(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
3 January 2014 (03.01.2014)

WIPO | PCT

(10) International Publication Number
WO 2014/003880 A1

(51) International Patent Classification:
F28D 7/16 (2006.01) *F28F 17/00* (2006.01)
F28F 9/02 (2006.01) *F04D 29/58* (2006.01)

(21) International Application Number: PCT/US2013/037741

(22) International Filing Date: 23 April 2013 (23.04.2013)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
13/538,387 29 June 2012 (29.06.2012) US

(71) Applicant: **PRAXAIR TECHNOLOGY, INC.** [US/US]; 39 Old Ridgebury Road, Danbury, CT 06810 (US).

(72) Inventors: **BAKER, Robert, L.**; 139 Brompton Road, Williamsville, NY 14221 (US). **SURYANARAYANAN, Arun**; 107 Paradise Lane #12, Tonawanda, NY 14150 (US). **SHELAT, Maulik, R.**; 5405 Village Station Circle, Williamsville, NY 14221 (US). **GOODBAND, Jeffrey, C.**; 1013 90th Street, Niagara Falls, NY 14304 (US).

(74) Agents: **ROSENBLUM, David, M.** et al.; Praxair, Inc., 39 Old Ridgebury Road, Danbury, CT 06810 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

[Continued on next page]

(54) **Title**: COMPRESSED GAS COOLING APPARATUS

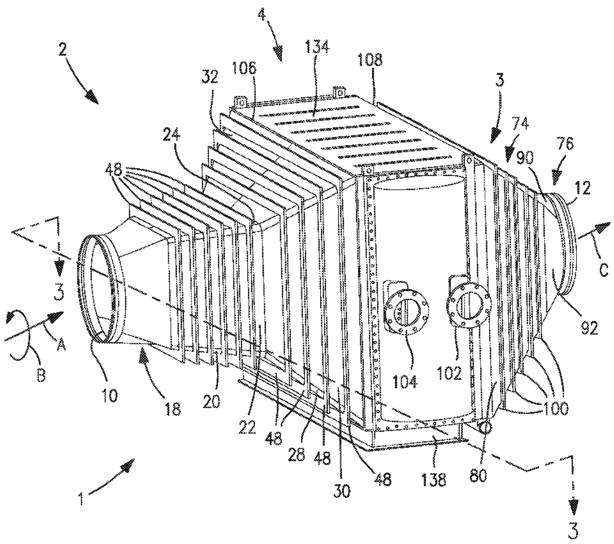


FIG. 1

(57) Abstract: A compressed gas cooling apparatus in which gas from an upstream compression stage enters an inlet section from an inlet opening and flows to a heat exchanger that cools the gas. The cooled gas then flows from the heat exchanger to the outlet section where the gas is discharged from an outlet opening. Pressure drop within the apparatus is decreased by providing the inlet and outlet sections with ever increasing and decreasing cross-sectional flow areas. In order to further decrease pressure drop due to a swirl within the gas flow imparted from the upstream compression stage, the inlet section is provided with first and second subsections wherein the cross-sectional flow area of the first subsection increases at lesser rate than the second subjection. Alternatively, or in addition, the inlet section can be provided with partitions to divide the gas flow into subflows in order to lessen pressure drop from swirl.

WO 2014/003880 A1

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

COMPRESSED GAS COOLING APPARATUS

Field of the Invention:

[0001] The present invention provides a compressed gas cooling apparatus that can function as an intercooler or an after-cooler and that is used to cool a gas between or after a series of compression stages. More particularly, the present invention relates to such a cooling apparatus in which both the inlet and outlet have sections of ever-increasing and ever-decreasing area, respectively, to feed gas to and from a heat exchanger positioned between the inlet and the outlet. Even more particularly, the present invention relates to such a cooling apparatus in which the ever-increasing section of the inlet is designed to further reduce pressure losses that occur due to the swirl in the gas flow imparted by the upstream compression stage introducing compressed gas into the cooling apparatus.

Background of the Invention:

[0002] Large volumes of gas are compressed in a variety of industrial applications within compression systems having a series of stages with intercooling between stages to cool the gas. The energy imparted to the gas in each of the compression stages heats the gas, also known as the heat of compression, is removed by the intercoolers. An after-cooler can be positioned after the last of the compression stages.

[0003] Typically, each of the compression stages is formed by a centrifugal compressor in which gas is drawn from an inlet to a vaned impeller that is driven to accelerate the gas and thereby increase the pressure and velocity of the gas. The pressure loss accompanying the increase in velocity is recovered in a diffuser that surrounds the impeller and that can have vanes. The gas is discharged from the impeller to a spiral-like volute having an outlet from which the pressurized gas is discharged and that surrounds the inlet. The intercooler is positioned between the outlet of the upstream stage and the inlet of the downstream stage. Where the gas, such as air, contains moisture, the decrease in temperature of the compressed gas through intercooling and after-cooling results in the condensation of such moisture which is discharged from the intercoolers and after-coolers so that the condensate is not carried to downstream stages or to equipment conducting processes that consume the compressed gas.

[0004] In air separation plants, the use of centrifugal compressors with intercoolers and after coolers is quite common. The compressors can be driven by a transmission in which an electric motor drives a bull gear that drives pinion-like gears that are attached to each of the compressors to in turn drive the impellers. Thus, the compressors are arranged about the bull gear with piping having bends to route the gas to and from intercoolers located between the compressors. As known in the art, the bends in such piping will induce a pressure drop within gas passing between the compressors. Intercoolers are typically of shell and tube construction in which the tubes are used to pass a coolant, that can be water, into indirect heat exchange with the gas passing at right angles to the tubes. Passages for the gas are formed by an arrangement of fins through which the tubes penetrate. The gas enters the shell of such a heat exchanger through an inlet plenum and is discharged, at the opposite end of the shell from an outlet plenum. Gas is introduced and discharged from such plenums at right angles to the shell through and inlet and outlet thereof. As can be appreciated there exists a further pressure loss from such arrangement due to the change in direction of flow and also, the rapid increase in cross-sectional flow area from the inlet to the inlet plenum and then from the outlet plenum to the outlet. In air separation plants, these pressure losses must be compensated for by increased compression and therefore, increased power consumption. The same considerations apply to other industrial application of multi-stage compression systems.

[0005] Considerably more freedom in the placement of compressors and intercoolers is possible where the compressors are independently and directly driven by high speed permanent magnet motors. The freedom in the placement of the compressors can be used to reduce pressure drops that accompany the intercooling and after-cooling of gases within multi-stage compression systems. For instance, in US Patent Publication No. 2010/0329895, the centrifugal compressors are independently driven and are positioned so that the inlet of a downstream compressor is located opposite to the outlet of an upstream compressor. Additionally, each of the inlets and outlets to the intercoolers have sections of ever-increasing transverse cross-sectional area and ever-decreasing transverse cross-sectional area, respectively, with the heat exchangers positioned between such sections. These sections can be formed by sets of four plates connected together in an arrangement of a four-side polyhedron and as such have a rectangular transverse cross-sectional flow area. The heat exchangers that incorporate a box-like housing are located between these sections and internally, the heat exchangers have gas passages for the flow of the gas directly from and to such inlet and outlet sections. The coolant passes through coolant passages at right angles to the gas passages. As can be appreciated, such an arrangement reduces pressure losses that would otherwise arise from prior art arrangements having piping bends between stages and pressure losses due to rapid changes of area and direction of flow to and from the heat exchanger and within the heat exchanger itself.

[0006] What has not been appreciated, even in the publication discussed above, is that pressure losses also arise from the swirl induced into the flow entering inlet and outlet sections of the intercooler or other compressed gas cooling apparatus used in connection with a compressor. When the centrifugal compressor compresses the gas such a swirl in the flow is induced by the impeller and diffuser arrangement. When such flow enters an inlet to the intercooler or after-cooler, even one having a gradually increasing cross-sectional flow area, the gas tends to accumulate on the walls and at one side of the inlet. This creates a high pressure area where the flow accumulates and a low pressure area adjacent the high pressure area. This causes separation of the flow from the walls and a recirculation within the inlet to the intercooler or after-cooler that in turn produces a yet further component of the overall pressure drop.

[0007] As will be discussed, the present invention, among other aspects, provides a compressed gas cooling apparatus that can function as an intercooler or an after-cooler that is designed to minimize pressure drops within the inlet to the compressed gas cooling apparatus that arise from the swirl imparted into the gas flow by the compressor.

Summary of the Invention

[0008] The present invention provides a compressed gas cooling apparatus having use as an intercooler or an after-cooler. The apparatus is provided with an inlet section and an outlet section. The inlet section has an inlet to receive a gas from an upstream compression stage and the outlet section has an outlet to discharge the gas, after having been cooled to a downstream compression stage. A heat exchanger connects the inlet section to the outlet section and has gas passages communicating between the inlet section and the outlet section for passage of the gas and coolant passages positioned in a heat transfer relationship with the gas passages for passage of a coolant to cool the gas passing through the gas passages through indirect heat exchange with a coolant. The inlet section portion comprises a first inlet portion and a second inlet portion. The first inlet portion is located between the inlet and the second inlet portion and the second inlet portion located between the first inlet portion and the heat exchanger. Each of the first inlet portion and the second inlet portion has an ever increasing transverse cross-sectional flow area. The ever increasing transverse cross-sectional flow area of the second inlet portion increasing at a greater rate than the first inlet portion so that the velocity of the flow of the gas gradually decreases as the gas flows through the inlet section to a lesser extent in the first inlet portion than the second inlet portion. This inhibits separation of the flow of the gas from sidewalls of each of the first inlet portion and the second inlet portion, due to swirl imparted into the flow of the gas from the upstream compression stage to reduce pressure drop. The outlet section comprises one outlet portion of ever-decreasing transverse cross-sectional flow area for flow of the gas from the heat exchanger to the outlet such that velocity of the flow of the gas gradually increases to also reduce pressure drop.

