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(71) Applicant: **JAGUAR LAND ROVER LIMITED**
[GB/GB]; Abbey Road, Whitley, Coventry Warwickshire
CV3 4LF (GB).

(72) Inventor: **HUTCHINS, William**; c/o Jaguar Land Rover,
Patents Department W/1/073, Abbey Road Whitley, Cov-
entry Warwickshire CV3 4LF (GB).

(74) Agent: **BORTON, Claire**; c/o Jaguar Land Rover, Patents
Department W/1/073, Abbey Road Whitley, Coventry
Warwickshire CV3 4LF (GB).

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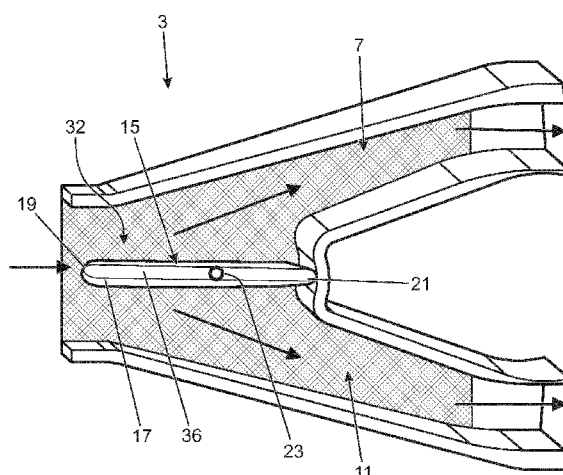


Fig. 5a

(57) Abstract: A valve arrangement (32, 34) for directing exhaust gas flow entering or exiting an energy recovery unit (8) for a vehicle exhaust system (6). The valve arrangement (32, 34) comprises a valve duct (3, 5) including a pair of branches (7, 9, 11, 13) that converge at a branch junction and a valve opening (24, 26) through which exhaust gas enters or exits the valve duct (3, 5). Each branch (7, 9, 11, 13) is arranged to provide communication with a respective flow passage (28, 30) of the energy recovery unit (8). The valve arrangement further comprises a flow directing member (36, 38) disposed within the valve duct (3, 5) at the branch junction. The flow directing member (36, 38) is operable to direct gas flow between the valve opening (24, 26) and a selected one of the branches (7, 9, 11, 13). The valve duct (3, 5) expands in a direction perpendicular to a plane through the centerlines of both branches with increasing longitudinal distance from the valve opening (24, 26).

VALVE ARRANGEMENT FOR AN ENERGY RECOVERY UNIT

TECHNICAL FIELD

- 5 The present disclosure relates to a valve arrangement for use in an energy recovery unit. Aspects of the invention relate to an energy recovery unit and to a vehicle incorporating such a valve arrangement.

BACKGROUND

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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.

- 15 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.

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- 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
25 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.

- 30 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 a valve arrangement for directing exhaust gas flow entering or exiting an energy recovery unit for a vehicle exhaust system. The valve arrangement comprises a valve duct including a pair of
5 branches that diverge from a branch junction, each branch being arranged to provide communication with a respective flow passage of the energy recovery unit. The valve arrangement further comprises a valve opening through which exhaust gas enters or exits the valve duct, and through which the exhaust gas flows in a gas flow direction.

10 The valve arrangement further comprises a flow directing member disposed within and following the sides of the valve duct extending from the branch junction toward the valve opening. The flow directing member is operable to direct gas flow between the valve opening and a selected one or both of the branches. The flow directing member is rotatably mounted within the valve duct for rotation about a valve axis. The valve
15 axis is located between a pair of parallel edges of the flow directing member and respective portions of the flow directing member defined to, or on, each side of the valve axis are of substantially equal surface area.

In this case the branch junction is the location most distal from the valve opening
20 where the proximal sides of the branches join. It will be appreciated that this definition serves only to clarify the location of the flow directing member.

Where the valve arrangement is used at an inlet to an energy recovery unit, the use of a single flow directing valve rather than multiple butterfly valves minimises restriction to
25 the flow. Correspondingly, where the valve arrangement is used at an outlet from an energy recovery unit, the valve duct gradually funnels the flow towards the valve opening through which gas exits, again minimising restriction to the flow.

In both cases, minimising restriction to the gas flow reduces attendant losses which
30 improves the overall efficiency of the engine system.

Furthermore, where the energy recovery unit includes thermoelectric generators, the valve arrangement advantageously helps to prevent overheating of leading edges of

those thermoelectric generators by spreading the exhaust gas evenly and therefore distributing heat energy throughout the unit, avoiding localised heat pockets.

5 The flow directing member may be rotatably mounted to a shaft extending between opposed internal walls of the valve duct along the valve axis.

Mounting the flow directing member to a shaft disposed along a valve axis as described beneficially balances the forces on each side of the flow directing member. Therefore, the energy required to move the flow directing member from one position to another is reduced compared to a flow directing member having a shaft disposed at
10 one end, for example.

The valve opening may be rectangular or trapezoidal, and the valve duct may be rectangular or have a trapezoidal profile. The valve duct may be rectangular or trapezoidal in a section perpendicular to the gas flow direction through the valve opening. A rectangular valve opening allows the device to be mounted within an exhaust system easily using known connectors. The trapezoidal profile of the duct beneficially ensures controlled and even expansion of the exhaust gas across the entire duct towards an attached energy recovery unit, if the arrangement is used as an
15 inlet, and the ability to smoothly funnel gas back towards an exhaust system if the arrangement is used as an outlet.
20

The flow directing member may be defined by a flap, and may have a pair of parallel sides joined by a pair of mutually inclined sides to define a trapezoidal structure. The flap provides minimal resistance to flow when in a neutral position, but maximal deflection when in a flow directing position. When the valve arrangement is used as an inlet, the trapezoidal structure of the flow directing member encourages exhaust gas to expand to occupy the entire width of the duct, ensuring an even heat distribution within an attached energy recovery unit.
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30 The inclined sides of the flow directing member may be oriented at an angle corresponding to an internal profile of the valve duct. The flow directing member may increase in width with increasing longitudinal distance from the valve opening. This is particularly advantageous in ensuring that exhaust gas flow is only directed by the flow

directing member and that no exhaust gas flows the wrong way around the sides of the member. This also ensures that the gas is directed to the full width of the duct.

