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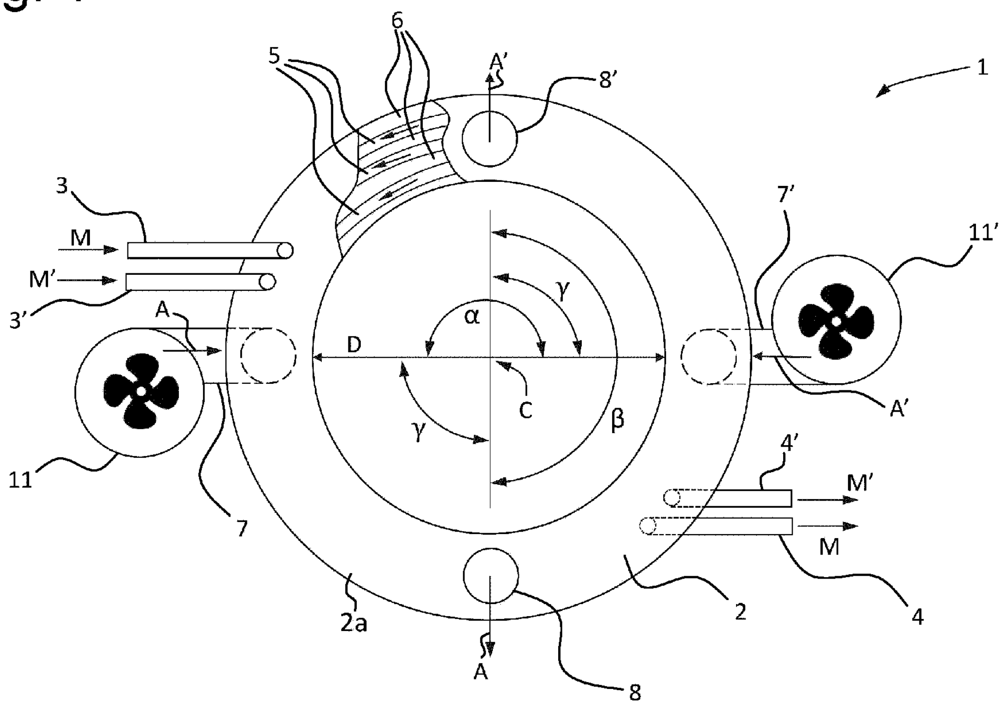
(54) **AIR COOLED HEAT EXCHANGER**

(57) An air cooled heat exchanger (1) for cooling a medium, comprising a hollow shell (2) provided with a tube inlet (3) for receiving a medium (M, M') to be cooled and a tube outlet (4) for discharging the medium (M), wherein the shell (2) houses a tube arrangement (5) connecting the tube inlet (3) to the tube outlet (4);wherein the shell (2) is filled with a thermally conductive air permeable material (6) in tight engagement with the tube arrangement (5); wherein the shell (2) is provided with an air inlet (7) for receiving air (A) and an air outlet (8) for di charging the air (A), and wherein the thermally conductive air permeable material (6) fluidly connects the air inlet (7) to the air outlet (8).

Fig. 1



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Description

Field of the invention

[0001] The present invention relates to an air cooled heat exchanger, in particular an air cooled heat exchanger for cooling compressed hydrogen.

Background art

[0002] Air cooled heat exchangers often comprise a serpentine arrangement of tubes through which a medium flows that is to be cooled, wherein outer surfaces of the tubes are cooled by air flow during operation. These outer surfaces of the tubes are often provided with fins for enlarging the air contact area of the tubes such that heat transfer between the tubes and the air flow is facilitated. However, air cooled heat exchangers may become relatively large for achieving sufficient heat transfer and as such these heat exchangers may be less suitable for applications where space is limited. Furthermore, when sharply bent U-shaped tubes are utilized for forming the serpentine arrangement of tubes, these U-shaped tubes may cause an increase in friction between the medium and inner surfaces of the U-shaped tubes. This increase in friction may in turn lead to heating of the medium as it flows through the U-shaped tubes, thereby reducing the overall cooling efficiency of the air cooled heat exchanger.

Summary of the invention

[0003] The present invention seeks to provide an air cooled heat exchanger that at least in part solves the problems of the prior art. The air cooled heat exchanger of the present invention allows for a compact and cost competitive design whilst exhibiting improved heat transfer efficiency. The air cooled heat exchanger is particularly advantageous for industrial applications such as cooling of compressed hydrogen for example.

[0004] According to the present invention, an air cooled heat exchanger as defined above is provided, comprising a hollow shell provided with a tube inlet for receiving a medium to be cooled and a tube outlet for discharging the medium, wherein the shell houses a tube arrangement connecting the tube inlet to the tube outlet. The shell is filled with a thermally conductive, air permeable material which is in tight engagement with the tube arrangement, and wherein the shell is provided with an air inlet for receiving air and an air outlet for discharging the air, wherein thermally conductive, air permeable material then fluidly connects the air inlet to the air outlet.

[0005] The thermally conductive, air permeable material inside the hollow shell provides a number of advantages. First, the surface area for thermal exchange between the tube arrangement and the air flowing though the shell is greatly increased to optimize thermal exchange between the medium and the air flowing through the shell. Second, the thermally conductive, air permeable material provides for heat accumulation, for example, so that a more continuous and consistent thermal exchange is provided with less short term variance. Furthermore, the thermally conductive, air permeable material allows for higher heat transfer through the air then the tube arrangement, thereby ensuring that maximum cooling of the medium is achieved.