[0009] The first inlet portion, the second inlet portion and the one outlet portion can be formed by sets of four sidewalls connected to one another such that the ever-increasing transverse cross-sectional flow area and the ever-decreasing transverse cross-sectional flow area are of rectangular configuration. The heat exchanger has an inlet side and an outlet side located opposite to the inlet side. The cooling passages extend between the inlet side and the outlet side and each of the inlet side and the outlet side is of rectangular configuration. The inlet section has a third inlet portion having a first transitional transverse cross-sectional flow area that transitions from a circle, at one end, to define the inlet and at the other end, a rectangle. The other end of the third portion in registry with and connected to one of the sets of four sidewalls forming the first part of inlet portion. The one outlet portion is a first outlet portion and the outlet section has a second outlet portion situated such that the first outlet portion is located between the second outlet portion and the heat exchanger. The second outlet portion has a second transitional transverse cross-section flow area transitioning from a circle, at one end, to define the outlet and at the other end, a rectangle. The other end of the second outlet portion is in registry with and connected to a further of the sets of four sidewalls forming the first outlet portion.

[0010] In a specific embodiment, another of the sets of four sidewalls forming the second inlet portion, at opposite ends, is in registry with and connected to the one of the sets of four sidewalls and the inlet side of the heat exchanger. The further of the sets of four sidewalls forming the first outlet portion, at opposite ends, is in registry with and connected to the other end of the second outlet portion and the outlet side of the heat exchanger.

[0011] In order to further reduce the pressure drop resulting from swirl within the gas flow, the first inlet portion can be subdivided into a first set of subpassages by a first set of partition elements oriented such that each of the subpassages is of rectangular configuration. The second inlet portion can be subdivided into a second set of subpassages by a second set of partition elements oriented such that each of the subpassages is of rectangular configuration. The second set of subpassages have more subpassages than the first set of subpassages. The first outlet portion can likewise be subdivided into a third set of subpassages by a third set of partition elements. The first set of partition elements, the second set of partition elements and the third set of partition elements are connected to the sidewalls and rectangular, frame-like stiffening members are connected to outer surfaces of each of the sets of the four sidewalls. In a specific embodiment, the first set of subpassages has four subpassages and the second set of subpassages has twenty-four subpassages.

[0012] An embodiment of the present invention also provides a compressed gas cooling apparatus in which the inlet section comprises one portion having at least one sidewall forming an ever-increasing transverse cross-sectional flow area. Partition elements subdivide the ever-increasing transverse cross-sectional flow area into a plurality of subpassages, each having ever-increasing transverse cross-sectional sub-flow areas so that velocity of the flow of the gas gradually decreases as the gas flows through the inlet section. The sub-flow areas reduce separation of the flow of the gas from the at least one sidewall, due to swirl imparted into the flow of the gas from the upstream compression stage, thereby reducing pressure drop. The outlet section comprises an outlet portion of ever-decreasing transverse cross-sectional flow area for flow of the gas from the heat exchanger to the outlet so that the velocity of the flow of the gas gradually increases as the gas flows in the outlet section to also reduce pressure drop.

[0013] In such embodiment, the inlet portion and the outlet portion are formed by sets of four sidewalls connected to one another such that the ever-increasing transverse cross-sectional flow area and the ever-decreasing transverse cross-sectional flow area are of rectangular configuration. The subpassages are each of rectangular configuration. The heat exchanger has an inlet side, an outlet side located opposite to the inlet side, the cooling passages that extend between the inlet side and the outlet side. Each of the inlet side and the outlet side is of rectangular configuration. The at least one sidewall of the inlet portion is one of the sets of four sidewalls. A further of the sets of four sidewalls form the outlet portion. The inlet portion is a first inlet portion and the outlet portion is a first outlet portion.

The inlet section has a second inlet portion and the outlet section has a second outlet portion. The second inlet portion has a first transitional transverse cross-sectional flow area transitioning from a circle, at one end, to define the inlet and at the other end, a rectangle. The other end of the second inlet portion in registry with the one of the sets of four sidewalls forming the first inlet portion. Similarly, the second outlet portion has a second transitional transverse cross-section flow area transitioning from a circle, at one end, to define the outlet and at the other end, a rectangle. The other end of the second outlet portion is in registry with the further of the sets of four sidewalls.

[0014] The one of the sets of four sidewalls forming the first inlet portion is connected to and in registry with the inlet side of the heat exchanger at a location of the inlet section opposite to the second inlet portion. The further of the sets of four sidewalls forming the first outlet portion is connected to and in registry with the outlet side of the heat exchanger at a location of the outlet section opposite to the second outlet portion. The partition elements of the first inlet portion can be a first set of partition elements and the subpassages are a first set of subpassages and the first outlet portion has a second set of partition elements that form a third set of subpassages of rectangular configuration. The first set of partition elements and the second set of partition elements are connected to the sidewalls. Rectangular, frame-like stiffening members are connected to outer surfaces of each of the sets of the four sidewalls.

[0015] In any embodiment of the present invention, the heat exchanger can be of cross-counter flow arrangement.

The cooling passages are formed between a plurality of parallel fins oriented at right angles with respect to the inlet side and the outlet side of the heat exchanger. The coolant passages are formed by coolant tubes that penetrate the parallel fins for circulation of the coolant and are in an orthogonal orientation with respect to the parallel fins.

[0016] Preferably, the coolant tubes comprise a set of inlet coolant tubes, a first set of intermediate coolant tubes, a second set of intermediate coolant tubes and a set of outlet coolant tubes. These inlet, intermediate and outlet coolant tubes are arranged to provide four passes within the heat exchanger. The heat exchanger has two end portions located opposite to one another and two spaced, transversely extending top and bottom panels connecting the end portions and forming the inlet side and the outlet side of the heat exchanger. An inlet plenum and an outlet plenum are situated, side by side, at one of the two end portions and are in flow communication with the inlet coolant tubes and the outlet coolant tubes, respectively, to introduce the coolant into the inlet coolant tubes and to discharge the coolant from the outlet coolant tubes. Reversal plenums are located at the end portions of the heat exchanger and are configured such that coolant from the inlet tubes flows into the first set of intermediate coolant tubes at the other of the end portions, after having traversed the heat exchanger. The coolant then flows from the first set of intermediate coolant tubes flows into the second set of intermediate coolant tubes at the one of the end portions, after having traversed the heat exchanger. Subsequently, coolant from the second set of intermediate coolant tubes flows into the set of outlet coolant tubes, after having traversed the heat exchanger and thereafter, flows from the set of outlet coolant tubes into the outlet plenum.

[0017] The heat exchanger can have a condensate disengagement chamber located between the outlet side and the coolant tubes and the parallel fins to allow condensed water to separate from the compressed gas passing through the heat exchanger. An elongated, tube-like drain is located at the bottom of the condensate disengagement chamber to collect the condensed water separated from the gas and to discharge the condensed water from the heat exchanger.

[0018] Further, within the heat exchanger, the coolant tubes can be connected to and supported at their ends by two opposed tube sheets.

Brief Description of the Drawings

[0019] While the specification concludes with claims distinctly pointing out the subject matter that Applicants regard as their invention, it is believed that the invention will be better understood when taken in connection with the accompanying drawings in which:

[0020] Fig. 1 is a perspective view of a compressed gas cooling apparatus of the present invention;

[0021] Fig. 2 is an exploded, perspective view of an inlet section used in the apparatus illustrated in Fig. 1;

[0022] Fig. 3 is a sectional, perspective view of the inlet section used in the apparatus illustrated in Fig. 1 taken along line 3-3 of Fig. 1;

[0023] Fig. 4 is a perspective view of an alternative embodiment of a compressed gas cooling apparatus of the present invention;

[0024] Fig. 5 is an exploded, perspective view of an inlet section used in the apparatus illustrated in Fig.4.

[0025] Fig. 6 is a sectional perspective view of the inlet section used in the apparatus illustrated in Fig. 1 taken along line 6-6 of Fig 4;

[0026] Fig. 7 is an exploded, perspective view of an outlet section used in the apparatus illustrated in Figs. 1 and 4;

[0027] Fig. 8 is a top plan view of a heat exchanger in accordance with the present invention that is used in the apparatus illustrated in Figs. 1 and 4;

[0028] Fig. 9 is a fragmentary, sectional perspective view of the heat exchanger illustrated in Fig. 8 taken along line 9-9 thereof, showing fins, cooling passages and coolant tubes used within the heat exchanger; and

[0029] Fig. 10 is a sectional, perspective view of the heat exchanger used in the apparatus illustrated in Figs. 1 and 4 with the fins removed to illustrate the coolant tubes, inlet, outlet and reversal plenums and a condensate disengagement chamber and drain thereof.

Detailed Description

[0030] With reference to Figure 1, a compressed gas cooling apparatus 1 in accordance with the present invention is illustrated. As mentioned above, such apparatus can function as an intercooler between compression stages or an after-cooler to cool the gas discharged from a compression stage to be used in downstream processing. Apparatus 1 has an inlet section 2, an outlet section 3 and a heat exchanger 4 connecting the inlet section 2 to the outlet section 3. The inlet section 2 has an inlet 10 to receive a gas flow “A” from an upstream compression stage, not illustrated. The upstream compression stage could be a centrifugal compressor or an axial compressor. In either case, the gas flow indicated by arrowhead "A" entering the inlet 10 has a swirl or a rotational component to the flow designated by curved arrowhead "B". Such swirl is imparted to the flow by the rotational components of the compressor, for instance, the impeller of a centrifugal compressor.

