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- (71) Applicant: JAGUAR LAND ROVER LIMITED  
[GB/GB]; Abbey Road, Whitley, Coventry Warwickshire  
CV3 4LF (GB).
- (72) Inventor: DESMOND, Alexander; c/o Jaguar Land  
Rover, Patents Department W/1/073, Abbey Road, Whitley  
, Coventry Warwickshire CV3 4LF (GB).
- (74) Agent: BORTON, Claire; c/o Jaguar Land Rover, Patents  
Department W/1/073, Abbey Road, Whitley, Coventry  
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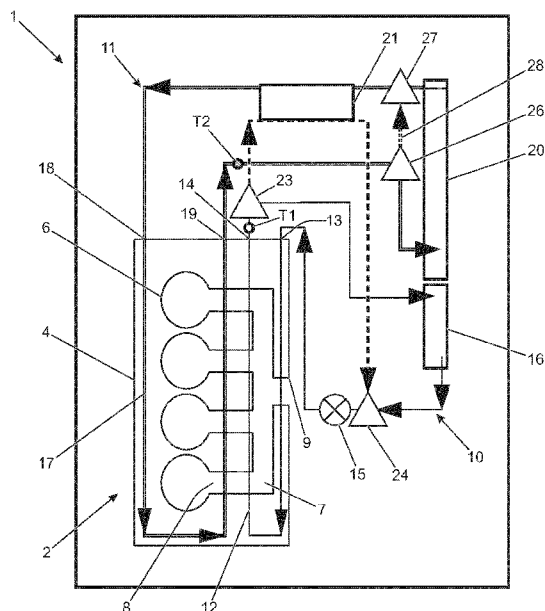


FIG. 2

(57) Abstract: The present disclosure relates to a cooling apparatus (1) for an internal combustion engine (2). The internal combustion engine (2) has an exhaust manifold (7). A first cooling circuit (10) including an exhaust manifold cooling line (12) is provided for cooling the exhaust manifold (7). A second cooling circuit (11) including an engine cooling line (17) is provided for cooling the cylinder head and engine (4). First heat exchanging means (16) is provided for rejecting heat from the first cooling circuit (10); and second heat exchanging means (20) is provided for rejecting heat from the second cooling circuits (11). A third heat exchanging means (21) is provided for transferring heat from the first cooling circuit (10) to the second cooling circuit (11). Alternatively, a circuit connecting means may be provided for selectively connecting the first cooling circuit (10) to the second cooling circuit (11). The cooling apparatus (1) may be provided in a vehicle (3).

## COOLING APPARATUS FOR AN INTERNAL COMBUSTION ENGINE OF A VEHICLE

## TECHNICAL FIELD

The present disclosure relates to a cooling apparatus. More particularly, but not exclusively,  
5 the present disclosure relates to a cooling apparatus for an internal combustion engine; to a controller; and to a vehicle.

## BACKGROUND

A conventional internal combustion engine is connected to an exhaust system to expel  
10 exhaust gases. An exhaust manifold connects the combustion chambers of the internal combustion engine to the exhaust system. Heat rejected into the exhaust system is often not useful energy. Due to increased requirements to create more efficient vehicles, automotive manufactures are seeking ways to use this energy. This has led to the automotive industry implementing integrated exhaust manifolds (IEM) into a cylinder head. The IEM may be  
15 water cooled and, in use, may cool the exhaust gasses. The thermal energy extracted from the exhaust gases may be used as an aid for engine warm up. Cooling the exhaust gases can also protect turbochargers in internal combustion engines where the exhaust temperatures are such that they exceed the operating limits of more conventional materials; this can allow for lower cost materials to be utilised in some applications. The IEM can  
20 remove the requirement for combustion enrichment for thermal protection. In certain embodiments, these benefits can result in a 0.5-2% reduction in CO<sub>2</sub> emissions over the New European Drive Cycle (NEDC). In part due to a faster engine heat-up, up to 20% faster, with a water cooled exhaust in comparison to an air cooled exhaust. Up to 15% reduction in Brake Specific Fuel Consumption (BSFC) at extreme operating points can be achieved due  
25 to avoiding over-fuelling for components protection. IEM typically lower engines cost through the removal of components and reduce the surface area pre turbocharger/catalyst, thereby helping to improve catalyst light-off times (i.e. the time taken for the catalyst to reach operating temperature).

30 Increasing market pressure for more powerful and more efficient engines is being met by producing engines with higher specific power. These engines require high levels of boosting to deliver power and torque whilst achieving improved fuel economy through downsizing. These highly boosted engines often reject too much heat into the exhaust system such that it would not be possible to cool the cylinder head or provide sufficient cooling surface area for  
35 the liquid-to-air heat exchanger. Therefore high specific power engines often remove the IEM at the expense of fuel economy.

Current IEM cooling is often limited by liquid temperature or the ability of the vehicle to dissipate heat to atmosphere. As a direct result of this, a greater wall thickness than may be optimal and/or flow paths and/or surfaces area exposure is often selected to limit the heat rejection. If the temperature limits of the liquid are increased, this allows for reduced wall thickness, thus more heat rejection and a lighter IEM through material reduction.

