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Berger et al.(10) **Pub. No.: US 2013/0227946 A1**(43) **Pub. Date: Sep. 5, 2013**(54) **TUBE BUNDLE HEAT EXCHANGER AND
WASTE GAS HEAT RECOVERY DEVICE**(76) Inventors: **Jürgen Berger**, Gerstetten (DE);
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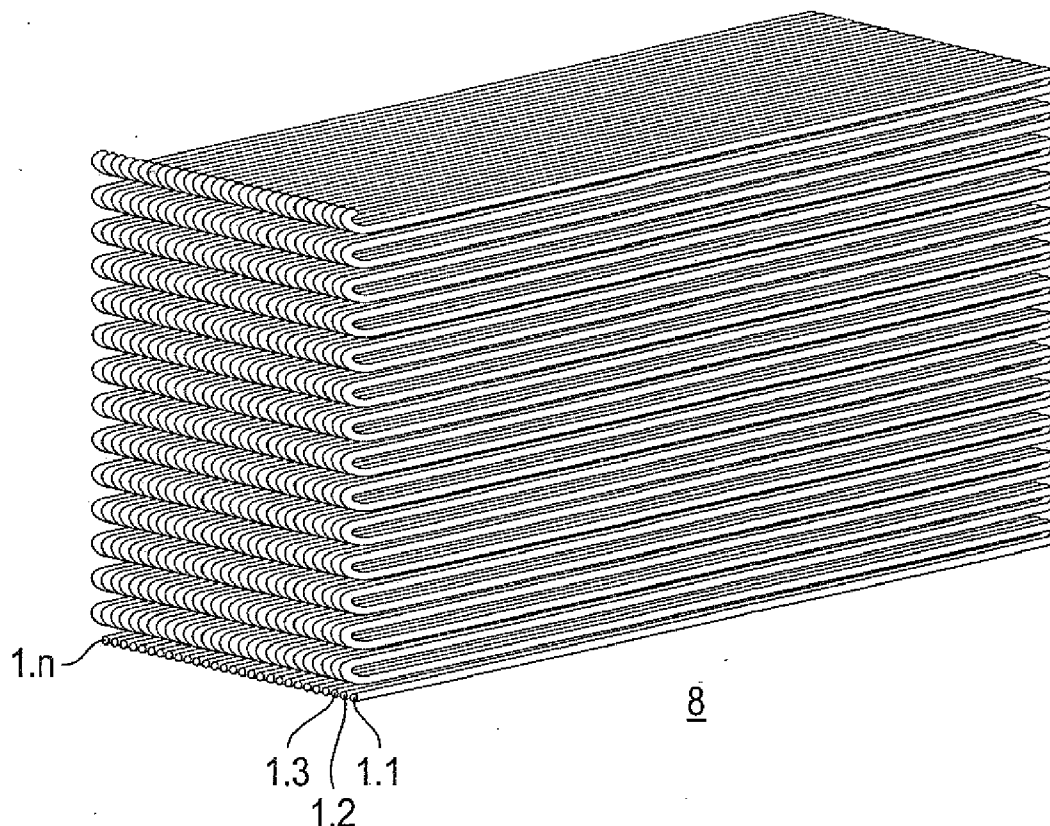
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(57)

ABSTRACT

The invention relates to a tube bundle heat exchanger having a plurality of tube windings (1) through which a heat transfer medium flows in parallel. The tube windings start from a common inlet chamber (2) for the heat transfer medium and open into a common outlet chamber (3). Each tube winding comprises an alternating sequence of tube sections (6) running alternately in two planes parallel to each other, and tube bends (7) connecting same, wherein within each of the two planes four or more pipe sections extend disposed side by side or parallel to each other, and wherein the pipe bends are designed to have a change of direction through 180° with respect to an associated bend axis and have the same bend radii. The invention is characterised in that along each tube winding the bend axes of tube bends that are connected to the same tube section are positioned at an angle of between 85° and 95° to each other, and the bend axes of tube bends, between which a tube section, a tube bend and a further tube section are arranged in immediate sequence, run parallel.