[0031] The gas flow "A", after having been cooled in the heat exchanger 4 is discharged from an outlet 12 of the outlet section 3 as a cooled gas flow shown as arrowhead "C".

[0032] With additional reference to Figures 2 and 3, inlet section 2 is provided with a first inlet portion 14, a second inlet portion 16 and optionally, a third inlet portion 18. As is apparent, all of these portions have an ever increasing transverse cross-sectional flow area that will act to gradually reduce the velocity of the gas flow before entering the heat exchanger 4. This will reduce pressure drop or loss in the flow due to turbulence that would otherwise be induced in the gas flow due to a sudden enlargement in cross-sectional flow area from the inlet opening 10. However, the pressure drop or loss in the gas flow also arises from the swirl "B" introduced into the flow by the upstream compressor. This "swirl" or rotation in the flow tends to cause the gas to accumulate on one side of the inlet section 2. This accumulation in turn creates a high pressure area and an adjacent low pressure area. As a result, a separation of the gas flow appears at wall regions of the inlet portion towards the adjacent low pressure region which in turn results in a backward circulation of the gas flow leading to an increase in pressure drop in the gas flow.

[0033] The first inlet portion 14 is formed by a set of four sidewalls 20, 22, 24 and 26 that are connected to one another such that the ever-increasing transverse cross-section flow area is of rectangular configuration. The second inlet portion 16 is formed by another set of four sidewalls 28, 30, 32 and 34 that are connected to one another to again form an ever-increasing transverse cross-sectional flow are of rectangular configuration. Specifically, the swirl “B” will tend to cause the gas flow “A” to accumulate along sidewalls 26 and 34 of the first and second sections 14 and 16 and portions of adjacent sidewalls 20, 24 and 28,32 located close to the sidewalls 26 and 34. This will create a high pressure field within the gas flow “A” at such sidewall regions. In more central regions of the first and second sections 14 and 16, located at a distance from the sidewalls 26 and 34, the flow is not subject to such accumulation and therefore, has a lower pressure. As mentioned above, this pressure difference will potentially cause recirculation of the gas flow “A” from the higher to the lower pressure regions resulting in a pressure drop.

[0034] However, as can best be seen in Figure 3, the ever-increasing transverse cross sectional flow area of the second inlet portion 16 increases at a greater rate than that of the first inlet portion 14. The effect of this is that the velocity of the gas flow through the first inlet portion 14 will decrease to a lesser extent than the gas flow within the second inlet portion 16. The resulting higher velocity of the gas flow within the first inlet portion 14 will tend to reduce the separation of the gas flow from the walls of the inlet section 2 and allow the swirl “B” to dissipate somewhat before the gas flow reaches the second inlet portion 16. Since flow velocity is also decreasing along the length of the second inlet portion 16, pressure drop in the gas flow that otherwise would have been produced by the swirl “B” and a sudden increase in area will be reduced. The second inlet portion abuts the heat exchanger 4 and thereby also serves to distribute the gas flow across the heat exchanger 4.

[0035] In order to best reduce the pressure drop resulting from the swirl “B”, the first and second sections 14 and 16 are preferably designed to lie tangent to a bell-shaped curve given by the formula for an ellipse (bell-shape) $((x-i)^2/a^2)+((y-j)^2/b^2) = 1$ where (i,j) is the centre of the ellipse, a and b are the half distances on x and y axes respectively. First section 14 would originate from the apex of such bell shape and second section 16 would terminate at the mount of such bell shape. Even more preferably, first section 14 has an aspect ratio of between 0.4 and 0.5. This aspect ratio is measured by dividing the maximum width of first section 14, as seen at the juncture of the first section 14 with the second section 16, by its length. The second section 16 preferably has an aspect ratio of between 0.2 and 0.4. This aspect ratio is measured by dividing the maximum width of second section 16, as seen at the juncture of the second section 16 with the heat exchanger 4, by its length.

[0036] While the first and second inlet portions 14 and 16 alone will tend to reduce pressure drop in the gas flow for reasons mentioned above, preferably, the rectangular cross-sectional flow areas of the first inlet portion 14 is divided into a first set of subpassages, for example subpassage 36 and the second inlet portion 16 is subdivided into a second set of subpassages, for example subpassage 38. These rectangular subdivisions serve to reduce pressure drop further by preventing gas flow from accumulating on one side of the inlet portion 2 as a result of the swirl “B”. The first set of subpassages 36 are formed by a first set of partition elements 40 and 42, positioned at right angles to one another and the second set of subpassages 38 are formed from sets of partition elements 40 and 42 and 44 and 46. Partition elements 40 and 42 extend the length of the first inlet portion 14 and the second inlet portion 16. Partition elements 44 and 46 are confined to the second inlet portion 16 and are positioned at right angles to one another. As illustrated each of the subpassages 36 and 38 are of rectangular configuration and are each of ever increasing area.

[0037] The partition element 40 is connected along its edges to sidewalls 20, 24 and 28, 32; and the partition element 42 is connected along its edges to sidewalls 22, 26; and 30, 34. Further, the partition elements 44 are connected to sidewalls 28 and 32 and the partition elements 46 are connected to sidewalls 30 and 34. These connections are preferred in order to help maintain structural integrity of the first inlet portion 14 and the second inlet portion 16 and are normally in tension during use of the apparatus 1. Further structural integrity is provided by frame-like stiffing members 48 connected to the set of sidewalls 20, 22, 24 and 26 forming the first inlet portion 14 and to sidewalls 28, 30, 32 and 34 forming the second inlet portion 16. As can be appreciated, such connections of the partition elements and the use of the frame-like stiffing members to reduce the thickness and weight of the sidewalls 20 through 34 that are necessary to contain compressed gases at high pressure.

[0038] As illustrated, the second inlet portion 16 has more subpassages 38 than the subpassages 36 of the first inlet portion 14. Preferably there are 24 of such subpassages 38 as compared with the four subpassages 36. A major reason for this is that since the first inlet portion 14 has a smaller cross-section than the second inlet portion 16, there is less stress and therefore, fewer partition elements are required in the first inlet portion for structural integrity.

[0039] Although first inlet section 14 could simply be provided with a circular opening to form the inlet 10, preferably, the third inlet portion 18 is provided having a transitional transverse, cross-sectional flow area that transitions from the circular inlet opening 10, at one end and a rectangle at the other end. The sidewalls 50 thereof are therefore, curved at the inlet opening 10 and are planar at the other end thereof to form the rectangle. This again helps to lower pressure drop by avoiding an abrupt transition between the circular inlet opening 10 and the rectangular cross-sectional flow areas provided by the first inlet portion 14 and the second inlet portion 16.

[0040] Preferably, the sidewalls 50 are connected to and in registry with the sidewalls 20, 22, 24 and 26 of the first inlet portion 14. The sidewalls 20, 22, 24 and 26 are also preferably connected to an in registry with the sidewalls 28, 30, 32 and 34 of the second inlet portion 16. The sidewalls 28, 30, 32 and 34 are connected to and in registry with the inlet side 106 of the heat exchanger 4. It is possible, however to provide a spacer section having a uniform, rectangular cross-sectional flow area between the second inlet section 16 and the heat exchanger 4. Likewise it is also possible to provide such a spacer section between either or both of the first inlet section 14 and the second inlet section 16 or between the third inlet portion 18 and the first inlet portion 14.

[0041] With reference to Figures 4 and 5, a compressed gas cooling apparatus 1' is illustrated that is an alternative embodiment of the apparatus 1. Apparatus 1' differs from apparatus 1 in that it is provided with an inlet section 2' having a first inlet portion 52 of ever increasing cross-sectional flow area and a second inlet portion 54 of similar configuration to the third inlet portion 18 of apparatus 1.

[0042] First inlet portion 52 is formed by a set of four sidewalls 56, 58, 60 and 62 that are connected to one another such that the ever-increasing transverse cross-section flow area is of rectangular configuration. Again, although a simple inlet opening could be provided, the second inlet portion 54 provided further pressure drop by provision of its transitional transverse cross-section flow area that transitions from the circular inlet opening 10', at one end and a rectangle at the other end. The sidewalls 64 thereof are therefore, curved at the inlet opening 10' and are planar at the other end thereof to form the rectangle. The sidewalls 64, at the other end of second inlet portion 54 are connected to an in registry with sidewalls 56, 58, 60 and 62 of the first inlet portion 56.

[0043] With additional reference to Figure 6, pressure drop within the inlet section 2' is reduced by provision of the ever-increasing transverse cross-section flow area provided by the first inlet portion 52. The pressure drop due to swirl is reduced by means of a set of partitions 66 and 68, positioned at right angles with respect to one another and that subdivide the transverse cross-sectional flow area into subpassages, for instance subpassage 70, each of ever increasing transverse cross sectional flow area. The partition elements 66 and 68 prevent the formation of a high pressure wall region, resulting from the swirl in the flow, from influencing the subflows in adjacent subpassages 70.

[0044] The partitions 66 and 68 are also connected to the sidewalls 56, 60 and 58, 62, respectively, to add to the structural integrity of the first portion 52 of the inlet section 2'. Additionally, optional frame-like stiffening members 72 connected to the outer surfaces of the sidewalls 56, 58, 60 and 62 add to the structural integrity and strength of the first portion 52.

[0045] With additional reference to Figure 7, outlet section 3 again has an ever decreasing transverse cross-section flow area to allow the velocity of the flow to gradually increase. The design of the outlet section 3 is less critical in decreasing pressure drop than the inlet sections 2 and 2' of the apparatus 1 and 1', respectively. In fact, the illustrated outlet section 3 is of the same design in both apparatus 1 and 1'. Alternatively, the outlet section 3 could have the same design as either of the inlet sections 2 and 2'.