[0006] In an advantageous embodiment, the thermally conductive air permeable material comprises a compacted arrangement of metal particles. Here, the compacted metal particles provide for snug and tight embedding of the tube arrangement in the metal particles to achieve optimal heat transfer between the tube arrangement and the thermally conductive air permeable material. The metal particles are able to tightly embed the tube arrangement irrespective of the layout and routing complexity thereof. In an exemplary embodiment, the metal particles may be copper alloy particles to achieve high thermal conductivity.

[0007] In a further embodiment, the metal particles may be substantially spherical and/or substantially irregularly shaped. The spherical or irregularly shaped particles can be chosen so as to achieve a desire level of compaction of metal particles, e.g. shell filling factor, level of heat accumulation, air permeability etc.

[0008] In an alternative embodiment, the thermally conductive, air permeable material may be a porous solid material rather than a granular type of material such as the metal particles mentioned above. Here, such a porous solid material may be advantageous to provide for higher levels of accumulation, for example, or higher thermal conductivity of the air permeable material.

Short description of drawings

[0009] The present invention will be discussed in more detail below, with reference to the attached drawings, in which

Figure 1 shows a schematic top view of an air cooled heat exchanger according to an embodiment of the present invention;
Figure 2 shows a schematic cross sectional view of an air cooled heat exchanger according to an embodiment of the present invention;
Figure 3 shows a schematic top view of a hydrogen gas cooling process utilizing an air cooled heat exchanger according to an embodiment of the present invention.

Description of embodiments

[0010] Referring to Figure 1 and 2, in Figure 1 a schematic top view of an air cooled heat exchanger 1 according to an embodiment of the present invention is depicted, where in Figure 2 a schematic cross sectional view of the air cooled heat exchanger 1 is depicted according to an embodiment. It is noted that both figures 1 and 2 are schematic in nature and do not reflect true proportions of various depicted features and elements.

[0011] As depicted, the air cooled heat exchanger 1 comprises a hollow shell 2 provided with a tube inlet 3 for receiving a medium M to be cooled and a tube outlet 4 for discharging the medium M. In an embodiment, the medium M may be gaseous hydrogen that needs to be cooled for example. The hollow shell 2 houses or encloses a tube arrangement 5 that connects the tube inlet 3 to the tube outlet 4. The tube arrangement 5 may be embodied in various ways for reasons set forth later below. For now, the tube arrangement 5 for carrying the medium M from the tube inlet 3 to the tube outlet 4 may be routed to achieve a particular heat transfer behaviour.

[0012] As shown, the shell 2 is filled with a thermally conductive, air permeable material 6 in tight engagement with the tube arrangement 5. That is, the thermally conductive, air permeable material 6 tightly embeds the tube arrangement 5 and makes snug contact therewith.

[0013] The shell 2 is further provided with an air inlet 7 for receiving air A and an air outlet 8 for discharging the air A, wherein the thermally conductive air permeable material 6 fluidly connects the air inlet 7 to the air outlet 8. Note that in an advantageous embodiment the air A may be ambient air requiring no special treatment before introduction into the air inlet 7, thereby reducing complexity of the air cooled heat exchanger 1 and costs thereof.

[0014] The shell 2 is tightly filled with the thermally conductive, air permeable material 6 and by virtue of the air permeability of the material, the air A is able to travel through the shell 2 from the tube inlet 3 to the tube outlet 4.

[0015] According to the present invention, the thermally conductive, air permeable material 6 inside the hollow shell 2 provides for a number of advantages. First, a surface area for thermal exchange between the tube arrangement 5 and the air A flowing through the shell 2 is greatly increased to optimize thermal exchange between the medium M and the air A as they flow through the tube arrangement 5 and the shell 2 respectively. Second, the thermally conductive, air permeable material 6 provides for heat accumulation, e.g. "thermal mass", allowing a more continuous and consistent thermal exchange to be provided with less short term variance. Furthermore, the thermally conductive, air permeable material 6 allows for high heat transfer by the air A than the tube arrangement 5 is able to provide, thereby ensuring that maximum cooling of the medium M is achieved.

[0016] As clearly depicted in Figure 2, in an advantageous embodiment the thermally conductive air permeable material 6 comprises a compacted arrangement of metal particles 9. Here, the compacted metal particles 9 may be seen as having a fine granular structure for snug and tight embedding of the tube arrangement 5 in the metal particles 9 to achieve optimal heat transfer between the tube arrangement 5 and the thermally conductive air permeable material 6. The metal particles 9 are able to tightly embed the tube arrangement 5 irrespective of the layout and routing complexity thereof. In a specific exemplary embodiment, the metal particles 9 may be copper alloy particles to achieve high thermal conductivity.

[0017] In Figure 2 it is further shown that in an embodiment, the metal particles 9 are substantially spherical and/or substantially irregularly shaped. Such spherical or irregularly shaped particles 9 can be chosen so as to achieve a desired level of compaction, a desired shell filling factor of metal particles 9, a level of heat accumulation, higher or lower levels of air permeability of the compacted metal particles and so forth. In an exemplary embodiment, the metal particles have a width "w" and/or height "h" of at most 3 mm, e.g. 2 mm. This allows for a sufficiently high surface area for thermal exchange, improved thermal accumulation and to provide sufficient air permeability through the shell 2 when the air A travels from the tube inlet 3 to the tube outlet 4.