It is against this backdrop that the present invention has been conceived. At least in certain embodiments, the present invention overcomes or ameliorates at least some of the problems or limitations associated with prior art arrangements.

## SUMMARY OF THE INVENTION

Aspects of the present invention relate to a cooling apparatus comprising first and second cooling circuits; to a vehicle comprising a cooling apparatus; and to a controller for controlling operation of a cooling apparatus as claimed in the appended claims.

According to a first aspect of the present invention there is provided a cooling apparatus for an internal combustion engine having an exhaust manifold; the cooling apparatus comprising:

- a first cooling circuit comprising an exhaust manifold cooling line for cooling the exhaust manifold;

- first heat exchanging means for rejecting heat from the first cooling circuit;

- a second cooling circuit comprising an engine cooling line for cooling the internal combustion engine;

- second heat exchanging means for rejecting heat from the second cooling circuit;

and

- third heat exchanging means for transferring heat from the first cooling circuit to the second cooling circuit. In use, the third heat exchanging means is for transferring thermal energy from the first cooling circuit to the second cooling circuit. At least in certain embodiments transferring thermal energy from the first cooling circuit to the second cooling circuit allows the first cooling circuit to operate over a broader range of operating conditions.

The engine cooling line may comprise a water jacket. The water jacket may, for example, be incorporated into a cylinder head. The engine cooling line may, for example, comprise a cylinder head cooling line.

The first and second cooling circuits in the cooling apparatus are split and can provide high and low temperature cooling. The engine cooling line may convey a low temperature liquid

coolant, such as a water-based coolant, for example at an operating temperature of up to approximately 110°C at 1.1 bar. The exhaust manifold cooling line may convey a high temperature liquid coolant, for example having a higher temperature boiling point, for example at an operating temperature of up to approximately 160°C. The higher operating temperature of the first cooling circuit can provide faster heat exchange and/or greater heat flux, thereby enabling a smaller capacity first heat exchanging means. This can provide improved control, enabling the first cooling circuit to be selectively activated only when required. The higher temperature fluid may be used to heat up the second cooling circuit, for example on start-up or after initial catalyst light-off has been achieved. The rejection of the exhaust heat into the second cooling circuit may be selectively controlled, for example to reduce the rejection of heat when operating at higher engine loads.

At least in certain embodiments, one or more of said first, second and third heat exchanging means may be controlled to increase rejection of heat from the internal combustion engine. For example, the third heat exchanging means may be by-passed when the internal combustion engine is operating in a high load condition. The transfer of heat from the first cooling circuit to the second cooling circuit may be reduced in a high load condition. The transfer of heat from the exhaust manifold to the internal combustion engine may be reduced under the high load condition.

The cooling system may comprise first valve means for connecting the exhaust manifold cooling line either to the first heat exchanging means or to the third heat exchanging means. When connected to the first heat exchanging means, the third heat exchanging means may be bypassed. Conversely, when connected to the third heat exchanging means, the first heat exchanging means may be bypassed.

The first valve means may comprise valves operable to connect the exhaust manifold cooling line to the first heat exchanging means; or to connect the exhaust manifold cooling line to the third heat exchanging means. The first valve means may comprise first and second valves. The first valve may be a first three-way valve for connecting an outlet of the exhaust manifold cooling line either to the first heat exchanging means or to the inlet of the engine cooling line. The second valve may be a second three-way valve for connecting either the first heat exchanging means or the third heat exchanging means to an inlet of the exhaust manifold cooling line.

The second heat exchanging means and the third heat exchanging means may be arranged in series.

The cooling apparatus may comprise second valve means for selectively connecting the engine cooling line to the second heat exchanging means. The second valve means may be operable to connect the engine cooling line to the second heat exchanging means or to bypass the second heat exchanging means. The second heat exchanging means may be arranged in series with the third heat exchanging means. The third heat exchanging means may remain connected to the engine cooling line.

The second valve means may comprise a third three-way valve for connecting an outlet of the engine cooling line either to the second heat exchanging means or to a bypass line for bypassing the second heat exchanging means; and a fourth three-way valve for connecting either the second heat exchanging means or the bypass line to an inlet of the engine cooling line.

A first cooling liquid may be provided in the first cooling circuit; and a second cooling liquid may be provided in the second cooling circuit, the first and second cooling liquids may be separated from each other. Thus, the first and second cooling liquids may not mix. The first and second cooling liquids may be the same as each other or may be different from each other. The first and second cooling liquids may be configured for different operating temperatures. The first cooling liquid may have a higher operating temperature than the second cooling liquid.

The first cooling circuit may be a high temperature cooling circuit. The second cooling circuit may be a comparatively lower temperature cooling circuit than the first cooling circuit.

The first heat exchanging means may comprise high temperature heat exchanging means. The first heat exchanging means may comprise a first liquid-to-air heat exchanger.

The second heat exchanging means may comprise low temperature heat exchanging means. The second heat exchanging means may comprise a second liquid-to-air heat exchanger.

The cooling apparatus may comprise a Thermo-Electric Generator (TEG) arranged in series or parallel to said first heat exchanging means and/or said second heat exchanging means.

The first heat exchanging means and/or the second heat exchanging means may comprise an occupant heating system. The occupant heating system may comprise a liquid-to-air heat exchanger for heating cabin air.