The flow directing member may comprise two gas-directing surfaces, and the gas-directing surfaces may have substantially equal surface area.

The valve arrangement may comprise an actuator to control operation of the flow directing member.

10 The flow directing member may move from the neutral position, in which it occludes neither branch, to a closed position, in which one branch is occluded. In the closed position, the flow directing member may make contact with an internal wall of the valve duct. The flow directing member's movement may be restricted by the internal wall of the valve duct. In the closed position, one surface of the flow directing member may align with the non-occluded branch of the duct.

The branch junction may comprise an internal junction wall extending between the upper and lower branches. The internal junction wall may incorporate a recess, which, in some embodiments, may be concave.

20 The angle traversed by the flow directing member when moving between closed positions, i.e. from occluding one branch to occluding the opposite branch, may be less than 45 degrees and/or greater than 15 degrees.

25 According to a further aspect of the invention, there is provided an energy recovery unit comprising the aforementioned valve arrangement.

According to a further aspect of the invention, there is provided an energy recovery unit comprising a first valve arrangement positioned to direct flow entering the energy recovery unit and a second valve arrangement positioned to direct flow exiting the energy recovery unit.

According to another aspect of the invention, there is provided a vehicle comprising the aforementioned valve arrangement or the aforementioned energy recovery unit.

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
5 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
10 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
15 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;

20 **Figure 2** is a transparent, perspective view of an energy recovery unit, which may be implemented in a vehicle exhaust system, such as that shown in Figure 1;

Figure 3 is an alternative perspective view of the energy recovery unit of Figure 2;

25 **Figure 4** is a perspective view of an inlet duct of a type that may be incorporated into the energy recovery unit of Figure 2;

Figures 5a and 5b are perspective, cross-sectional views of an inlet duct of the energy recovery unit shown in Figure 2, showing a valve flap in accordance with
30 various embodiments of the present invention;

Figure 6 is an exploded, perspective view of a TEG module that may be incorporated into the energy recovery unit shown in Figure 2; and

Figures 7a to 7c are schematic plan views of the energy recovery unit shown in Figure 2, operating in different modes.

DETAILED DESCRIPTION

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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).

10

15 Figures 2 and 3 respectively show a transparent, perspective view and an alternative non-transparent perspective view of the energy recovery unit 8 of Figure 1. 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 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.

20

As seen most clearly in Figure 3, immediately beyond each end of the TEG module 20 the bypass ducts 28, 30 turn inwardly toward one another to converge, before merging with the inlet pipe 24 or the outlet pipe 26. These converging portions define, respectively, an inlet valve duct 3 leading to the inlet pipe 24, and an outlet valve duct 5 leading to the outlet pipe 26. The inlet and outlet valve ducts 3, 5, which will be referred to hereafter as inlet and outlet ducts 3, 5, therefore each have a pair of branches, an upper branch 7, 9 and a lower branch 11, 13 as viewed in Figure 3, that diverge from a branch junction, each branch 7, 9, 11, 13 originating at a respective bypass duct 28, 30. In consequence, the inlet and outlet ducts 3, 5 are generally V-shaped as viewed from the side, as in Figure 3.

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As can be seen in Figures 2, 3 and 4, the latter of which shows the inlet duct 3 in isolation, the inlet and outlet ducts 3, 5 also taper longitudinally as viewed from above, to define a trapezoidal cross-section. As a result of tapering in two orthogonal axes, the inlet and outlet ducts 3, 5 are generally in the form of truncated, rectangular-based pyramids that narrow outwardly from the bypass ducts 28, 30.

This structure means that the inlet and outlet ducts 3, 5 have a transverse cross-sectional area that increases with longitudinal displacement between the inlet or outlet pipe 24, 26 towards the bypass ducts 28, 30. This increasing area allows gas flowing through the inlet and outlet ducts 3, 5 to expand gradually, which ensures that the exhaust gas spreads evenly into and throughout the bypass ducts 28, 30. This in turn ensures that the gas flow covers the entire TEG module for optimised energy recovery.

Returning now to Figure 2, a rotatable inlet valve flap 36 is disposed within the inlet duct 3, the inlet duct 3 and the inlet valve flap 36 between them defining an inlet valve arrangement, or more simply, an inlet valve 32. The inlet pipe 24 acts as an inlet valve opening through which exhaust gas enters the inlet valve 32. Correspondingly, a rotatable outlet valve flap 38 is located in the outlet duct 5, so that the outlet duct 5 and the outlet valve flap 38 define an outlet valve arrangement or outlet valve 34, with the outlet pipe 26 defining an outlet valve opening.

The valve flaps 36, 38 can be rotated to act as flow directing members that control the direction of exhaust gas flow through their respective ducts 3, 5, by occluding or partially occluding one of the branches 7, 9 of the duct 3 to guide exhaust flow into (or out of) the opposite branch 7, 9 and in turn into the bypass duct 28, 30 with which that branch 7, 9 communicates. The inlet valve flap 36 is shown in more detail in Figures 5a and 5b, which are described below.

It is first noted that the energy recovery unit 8 is operable in various modes according to how the inlet and outlet valves 32, 34 are configured. In some modes of operation, exhaust gas passing from the inlet pipe 24 to the outlet pipe 26 bypasses the TEG module 20 entirely, and flows exclusively through one or both of the bypass ducts 28, 30, 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 7a to 7c.

5 Figures 5a and 5b show the inlet valve 32 in cross-section in two different configurations. In general terms, Figure 5a shows a neutral configuration, in which the valve flap 36 occludes neither branch of the inlet duct 3 and thus exhaust gas flows into both bypass ducts (not shown in Figures 5a and 5b). Figure 5b shows the valve flap 36 in one of two possible closed positions, in which the upper branch 7 of the inlet
10 duct 3, as viewed in Figure 5b, is occluded, so that exhaust gas flow is directed into the lower branch 11 and on to the lower bypass duct.