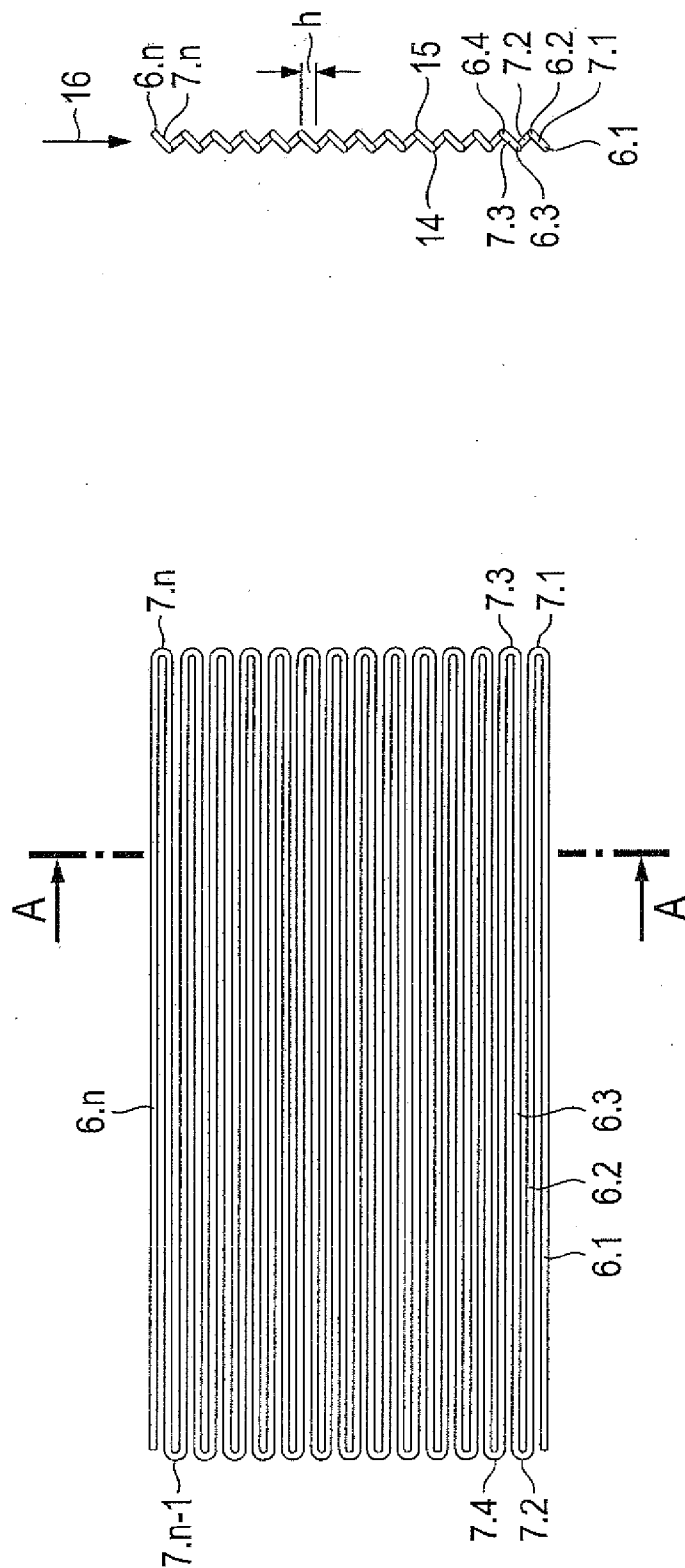


Fig. 1b

Fig. 1a

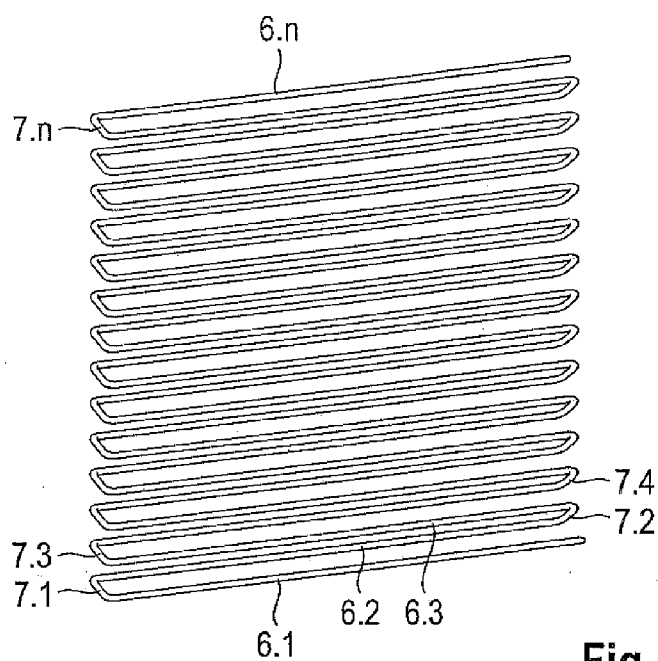


Fig. 2

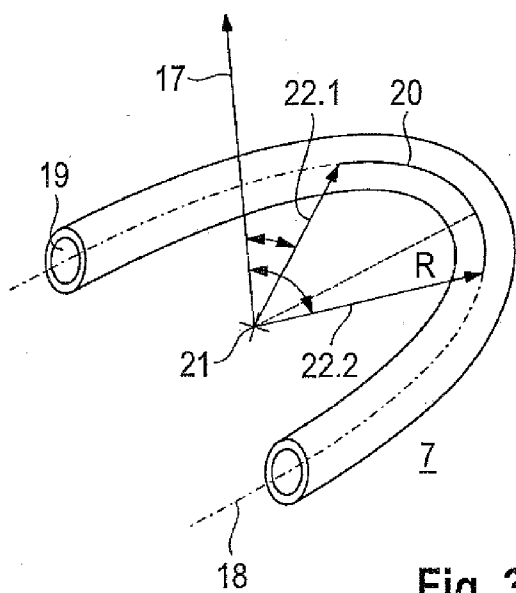


Fig. 3

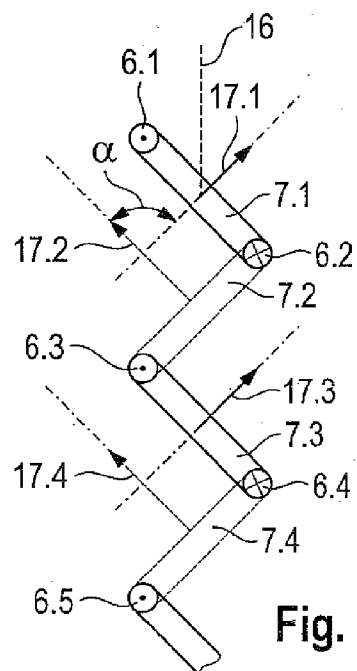


Fig. 4

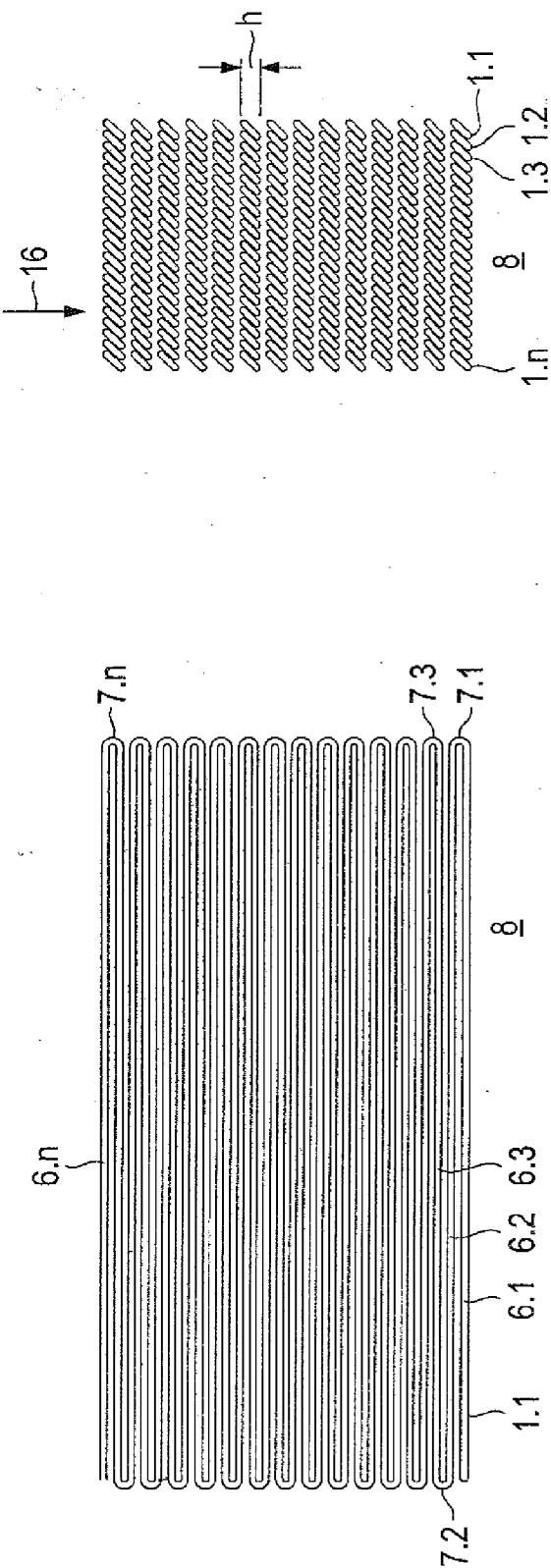


Fig. 5a

Fig. 5b

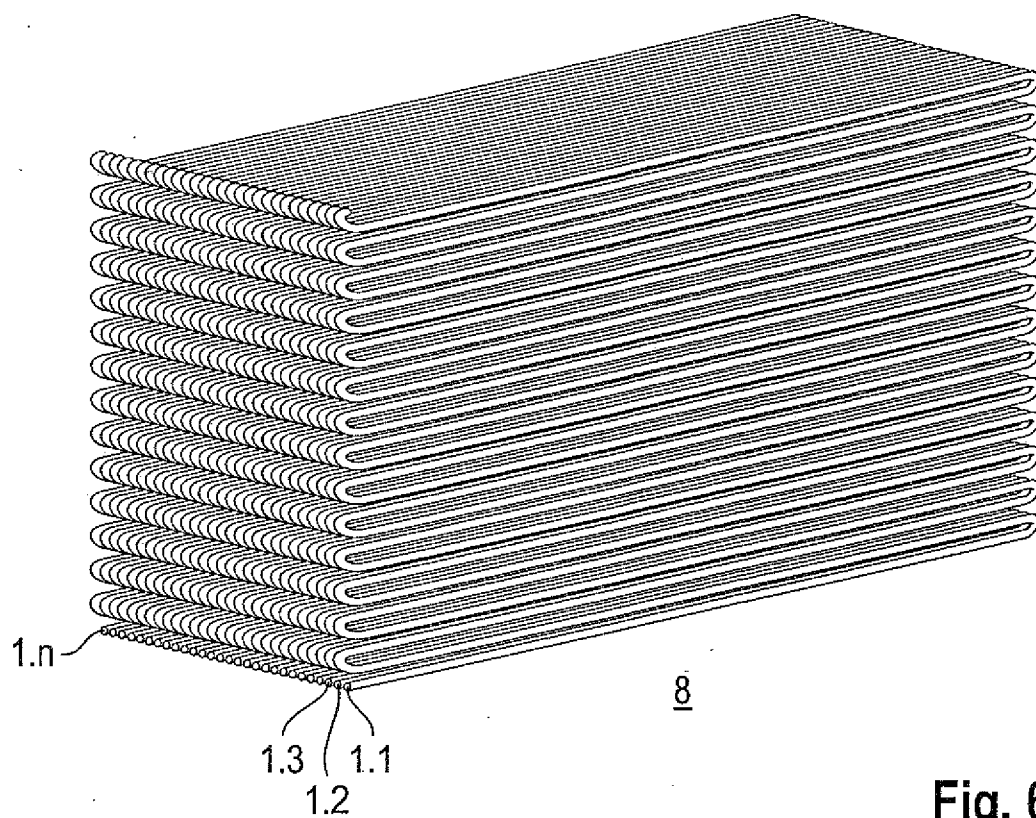
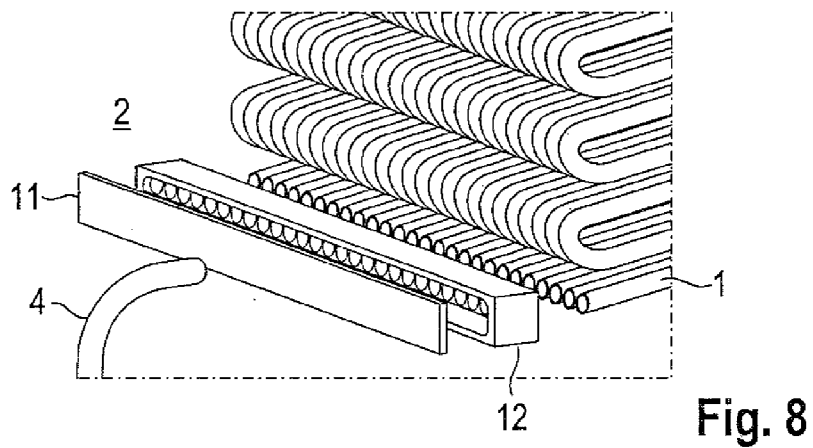
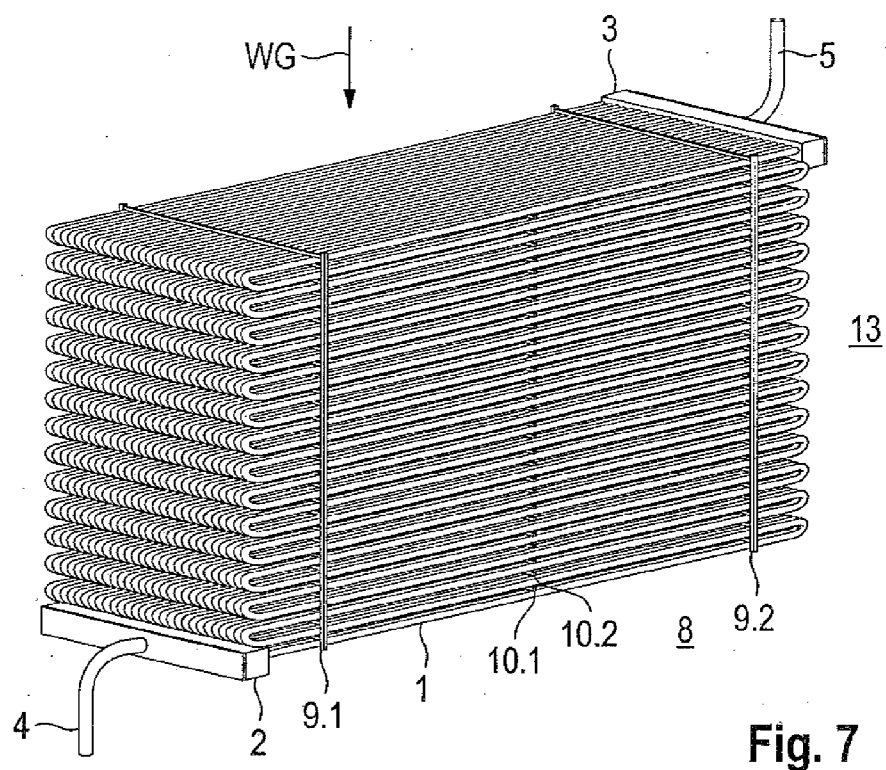


Fig. 6



TUBE BUNDLE HEAT EXCHANGER AND WASTE GAS HEAT RECOVERY DEVICE

[0001] The invention concerns a tube bundle heat exchanger, in particular for obtaining an evaporator for a waste gas heat recovery device.

[0002] Heat exchangers are known in different designs. A heat exchanger can be acted upon with a hot exhaust-gas flow for waste heat recovery of internal combustion engines so as to transfer a working fluid from the liquid phase into the vapour phase, which hereafter expands in an expander by carrying out mechanical work. Such steam-powered energy recovery systems for internal combustion engine of vehicles can be used for feeding auxiliary devices or for supporting drive systems. Further applications of evaporators in vehicles concern cooling and air conditioning systems.

[0003] Heat exchangers, which are used as evaporators, can be arranged in the form of a stack of plates, in which flow channels for the heating fluid, for instance for an exhaust-gas flow and separate channels for a heat carrier medium in the form of discontinuities in the individual plates of the sequence of plates are provided. Typical configurations entail heat exchangers according to the counterflow or cross counterflow principle. See for instance document DE 10 2008 029 096 A1.

[0004] Alternative configurations of heat exchangers use tube bundles, in which the heat transfer medium is conveyed, whereas the heat exchange uses the envelope surfaces of the individual tube windings of the tube bundle. Such tube bundle heat exchangers are known from DE 41 41 051 A1, EP 1 321 644 B1 and DE 10 2009 011 847 A1 for the preferred application in a waste gas heat recovery device for internal combustion engines.