- 5 The internal combustion engine may comprise a cylinder head. The exhaust manifold may be formed integrally with the cylinder head. In alternate embodiments the exhaust manifold may be a separate component mounted to the cylinder head.

10 According to a further aspect of the present invention there is provided a controller for the cooling apparatus described herein. The controller may comprise at least one processor. The at least one processor may be configured to control operation of the cooling apparatus in dependence on the measured temperature of the liquid coolant in the first and second cooling circuits. The controller may, for example, receive first and second temperature signals from first and second temperature sensors associated with the first and second  
15 cooling circuits. First cooling circuit upper and lower temperature thresholds may be predefined in relation to the first cooling circuit. Second cooling circuit upper and lower temperature thresholds may be predefined in relation to the second cooling circuit.

The at least one processor may be configured to control the cooling apparatus to bypass the  
20 first heat exchanging means and/or the second heat exchanging means when a temperature of the second cooling circuit is less than the predefined second cooling circuit lower temperature threshold. This may correspond to a warm-up procedure for the internal combustion engine. When the temperature of the second cooling circuit is greater than the predefined second cooling circuit lower temperature, the at least one processor may be  
25 configured to connect the first heat exchanging means to the exhaust manifold cooling line; and/or to connect the second heat exchanging means to the engine cooling line. When the temperature of the second cooling circuit is less than the predefined second cooling circuit lower temperature threshold, the at least one processor may be configured to actuate the first valve means to connect the exhaust manifold cooling line and the engine cooling line to  
30 the third heat exchanging means. When the temperature of the second cooling circuit is greater than the predefined second cooling circuit lower temperature threshold, the at least one processor may be configured to actuate the second valve means to bypass the third heat exchanging means. When the temperature of the first cooling circuit is greater than the predefined second cooling circuit upper temperature threshold, the at least one processor  
35 may be configured to actuate the first valve means and/or the second valve means to bypass the third heat exchanging means. When the temperature of the second cooling circuit is greater than the predefined second cooling circuit upper temperature threshold, the

at least one processor may be configured to actuate the second valve means to connect the second heat exchanging means.

According to a further aspect of the present invention there is provided a cooling apparatus  
5 for an internal combustion engine having an exhaust manifold;

a first cooling circuit comprising an exhaust manifold cooling line for cooling the exhaust manifold;

first heat exchanging means for rejecting heat from the first cooling circuit;

10 a second cooling circuit comprising an engine cooling line for cooling the internal combustion engine;

second heat exchanging means for rejecting heat from the second cooling circuits;  
and

circuit connecting means for selectively connecting the first cooling circuit to the second cooling circuit.

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The circuit connecting means may comprise:

first valve means for selectively connecting an outlet of the exhaust manifold cooling line to an inlet of the engine cooling line; and

20 second valve means for selectively connecting an outlet of the engine cooling line to an inlet of the exhaust manifold cooling line.

The first valve means may comprise a first three-way valve for connecting the outlet of the exhaust manifold cooling line either to the first heat exchanging means or to the inlet of the second heat exchanging means.

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The second valve means may comprise a second three-way valve for connecting the outlet of the engine cooling line to the second heat exchanging means or to the inlet of the exhaust manifold cooling line.

30 The first cooling circuit may be a high temperature cooling circuit. The second cooling circuit may be a low temperature cooling circuit.

The first heat exchanging means may comprise high temperature heat exchanging means.  
The first heat exchanging means may comprise a first liquid-to-air heat exchanger.

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The second heat exchanging means may comprise low temperature heat exchanging means. The second heat exchanging means may comprise a second liquid-to-air heat exchanger.

- 5 The cooling apparatus may comprise a Thermo-Electric Generator(TEG) arranged in series or parallel to said first heat exchanging means and/or said second heat exchanging means.

The first heat exchanging means and/or the second heat exchanging means may comprise an occupant heating system. The occupant heating system may comprise a liquid-to-air heat  
10 exchanger for heating cabin air.

The internal combustion engine may comprise a cylinder head. The exhaust manifold may be formed integrally with the cylinder head. In alternate embodiments the exhaust manifold may be a separate component mounted to the cylinder head.

15 According to a further aspect of the present invention there is provided a controller for the cooling apparatus described herein. The controller may comprise at least one processor. The at least one processor may be configured to control operation of the cooling apparatus in dependence on the measured temperature of the liquid coolant in the first and second  
20 cooling circuits. The controller may, for example, receive first and second temperature signals from first and second temperature sensors associated with the first and second cooling circuits. First cooling circuit upper and lower temperature thresholds may be predefined in relation to the first cooling circuit. Second cooling circuit upper and lower temperature thresholds may be predefined in relation to the second cooling circuit.

25 The at least one processor may be configured to control the cooling apparatus to connect the first cooling circuit to the second cooling circuit when a temperature of the second cooling circuit is less than the predefined second cooling circuit lower temperature threshold. The at least one processor may be configured to control the cooling apparatus to bypass the  
30 first heat exchanging means and/or the second heat exchanging means when the temperature of the second cooling circuit is less than the predefined second cooling circuit lower temperature threshold. The at least one processor may be configured to disconnect the first cooling circuit from the second cooling circuit when the temperature of the second cooling circuit is greater than the predefined second cooling circuit lower temperature  
35 threshold. When the temperature of the first cooling circuit is greater than the predefined second cooling circuit upper temperature threshold, the at least one processor may be configured to disconnect the first cooling circuit from the second cooling circuit. When the

temperature of the second cooling circuit is greater than the predefined second cooling circuit upper temperature threshold, the at least one processor may be configured to actuate the second valve means to connect the second heat exchanging means.