It is noted that the internal structure and operation of the outlet valve 34 is identical to that of the inlet valve 32 described below, with the exception that the direction of
15 exhaust gas flow is reversed.

In the embodiment shown, the inlet valve flap 36 is generally sheet-like in form, having planar, trapezoidal upper and lower gas-directing surfaces 15, 17, each having a pair of parallel sides joined by a pair of inclined sides set at an angle corresponding to the
20 internal profile of the inlet duct 3. As noted above, a trapezoidal duct facilitates a better distribution of flow across the entire width of each bypass duct if the bypass ducts are substantially wider than the inlet and outlet pipes. In other embodiments, the gas-directing surfaces are rectangular.

25 In use, the inlet valve flap 36 comprises a leading end 19, which is the shorter of the parallel sides of the trapezium and which faces exhaust gas flow, and a trailing end 21 which is the longer of the parallel sides. The inlet valve flap 36 is rotatably mounted to a shaft 23 extending between opposed internal walls of the inlet duct 3. The shaft 23 lies along an inlet valve axis and extends through the inlet valve flap 36 at a location at
30 or near to a midpoint between the leading and trailing ends 19 and 21. The inlet valve axis is perpendicular to the main gas flow direction through the bypass ducts 28, 30 and longitudinally offset from either end of the valve flap 36, 38.

Rotating the inlet valve flap 36 from the neutral valve position to the closed position for directing flow into the lower bypass duct 30, corresponding to moving from the configuration shown in Figure 5a to that of Figure 5b, requires clockwise rotation of the inlet valve flap 36 about the inlet valve axis as viewed in Figures 5a and 5b. The clockwise movement and the configuration of the inlet valve flap 36 on its shaft 23 means that the leading end of the flap 36 moves in a generally upwards direction until it makes contact with an upper internal wall of the inlet duct 3. In making contact with the upper internal wall, the flap 36 can be considered to be in the closed configuration, and rotation of the flap 36 is stopped by making contact with the upper internal wall of the inlet duct 3. Meanwhile, the trailing end of the flap 36 moves in a generally downwards direction until it generally aligns with a lower surface of the upper branch 7 of the inlet duct 3.

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 into the energy recovery unit 8.

Pivoting the inlet valve flap 36 near to its mid-point ensures that when the valve flap 36 moves away from its neutral position and exposes one of its gas directing surfaces 15, 17 to exhaust gas flow, the flow exerts similar forces to each side of the shaft 23 on that surface. This produces opposed rotational moments to each side of the shaft 23 which balance each other. The turning force required from the valve actuator is therefore minimised, and so the actuator can be smaller and less powerful than if the valve flap 36 were pivoted at one of its ends, providing no balancing of forces. The skilled reader will appreciate that this balancing effect is optimised when the shaft 23 is positioned such that there is an equal area of gas directing surface to each side. For a trapezoid valve flap, this implies positioning the shaft 23 slightly closer to the longer of the parallel edges, corresponding to the trailing end 21 of the inlet valve flap 36.

To facilitate the movement of the valve flap 36, an internal junction wall extending between the upper and lower branches 7, 11 of the inlet duct 3 where they converge incorporates a concave recess 25. The profile of the recess 25 generally corresponds to a path of the trailing edge 21 of the inlet valve flap 36, which minimises the gap between the inlet valve flap 36 and the internal wall for all inlet valve flap positions,

thereby avoiding the creation of leak paths between the inlet valve flap 36 and the recess 25.

Due to the positioning of the valve flap 36 within the inlet duct 3, and the shallow angle at which the upper and lower branches 7, 11 of the inlet duct 3 converge, the height of the junction wall 27 between the upper and lower branches 7, 11 is similar to the height of each of the upper and lower branches 7, 11. The skilled reader will appreciate that the height of the junction 27 is dictated by the angle through which the inlet valve flap 36 must move between closed positions. The arrangement shown in Figures 5a and 5b therefore represents the shortest junction wall 27 that is practically achievable within the constraints of the energy recovery unit 8 as a whole. As the junction wall 27 does not contribute to turning exhaust gas flow towards either bypass duct 28, 30, the junction wall 27 is effectively an obstruction to flow, and so it is a benefit to minimise its size.

The inlet valve flap 36 is inclined at a relatively shallow angle with respect to the direction of exhaust gas flow from the inlet pipe 24, even when in a closed position. Noting that the angle through which the valve flap 36 moves between closed positions generally corresponds to the angle that the exhaust gas must turn through, the shallow angle arrangement minimises the restriction to the gas flow caused by the inlet valve flap 36. This allows a smooth transition of exhaust gas from the inlet pipe 24 to the bypass ducts 28, 30, which minimises any loss of gas pressure or speed, and avoids a build-up of back pressure that may cause problems upstream in the exhaust system 6.

In this embodiment, the angle traversed by the inlet valve flap 36 when moving between closed positions is around 30°. The angle may be as high as 45° or as low as 15°. In contrast, a conventional gas switchover valve typically has a turning angle of approximately 90° and so suffers from greater losses. Reducing losses of any kind is critical in an energy recovery system 8 for effective operation.

Although not shown, it should be appreciated that the inlet valve flap 36 can rotate in the opposite sense so as to close off the lower branch 11 of the inlet duct and the associated bypass duct 28, 30. The inlet valve 32 can therefore switch between two

flow paths using a single valve flap 36, which reduces the complexity of the valve 32 compared with using a respective flap for each flow path.

5 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.

10 To provide further context for the embodiments of the invention described above, Figure 6 shows an exploded, perspective view of a TEG module 20 that is incorporated into the energy recovery unit 8 of Figures 2 and 3.

15 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 from neighbouring TEG unit(s) at regular intervals along the main axis 42.