[0018] Instead of filling the hollow shell 2 with a granular type of material such as the metal particles 9, an alternative embodiment is conceivable wherein the thermally conductive air permeable material 6 is a porous solid material. Such a porous solid material may be advantageous to provide for, e.g., higher levels of accumulation and/or thermal conductivity of the air permeable material 6. In an exemplary embodiment, the porous solid material may comprise brass, e.g. solid brass having a porous structure that provides small channels for the air A to travel through the shell 2. The porous solid material may be cast around the tube arrangement 5, for example, to achieve good contact therewith for optimal heat transfer.

[0019] From Figure 1 and 2 it is further seen that, in advantageous embodiment, the shell 2 may be a toroidal or cylindrical shell 2, wherein the tube arrangement 5 comprises a plurality of tubes 10 forming a wounded tube bundle that extends through the toroidal or cylindrical shell 2 around a centre C thereof. Such a toroidal or cylindrical shell 2 allows for a small yet efficient air cooled heat exchanger 1 with minimal resistance on the medium M flowing through the tube arrangement 5. In particular, the wounded tube bundle avoids sharp U-bends that may increase flow resistance considerably, so the toroidal or cylindrical shell 2 allows for a wounded tube arrangement 5 that minimizes friction along inner walls thereof and as such unwanted heating of the medium M is minimized when it flows from the tube inlet 3 to the tube outlet 4.

[0020] As depicted, a toroidal shell 2 may comprise an upper and lower surface 2a, 2b which are rounded, e.g. circular, as well as a rounded/circular side surface 2c. Although not shown, a cylindrical shell 2 may have upper and lower surfaces 2a, 2b that are substantially flat, and wherein the side surface 2c will be substantially straight in vertical direction. In any case, both the toroidal and cylindrical shell 2 provide for a the tube arrangement 5 having the plurality of tubes 10 forming a continuously wounded tube bundle with mild and gentle bends around the centre C.

[0021] In an exemplary embodiments, flow friction along inner walls of the tube arrangement 5 may be minimized by increasing an inner diameter D of the toroidal or cylindrical shell 2. In particular, by increasing the inner diameter D provides for a wounded tube bundle that increases in diameter as well, thereby offering mild, longer tube bends to decrease friction along the inner walls of the tube arrangement 5. In a specific embodiment, the toroidal or cylindrical shell 2 has an inner diameter D of at least 150 mm. This diameter ensures that internal friction in the wounded tube bundle is kept to a minimum. The inner diameter D can of course be enlarged to meet particular cooling and/or efficiency requirements. In an exemplary embodiment, the inner diameter D may be 300 mm or larger, e.g. about 400 mm, depending on a required cooling capacity of the air cooled heat exchanger 1.

[0022] As further depicted in Figure 1 and 2, in an embodiment the shell 2 is provided with one or more further tube inlets 3' for receiving a further medium M' to be cooled and a corresponding number of one or more further tube outlets 4' for discharging the further medium M', wherein the tube arrangement 5 connects each of the one or more further tube inlets 3' to a corresponding further tube outlet of the one or more further tube outlets 4'. This embodiment is particular advantageous when different mediums M, M' need to be cooled and/or when particular mediums M, M' are provided at different pressures and/or flow speeds and so forth.

[0023] In an advantageous embodiment, wherein the shell 2 is a toroidal or cylindrical shell 2, the tube inlets 3, 3' and tube outlets 4, 4' may tangentially enter and exit the shell 2, respectively, to minimize sharp bends to decrease internal flow friction and thus heating of the medium M, M'.

[0024] Advantageously, the tube arrangement 5 in the shell 2 remains fully embedded in the thermally conductive air permeable material 6 to achieve optimal cooling. Moreover, the air cooled heat exchanger 1 still provides for a compact form factor for a toroidal or cylindrical shell 2 with minimal internal friction as the tube arrangement 5 carrying the various mediums M, M' maintains the wounded tube bundle with gentle, long bends in correspondence with the inner diameter D as mentioned earlier.

[0025] In an advantageous embodiment, the air cooled heat exchanger 1 may further comprise an air blower 11 connected to the air inlet 7, wherein the air blower 11 is configured for providing the air A to the air inlet 7. In this embodiment, the air A for cooling is provided by the air blower 11, e.g. a fan-based air blower, and wherein the air A is urged through the thermally conductive, air permeable material 6 filling the shell 2.

[0026] In a further embodiment, the shell 2 may be provided with one or more further air inlets 7' for receiving further air A' and one or more further air outlets 8' for discharging the further air A', wherein the thermally conductive air permeable material 6 fluidly connects the air inlet 7 and the one or more further air inlets 7' to the air outlet 8 and the one or more further air outlets 8'. In this embodiment, the one or more further air inlets 7'and further air outlets 8' allow for increased cooling capacity of the tube agreement 5. To do so it is advantageous to evenly distribute the air inlet 7 and the one or more further air inlets 7' along the shell 2, as well as evenly distributing the air outlet 8 and the one or more further air outlets 8' along the shell 2. By evenly distributing all air inlets 7, 7'and all air outlets 8, 8', the air A and further A' may traverse the shell 2 over longer distances for improved thermal transfer.

[0027] In an advantageous embodiment, one or more further air blowers 11' may be provided each of which is connected to a corresponding further air inlet of the one or more further air inlets 7', and wherein each of the one or more further air blowers 11' is configured for providing the further air A' to the corresponding further air inlet of the one or more further air inlets 7'. As with the air blower 11 as mentioned earlier, the one or more further air blowers 11' (e.g. fan based) urge the further air A' through the thermally conductive, air permeable material 6.