[0046] The illustrated outlet section 3 is preferably provided with a first outlet portion 74 and a second outlet portion 76. The first outlet portion 74 is formed by a set of four sidewalls 78, 80, 82 and 84 connected together to provide a rectangular, transverse cross-section flow area. Although the first outlet portion 74 could terminate in an outlet opening, preferably, to reduce pressure drop, the second outlet portion 76 has a second transitional transverse cross-section flow area formed by a set of four sidewalls 86, 88, 90 and 92 that transitions from a circle, at one end, to define an outlet 94 from which the outlet stream "C" is discharged and at the other end, a rectangle. Sidewalls 86, 88, 90 and 92 are connected to and in registry with the four sidewalls 78, 80, 82 and 84 forming the first outlet portions 74.

[0047] Preferably, for purposes of structural integrity, sets of partitions 96 and 98 are provided that are connected to sidewalls 80, 84 and sidewalls 78, 82, respectively. Additionally, rectangular frame-like members 100 can be connected to the sidewalls 78, 80, 82 and 84 to provide additional strength.

[0048] With additional reference to Figure 8, heat exchanger 4 is of common design with respect to apparatus 1 and apparatus 1' and functions to remove the heat of compression from the incoming gas stream "A" by providing indirect heat exchange between a cooling fluid and the gas stream. The cooling fluid, which can be water, enters through an inlet 102 and is discharged from an outlet 104. As illustrated in Figure 1, heat exchanger 4 connects the inlet section 2 to the outlet section 3 with respect to apparatus 1. Similarly, heat exchanger 4 also connects inlet section 2' to outlet section 3 in apparatus 1'. Heat exchanger 4 is provided with an inlet side 106 connected to inlet sections 2 and 2' and an outlet side 108 connected to outlet section 3. As mentioned above, the connections need not be direct and rectangular spacer-like elements could be provided within such sections. The gas to be cooled enters the heat exchanger 4 from the inlet sections 2 and 2'at the inlet side 106 and the cooled gas is discharge from the heat exchanger 4 from the outlet side 108 to the outlet section 3.

[0049] As can best be seen in Figure 9, the indirect heat exchange within heat exchanger 4 is accomplished by means gas passages 110 that are formed between a series of parallel, fin-like plate elements 112. The fin-like plate elements 112 are penetrated by a set of outlet coolant tubes 122 which provide the coolant passages for the coolant. Although not illustrated, the fin-like plate elements 112 are also penetrated by other sets of coolant tubes designated by reference numbers 116, 118 and 120 and to be discussed hereinafter. In this regard, inlet side 106 is an open rectangular area that is framed to receive the gas flow “A” and pass into the gas passages 110. Similarly, the outlet side 108 is an open rectangular area that is framed to discharge the gas flow “A”, after having been cooled, to the outlet section 3. In the illustrated apparatus 1 and 1’, the rectangular areas are equal to those provided by inlet section 2 and 2’ and outlet section 3.

[0050] With additional reference to Figure 10, the coolant tubes comprise a set of inlet coolant tubes 116, first and second sets of intermediate coolant tubes 118 and 120 and a set of outlet coolant tubes 122. The aforementioned coolant tubes are supported at opposite ends by perforated tube sheets 124 and 126 and at intermediate locations by the fin-like plate elements 112. Optional support plates 128 are connected at opposite ends to transversely extending top and bottom panels 134 and 136 to assist in maintaining structural integrity against internal pressures. It is to be noted that the heat exchanger 4 has two end portions 130 and 132 located opposite to one another that are connected the two spaced, transversely extending top and bottom panels 134 and 136 thereby forming the inlet side 106 and the outlet side 108 of the heat exchanger which are rectangular openings to the heat exchanger by virtue of such construction. A base 138 is connected to the bottom panel 136 to elevate the bottom panel 132 above ground level.

[0051] Contained within end portion 130 is an inlet plenum 140 and an outlet plenum 142 that are located side-by-side, are situated within end portion 130. Inlet plenum 140 and outlet plenum 142 are in flow communication with the inlet coolant tubes 116 and the outlet coolant tubes 122, respectively. The coolant is introduced into the inlet coolant tubes 116 from the inlet 102 in direction of the arrowhead "D" and is discharged from the outlet coolant tubes through the outlet plenum 142 and to the outlet 104 in direction of arrowhead "E". A reversal plenum 144 is located between the inlet plenum 140 and the outlet plenum 142 and two reversal plenums 146 and 148 are formed within the other end portion 132 by provision of a dividing plate 150. The coolant enters the inlet tubes 116 from the inlet plenum 140. After traversal of the heat exchanger, the coolant reverses flow direction within reversal plenum 146 in the direction of arrowhead "G" and then flows through the first set of intermediate coolant tubes 118 until the coolant reaches the reversal plenum 144. Within reversal plenum 144, the coolant again reverses direction and flows through the second set of intermediate coolant tubes 120 until reaching reversal plenum 148. At reversal plenum 148, the coolant again reverses direction in the direction of arrowhead "H" and flows through the outlet coolant tubes

122 to the outlet plenum 142 from which the coolant is discharged from heat exchanger 4 from the outlet 104.

[0052] In case of such gases as air, the incoming air will contain water vapor that will be condensed by the coolant. In order to disengage the water, a disengagement chamber 152 is provided adjacent to the outlet side 108 of the heat exchanger 4. The disengaged water, collects in the bottom panel 136 and is discharged from openings 154 and 156 to an elongated, tube-like drain 158 located beneath the bottom panel 136 and adjacent the base 138 for discharge of the collected water.

[0053] While the present invention has been described with reference to preferred embodiments, as will occur to those skilled in the art, numerous changes, additions and omissions can be made without departing from the spirit and scope of the present invention as set forth in the appended claims.

We Claim:

1. A compressed gas cooling apparatus comprising:

an inlet section having an inlet to receive a gas from an upstream compression stage;

an outlet section having an outlet to discharge the gas, after having been cooled to a downstream compression stage;

a heat exchanger connecting the inlet section to the outlet section and having gas passages communicating between the inlet section and the outlet section for passage of the gas and coolant passages positioned in a heat transfer relationship with the gas passages for passage of a coolant to cool the gas passing through the gas passages through indirect heat exchange with a coolant;

the inlet section comprising a first inlet portion and a second inlet portion, the first inlet portion located between the inlet and the second inlet portion and the second inlet portion located between the first inlet portion and the heat exchanger; and

each of the first inlet portion and the second inlet portion having an ever increasing transverse cross-sectional flow area, the ever increasing transverse cross-sectional flow area of the second inlet portion increasing at a greater rate than the first inlet portion so that the velocity of the flow of the gas gradually decreases as the gas flows through the inlet section to a lesser extent in the first inlet portion than the second inlet portion and separation of the flow of the gas from sidewalls of each of the first inlet portion and the second inlet portion, due to swirl imparted into the flow of the gas from the upstream compression stage, is inhibited to reduce pressure drop; and

the outlet section comprising one outlet portion of ever-decreasing transverse cross-sectional flow area for flow of the gas from the heat exchanger to the outlet such that velocity of the flow of the gas gradually increases to also reduce pressure drop.

2. The apparatus of claim 1, wherein:

the first inlet portion, the second inlet portion and the one outlet portion are formed by sets of four sidewalls connected to one another such that the ever-increasing transverse cross-sectional flow area and the ever-decreasing transverse cross-sectional flow area are of rectangular configuration;

the heat exchanger has an inlet side, an outlet side located opposite to the inlet side, the cooling passages extend between the inlet side and the outlet side and each of the inlet side and the outlet side is of rectangular configuration;

the inlet section has a third inlet portion having a first transitional transverse cross-sectional flow area transitioning from a circle, at one end, to define the inlet and at the other end, a rectangle, the other end of the third portion in registry with and connected to one of the sets of four sidewalls forming the first inlet portion;

the one outlet portion is a first outlet portion;

the outlet section has a second outlet portion situated such that the first outlet portion is located between the second outlet portion and the heat exchanger, the second outlet portion having a second transitional transverse cross-section flow area transitioning from a circle, at one end, to define the outlet and at the other end, a rectangle; and

the other end of the second outlet portion is in registry with and connected to a further of the sets of four sidewalls forming the first outlet portion.

3. The apparatus of claim 2, wherein

another of the sets of four sidewalls forming the second inlet portion, at opposite ends, is in registry with and connected to the one of the sets of four sidewalls and the inlet side of the heat exchanger; and

the further of the sets of four sidewalls forming the first outlet portion , at opposite ends, is in registry with and connected to the other end of the second outlet portion and the outlet side of the heat exchanger.

4. The apparatus of claim 2, wherein:

the first inlet portion is subdivided into a first set of subpassages by a first set of partition elements oriented such that each of the subpassages is of rectangular configuration;

the second inlet portion is subdivided into a second set of subpassages by a second set of partition elements oriented such that each of the subpassages is of rectangular configuration;

the second set of subpassages having more subpassages than the first set of subpassages.

5. The apparatus of claim 4, wherein:

the first outlet portion is subdivided into a third set of subpassages by a third set of partition elements;

the first set of partition elements, the second set of partition elements and the third set of partition elements are connected to the sidewalls; and

rectangular, frame-like stiffening members are connected to outer surfaces of each of the sets of the four sidewalls.

6. The apparatus of claim 4, wherein the first set of subpassages has four subpassages and the second set of subpassages has twenty-four subpassages.