[0005] Patent specification DE 102 22 974 B4 shows a heat exchanger for transferring heat from a hot gas flow into a fluid with tube windings running in a serpentine way whose tube bends all extend vertically.

[0006] Patent specification GB 501 202 describes a relatively densely packed tube bundle heat exchanger, having tubes running in two vertical planes, whereas a first group of tube bends runs respectively in a horizontal and a second group of tube bends runs diagonally between two horizontal planes arranged on top of one another. The angles between the tube bends amount accordingly to 45°.

[0007] U.S. Pat. No. 4,446,915 describes a complex structure of tube windings of different geometry which are nested into one another, whereas the tube sections extend in three vertical planes arranged side by side.

[0008] The object of the invention is to further develop a heat exchanger by means of tube bundles in a manner that for a compact construction form, which enables in particular to be accommodated in existing exhaust gas pipes for internal combustion engines a highly efficient heat exchanging surface is provided. To do so, the heat exchanger must be usable as an evaporator of a waste gas heat recovery device and have tube windings which can be produced and piled up easily. Beside the simplified production, the tube bundle heat exchanger must be supported on existing components of an exhaust gas pipe with minimal structural means implemented. Moreover, the stacking order of the tube windings should permit the easy design of inlet and outlet pipes for the heat transfer medium. The heat exchanger according to the invention should optimise the flow guidance for the heat transfer medium, if the packing can be quite dense and hence the space requirements are quite minimal so that the pressure

losses, imposed upon the heat transfer medium when entering through the heat exchanger, are as small as possible.

[0009] The object of the invention is solved by the features of the independent claim 1. Advantageous embodiments result from the sub-claims.

[0010] Consequently, stackable tube windings in a serpentine design as per the introductory features form the base of the invention. Accordingly, the tube windings forming a tube bundle of the heat exchanger, extending between a common inlet chamber and a common outlet chamber for the supply and removal of the heat transfer medium, have an alternating sequence of tube sections and tube bends. To do so, the tube bends cause a change of direction of the heat transfer medium essentially of 180° as regards an associated bend axis and exhibit identical bend radii. A material bond of tube sections and tube bends, separately constructed, is preferred for producing the tube windings. Alternately, a tube winding can be arranged as a single piece, whereas the tube bends are constructed by an appropriate forming process.

[0011] According to the invention, the tube sections are arranged alternately, in two planes which are parallel to one another, in particular vertical planes. In particular, exclusively both these planes and no additional plane parallel thereto, are provided with tube sections. The tube bends connect the tube sections of the different planes so that each tube bend advantageously has a first end in the first plane and a second end in the second plane, to link two tube sections positioned in different planes. The tube bends are in particular inclined or diagonally on both planes, advantageously they extend inside a tube bend plane which is at an angle of approximately or exactly 45° on both planes.

[0012] By approximately should be understood an angular range of 35°-55°, in particular 40°-50°. The angle ideally should be 45°. If tube sections with straight orientation and matching length are used and are respectively connected in alternating sequence with tube bends describing a semi-circle, a flow path is generated for the heat transfer medium whose substantial track length can be oriented crosswise to the heating medium, i.e. the exhaust-gas flow of an internal combustion engine to apply a cross-counterflow principle.

[0013] The invention is characterised by tube bends designed in that way for connecting tube sections of each individual tube winding, whose bend axes for adjoining tube bends are positioned at an angle to one another and tube bends provided in a next but one arrangement which for run parallel. According to the invention, the angular position of the bend axes of adjoining tube bends has an angle in the range of 85°-95°, preferably of 90°. Additionally, the tube windings are preferably designed in such a way that every tube section for the respective tube winding is associated with a first group of tube sections or a second group of tube sections. This enables to define a direction of projection for which projections of all tube sections belonging to a group of tube sections are congruent.

[0014] Besides, straight tube sections are used preferably since these advantageously can be produced simply and can be manipulated for producing tube windings. Additionally stackable tube windings, geometrically matching, can be produced in a simple manner, which according to the invention form a zigzag pattern for a cutting plane running vertically to the straight tube sections, due to the alternating angular position of the bend axes of the tube bends. The result is an improved stackability of the tube windings, with a tube bundle heat exchanger having a larger number of parallel flow

paths. These parallel flow paths are acted upon substantially vertically by the heat-injecting fluid flow, i.e. an averaged direction of incoming flow, for applying the cross-counter-flow principle. The inlet for the heat transfer medium is suitably provided below in the stack or the outlet above in the stack and the heat-introducing medium, in particular an exhaust-gas flow surrounds or flows through them vertically or substantially vertically from top to bottom through the stack between the tube sections.

[0015] For simplified stackability and in view of a compact arrangement of the tube windings the tube bends have preferably a matching geometry whereas most preferably the tube bends are designed as semi-circular arcs, which are easy to produce, with a flat running central line.

[0016] Deviations from a straight design of the tube sections and a semi-circular configuration of the tube bends form embodiments of the invention which are more complex as regards the production of the tube bundle heat exchangers. Indeed, a geometry, there again matching but warped, of the individual tube bends and/or tube sections, enables improving the meshing in a positively locking manner when forming the stack, which raises the whole stability of the tube bundle heat exchanger. This constitutes an improvement in particular for vehicle usages in which the tube bundles of the heat exchangers are subjected to vibrations and impacts on a permanent basis, since the individual tube windings of the tube bundle are supported more strongly mutually and hence the holding systems for joining together the tube bundle of the heat exchangers and placing it in the allocated space requirement, can be designed in a simplified fashion from the construction viewpoint.