[0028] As shown in Figure 1 and 2, for a toroidal or cylindrical shell 2 there is provided an embodiment wherein the air inlet 7 and the one or more further air inlets 7' are provided on the lower surface 2b of the shell 2 and wherein the air outlet 8 and the one or more further air outlets 8' are provided on the upper surface 2a of the shell 2. In this way the air A and further air A' traverse the toroidal or cylindrical shell 2 optimally in vertical directional for maximized heat transfers. To achieve horizontal air distribution throughout the toroidal or cylindrical shell 2, the air inlet 7 and the one or more further air inlets 7' may be evenly distributed along a circumference/perimeter of the toroidal or cylindrical shell 2 as well as the air outlet 8 and the one or more further air outlets 8' may be evenly distributed along a circumference/perimeter of the toroidal or cylindrical shell 2. For example, going clockwise or counter clockwise around the toroidal or cylindrical shell 2, then the air inlets 7, 7' and air outlets 8, 8' may be arranged in alternating fashion around the circumference/perimeter as shown in Figure 1.

[0029] To further elaborate on arrangements of air inlets 7, 7' and air outlets 8, 8', in further embodiments the air inlet 7 and the one or more further air inlets 7' may be mutually spaced apart over a common, maximized inlet angle "α", so that the air A and further air A' is evenly introduced into the toroidal or cylindrical shell 2. So in the depicted embodiment with one further air inlet 7', the air inlet 7 and the further air inlet 7' are spaced apart over an inlet angle α of 180°.

[0030] The above also applies to the air outlet 8 and one or more further air outlets 8'. That is, to achieve even distribution of air flow through the toroidal or cylindrical shell 2, the air outlet 8 and the one or more further air outlets 8' may be mutually spaced apart over a common, maximized outlet angle "β". So in the depicted embodiment with one further air outlet 8', the air outlet 8 and the further air outlet 8' are spaced apart over an outlet angle β of 180° as depicted.

[0031] Furthermore, the circumferential/peripheral distance between air inlets 7, 7' and air outlets 8, 8' may be maximized as well to ensure that the air A and further A' travels from an air inlet 7, 7' to an air outlet 8, 8' along a maximum distance to maximize heat transfer.

[0032] Therefore, in case of a single inlet/outlet pair, the air inlet 7 and the air outlet 8 may be arranged on opposing sides of a toroidal or cylindrical shell 2 to allow the air A to completely traverse the shell 2. In an embodiment having two inlet/out pairs, i.e. having the air inlet 7, one further air inlet 7', the air outlet 8 and one further air outlet 8', then the air inlet 7 and further air inlet 7' may be arranged on opposing sides of a toroidal or cylindrical shell 2 and wherein the air outlet 8 and the further air outlet 8' may also be arranged on opposing sides of the shell 2. The opposing air inlets 7, 7' and the opposing air outlets 8, 8' are then mutually spaced apart/rotated over an 180° angle as depicted in Figure 1. Therefore, from a general point of view, all air inlets 7, 7' and all air outlets 8, 8' may be mutually separated over a maximized inlet-outlet angleyto prevent "short circuits" between one or more air inlets 7, 7' and one or more air outlets 8, 8'.

[0033] So by maximizing the circumferential/peripheral distance between all air inlets 7, 7' and all air outlets 8, 8' ensures that the air A, A' travels through the thermally conductive, air permeable material 6 over a maximum distance to maximize thermal transfer therewith.

[0034] As schematically depicted in Figure 1 and 2, the tube inlet 3 and the one or more further tube inlets 3' may be positioned on the shell 2 in various ways. The same applies to the tube outlet 4 and the one or more further tube outlets 4'.

[0035] For example, in embodiments with a toroidal or cylindrical shell 2, the tube inlet 3 and the one or more further tube inlets 3' may be connected to the shell proximal to the upper surface 2a, and wherein the tube outlet 4 and the one or more further tube outlets 4' may be connected to the shell 2 proximal to the lower surface 2b. This embodiment allows the tube arrangement 5 to be formed as a helically wounded tube bundle extending from all tube inlets 3, 3' proximal to the upper surface 2a of the shell 2 to all tube outlets 4, 4' proximal to the lower surface 2b of the shell 2.

[0036] As mentioned hereinabove, the air cooled heat exchanger 1 of the present invention is advantageous for industrial applications such as cooling of compressed hydrogen gas. For example, the air cooled heat exchanger 1 may be utilized in hydrogen refuelling stations which compress gaseous hydrogen to a required pressure for dispensing the hydrogen gas into a vehicle. However, compression may raise the temperature of the hydrogen gas well over 100 °C (Celsius) and so cooling of the hydrogen will be required before it can be dispensed.

[0037] Referring to Figure 3, in this figure a schematic view of a hydrogen gas cooling process is depicted, wherein the cooling process utilizes an air cooled heat exchanger 1 as depicted. Such a process may be used to describe a general method for cooling a gaseous medium M using the air cooled heat exchanger 1 as explained above. As shown, consider a gaseous medium M that needs to be compressed and subsequently cooled by the air cooled heat exchanger 1. To that end, the method involves the step of compressing the medium M using a compressor 12. Once compressed, the method continues with the step of feeding the compressed medium M to the tube inlet 3 of the air cooled heat exchanger 1 at a first temperature T1. Typically, the first temperature T1 will be higher than the temperature of the gaseous medium M entering the compressor 12 as the compression will have raised the temperature.

[0038] The method then comprises the step of feeding air A to the air inlet 7 of the air cooled heat exchanger 1. In this step, air A is introduced into the air inlet 7 and travels through the shell 2 filled with the thermally conductive, air permeable material 6, where the air A discharges through the air outlet 8. In an embodiment, the air A, e.g. ambient air A, may be provided by an air blower 11.

