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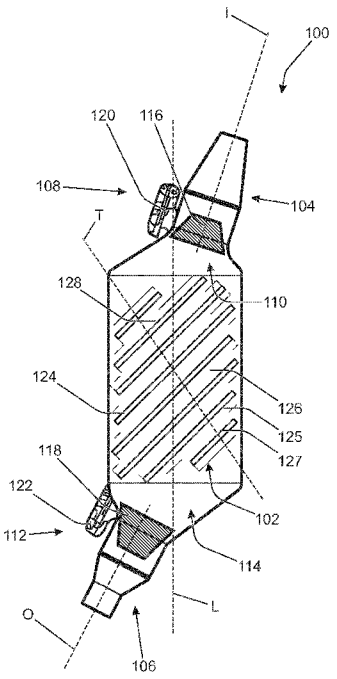


Fig. 5a

(57) Abstract: An energy recovery unit (100) for use in a vehicle exhaust system (6), the energy recovery unit (8) comprising an inlet (104) for receiving exhaust gas from the exhaust system (6), an outlet (106) for returning exhaust gas to the exhaust system (6), and a plurality of thermoelectric generators (102) disposed between the inlet (104) and the outlet (106). The energy recovery unit further comprises a gas pipe network configured to connect the inlet (104) and the outlet (106). The gas pipe network comprises a first duct (28) and a second duct (30), which both extend between the inlet (104) and the outlet (106) and are disposed along respective opposing ends of the plurality of thermoelectric generators (102). A generator axis (T) extending orthogonally to at least one of the plurality of thermoelectric generators (102) is inclined relative to a central longitudinal axis (L) of the energy recovery unit (100).

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ENERGY RECOVERY UNIT FOR VEHICLE USE

TECHNICAL FIELD

The present disclosure relates to an energy recovery unit for use in a vehicle exhaust system. Aspects of the invention relate to an energy recovery unit, and to a vehicle exhaust system or a vehicle incorporating such an energy recovery unit.

BACKGROUND

Thermoelectric generators (TEGs) convert heat energy to electrical energy using the Seebeck effect. A typical TEG comprises a pair of metal plates having high thermal conductivities with thermoelectric materials sandwiched between them.

It is well-known that vehicle engines are only about 30% efficient, and in normal use generate significant waste heat. Over recent years, TEG devices have been incorporated into vehicle exhaust systems in order to harness waste heat from the exhaust gas. This decreases the load of an electric generator such as an alternator on the engine, in turn improving fuel consumption.

A problem associated with using TEGs in this way is that they only operate efficiently over a relatively narrow temperature range – at low temperatures, energy generation is very inefficient; and at high temperatures, the thermoelectric materials are in danger of damage from overheating. In certain scenarios, it has been found that the leading edges of the TEGs may overheat before the majority of the TEG has reached a suitably high temperature for efficient operation to occur. As a result, the hot exhaust air must be diverted away from the thermoelectric materials using bypass valves to prevent damage to the TEG, thereby decreasing the system performance.

The present invention has been devised to mitigate or overcome at least some of the above-mentioned problems.

SUMMARY OF THE INVENTION

According to an aspect of the present invention there is provided an energy recovery unit for use in a vehicle exhaust system. The energy recovery unit comprises an inlet for receiving exhaust gas from the exhaust system, an outlet for returning exhaust gas to the exhaust system, and a plurality of thermoelectric generators disposed between the inlet and the outlet. The energy recovery unit further comprises a gas pipe network configured to connect the inlet and the outlet. The gas pipe network comprises a first duct and a second duct, which both extend between the inlet and the outlet and are disposed along respective opposing ends of the plurality of thermoelectric generators. A generator axis extending orthogonally to a heat-exchanging surface of at least one of the plurality of thermoelectric generators is inclined relative to a central longitudinal axis of the energy recovery unit.

By inclining the generator axis, the flow of exhaust gas between the inlet and the outlet can be guided in a desired direction. This can enable the exhaust gas flow to spread more evenly throughout the energy recovery unit in situations where the positioning and/or the orientation of the inlet and/or the outlet may otherwise concentrate flow in a portion of the energy recovery unit. Spreading the flow evenly throughout the energy recovery unit is desirable as it enables each thermoelectric generator to produce electrical energy at a similar level, which optimises energy generation by the unit as a whole.

The inlet of the energy recovery system may comprise an inlet passage that is inclined relative to the central longitudinal axis of the energy recovery unit, so that the inlet passage is inclined relative to the generator axis. Similarly, the outlet of the energy recovery unit may comprise an outlet passage that is inclined relative to the central longitudinal axis of the energy recovery unit. The option to incline the inlet and/or outlet of an energy recovery system without significantly compromising its energy generation is desirable as it allows the unit to be mounted at any point within the exhaust system.

The generator axis may be inclined relative to the central longitudinal axis in an opposite sense to the inlet passage and/or to the outlet passage.

In an embodiment, the generator axis may extend in a direction that is inclined relative to a direct path connecting the inlet and the outlet, so that the generator axis leads away from the outlet longitudinally. Orienting the thermoelectric generators in this manner is particularly advantageous in causing gas to spread out and increase energy generation by the generators. This is because leading edges of each thermoelectric generator create vortices that cause the gas to follow a longer, indirect path to the outlet. An added benefit of this feature is a reduction in back-pressure created within the system due to the spreading out of gas. This in turn improves engine performance.

The inlet and/or the outlet may be offset transversely from the central longitudinal axis. This is particularly useful for mounting purposes where space within a vehicle exhaust system is limited.

The thermoelectric generators may be disposed in parallel relation to one another, and may be spaced at regular intervals along the generator axis.

The energy recovery unit may further comprise a valve arrangement operable to direct exhaust gas entering the inlet between the first and second ducts, across each thermoelectric generator. The valve arrangement is therefore operable to vary the direction of exhaust gas flow across each thermoelectric generator. The valve arrangement may be operable to determine whether the exhaust gas flows from the first duct of the gas pipe network to the second duct, or from the second duct to the first duct.

This is a desirable feature that helps to prevent overheating of the leading edges of the thermoelectric generator. In addition, this feature advantageously allows an even heat distribution across the thermoelectric generators, allowing the level of generation of each generator to be similar.

The generator axis may be inclined at an acute angle relative to the central longitudinal axis of the energy recovery unit.

The opposing ends of the thermoelectric generators along which the first and second ducts extend may be inclined relative to the central longitudinal axis of the energy recovery unit.

The heat-exchanging surfaces of the plurality of thermoelectric generators may extend transversely across and/or longitudinally along the energy recovery unit.

The thermoelectric generators may be disposed with their heat-exchanging surfaces substantially orthogonal to walls of the energy recovery unit that at least partially define the first and second ducts.

The opposing ends of the thermoelectric generators along which the first and second ducts extend are optionally substantially parallel to walls of the energy recovery unit that at least partially define the first and second ducts.

According to another aspect of the invention, there is provided a vehicle exhaust system comprising the energy recovery unit of any preceding claim.

According to another aspect of the invention, there is provided a vehicle comprising the abovementioned energy recovery unit, or the abovementioned vehicle exhaust system.

Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination, unless such features are incompatible. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic block diagram of a vehicle incorporating an energy recovery unit according to an embodiment of the present invention, which may be implemented in a vehicle exhaust system;

Figure 2 is a transparent, perspective view of an example energy recovery unit showing an internal TEG module;

Figure 3 is an exploded, perspective view of the TEG module in the energy recovery unit of Figure 2;

Figures 4a to 4c are schematic side views of the energy recovery unit of Figure 2 shown operating in different modes; and

Figures 5a to 8 are transparent, plan views of the energy recovery unit of Figure 1 according to various embodiments of the present invention.

DETAILED DESCRIPTION

Figure 1 is a schematic block diagram of a vehicle 2 which comprises an engine 4 connected to a vehicle exhaust system 6. An energy recovery unit 8 is incorporated in the vehicle exhaust system 6 in accordance with an embodiment of the present invention. The hot exhaust gas from the vehicle exhaust system 6 passes through the energy recovery unit 8 before it is expelled from the vehicle 2. The energy recovery unit 8 harnesses the heat energy from the exhaust gas passing through it, converting the heat energy into electrical energy using thermoelectric generators (not shown in Figure 1).

Referring now to Figure 2, a transparent and perspective view of an energy recovery unit 8 is shown. It should be noted that in the interests of simplicity the energy recovery unit 8 of Figure 2 has TEG units 40 oriented orthogonally to a main flow direction of exhaust gas, unlike units of embodiments of the invention which are described later

and which have TEG units 40 inclined away from an orthogonal orientation. The energy recovery unit 8 shown in Figure 2 is therefore for informative purposes only to provide context regarding the structure of such energy recovery units in general terms, before moving on to consider the concepts and principles of operation that relate to the invention.

The energy recovery unit 8 comprises a TEG module 20 surrounded by a gas pipe network. The gas pipe network comprises an inlet in the form of an inlet pipe 24 and an outlet in the form of an outlet pipe 26, the inlet and outlet pipes 24, 26 being disposed at respective opposed ends of the energy recovery unit 8. Two separate bypass ducts 28, 30 are positioned above and below the TEG module 20 to connect the inlet and outlet pipes 24 and 26. The TEG module 20 comprises a plurality of TEG units 40 arranged in parallel to each other, orthogonal to and positioned at regular intervals along a main axis 42 of the TEG module 20, and spaced from the adjacent or neighbouring TEG unit(s) 40.

