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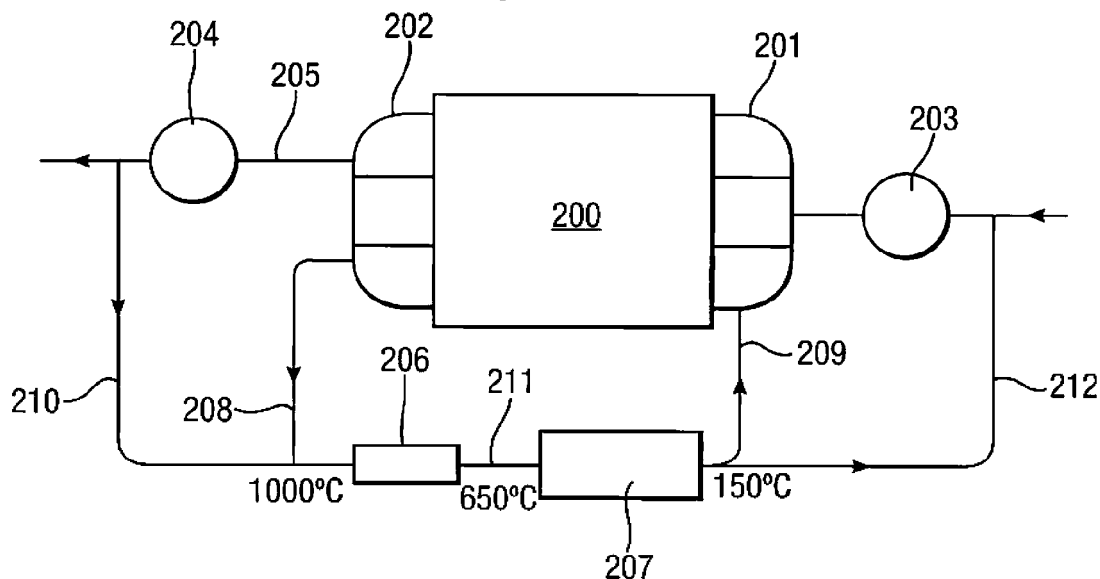
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(54) **High gas inlet temperature EGR system**

(57) An exhaust gas re-circulation system for an internal combustion engine, said system comprising a first cooling device configured for receiving exhaust gas from said internal combustion engine; and a second cooling

device connected in series with said first cooling device for receiving cooled exhaust gas from an outlet of said first cooler device, an outlet of said second cooler device being connected to an inlet of said internal combustion engine.

Fig.8.



Description

Field of the Invention

[0001] The present invention relates to gas heat exchangers, and particularly although not exclusively to exhaust gas re-circulation coolers for use in automotive applications.

Background to the Invention

[0002] There are many applications in which it is desirable to use gas heat exchangers. These include applications where it is desirable to cool down a gas, for example in exhaust gas re-circulation (EGR) coolers.

[0003] Exhaust gas re-circulation cooling is used extensively on diesel engines to aid the reduction of nitrus oxide emissions. To aid overall emissions reduction, the EGR cooling on diesel engines may also be bypassed so that the re-circulated exhaust gas is not subject to additional cooling.

[0004] Under some circumstances heat exchange from the gas may be required, but under other circumstances it may be undesirable. For example in cold engine conditions, it is desirable not to additionally cool the gas so that the engine can heat up more quickly. Under hot engine conditions, it may be desirable to cool the gas.

[0005] Exhaust gas re-circulation and the cooling of re-circulating exhaust gases can also be applied in gasoline (petrol) engines. This is of particular use when downsizing a gasoline engine and utilising turbo charging. Cooled exhaust gas re-circulation can help to significantly improve emissions whilst also reducing fuel consumption. A technical challenge of gasoline exhaust gas re-circulation cooling is that the exhaust gas at the inlet to the exhaust gas re-circulation system is much hotter than in the comparable situation with diesel engines. For example, the temperature of re-circulated exhaust gas in a gasoline engine can be up to 1100 °C, but more typically up to around 1000 °C, compared to the equivalent situation in a diesel engine, where the gas temperature at the inlet to the EGR system is typically of the order of up to 650 °C.

[0006] A common failure mode of diesel exhaust gas re-circulation coolers is that thermal loading causes high stress at the gas inlet interface.

[0007] Referring to figure 1 herein, there is illustrated schematically in cut away view the inlet of a known exhaust gas re-circulation cooling device. The device comprises an outer casing 1 having a bulkhead 2 which extends across a width of the outer casing, the bulkhead contains a plurality of gas conduits 3.

[0008] When gas flows the gas conduits expand due to their increased temperature from the gas, the outer casing 1 also expands but at a slower rate and as is at the coolant temperature has a thermal expansion which is less than the thermal expansion of the gas conduits, resulting in high stresses in the bulkhead and the gas

conduits, for example as shown at position A in figure 1. The result can include failure of the bulkheads, failure of the joints between the conduit tubes and the bulkhead, failure of tube to tube joints, and collapse of gas tubes.

[0009] A typical failure of a tube to bulkhead joint may comprise a crack through the tubular conduit wall, at the position of the weld/braze between the tubular conduit wall and the bulkhead, resulting in mixture of coolant with the exhaust gas re-circulation path.

[0010] For diesel engines, other common problems with exhaust gas re-circulation systems include:

- Where the cooled gas inlet temperature is too high, this causes damage to components on the normally cool induction side of the engine.
- Exhaust gas re-circulation valves tend to stick due to being at the cold side, which causes "excessive wet" soot fouling on the valve.
- The exhaust gas re-circulation valve control system gets too hot.

Summary of the Invention

[0011] Specific embodiments herein aim to provide an exhaust gas re-circulation system which is capable of being robust against the thermal loadings caused by high inlet gas temperatures, whilst giving improved heat exchange.

[0012] According to a first aspect there is provided an exhaust gas cooling device comprising:

an inner tubular member having an inlet end and an outlet end, said inner tubular member forming a gas passage; and

an outer tubular member, surrounding an outer portion of said inner tubular member and forming a cavity there between for containing a liquid coolant,

wherein said inner tubular member comprises a plurality of corrugations for absorbing thermal expansion and/or contraction of said inner member; and

wherein said outer tubular member comprises a plurality of corrugations for absorbing thermal expansion and/or contraction of said outer member.

[0013] According to a second aspect there is provided an exhaust gas cooler comprising:

a tubular outer canister forming an inlet cavity, an outlet cavity, and a cooling cavity position between said inlet and said outlet cavities;

a plurality of tubular gas conduits, contained within said cooling cavity;

a first bulk head positioned between said inlet cavity

and said cooling cavity;

a second bulk head position between said cooling cavity and said outlet cavity; and

a plurality of tubular gas conduits in said cooling cavity between said first and second bulk heads for transferring exhaust gases through said cooling cavity,

wherein said plurality of gas conduits each comprise a corrugated wall for accommodating thermal expansion and contraction between said first and second bulk heads.

[0014] According to a third aspect there is provided an exhaust gas re-circulation system for an internal combustion engine, said system comprising:

a first cooling device configured for receiving exhaust gas from said internal combustion engine; and

a second cooling device connected in series with said first cooling device and arranged for receiving cooled exhaust gas from an outlet of said first cooler device, an outlet of said second cooling device being connected to an inlet of said internal combustion engine.

[0015] Other aspect are as recited in the claims herein.

Brief Description of the Drawings

[0016] For a better understanding of the invention and to show how the same may be carried into effect, there will now be described by way of example only, specific embodiments, methods and processes according to the present invention with reference to the accompanying drawings in which:

Figure 1 illustrates schematically a known exhaust gas cooler device having a plurality of gas conduits arranged between a pair of bulkheads within an external casing;

Figure 2 illustrates schematically a first exhaust gas re-circulation cooler device according to a first specific implementation;

Figure 3 illustrates schematically a second exhaust gas re-circulation cooler according to a second specific implementation;

Figure 4 illustrates schematically a third exhaust gas re-circulation cooler according to a third specific implementation;

Figure 5 illustrates schematically a fourth exhaust

gas re-circulation cooler according to a fourth specific implementation;

Figure 6 illustrates schematically a fifth exhaust gas re-circulation cooler, according to a fifth specific embodiment;

Figure 7 illustrates schematically a sixth exhaust gas re-circulation cooler according to a sixth specific embodiment.

Figure 8 illustrates schematically a first exhaust gas re-circulation system according to a seventh specific embodiment;

Figure 9a illustrates schematically a second exhaust gas re-circulation system according to an eighth specific embodiment;

Figure 9b illustrates schematically the second exhaust gas re-circulation system in a second mode of operation;

Figure 10 illustrates schematically a third exhaust gas re-circulation system according to a ninth specific embodiment;

Figure 11 illustrates schematically a fourth exhaust gas re-circulation system according to a tenth specific embodiment;

Figure 12 illustrates schematically a fifth exhaust gas re-circulation system according to an eleventh specific embodiment;

Figure 13 illustrates schematically a pre-cooler device of an exhaust gas re-circulation system according to a twelfth specific embodiment;

Figure 14 illustrates schematically an inner tubular member of the pre-cooler device of figure 13.

Figure 15 illustrates schematically a cross sectional view of a portion of the pre-cooler device figure 13;

Figure 16 illustrates schematically a section of side wall of the tubular inner member of figure 14; and

Figure 17 illustrates schematically an impartial cut away view a first (gas inlet) end of the pre-cooler component of figures 13 to 16 herein.

Detailed Description

[0017] There will now be described by way of example a specific mode contemplated by the inventors. In the following description numerous specific details are set forth in order to provide a thorough understanding. It will

be apparent however, to one skilled in the art, that the present invention may be practiced without limitation to these specific details. In other instances, well known methods and structures have not been described in detail so as not to unnecessarily obscure the description.

[0018] Referring to figure 2 herein, there is illustrated schematically a first exhaust gas re-circulation cooler device according to a first specific embodiment. The first EGR cooler represents an improvement on the known EGR coolers by accepting a higher inlet gas temperature, of up to around 700 °C, and by being capable of being subjected to a higher temperature gradient between the gas inlet and gas outlet, over a temperature range of 700 °C to 150 °C or less.

[0019] The first EGR cooler comprises an external canister housing 200, which may be tubular in shape; the canister having an inlet end 201 having a frusto-conical chamber 202, and an outlet end 203 having a second frusto conical chamber 204; a plurality of conduit tubes 205 positioned length wise within the cooler, through which gas passes from the inlet chamber 202 to the outlet chamber 204, the plurality of gas conduit tubes 205 being secured between first and second bulk heads 206, 207 respectively, which are positioned across a width dimension of the EGR cooler, in a direction transverse to its main length; and, the outer canister being provided with a coolant inlet pipe 208 and a coolant outlet pipe 209 for passage of coolant through the canister between the bulkheads, and around the plurality of gas conduit tubes 205.

[0020] Each of the conduit tubes 205 comprises an annually corrugated or helically corrugated metal wall. The corrugations of the gas conduit tubes serve to allow the conduit tubes to expand and contract in an axial direction, absorbing the thermal stresses of expansion and contraction, within the bellows-like shape of the tube, and thereby reducing the stresses and strains due to thermal expansion on the bulkheads 206, 207 respectively. The annular or helical corrugations allow the gas a greater surface area in contact with the metal wall, and therefore increase the efficiency of cooling, since on the other side of the conduit wall, there is provided liquid coolant, to which waste heat is transferred.

[0021] Respective first and second ends of each of the gas conduit tubes are welded or brazed to the bulkheads 206, 207, which in the best mode, may be circular and disc shaped, and are provided with a plurality of circular apertures, through which the ends of the gas conduit pipe pass.

[0022] Referring to figure 3 herein, there is illustrated schematically a second exhaust gas re-circulation cooler device according to a second specific embodiment. The second EGR cooler is similar to the first EGR cooler, except it has a set of annular or helical corrugations on its outer casing, to absorb thermal stresses and strains in an axial and/or skew direction on the external canister housing itself.

[0023] The second EGR cooler comprises an external canister housing, which is tubular and in the best mode

substantially cylindrical in shape. The canister having a gas inlet end 301 and a gas outlet end 302, each of the inlet ends and outlet ends having a frusto-conical chamber 303, 304 respectively; a plurality of conduit tubes 305; an inlet bulkhead 306 and an outlet bulkhead 307, the inlet and outlet bulkheads being positioned respectively adjacent the inlet end and outlet end of the EGR cooler and extending across a width of the internal cavity formed within the external canister housing 300. The outer canister housing is provided with a coolant inlet 308 and a coolant outlet 309 for passing coolant into a chamber surrounding the plurality of conduits 305, between the first and second bulkheads 306, 307.

[0024] The outer canister 300 is provided with a plurality of helical or annular corrugations, which allow the outer casing to expand or contract in an axial direction, and also allowing a small degree of movement in a skew motion transverse to the main central longitudinal axis of the EGR cooler device.

[0025] Respective first and second ends of each of the plurality of gas conduits 305 are welded or brazed to the bulkheads, the ends of the gas conduit tubes fitting into circular apertures in the bulkheads, and the material of the ends of the gas conduits being welded or brazed to the bulkheads,

[0026] Referring to figure 4 herein, there is illustrated schematically a first high temperature EGR cooler device for use upstream in a gas channel, with the first or second lower temperature EGR coolers of figures 1, 2 or 7 herein, or a standard EGR cooler.