- 5 The at least one processor may be configured to control operation of the cooling apparatus in dependence on the measured temperature of the liquid coolant in the first and second cooling circuits. The controller may, for example, receive first and second temperature signals from first and second temperature sensors associated with the first and second cooling circuits.

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As used herein the term "processor" will be understood to include both a single processor and a plurality of processors collectively operating to provide any stated control functionality. To configure a processor, a suitable set of instructions may be provided which, when executed, cause said processor to implement the control techniques specified herein. The set of instructions may suitably be embedded in said one or more processors. Alternatively, the set of instructions may be provided as software saved on one or more memory associated with said processor to be executed on said processor. The instructions may be provided on a non-transitory computer readable media.

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- 20 According to a further aspect of the present invention there is provided a vehicle comprising a cooling apparatus, a controller and a processor as herein before described.

Within the scope of the claims it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs 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.

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#### BRIEF DESCRIPTION OF THE DRAWINGS

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

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Figure 1 shows a schematic representation of a vehicle comprising a cooling apparatus in accordance with an embodiment of the present invention;

Figure 2 shows a schematic representation of a cooling apparatus in accordance with an embodiment of the present invention; and

Figure 3 shows a schematic representation of a modified arrangement of the cooling apparatus shown in Figure 2; and

5 Figure 4 shows a schematic representation of an alternate embodiment of the cooling apparatus shown in Figure 1.

#### DETAILED DESCRIPTION

A cooling apparatus 1 of an internal combustion engine 2 in accordance with an embodiment  
10 of the present invention will now be described with reference to the accompanying figures. As shown in Figure 1, the cooling apparatus 1 and the internal combustion engine 2 are adapted for use in a vehicle 3, such as an automobile. The internal combustion engine 2 in the present embodiment is a spark-ignition engine using gasoline (petrol) as a fuel, but the invention is not limited in this respect and could be implemented in a compression-ignition  
15 combustion engine, such as diesel. Equally, the present invention could be implemented in an alternative fuel engine, such as ethanol or methanol.

With reference to Figures 1 and 2, the internal combustion engine 2 comprises a cylinder head 4; and an exhaust apparatus 5 (shown in Figure 1). The cylinder head 4 is mounted to  
20 a cylinder block (not shown) having a plurality of cylinders in which pistons reciprocate. The cylinder head 4 comprises a plurality of combustion bowls 6 which close the cylinders to form combustion chambers in which fuel is combusted. In the illustrated arrangement, the internal combustion engine 2 has four combustion chambers disposed in-line, but it will be understood that the present invention is applicable to other configurations of the internal  
25 combustion engine 2. The exhaust apparatus 5 comprises an exhaust manifold 7 having a plurality of exhaust ports 8 and an exhaust outlet 9. In alternate embodiments, the exhaust manifold 7 may comprise multiple exhaust outlets 9. The exhaust ports 8 are associated with respective combustion bowls 6 of the internal combustion engine 2. The exhaust outlet 9 is connected to a conventional exhaust apparatus (not shown), for example comprising one or  
30 more catalytic converter and/or one or more silencer. The internal combustion engine 2 may comprise a turbocharger having a turbine (not shown) which is driven by the exhaust gases expelled through the exhaust outlet 9.

The exhaust manifold 7 in the present embodiment is an integrated exhaust manifold (IEM)  
35 formed integrally with the cylinder head 4 although in a modified arrangement, the cylinder head 4 and the exhaust manifold 7 may be formed separately. The cylinder head 4 and the exhaust manifold 7 are thereby formed as a combined head component mounted to the

cylinder block. With respect to the integrated arrangement, the term “cylinder head” is used herein to refer to the portion of the head component comprising the combustion bowls 6 which close the cylinders in the cylinder block; and the term “exhaust manifold” is used herein to refer to the portion of the head component which forms the exhaust manifold. It is noted that the second cooling circuit 11 may include one or more water jacket which are not illustrated. The second cooling circuit 11 may, for example, comprise a cylinder block having a water jacket which is connected to a cylinder head water jacket.

The cooling apparatus 1 comprises a first cooling circuit 10 (shown throughout its full extent as a single line) and a second cooling circuit 11 (shown throughout its full extent as a pair of lines). In the present embodiment the first and second cooling circuits 10, 11 are separated from each other. As described herein, liquid coolant is pumped through the first and second cooling circuits 10, 11 to transfer thermal energy from the internal combustion engine 2. The first and second cooling circuits 10, 11 are isolated from each other such that the liquid coolant in the first and second cooling circuits 10, 11 is not mixed. It will be appreciated, therefore, that the first and second cooling circuits 10, 11 may use different liquid coolants, for example to accommodate different operating temperatures. The configuration of the first and second cooling circuits 10, 11 will now be described.