[0017] The invention is described more in detail below using an exemplary embodiment and in connection with the illustrations in the figures. The following details are shown:

[0018] FIG. 1a shows a tube winding of a tube bundle heat exchanger in elevation view designed according to the invention.

[0019] FIG. 1b shows a section of FIG. 1a along the cutting line A-A.

[0020] FIG. 2 shows the tube winding of FIGS. 1a and 1b in three-dimensional

[0021] FIG. 3 shows a portion of the sectional view of FIG. 1b.

[0022] FIG. 4 shows an enlarged view of FIG. 1b

[0023] FIG. 5a shows a tube bundle heat exchanger with a plurality of tube windings in elevation view.

[0024] FIG. 5b shows a section along the line C-C of FIG. 5a.

[0025] FIG. 6 shows the tube bundle heat exchanger of FIGS. 4a and 4b in enlarged, three-dimensional view.

[0026] FIG. 7 shows a tube bundle heat exchanger according to the invention for waste gas heat recovery device.

[0027] FIG. 8 shows a connection piece for the evaporator of FIG. 7.

[0028] FIG. 1a represents an individual tube winding 1 for a tube bundle heat exchanger realised according to the invention. The tube winding 1 is formed by an alternating sequence of tube sections 6.1-6.n and tube bends 7.1-7.n. The sectional view represented on FIG. 1b along the line A-A in FIG. 1a shows a configuration in the form of a zigzag which results from the fact that tube bends 7.1-7.n arranged consecutively and close to one another, that is to say the tube bends 7.1-7.n which are connected to the same tube section 6.1-6.n, are at an angular position a relative to one another. The angle a is equal

to 90°. This can be seen by way of example in FIG. 1b by means of the adjoining tube sections 6.1 and 6.2 or 6.2 and 6.3. Additionally, the bend axes of tube bends 7.1-7.n forming a next but one arrangement, that is to say of such a couple, for which a tube section, a tube bend and an additional tube section are arranged between two tube bends in immediate sequence, are disposed to extend in parallel. Consequently, the tube sections 6.1-6.n run as viewed from bottom to top alternately in two vertical planes arranged parallel to one another.

[0029] For the protruding and recessing shape of a tube winding 1 according to the invention, the transverse distance h of the tube sections 6 is reduced as compared to a flat serpentine winding 6.1-6.n. In this direction the main inflow direction occurs through the thermal fluid which comes into heat exchange with the heat transfer medium guided in the tube winding 1. This is described in detail more hereafter.

[0030] Another advantage for a serpentine tube winding 1 applied in a zigzag pattern according to the invention results from an improved stackability. FIG. 2 clearly shows that the tube winding of FIGS. 1a and 1b are represented in a three-dimensional view. As can be seen from FIG. 1b, the tube sections 6.1-6.n can be divided in two groups from every single tube winding 1 due to the angular position of the tube bends 7.1-7.n. Tube sections 6.1-6.n which run inside a common plane side by side, predominantly parallel to one another, belong to each of the group of tube sections. This can be clearly seen in a correlation of the tube sections 6.1 and 6.3 to a first group of tube sections 14, whose tube sections 6.1, 6.3 extend in the first, here vertical plane, and of the tube sections 6.2 and 6.4 to a second group of tube sections 15, whose tube sections 6.2 and 6.4 run in a second, here also vertical plane, which is parallel to the first plane. The projections for a predetermined direction of projection, in this case the direction to determine the transverse distance h, are congruent. If now a large number of the serpentine tube windings 1 illustrated and arranged in a zigzag pattern is assembled side by side to form a stack so that the inlets for the heat transfer medium lie side by side for the heat transfer medium in a lower horizontal plane, designated in this instance as an inlet plane, that is to say on the plane of the tube sections 6.1 of each tube winding 1, and the outlets from the last tube sections 7.n lie in an upper horizontal plane, in this instance called an outlet plane so the inlet plane is parallel to the outlet plane and both planes are perpendicular to the first plane previously described with the tube sections of the group of tube sections 14 and the second plane with the tube sections of the group of tube sections 15.

[0031] Every group of tube sections 14, 15 includes numerous, i.e. four or more, in particular six, eight or ten or more tube sections respectively inside the first plane and the second plane. Also three, four, six, eight or more tube sections can be provided side by side inside the inlet plane and/or inside the outlet plane.

[0032] Moreover, FIG. 3 shows a sketch to determine the concept of a bend axis 17 for a tube bend 7. In the easiest case, the tube bend 7 is a flat semi-circular arc so that the bend axis 17 is defined by the normal vector through the centre of the associated semi-circle. Deviating forms of embodiment can be envisioned similarly, for which a tube bend 7 is curved in several spatial directions. In this case, a bend axis 17 is associated starting from a central line 18, which is defined as a threading line 18 of the centres of gravity of the cross-sectional surfaces 19 along the tube bend 7. For sections of arc

20 chosen sufficiently small, along the threading line **18**, radial vectors **22.1**, **22.2** extending from a centre **21** to the section of a circle **20**, can be determined. A vector is defined for the radial vectors **22.1**, **22.2**, perpendicular which determines the contribution to the bend axis **17**, which is associated to the arc of circle **20** considered. The bend axis **17** associated to the whole tube bend **7** then results from a weighted averaging of the aforementioned contributions. The weighting covers the lengths of arc of the sections of arc **20** used for the determination.