[0027] The first high temperature EGR cooler 400 comprises an inner tubular member 401, preferably formed of metal, and having a plurality of annular or helically wound corrugations 402, and an outer tubular member 403, in the best mode substantially cylindrical, and having a swaged first end 404, a swaged second end 405, a region of helically wound or annular corrugations 406, an inlet pipe 407 for receiving liquid coolant, and an outlet pipe 408 for draining liquid coolant.

[0028] The inner tubular member 401 is positioned within side of the outer tubular member 403 so that the two members are located and aligned co-axially, the ends of the inner and outer tubular members being fixed together typically either by welding or brazing, and forming a substantially cylindrical cavity 409 there between, through which coolant fluid may pass.

[0029] The ends of the gas conduit, which are substantially cylindrical, and are fitted into a pair of corresponding circular apertures 411, 412 formed in first and second swaged ends 404 and 405 respectively. By using a single gas conduit fitted directly to the swaged ends of the coolant conduit the need for a bulkhead is removed. The bulkhead being the weak spot in traditional heat exchanger designs.

[0030] The inner tubular member 401 is exposed to hot exhaust gases, typically having a maximum temperature in the range up to 1100 °C. Consequently, the wall of the inner tubular member 401, being relatively thin and

of metal, heats up to a high temperature in the absence of any cooling. In figure 4, there is no direct cooling of the ends of the EGR cooler.

[0031] The EGR cooler as shown in figure 4 may be capable of reducing the temperature of gas flowing through the inlet from a maximum temperature of around 1100 °C, to a maximum temperature of around 700 °C at the outlet.

[0032] In the cooler device of figure 4, the ends of the cooler are not directly cooled, since they are welded or brazed together, at their respective ends, and the outer tube is swaged down to an internal diameter which coincides with the external diameter of the inner tube. The inner tubular member and the outer tubular member do not contact each other, except at their respective corresponding ends, where they are connected together.

[0033] The outer tubular member 403 and the inner tubular member 401 have no contact with each other except at the ends of the cooler device. The cooler device may be fitted into an exhaust system, connecting first and second connecting pipes to the ends of the cooler device, so that the cooler devices forms an integral structural part of the EGR system, without the need for any further support from other components, for example without any external mountings to body work or to the engine block.

[0034] Referring to figure 5 herein, there is illustrated schematically a second high temperature exhaust gas cooler according to a fourth specific embodiment. The second exhaust gas re-circulation cooler 500 comprises a metallic inner tubular substantially cylindrical member 501, and a co-axially aligned substantially cylindrical tubular outer member 502, surrounding the inner member, and spaced apart therefrom, providing a sealed cavity between the inner and outer members, which provides a fluid fillable jacket around a central passage 503 through the inner tubular member, for cooling hot exhaust gases which pass through the cooling device.

[0035] The inner tubular member 501 comprises a plurality of annular or helical corrugations 503.

[0036] The primary purpose of the corrugations is for absorbing expansion and contraction stresses in a direction axially of the inner tubular member, thereby enabling the inner tubular member to operate with an elevated temperature gradient along the cooler, between an inlet temperature of 1100°C maximum and an outlet temperature of around 700 °C maximum. Similarly, the outer tubular member 502 is also provided with a plurality of annular or helical corrugations 505 for a similar purpose, that is, to absorb axial expansion and contraction and axial stresses and strains between the two ends of the cooler, and to enable the cooler to operate over a temperature gradient between a maximum of around 1100 °C at one end and a maximum temperature of around 700 °C at the other end. The outer tubular member 502 is provided with a fluid inlet tube 506, and a fluid outlet tube 507 for entry and outlet of a liquid coolant which fills the cavity between the inner and outer tubular members.

[0037] The corrugations also have the effect of increasing the surface area in contact with the hot exhaust gases flowing through the inner tube, and creating local turbulence at the interface between the gas and the tube wall, thereby increasing the heat transfer rate between the gas and the tubular wall.

[0038] The inner and outer tubular members are joined at the inlet end by a first annular plate member 508 extending between the substantially parallel cylindrical walls of the respective inner and outer tubular members 502, 505. Similarly, at the outlet end of the cooler, a second annular plate member 509 joins the other ends of the inner and outer tubular members. Said annular plates may be formed as part of the gas conduit. Alternatively, said annular plates may be formed as part of the coolant conduit.

[0039] In the embodiments shown, there are no internal bulkheads in the gas flowpath, and the ends of the cooler are liquid cooled. The interface components to this embodiment would have a gas path diameter not greater than the diameter of the gas conduit ends, such that said annular plates are not in the gas flow path. The inner tubular member and the outer tubular member do not contact each other, except at their respective corresponding ends, where they are connected together.

[0040] Referring to figure 6 herein, there is illustrated schematically a third higher temperature exhaust gas re-circulation cooler device according to a fifth specific embodiment.

[0041] The third cooler device comprises an inner tube 600 manufactured as a single metal piece, which is substantially cylindrical in parts, and is bent at an angle between its inlet and outlet, in the example shown, the tube being bent at an angle of 90 °; and an outer tube 601 which surrounds the inner tube, and is also bent at an angle between the inlet and outlet, in the example shown at an angle of 90 °, and which forms a cavity between the inner tube and the outer tube, suitable for through flow of a liquid coolant.

[0042] The wall of the inner tube 600 is provided with a plurality of annular or helical corrugations 602, with substantially annular corrugations being depicted in the example shown in figure 6. The purpose of the corrugated undulations in the tubular wall is to absorb stresses and strains due to thermal expansion along the tube, due to the temperature difference of around a maximum of 1100 °C at the inlet, reducing to a maximum of around 700 °C at the outlet.

[0043] The outer tube 601 is provided with a second plurality of annular or helical corrugations formed in the metallic wall of the outer tube. The purpose of the annular or helical corrugations is to absorb thermal stresses and strains between the inlet and outlet of the cooler, as the cooler heats up and contracts in use.

[0044] At an inlet end 604 of the cooler, the outer tubular member 601 is swaged down to a smaller diameter, so that an internal diameter of the inlet of the outer tube 601 is substantially the same as the outer diameter of

the inner tube 600, so that the tubes can be joined together by welding or brazing, or press forming, so that the cavity 605 between the inner and outer tubular members is sealed to be fluid tight.

[0045] Similarly, the outlet end of the cooler is sealed, where the outer tube 601 joins to the inner tube 600, the end of the outer tube 601 being swaged down to a reduced diameter compared to its diameter along the remainder of its length, so as to rigidly secure to the outlet end of the inner tubular member.

[0046] The outer tubular member is provided with a liquid coolant inlet 606, and a coolant outlet 607.

[0047] The third cooler device shown in figure 6 has a single bend along its length, however in the general case, such cooler devices are not restricted to a single bend, but may have a plurality of bends, for example so as to form an "S" shape, or other shape having multiple bends, provided that such shape can be formed by a pair of concentric tubular members, maintaining a cavity there for passage of coolant fluid in contact with the outer surface of the inner tubular member. The inner tubular member and the outer tubular member do not contact each other, except at their respective corresponding ends, where they are connected together

[0048] Referring to figure 7 herein, there is illustrated schematically a fourth cooler, being a "U" shaped cooler according to a sixth specific embodiment. The cooler is suitable for use as a second, relatively lower temperature cooler in a system as disclosed herein, and capable of receiving exhaust gas at an inlet temperature in the range up to 700°C and capable of cooling the gas to a temperature of 150°C or lower.

[0049] The fourth cooler comprises a "U" shaped canister 700 (shown in cut away view dashed lines) having a coolant inlet port 701 for inlet of cooling fluid and a coolant outlet port 702 for outlet of the cooling fluid, such that the cooling fluid can flow internally throughout the canister 700; and one or a plurality of cooling plates 704, each cooling plate comprising a plurality of cooling channels 705 through which a gas may be passed. The canister may be constructed from a single component or from a plurality of components. The one or plurality of cooling plates 704 are attached to the canister directly or via a connector plate 706 at or near the region of the inlet and outlet ports through which gases flow into the U shaped cooler, and are exhausted out of the U shaped cooler.

[0050] Each conduit is formed in a plate like structure, an exterior surface of which is exposed to coolant fluid within the coolant canister 700 which flows around and between the plates, and the interior of which is exposed to the gas flow. The plurality of plates are connected to each other at one end of the cooler, by being welded or soldered either to each other and the canister or to a connector plate 707. A pair of spacers (one shown at 710) may be fitted to the straight edges of the single or center most cooling plate. The spacers serve as a guide for positioning and locating the outer canister 700, so that the plurality of cooling plates lie within the canister,

spaced apart from the edges of the canister, so that each of the cooling plates does not come into direct contact with the canister, there being enough space for passage of coolant fluid between the cooling plate and the canister wall. This has the advantage that as the cooler heats up and cools down, and the canister and cooling plates experience thermal expansion or contraction, because the cooling plates are not physically abutting the canister walls, there are fewer physical stresses due to expansion or cooling, between the cooling plates and the canister wall. The spacers can also act as coolant barriers to direct flow from the coolant inlet spigot to the return end of the cooler and back to the coolant outlet spigot.

[0051] The gas can either flow across the connector plate 707 bypassing the cooler, or can be directed to flow through the cooler, via the one of plurality of "U" shaped channels 705, so that the gas comes into contact with the cooling walls of the plates, the other sides of which are in contact with the liquid coolant in the canister. A plurality of indents 711 causes the gas to follow a serpentine path within the conduits 705, thereby inducing a greater heat exchange between the gas and the plate walls, with minimum retardation of the gas flow.

[0052] The cooler may be connected to a gas flow tube which contains a gas bypass valve, and which is actuable via a protruding external shaft. An electrical or vacuum operated actuator mechanism may be attached to the shaft for electrically actuating the bypass valve within the cooling tube either to pass incoming gas through the U shaped cooler, or to bypass the gas from the U shaped cooler altogether. The gas flow tube may connect to the cooler via a flange surface 707, which contains a gas inlet 708 and a gas outlet 709.

[0053] The cooler and gas flow tube may be welded or brazed together to form a compact unit. The gas flow tube is provided with a plurality of flanges one at each end of the tube, for fitting the tube into a gas flow path of a combustion engine, or other gas flow system, where cooling of the gas may be selectively required.

[0054] The coolant inlet and outlets 701, 702 are shown in figure 7 as being on a same side of the U shaped cooler. However, in other embodiments, the inlet 701 may be positioned on an opposite side of canister to the outlet 702. Alternatively the inlet 701 and the outlet 702 may be positioned in any location around the canister but remaining the same distance from the first end of the gas conduits.

[0055] In use, gas flowing through the gas flow tubes 704 in a direction A-B as shown by the arrows may be directed by the bypass valve either through the U shaped cooler, entering the cooler at the bottom, and passing into the curved periphery of the "U" shaped canister and returning to exit at the top of the cooler and then out of the gas flow tube. Alternatively, where the bypass valve is actuated to bypass the cooler, then the gas flow A-B flows straight through the gas flow tube without entering the cooler. Of course, if the cooler is inverted, then the gas flow would enter at the top of the cooler, and exhaust

out of the bottom of the cooler. Further, if the gas flow were reversed, then the gas may enter the top of the cooler and exhaust through the bottom of the cooler, so that orientation of the U shaped cooler relative to the gas flow can be reversed, without any significant difference in cooling operation.

[0056] Where the gas bypass valve is placed at an intermediate setting, so that it directs some gas through the cooler and some gas directly from the gas flow tube inlet to the gas flow tube outlet, then a partial cooling of the gas flow may result.

[0057] Referring to figure 8 herein, there is illustrated schematically an arrangement of an engine and a first exhaust gas re-circulation bypass system according to a seventh specific embodiment herein.

[0058] An internal combustion engine 800 comprises an inlet manifold 801 for drawing air into the combustion chambers of the engine, and an outlet manifold 802 for channeling exhaust gases out of the engine. Air being input into the inlet manifold may be compressed by a compressor 803. Additionally and optionally, a turbo 204 may be fitted after the exhaust manifold to an exhaust channel 805 of the engine.

[0059] To improve combustion efficiency and reduce harmful emissions, the engine may be fitted with an exhaust gas re-circulation EGR system. The EGR system comprises a first exhaust gas cooler 806 through which exhaust gases flow, and a second exhaust cooler 807, the first and second exhaust coolers being connected in series.

[0060] A high pressure exhaust gas re-circulation circuit takes high pressure exhaust gas from the outlet manifold 802, through a feed pipe 808 to the inlet of the first EGR cooler 806, and from an outlet of the second EGR cooler 807, directly to the inlet manifold 801 via a second feed pipe 809. High pressure re-circulated exhaust gas is cooled, but does not pass through the compressor 203 or the turbo 804.

[0061] An alternative low pressure EGR system takes the exhaust gas downstream of the turbo 804 and feeds it via a third feed pipe 810 to the inlet of the first EGR cooler 806, through the first EGR cooler 806 via a connecting pipe 811 to the inlet of the second EGR cooler 807, and from the outlet of the second EGR cooler 807, to an air channel inlet upstream of compressor 803, via a fourth feed pipe 812.

