Related U.S. Application Data

Continuation of application No. 13/305,022, filed on Nov. 28, 2011, which is a continuation of application No. PCT/EP2010/057317, filed on May 27, 2010.

ABSTRACT

A layer heat exchanger for high temperatures is provided that includes a layer block having layer plates and cover plates and a housing that accommodates the layer block. The housing has a high heat resistance, combined with a high stiffness, and the layer block has a core that is soft and tough relative to the housing.
LAYER HEAT EXCHANGER FOR HIGH TEMPERATURES

[0001] This nonprovisional application is a continuation of International Application No. PCT/EP2010/057317, which was filed on May 27, 2010, and which claims priority to German Patent Application No. DE 10 2009 022 984.21, which was filed in Germany on May 28, 2009, and which are both herein incorporated by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The invention relates to a layer heat exchanger for high temperatures.

[0004] 2. Description of the Background Art

[0005] Layer heat exchangers are known from the conventional art and include a layer block, which is made up of stacked layer plates and cover plates and is used for the heat exchange between two media, and a housing, which accommodates and seals the layer block and has connections for supplying and removing the media. Layer heat exchangers of this type are notable for a high specific heat transfer performance, based on their volume.

[0006] German Offenlegungsschrift No. DE 103 28 274 A1 of the applicant disclosed this type of layer heat exchanger and a method for the manufacture thereof. The layer block of the prior-art heat exchanger has separating and cover plates, which are fully soldered to one another, i.e., at their points of contact. This produces a relatively stiff layer block, which is welded and/or soldered to the housing. A similar layer heat exchanger was disclosed in German Offenlegungsschrift No. DE 10 2007 006 615 A1. German Offenlegungsschrift DE 10 2006 011 508 A1 of the applicant disclosed a layer heat exchanger with a layer block of layer plates, which have an edge region bent by 180°, which is connected by bonding to a similar edge region of a neighboring layer plate, particularly by soldering with use of solder adhesive tape. This creates the advantage of a layer heat exchanger with a relatively soft layer block with respect to its mechanical properties, which nonetheless has a high tightness.

[0007] German Offenlegungsschrift No. DE 10 2007 008 341 A1 of the applicant disclosed a layer heat exchanger for use as a high-temperature heat exchanger, particularly in the periphery of a high-temperature fuel cell (solid oxide fuel cell—SOFC). High-temperature fuel cells of this type are used for providing electric power in motor vehicles as a so-called ARU (auxiliary power unit). Heat exchangers for SOFCs are used, for example, for heating process air and are supplied with hot combustion gases within a temperature range of about 950°C. This application of a greatly and rapidly changing temperature leads in the heat exchanger structure to thermomechanical stress, which leads to problems with respect to the tightness of the layer block in the interior and tightness of the heat exchanger outwardly. To counter this problem, it was proposed in the layer heat exchanger disclosed in DE 10 2007 008 341 A1 to solder the layer block only on the front side, so that any internal soldering of the sheet metal layers is avoided. It is advantageous in a layer block soldered only outwardly in such a way that the sheet metal layers can avoid the stresses better by elastic or optionally plastic deformations. This results in a reduction of damage but is not sufficient.

[0008] Another solution to the problem of the thermally induced mechanical stress was proposed by the applicant in German Offenlegungsschrift No. DE 10 2007 055 182 A1 for a layer heat exchanger, whereby the layer block is supported elastically within the housing by a decoupling device. Thermally induced expansions of the layer block, which is stiff in itself, are compensated by the decoupling device, e.g., in the form of mineral fiber mats and thus kept away from the housing. The layer block is arranged virtually floating within the housing and can be used advantageously for high temperature differences up to 900°C. The structure-related high internal leak rate of the heat exchanger is disadvantageous here, however.

SUMMARY OF THE INVENTION

[0009] It is therefore an object of the present invention to design and construct a layer heat exchanger in such a way that it withstands high temperatures, particularly stress caused by cyclical temperature changes to about 950°C, so that a sufficient internal tightness, however, especially an absolute tightness of the heat exchanger toward the outside, is assured during operation. The outer tightness is especially important, for example, during use of the heat exchanger for SOFC systems.