20 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
25 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
30 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 6, 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.

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 arrangements 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 7a to 7c are schematic side views of the energy recovery unit of Figure 2 as viewed from the side and illustrate different operating modes of the energy recovery unit.

Each operating mode is associated with a different configuration of the inlet and outlet valves. 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 7a; a ‘full flow’ mode, illustrated in Figure 7b; and a ‘feathering’ mode, illustrated in Figure 7c.

In the bypass mode, the inlet valve flap 36 and the outlet valve flap 38 are both in their neutral configuration, in which they 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, into the bypass ducts 28, 30, past the outlet valve 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 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 7b, 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 7b).

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 40.

In the illustrated arrangement, 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 7c, 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 7c, 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 7c) 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 7c 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 water cooling capabilities of the coolant pipe array 43.

Although specific valve deflections are shown in Figures 7a to 7c, 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.

CLAIMS

1. A valve arrangement for directing exhaust gas flow entering or exiting an energy recovery unit for a vehicle exhaust system, the valve arrangement comprising:
- 5 a valve duct including a pair of branches that diverge from a branch junction, each branch being arranged to provide communication with a respective flow passage of the energy recovery unit;
- a valve opening through which exhaust gas enters or exits the valve duct, the exhaust gas flowing through the valve opening in a gas flow direction; and
- 10 a flow directing member disposed within and following the sides of the valve duct extending from the branch junction toward the valve opening, the flow directing member being operable to direct gas flow between the valve opening and a selected one or both of the branches, and the flow directing member being rotatably mounted within the valve duct for rotation about a valve axis; and wherein:
- 15 the valve axis is located between a pair of parallel edges of the flow directing member; and
- respective portions of the flow directing member defined to each side of the valve axis are of substantially equal surface area.
- 20 2. The valve arrangement of claim 1, wherein the flow directing member is rotatably mounted to a shaft extending between opposed internal walls of the valve duct along the valve axis.
3. The valve arrangement of any preceding claim, wherein the valve duct in the
- 25 area of the flow directing member is rectangular in a section perpendicular to the gas flow direction through the valve opening.
4. The valve arrangement of any preceding claim wherein the valve duct in the area of the flow directing member has a trapezoidal profile in a section through the
- 30 valve axis parallel with the gas flow direction through the valve opening.
5. The valve arrangement of any preceding claim, wherein the flow directing member is defined by a flap.

6. The valve arrangement of any preceding claim, wherein the flow directing member has a pair of parallel sides joined by a pair of mutually inclined sides to define a trapezoidal structure.

5 7. The valve arrangement of claim 6, wherein the inclined sides are oriented at an angle corresponding to an internal profile of the valve duct.

8. The valve arrangement of any preceding claim, wherein the flow directing member increases in width with increasing longitudinal distance from the valve
10 opening.

9. The valve arrangement of any preceding claim, wherein the flow directing member comprises two gas-directing surfaces.

15 10. The valve arrangement of claim 9, wherein the gas-directing surfaces have substantially equal surface area.

11. The valve arrangement of any preceding claim, comprising an actuator to control operation of the flow directing member.

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12. An energy recovery unit comprising at least one valve arrangement of any preceding claim.

13. The energy recovery unit of claim 12, comprising a first valve arrangement
25 according to any of claims 1 to 11 positioned to direct flow entering the energy recovery unit, and a second valve arrangement according to any of claims 1 to 11 positioned to direct flow exiting the energy recovery unit.

14. A vehicle comprising the valve arrangement of any of claims 1 to 10 or the
30 energy recovery unit of claim 12 or claim 13.

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/058186

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01N5/02
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 F02M

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	US 2014/246173 A1 (CHEADLE BRIAN E [CA] ET AL) 4 September 2014 (2014-09-04) abstract; figures 2,3,10 -----	1-12,14
X	US 2014/251579 A1 (SLOSS CLAYTON A [CA]) 11 September 2014 (2014-09-11) abstract; figures 1,2,3,4 -----	1-5, 8-12,14
X	FR 2 907 890 A1 (VALEO SYS CONTROLE MOTEUR SAS [FR]) 2 May 2008 (2008-05-02) abstract; figures 1-4 -----	1-5, 8-12,14
X	DE 10 2005 012842 A1 (DAIMLER CHRYSLER AG [DE]) 21 September 2006 (2006-09-21) abstract; figures 1-4 -----	1,2,5, 9-11 12-14
Y	----- -/-	



Further documents are listed in the continuation of Box C.



See patent family annex.

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Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Blanc, Sébastien