[0062] The purpose of the first EGR cooler 806 is to cool the high temperature exhaust gases from a temperature of 1000 to 1100 °C down to a temperature of around 650 °C prior to entry to the second EGR cooler 807. Gas is entering the second EGR cooler 807 at an inlet temperature of around 650 °C may exit the second EGR cooler at a reduced temperature of around 150 °C.

[0063] By using a single gas conduit first EGR cooler 806 in the hot exhaust gas, before a multi gas conduit EGR cooler 807, the first EGR cooler can be used to cool the exhaust gas from a relatively higher temperature having a maximum temperature in the range 1000 °C - 1100

°C, to a relatively lower temperature of the order of 650 °C. Since the exhaust gas has been cooled prior to entry on the multi gas conduit EGR cooler 807, the multi gas conduit EGR cooler will not suffer cracking of the gas conduits where they connect to the bulkhead inside the EGR cooler.

[0064] It will be appreciated by the person skilled in the art that variations on the high pressure EGR and the low pressure EGR may be provided.

[0065] In a first variation, the exhaust gas is taken at a relatively lower pressure, after the turbo 804 and via the second feed pipe 810, through the first and second EGR coolers, and through the second feed pipe 809 directly into the inlet without going through the compressor. In a second variation, high pressure exhaust gas may be taken by the first feed pipe 808 through the first and second EGR coolers 806, 807, and fed into the compressor 803 via four feed pipe 212.

[0066] The exhaust gas re-circulation system may operate to cool gas from a maximum inlet temperature of 1100 °C, to a maximum temperature of around 700 °C at the outlet of the first cooler device. This may not be a highly effective cooler. The first cooler device may be robust so as to withstand thermal shock, thermal loading and thermal growth as experienced in automotive applications. The gas may be cooled from an inlet temperature of the second cooler device of around 700 °C to around 150 °C, with a thermal effectiveness of at least 80%. Preferably, the thermal effectiveness of the second cooler section is in the range 90% to 95%.

[0067] The exhaust gas re-circulation system may be fully integrated as a set of connecting pipes and cooler devices being of welded, brazed or soldered construction, without the need for being joined by fasteners, external clamps or other additional mechanical fixings.

[0068] Referring to figure 9a herein, there is illustrated schematically a second specific embodiment EGR system.

[0069] The second system for re-circulating exhaust gas from an internal combustion engine having an inlet manifold 901 and an outlet manifold 902, an inlet air compressor 903 and a turbo 904 operating of the exhaust gas, and comprises a first EGR cooler 905, an inlet of which is supplied with exhaust gas from the exhaust manifold 902 of the internal combustion engine via an exhaust feed pipe 906, the first EGR cooler receiving high temperature exhaust gas at a temperature in the range 1000 °C - 1100 °C; and a second EGR cooler 907 which receives relatively lower temperature exhaust gas, typically at a maximum inlet temperature of around 650 °C, and which cools the gas down to a temperature around 150 °C. The cooled exhaust gas being fed through the outlet of the second EGR cooler directly into the inlet manifold 901.

[0070] Referring to figure 9b herein, the system of fig 9a is shown during a warm up phase of the engine, when the engine has just been started and is raising towards its normal operating temperature.

[0071] In these circumstances, the second EGR cooler 907 is bypassed, but the first EGR cooler 906 remains in the EGR circuit. Under warm up conditions, a temperature at the inlet of the first EGR cooler 906 may be of the order of 400 °C, and gradually rises as the engine warms up, towards a maximum temperature in the range 1000 °C - 1100 °C. As long as the exhaust gas at the outlet of the EGR system remains at a maximum temperature in the range 150 °C or less, then the second EGR cooler 907 can be bypassed, thereby enabling the engine to heat up to its optimum running temperature more quickly, improving efficiency of the engine.

[0072] However, once the engine gets up to operating temperature, and the temperature of the exhaust gas at the outlet of the first EGR cooler rises above around 150 °C, then the second EGR cooler 907 is switched into circuit via a valve mechanism to provide further cooling of the exhaust gas before it is fed back into the inlet manifold 901.

[0073] Referring to figure 10 herein, there is illustrated schematically a third exhaust gas re-circulation system according to a ninth specific embodiment. The third exhaust gas re-circulation cooling system is configured for cooling an engine 1000 having an inlet manifold 1001, an outlet manifold 1002, optionally, a compressor 1003 for compressing air before entry to the inlet manifold 1001; and optionally a turbo 1004, which is driven from exhaust gases vented from the outlet manifold 1002.

[0074] The third EGR system comprises a higher temperature EGR cooler as herein before described; a relatively lower temperature EGR cooler 1006 as herein before described. A first feed pipe 1007 for feeding exhaust gases from the outlet manifold 1002 to an inlet of the higher temperature EGR cooler 1005; a connecting pipe 1008 for connecting the outlet of the higher temperature EGR cooler to the inlet of the lower temperature EGR cooler 1006; and a return connecting pipe 1009 for connecting the outlet of the lower temperature EGR cooler to the inlet manifold 1001.

[0075] The relatively higher temperature EGR cooler accepts hot exhaust gases at a maximum temperature of up to 1100 °C and cools these down to a relatively lower temperature of around 700 °C at its outlet. The higher temperature EGR cooler comprises a single gas passage type as described herein with reference to figures 4 to 7 herein before. The relatively lower temperature EGR cooler 1006 is of the multiple internal gas passage type having multiple internal gas conduits secured to a pair of bulkheads within an outer canister as described with reference 2 and 3 herein before, and which typically operates at a maximum inlet gas temperature of up to 700 °C, cooling the gases down to an outlet temperature of approximately 150 °C before returning the cooled gases to the inlet manifold 1001 via the return CONDUIT 1009.

[0076] Referring to figure 11, there is illustrated schematically a fourth exhaust gas re-circulation system according to a ninth specific embodiment herein.

[0077] The fourth EGR cooling system is suitable for fitting to an internal combustion engine having an inlet manifold 1101, an outlet manifold 1102, an optional compressor 1103 for compressing inlet gases prior input into the inlet manifold; and optional turbo 1104 operating off the exhaust gas from the exhaust manifold 1102.

[0078] The fourth exhaust gas re-circulation system comprises a high temperature EGR cooler 1105 receiving hot high pressure exhaust gases from the outlet manifold 1102 via a feed pipe 1106; a flow control valve 1107 receiving exhaust gases from the outlet of the high temperature EGR cooler 1105 and for controlling an overall flow rate of gas through the EGR system; a low temperature EGR cooler 1108 connected down stream of the flow control valve, and downstream of the high temperature EGR cooler, for applying further cooling to the exhaust gases; a bypass valve 1109 for directing exhaust gases straight past the low temperature cooler 1108, or alternatively routing gases through the low temperature EGR cooler, or for selecting a proportion of exhaust gases for routing through the low temperature EGR cooler 1108, as required by the engine temperature during start up of the engine, and a return pipe 1110, connected to the outlet of the bypass valve for receiving exhaust gases either bypassing the low temperature EGR cooler, or having been routed through the low temperature EGR cooler and returning those exhaust gases to the inlet manifold 1101 of the engine.

[0079] The fourth EGR system comprises a high pressure system, taking the exhaust gases directly from the outlet manifold, and returning them directly to the inlet manifold of the internal combustion engine 1100.

[0080] In use, the high temperature EGR cooler is permanently connected, but the flow of gas through that cooler is regulated by the flow control valve 1107. Under cold conditions, the high temperature EGR cooler can be used alone using bypass valve 1109 to bypass the lower temperature cooler 1108. As the engine temperature raises, up towards full operating temperature, for additional cooling, the low temperature EGR cooler 1108 can be brought into circuit using the bypass control valve 1109, which can be varied to allow different flow rates of exhaust gas through the low temperature EGR cooler 1108. When the engine is at full operating temperature, the temperature gradient between the inlet of the high temperature EGR cooler and the outlet of the low temperature EGR cooler is between 1100 °C maximum, and around 150 °C at the exhaust returned system. In order to prevent over heating of the high temperature EGR cooler 1105, as the temperature gradient across the high temperature EGR cooler rises towards 400 °C, the low temperature EGR cooler is brought into circuit using the bypass valve, so that when the circuit is fully operational and the engine is running at full temperature, the inlet of the high temperature EGR cooler is at a maximum temperature of 1100 °C, the outlet of the high temperature is at a maximum temperature of around 700 °C, the inlet of the low temperature EGR cooler is at a maximum temperature

of around 700 °C and the outlet of the second EGR cooler is at a maximum temperature of around 150 °C. In this embodiment the EGR control valve never has exhaust gas hotter than 700 °C passing through it.

[0081] Referring to figure 12 herein, there is illustrated a fifth EGR system according to a tenth specific embodiment herein.

[0082] The fifth EGR system is suitable for cooling re-circulated exhaust gases of an internal combustion engine 1200 having an inlet manifold 1201, an outlet manifold 1202, an optional compressor 1203, and an optional turbo 1204 as described with reference to figure 11.

[0083] The fifth EGR system comprises a high temperature EGR cooler 1205 which is connected to an outlet of the outlet manifold 1202 by an outlet feed pipe 1206; a low temperature EGR cooler, an inlet of which is connected to an outlet of the high temperature EGR cooler 1205 via a bypass valve 1207; and a flow control valve 1208 positioned downstream of the bypass valve 1207 and low temperature EGR cooler 1206, the flow control valve being connected to the inlet manifold of the internal combustion engine by a return flow path 1209.

[0084] In the arrangement of figure 12, the flow control valve is provided downstream of both the high temperature and low temperature EGR coolers, which means that the bypass valve 1207 operates at a maximum temperature of around 700 °C, and the flow control valve operates at a maximum temperature of around 150 °C.

[0085] When the engine is fully up and running, at maximum operating temperature, the temperature gradient extends from an inlet gas temperature at the inlet of the high temperature EGR cooler at around 1100 °C, which cools the gas to a maximum temperature of around 700 °C at the outlet of the high temperature EGR cooler and at the bypass valve. The low temperature EGR cooler when fully operational cools the gas from a maximum temperature of around 700 °C to a temperature of around 150 °C at its outlet, returning the exhaust gas to the inlet manifold via the flow control valve 1208 at a maximum temperature of around 150 °C. The whole of the EGR system is under relatively high pressure, taking exhaust gas directly from the exhaust manifold and returning it to the inlet manifold 1201.

[0086] In the above embodiments, it will be appreciated that variations may be effected as follows:

In the exhaust gas re-circulation system, non cooled gas transfer conduits may be positioned before the high gas inlet temperature cooler, between the high gas inlet temperature cooler and the second lower gas inlet temperature cooler, and/or after the lower gas inlet temperature cooler. The exhaust gas re-circulation system may have two distinct sections of cooling, and a section of non cooled gas transfer conduit.

[0087] A higher gas inlet temperature cooler may feed partially cooled gas to a lower gas inlet temperature cool-

er as shown herein above.

[0088] A non-cooled gas transfer conduit may be positioned either before a relatively higher gas inlet temperature cooler, or between a higher gas inlet temperature cooler and a lower gas inlet temperature cooler, or after a lower gas inlet temperature cooler. The non cooled gas transfer conduit may have corrugations, either helical or annular, in order to give it flexibility.

[0089] Referring to figure 13 herein, there is illustrated schematically in cut away view a pre-cooler device of an exhaust re-circulation system, according to a twelfth specific embodiment.

[0090] The pre-cooler device comprises an outer tubular conduit member 1300, the outer conduit surrounding an inner tubular conduit member 1301. The inner conduit 1301 provides a gas passage between a first end 1302 and a second end 1303. The outer conduit 1300 surrounds the inner conduit 1301, and the cavity between the inner and outer tubular conduit members forms a cavity, through which a coolant fluid may be passed.

[0091] Outer tubular member 1300 comprises a corrugated portion 1304, capable of absorbing vibration and thermal expansion/contraction in an axial direction and in direction transverse to axial as the component heats up or cools down.

[0092] The inner tubular member comprises a corrugated portion 1305, also capable of absorbing vibration and thermal expansion and contraction as the component heats and cools. In the embodiment shown, the inner tubular member is corrugated for its entire length, and preferably is deeply corrugated mainly on the bend, whereas the outer tubular member 1300 has first and second regions 1306, 1307 which are smooth and cylindrical, and toroidal respectively.

[0093] In the embodiments shown, the inner tubular member and the outer tubular member are connected only at their respective first and second ends. For the remaining lengths of the first and second outer tubular members, those members do not touch each other, the inner tubular member being suspended within the outer tubular member along substantially all of the length of the outer tubular member.

[0094] The inner tubular member comprises a first region 1308, in which the corrugated wall is indented with first and second relatively deep elongate indents.

[0095] A first end 1303 is shown in more detail in Figure 17. A second (outlet) end of the device comprises a tubular outer end connector 1309 which connects the respective first ends of the inner and outer tubular members together such that the first and second ends of the tubular members do not touch each other. The end connector 1309 comprises a swaged tube 1310, having a substantially cylindrical inner surface 1311 in to which an outer cylindrical end surface of the inner tubular member locates, for example by a force fit or an interference fit, and which can be secured in addition by welding or brazing; and a substantially cylindrical second inner surface 1312 which locates with a substantially cylindrical outer sur-

face of a first end of the outer tubular member. The end member 1309 comprises a flange 1313 having one or a plurality of apertures 1314, by means of which the component may be bolted to the second stage of the EGR system.