[0010] According to the invention, the layer heat exchanger is characterized by a housing with a high heat resistance and stiffness, as well as a layer block with a soft and tough core relative to the housing. Compared with the layer block, the housing is designed as a relatively stiff counter support, which is based on its novel design is capable, particularly at high temperatures, of absorbing thermally induced expansion forces originating from the layer block. Based on this firm counter support, the soft and tough core of the layer block will deform elastically or also plastically in part, which is taken into account. It turned out surprisingly that the internal leakage of the layer heat exchanger of the invention is much lower than in the aforementioned prior art layer heat exchangers. The internal leakage arises during operation, e.g., during use of the heat exchanger in the periphery of a high-temperature fuel cell because gas that has a temperature of 900 to 950°C encounters the cold layer block during a cold start. The thin layer plates heat more rapidly than the thicker housing material, so that because of the thus predefined thermal expansion of the plates, according to Hook’s law, a force F=E·ε (E=elasticity modulus) on the housing arises. When the housing of the invention opposes the force exerted by the plates with a sufficiently high heat resistance, the layer plates in the interior (of the layer block) are more likely to deform elastically or plastically and thereby to reduce the force. It is accepted in this case that the layer plates in the interior may be damaged with often repetition of the cold start; i.e., a relative internal leakage is permitted according to the invention. It is advantageous that the damage is limited locally, namely, to regions that reach the highest temperatures. This limits the internal leakage. The extent to which an internal leakage forms during operation depends on the selection of the materials, particularly the material of the layer plate. The external tightness is absolutely assured, however, i.e., the escape to the outside of gas that has a temperature of 950°C and may also contain hydrogen is prevented in each case.

[0011] Materials and structural realizations for the housing and the layer and cover plate, which satisfy the aforementioned criteria, will be indicated hereafter.
According to an embodiment, the housing is made of a material with a high heat resistance. A high heat resistance is understood to be a high hot yield strength $\sigma_{0.2}$. Nickel alloys are preferred, particularly a readily available high-temperature-resistant material with the material No. 2.4856 according to DIN EN 10095 and the material designation NiCr22Mo5Nb. This material is notable for its good mechanical behavior at temperatures above 500° C. Thus, the yield strength of this material occurs at 500° C. at a high 200 N/mm².

According to another embodiment, austenitic high-temperature stainless steel with the material No. 1.4876 and the material designation X10NiCrAlTi 32-20 is used as material for the housing. The austenitic stainless steels are more cost-effective than the aforementioned nickel alloy, but do not have the very high heat resistance of the material with the material No. 2.4856.

According to another embodiment, the cover and layer plates are made of a material that has a lower heat resistance compared with the material of the housing, particularly a low hot yield strength $\sigma_{0.2}$. By means of this pairing of materials with different heat resistance for the housing, on the one hand, and the layer block, on the other, the aforementioned expansion behavior of the layer block is achieved at high temperature stresses; i.e., a sufficient internal tightness and a complete external tightness are assured.

According to another embodiment, a high-temperature stainless steel with the material No. 1.4876 and the material designation X10NiCrAlTi 32-20 is used. This material occurs at the layer plate and cover plates. If the layer plate material 1.4876 were to lead to unacceptably high internal damage, a relatively cost-effective Ni base material such as 2.4851 (NiCr25Fe) can also be used as the layer plate material. 2.4851 has a higher heat resistance compared with 1.4876 but a lower heat resistance than 2.4856.

According to another embodiment, a ferritic material can also be selected for the material of the layer and cover plates. With a view to the use of the layer heat exchanger in the periphery of the SOFC’s, particularly an Al-containing material is selected as the ferritic material, because this material has a high high-temperature corrosion resistance and low Cr evaporation. For example, a material with the material No. 1.4725 according to DIN 17470 and the material designation CrAl14 4 is suitable.

Alternatively, another ferritic material with the material No. 1.4767 according to DIN 17470 and the material designation CrAl20 5 can be selected. These ferritic materials are especially advantageous in a pairing with the aforementioned austenitic housing materials with the material number 1.4876 (material designation: X10NiCrAlTi 32-20) or 1.4835. An advantage during use of ferritic stainless steels for layer and cover plates is their high elongation at break; i.e., the layer plates deform plastically in fact, but because of their high heat ductility have only a low tendency for developing leakage such as cracks. It should be emphasized that the conventional reservations in regard to different thermal expansion coefficients in the welding of ferrites and austenitics do not apply here, because the expansion coefficients of the ferritic FeCrAl and austenitic Ni alloys selected here have only minor differences.

According to another embodiment, during use of the aforementioned ferritic materials for layer and cover plates, an especially relatively high-temperature-resistant ferritic material such as, for example, 1.4750 can also be selected advantageously for the housing.