The first cooling circuit 10 operates as a high-temperature cooling circuit operative to cool the exhaust manifold 7. The first cooling circuit 10 comprises an exhaust manifold cooling line 12 in the form of a first passage formed in the exhaust manifold 7. The exhaust manifold 7 comprises a first coolant inlet 13 and a first coolant outlet 14 connected to the exhaust manifold cooling line 12. The liquid coolant is introduced into the exhaust manifold cooling line 12 through the first coolant inlet 13 and exits through the first coolant outlet 14. A first pump 15 is provided for pumping the liquid coolant through the first cooling circuit 10. The liquid coolant may be pumped through the first cooling circuit 10 at a pressure higher than atmospheric pressure, for example approximately 1.1bar. In use, the liquid coolant transfers thermal energy from the exhaust manifold 7, thereby reducing the exhaust gas temperature. A typical operating temperature of the liquid coolant in the exhaust manifold cooling line 12 is up to approximately 160-180°C. The first cooling circuit 10 comprises first heat exchanging means 16 for rejecting heat from the liquid coolant. In the present embodiment the first heat exchanging means 16 comprises a conventional first liquid-to-air heat exchanger. The first heat exchanging means 16 has an inlet which is a top hose of the first liquid-to-air heat exchanger; and an outlet which is a bottom hose on the first liquid-to-air heat exchanger. In use, the cooled liquid is removed from the bottom of the first liquid-to-air heat exchanger. The first heat exchanging means 16 is referred to herein as a high temperature heat

exchanging means. A first temperature sensor T1 is provided to measure the temperature of the liquid coolant in the exhaust manifold cooling line 12. The first temperature sensor T1 outputs a first temperature signal ST1.

5 The second cooling circuit 11 operates as a low-temperature cooling circuit operative to cool the cylinder head 4 and the cylinder block. The second cooling circuit 11 comprises an engine cooling line 17 which in the present embodiment is in the form of a first passage formed in the cylinder head 4. The cylinder head 4 comprises a second coolant inlet 18 and a second coolant outlet 19 connected to the engine cooling line 17. The liquid coolant is  
10 introduced into the engine cooling line 17 through the second coolant inlet 18 and exits through the second coolant outlet 19. A separate pump (not shown), such as a conventional water pump, is provided for pumping the liquid coolant through the second cooling circuit 11. The liquid coolant may be pumped through the second cooling circuit 11 at a pressure higher than atmospheric pressure, for example approximately 1.1bar. In use, the liquid coolant  
15 transfers thermal energy from the cylinder head 4. A typical operating temperature of the liquid coolant in the engine cooling line 17 is up to approximately 110 °C. The second cooling circuit 11 comprises second heat exchanging means 20 for rejecting heat from the liquid coolant. The second heat exchanging means 20 in the present embodiment comprises a conventional second liquid-to-air heat exchanger. The second heat exchanging means 20  
20 has an inlet which is a top hose of the second liquid-to-air heat exchanger; and an outlet which is a bottom hose on the second liquid-to-air heat exchanger. In use, the cooled liquid is removed from the bottom of the second liquid-to-air heat exchanger. The second heat exchanging means 20 is referred to herein as a low temperature heat exchanging means. A second temperature sensor T2 is provided to measure the temperature of the liquid coolant  
25 in the engine cooling line 17. The second temperature sensor T2 outputs a second temperature signal ST2.

The first cooling circuit 10 comprises a third heat exchanging means 21. In the present embodiment the third heat exchanging means 21 is a liquid-to-liquid heat exchanger. The  
30 third heat exchanging means 21 is suitable for transferring thermal energy from the first cooling circuit 10 to the second cooling circuit 11. In use, the first and second cooling circuits 10, 11 are selectively connected to the third heat exchanging means 21. In the present embodiment the connections are arranged such that the liquid coolant from the first and second cooling circuits 10, 11 flows in opposite directions through the third heat exchanging  
35 means 21. In alternate embodiments, the liquid coolant in the first and second cooling circuits 10, 11 may flow in the same direction through the third heat exchanging means 21. The liquid coolant in the first cooling circuit 10 is used to heat the liquid coolant in the second

cooling circuit 11, for example on start-up of the internal combustion engine 2 or after a catalytic converter has achieved an operating temperature (i.e. after a catalyst light-off time). A catalyst temperature sensor (not shown) may be provided to measure the temperature of the catalyst.

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The first cooling circuit 10 is a high temperature cooling circuit. The first cooling circuit 10 comprises first valve means for connecting the exhaust manifold cooling line 12 either to the first heat exchanging means 16 or to the third heat exchanging means 21. In particular, the first valve means comprises a first three-way valve 23 and a second three-way valve 24. The first three-way valve 23 is arranged to control the flow of the liquid coolant exiting the exhaust manifold cooling line 12 from the first coolant outlet 14. The first three-way valve 23 is arranged selectively to connect the exhaust manifold cooling line 12 to the first heat exchanging means 16 or to the third heat exchanging means 21 via the line shown as a single dashed line. The second three-way valve 24 is arranged to control the return flow of the liquid coolant into the exhaust manifold cooling line 12. The second three-way valve 24 is arranged selectively to connect either the first heat exchanging means 16 or the third heat exchanging means 21 to the exhaust manifold cooling line 12. It will be appreciated that the first and second three-way valves 23, 24 are operated in conjunction with each other to maintain circulation of the liquid coolant within the first cooling circuit 10. In a first operating configuration the first and second three-way valves 23, 24 can be actuated to connect the first heat exchanging means 16 to the exhaust manifold cooling line 12 whilst bypassing the third heat exchanging means 21. In a second operating configuration the first and second three-way valves 23, 24 may be actuated to connect the third heat exchanging means 21 to the exhaust manifold cooling line 12 whilst bypassing the first heat exchanging means 16.