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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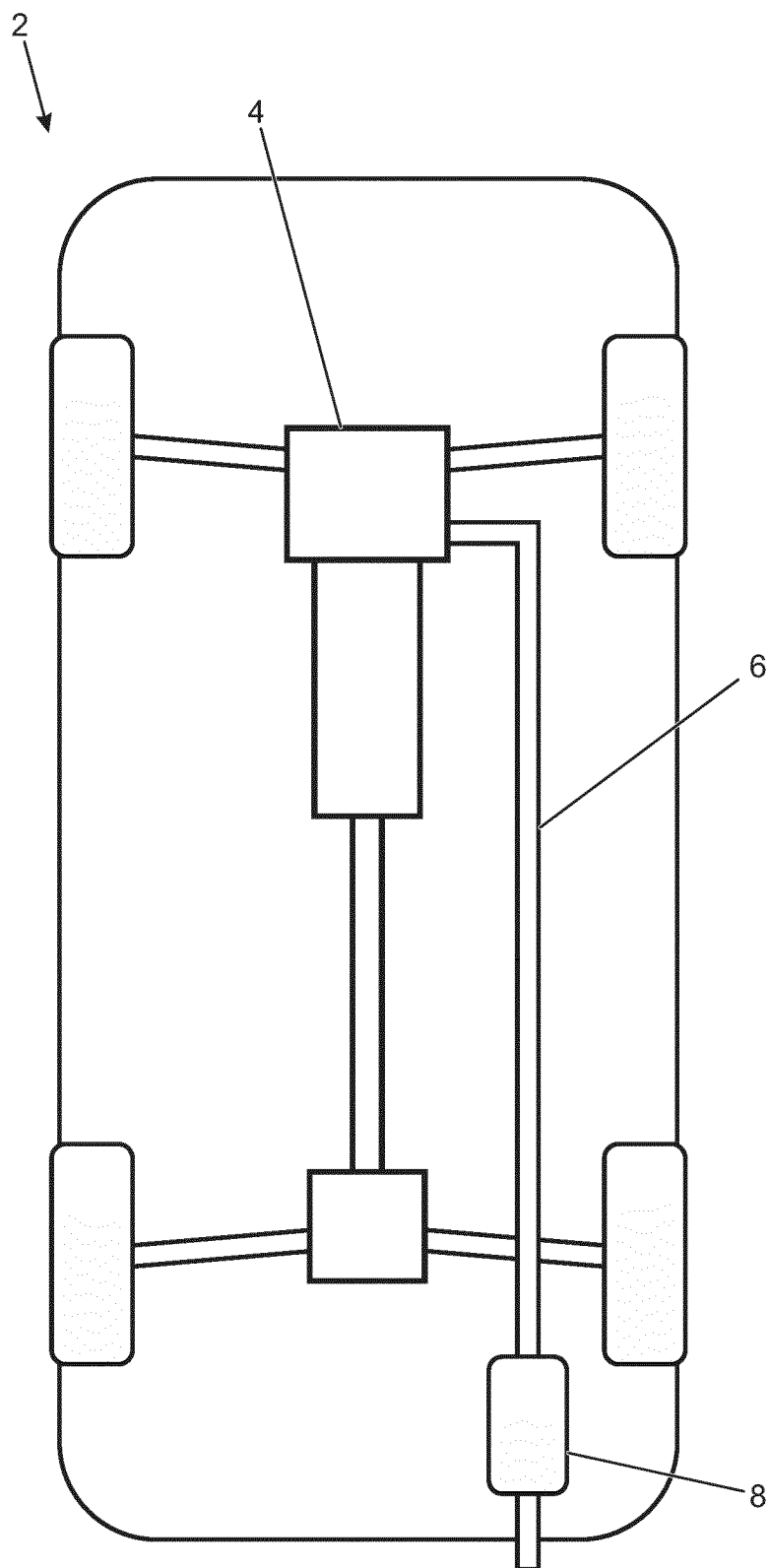