Alternatively or also cumulatively to the aforementioned material pairing, different wall thicknesses can be selected for the housing, on the one hand, and the layer and cover plates, on the other, i.e., a high wall thickness for the housing material and a considerably lower wall thickness for the plate material. A stiff housing and layer block with a particularly deformable core of the layer block with the aforementioned advantages of an internal and external tightness are achieved by means of this dimensioning of the wall thicknesses.

According to an embodiment, the wall thickness of the housing is about 1.5 mm and that of the layer plates about 0.3 mm. The wall thickness of the housing material, in contrast to the wall thickness of the layer and cover plate material, can be relatively low, when the heat resistance of the housing material is high relative to the heat resistances of the layer plate material. It is especially preferable accordingly when the housing material consists of a high-temperature-resistant material with a low thickness such as, for example, 2.4856 with a 1.0 mm or 0.5 mm wall thickness and the layer and cover plate material of a soft material such as the aforementioned FeCrAl alloys. The especially minor difference in mass between the housing, on the one hand, and the layer and cover plates, on the other, leads to especially low thermal stresses. An Al content of ±2%, especially preferably ±3% is especially useful in this case.

According to another embodiment, it is provided alternatively or cumulatively that the layer and cover plates are connected to one another by bonding or welding on the front side at their sealing edges, preferably by soldering or welding. Ribs or nubs, which are located in the interior of the heat exchanger or lead from the outside into the interior of the heat exchanger, should thereby not be connected to one another by bonding or at least to the lowest extent possible. The advantage is achieved thereby that the layer block is securely sealed toward the outside and remains soft and elastically deformable in the interior in its core.

In an alternative construction form, the housing and the cover plates consist of the same highly temperature-resistant material and only the layer plates consist of the soft material.

Finally, according to another embodiment, the housing and the layer and cover plates can be made of the same material. In this regard, the soft core of the layer block can be achieved by a lower plate wall thickness compared with the wall thickness of the housing and/or by the soldering or welding of the layer block on the front side.

The use of the layer heat exchanger of the invention proves to be advantageous particularly in the periphery of a high-temperature fuel cell, preferably in motor vehicles, to meet the strict conditions applicable there in regard to an internal and external tightness of the heat exchanger.

Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.
BRIEF DESCRIPTION OF THE DRAWINGS

[0026] The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus, are not limiting of the present invention, and wherein:

[0027] FIG. 1 shows a layer heat exchanger in an exploded view; and

[0028] FIG. 1a shows a layer block in an exploded view.

DETAILED DESCRIPTION

[0029] FIG. 1 shows a layer heat exchanger 1 in an exploded view. Such a layer heat exchanger 1 is known from the aforementioned state of the art with respect to its structure. A partially shown layer block 2, through which two media can flow in crossflow, is arranged in the interior of layer heat exchanger 1. Layer block 2 is housed in a box-like housing sections 3, 4, 5, 6, which in turn have connecting pieces 3a, 4a, 5a, 6a for supplying and removing the media flowing through layer block 2. The four box-like housing sections 3, 4, 5, 6 including the connecting pieces 3a, 4a, 5a, 6a are together also called a housing 7 below. Layer block 2 and housing 7 are connected together by twelve welding seams, of which welding seams 8a, 8b, 8c are designated by way of example.

[0030] In FIG. 1a, layer block 2 according to FIG. 1 is shown schematically by a bottom cover plate 9 and a top cover plate 10 and by two layer plates 11, 12. Layer plates 11, 12, also called layer sheets 11, 12, are formed contoured; i.e., they have flow channels and sealing edges 11a, 11b, 11c, 12a, 12b, 12c intersecting at 90° (which are not provided with reference numbers). All parts are connected together by bonding, preferably soldered and/or welded, as emerges in particular from the aforementioned state of the art, to which reference is made hereinabove.

[0031] According to the invention, housing 7 has a high heat resistance in relation to layer block 2; i.e., cover plates 9, 10 and layer plates or sheets 11, 12 have a lower heat resistance. As a result, for layer block 2 a softer and tougher core is achieved, which is capable of deforming elastically or plastically with high temperature-induced expansions in the internal region, for example, to curve. Housing 7, in contrast, owing to its elevated heat resistance and stiffness should preferably not deform, but absorb the reaction forces resulting from the layer block.