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The second cooling circuit 11 is a low temperature cooling circuit. The second cooling circuit 11 comprises second valve means for selectively connecting the engine cooling line 17 to the second heat exchanging means 20. In particular, the second valve means comprises a third three-way valve 26 and a fourth three-way valve 27. A first by-pass line 28 shown as a pair of dashed lines is arranged in parallel to the second heat exchanging means 20. The third and fourth three-way valves 26, 27 are actuated selectively to connect or disconnect the first by-pass line 28. The second heat exchanging means 20 may thereby be connected to or disconnected from the engine cooling line 17. The third three-way valve 26 is arranged to control the flow of the liquid coolant exiting the engine cooling line 17. The third three-way valve 26 is arranged selectively to connect the engine cooling line 17 to the second heat exchanging means 20 or to the by-pass line 28. The fourth three-way valve 27 is arranged to control the flow of the liquid coolant from the first by-pass line 28 to the third heat

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exchanging means 21. It will be appreciated that the second and third three-way valves 26, 27 are operated in conjunction with each other to maintain circulation of the liquid coolant within the second cooling circuit 11. The third and fourth three-way valves 26, 27 are optional and may be omitted in certain embodiments. In a first operating configuration the third and fourth three-way valves 26, 27 are actuated to connect the second heat exchanging means 20 to the engine cooling line 17. In a second operating configuration the third and fourth three-way valves 26, 27 are actuated to connect the second heat exchanging means 20 to the engine cooling line 17. In the present embodiment, the third heat exchanging means 21 is connected to the engine cooling line 17 in both said first and second operating configurations. As shown in Figure 1, the third heat exchanging means 21 is downstream of the second heat exchanging means 20.

By providing separate first and second cooling circuits 10, 11, the cylinder head 4 and the exhaust manifold 7 may operate at different temperatures. The second cooling circuit 11 for the cylinder head 4 could utilise a liquid coolant having a low operating temperature, for example up to approximately 110°C; and the first cooling circuit 10 for the exhaust manifold 7 could utilise a liquid coolant having a high operating temperature, for example up to approximately 160-180°C. The liquid coolant in the second cooling circuit 11 could be a water-based coolant; and the liquid coolant in the first cooling circuit 10 could be a higher temperature boil-point liquid. By operating at elevated temperatures, a faster heat exchange and/or greater heat flux is achievable, therefore allowing a reduction in the size of the first heat exchanging means 16, for example allowing use of a smaller separate liquid-to-air heat exchanger. This can provide improved control, for example allowing the first cooling circuit 10 to be activated only when required. By controlling operation of the third heat exchanging means 21, the excessive transfer of heat from the first cooling circuit 10 to the second cooling circuit 11, for example under high load situations, may be avoided. At least in certain embodiments this may allow an increase in the heat rejection (potentially up to 20%) due to increased temperature limits. Alternatively, this could allow a reduction in the size of the required cooling area (potentially as much as 20%).

A controller 29 (shown in Figure 1) is provided for controlling operation of the cooling apparatus 1. In the present embodiment the electronic processor 30 controls operation of the pump 15 and the first, second, third and fourth three-way valves 23, 24, 26, 27. The controller 29 comprises an electronic processor 30 and a system memory 31. The electronic processor 30 executes an instruction set stored on a non-transitory computer-readable medium. When executed, the instruction set causes the electronic processor 30 to implement the method(s) described herein. The electronic processor 30 receives the first

and second temperature signals ST1, ST2 from said first and second temperature sensors T1, T2. The first temperature signal ST1 provides an indication of a first temperature in the first cooling circuit 10; and the second temperature signal ST2 provides an indication of a second temperature in the second cooling circuit 11.

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A first cooling circuit lower temperature threshold and a first cooling circuit upper temperature threshold are defined for the first cooling circuit 10. The first cooling circuit lower temperature threshold corresponds to a lower operating temperature for the exhaust manifold 7; and the first cooling circuit upper temperature threshold corresponds to an upper  
10 operating temperature for the exhaust manifold 7. A second cooling circuit lower temperature threshold and a second cooling circuit upper temperature threshold are defined for the second cooling circuit 11. The second cooling circuit lower temperature threshold corresponds to a lower operating temperature for the cylinder head 4; and the second cooling circuit upper temperature threshold corresponds to an upper operating temperature  
15 for the cylinder head 4. In the present embodiment the second cooling circuit lower temperature threshold is defined as 80°C and the second cooling circuit upper temperature threshold is defined as 90°C (at a pressure of 1.1bar). The temperature thresholds are stored in a look-up table stored in the system memory 31 and can be accessed by the electronic processor 30. In the event that the first temperature of the coolant in the first  
20 cooling circuit 10 exceeds the upper temperature threshold of the second cooling circuit 11, the electronic processor 30 is configured to bypass the third heat exchanger 21 in order to separate the first and second cooling circuits 10, 11.