[0039] As a next step, the method involves discharging the compressed medium M through the tube outlet 4 at a second temperature T2, wherein the second temperature T2 is lower than the first temperature T1. As expected, the air cooled heat exchanger 1 cools the medium M as it traverses the tube arrangement 5 toward the tube outlet 4.

[0040] The final step then involves feeding the discharged compressed medium M to a further heat exchanger 13 for further cooling to a third temperature T3, the third temperature T3 being lower than the second temperature T2. In this step, the further heat exchanger 13 allows the medium M to be further cooled. The further heat exchanger 13 may comprise an inlet 14 for receiving the medium M and an outlet 15 for discharging the medium M. Although not shown, the further heat exchanger 13 may comprise a further tube arrangement connecting the inlet 13 and the outlet 14, and wherein the medium M entering the inlet 14 travels through the further tube arrangement which is subjected to further cooling.

[0041] From the above it follows that the method provides a two stage cooling process, which is advantageous as the air cooled heat exchanger 1 may not be able to sufficiently cool the medium M from the second temperature T2 to the third temperature T3. Then to achieve further cooling, the further heat exchanger 13 need not utilize air as a coolant inside the further heat exchanger 13. Instead, the further heat exchanger 13 may utilize mechanical cooling to achieve the third temperature T3. For example, a secondary cooling loop 16 may be used comprising a secondary tube arrangement 17 configured for a condenser type cooling cycle. The further tube arrangement inside the further heat exchanger 13 is then arranged for heat transfer with the secondary tube arrangement 17 which also traverses through the further heat exchanger 13.

[0042] In an embodiment of the method, the medium M may be gaseous hydrogen, wherein the first temperature T1 lies above 100 °C, wherein the second temperature T2 lies between 100 °C and 10 °C, and wherein the third temperature T3 lies below 10 °C. For hydrogen refuelling applications for example, in an exemplary embodiment the first temperature T1 may be around 150 °C, the second temperature T2 may be around 40 °C, and wherein the third temperature T3 may be around 6 °C. In another exemplary embodiment, the first temperature T1 may be around 150 °C, the second temperature T2 may be around 65 °C, and wherein the third temperature T3 may be around 5 °C.

[0043] By using the air cooled heat exchanger 1, the medium (e.g. hydrogen) may be precooled using relatively little energy, before the medium enters the further heat exchanger 13. In doing so, the overall efficiency may be improved.

[0044] Taking the above into account, the present invention can now be summarised by the following embodiments:

Embodiment 1. An air cooled heat exchanger (1) for cooling a medium, comprising a hollow shell (2) provided with a tube inlet (3) for receiving a medium (M, M') to be cooled and a tube outlet (4) for discharging the medium (M), wherein the shell (2) houses a tube arrangement (5) connecting the tube inlet (3) to the tube outlet (4);

wherein the shell (2) is filled with a thermally conductive air permeable material (6) in tight engagement with the tube arrangement (5);
wherein the shell (2) is provided with an air inlet (7) for receiving air (A) and an air outlet (8) for discharging the air (A), and wherein the thermally conductive air permeable material (6) fluidly connects the air inlet (7) to the air outlet (8).

Embodiment 2. The air cooled heat exchanger according to embodiment 1, wherein the thermally conductive air permeable material (6) comprises a compacted arrangement of metal particles (9).

Embodiment 3. The air cooled heat exchanger according to embodiment 2, wherein the metal particles are substantially spherical and/or substantially irregularly shaped.

Embodiment 4. The air cooled heat exchanger according to embodiment 2 or 3, wherein the metal particles have a width (w) and/or height (h) of at most 3 mm.

Embodiment 5. The air cooled heat exchanger according to any one of embodiments 2-4, wherein the metal particles (9) are copper alloy particles.

Embodiment 6. The air cooled heat exchanger according to embodiment 1, wherein the thermally conductive air permeable material (6) is a porous solid material.

Embodiment 7. The air cooled heat exchanger according to embodiment 6, wherein the porous solid material comprises brass.

Embodiment 8. The air cooled heat exchanger according to any one of embodiments 1-7, wherein the shell (2) is a toroidal or cylindrical shell, and wherein the tube arrangement (5) comprises a plurality of tubes (10) forming a wounded tube bundle extending through the toroidal or cylindrical shell (2) around a centre (C) thereof.

Embodiment 9. The air cooled heat exchanger according to embodiment 8, wherein the toroidal or cylindrical shell (2) has an inner diameter (D) of at least 150 mm.

Embodiment 10. The air cooled heat exchanger according to any one of embodiments 1-9, further comprising an air blower (11) connected to the air inlet (7), wherein the air blower (11) is configured for providing air (A) to the air inlet (7).

Embodiment 11. The air cooled heat exchanger according to any one of embodiments 1-10, wherein the shell (2) is provided with one or more further tube inlets (3') for receiving a further medium (M') to be cooled and a corresponding number of one or more further tube outlets (4') for discharging the further medium (M'), wherein the tube arrangement (5) connects each of the one or more further tube inlets (3') to a corresponding further tube outlet of the one or more further tube outlets (4').

Embodiment 12. The air cooled heat exchanger according to any one of embodiments 1-11, wherein the shell (2) is provided with one or more further air inlets (7') for receiving further air (A') and one or more further air outlets (8') for discharging the further air (A'), and wherein the thermally conductive air permeable material (6) fluidly connects the air inlet 7 and the one or more further air inlets (7') to the air outlet 8 and the one or more further air outlets (8').