[0032] According to an exemplary embodiment, layer heat exchanger 1 is used in the periphery of a high-temperature fuel cell (SOFC), which is not shown, as it is employed for providing electric power in motor vehicles as a so-called ARU (auxiliary power unit). Layer heat exchanger 1 is used in particular here for the recovery of exhaust gas heat of the fuel cell and for heating process air for the SOFC. A fuel cell system of this type was disclosed in US 2003/0031904 A1. The exhaust gases of the SOFC with a temperature of about 950° C. encounter the structure of layer heat exchanger 1, in which the process air for the cathode of the SOFC is to be heated to about 750° C. Particularly in the case of a cold start, this would lead to great thermomechanical stresses in the heat exchanger structure. Because of the tough and soft core of layer heat exchanger 1 constructed as taught by the invention, these stresses can be reduced, however, by the elastic or plastic deformations of the core. Layer block 2 is supported thereby by the highly heat-resistant solid housing 7, which absorbs the reaction forces without significantly deforming in so doing. Layer heat exchanger 1 therefore remains outwardly tight in each case, so that no hot exhaust gases can escape from the system. It is possible that the layer plates are deformed beyond their yield strength, i.e., permanently. This can be accepted, however, because such damage is limited locally to areas where the highest temperatures are reached. As a result, the internal leakage of layer heat exchanger 1 is limited.

[0033] According to an embodiment, materials with different heat resistance values are selected for housing 7 and layer and cover plates 9, 10, 11, 12, particularly with a focus on the hot yield strength ϒ3,6. Preferably, a nickel alloy with the material No. 2.4856 and the material designation NiCr22Mo9Nb according to DIN EN 10005 is selected as the material for housing 7, therefore box-like housing sections 3, 4, 5, 6. In contrast, a material with a lower heat resistance, namely, a heat-resistant high-temperature stainless steel, e.g., with the material No. 1.4876, is provided as the material for the cover and layer plates 9, 10, 11, 12. The housing material with the material No. 2.4856 has a yield strength of ϒ3,6=345 MPa at 700° C., whereas the corresponding hot yield strength in the case of the plate material with the material No. 1.4876 is only 90 MPa (1 MPa=1 N/mm²). When the thermomechanical stresses occurring during operation in the plates exceed their yield strength, these stresses in the plates are reduced by plastic deformation, whereas the housing is at most slightly elastically deformed; i.e., no permanent damage occurs in the housing and the layer heat exchanger remains outwardly securely tight. The Ni base material 2.4851 can be used for higher thermomechanical requirements for the layer plate material.

[0034] According to another embodiment, ferritic materials, particularly Al-containing ferritic materials, can also be used advantageously for the cover and layer plates 9, 10, 11, 12 of layer block 2, e.g., with the tool numbers 1.4725 or 1.4767, which according to DIN 17470 correspond to the material designations CrAl14 4 or CrAl20 5. For these plate materials, i.e., a ferritic core of the layer block, a more cost-effective housing material would also be advantageous, namely, an austenitic high-temperature stainless steel, e.g., with the material numbers 1.4876 or 1.4834 or a ferritic stainless steel such as the 1.4750.

[0035] According to another embodiment of the invention, the aforementioned measures of different materials for the housing and plates can be supported by structural measures, particularly by the selection of wall thicknesses. In an alternative, the wall thickness of housing 7 or the box-like housing sections 3, 4, 5, 6 are selected as high as possible and the wall thickness of cover and layer plates 9, 10, 11, 12 as low as possible. In a preferred exemplary embodiment, a wall thickness of about 1.5 mm is provided for housing 7 and a wall thickness of about 0.3 mm for the plates. Such a selection of different wall thicknesses would support the aforementioned selection of different materials or strengthen the effect of the invention.

[0036] In another embodiment, the wall thicknesses of the housing, i.e., of material for the box-like sections and cover plates, are selected as low as possible, for example, 1.0 mm or even 0.5 mm, in comparison with 0.3 mm- or 0.4 mm-thick layer plate material. The advantage here is that with rapid heating of the block formed from the layer plate the temperature difference relative to the housing is low and thereby the thermomechanical stresses are low. The relative stiffness...
of the housing must then be achieved with the heat resistances of the materials used for the housing. An exemplary combination of materials for the housing (plates for the box-like sections and covers) would be a high-temperature-resistant Ni base material, such as, for example, 2.4856 or 2.4851 and for the layer plates (folded sheets) of the block, a low-temperature-resistant but ductile ferritic stainless steel. Especially preferred in this case are Al-containing ferritic stainless steels because of their good high-temperature corrosion resistance and the low Cr evaporation.