The energy recovery system 8 also comprises an inlet valve 32 positioned at the junction of the bypass ducts 28, 30 directly opposite and in the vicinity of the inlet pipe 24, and an outlet valve 34 positioned at the junction of the bypass ducts 28, 30 directly opposite and in the vicinity of the outlet pipe 26. The inlet valve 32 and the outlet valve 34 each comprise a valve flap 36, 38 which can be rotated to alter the orientation of the valves 32, 34, thereby controlling the direction of exhaust gas flow through the energy recovery unit 8, typically by guiding exhaust flow into and out of one of the bypass ducts 28, 30. Movement of each valve flap 36, 38 is controlled by a respective valve actuator (not shown) which controls the degree and direction of deflection of each valve flap 36, 38, thereby controlling the direction of exhaust gas flow through the energy recovery unit 8.

In some embodiments, the valve actuators are independently operable, such that one valve may be open to a greater extent than the other. In other embodiments, the valve actuators are operated using a single ‘master’ lever (not shown), enabling both valves to be controlled simultaneously, such that the deflections of the valve flaps mirror one another.

In some modes of operation, the exhaust gas passes from the inlet pipe 24 to the outlet pipe 26 exclusively through one or both of the bypass ducts 28, 30, bypassing the TEG module 20 entirely and defining a main gas flow direction. In other modes of operation, some or all of the exhaust gas flows through the TEG module 20 in a cross-flow direction that is substantially orthogonal to the main flow direction. A more detailed description of modes of operation of the energy recovery unit 8 is provided subsequently with reference to Figures 4a to 4c.

Figure 3 shows an exploded, perspective view of the TEG module 20 that is incorporated into the energy recovery unit 8 of Figure 2. As Figure 3 corresponds to Figure 2, it is again noted that the energy recovery unit 8 shown is for contextual purposes only.

The TEG module 20 comprises a plurality of TEG units 40 arranged in parallel to one another, and lying orthogonal to a plane containing a main axis 42 of the TEG module 20. The TEG units 40 are spaced at regular intervals along the main axis 42.

Each TEG unit 40 comprises a plurality of metal plates having high thermal conductivities with thermoelectric materials between them, sandwiched between covers made of a dielectric, substrate material (such as a ceramic). Outer faces of the dielectric covers define heat-exchanging surfaces of the TEG unit 40 – a hot-side heat-exchanging surface and a cold-side heat-exchanging surface. The hot-side heat exchanging surfaces of opposed TEG units 40 are defined by a common metal structure comprising a metal plate of each TEG unit 40 joined by a bridge to create a structure of generally ‘U’ shaped cross-section.

The TEG units 40 are arranged in use such that the main heat-exchanging surfaces are substantially orthogonal to the main axis 42 of the TEG module 20, with the TEG units 40 disposed in alternating orientation such that the hot-side heat exchanging surface of each TEG unit 40 faces the hot-side heat exchanging surface of a facing TEG unit 40.

The TEG module 20 further comprises a coolant pipe array 43. The coolant pipe array 43 comprises a plurality of U-flow coolant pipes 44 having an inlet end and an outlet

end, wherein both the inlet end and the outlet end are disposed at the same end of each U-flow coolant pipe 44, with one positioned above the other in the vertical direction. The coolant fluid within each U-flow coolant pipe 44 therefore flows in one direction into the U-flow coolant pipe 44 from the inlet, and in the opposite direction towards the outlet and out of the U-flow coolant pipe 44. The plurality of U-flow coolant pipes 44 are interspersed within the TEG module 20, such that each U-flow coolant pipe 44 is disposed between and in substantially parallel alignment with each pair of cold-side heat exchanging surfaces of opposed TEG units 40, and adjacent to the outward facing cold-side heat exchanging surfaces of the TEG units 40 at each end of the TEG module 20. Each U-flow coolant pipe 44 is arranged such that the portion of the pipe in which the coolant fluid flows in from the inlet extends substantially parallel to, and in contact with, the cold-side heat exchanging surface of the associated TEG unit 40.

The TEG module 20 further comprises a pair of parallel metal plates that extend substantially parallel to, and in contact with, the hot-side heat exchanging surface of each TEG unit 40. These plates create a series of channels defining exhaust gas passages 46 through which the exhaust gas may flow through the TEG module 20.

A plurality of wedges 48 are inserted in the TEG module 20 to separate adjacent U flow coolant pipes 44 of adjacent TEG units 40. A clamping band 50 extends around the perimeter of the TEG module 20, co-planar with the main axis 42 along which the components of the TEG module 20 are arranged. The TEG module 20 is further provided with a pair of bridge-like end buffers 52 positioned at either end of the main axis of the TEG module 20. After assembly, the wedges 48 remain in place in the TEG module 20 to ensure the coolant pipes 44 remain firmly in place.

Accordingly, in the TEG module arrangement shown in Figure 3, the main component parts are provided in the following order: U-flow coolant pipe 44, TEG unit 40, exhaust gas passage 46, TEG unit 40, U-flow coolant pipe 44, wedge 48, U-flow coolant pipe 44, TEG unit 40, exhaust gas passage 46, TEG unit 40, U-flow coolant pipe 44, wedge 48, and so on.

In use, hot exhaust gas is directed through the exhaust gas passages 46 of the TEG module 20, increasing the temperatures of the hot-side heat-exchange surfaces. Meanwhile cooling fluid (e.g. water) is passed through the cooling pipe array 43 of the TEG module 20 to maintain the temperatures of the cold-side heat exchange surfaces. This produces the necessary temperature gradient across each TEG unit 40 to produce energy. The use of cooling fluid maximises the temperature gradient and in turn the electrical output of each TEG unit.

In some embodiments, convector fins 53 such as those found in standard convection radiators may extend from each hot-side heat exchanging surface into the exhaust gas passages 46. The presence of the convector fins 53 increases the surface area of heat conductive material in contact with the hot exhaust gas, thereby increasing the heat transfer to the hot-side heat exchange surfaces along the exhaust gas passages 46.

Various measures are taken to ensure that the cold-side heat exchange surfaces are held in close contact with the U-flow coolant pipes 44 for maximised heat transfer. For example, as noted above wedges 48 are inserted between the adjacent U-flow coolant pipes 44. The clamping band 50 also generates an inwardly-directed clamping force on the TEG module 20 components, and the end buffers 52 spread the effects of this clamping force more evenly across the cross-section of the TEG module 20 to prevent any warping or deformation of the components due to uneven pressure.

It should be noted that all directional references herein, for example references to ‘left, ‘right’, ‘up’, ‘down’, ‘vertical’, and ‘horizontal’, are made with respect to the embodiments shown in the appended figures. However it will be appreciated that the energy recovery unit and its constituent components may be arranged and mounted in use in different orientations to those shown in the appended figures, and that such arrangements should be deemed to fall within the scope of the present invention, as defined by the accompanying claims.

Figures 4a to 4c are schematic side views of the energy recovery unit 8 of Figure 2, and illustrate different operating modes of the energy recovery unit 8. While applied here to the energy recovery unit 8 of Figures 2 and 3, which as already noted differs from energy recovery units of embodiments of the invention and is shown only to

provide context, the skilled reader will appreciate that the principles and operating modes discussed below are applicable to energy recovery units according to embodiments of the invention, such as those described later with reference to Figures 5a to 8.

Each operating mode is associated with a different configuration of the inlet and outlet valves 32, 34. Specifically, each operating mode is defined by the relative proportions of exhaust gas flowing through the TEG module 20 and the bypass ducts 28, 30, which are determined by the degree to which each valve flap 36, 38 is deflected relative to the main flow direction of the exhaust gas, and the directions in which the deflections occur. Three main modes of operation exist – a 'bypass' mode, illustrated in Figure 4a; a 'full flow' mode, illustrated in Figure 4b; and a 'feathering' mode, illustrated in Figure 4c.

In the bypass mode, neither the inlet valve flap 36 nor the outlet valve flap 38 is substantially deflected, and so remain substantially parallel to the main flow direction of the exhaust gas. This allows the exhaust gas to flow unimpeded from the inlet pipe 24 past each side of the inlet valve 32, into the bypass ducts 28, 30, past the outlet valve 34 and subsequently exit the energy recovery unit 8 through the outlet pipe 26 without entering the TEG module 20 at all.

It is noted that the exhaust gas will not change direction so as to enter an exhaust gas passage 46 of the TEG module 20 unless there is significant resistance to flow along the bypass ducts 28, 30. Therefore, in the bypass mode substantially all of the exhaust gas flows through the bypass ducts 28, 30.

The energy recovery unit 8 is operated in the bypass mode when the TEG module 20 is in danger of overheating. For example, this can occur when the exhaust gas entering the energy recovery unit 8 is at too high a temperature, or when the exhaust gas has been flowing through the TEG module 20 for a prolonged period of time.

In the full flow mode, the inlet valve flap 36 and outlet valve flap 38 are maximally deflected in opposite directions, each extending completely across a mouth of a different one of the bypass ducts 28, 30. This prevents the gas flow from exiting the

energy recovery unit 8 from the same bypass duct through which it entered, and so forces all of the exhaust gas through the TEG module 20, as no direct route through either bypass duct 28, 30 from the inlet pipe 24 to the outlet pipe 26 is available for the gas to flow.