[0033] FIG. 4 shows an enlarged illustration of FIG. 1b. Tube sections **6.1**, **6.2**, **6.3**, **6.4**, **6.5** are represented diagrammatically being truncated in transversal direction with tube bends **7.1**, **7.2**, **7.3**, **7.4** arranged therebetween. The bend axes **17.1**, **17.2**, **17.3**, **17.4** associated with the tube bends **7.1**, **7.2**, **7.3**, **7.4** have an alternating angular deviation from the direction of projection **16**. The angle amounts in particular of between 40° and 50°, advantageously 45°. In so doing, adjoining tube sections **7.1**, **7.2** as regards their bend axes, for instance **17.1** and **17.2**, are in a preset angular position a, consequently 90° relative to one another and tube sections in a next but one arrangement, approx. **7.1**, **7.3**, have essentially parallel bend axes **17.1** and **17.3**. Certain angular deviations for a tube winding **1** are then tolerable if the stackability is not affected.

[0034] Additionally, to each tube bend **7**, **7.1-7.n** is associated a bending radius **R** whereas more advantageously all the bend radii **R** of the tube bends **7**, **7.1-7.n** are in arrangement. In the case of a tube section (**7**, **7.1-7.n**) which is not arranged as a semi-circular arc, as bending radius **R** a weighted averaging of the length of all radial vectors **22.1**, **22.2** is formed.

[0035] FIG. 5a shows a tube bundle heat exchanger **8** according to the invention in elevation view which is formed as a stack out of the tube windings **1.1-1.n** with a geometry according to FIGS. 1a, 1b, and 2. The sectional view along the line C-C, shown in FIG. 5b, clearly illustrates in particular the compact alternate construction of the tube windings **1.1-1.n**, which results from the alternating angular position of the tube bends **7.1**, **7.n** along the individual tube windings **1.1-1.n**. In an advantageous embodiment, the tube bends **7.1**, **7.n** are arranged in an alternating angle of $\pm 45^\circ$ to the direction of projection **16**. This corresponds to an angular position a of the bend axes **17.1**, **17.n** of adjoining tube bends **7.1**, **7.n** of 90°. The meshing with an interlocking fit of the tube windings **1.1-1.n** and the compact construction form having a reduced transverse distance **h** of the tube sections **6.1**, **6.n** running parallel for every individual of the tube windings **1.1-1.n** results particularly clearly from the spatial illustration shown in FIG. 6, of a tube bundle heat exchanger **8** according to the invention.

[0036] FIG. 7 shows schematically simplified the use of a tube bundle heat exchanger **8** according to the invention for producing an evaporator of a waste gas heat recovery device. For that purpose, the tube bundle heat exchanger **8** includes an inlet chamber **2** for a heat transfer medium which is in connection with a feed pipe **4**. A preferred embodiment of the inlet chamber **2** is shown in the enlarged illustration of FIG. 8. It has a connection piece **12** which for instance is formed as a milled part. This connection piece **12** comprises supply ducts for the heat transfer medium on the side pointing to the ends of the tube sections **6.1-6.n**. Moreover, a lid **11** is provided on the front face of the connection piece **12** pointing on the feed pipe **4** and leading to the liquid-tight termination of the inlet

chamber **2**. Alternately, the connection piece **12** can be designed as a tube section which is not represented in detail on the figures.

[0037] In deviation from the illustration represented here, the feed pipe **4** can run at least partially or wholly in the direction of the longitudinal extension of the inlet chamber **2** or the connection piece **12**, advantageously crosswise to the longitudinal direction of the individual tube sections. The same goes for the connection piece **12**, when said is designed as a tube section.

[0038] Accordingly, the outlet chamber **3** for the heat transfer medium can embrace the endpieces of the tube sections **6.1-6.n** on the outlet side. From this outlet chamber **3**, an exhaust pipe **5** opens out which has an enlarged cross-section with respect to the feed pipe **4** for the represented configuration, since the heat transfer medium is evacuated in gas phase. What has been said for the outlet chamber or the exhaust pipe **5** goes for the inlet chamber **2** and the feed pipe **4**.

[0039] The tube bundle heat exchanger **8** of the evaporator **13** is acted upon by an exhaust-gas flow for the exemplary embodiment represented. For that purpose, FIG. 7 shows the main flow direction of the exhaust-gas flow **WG**. This direction extends substantially vertically to the tube sections **6.1-6.n** of the individual tube windings **1.1-1.n**. To do so, the distance of the tube sections **6.1-6.n** can be reduced in the main flow direction of the exhaust-gas flow **WG** due to the angular position according to the invention of neighbouring tube sections **7.1-7.n**. With a simultaneously compact tube bundle heat exchanger, the result is an advantageously enlarged heat exchange surface with crossing flow guidance of the heat transfer medium with respect to the heating fluid, in this instance to the exhaust-gas flow. Alternately, the exhaust-gas flow could however run also in the direction of the tube sections to obtain at least partially a counter-flow heat exchanger or a parallel flow heat exchanger.

[0040] According to an exemplary embodiment, the tube bundle heat exchanger shown is surrounded by a cylindrical or essentially cylindrical space, whose longitudinal axis is in particular parallel to the longitudinal axis of the tube sections and through which the exhaust-gas is conveyed.