Embodiment 13. The air cooled heat exchanger according to embodiment 12, further comprising one or more further air blowers (11') each of which is connected to a corresponding further air inlet of the one or more further air inlets (7'), and wherein each of the one or more further air blowers (11') is configured for providing the further air (A') to the corresponding further air inlet of the one or more further air inlets (7').

Embodiment 14. A method of cooling a gaseous medium (M) using an air cooled heat exchanger (1) according to any one of embodiments 1-13; comprising the steps of:

compressing a medium (M) using a compressor (12);
feeding the compressed medium (M) to the tube inlet (3) of the air cooled heat exchanger (1) at a first temperature (T1);
feeding air (A) to the air inlet (7) of the air cooled heat exchanger (1);
discharging the compressed medium (M) through the tube outlet (4) at a second temperature (T2), the second temperature (T2) being lower than the first temperature (T1), and
feeding the discharged compressed medium (M) to a further heat exchanger (13) for further cooling to a third temperature (T3), the third temperature (T3) being lower than the second temperature (T2).

Embodiment 15. The method according to embodiment 14, wherein the medium (M) is gaseous hydrogen and wherein the first temperature (T1) lies above 100 °C, wherein the second temperature (T2) lies between 100 °C and 10 °C, and wherein the third temperature (T3) lies below 10 °C.

[0045] The present invention has been described above with reference to a number of exemplary embodiments as shown in the drawings. Modifications and alternative implementations of some parts or elements are possible, and are included in the scope of protection as defined in the appended claims.

Claims

1. An air cooled heat exchanger (1) for cooling a medium, comprising a hollow shell (2) provided with a tube inlet (3) for receiving a medium (M, M') to be cooled and a tube outlet (4) for discharging the medium (M), wherein the shell (2) houses a tube arrangement (5) connecting the tube inlet (3) to the tube outlet (4);

wherein the shell (2) is filled with a thermally conductive air permeable material (6) in tight engagement with the tube arrangement (5);
wherein the shell (2) is provided with an air inlet (7) for receiving air (A) and an air outlet (8) for discharging the air (A), and wherein the thermally conductive air permeable material (6) fluidly connects the air inlet (7) to the air outlet (8).

2. The air cooled heat exchanger according to claim 1, wherein the thermally conductive air permeable material (6) comprises a compacted arrangement of metal particles (9).

3. The air cooled heat exchanger according to claim 2, wherein the metal particles are substantially spherical and/or substantially irregularly shaped.

4. The air cooled heat exchanger according to claim 2 or 3, wherein the metal particles have a width (w) and/or height (h) of at most 3 mm.

5. The air cooled heat exchanger according to any one of claims 2-4, wherein the metal particles (9) are copper alloy particles.

6. The air cooled heat exchanger according to claim 1, wherein the thermally conductive air permeable material (6) is a porous solid material.

7. The air cooled heat exchanger according to claim 6, wherein the porous solid material comprises brass.

8. The air cooled heat exchanger according to any one of claims 1-7, wherein the shell (2) is a toroidal or cylindrical shell, and wherein the tube arrangement (5) comprises a plurality of tubes (10) forming a wounded tube bundle extending through the toroidal or cylindrical shell (2) around a centre (C) thereof.

9. The air cooled heat exchanger according to claim 8, wherein the toroidal or cylindrical shell (2) has an inner diameter (D) of at least 150 mm.

10. The air cooled heat exchanger according to any one of claims 1-9, further comprising an air blower (11) connected to the air inlet (7), wherein the air blower (11) is configured for providing air (A) to the air inlet (7).

11. The air cooled heat exchanger according to any one of claims 1-10, wherein the shell (2) is provided with one or more further tube inlets (3') for receiving a further medium (M') to be cooled and a corresponding number of one or more further tube outlets (4') for discharging the further medium (M'), wherein the tube arrangement (5) connects each of the one or more further tube inlets (3') to a corresponding further tube outlet of the one or more further tube outlets (4').

12. The air cooled heat exchanger according to any one of claims 1-11, wherein the shell (2) is provided with one or more further air inlets (7') for receiving further air (A') and one or more further air outlets (8') for discharging the further air (A'), and wherein the thermally conductive air permeable material (6) fluidly connects the air inlet 7 and the one or more further air inlets (7') to the air outlet 8 and the one or more further air outlets (8’).

13. The air cooled heat exchanger according to claim 12, further comprising one or more further air blowers (11’) each of which is connected to a corresponding further air inlet of the one or more further air inlets (7’), and wherein each of the one or more further air blowers (11’) is configured for providing the further air (A’) to the corresponding further air inlet of the one or more further air inlets (7’).

14. A method of cooling a gaseous medium (M) using an air cooled heat exchanger (1) according to any one of claims 1-13; comprising the steps of:

compressing a medium (M) using a compressor (12);
feeding the compressed medium (M) to the tube inlet (3) of the air cooled heat exchanger (1) at a first temperature (T1);
feeding air (A) to the air inlet (7) of the air cooled heat exchanger (1);
discharging the compressed medium (M) through the tube outlet (4) at a second temperature (T2), the second temperature (T2) being lower than the first temperature (T1), and
feeding the discharged compressed medium (M) to a further heat exchanger (13) for further cooling to a third temperature (T3), the third temperature (T3) being lower than the second temperature (T2).

15. The method according to claim 14, wherein the medium (M) is gaseous hydrogen and wherein the first temperature (T1) lies above 100 °C, wherein the second temperature (T2) lies between 100 °C and 10 °C, and wherein the third temperature (T3) lies below 10 °C.