7. A compressed gas cooling apparatus comprising:

an inlet section having an inlet to receive a gas from an upstream compression stage;

an outlet section having an outlet to discharge the gas, after having been cooled to a downstream compression stage;

a heat exchanger connecting the inlet section to the outlet section and having gas passages communicating between the inlet section and the outlet section for passage of the gas and coolant passages positioned in a heat transfer relationship with the gas passages for passage of a coolant to cool the gas passing through the gas passages through indirect heat exchange with a coolant;

the inlet section comprising one portion having at least one sidewall forming an ever-increasing transverse cross-sectional flow area and partition elements subdividing the ever-increasing transverse cross-sectional flow area into a plurality of subpassages, each having ever-increasing transverse cross-sectional sub-flow areas so that velocity of the flow of the gas gradually decreases as the gas flows through the inlet section and the sub-flow areas reduce separation of the flow of the gas from at least one sidewall, due to swirl imparted into the flow of the gas from the upstream compression stage, thereby reducing pressure drop; and

the outlet section comprising an outlet portion of ever-decreasing transverse cross-sectional flow area for flow of the gas from the heat exchanger to the outlet so that the velocity of the flow of the gas gradually increases as the gas flows in the outlet section to also reduce pressure drop.

8. The apparatus of claim 7, wherein:

the inlet portion and the outlet portion are formed by sets of four sidewalls connected to one another such that the ever-increasing transverse cross-sectional flow area and the ever-decreasing transverse cross-sectional flow area are of rectangular configuration;

the subpassages are each of rectangular configuration;

the heat exchanger has an inlet side, an outlet side located opposite to the inlet side, the cooling passages extend between the inlet side and the outlet side and each of the inlet side and the outlet side is of rectangular configuration;

the at least one sidewall of the inlet portion is one of the sets of four sidewalls;

a further of the sets of four sidewalls form the outlet portion;

the inlet portion is a first inlet portion, the outlet portion is a first outlet portion, the inlet section has a second inlet portion and the outlet section has a second outlet portion;

the second inlet portion has a first transitional transverse cross-sectional flow area transitioning from a circle, at one end, to define the inlet and at the other end, a rectangle, the other end of the first inlet portion in registry with the one of the sets of four sidewalls forming the first inlet portion;

the second outlet portion has a second transitional transverse cross-section flow area transitioning from a circle, at one end, to define the outlet and at the other end, a rectangle; and

the other end of the second outlet portion is in registry with the further of the sets of four sidewalls.

9. The apparatus of claim 8, wherein:

the one of the sets of four sidewalls forming the first inlet portion is connected to and in registry with the inlet side of the heat exchanger at a location of the inlet section opposite to the second inlet portion; and

the further of the sets of four sidewalls forming the first outlet portion is connected to and in registry with the outlet side of the heat exchanger at a location of the outlet section opposite to the second outlet portion.

10. The apparatus of claim 8 wherein:

the partition elements of the first inlet portion are a first set of partition elements and the subpassages are a first set of subpassages;

the first outlet portion has a second set of partition elements that form a third set of subpassages of rectangular configuration;

the first set of partition elements and the second set of partition element are connected to the sidewalls; and rectangular, frame-like stiffening members are connected to outer surfaces of each of the sets of the four sidewalls.

11. The apparatus of claim 2 or claim 4 or claim 5 or claim 8 or claim 10, wherein:

the heat exchanger is of cross-counter flow arrangement;

the cooling passages are formed between a plurality of parallel fins oriented at right angles with respect to the inlet side and the outlet side of the heat exchanger; and

the cooling passages are formed by coolant tubes that penetrate the parallel fins for circulation of the coolant and are in an orthogonal orientation with respect to the parallel fins.

12. The apparatus of claim 11, wherein:

the coolant tubes comprise a set of inlet coolant tubes a first set of intermediate coolant tubes, a second set of intermediate coolant tubes and a set of outlet coolant tubes arranged to provide four passes within the heat exchanger;

the heat exchanger has two end portions located opposite to one another and two spaced, transversely extending top and bottom panels connecting the end portions and forming the inlet side and the outlet side of the heat exchanger;

an inlet plenum and an outlet plenum are located side-by-side, are situated at one of the two end portions and are in flow communication with the inlet coolant tubes and the outlet coolant tubes, respectively, to introduce to the coolant into the inlet coolant tubes and to discharge the coolant from the outlet coolant tubes; and

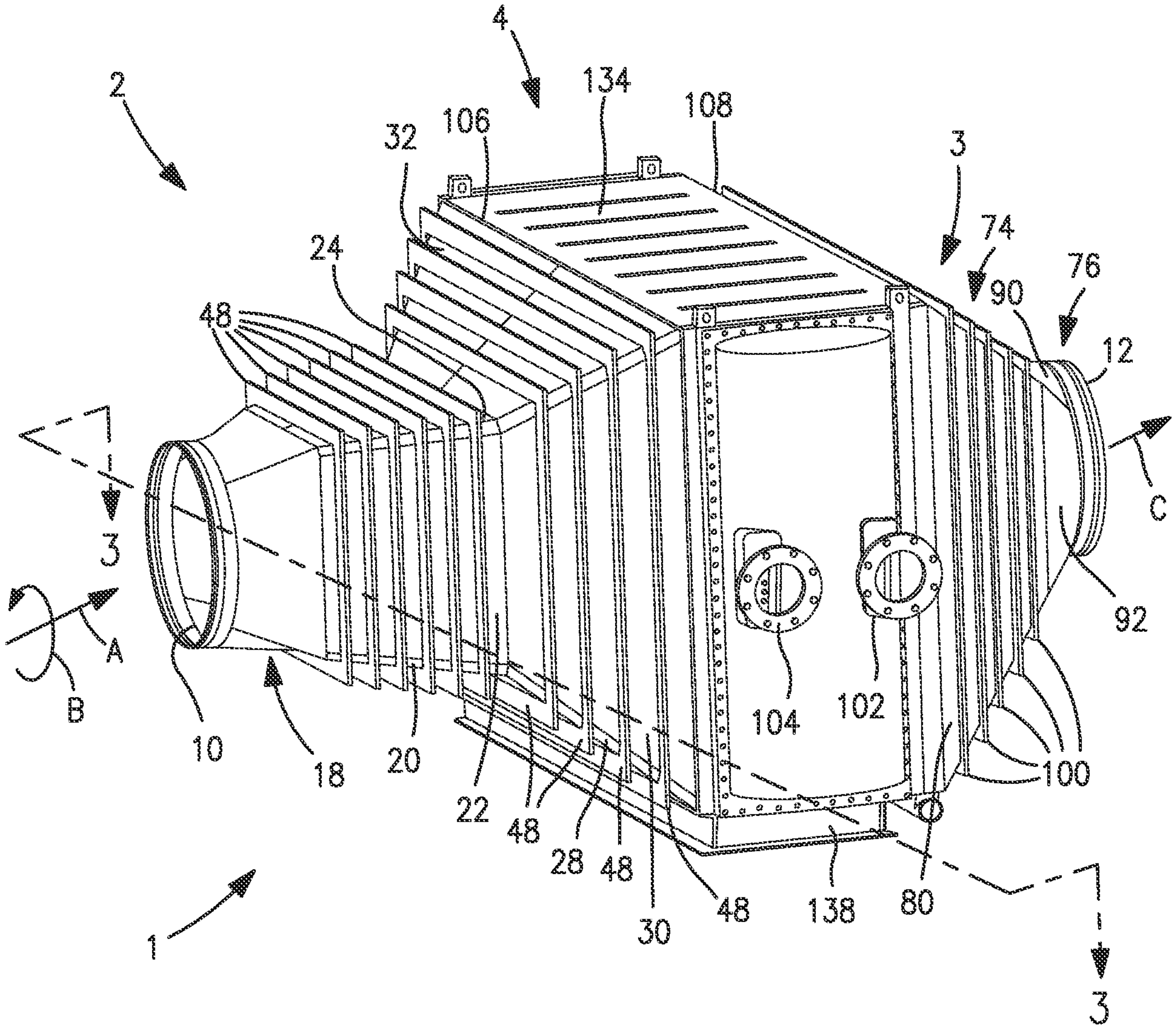
reversal plenums are located at the end portions of the heat exchanger and are configured such that coolant from the inlet tubes flows into the first set of intermediate coolant tubes at the other of the end portions, after having traversed the heat exchanger, coolant from the first set of intermediate coolant tubes flows into the second set of intermediate coolant tubes at the one of the end portions, after having traversed the heat exchanger, coolant from the second set of intermediate coolant tubes flows into the set of outlet coolant tubes, after having traversed the heat exchanger and thereafter, flows from the set of outlet coolant tubes into the outlet plenum.

13. The apparatus of claim 11, wherein the heat exchanger has a condensate disengagement chamber located between the outlet side and the coolant tubes and the parallel fins to allow condensed water to separate from the compressed gas passing through the heat exchanger and an elongated, tube-like drain located at the bottom of the condensate disengagement chamber to collect the condensed water separated from the gas and to discharge the condensed water from the heat exchanger.

14. The apparatus of claim 12, wherein the heat exchanger has a condensate disengagement chamber located between the outlet side and the coolant tubes and the parallel fins to allow condensed water to separate from the compressed gas passing through the heat exchanger and an elongated, tube-like drain located at the bottom of the condensate disengagement chamber to collect the condensed water

separated from the gas and to discharge the condensed water from the heat exchanger.

15. The apparatus of claim 13, wherein the coolant tubes are connected to and supported at their ends by two opposed tube sheets.