[0041] Additionally, FIG. 7 shows components of a holding system for the individual tube windings **1.1-1.n** of the tube bundle heat exchanger **8**. Lateral holding systems **9.1-9.2** are represented by way of example, which mesh into the inter-spaces of neighbouring tube sections **6.1-6.n** over plug-shaped protrusions. The plug-shaped protrusions can for instance have a surface which is complementary to the surface of the tube sections facing them. Additionally or alternately, the lateral holding systems **9.1**, **9.2** can also have enclose in particular metal sheets with bores, whereas the tube sections are guided through the individual bores.

[0042] Additionally, the stacking order is stabilised by cross bars **10.1-10.n**, which run through the stacking order of the tube windings **1.1-1.n**. In deviation from the representation shown, cross bars need not be provided in all interspaces. It may also be sufficient to arrange them only in the upper region of the stack.

[0043] According to a particularly advantageous embodiment, the stack of tube sections is mounted in an axial fixed bearing, for instance in the region thereof or formed by the holding system **9.1** and in an axial floating bearing, for instance in the region thereof or formed by the holding system **9.2**.

[0044] Further embodiments of the invention can be contemplated. So the tube windings 1.1, 1.n can by way of example be formed of a sequence of tube sections 6.1-6.n with tube bends 7.1-7.n connected thereto, in the angular position according to the invention, whereas the tube sections 6.1-6.n have different lengths, so that not all tube bends 7.1-7.n are flush-mounted with one another. Individually protruding tube bends 7.1-7.n can be formed in this fashion on the tube bundle, on which additional holding systems are provided for stabilising the tube bundle heat exchanger 8. Further embodiments of the invention can be found in the appended claims.

LIST OF REFERENCE NUMERALS

[0045]	1, 1.1-1.n	Tube winding
[0046]	2	Inlet chamber
[0047]	3	Outlet chamber
[0048]	4	Feed pipe
[0049]	5	Exhaust pipe
[0050]	6.1-6.n	Tube section
[0051]	7, 7.1-7.n	Tube bend
[0052]	8	Tube bundle heat exchanger
[0053]	9.1, 9.2	Lateral holding system
[0054]	10, 10.2	Cross bar
[0055]	11	Lid
[0056]	12	Connection piece
[0057]	13	Evaporator
[0058]	14	First group of tube sections
[0059]	15	Second group of tube sections
[0060]	16	Direction of projection
[0061]	17-17.n	Bend axis
[0062]	18	Central line
[0063]	19	Cross-sectional surface
[0064]	20	Section of an arc of a circle
[0065]	21	Centre
[0066]	22, 22.2	Radial vector
[0067]	h	Transverse distance
[0068]	WG	Main flow direction of an exhaust-gas flow
[0069]	a	Angular position

1: A tube bundle heat exchanger having a plurality of tube windings through which a heat transfer medium flows in parallel, which tube windings start from a common inlet chamber for the heat transfer medium and open into a common outlet chamber; whereas each tube winding has an alternating sequence of tube sections running alternately in two planes parallel to each other as well as tube bends connecting said sections, whereas within each of the two planes four or more tube sections extend, arranged side by side or parallel to one another and

wherein the tube bends are designed to have a change of direction of 180° with respect to an associated bend axis and have the same bend radii;

characterised in that

along each tube winding the bend axes of tube bends, which are connected to the same tube section, are positioned at an angle of 85°-95° to each other and the bend axes of tube bends run parallel, between which are arranged in immediate sequence a tube section, a tube bend and a further tube section.

2: The tube bundle heat exchanger according to claim 1, characterised in that both planes which are parallel to one another are vertical on an inlet plane, inside which inlets are positioned into the tube windings from the common inlet chamber, and are in particular vertical on an outlet plane parallel to the inlet plane, inside which outlets are positioned from the tube windings into the common outlet chamber.

3: The tube bundle heat exchanger according to claim 1 or 2, characterised in that the tube sections have a matching length.

4: The tube bundle heat exchanger according to claim 1 or 2, characterised in that the tube sections are designed as straight tube sections.

5: The tube bundle heat exchanger according to claim 1 or 2, characterised in that the tube bends have a matching geometry.

6: The tube bundle heat exchanger according to claim 1 or 2, characterised in that the tube bends are designed as semi-circular arcs with a level running central line.

7: The tube bundle heat exchanger according to claim 1 or 2, characterised in that the tube windings have a matching geometry and form a pile of windings abutting against one another.

8: The tube bundle heat exchanger according to claim 1 or 2, characterised in that the bend axes of tube bends, which are connected to the same tube section, have an angular position (a) of 90°.

9: The tube bundle heat exchanger according to claim 1 or 2, characterised in that the tube sections and tube bends are materially connected to each tube winding or the tube winding is formed as a single piece.

10: A waste gas heat recovery device with an evaporator for a heat transfer medium, which is acted upon by a exhaust-gas flow of an internal combustion engine, characterised in that the evaporator includes a tube bundle heat exchanger according to claim 1.

11: The waste gas heat recovery device according to claim 10, characterised in that the main flow direction of the exhaust-gas flow runs substantially vertically or parallel to the tube sections of the tube bundle heat exchanger.

12: The waste gas heat recovery device according to claim 10 or 11, characterised in that the tube windings of the tube bundle heat exchanger consist of stainless steel.

* * * * *