For example, as may be seen from the plan view of Figure 4b, the inlet valve flap 36 is deflected maximally downwards, causing the exhaust gas to flow entirely into the upper bypass duct 30; however, as the outlet valve flap 38 is deflected maximally upwards, the exhaust gas cannot exit the energy recovery unit 8 through the outlet pipe 26 directly from the upper bypass duct 30. Instead, the exhaust gas from the upper bypass duct 30 is forced through the exhaust gas passages 46 of the TEG module 20 and into the lower bypass duct 28, in order to reach the outlet pipe 26. The direction of cross-flow through the gas passages 46 of the TEG module 20 may be reversed by reversing the direction of deflection of the input and output valve flaps 36, 38 (as indicated by the dotted lines in Figure 4b).

As a result of efficient heat exchange between the exhaust air and the metal plates of the TEG units 40, and the electrical energy generated from that heat, the exhaust gas cools significantly as it passes through each exhaust gas passage 46. Therefore the leading edges of each TEG unit 40 heat up much more quickly than the rest of the unit.

In an embodiment of the present invention, the direction of deflection of the valve flaps 36, 38, and hence the direction of cross-flow through the exhaust gas passages 46 of the TEG module 20, is periodically alternated. This prevents overheating of the leading edges of the TEG module 20, thereby prolonging its lifespan.

The performance of the energy recovery unit 8 is also improved as the alternating flow creates a more even temperature profile across each hot-side heat exchanging surface than is achieved with a single direction flow. This means that the bypass mode is used less frequently, and more of the exhaust gas is utilised by the TEG module 20 to generate electricity.

In the feathering mode, shown in Figure 4c, the inlet and outlet valve flaps 36, 38 are deflected to different degrees, with neither bypass duct 28, 30 fully closed. This allows

some gas flow through the bypass ducts 28, 30, but creates sufficient resistance to flow to force some of the exhaust gas into the TEG module 20. The feathering mode may therefore be thought of as a combination of the bypass and full flow modes.

For example, as may be seen in Figure 4c, the inlet valve flap 36 is deflected maximally downwards, while the output valve flap 38 remains substantially parallel to the main flow direction. The exhaust gas therefore flows along one of two paths: the first path corresponds to direct flow from the inlet pipe 24 to the outlet pipe 26 through the upper bypass duct 30; the second path corresponds to flow from the upper bypass duct 30, through the gas passages 46 of the TEG module 20 to the lower bypass duct 28, and into the outlet pipe 26.

The degree and direction of deflection of the output valve flap 38 may be varied (as indicated by the dotted line in Figure 4c) depending on the proportion of gas that is intended to flow through the gas passages 46 of the TEG module 20. A greater upwards deflection of the outlet valve flap 38 in Figure 4c results in a higher proportion of gas passing through the TEG module 20.

This mode is useful to ensure that at high gas temperatures the amount of exhaust gas passing through the TEG module 20 (and hence the amount of heat input to each TEG unit 40) is supported by the cooling capabilities of the coolant pipe array 43.

Although specific valve deflections are shown in Figures 4a to 4c, it should be noted that the functionality of the energy recovery unit 8 would not be substantially affected if the deflections of the inlet valve flap 36 and the outlet valve flap 38 were to be reversed from that which is illustrated. For example, in the feathering mode, it is sufficient for either one of the valve flaps 36, 38 to be maximally deflected in a particular direction, so long as the angle of deflection of the other valve flap remains variable, in order to control the amount of exhaust gas flowing through the TEG module 20.

It should be noted that the presence of independently operable valves would be a useful element of those embodiments where the energy recovery unit operates in the feathering mode, as this would enable precision control of each valve flap. By

comparison, the presence of a 'master' lever would be a useful addition in those embodiments where the energy recovery unit operates in the bypass or full flow modes, as the degree of deflection of the two valve flaps should ideally mirror each other. The use of the master lever to automate the valve deflections would be particularly useful when periodically alternating flow is required.

At this point, it is noted that the energy recovery units described above provide context for the present invention which may alternatively be applied to other types of unit, for example units incorporating only a single bypass duct. It will be appreciated that the concepts described above in relation to Figures 2 to 4 are applicable and adaptable to be used in conjunction with embodiments of the present invention described below with reference to Figures 5a to 8.

Figures 5a and 5b illustrate complementary embodiments of the invention which mirror each other. As will become clear in the description that follows, embodiments of the invention provide energy recovery units having inlet and outlet pipes that are offset from a central longitudinal axis of the unit and/or angled with respect to the central axis. These arrangements increase flexibility in positioning of energy recovery units within a vehicle environment. For example, these features may allow an energy recovery unit to be mounted in the vicinity of a bend in the exhaust system, and thus use the available space efficiently.

However, configuring the inlet and/or outlet in this manner influences the direction of exhaust gas flow into and through the energy recovery unit, which may lead to an uneven flow distribution. This in turn creates unequal heat flux across each TEG unit within the energy recovery unit, which reduces the efficiency of energy recovery. In this respect, it is noted that optimised energy recovery requires equal flow through each exhaust gas passage so that each TEG unit receives the same heat flux, with that flow spread evenly across the hot-side heat exchanging surface of the TEG unit.

To mitigate the uneven flow distribution that may otherwise be caused by inclining or offsetting the inlet or the outlet, embodiments of the invention provide TEG modules in which the TEG units are not orthogonal to a longitudinal axis of the energy recovery unit; instead, the TEG units are oriented diagonally. As shall be explained, this

configuration draws exhaust gas flow in a desired direction to improve flow distribution through the energy recovery unit.

This configuration also provides an added benefit in allowing each TEG unit to be bolted to adjacent units, whereas in the module shown in Figures 2 and 3 in which all TEGs are in alignment a common bolt is typically used to couple all of the TEG units together. The relative thermal expansion of adjacent units is less than the relative expansion of the first and last units, and so the ability to couple adjacent units provides lower thermal stresses in the module during use than would be present with the clamp discussed in relation to the module of Figures 2 and 3.

Considering the embodiments shown in Figures 5a and 5b specifically now, these embodiments, similarly to the energy recovery unit 8 of Figures 2 to 4, provide an energy recovery unit 100 that comprises a TEG module 102 surrounded by a gas pipe network. The gas pipe network comprises an inlet in the form of an inlet pipe 104, and an outlet in the form of an outlet pipe 106, the inlet and outlet being disposed at respective opposed ends of the energy recovery unit 100. Two separate bypass ducts (not shown in Figures 5a and 5b) are positioned above and below the TEG module 102, enclosed by outer walls (also not shown in Figures 5a and 5b) of the energy recovery unit 100, to connect the inlet and outlet pipes 104, 106.

Both the inlet pipe 104 and the outlet pipe 106 are oriented at an acute angle relative to the bypass ducts. Therefore, the direction in which gas flows through the bypass ducts of the unit varies longitudinally, and so there is no identifiable coherent main flow direction as in the arrangement shown in Figure 2. Therefore, a central longitudinal axis L of the energy recovery unit 100 shall be used as a reference point instead in the description that follows. As can be seen in Figure 5a, the central longitudinal axis L extends longitudinally through the energy recovery unit 100 between an end of the unit 100 including the inlet pipe 104 and an end including the outlet pipe 106, and is disposed midway between opposed sides of the energy recovery unit 100 in the transverse direction.

Unlike the Figure 2 arrangement, in the embodiments shown in Figures 5a and 5b the inlet and outlet pipes 104, 106 are offset from the central longitudinal axis L of the unit

100, each pipe 104, 106 being disposed to a respective side of the central longitudinal axis L so that the inlet and outlet pipes 104, 106 are almost in alignment with one another despite being inclined relative to the central longitudinal axis L of the energy recovery unit 100.

The energy recovery system 100 also comprises an inlet valve 108 positioned at the junction 110 of the bypass ducts directly opposite and in the vicinity of the inlet pipe 104, and an outlet valve 112 positioned at the junction 114 of the bypass ducts directly opposite and in the vicinity of the outlet pipe 106. The inlet valve 108 and the outlet valve 112 each comprise a valve flap 116, 118, which can be rotated to alter the orientation of the valves 110, 112, thereby controlling the direction of exhaust gas flow through the energy recovery unit 100, typically by guiding exhaust flow into and out of one of the bypass ducts. Movement of each valve flap 116, 118 is controlled by a respective valve actuator 120, 122 which controls the degree and direction of deflection of each valve flap 116, 118, thereby controlling the direction of exhaust gas flow through the energy recovery unit 100.

The inlet and outlet valve flaps 116 and 118 are also angled relative to the longitudinal axis L of the energy recovery unit 100. That is to say, the angle at which gas predominantly flows across the valve flaps 116, 118 is not aligned with the longitudinal axis L of the energy recovery unit 100. The valve flaps are trapezoidal in form, and are pivoted for rotation about a shaft positioned along an axis located at or near a midpoint between the leading and trailing ends of each flap 116, 118.

The TEG module 102 is disposed between the bypass ducts and comprises a plurality of TEG units 125, wedges and U-flow cooling pipe combinations 124 of varying lengths arranged in parallel to one another, so that the heat-exchanging surfaces of the TEG units 125 are substantially orthogonal to the outer walls of the TEG module 102 that in part define the bypass ducts. The TEG unit 125, wedge, U-flow cooling pipe combinations 124 are spaced from each other at regular intervals along a TEG axis T so as to define a plurality of exhaust gas passages 126. The bypass ducts extend along respective opposing ends of the TEG units 125 so that the gas passages 126 provide communication between the bypass ducts in directions into and out of the page as viewed in Figures 5a and 5b.