Fig. 1

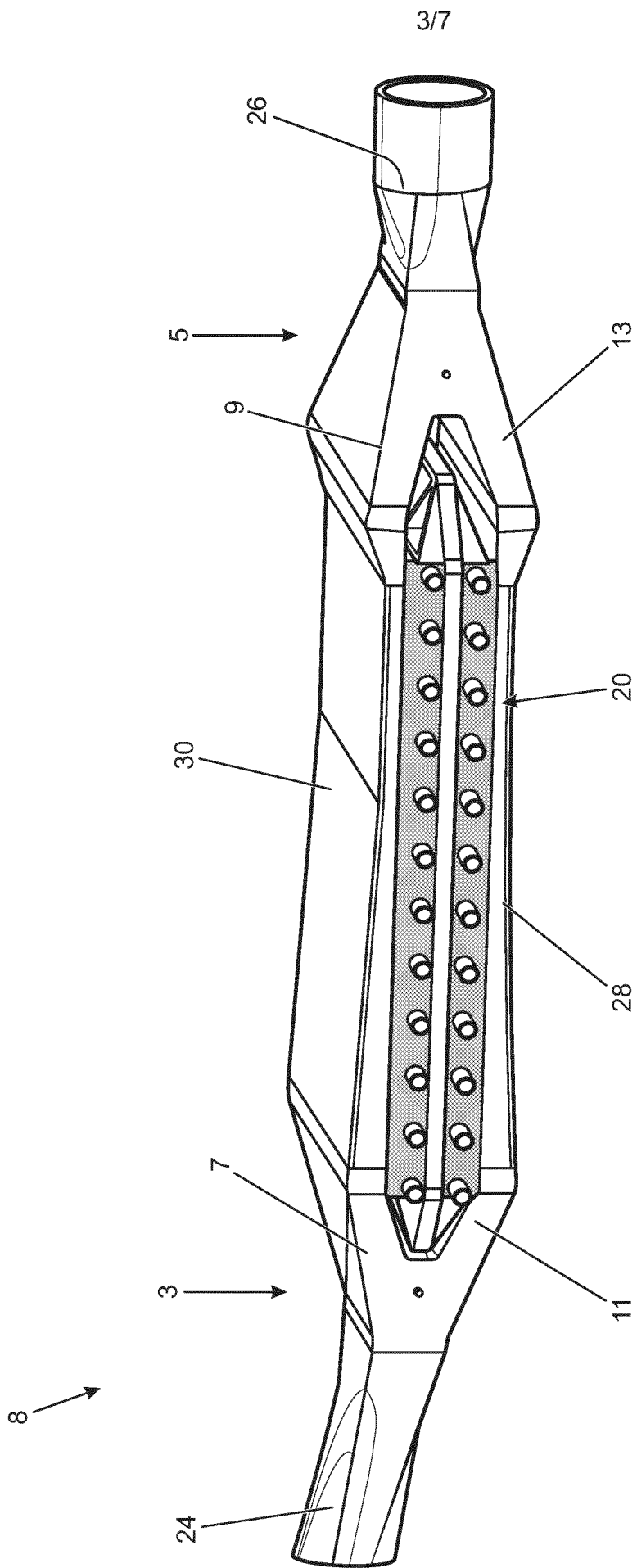


Fig. 3

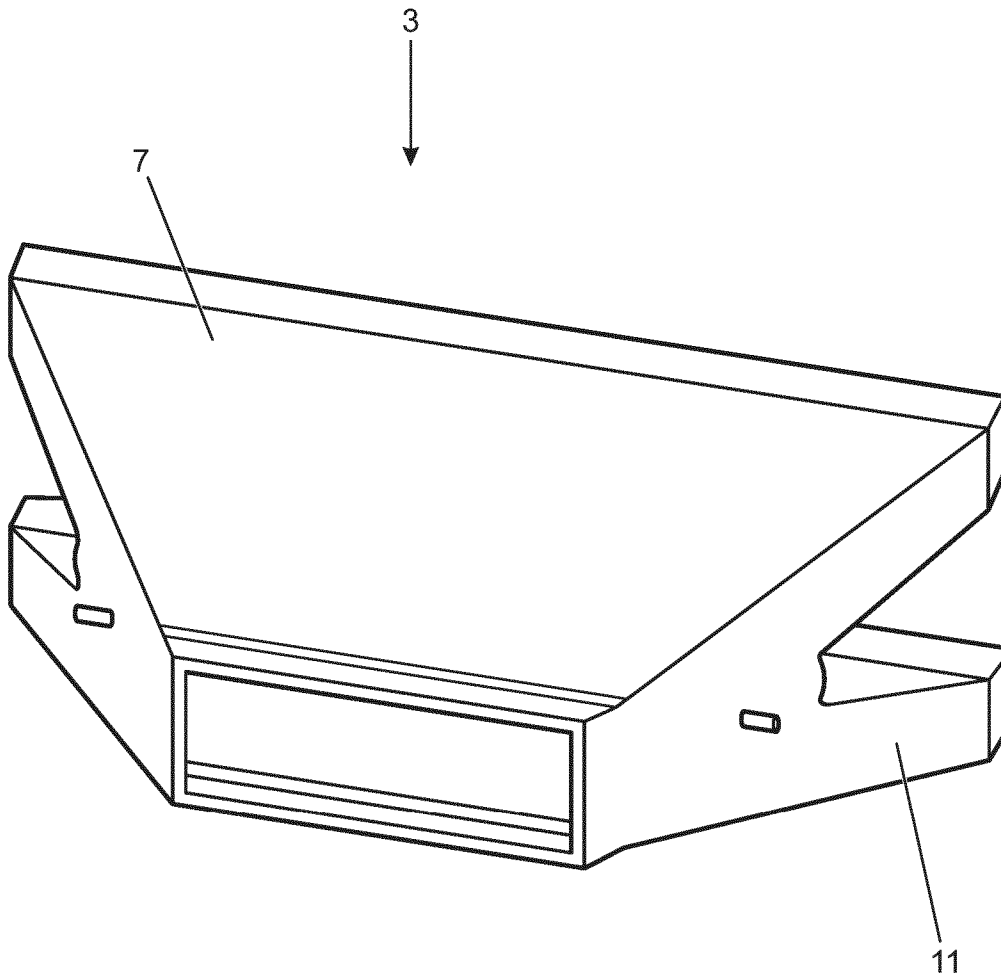


Fig. 4

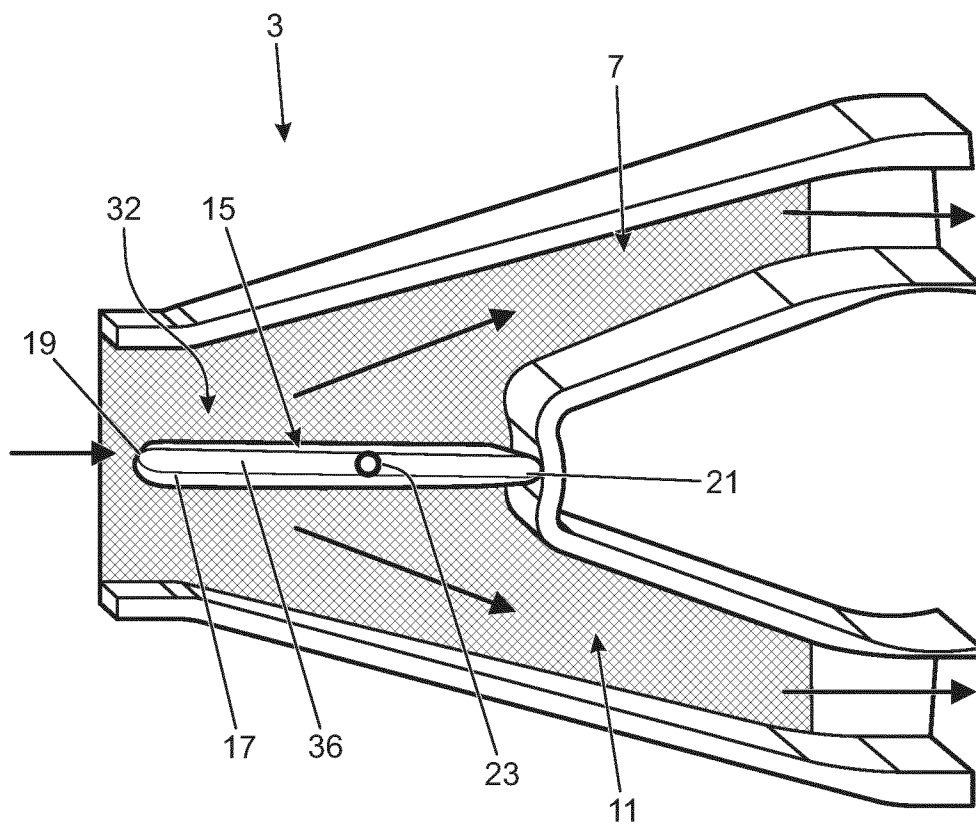


