherwise, the conditions are as described in conjunction with Fig. 2A, 2B and 4 as well as 6. This means that the actual primary heat exchange ducts 21k, 21k' are roughly wave shaped, that no 1-to-1 correspondence or allocation exists between the supply and removal ducts 22k, 22k', 23k, 23k' on the one hand and the primary heat exchange ducts 21k, 21k' on the other, and that the webs 20s, 20s'—meaning in particular 22s, 22s', 23s, 23s'—of the underlying flow ducts 20k, 20k' have a trapezoidal shape in cross section, with a tapering progression going away from the respective duct floor 20b, 20b'.
Reference List

1    Heat exchanger plate, recuperator plate according to the invention
1j   Heat exchanger plate, recuperator plate according to the invention given an arrangement of a plurality of j=1, ..., n heat exchanger plates, recuperator plates according to the invention
2    Supply opening (first fluid F1)
2'   Supply opening (second fluid F2)
3    Removal opening (first fluid F1)
3'   Removal opening (second fluid F2)
4-1  First secondary gasket (front side 10o / for supply opening, second fluid F2)
4-1' First secondary gasket (rear side 10u / for supply opening, first fluid F1)
4-2  Second secondary gasket (front side 10o / for supply opening, second fluid F2)
4-2' Second secondary gasket (rear side 10u / for supply opening, first fluid F1)
6    Primary gasket (front side 10o / first fluid F1)
6'   Primary gasket (rear side 10u / second fluid F2)
7    Supply area / distribution area (front side 10o / first fluid F1)
7'   Supply area / distribution area (rear side 10u / second fluid F2)
8    Bundling area / removal area (front side 10o / first fluid F1)
8'   Bundling area / removal area (rear side 10u / second fluid F2)
9    Primary heat exchange area / primary heat transfer area (front side 10o / first fluid F1)
9'   Primary heat exchange area / primary heat transfer area (rear side 10o / second fluid F2)
10   Substrate of the heat exchanger plate 10, plate substrate
10' Material of the plate substrate, ceramic material, SiC or SSiC material
10o Upper side / front side of the substrate 10
10u Bottom side / rear side of the substrate 10
20 Duct arrangement / flow duct arrangement (front side 10o / first fluid F1)
20' Duct arrangement / flow duct arrangement (rear side 10u / second fluid F2)
20b, 20b' Duct floor
20k, 20k' Flow duct, duct, heat exchange duct
20p, 20p' Duct plateau
20r, 20r' Duct groove
20s, 20s' Duct web
20w, 20w' Duct wall
21, 21' Primary heat exchange duct arrangement, primary duct arrangement
21b, 21b' Duct floor
21k, 21k' Primary heat exchange duct, primary duct
21p, 21p' Duct plateau
21r, 21r' Duct groove
21s, 21s' Duct web
21w, 21w' Duct wall
22, 22' Supply duct arrangement / distribution duct arrangement
22b, 22b' Duct floor
22k, 22k' Distribution duct
22p, 22p' Duct plateau
22r, 22r' Duct groove
22s, 22s' Duct web
22w, 22w' Duct wall
23, 23' Bundling arrangement / removal duct arrangement
23b, 23b' Duct floor
23k, 23k' Bundling duct, merging duct, removal duct
23p, 23p' Duct plateau
23r, 23r' Duct groove
23s, 23s' Duct web
23w, 23w' Duct wall
100 Plate heat exchanger or plate recuperator according to the invention
100' Arrangement for a plate heat exchanger 100 or plate recuperator 100 according to the invention
110 Stack comprised of a plurality of heat exchanger plates 1 or recuperator plates 1
120 Clamping plate, clamping arrangement
130 Screw device, screw joint, clamping screw

F1 First fluid, first heat exchange fluid
F2 Second fluid, second heat exchange fluid
k Short edge of the plate substrate 10
l Long edge of the plate substrate 10
t Depth of the duct 20k, 20k' or the duct groove 20r, 20r'
U Undulating direction
CLAIMS

1. A heat exchanger plate (1) for a plate heat exchanger (100),
- with a plate substrate (10), which contains or consists of an SiC material (10') or a silicon carbide material (10'), and which exhibits a front or upper side (10o) and a rear or bottom side (10u),
- wherein at least the front or upper side (10o) of the plate substrate (10) is comprised of a flow duct arrangement (20) with a plurality of flow ducts (20k), and
- wherein some or all of the flow ducts (20k) of the flow duct arrangement (20) are entirely or sectionally provided with duct webs (20s) that border duct grooves (20r) and form duct walls (20w).

2. The heat exchanger plate (1) according to claim 1,

   wherein the plate substrate (10) contains or consists of a sintered silicon carbide material (10') or SSiC material (10).