The TEG units 125 are oriented in parallel to respective planes of the opposed outer walls of the energy recovery unit 100 that in part define the bypass ducts, so that the bypass ducts have a substantially uniform cross-section longitudinally along the central longitudinal axis.

The TEG axis T is orthogonal to the heat-exchanging surfaces of each TEG unit 125, and is inclined at an acute angle relative to the longitudinal axis L of the energy recovery unit 100. As a result, the opposing ends of the TEG units 125 along which the bypass ducts extend, defining leading edges 128 of the TEG units 125, are inclined relative to the longitudinal axis L. This means that the TEG units 125 extend both transversely across and longitudinally along the energy recovery unit 100.

It should be noted that the TEG axis T and respective axes I, O of the inlet and/or outlet pipes 104, 106 are angled in opposite senses relative to the longitudinal axis L of the energy recovery unit 100, to the extent that the TEG units 125 are almost parallel to the axes I, O of the inlet and outlet pipes 104, 106. That is, that the angle between the TEG axis T and the axis I, O of either the inlet pipe or the outlet pipe 104, 106 is greater than or equal to the angle between the longitudinal axis L of the energy recovery unit 100 and the TEG axis T or between the longitudinal axis L of the energy recovery unit 100 and the axis I, O of an inlet or outlet pipe 104, 106.

In use, the valve flaps 116, 118 are actuated according to the schematic diagrams shown in Figures 4a to 4c. When in full flow mode, corresponding to the valve configuration shown in Figure 4b, all hot exhaust gas passes through the angled exhaust gas passages 126.

At this stage, it is noted that exhaust gas flowing out of the inlet pipe 104 will not change direction unless an external force acts on it. As the inlet pipe 104 is inclined relative to and offset from the central longitudinal axis L of the energy recovery unit 100, exhaust gas exiting the inlet pipe 104 flows generally diagonally across the TEG module 102 and almost directly towards the outlet pipe 106, unless that flow is diverted from this path. If not diverted, the majority of exhaust gas would flow across one side of the TEG module 102 only, resulting in poor heat distribution throughout the TEG

module 102 and therefore inefficient energy generation. For example, in the embodiment shown in Figure 5a, exhaust gas will tend to flow mainly down the left side as viewed in the figure, unless that gas is re-directed.

It is for this reason that the TEG units 125 are angled as they are in the embodiments of Figures 5a and 5b. As shall now be explained, by orienting the TEG units 125 almost parallel to the angle at which exhaust gas enters the energy recovery unit 100, the exhaust gas can be re-directed and distributed more evenly across the TEG module 102. This allows more efficient recovery of heat energy from those gases.

It is first noted that the leading edges 128 of the TEG units 125 act as vortex generators as exhaust gas passes over them. The creation of vortices at the leading edges 128 creates low pressure areas immediately beneath those edges. The resulting pressure differential acts to draw gas along the leading edges 128 and into the respective exhaust gas passages 126. The succession of vortices created by the series of TEG units 125 of the TEG module 102 therefore has the net effect of drawing exhaust gas towards the furthest TEG unit 127 from the inlet 104. If there are a sufficient number of TEG units 125, this ultimately has the effect of diverting the exhaust gas flow until it aligns with the TEG axis T.

In this way, the orientation of the TEG units 125 influences the path that exhaust gas takes through the bypass ducts. So, the angle at which the TEG units 125 are oriented can be determined to provide optimised heat distribution throughout the energy recovery unit 100, and in turn maximise generation of electrical energy.

Due to the angling of the TEG units 125 relative to the longitudinal axis L of the energy recovery unit 100, resulting in the furthest TEG unit 127 being positioned in the adjacent corner of the energy recovery unit 100 to the outlet pipe 106, the vortices created by the TEG units 125 act to divert exhaust gas flow away from the outlet pipe 106. This spreads the exhaust gas more evenly across the TEG module 102, which improves the flow of heat throughout the bypass ducts in full flow mode. In turn, the efficiency of the energy recovery unit 100 is improved compared with a module such as that shown in Figure 2 having TEG units 40 oriented orthogonally to the longitudinal axis L.

In other embodiments, in certain circumstances energy recovery units with both inlet and outlet pipes extending substantially parallel to the central longitudinal axis of the unit and an angled TEG module will benefit from a TEG axis that is inclined relative to the longitudinal axis, so as to draw gas flow away from the outlet pipe as in the above embodiments. For example, if the inlet pipe and the outlet pipe are opposite one another and offset from the central axis of the unit, an angled TEG axis prevents gas flowing entirely down one side of the unit between the inlet and outlet pipes, which would result in poor energy recovery. In this example, as in other embodiments, the TEG axis is angled to lead gas flow away from the corner of the TEG module nearest the outlet pipe, towards the opposite side of the TEG module. This effectively leads the gas flow away from the outlet, causing the gas to take a longer path to the outlet and thereby spread out more throughout the TEG module. Beneficially, causing the gas to spread out more reduces back pressure created within the system, and so minimises the impact of the TEG module on engine performance.

Figures 6a and 6b and Figures 7a and 7b illustrate respective pairs of complementary, mirror-image energy recovery units 200, 300 according to respective embodiments of the invention. Each of these four embodiments relates to an energy recovery unit having only one angled inlet or outlet pipe. In Figures 6a and 6b, energy recovery units with an angled outlet pipe 204 and a straight inlet pipe 202 are shown, whereas Figures 7a and 7b illustrate energy recovery units 300 with an angled inlet pipe 302 but a straight outlet pipe 304.

Aside from the altered configurations of the inlet and outlet pipes, the energy recovery units 200, 300 shown in Figures 6a to 7b are generally identical to those described above with reference to Figures 5a and 5b. In particular, it should be noted that, as for the embodiments of Figures 5a and 5b, in the energy recovery units shown in Figures 6a to 7b the angle of the TEG axis relative to the inlet or outlet pipe is greater than or equal to the angle between the longitudinal axis of the energy recovery unit and either axis. It is envisaged that the angle of the TEG axis relative to the inlet or outlet pipe would typically be between 30 and 70 degrees. An angle in this range generates an advantageous vortex on the inlet edge of each TEG unit, improving flow distribution within the energy recovery unit.

In addition, in each embodiment the TEG axis is oriented to lead away from the outlet, such that the TEG unit that is furthest from the inlet pipe is disposed in an adjacent corner of the energy recovery unit to a corner nearest to the outlet pipe. Said another way, the TEG axis is inclined relative to a hypothetical direct, straight line path drawn between the inlet pipe and the outlet pipe. As in the earlier embodiments, this configuration ensures that exhaust gas is drawn away from the outlet pipe as it travels through the bypass ducts, and so is dispersed across the TEG module effectively for optimised energy recovery.

Figure 8 illustrates an alternative embodiment of an energy recovery unit 400, which similarly to previous embodiments has an inlet pipe 402 and an outlet pipe 404 having respective axes I, O that are inclined relative to the central longitudinal axis L of the unit 400. Unlike previous embodiments, the unit 400 includes a TEG module 102 that is positioned within the unit 400 so that its TEG units 125 lie on a TEG axis T that is inclined relative to the central longitudinal axis L in the same sense as the inlet/outlet axes I, O; in the previously described embodiments, the TEG axis T and the inlet/outlet axes I, O are inclined in opposite senses with respect to the central longitudinal axis L.

Configuring the TEG module 102 in this way relative to the inlet pipe 402 and the outlet pipe 404 represents an alternative way to improve flow distribution within the energy recovery unit 400. Due to the slight angle between the TEG axis T and the inlet axis I, a vortex forms across the inlet, urging flow to deviate from the path it would ordinarily take through the unit 400 across the TEG units 125, thus causing the exhaust gas to take an indirect route to the outlet pipe 404. As in previous embodiments, this improves energy recovery by spreading heat energy more evenly across the TEG module 102.

In further embodiments it is conceivable that an inlet and outlet may be oriented in opposite directions, in which case the TEG axis T would be in an opposite direction to the angle of the inlet pipe.

Although the illustrations shown in Figures 5a to 8 are plan views only, it will be appreciated that the angling of the inlet and outlet pipes of each embodiment need not

be restricted to a single plane. Rather, it may be advantageous in certain situations to have an inlet pipe acutely angled in two planes relative to the longitudinal axis of the energy recovery unit.

Many modifications may be made to the above examples without departing from the scope of the present invention as defined in the accompanying claims.

CLAIMS

1. An energy recovery unit for use in a vehicle exhaust system, the energy recovery unit comprising:

an inlet for receiving exhaust gas from the exhaust system;

an outlet for returning exhaust gas to the exhaust system;

a plurality of thermoelectric generators disposed between the inlet and the outlet; and

a gas pipe network configured to connect the inlet and the outlet, the gas pipe network comprising a first duct and a second duct, the first and second ducts extending between the inlet and the outlet and disposed along respective opposing ends of the plurality of thermoelectric generators;

wherein a generator axis (T) extending orthogonally to a heat-exchanging surface of at least one of the plurality of thermoelectric generators is inclined relative to a central longitudinal axis (L) of the energy recovery unit.