[0096] The outer tubular member may be formed as a single piece, or alternatively may be constructed from one or more members assembled together. For example the outer tubular member may comprise a first piece 1315 comprising a tubular cylindrical wall having a frusto conical end shaped for fitment in to the end piece 1309. The second outer tubular member piece 1316 may comprise a series of annular corrugations disposed between first and second substantially cylindrical tubular portions. The third outer tubular member piece 1317 may comprise a tubular torodiol or angled component having an extended substantially cylindrical piece on the end. The three components may be connected together by push-fit, interference fit and/or by welding or brazing.

[0097] Alternatively the other tubular member may be formed as a single metal tube component for example by hydraulic forming.

[0098] Referring to figure 14 herein, there is illustrated schematically in perspective view, the inner tubular member 1301 of the pre-cooler device of figure 13. Preferably the inner tubular member is formed from a single piece of metal, for example by formation under hydraulic pressure. The inner tubular member comprises a relatively longer substantially straight substantially cylindrical region 1401 forming an outlet of the member; a substantially curved torodiol, or doughnut shaped portion 1402, and a second relatively shorter substantially straight substantially cylindrical portion 1403 which is at an inlet end of the member.

[0099] The first substantially straight substantially cylindrical portion 1401 comprises a pair of opposing indents 1404, 1405 which protrude in to the otherwise substantially cylindrical corrugated passage through the first tubular member, and extending longitudinally along a length of the first portion 1401, so that in cross section in a direction transverse to the main length of the passage, the internal passageway has a substantially butterfly, double mushroom, batwing shaped or double cardioid cross section,

[0100] The first substantially cylindrical section comprises as first series of corrugations 1406 of a first type, and a second set of corrugations 1407 of a second type.

[0101] The second, partially substantially torodial section 1402 comprises a plurality of annular corrugations of a second type, and the third substantially straight cylindrical section 1403 comprises a plurality of indentations of the first type.

[0102] Referring to figure 15 herein, there is illustrated schematically in cross-sectional view along a main length axis of the first section of the first inner tubular member, across the section A-A, showing the substantially butterfly, batwing, double mushroom or double cardioid shaped of the internal gas passage.

[0103] In the embodiment shown, in cross section across the main axis of the tube, the wall of the inner tubular member comprises a substantially circular profile having first and second laterally opposing indents 1500, 1501, each indent extending from a position on a nominal outer circle, towards the center of the circular profile a distance of 60% - 90% of the radius of the circle (corresponding to 30% to 45% of the distance across the inner tubular member), and in the best mode, approximately 77% of the radial distance, but may be as much as 15% to 90% of the radial distance across the inner tubular member. In the best mode, each indent occupies an arc of angle in the range 30° - 50°. Each indent, in cross-sectional profile comprises a substantially "V" shape, having a rounded point at the inter-section of two substantially straight side walls.

[0104] Provision of the first and second indents, which present in to the gas passage over an extended length of the inner tubular member, and which have corrugated walls, presents a relatively increased surface area in contact with gas flowing through the inner tubular member. Since coolant fluid flows around the outside of the inner tubular member, the surface area of metal wall of the inner tubular member through which heat is transferred between the gas inside the tubular member and the coolant fluid flowing outside the tubular member is enhanced compared to a substantially cylindrical tubular member, thereby increasing the efficiency of heat transfer and enabling a relative reduction in size of the component for a given rate of gas to coolant heat transfer.

[0105] Referring to figure 16 herein, there is illustrated schematically in cross-sectional view one side wall portion of the tubular member at a position A-A as shown in figure 15. The side wall portion comprises a plurality of corrugations of the first type. In the best mode, of pitch between peaks of the corrugations is 6mm or thereabouts, corresponding to a peak to peak spacing of around 16% to 20% of the distance across the tubular member. The corrugations are substantially triangular or sinusoidal in profile, and have an amplitude in the range of 10% - 20% of the peak to peak distance between corrugations, and in the best mode of the order of 16%. The corrugations have a peak to trough distance in the radial direction of the order of 6% to 8% of the internal radial distance of the inner tubular member.

[0106] In best mode embodiment, a pitch between peaks of the corrugations may be of the order of 6mm. In one embodiment, the radius of the inner tubular member is of the order of 16.5mm.

[0107] Referring to figure 17 herein, there is illustrated schematically in partial cut away view the first end of the pre-cooler component of figures 13 to 16.

[0108] There is illustrated schematically the first and second types of corrugation 1700, 1701 respectively of the inner tubular member. The first type of corrugation as described herein with reference to figures 13-16 comprises a relatively lower peak to trough variation in radius, and the second type of corrugation comprises a relatively

greater peak to trough radial variation.

[0109] The second type of corrugation comprises a variation in wall shape substantially in the form of a toroidal ring protruding out of the wall, successive rings being spaced apart from each other by a plurality of substantially cylindrical trough regions 1702 (in the case of a region of the inner tubular member which is substantially cylindrical). In the best mode, the peak to peak pitch between successive second rings is of the order of 6mm, and is approximately the same as the successive peak to peak distance between annular corrugations 1700 of the first type. A peak to trough distance of the second corrugation type may be in of the order of 10% to 14% of a maximum radius of the inner tubular member, or 5% to 7% of the distance across the inner tubular member.

[0110] Also illustrated in figure 17 in cut away view is a tubular end piece member 1703 in to which the inner tubular member and the outer tubular member each fit. The end piece 1704 comprises a cast or otherwise formed tubular metal component having a first locating inner surface 1705 for locating an end 1706 of the inner tubular member; and a second cylindrical inner surface 1707 to which fits an outer surface of the outer tubular member. The first substantially cylindrical inner surface 1705 is spaced apart laterally from the second annular inner surface 1707 in a direction along a main length axis of the component, such that the inner and outer tubular members can both be inserted in to the tubular end component and are retained by friction (a force fit or an interference fit) plus welding or brazing between the inner tubular member and the end component and the outer tubular member component.

[0111] The end component comprises a circular passageway 1708, through which coolant fluid may flow in to or out of the cavity 1709 formed between the outer tube member and the inner tubular member.

[0112] The pre-cooler device of figures 13 to 17 may provide an efficient precooling temperature drop with an inlet temperature of 1100°C down to around a temperature of around 700°C at the outlet of the pre-cooler.

[0113] It will be appreciated by those skilled in the art that although annular corrugations have been shown for the inner and outer tubular members of the pre-cooler device, the corrugations could be made helical as an alternative embodiment. The corrugations extend in either case around a circumference of the inner tubular member, and similarly for the outer tubular member.

[0114] A high gas inlet temperature cooler as described herein may be designed to function with relatively high inlet gas temperatures (up to 1100 °C) and be able to withstand the associated thermal shock loading by using a single gas tube to form the gas conduit. The gas conduit may be substantially concentric within an outer cooler conduit, and an annular space between said gas tube and said outer cool tube may form a cavity for a coolant fluid. The cooler may avoid having any bulkhead interfacing between the gas conduit and any other component within the cooler.

[0115] In the exhaust gas re-circulation systems described herein, a high gas inlet temperature cooler may be used to cool an EGR valve, thus enabling the EGR valve to be located after the high gas inlet temperature cooler and therefore upstream of a relatively lower temperature gas cooler, operating typically at a maximum temperature of around 700 °C.

[0116] The relatively higher gas inlet temperature cooler may be used to cool an exhaust gas re-circulation valve, which enables a lower temperature cooler to be located after the EGR valve.

[0117] A relatively high gas inlet temperature cooler may have at least two bends along its main axis. The relatively high gas inlet temperature cooler may have a gas inlet interface joint between a gas conduit and the rest of the cooler, which is substantially cooled by the cooler coolant.

[0118] The EGR system may be used for "high pressure" exhaust gas re-circulation, ie taking gas from pre turbo in the gas flow through an internal combustion engine.

[0119] The EGR system may also be used for "low pressure" exhaust gas re-circulation, i.e. taking exhaust gases after passing through a turbo.

[0120] The lower gas inlet temperature cooler may have a bypass valve such that gas can bypass the cooler without being significantly cooled. The whole of the EGR system may not be bypassed as this would cause the gas inlet to the induction side to be too hot.

[0121] The lower gas inlet temperature cooler, may have one or a plurality of internal gas conduits, all of which are flexible along their axis and have either annular or helical corrugations along their walls. The corrugations may be present substantially all the way along the internal gas conduits, or in a restricted section of the gas conduits.

[0122] An outer casing of the lower temperature gas cooler may have annular or helical corrugations to allow flexibility along the length of the casing. The corrugations may be present along substantially the entire outer cooler conduit, or may be restricted to a section of its length.

[0123] The embodiments disclosed above may provide an EGR system capable of cooling re-circulated exhaust gas from a maximum temperature of around 1100 °C at a gas inlet to the system, down to a first stage of cooling at a maximum temperature of around 700 °C within a specially designed section which is robust against thermal shock, thermal loading and thermal growth. The gas may then be further cooled down from a maximum temperature of around 700 °C within a second cooling section which has a thermal effectiveness of at least 90%, and preferably at least 95%.

[0124] In the EGR system embodiments shown above, the whole system may be fully integrated, without the use of additional fasteners or connectors between the tubes and sections, to form a unitary welded, brazed or soldered construction.

Claims**1.** An exhaust gas cooling device comprising:

an inner tubular member having an inlet end and an outlet end, said inner tubular member forming a gas passage; and
 an outer tubular member, surrounding an outer portion of said inner tubular member and forming a cavity there between for containing a liquid coolant,
 wherein said inner tubular member comprises a plurality of corrugations for absorbing thermal expansion and/or contraction of said inner member; and
 wherein said outer tubular member comprises a plurality of corrugations for absorbing thermal expansion and/or contraction of said outer member.

2. The cooling device as claimed in claim 1, wherein the inner and outer tubular members are arranged so as not to contact each other, other than at the first ends of the inner and outer members, and at the second ends of the inner and outer tubular members.

3. The cooling device as claimed in claim 1 or 2, wherein said outer member has first and second ends and is swaged at each of its first and second ends, such that an internal diameter of said outer member at each said end is substantially the same as an outer diameter of a corresponding end of said inner member, said inner and outer members being joined together at said first and second ends.

4. The cooling device as claimed in any one of the preceding claims, wherein said cooling device has no bulkhead component to join the gas conduit to the coolant conduit.

5. The cooling device as claimed in any one of the preceding claims, wherein said cavity comprises a substantially cylindrical annular cavity.

6. The cooling device as claimed in any one of the preceding claims, wherein said cavity extends substantially a full length along said inner and outer members, such that first and second end extremities of said cooling device are cooled in use by a coolant fluid flowing through said substantially annular cavity.

7. The cooling device as claimed in any one of the preceding claims, wherein said outer tubular member comprises an inlet feed pipe for accepting a supply of fluid coolant, and an outlet feed pipe for draining said supply of coolant fluid.

8. The cooling device as claimed in any one of the preceding claims, wherein said annular corrugations on said inner tubular member extend over a length of between 10% and 85% of an overall length of said inner tubular member.

9. The cooling device as claimed in any one of the preceding claims, wherein said outer tubular member has a set of corrugations which extend over a proportion of between 10% and 100% of the length of the outer tubular member.

10. The cooling device as claimed in any one of the preceding claims, wherein a main central axis of an inlet end of said inner tubular member lies at an angle with respect to a main central axis of an outlet of said inner tubular member, and said inner and outer members are bent, such that the cooler device forms a curved or bent component.

11. The cooling device as claimed in any one of the preceding claims, capable of operating in a temperature range of -60 °C to 1100 °C.

12. The cooling device as claimed in any one of the preceding claims, wherein said inner tubular member comprises a plurality of annular or helical corrugations.

13. The cooling device as claimed in any one of the preceding claims, wherein said outer tubular member comprises a plurality of annular or helical corrugations.

14. The cooling device as claimed in any one of the preceding claims, wherein said inner tubular member comprises;
 a first type of ring corrugation having a peak to peak spacing between adjacent corrugations in a direction along the main length of the inner tubular member of a distance corresponding to 16% to 20% of the distance across the tubular member.

15. The cooling device as claimed in any one of the preceding claims, comprising a first type of corrugation, having a peak to trough distance in the range of 6% to 8% of the internal radial distance of the inner tubular member.

16. The cooling device as claimed in any one of the preceding claims, having a second type of corrugation comprising a substantially toroidal surface.

17. The cooling device as claimed in claim 16, wherein said corrugations of said second type have a peak to trough radial distance in the range of 10% to 14% of a maximum radius of the inner tubular member.