3. The heat exchanger plate (1) according to one of the preceding claims,

   wherein a minimal layer thickness Dmin and/or an average layer thickness Dm of the plate substrate (10) ranges between about 2 mm and about 4 mm, in particular measures about 3 mm or less, preferably about 2 mm.
4. The heat exchanger plate (1) according to one of the preceding claims,

wherein the layer thickness $D_s$ of the plate substrate (10) in the area of a duct web (20s) is greater than the minimum layer thickness $D_{\text{min}}$ of the plate substrate (10) and/or than the average layer thickness $D_m$ of the plate substrate (10),

thereby roughly satisfying the correlation

$$D_s \geq D_{\text{min}}$$

or roughly the correlation

$$D_s \geq D_m.$$

5. The heat exchanger plate (1) according to one of the preceding claims,

wherein a local width $B_b$ of the floor (20b) of the duct groove (20w) of the flow duct (20k) and the local width $B_{sb}$ of a base of the duct web (20s) of the flow duct (20k) at the height of the floor (20b) of the duct groove (20r) of the flow duct (20k)—each measured perpendicular to the local direction of the flow duct (20k)—exhibits a ratio $B_b : B_{sb}$ of about 1 : 4,

thereby roughly satisfying the correlation

$$B_b : B_{sb} = 10 : 4.$$

6. The heat exchanger plate (1) according to one of the preceding claims,

wherein the local width $B_b$ of the floor (20b) of the duct grooves (20r) of the flow duct (20k) and the
local width Bsp of a plateau (20sp) of a duct web (20s) of a flow duct (20k) on the side facing away from the floor (20b) of the duct groove (20r) of the flow duct (20k)—each measured perpendicular to the local direction of the flow duct (20k)—exhibits a ratio Bb : Bsp within a range of about 10 : 3,

thereby roughly satisfying the correlation

\[ 10 : 4 \leq Bb : Bsp \leq 10 : 2 \]

or preferably roughly the correlation

\[ Bb : Bsp = 10 : 3. \]

7. The heat exchanger plate (1) according to one of the preceding claims,

wherein the local width Bsb of the base (20sb) of the duct web (20s) of the flow duct (20k) at the height of the floor (20b) of the duct groove (20r) of the flow duct (20k) and the local width Bsp of the plateau (20sp) of the duct web (20s) of the flow duct (20k) on the side facing away from the floor (20b) of the duct groove (20r) of the flow duct (20k)—each measured perpendicular to the local direction of the flow duct (20k)—exhibits a ratio Bsb : Bsp ranging from about 1 : 1 to about 4 : 2, preferably of about 4 : 3,

thereby roughly satisfying the correlation

\[ 4 : 2 \leq Bsb : Bsp \leq 1 : 1 \]

or preferably roughly the correlation

\[ Bsb : Bsp = 4 : 3. \]
8. The heat exchanger plate (1) according to one of the preceding claims 1 to 6,

wherein the duct walls (20w) of a flow duct (20k) include an angle $\alpha$ with the normal relative to the floor (20b) of the duct groove (20r) of the flow duct (20k) ranging from greater than $0^\circ$ to less than $30^\circ$, preferably lying at about $15^\circ$,

thereby roughly satisfying the correlation

$$0^\circ < \alpha \leq 30^\circ$$

or preferably roughly the correlation

$$\alpha = 15^\circ.$$

9. The heat exchanger plate (1) according to one of the preceding claims,

wherein the local width $B_b$ of the floor (20b) of the duct groove (20r) of the flow duct (20k)—measured perpendicular to the local direction of the flow duct (20k)—and the depth $t$ of the duct groove (20r) of the flow duct (20k)—measured perpendicular to the floor (20b) of the duct groove (20r) of the flow duct (20k)—exhibits a ratio $B_b : t$ ranging from about $10 : 10$ to about $10 : 4$, preferably of about $10 : 4$,

thereby roughly satisfying the correlation

$$10 : 10 \leq B_b : t \leq 10 : 4$$

or preferably roughly the correlation

$$B_b : t = 10 : 4.$$
10. The heat exchanger plate (1) according to one of the preceding claims,

- wherein supply and removal openings (2, 3) that penetrate the plate substrate (10o) from the upper side (10o) to the bottom side (10u) are provided for supplying or removing a first heat exchange fluid (F1) to or from the upper side (10o) of the plate substrate (10), and

- wherein the flow duct arrangement (20) is designed to transport the first heat exchange fluid (F1) from the supply opening (2) to the removal opening (3).