2. The energy recovery unit of claim 1, wherein the inlet comprises an inlet passage that is inclined relative to the central longitudinal axis (L) of the energy recovery unit, so that the inlet passage is inclined relative to the generator axis (T).

3. The energy recovery unit of claim 2, wherein the generator axis (T) is inclined relative to the central longitudinal axis (L) in an opposite sense to the inlet passage.

4. The energy recovery unit of any preceding claim, wherein the outlet comprises an outlet passage that is inclined relative to the central longitudinal axis (L) of the energy recovery unit.

5. The energy recovery unit of claim 4, wherein the generator axis (T) is inclined relative to the central longitudinal axis (L) in an opposite sense to the outlet passage.

6. The energy recovery unit of any preceding claim, wherein the generator axis (T) extends in a direction that is inclined relative to a direct path connecting the inlet and the outlet.

7. The energy recovery unit of any preceding claim, wherein the inlet and/or the outlet is offset transversely from the central longitudinal axis (L).

8. The energy recovery unit of any preceding claim, wherein the thermoelectric generators are disposed in parallel relation to one another.

9. The energy recovery unit of any preceding claim, wherein the thermoelectric generators are spaced at regular intervals along the generator axis (T).

10. The energy recovery unit of any preceding claim, further comprising a valve arrangement operable to direct exhaust gas entering the inlet between the first and second ducts across each thermoelectric generator, wherein the valve arrangement is operable to vary the direction of exhaust gas flow across each thermoelectric generator.

11. The energy recovery unit of claim 10, wherein the valve arrangement is operable to determine whether the exhaust gas flows from the first duct of the gas pipe network to the second duct, or from the second duct to the first duct.

12. The energy recovery unit of any preceding claim, wherein the generator axis is inclined at an acute angle relative to the central longitudinal axis (L) of the energy recovery unit.

13. The energy recovery unit of any preceding claim, wherein the opposing ends of the thermoelectric generators along which the first and second ducts extend

are inclined relative to the central longitudinal axis (L) of the energy recovery unit.

14. The energy recovery unit of any preceding claim, wherein the heat-exchanging surfaces of the plurality of thermoelectric generators extend transversely across the energy recovery unit.

15. The energy recovery unit of any preceding claim, wherein the heat-exchanging surfaces of the plurality of thermoelectric generators extend longitudinally along the energy recovery unit.

16. The energy recovery unit of any preceding claim, wherein the thermoelectric generators are disposed with their heat-exchanging surfaces substantially orthogonal to walls of the energy recovery unit that at least partially define the first and second ducts.

17. The energy recovery unit of any preceding claim, wherein the opposing ends of the thermoelectric generators along which the first and second ducts extend are substantially parallel to walls of the energy recovery unit that at least partially define the first and second ducts.