2
4
134
108
106
32
3
74
76
24
90
12
48
3
C
92
A
B
104
102
10
18
20
22
48
28
48
30
48
138
80
100
1
3

FIG. 1

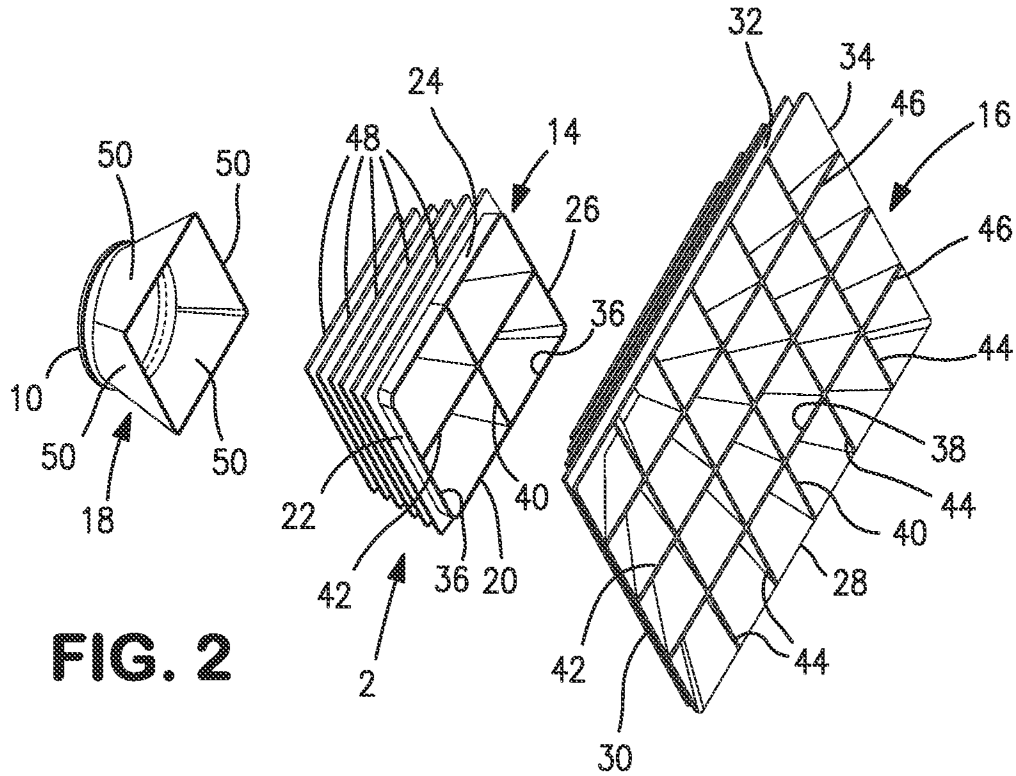

50
50
10
50
50
18
48
24
14
22
42
36
20
40
26
36
2
32
34
46
16
46
44
38
44
40
28
42
44
30