18. The cooling device as claimed in any one of the preceding claims, comprising at least one elongate indent, said elongated indent extending along a main axial length of said inner tubular member; said indent comprising a wall portion which extends in to a main inner passage of said inner tubular member to a distance in the range 15% - 90% of a distance across said inner tubular member.
19. The cooling device as claimed in claim 18, comprising a plurality of said elongate indents, said plurality of indents opposing each other, such that an internal cross sectional profile of an internal passage of inner tubular member forms a substantially butterfly or double mushroom shape.
20. The cooling device as claimed in claim 18 or 19, wherein each said elongate indent has super imposed a plurality of corrugations extending circumferentially around said inner tubular member.
21. The cooling device as claimed in any one of the preceding claims, comprising a first tubular end piece in to which connects a first end of said inner tubular member and a first end of said outer tubular member, such that said inner and outer tubular members are spaced apart from each other with the cavity there between, and do not touch each other.
22. The cooling device as claimed in any one of the preceding claims, comprising a second tubular end piece in to which connects a second end of said inner tubular member and a second end of said outer tubular member, such that said inner and outer tubular members are spaced apart from each other with the cavity there between, and do not touch each other.
23. The exhaust gas cooling device as claimed in any one of the preceding claims, wherein said inner tubular member and said outer tubular member are constructed so as not to contact each other except at said inlet end and said outlet end.
24. The exhaust gas cooling device as claimed in any one of the preceding claims, wherein said first cooling device is capable of cooling said exhaust gas from a maximum inlet temperature of 1100 °C, to a maximum outlet temperature of 700 °C.
25. The exhaust gas cooling device as claimed in any one of the preceding claims, wherein said inner tubular member and said outer tubular member are constructed so as not to contact each other except at said inlet end and said outlet end.
26. The exhaust gas cooling device as claimed in any one of the preceding claims, wherein said first cooling device is capable of cooling said exhaust gas from a maximum inlet temperature of 1100 °C, to a maximum outlet temperature of 700 °C.
27. An exhaust gas re-circulation system for an internal combustion engine, said system comprising:
- a first cooling device as claimed in any one of claims 1 to 24, configured for receiving exhaust gas from said internal combustion engine; and a second cooling device connected in series with said first cooling device and arranged for receiving cooled exhaust gas from an outlet of said first cooler device, an outlet of said second cooling device being connected to an inlet of said internal combustion engine.
28. The exhaust gas re-circulation system as claimed in claim 27, wherein said second cooling device is capable cooling exhaust gas from a maximum inlet temperature of 700 °C, to a maximum outlet temperature of 150 °C.
29. The exhaust gas re-circulation system as claimed in any one of claims 27 to 28, further comprising a flow control valve for controlling a flow rate of exhaust gas through said first and second cooling devices.
30. The exhaust gas re-circulation system as claimed in claim 29, wherein said flow control valve is positioned between an outlet of said second cooling device and an inlet of said internal combustion engine, such that gas flows through said second cooling device, and through said flow control valve to said internal combustion engine inlet.
31. The exhaust gas re-circulation system as claimed in claim 29 or 30, wherein said flow control valve is positioned between an outlet of said first cooling device and an inlet of said second cooling device, and is operable for transferring partially cooled exhaust gas from said first cooling device to said second cooling device.
32. The exhaust gas re-circulation system as claimed in any one of claims 29 to 31, wherein said first cooling device comprises a relatively high gas inlet temperature cooler, configured to supply partially cooled gas to said valve, said valve being operable to supply said second cooling device, which operates at a relatively lower gas inlet temperature than said first cooling device.
33. The exhaust gas re-circulation system as claimed in any one of claims 29 to 32, further comprising a plurality of gas conduits for connecting said first and second cooling devices, a gas transfer conduit for transferring uncooled exhaust gas comprising a tubular corrugated wall.

34. The exhaust gas re-circulation system as claimed in any one of claims 27 to 33, further comprising a bypass valve for bypassing and/or controlling a flow of exhaust gas through said second cooling device. 5
35. The exhaust gas re-circulation system as claimed in any one of claims 28 to 34, wherein an inlet of first cooling device is connected to a relatively high pressure outlet of an internal combustion engine. 10
36. The exhaust gas re-circulation system as claimed in any one of claims 27 to 35, wherein an inlet of said first cooling device is connected to an outlet of a turbo charger positioned in an exhaust channel of said internal combustion engine. 15
37. The exhaust gas re-circulation system as claimed in any one of claims 27 to 36, wherein an outlet of said second cooling device is connected to an input of a super charger connected to an internal combustion engine. 20
38. An exhaust gas re-circulation system capable of being fitted to an internal combustion engine, said system comprising: 25
- a first cooler device as claimed in any one of claims 1 to 26, adapted for cooling exhaust gases having a relatively higher gas inlet temperature; and 30
 - a second cooler for cooling gases having a relatively lower gas inlet temperature;
 - a flow control valve for controlling a flow of exhaust gas; and 35
 - a bypass valve for bypassing said second cooler;
 - said first cooler arranged for supplying partially cooled said exhaust gas to said second cooler; and 40
 - said flow control valve arranged for controlling a flow of exhaust gas through said first cooler and said second cooler, and said bypass valve arranged for controlling a flow of gas through said second cooler only. 45
39. An exhaust gas re-circulation as claimed in claim 38, wherein said second cooler comprises: 50
- a tubular outer canister forming an inlet cavity, an outlet cavity, and a cooling cavity position between said inlet and said outlet cavities;
 - a plurality of tubular gas conduits, contained within said cooling cavity;
 - a first bulk head positioned between said inlet cavity and said cooling cavity; 55
 - a second bulk head position between said cooling cavity and said outlet cavity; and
 - a plurality of tubular gas conduits fixed between
- said first and second bulk heads for transferring exhaust gases through said cooling cavity, wherein said plurality of gas conduits each comprise a corrugated wall for accommodating thermal expansion and contraction between said first and second bulk heads.
40. The exhaust gas re-circulation system as claimed in claim 38 or 39, further comprising a plurality of feed pipes for connecting said first and second cooler devices to an inlet and exhaust system of an internal combustion engine, wherein at least one said feed pipe comprises a rigid tubular wall having a plurality of annular corrugations or helical corrugations.
41. The exhaust gas re-circulation system as claimed in claim 40, wherein said second cooler comprises: 60
- at least one cooling plate, said cooling plate comprising: 65
 - an upper plate wall and a lower plate wall
 - said upper and lower plate walls defining a plurality of gas passages which have a gas inlet at a first end of cooling plate and a gas outlet at said first end of said cooling plate; each said passage directing a gas flow between said inlet and said outlet and around a length of said plate; 70
 - said plate being sealed so as to be gas tight along a length of said plate, and at a second end of said plate.
42. The exhaust gas re-circulation system as claimed in claim 41, wherein a plurality of said gas passages are nested concentrically within each other in a main plane of the cooling plate.
43. The exhaust gas re-circulation system as claimed in claim 41 or 42, wherein said plurality of gas passages are isolated from each other.
44. The exhaust gas re-circulation system as claimed in any one of claims 39 to 43, wherein said plurality of gas passages are partially isolated from each other, wherein a main flow of gas passes along a main length of each said gas passage, but a restricted passage of gas between adjacent gas passages within a same cooling plate is also provided for.
45. The exhaust gas re-circulation system as claimed in any one of claims 39 to 44, comprising a plurality of indents arranged along said plurality of gas conduits, said plurality of indents extending into said gas passages, for distributing a flow of gas passing through said passages and thereby creating a mixing of gas flow within one or more said gas passages.

46. The exhaust gas re-circulation system as claimed in any one of the claims 39 to 45, wherein said gas passages are arranged such that gas flows in an alternating serpentine path along a length of each of said gas passage. 5
47. The exhaust gas re-circulation system as claimed in any one of the claims 39 to 46, wherein each said gas passage comprises a substantially "U" shaped tubular passage. 10
48. The cooler device as claimed in any one of claims 39 to 47, comprising a plurality of said cooling plates stacked side by side, said plurality of cooling plates connected at their respective first ends, such that a plurality of inlets to said plurality of cooling plates lay adjacent each other, and a plurality of outlets of said cooling plates lay adjacent each other. 15
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- 55

Fig.1.
(Prior Art)

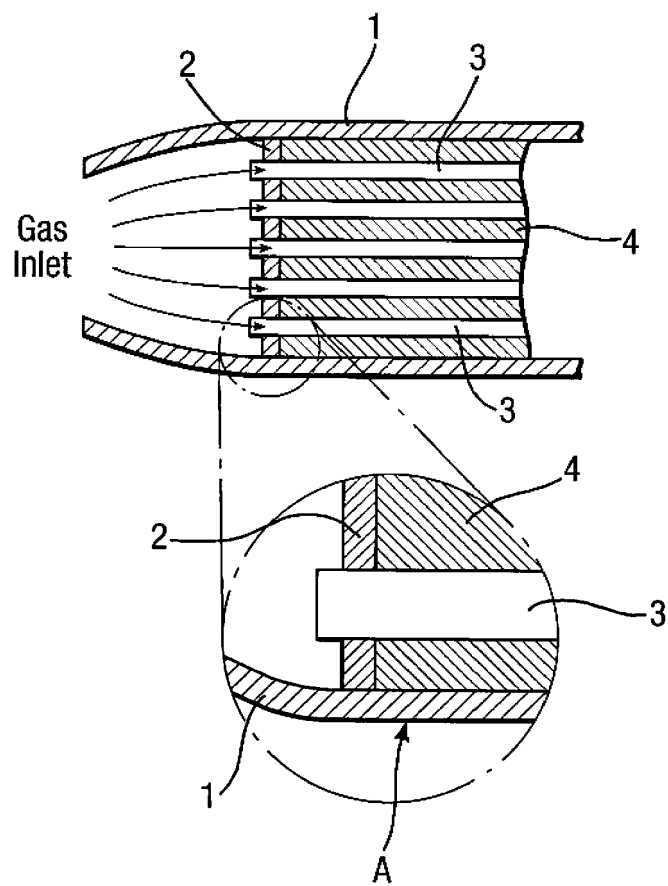


Fig.2.

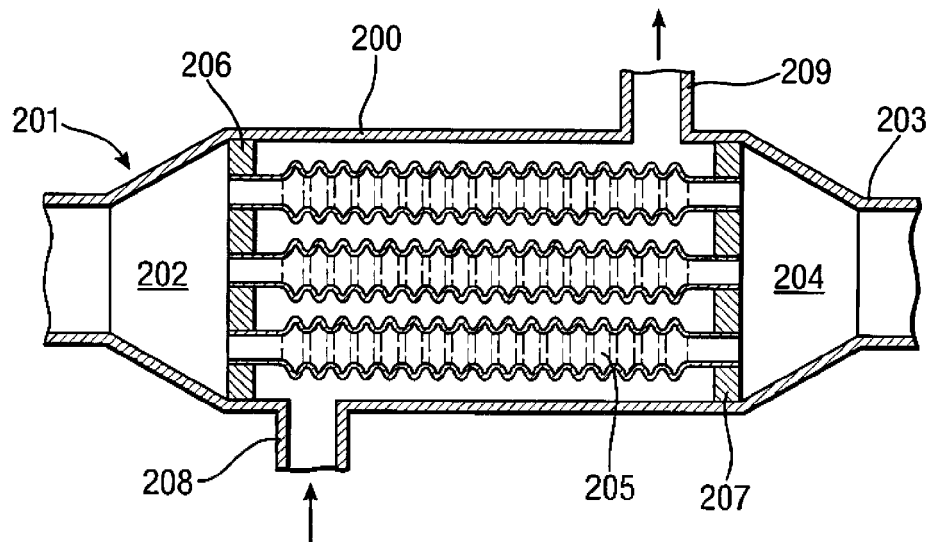


Fig.3.

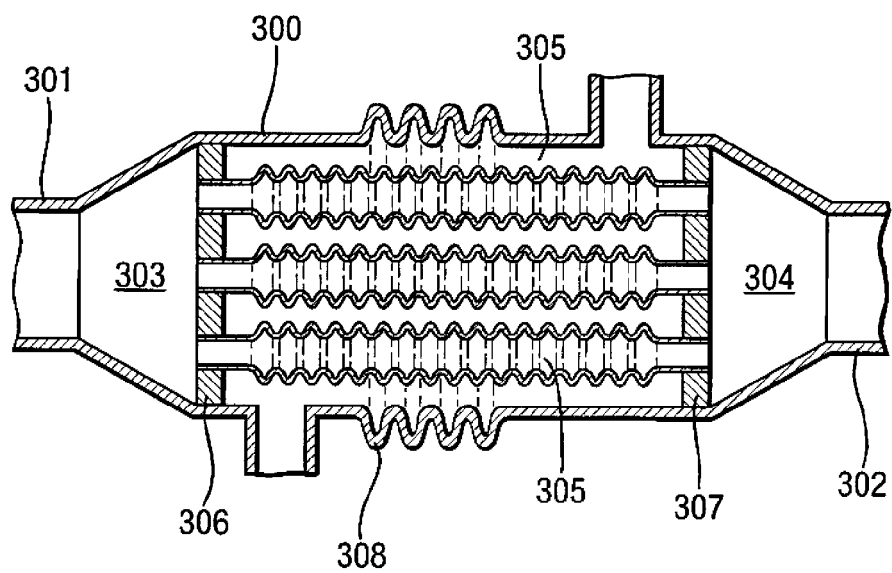


Fig.4.