During a start-up procedure, the electronic processor 30 is configured to actuate the first and  
25 second three-way valves 23, 24 to bypass the first heat exchanger 16 in the first cooling circuit 10; and to actuate the third and fourth three-way valves 26, 27 to bypass the second heat exchanger 20 in the second cooling circuit 11. This control function can help to expedite heating of the cylinder head 4. The pump 15 may initially be deactivated until the first temperature exceeds the first cooling circuit lower temperature threshold. If the internal  
30 combustion engine 2 has been operated for a period of time and is re-started while still cooling down, the first temperature may be less than the second temperature due to the different thermal properties of the cylinder head 4 and the exhaust manifold 7. If the first temperature is initially lower than the second temperature, the electronic processor 30 actuates the first and second three-way valves 23, 24 to connect the first heat exchanger 16  
35 in order to bypass the third heat exchanger 21.

The electronic processor 30 is configured to activate the pump 15 when the first temperature exceeds the first cooling circuit lower temperature threshold. When the electronic processor 30 determines that the second temperature is greater than the second cooling circuit lower temperature threshold, the electronic processor 30 is configured to actuate the first and second three-way valves 23, 24 to connect the first heat exchanger 16, thereby bypassing the third heat exchanger 21. The third and fourth three-way valves 26, 27 are held such that the second heat exchanger 20 is bypassed to promote heating of the cylinder head 4. When the second temperature exceeds the second cooling circuit upper temperature threshold, the electronic processor 30 is configured to actuate the third and fourth three-way valves 26, 27 to connect the second heat exchanger 20 to the second cooling circuit 11. The electronic processor 30 may continue to control the third and fourth three-way valves 26, 27 to maintain the coolant in the second cooling circuit at a target operating temperature.

The operation of the cooling apparatus 1 will now be described with reference to Figures 1 and 2. When the internal combustion engine 2 is operating, the cylinder head 4 is heated by combustion of fuel in the combustion chambers. The gasses are exhausted through the exhaust manifold 7, typically when poppet valves (not shown) are operated to open the combustion chambers. The exhaust gases enter the exhaust manifold 7 through the exhaust ports 8 and exit through the exhaust outlet 9. The exhaust gases then travel through the downstream exhaust apparatus in conventional manner.

During an initial start-up cycle, the cooling apparatus 1 is controlled to expedite heating of the internal combustion engine. During a cold-start of the internal combustion engine 2, the temperature of the coolant in the second cooling circuit 11 is below the second cooling circuit lower temperature threshold. When the second temperature is less than the second cooling circuit lower temperature threshold, the electronic processor 30 actuates the third and fourth three-way valves 26, 27 to bypass the second heat exchanging means 20. The liquid coolant in the second cooling circuit 11 is circulated around the internal combustion engine 2, specifically through the engine cooling line 17 entering at the second coolant inlet 18 and exiting at the second coolant outlet 19. The cylinder head 4 is heated by the combustion of the fuel in the combustion chambers. The liquid coolant in the engine cooling line 17 is heated at least in part due to its proximity to the combustion bowls 6 and the exhaust ports 8.

The first and second three-way valves 23, 24 are configured to bypass the first heat exchanging means 16. The liquid coolant in the exhaust manifold cooling line 12 is heated by gasses passing through the exhaust manifold 7. The coolant in the first cooling circuit 10

is typically at a higher temperature than the coolant in the second cooling circuit 11. The first pump 15 may be activated when the first temperature is greater than the first cooling circuit lower temperature threshold. The first three-way valve 23 is actuated such that the relatively high temperature liquid coolant in the first cooling circuit 10 flows from the exhaust manifold cooling line 12 to the third heat exchanging means 21. The thermal energy is transferred from the first cooling circuit 10 to the second cooling circuit 11 and promotes heating of the cylinder head 4. It will be appreciated that the liquid coolant in the first and second cooling circuits 10, 11 does not mix in this embodiment. This retains the conventional low temperature advantages, such as allowing micro boiling to extract additional heat energy from critical areas. The second three-way valve 24 is configured to allow the liquid coolant from the third heat exchanging means 21 to continue to circulate within the first cooling circuit 10.

By controlling operation of the first and second cooling circuits 10, 11, the cylinder head 4 may reach a target operating temperature more quickly, typically in the range 90-110 °C (at a pressure of 1.1bar). When the second cooling circuit 11 reaches the second cooling circuit upper temperature threshold, the third and fourth three-way valves 26, 27 may be actuated to allow the liquid coolant in the second cooling circuit 11 to flow through the second heat exchanging means 20. The second heat exchanging means 20 may then operate in conventional manner to reject thermal energy to the ambient environment, typically to atmosphere. By controlling the third and fourth three-way valves 26, 27, the cylinder head 4 may be maintained at the target operating temperature.