FIG. 2

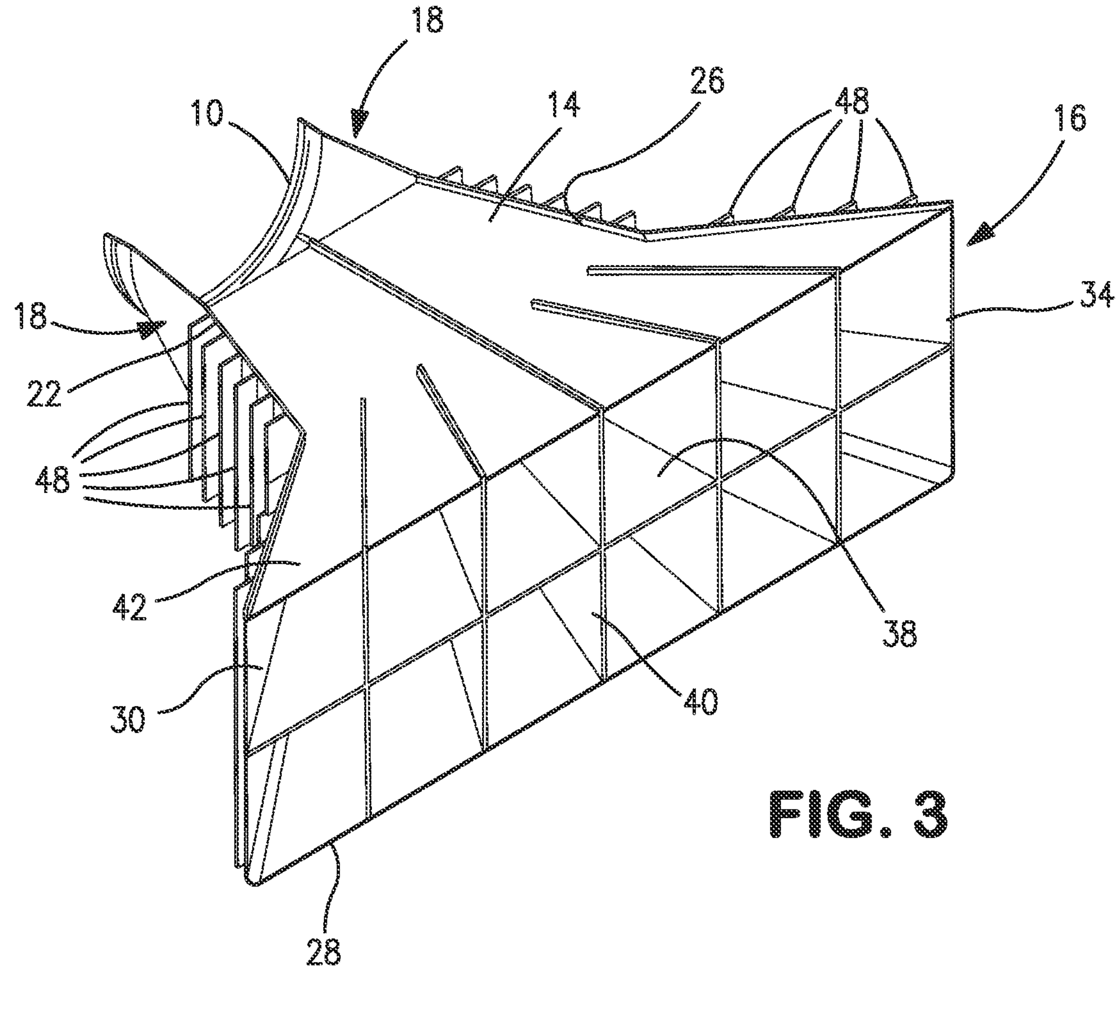

18
10
14
26
48
16
34
18
22
48
42
38
30
40
28

FIG. 3

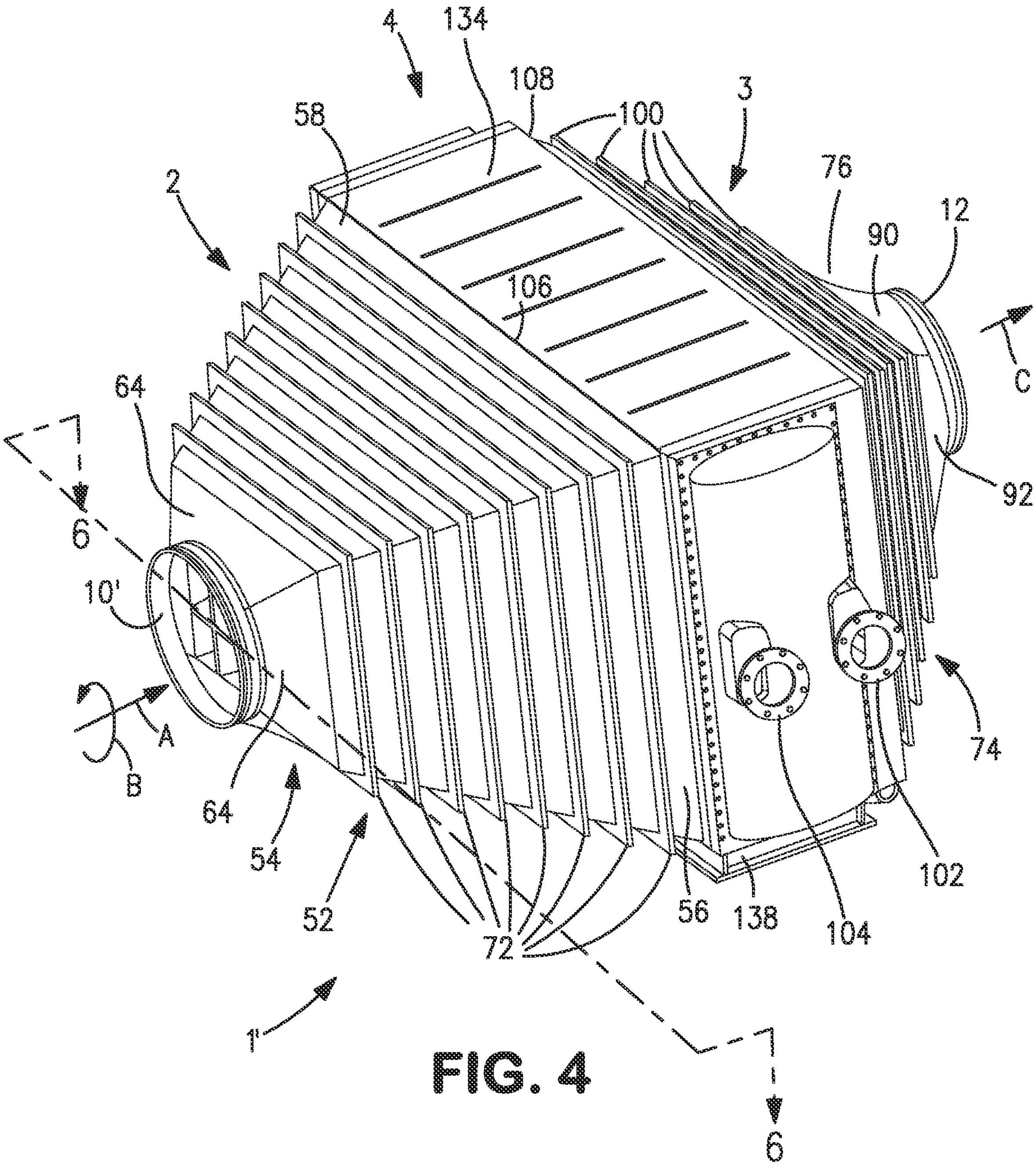

4
134
108
58
100
3
2
76
90
12
106
C
64
92
6
10'
74
A
B
64
54
102
52
56
138
104
72
1'
6

FIG. 4

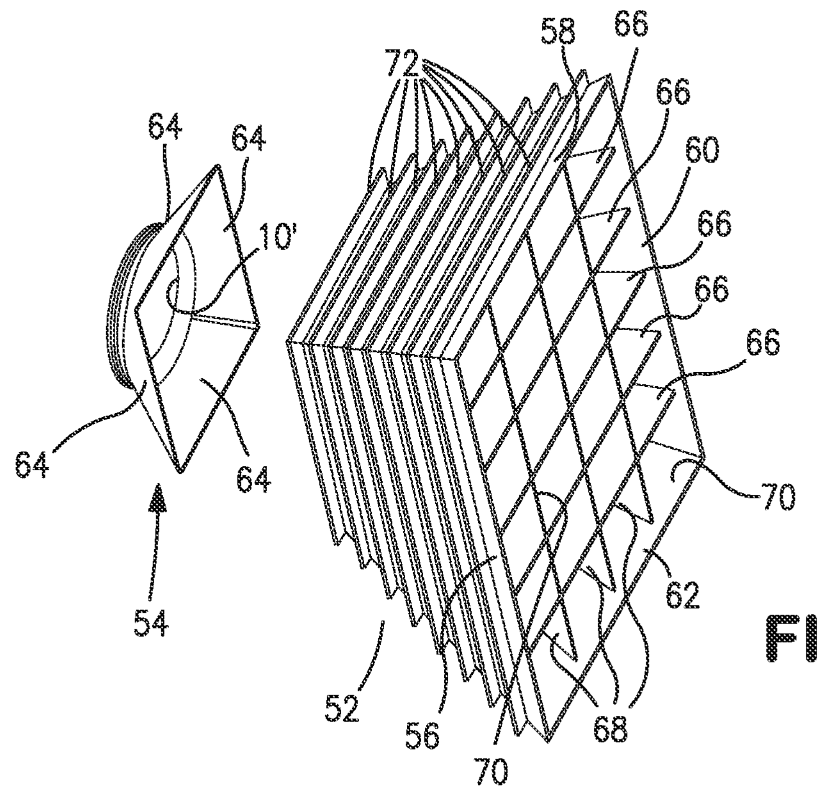

72
58
66
66
64
64
10'
60
66
66
66
64
64
70
54
62
52
56
70
68

FIG. 5

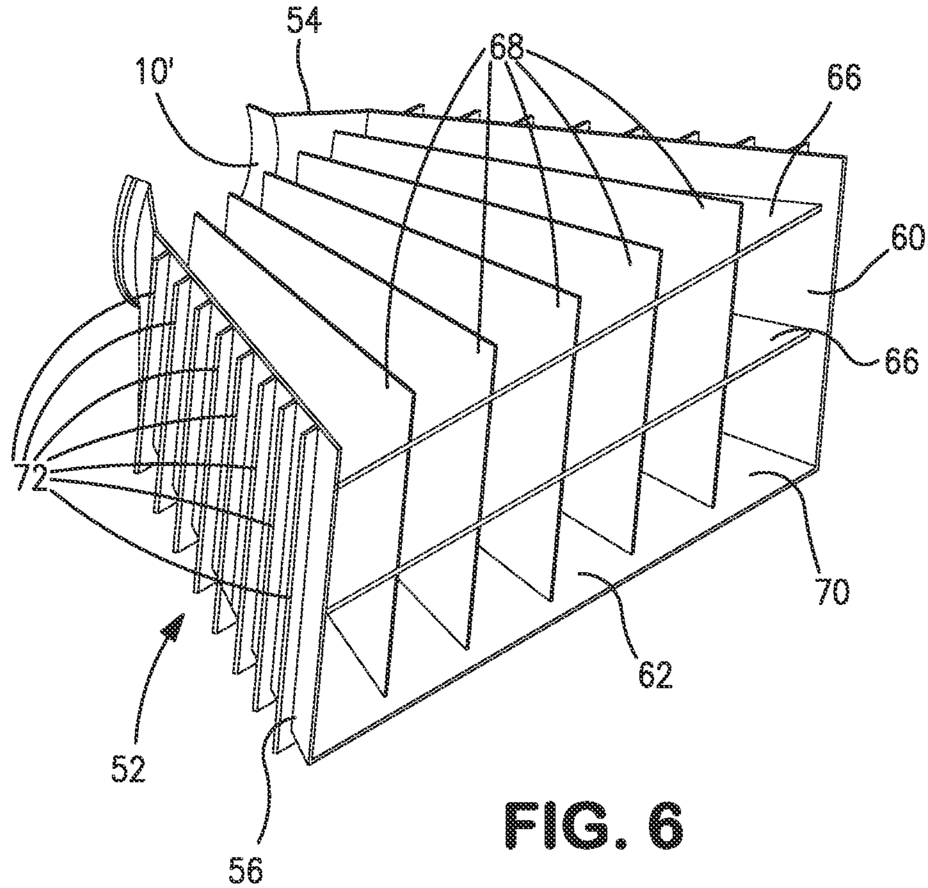

54
10'
68
66
60
66
72
70
62
52
56

FIG. 6

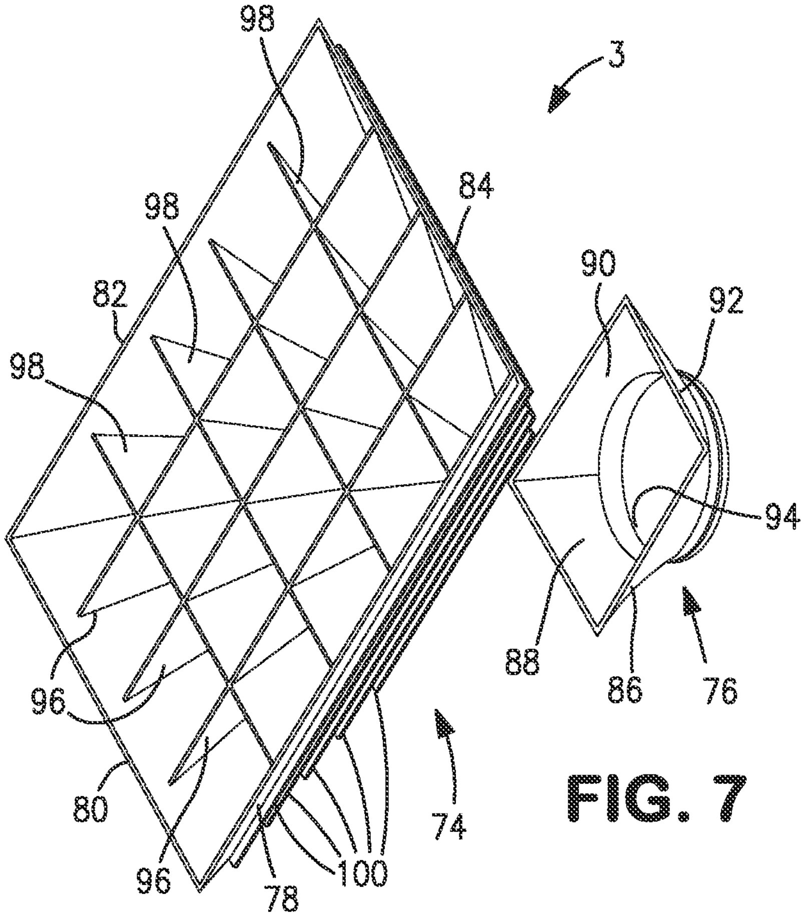

3
98
98
84
90
92
82
98
94
88
86
76
96
80
74
96
78
100

FIG. 7

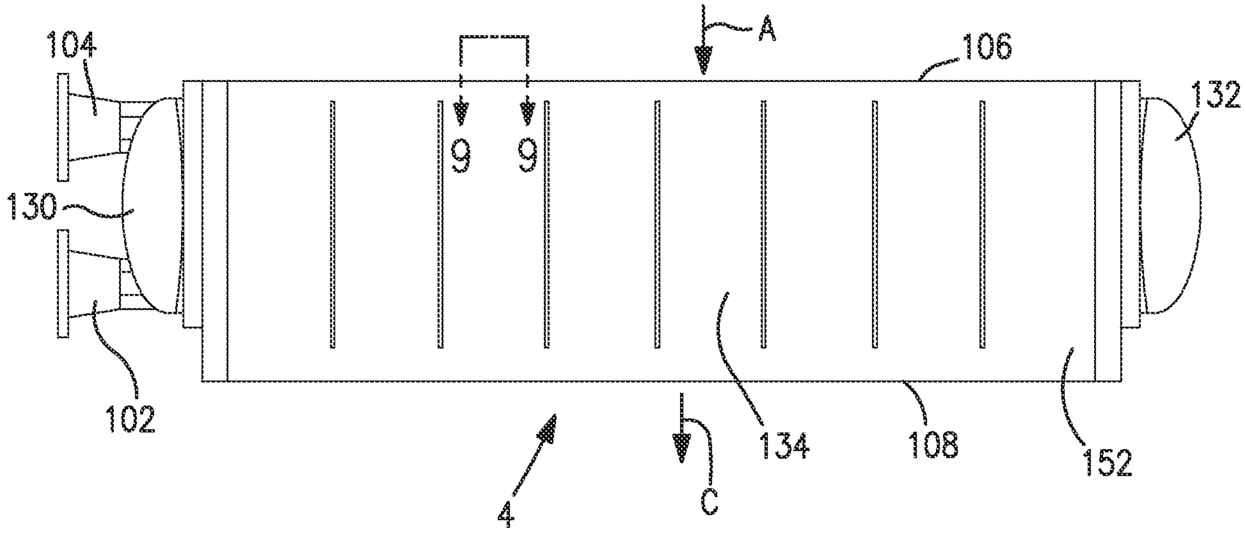

A
104
106
132
9
9
130
102
134
108
152
4
C

FIG. 8

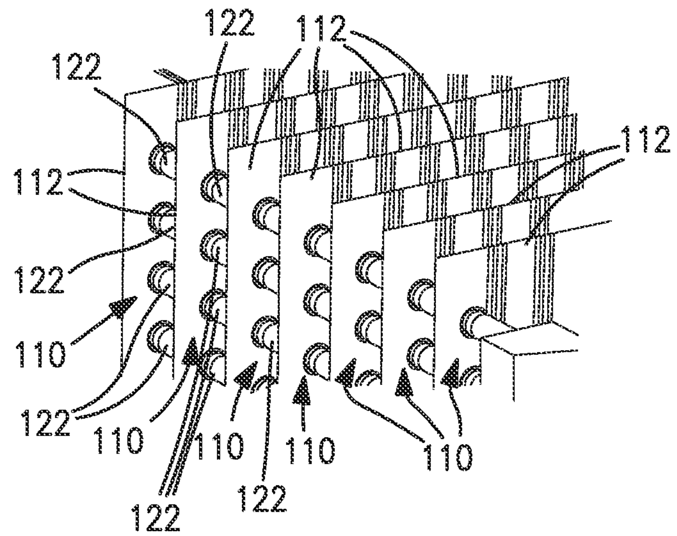

122
122
112
112
112
112
122
110
122
110
110
110
110
122
122

FIG. 9

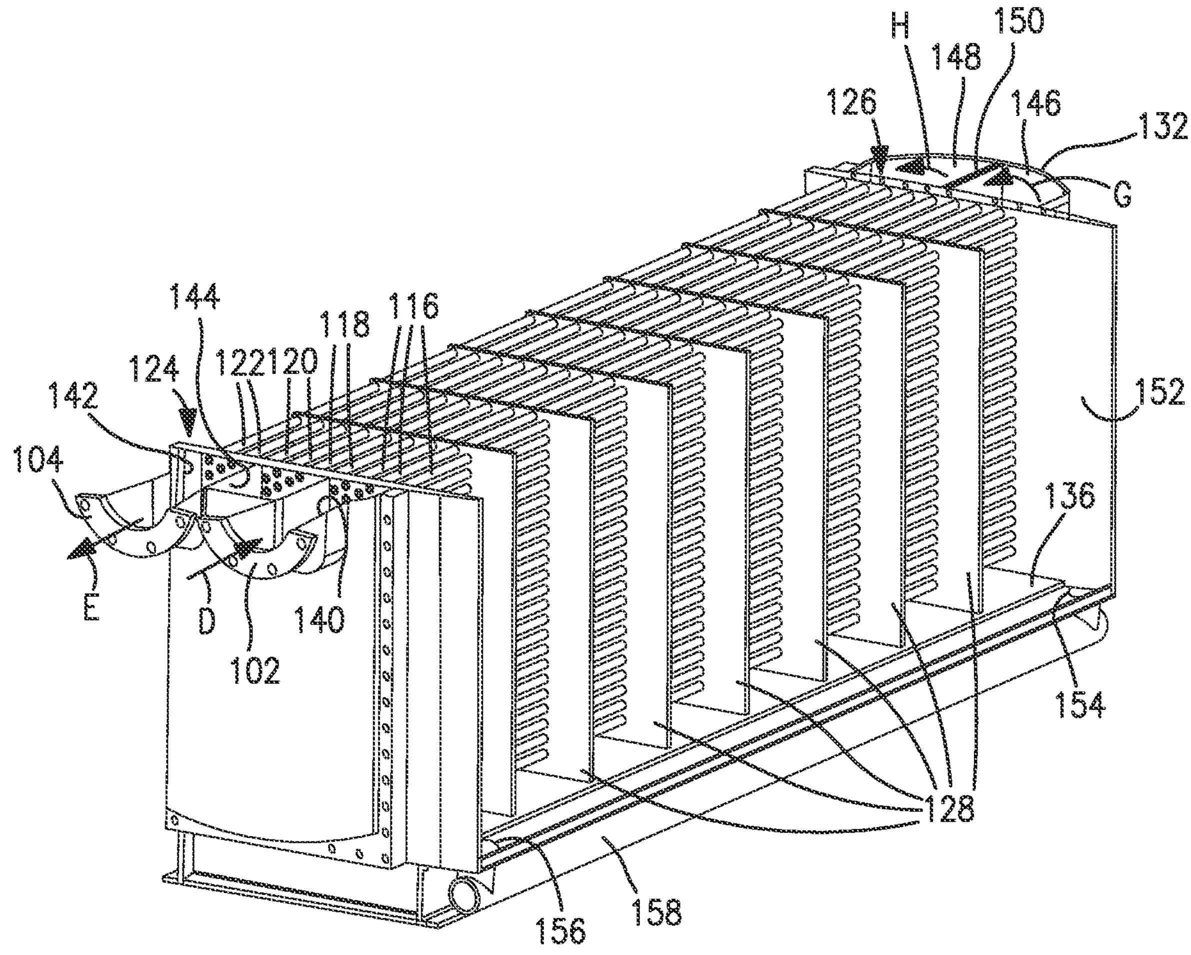

H
150
148
126
146
132
G
144
116
118
124
122
120
142
152
104
136
E
D
140
102
154
128
156
158

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/037741

A. CLASSIFICATION OF SUBJECT MATTER
INV. F28D7/16 F28F9/02 F28F17/00 F04D29/58
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F28D F28F F04D F02B F01P F02C F25J B01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 090 631 A (INGERSOLL RAND CO) 14 July 1982 (1982-07-14) page 1, line 91 - page 2, line 94; figures 1,2A,2B	1
X	EP 0 864 839 A2 (BEHR GMBH & CO [DE]) 16 September 1998 (1998-09-16)	1
Y	column 4, line 9 - column 7, line 47;	7
A	figures 1-6	2,3
Y	US 4 452 216 A (PATCHEN II PAUL [US] ET AL) 5 June 1984 (1984-06-05)	7
A	the whole document	11,12
A	US 2003/111209 A1 (TSUJITA MAKOTO [JP] ET AL) 19 June 2003 (2003-06-19) paragraphs [0002], [0061] - [0070]; figures 13-17	1,7

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 October 2013	06/11/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Leclaire, Thomas

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/037741

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☒ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-15

   gas cooling apparatus with diffuser inlet and decreasing outlet section