Fig. 5a

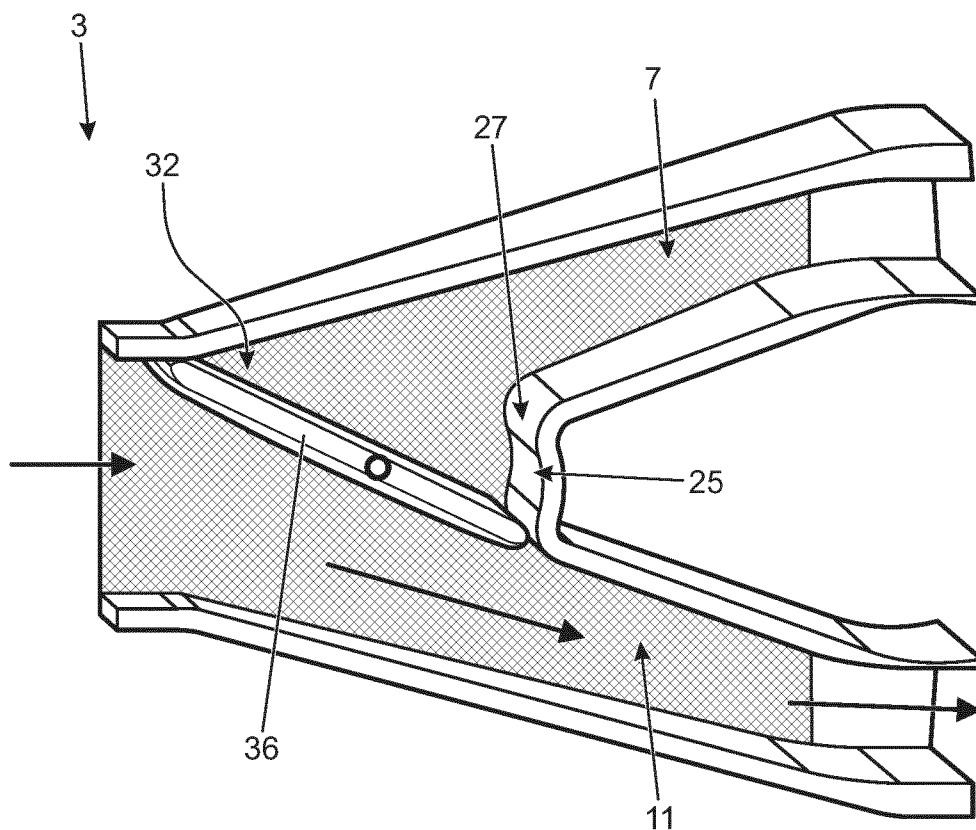


Fig. 5b

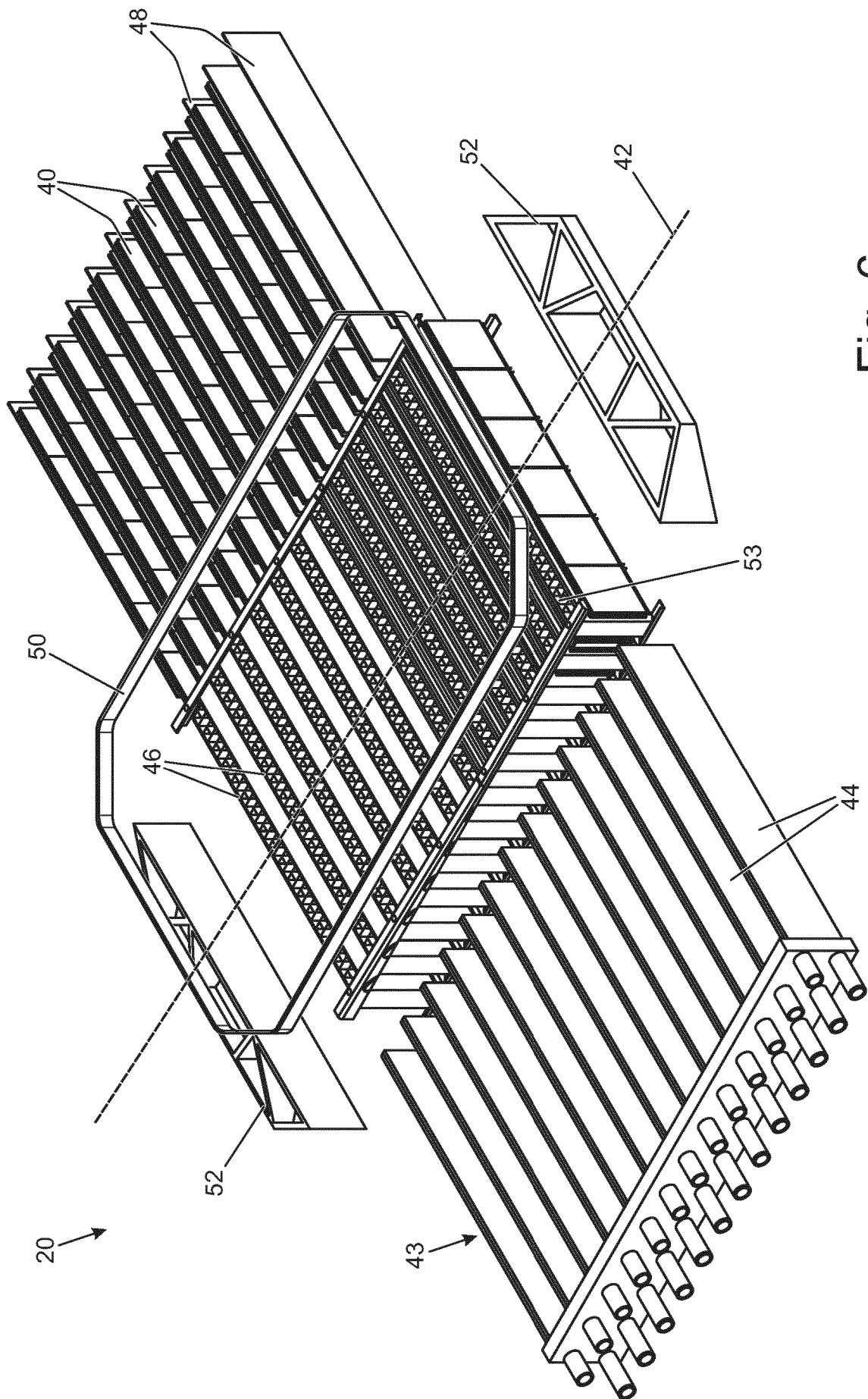


Fig. 6