18. A vehicle exhaust system comprising the energy recovery unit of any preceding claim.

19. A vehicle comprising the energy recovery unit of any of claims 1 to 17, or the vehicle exhaust system of claim 18.

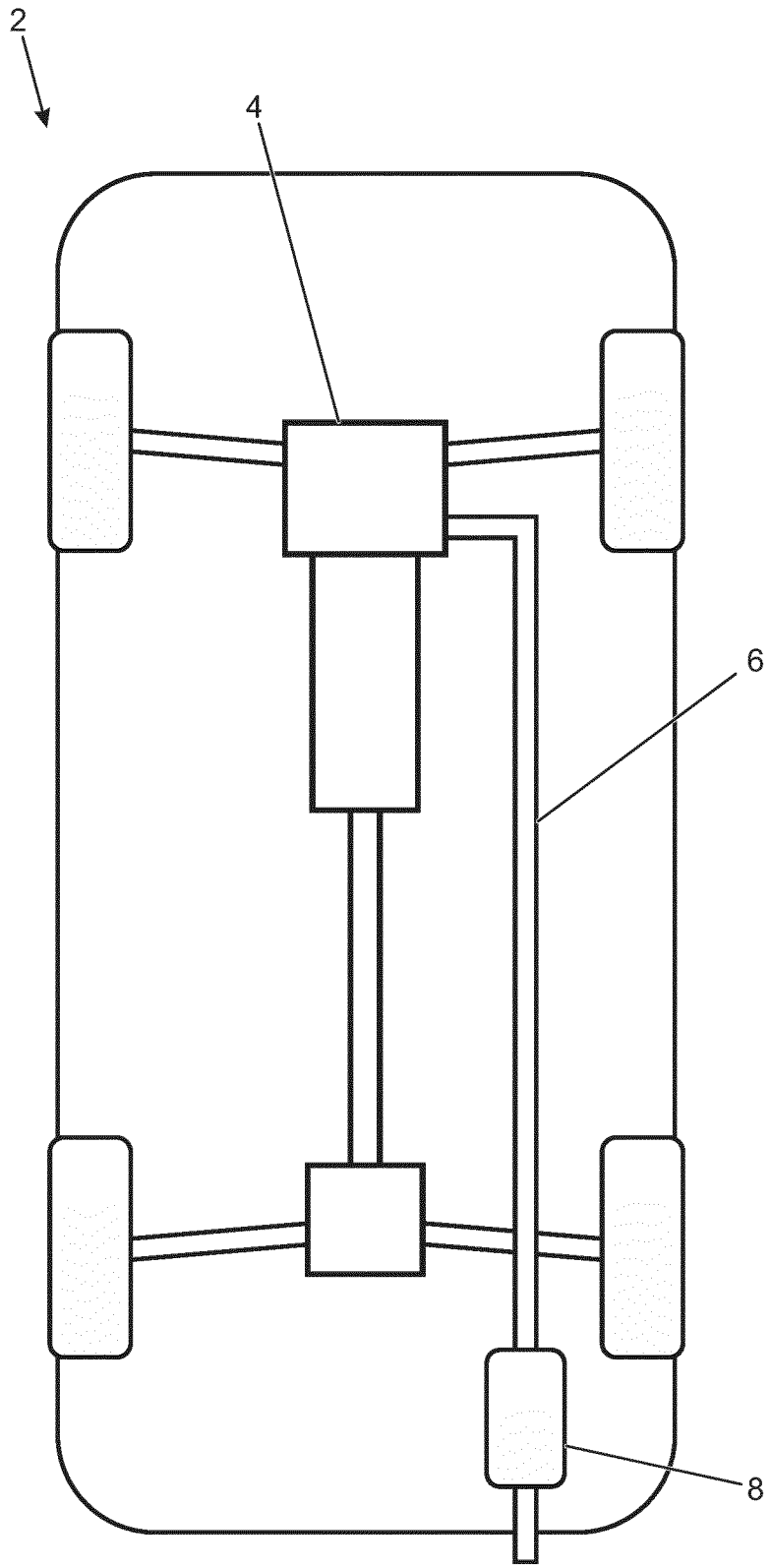


Figure 1

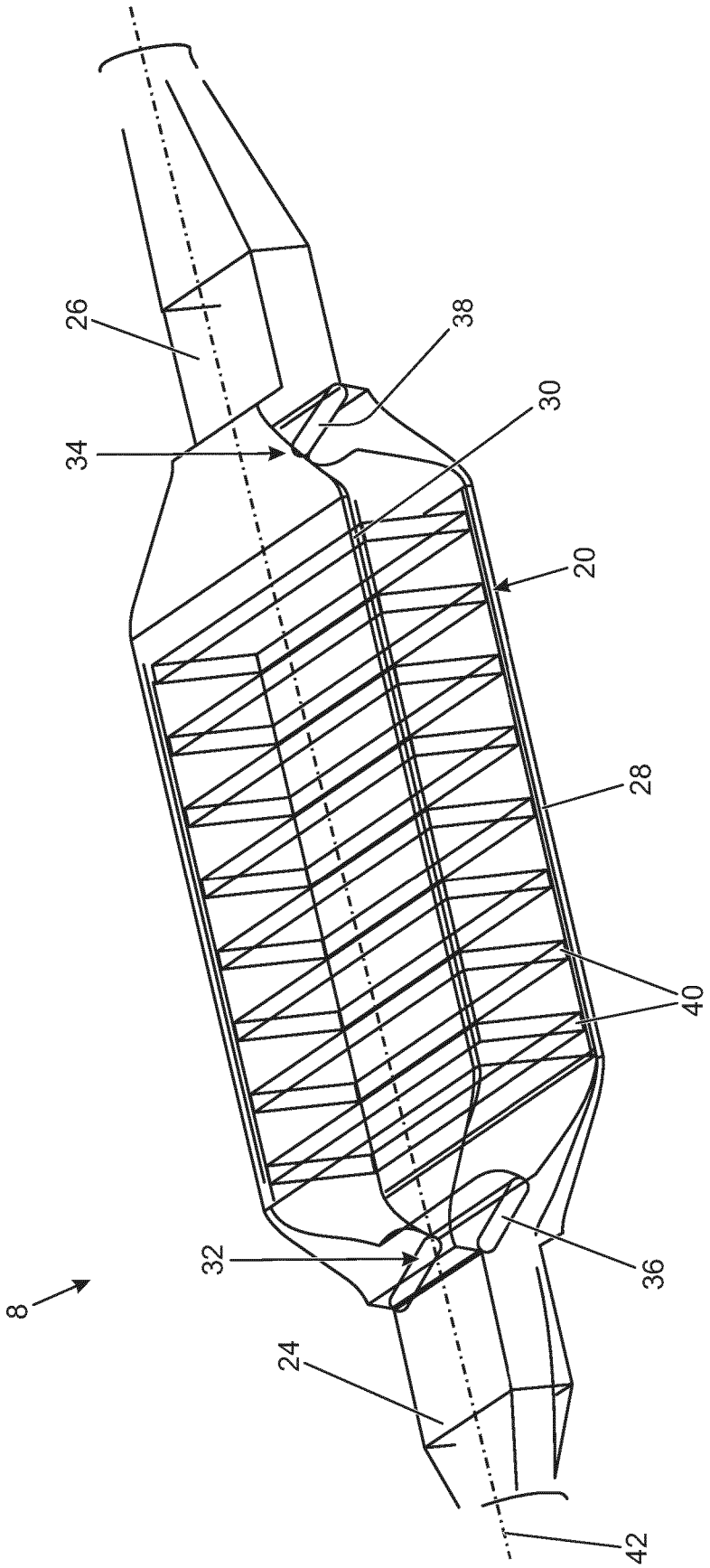


Figure 2

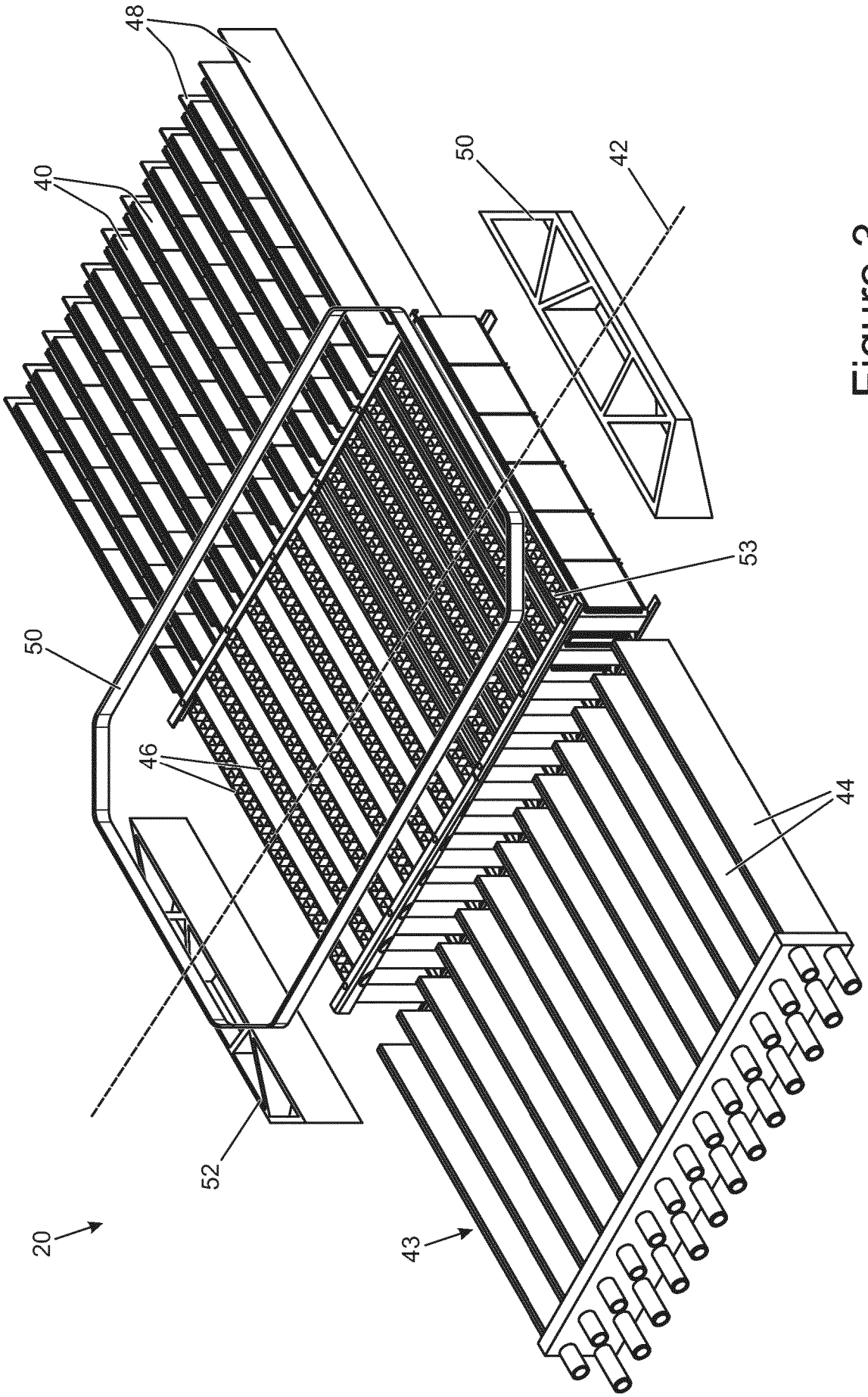


Figure 3

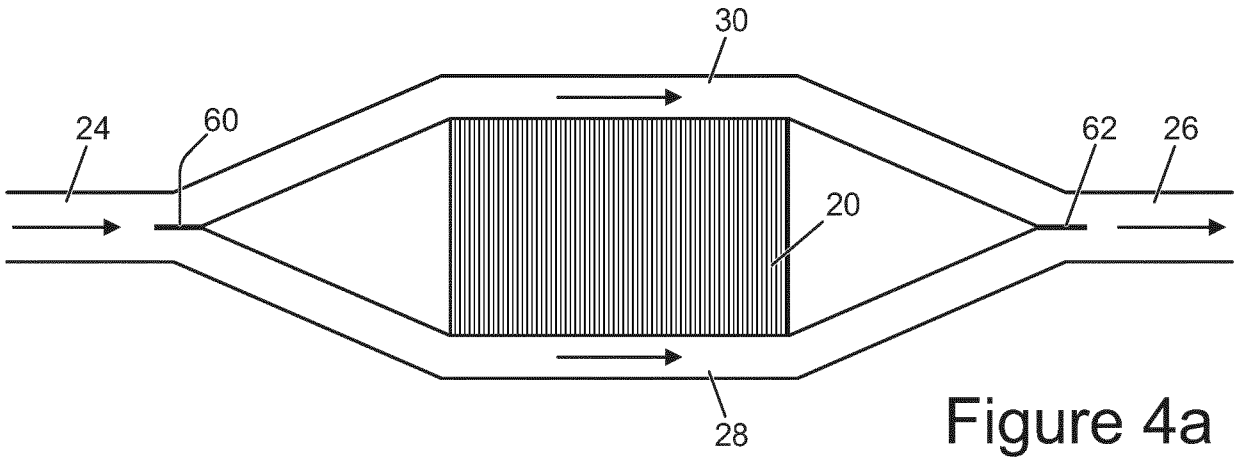


Figure 4a

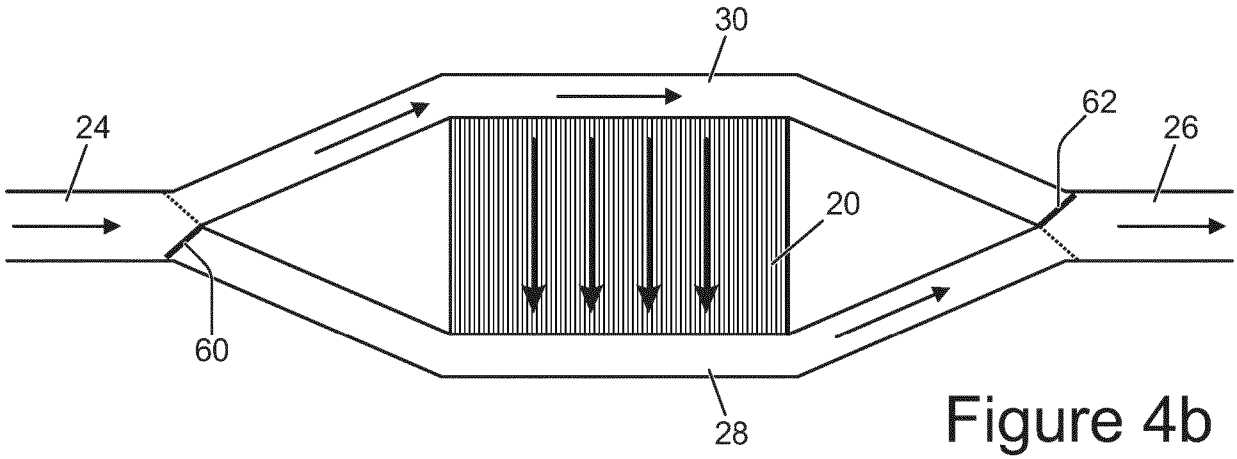


Figure 4b

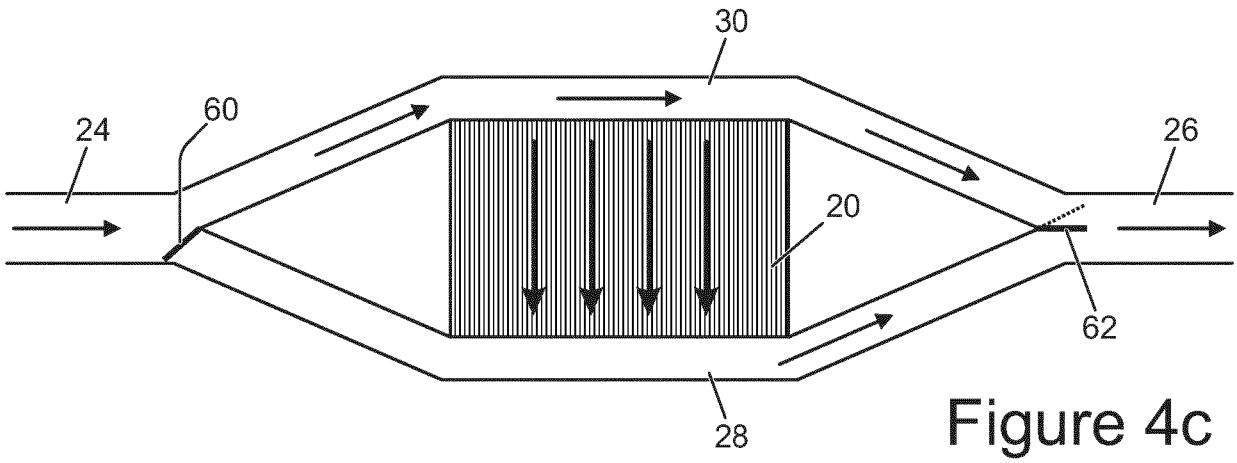


Figure 4c

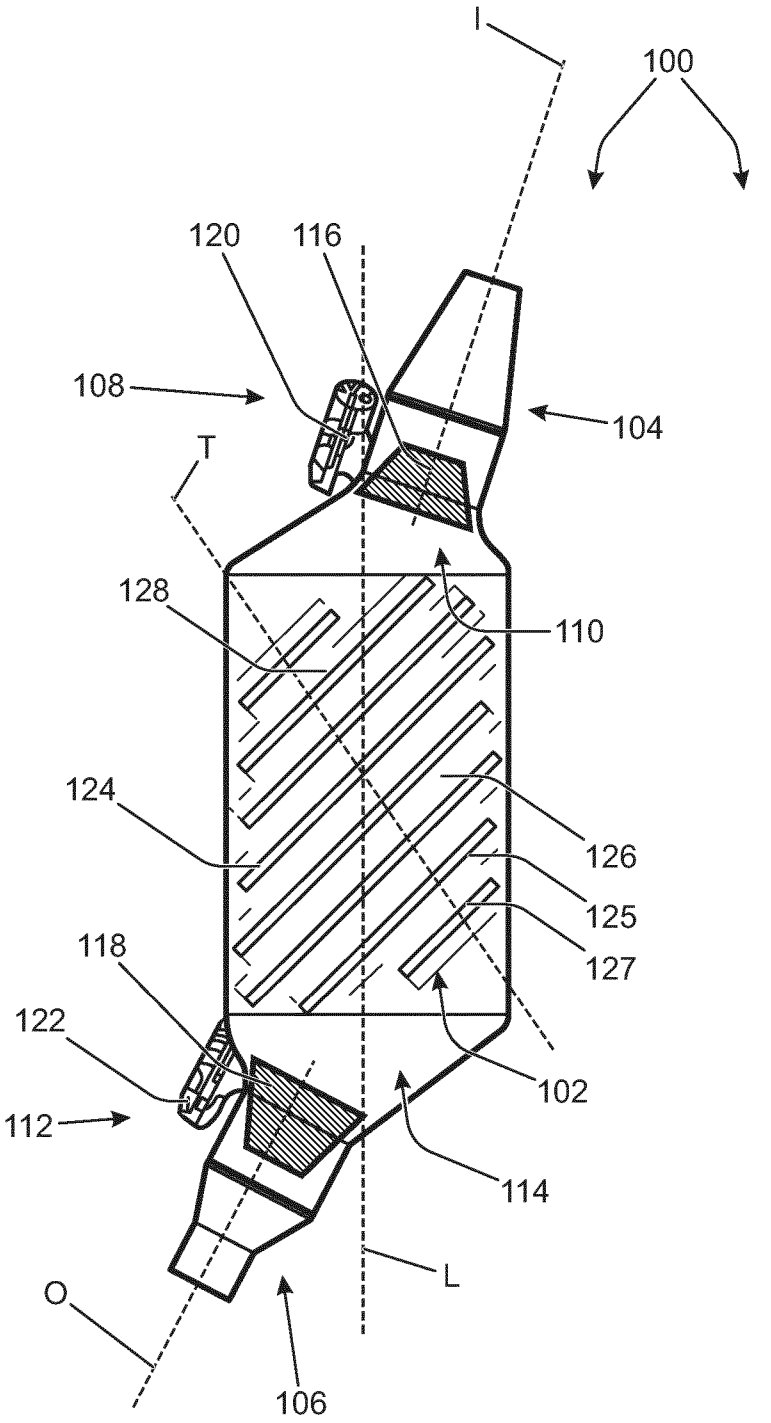

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Fig. 5a