1.1. claims: 1-6(completely); 11-15(partially)

   two inlet sections with different increasing rate

1.2. claims: 7-10(completely); 11-15(partially)

   inlet section with subdividing partition elements

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2010/329895 A1 (BAKER ROBERT LEROY [US] ET AL) 30 December 2010 (2010-12-30) cited in the application the whole document -----	1-15
A	US 5 110 560 A (PRESZ JR WALTER M [US] ET AL) 5 May 1992 (1992-05-05) columns 1-3; figures 1-8,21,26-28 -----	1-4,7-10
A	US 4 778 003 A (HELBERG GUNNAR I [US]) 18 October 1988 (1988-10-18) column 1, line 1 - column 3, line 38; figure 1 -----	1
A	US 3 392 211 A (KARL BUSCHMANN ET AL) 9 July 1968 (1968-07-09) the whole document -----	1
A	GB 1 190 958 A (LUMMUS CO [US]) 6 May 1970 (1970-05-06) the whole document -----	1

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2013/037741

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB 2090631 A	14-07-1982	CA 1167771 A1	22-05-1984
		CH 655364 A5	15-04-1986
		DE 3131720 A1	05-08-1982
		GB 2090631 A	14-07-1982
		JP S57114000 A	15-07-1982
EP 0864839 A2	16-09-1998	EP 0864839 A2	16-09-1998
		JP 3996258 B2	24-10-2007
		JP H10292996 A	04-11-1998
US 4452216 A	05-06-1984	NONE	
US 2003111209 A1	19-06-2003	US 2003111209 A1	19-06-2003
		US 2003111210 A1	19-06-2003
US 2010329895 A1	30-12-2010	CN 101929470 A	29-12-2010
		EP 2446148 A1	02-05-2012
		US 2010329895 A1	30-12-2010
		US 2013129531 A1	23-05-2013
		WO 2011005410 A1	13-01-2011
US 5110560 A	05-05-1992	CA 2021502 A1	26-01-1991
		DE 69015722 D1	16-02-1995
		DE 69015722 T2	11-05-1995
		EP 0410924 A2	30-01-1991
		JP H0364614 A	20-03-1991
		NO 903163 A	28-01-1991
		US 5110560 A	05-05-1992
US 4778003 A	18-10-1988	NONE	
US 3392211 A	09-07-1968	BE 660726 A	06-09-1965
		DE 1217944 B	02-06-1966
		FR 1432867 A	25-03-1966
		GB 1032690 A	15-06-1966
		NL 128466 C	22-10-2013
		NL 6502860 A	08-09-1965
		US 3392211 A	09-07-1968
GB 1190958 A	06-05-1970	DE 1551479 A1	23-04-1970
		ES 342178 A1	16-07-1968
		GB 1190958 A	06-05-1970
		NL 6708792 A	27-12-1967