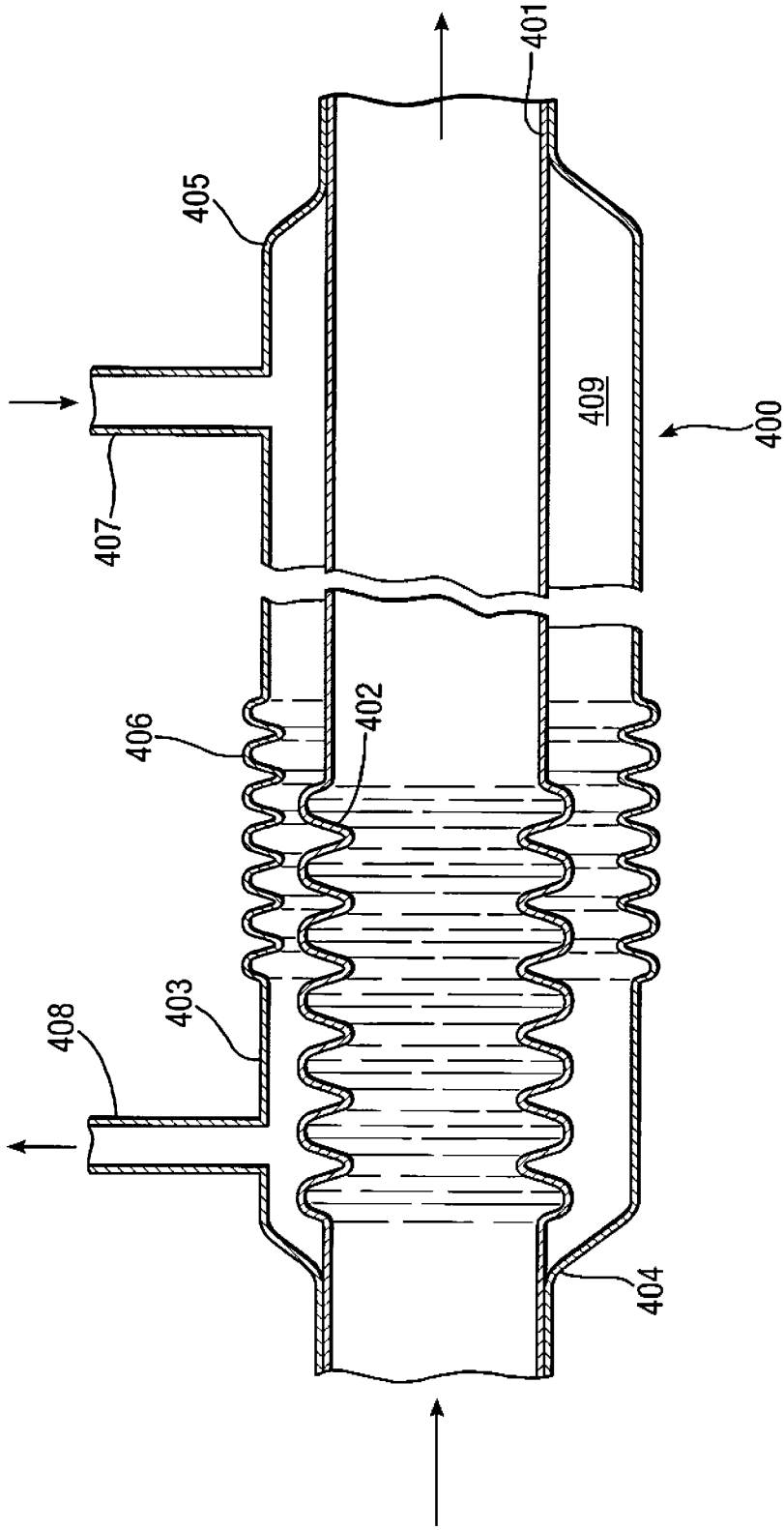


Fig.5.

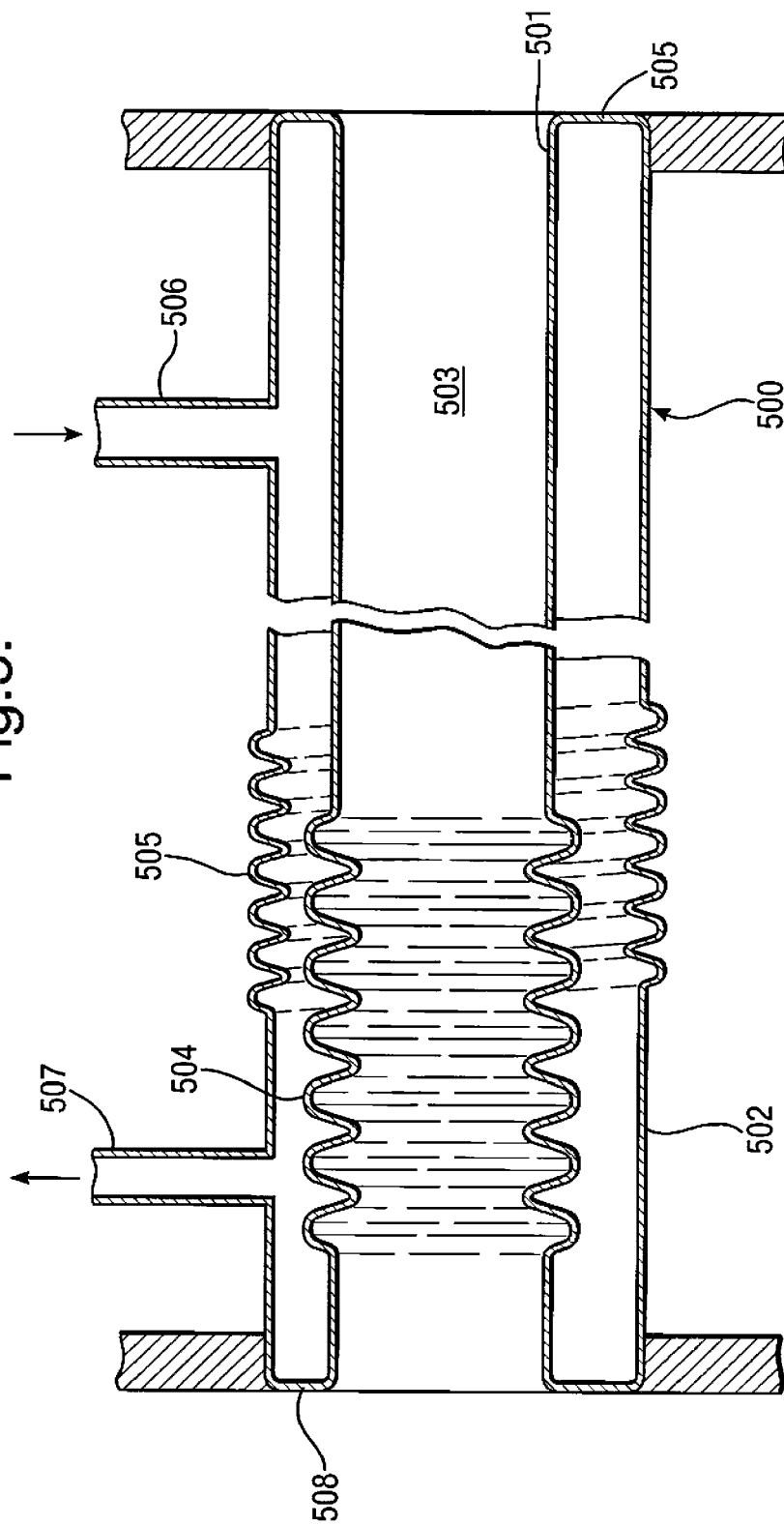


Fig.6.

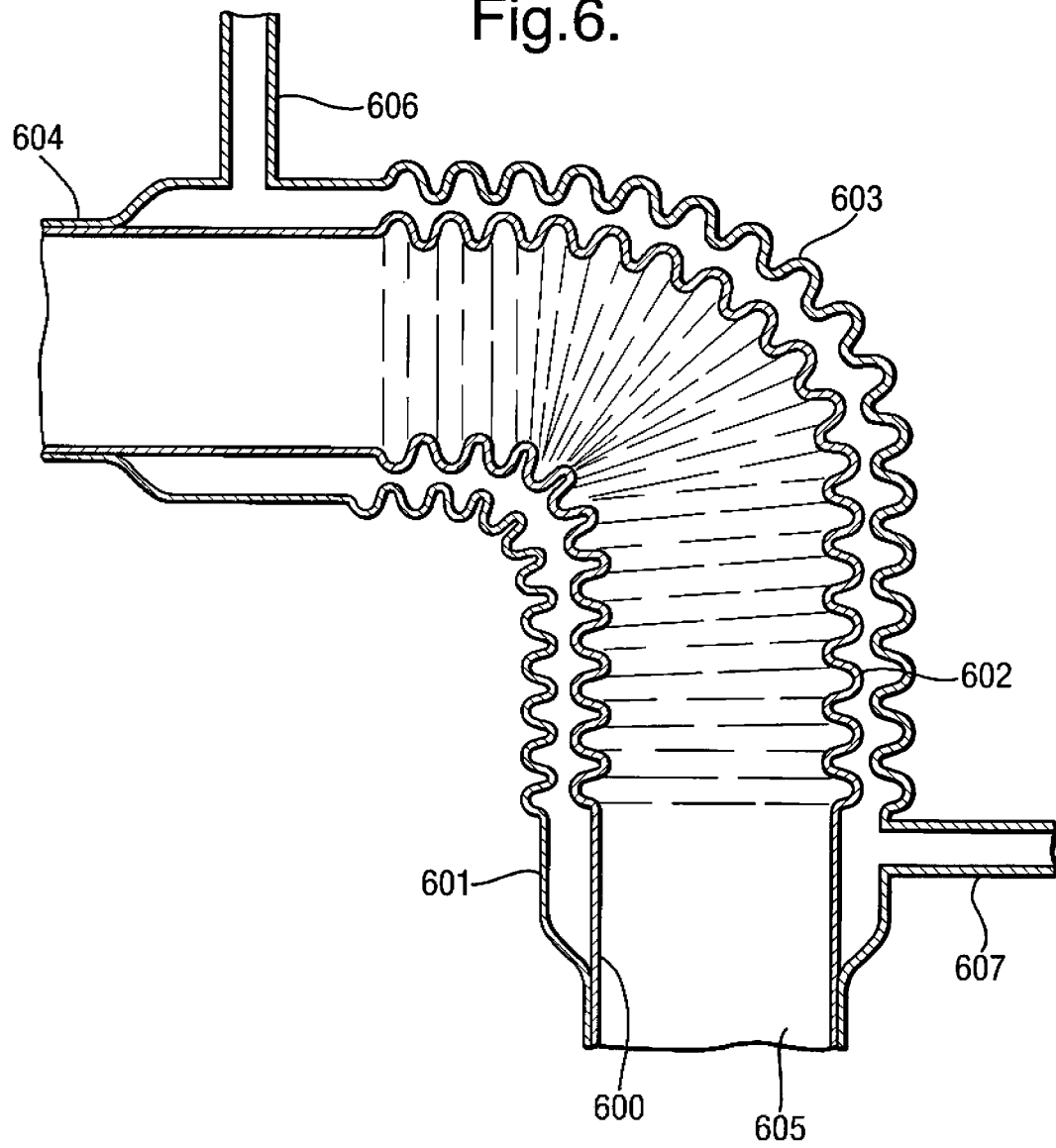


Fig.7.

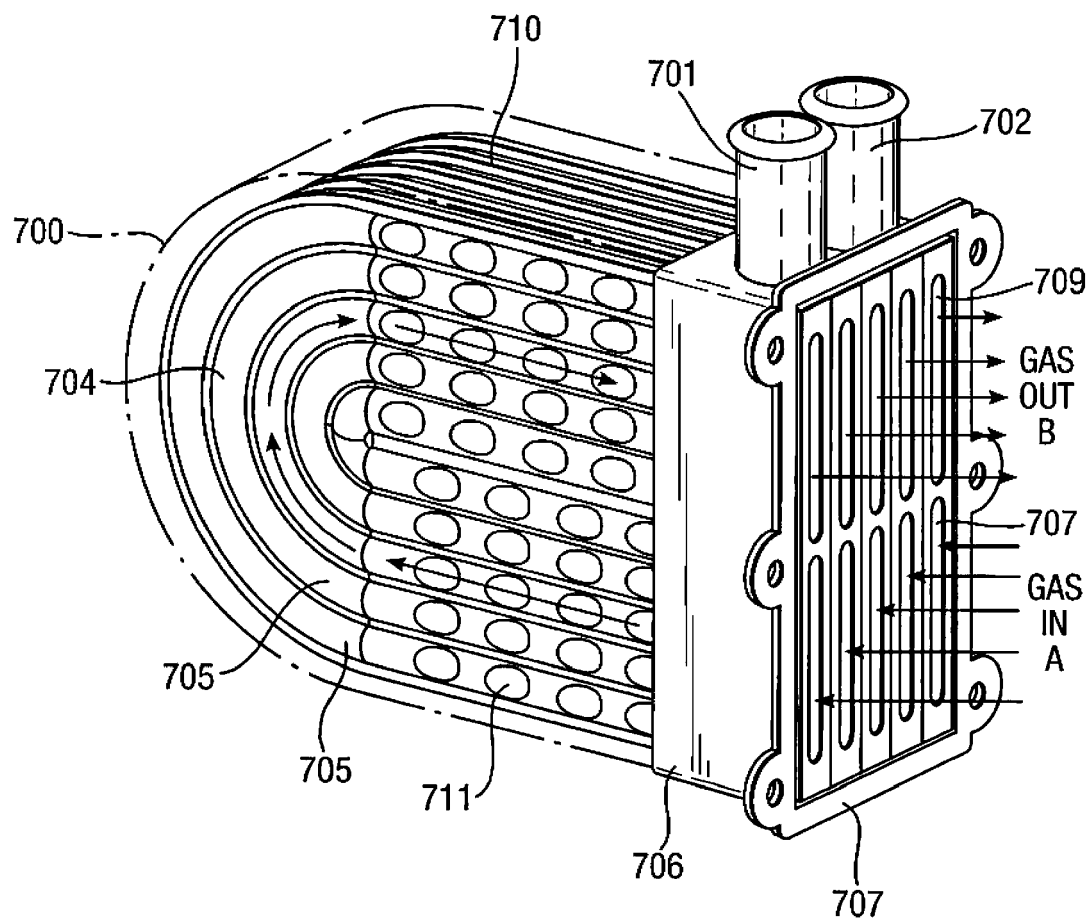


Fig.8.