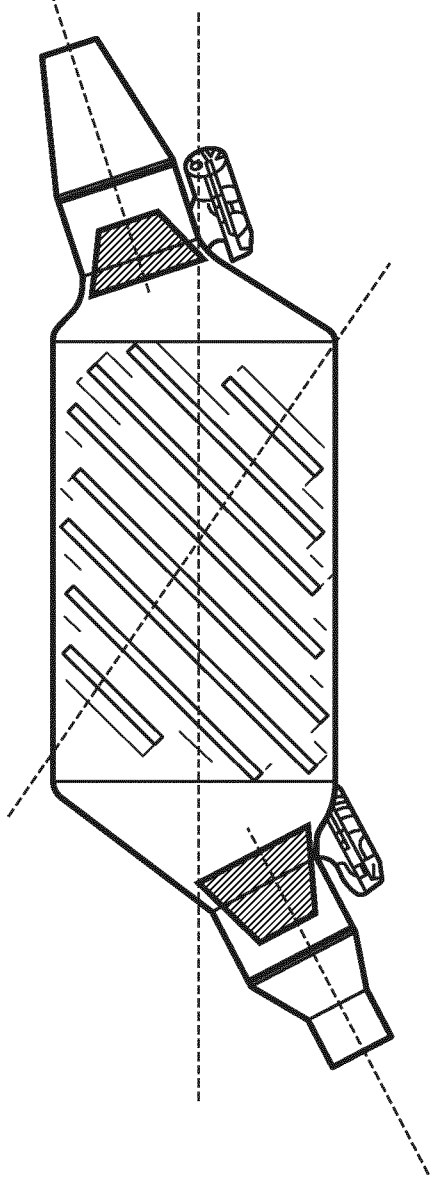


Fig. 5b

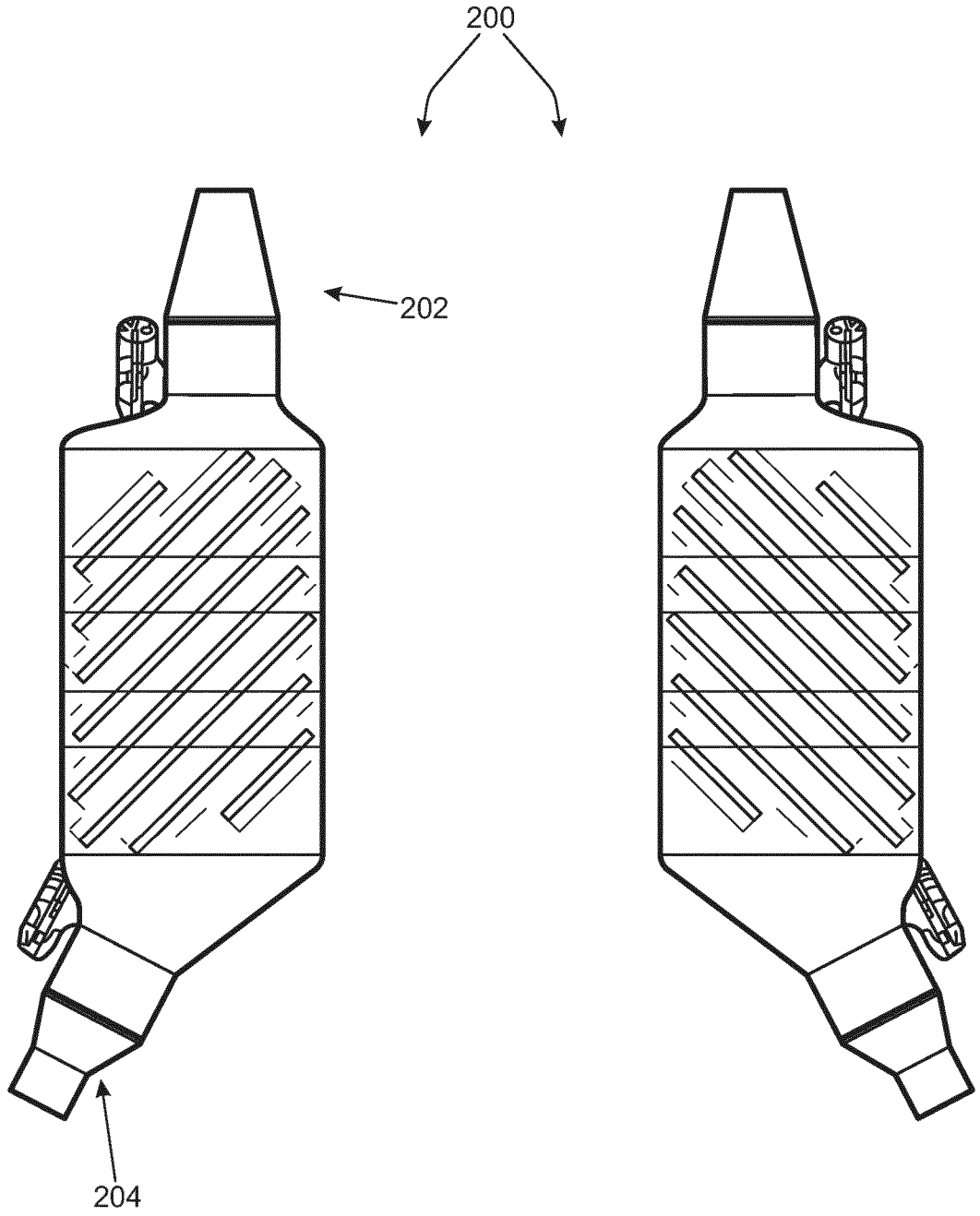


Fig. 6a

Fig. 6b

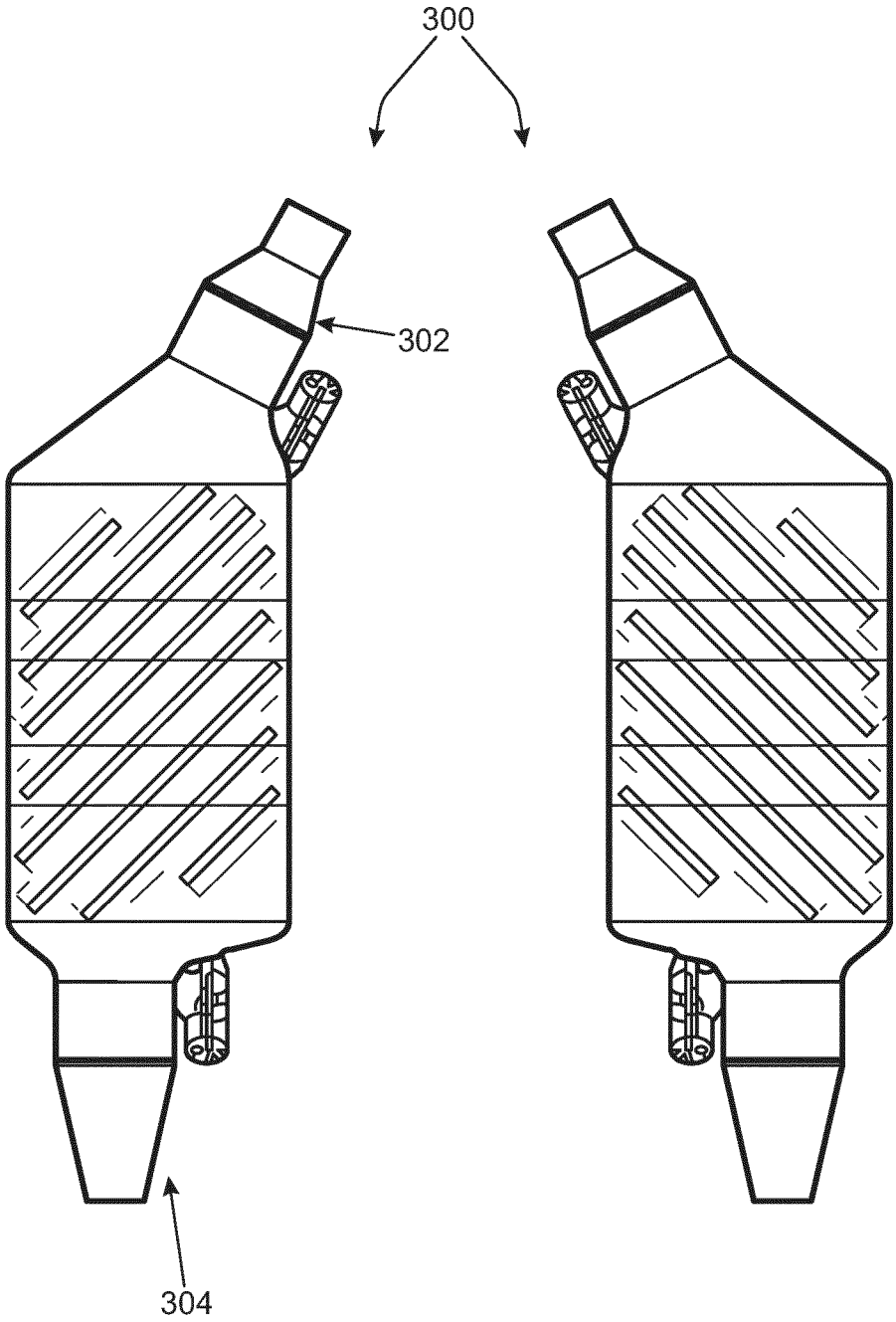


Fig. 7a

Fig. 7b

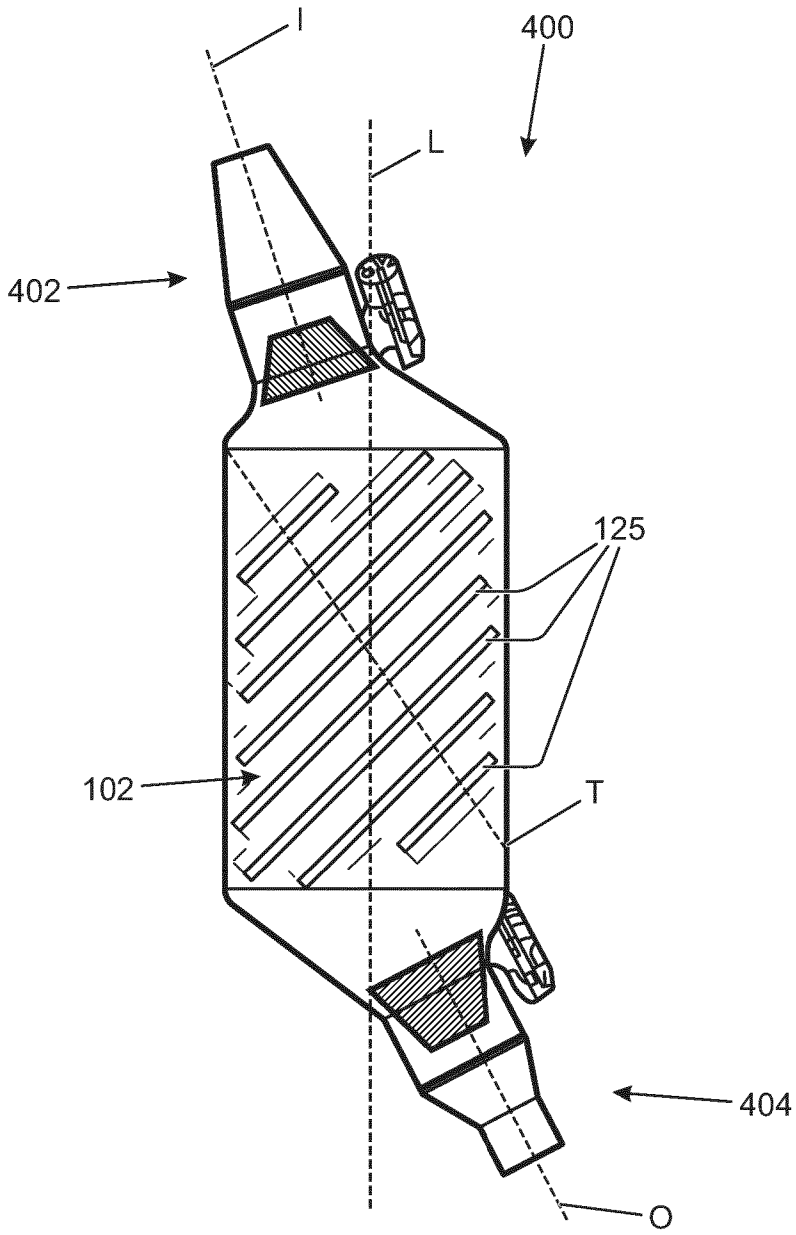


Fig. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/058182

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01N5/02 H01L35/00
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)
F01N H01L

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2014/095988 A1 (VALEO SYSTEMES THERMIQUES [FR]) 26 June 2014 (2014-06-26) page 4, line 26 - page 10, line 33; figures 1,2	1-9, 12-19
X	WO 2010/112961 A1 (RENAULT TRUCKS [FR]; AIXALA LUC [FR]) 7 October 2010 (2010-10-07)	1,6, 8-11,15, 17-19
A	page 6, line 34- - page 10, line 7; figures 1-3	2-5,7
X	DE 10 2011 111954 A1 (FAURECIA EMISSIONS CONTROL TECHNOLOGIES GERMANY GMBH [DE]) 28 February 2013 (2013-02-28)	1,6,8,9, 12,14, 16,18,19
A	paragraphs [0038], [0039]; figure 1 paragraphs [0044], [0047] - [0049]; figures 2-4	10,11,13

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 May 2017	02/06/2017

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	Kolland, Ulrich

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/058182

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