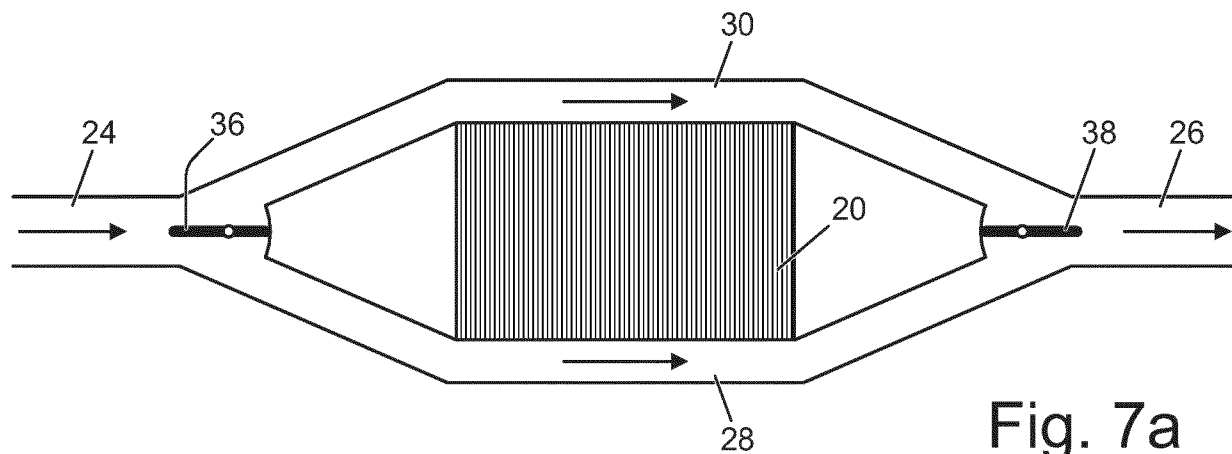


Fig. 7a

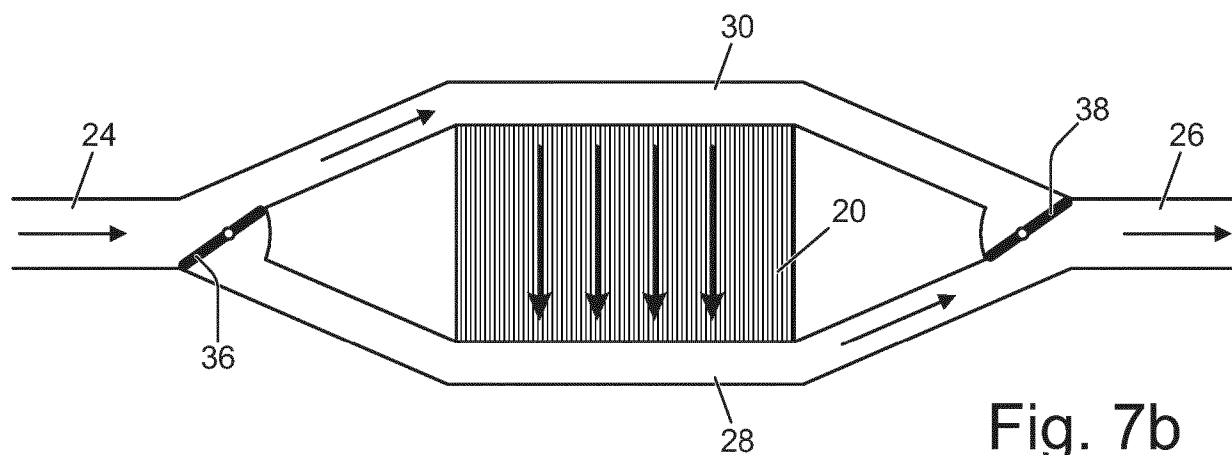


Fig. 7b

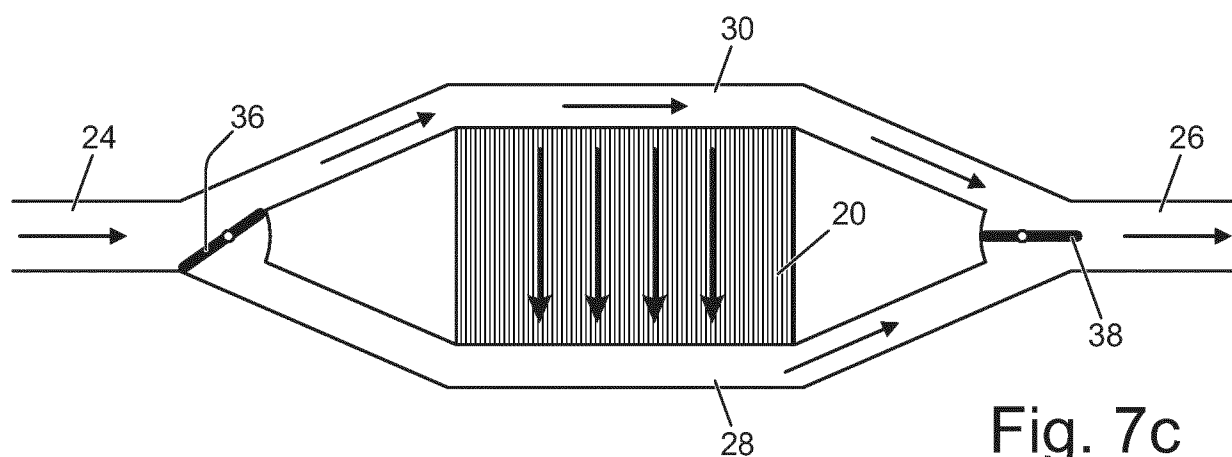


Fig. 7c