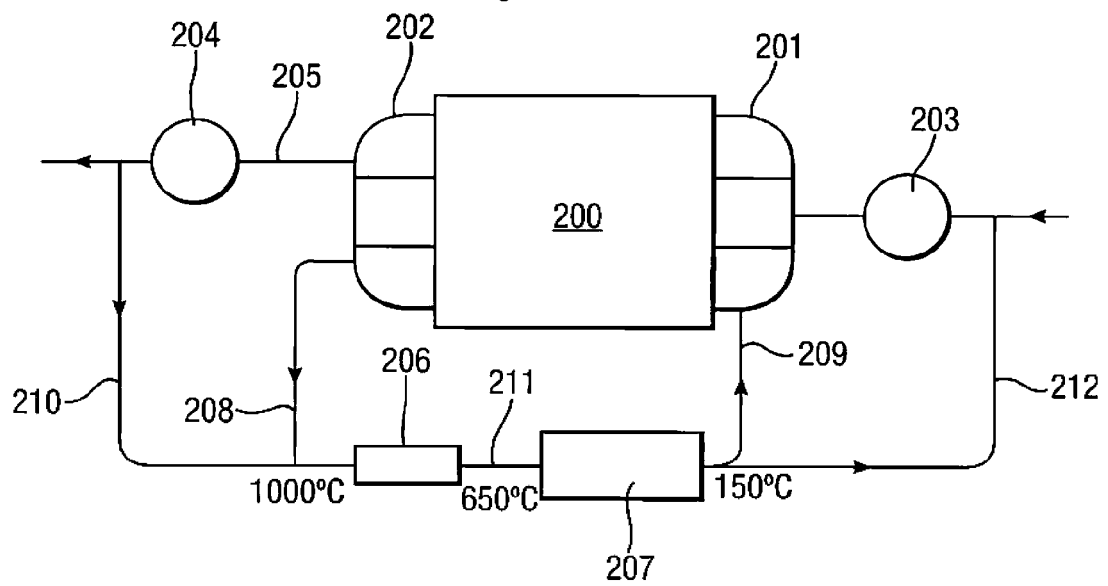


Fig.9a.

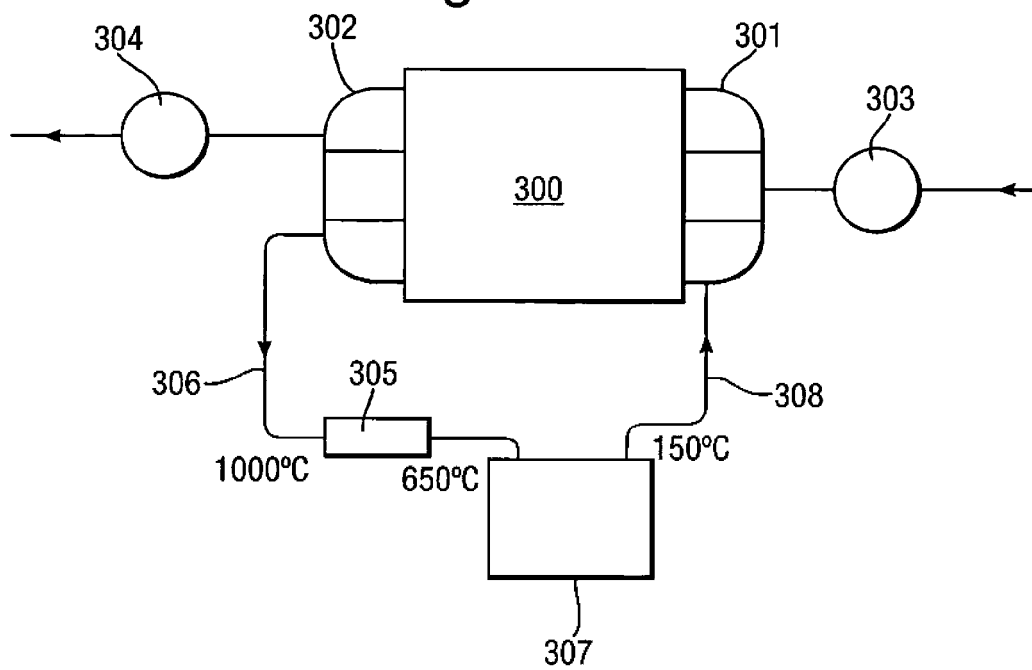


Fig.9b.

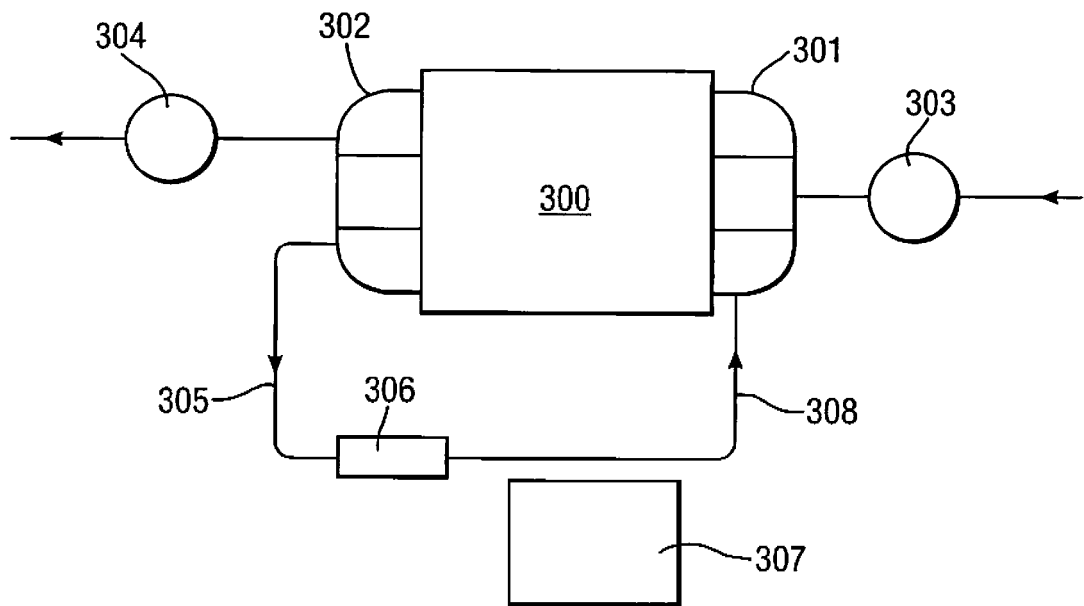


Fig.10.

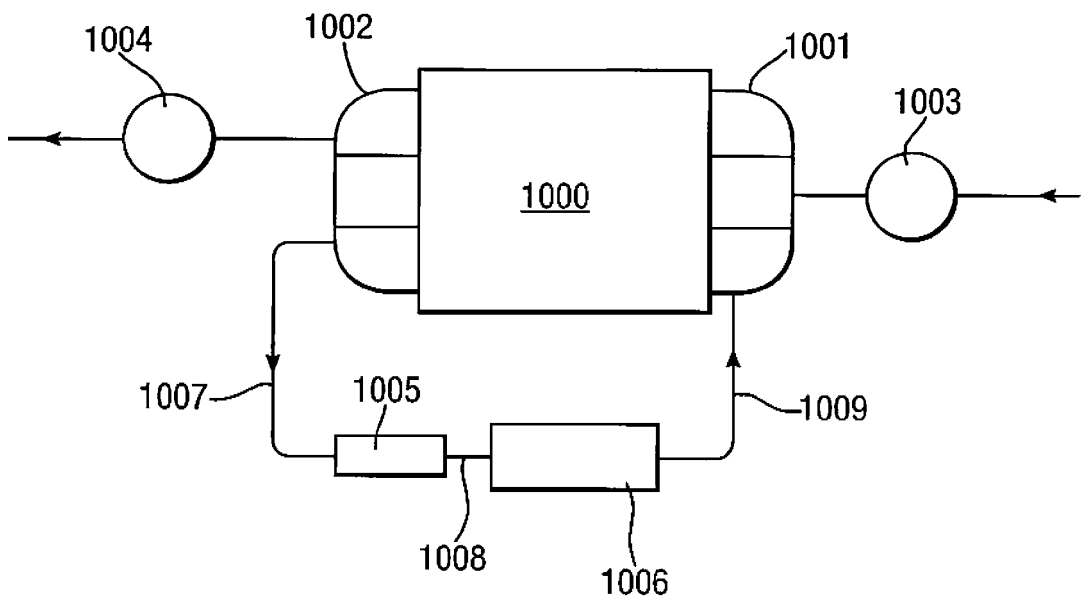


Fig.11.

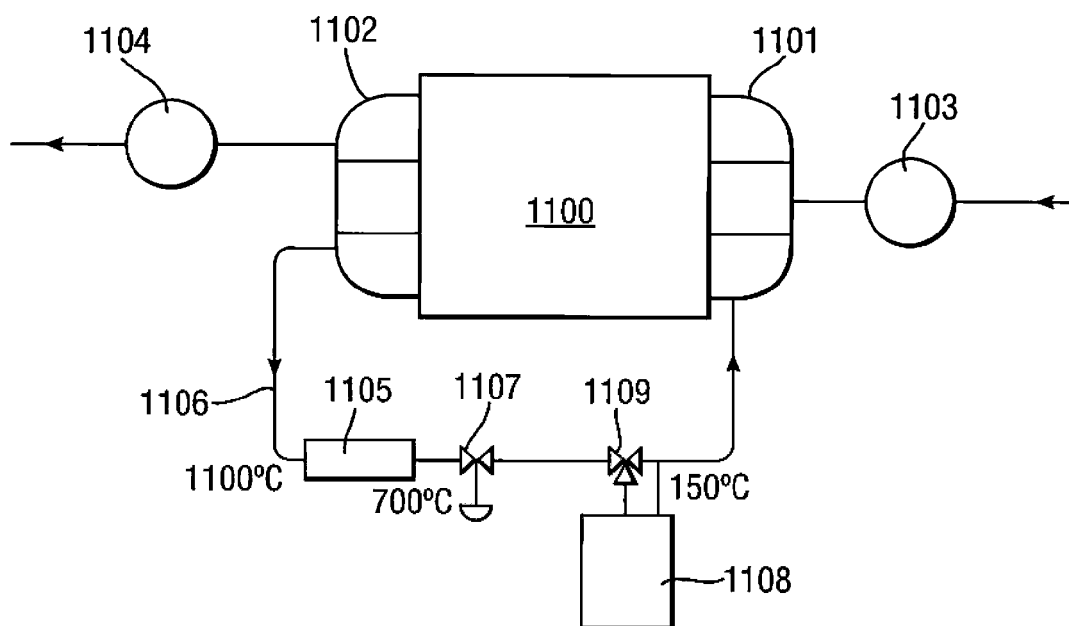


Fig.12.