Fig. 1

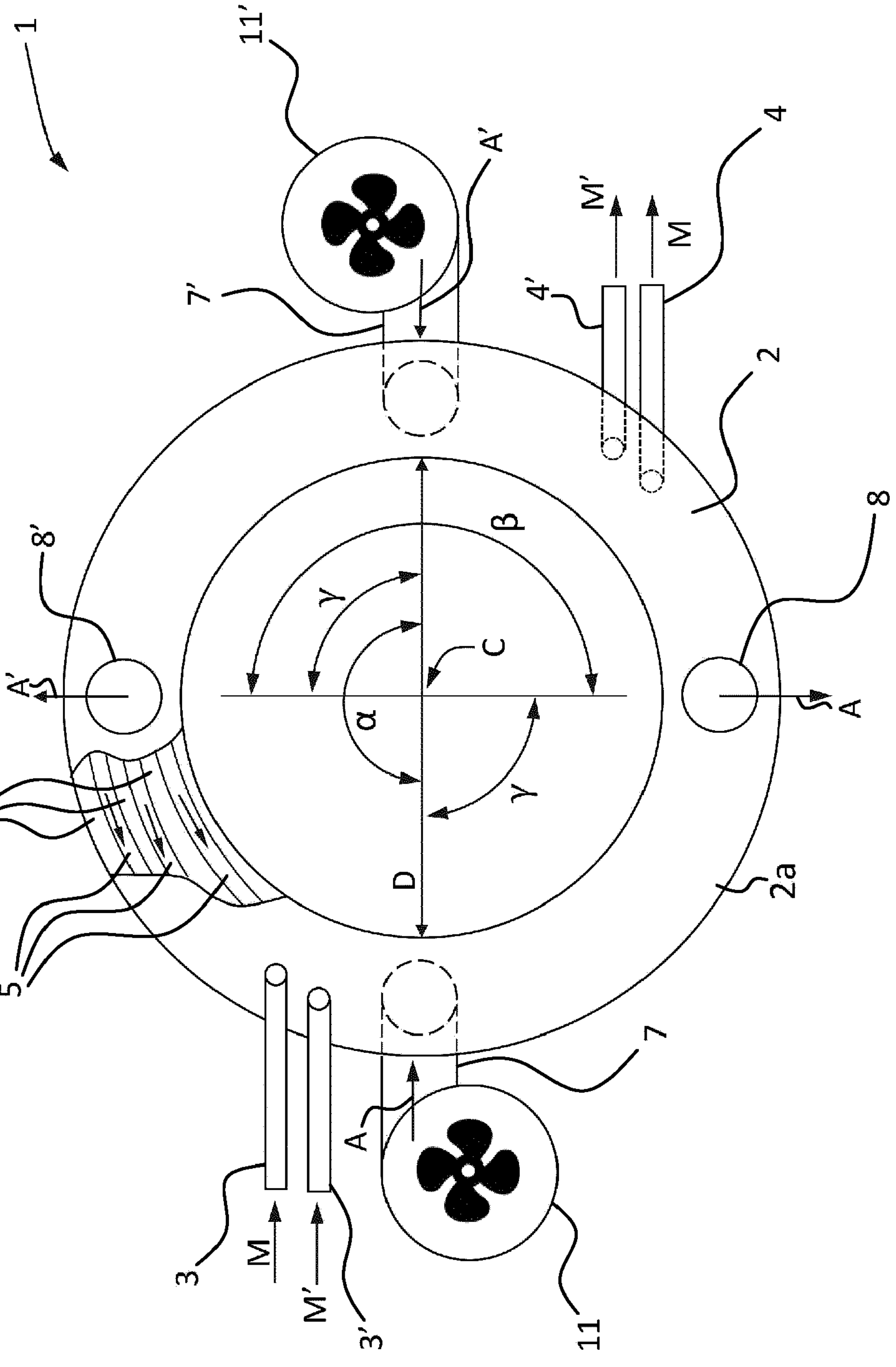


Fig. 2

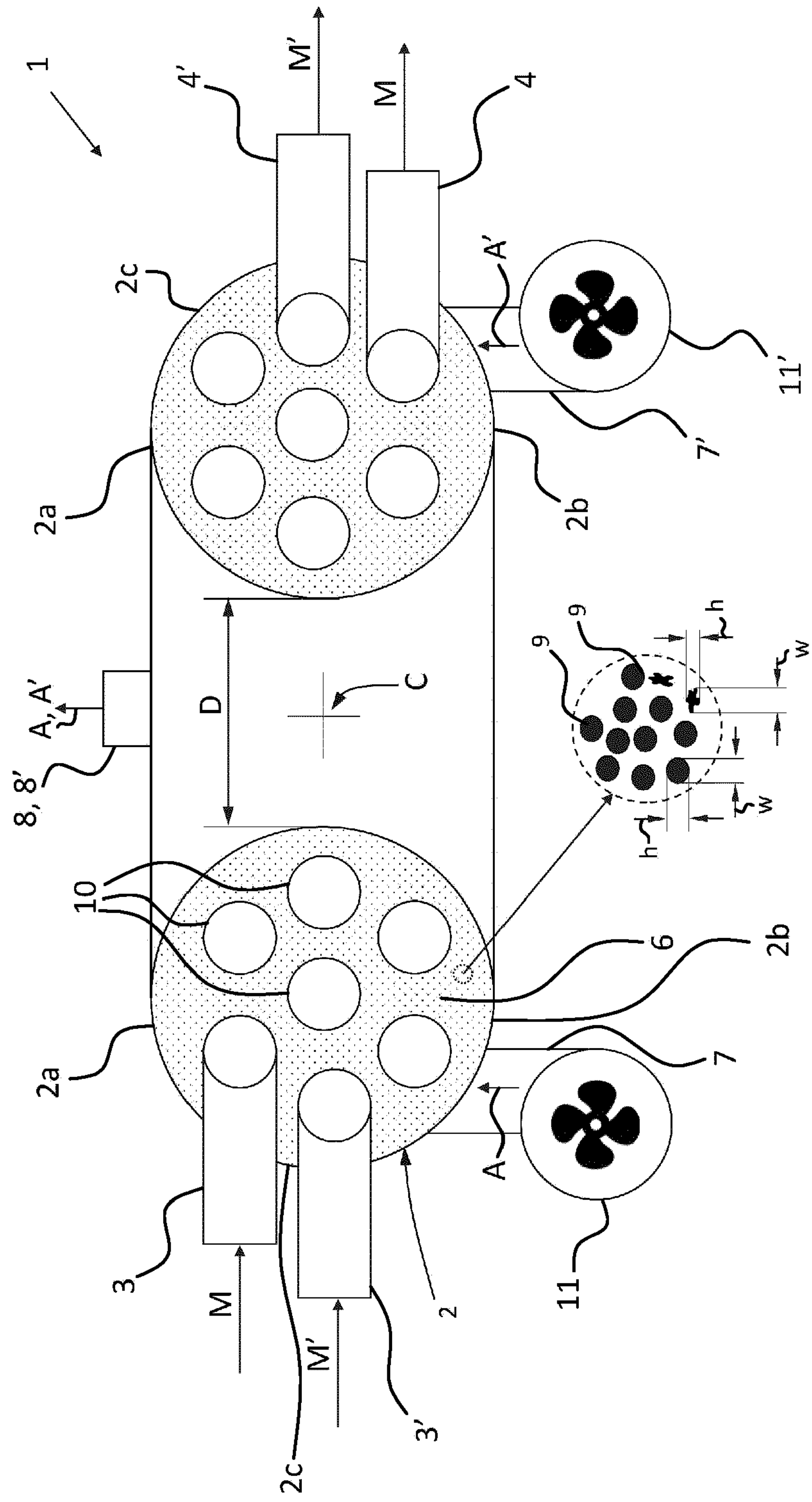
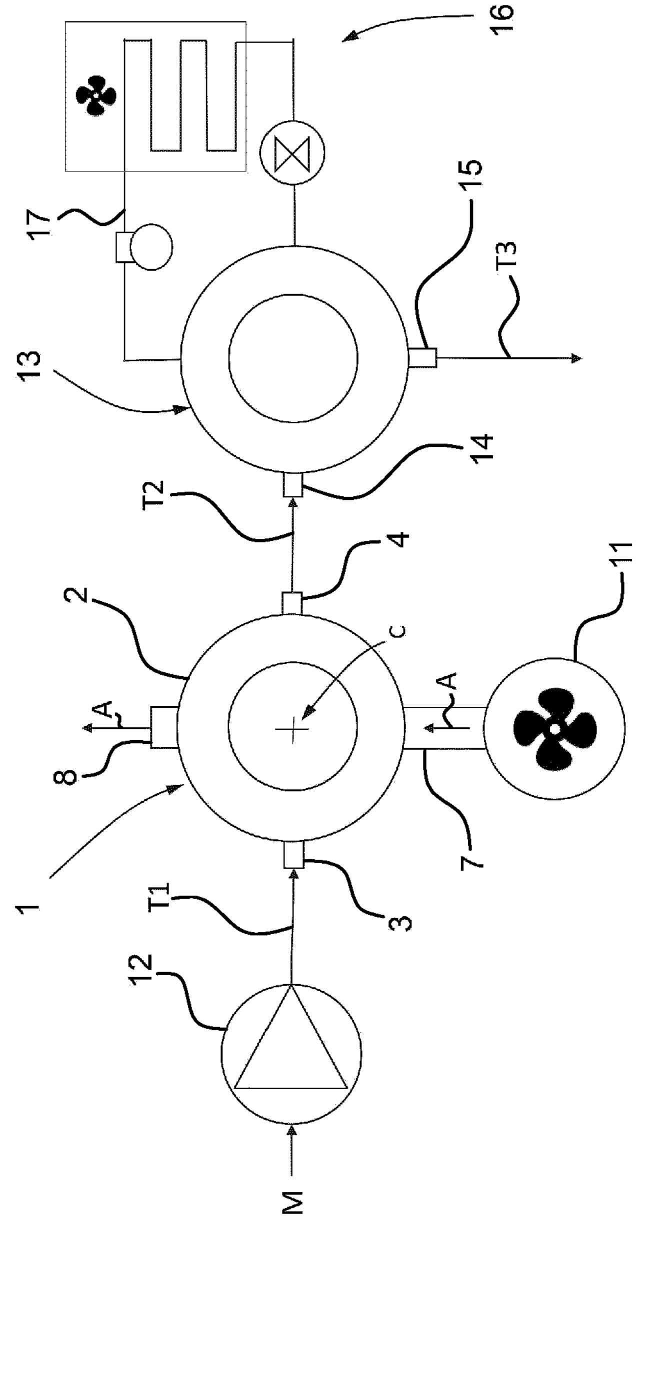


Fig. 3



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EUROPEAN SEARCH REPORT

Application Number
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1 The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	24 January 2022	Martínez Rico, Celia

CATEGORY OF CITED DOCUMENTS

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