11. The heat exchanger plate (1) according to one of the preceding claims,

- wherein all or sections of the flow ducts (20k) of the flow duct arrangement (20) exhibit a multi-undulating progression, and

- wherein the undulating direction (U) runs in a surface or plane defined by the plate substrate (10) and/or perpendicular to the flowing direction defined by the respective flow duct (20k) locally and/or on average.

12. The heat exchanger plate (1) according to one of the preceding claims,

wherein the shape of the undulation for a respective flow duct (20k) can be a shape from a group of shapes that includes sawtooth shapes, alternating echelon shapes, wave shapes, sinus shapes and combinations thereof.
13. The heat exchanger plate (1) according to one of the preceding claims,

wherein the rear or bottom side (1u) of the plate substrate (1) exhibits a second flow duct arrangement (20') for a second heat exchange fluid (F2) with a plurality of corresponding flow ducts (20k').

14. The heat exchanger plate (1) according to claim 13,

- wherein second supply and removal openings (2',3') that penetrate the plate substrate (10) from the upper side (10o) to the bottom side (10u) are provided to supply or remove the second heat exchange fluid (F2) to or from the rear or bottom side (10u) of the plate substrate (10), and

- wherein the second flow duct arrangement (20') is designed to transport the second heat exchange fluid (F2) from the second supply opening (2') to the second removal opening (3').

15. The heat exchanger plate (1) according to one of the preceding claims,

which is designed to be rotationally symmetrical by 180° with respect to the front or upper side (10o) and the rear or bottom side (10u) in relation to a symmetry axis (S) running in the plate substrate (10).

16. The heat exchanger plate (1) according to one of the preceding claims,

- wherein the plate substrate (10) essentially has a rectangular shape,
wherein the supply and/or removal openings (2, 2', 3, 3') are formed in the area on opposing first—preferably shorter—sides of the rectangular shape, and

wherein directions in which the first and/or second heat exchange fluids (F1, F2) flow and/or the primary directions in which the flow ducts (20k, 20k') are essentially formed along the directions in which opposing second—preferably longer—sides of the rectangular shape extend.

17. A plate heat exchanger (100),

- with a plurality of heat exchange plates (1; 1j, j=1, ..., n) according to one of claims 1 to 16,

- wherein the heat exchange plates (1; 1j, j=1, ..., n) are designed and arranged in such a way:

  - that the rear or bottom side (10u) of the plate substrate (1) of a respective preceding heat exchanger plate (1; 1j=1, ..., n-1) lies directly opposite the front or upper side (10o) of the plate substrate (1) of a respective directly ensuing heat exchanger plate (1; 1j+1, j=1, ..., n-1) or abuts against the latter directly, or with a sealing arrangement (6, 4-1, 4-2) interspersed,

  - that the sequence of heat exchange plates (1; 1j, j=1, ..., n) and/or in particular the creation of the sealing arrangement (6, 4-1, 4-2) cause directly sequential through-flow spaces (R1, ..., Rn+1) separated from each other in terms of flow to form,
that directly adjacent through-flow spaces (Rj, Rj+1, j=1, ..., n) are separated in pairs in terms of flow, and

that respective next but one adjacent through-flow spaces (Rj, Rj+2, j=1, ..., n-1) are joined together in pairs in terms of flow, are each allocated to a heat exchange fluid (F1, F2) and designed to allow respectively allocated heat exchange fluid (F1, F2) to flow from the respective supply opening (2, 2') to the respective removal opening (3, 3').

18. A method for manufacturing a heat exchanger plate (1) for a plate heat exchanger (100), with the following steps:

- providing or forming a plate substrate (10) that contains or consists of an SiC material (10') or a silicon carbide material (10') with a front or upper side (10o) and a rear or bottom side (10u),

- forming a flow duct arrangement (20) with a plurality of flow ducts (20k) on the front or upper side (10o) of the plate substrate (10),

- wherein some or all of the flow ducts (20k) of the flow duct arrangement (20) are fabricated entirely or sectionally with duct webs (20s) that border duct grooves (20r) and form duct walls (20w).

19. The method according to claim 18,
wherein the plate substrate (10) contains or consists of a sintered silicon carbide material (10) or SSiC material (10').

20. The method according to one of the preceding claims 18 or 19,

- wherein flow ducts (20k) of the flow duct arrangement (20) are designed to exhibit a completely or sectionally multi-undulating progression,

- wherein the undulating direction (U) is designed to run in a surface or plane defined by the plate substrate (10) and/or perpendicular to the flowing direction defined by the flow duct (20k) locally or on average.

- wherein in particular the shape of the undulation is a shape from a group of shapes that includes sawtooth shapes, alternating echelon shapes, wave shapes, sinus shapes and combinations thereof.
Fig. 6
Fig. 7
Fig. 8D