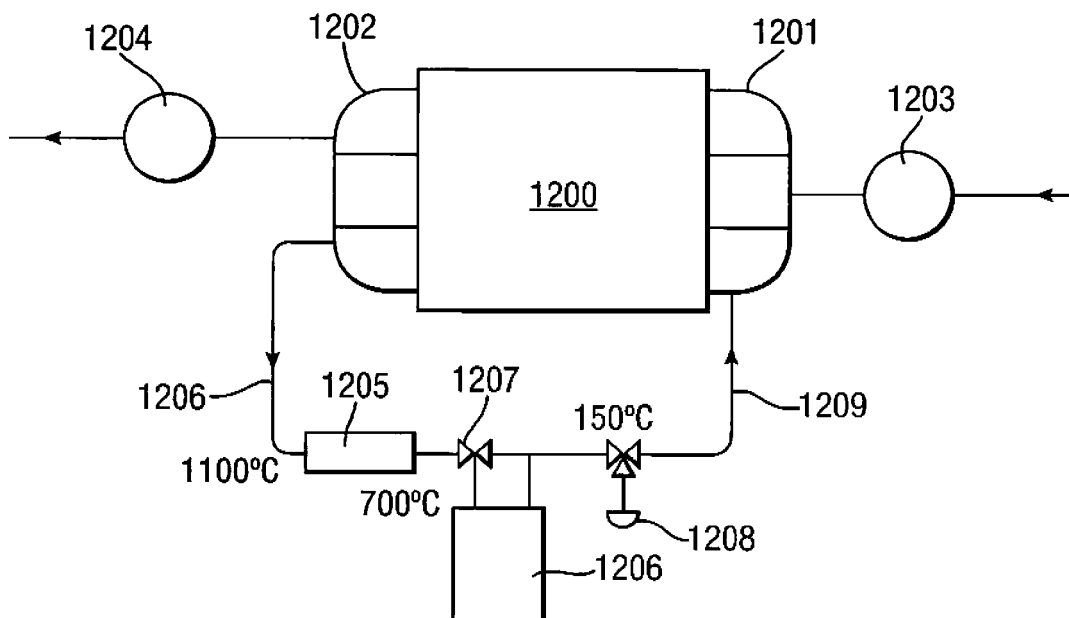
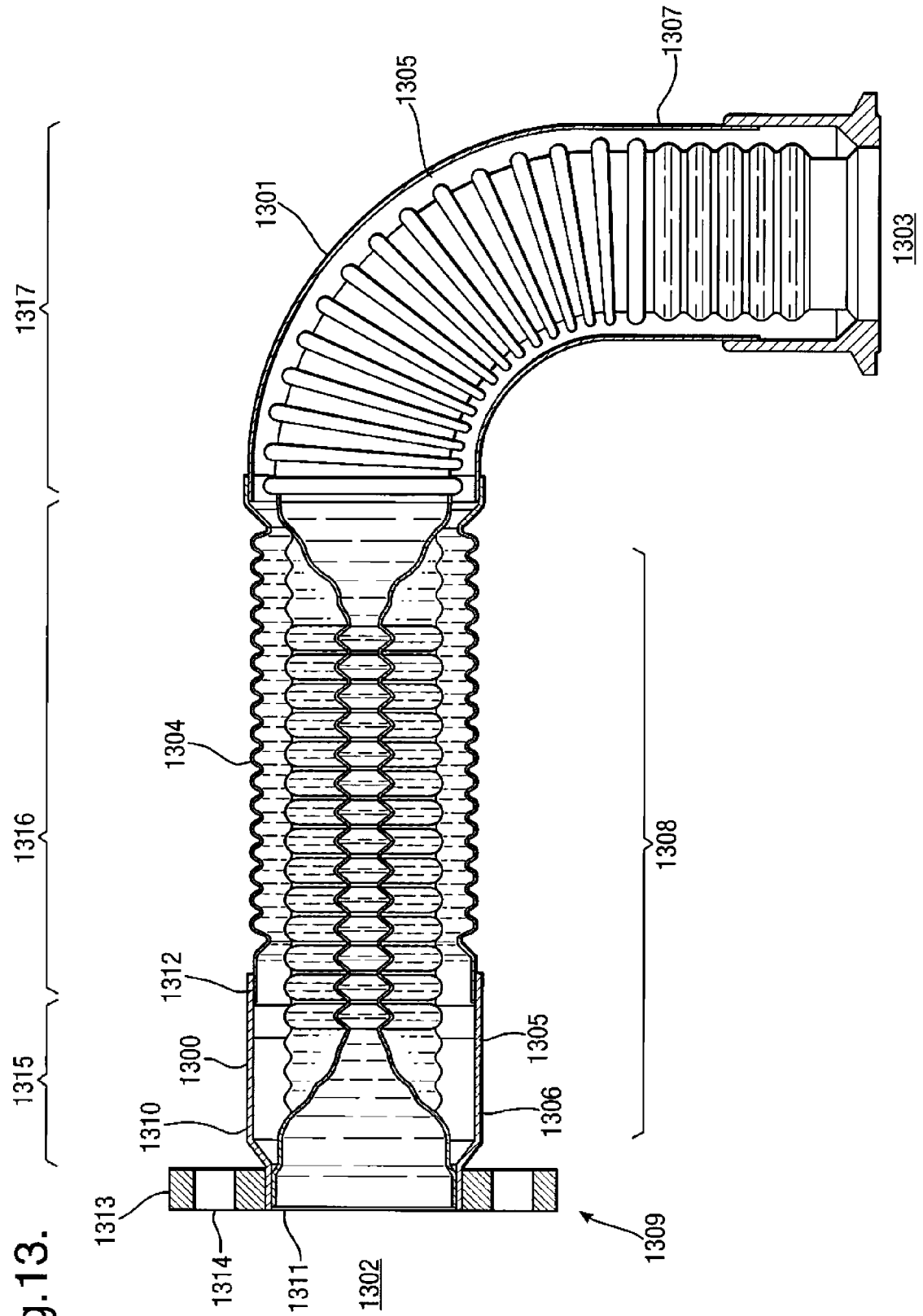


Fig.13.



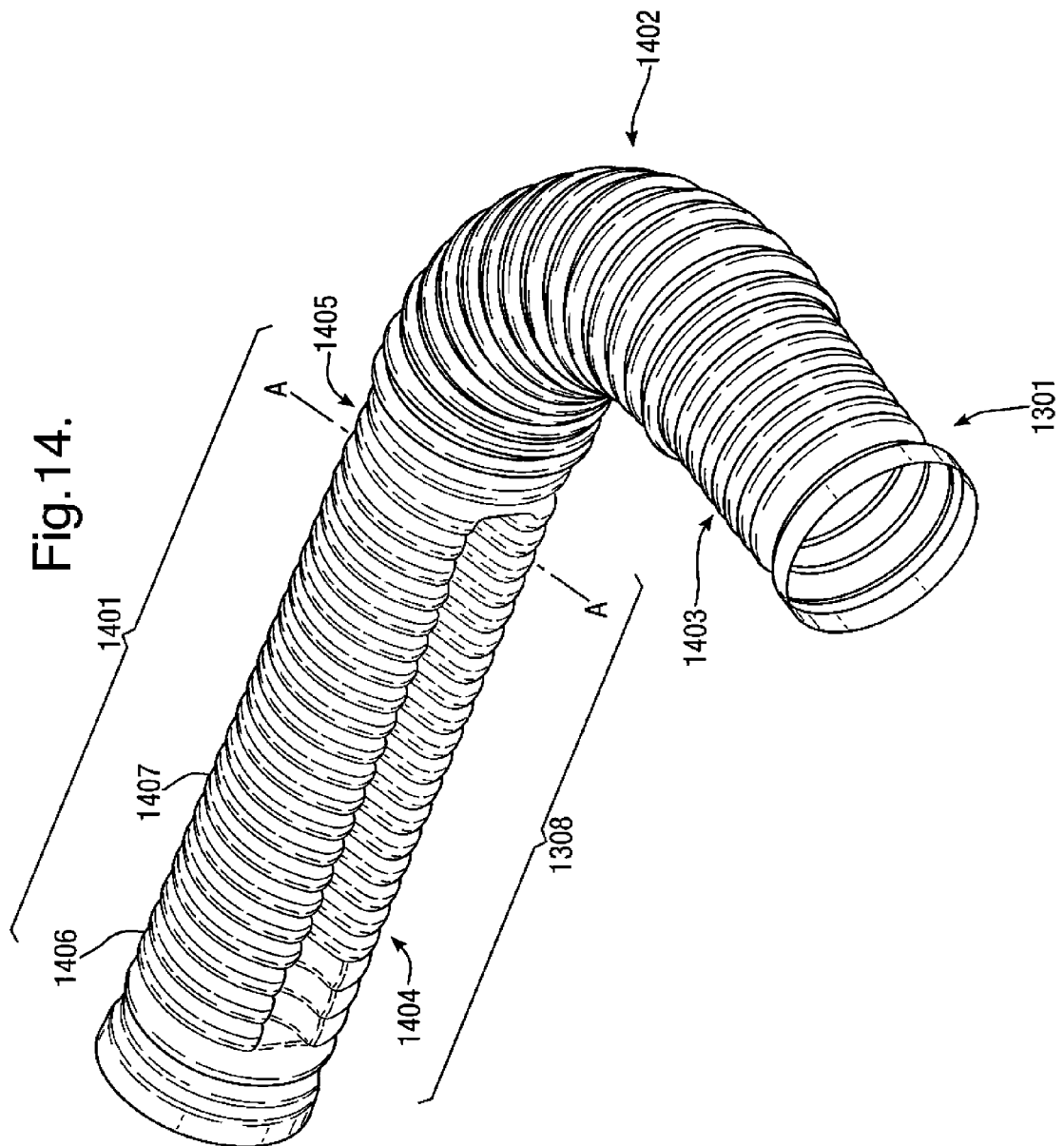


Fig.15.

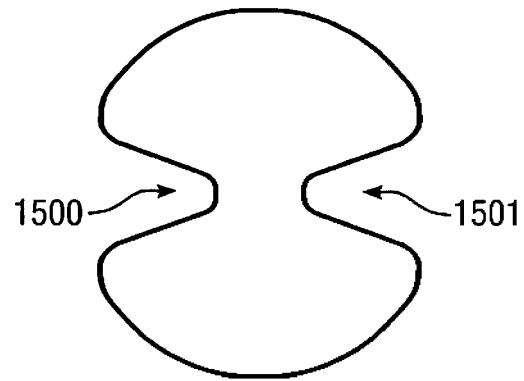


Fig.16.

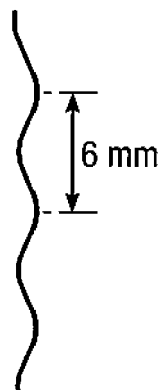
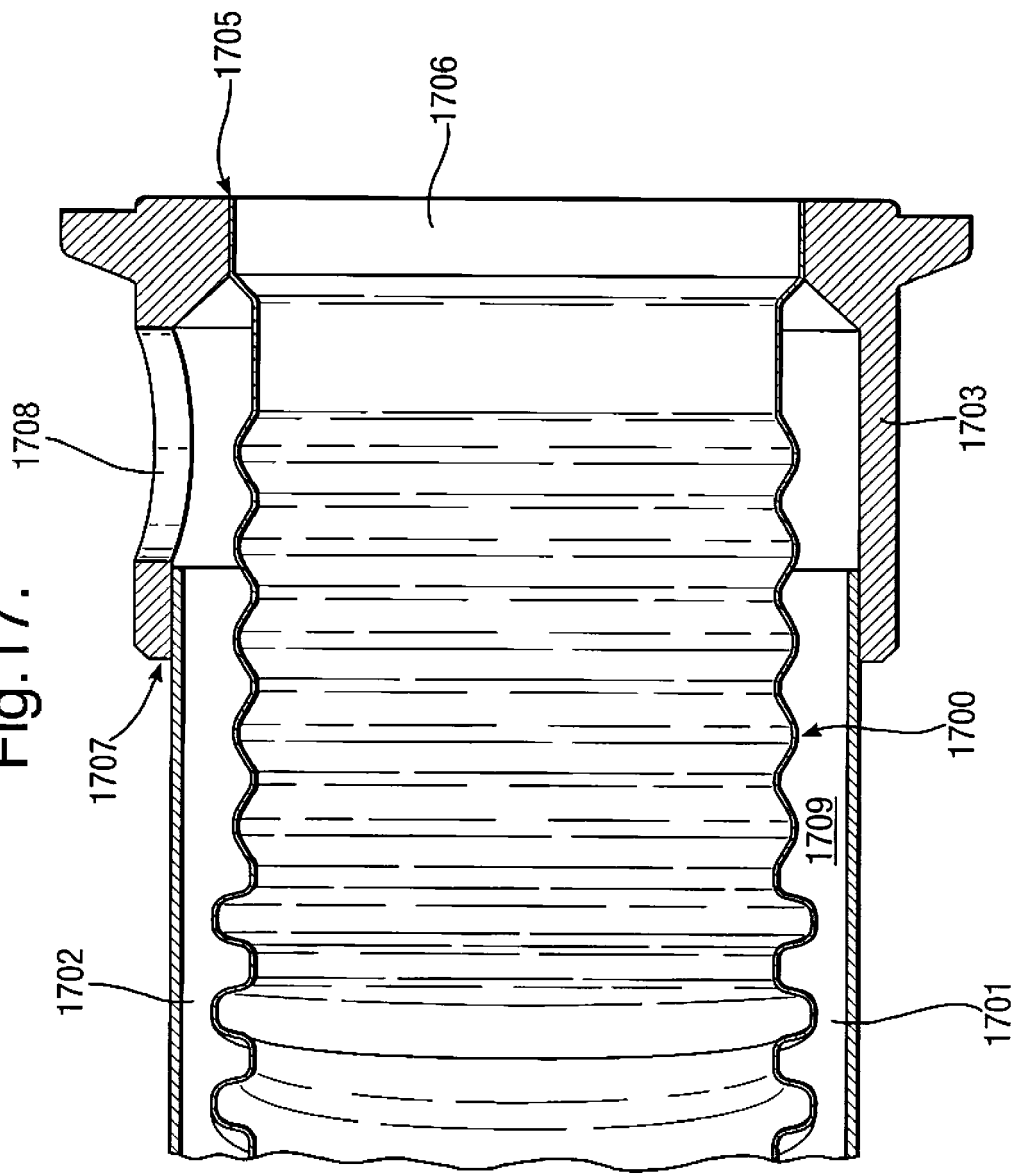


Fig.17.





EUROPEAN SEARCH REPORT

Application Number
EP 12 17 3479

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