[0037] According to another embodiment of the invention, the aforementioned measures of the invention can be supplemented and supported by a suitable joining technology for layer block 2. Thus, according to a first exemplary embodiment, it is provided that layer block 2 is soldered only on the front side, which is known per se, namely, from DE 10 2007 008 341 A1 of the applicant. The object of this publication is incorporated in its entirety in the disclosed content of the present application. A soft, i.e., movable core arises as an advantage of this front-side soldering, i.e., an elimination of a complete soldering of the layer plates, because the individual layer plates in the core region can slide one on top of another. Thus, discrete flow channels are no longer present, as could emerge from Fig. 1a. An elastic yielding to the thermal stresses arising during operation is thus supported. Instead of soldering, there is also the possibility of welding layer block 2 only at sealing edges 11a, 11b, 12a, 12b (cf. FIG. 1d) and avoiding soldering completely. A still greater mobility of layer block 2 or its layer plates 11, 12 is achieved thereby.

[0038] According to another aspect of the invention, it is possible to select the same material for housing 7 and cover and layer plates 9, 10, 11, 12, when it is assured simultaneously that housing 7 has a sufficiently greater heat resistance than layer block 2 or cover and layer plates 9, 10, 11, 12.

[0039] The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are to be included within the scope of the following claims.

What is claimed is:

1. A layer heat exchanger for high temperatures, the heat exchanger comprising:
   a layer block having layer plates and cover plates; and
   a housing configured to accommodate the layer block, the housing having a high heat resistance, associated with a high stiffness, and the layer block having a soft and tough core relative to the housing.

2. The layer heat exchanger according to claim 1, wherein the housing is made of a material with a high heat resistance.

3. The layer heat exchanger according to claim 2, wherein the material of the housing is a nickel alloy with the material No. 2.4856 according to DIN EN 10095 and the material designation NiCr22Mo9Nb or a ferritic high-temperature stainless steel with the material No. 1.4750.

4. The layer heat exchanger according to claim 2, wherein the material of the housing is an austenitic high-temperature stainless steel with the material No. 1.4876 and with the material designation X10NiCrAlTi 32-20 or with the material No. 1.4835 and with the material designation X3CrNiMoN31-21-11.2.

5. The layer heat exchanger according to claim 2, wherein the cover and layer plates are made of a material with a lower heat resistance than the housing material.

6. The layer heat exchanger according to claim 3, wherein the material for the cover and layer plates is a high-temperature stainless steel with the material No. 1.4876 with the material designation X10NiCrAlTi 32-20 or a Ni base material with the material No. 2.4851 with the material designation NiCr23Fe.

7. The layer heat exchanger according to claim 3, wherein the material for the cover and layer plates is a ferritic material with the material No. 1.4725 according to DIN 17470 and the material designation CrAl144 or the material No. 1.4767 according to DIN 17470 with the material designation CrAl20 5.

8. The layer heat exchanger according to claim 7, wherein the material for the cover and layer plates contains Al with a content of ≥2%, especially preferably of ≥3%.

9. The layer heat exchanger according to claim 1, wherein the wall thickness of the housing is as great as possible in regard to the wall thickness of the cover and layer plates.

10. The layer heat exchanger according to claim 9, wherein the wall thickness of the housing is about 1.5 mm.

11. The layer heat exchanger according to claim 9, wherein the wall thickness of the cover and layer plates is about 0.5 mm, preferably 0.4 mm, especially preferably 0.3 mm.

12. The layer heat exchanger according to claim 1, wherein the housing material includes an especially high-temperature-resistant material with low wall thickness, particularly 2.4856 with a thickness of 1.0 mm or 0.5 mm, and the layer and cover plate material includes an especially soft and thin material, particularly a ferritic material having a thickness of 0.3 mm or 0.4 mm.

13. The layer heat exchanger according to claim 1, wherein the housing and cover plate material is the same high-temperature-resistant material and the layer plates are of the soft material.

14. The layer heat exchanger according to claim 1, wherein the cover and layer plates of the layer block are connectable to one another by bonding on the front side.

15. The layer heat exchanger according to claim 14, wherein the cover and layer plates are soldered to one another on the front side.

16. The layer heat exchanger according to claim 14, wherein the layer plates have sealing edges and wherein the layer plates are welded to one another in the area of their sealing edges.

17. The layer heat exchanger according to claim 1, wherein the housing and the layer block are made of the same material.

18. A layer heat exchanger for high temperatures, the heat exchanger comprising:
   a layer block having layer plates, a top cover plate and a bottom plate; and
   a housing configured to accommodate the layer block, the housing having a higher heat resistance and a higher stiffness than the layer block such that the layer block is softer than the housing,
   wherein the cover and layer plates are made of a material with a lower heat resistance than the housing material, and
   wherein the material for the cover and layer plates contains Al with a content of ≥2%.

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