In a low load condition of the internal combustion engine 2, it may be determined that it is not necessary to transfer heat from the first cooling circuit 10 to the second cooling circuit 11 or to reject heat from the first cooling circuit 10 to atmosphere. In this situation, the first pump 15 may not be required and it may be de-activated. Conversely, in a high load condition of the internal combustion engine 2, it may be determined that it is necessary to reject as much engine heat as possible to atmosphere. In this situation, the first pump 15 would be engaged and the first and second three-way valves 23, 24 may be configured so as to bypass the third heat exchanging means 21 and to pump the liquid coolant in the first cooling circuit 10 to the first heat exchanging means 16.

It will be appreciated that various changes and modifications can be made to the cooling apparatus 1 according to the previous embodiment. In one arrangement a Thermo-Electric Generator (TEG) device may be incorporated into the cooling apparatus 1. As a result of the higher operating temperature of the first cooling circuit 10, this is a suitable location to

position a TEG device. This could be laid out according to the embodiment shown in Figure 2 with the TEG device disposed in parallel to, or in series with the first heat exchanging means 16. One or more valve may be provided to control the flow of liquid coolant through the TEG device. Alternatively, the TEG device could be used to replace the first heat exchanging means 16. The TEG device may also be used without the second heat exchanging means 20.

In a further modification, the cooling apparatus 1 comprises a separate fast cabin heat-up circuit. In one arrangement an occupant heating circuit is incorporated into the cooling apparatus 1. As a result of the higher operating temperature of the first cooling circuit 10, this is a suitable location to position the occupant heating circuit. This could be laid out according to the arrangement illustrated in Figure 2 with the occupant heating device disposed in parallel to, or in series with the first heat exchanging means 16. One or more valve may be provided to control the flow of liquid coolant through the occupant heating device. The occupant heating device may also be used without the second heat exchanging means 20. The first cooling circuit 10 may be used to reduce the time for the occupant heating device to reach a predetermined temperature.

The cooling apparatus 1 has been described as having the exhaust manifold 7 integrated into the cylinder head 4. In a modified arrangement, the cylinder head 4 and the exhaust manifold 7 may be formed separately, as illustrated in Figure 3. The functional layout of the cooling apparatus 1 remains substantially unchanged from the above embodiment. The cylinder head 4 and the exhaust manifold 7 are separated by an exhaust flange joint 32 which may comprise a gasket to ensure a good seal for the exhaust gases. This change allows for further increases in design flexibility in terms of coolant operating temperature limits by allowing for different materials to be used for the cylinder head 4 and the exhaust manifold 7.

The cooling apparatus 1 allows formation of efficient cooling paths for the exhaust manifold cooling line 12 and/or the engine cooling line 17. The wall thickness and/or materials of the cooling apparatus 1 may be varied, for example depending on whether the exhaust manifold 7 is integrated into the cylinder head 4 or is a separate component. Further fuel economy benefits of the internal combustion engine 2 may be achieved by a reduction in the required surface area for the first and second heat exchanging means 16, 20 at the front of the vehicle 3 and by reducing mass of the cooling circuits due to greater heat flux capability.

The cost of the cooling apparatus 1 may be offset by the removal of heat shields, electric cabin heaters and a separate exhaust manifold in some cases.

Cooling apparatus 1 in accordance with a further embodiment of the present invention is shown in Figure 4. This embodiment of the cooling apparatus 1 is a development of the embodiment shown in Figure 2 and the description focuses on the key differences. Like reference numerals are used herein for like components.

The third heat exchanging means 21 is omitted from the cooling apparatus 1 according to the present embodiment. The cooling apparatus 1 comprises circuit connecting means 33 for selectively connecting the first and second cooling circuits 10, 11. The circuit connecting means 33 in the present embodiment comprises a second by-pass line 34, a fifth three-way valve 35, a sixth three-way valve 36 and a third by-pass line 37.

The fifth three-way valve 35 is disposed between the second heat exchanging means 20 and the engine cooling line 17. The second by-pass line 34 connects the first three-way valve 23 and the fifth three-way valve 35. The fifth three-way valve 35 is operable in conjunction with the first three-way valve 23 to connect the first coolant outlet 14 to the second coolant inlet 18. By controlling the first and fifth three-way valves 23, 35, the second by-pass line 34 can be connected between the first and second cooling circuits 10, 11 to by-pass the first heat exchanging means 16.

The sixth three-way valve 36 is disposed between the second coolant outlet 19 and the third three-way valve 26. The third by-pass line 37 connects the sixth three-way valve 36 and the second three-way valve 24. The sixth three-way valve 36 is operable in conjunction with the second three-way valve 24 to connect the second coolant outlet 19 to the first coolant inlet 13 (via the first pump 15). By controlling the second and sixth three-way valves 24, 36, the third by-pass line 37 can be connected between the first and second cooling circuits 10, 11 to by-pass the second heat exchanging means 20.

The circuit connecting means 33 is operable selectively to connect or disconnect the first and second cooling circuits 10, 11. The same liquid coolant is used in both the first and second cooling circuits 10, 11, but this has a high boiling temperature to accommodate the higher temperatures in the first cooling circuit 10. The first and second cooling circuits 10, 11 may be split to allow the second cooling circuit 11 to operate at a low temperature, for example 110°C, whilst allowing the first cooling circuit 10 to operate at a high temperature, for example 160°C. The cooling apparatus 1 comprises first and second temperature

sensors T1, T2 for measuring the temperature of the liquid coolant in the first and second cooling circuits 10, 11.

It will be appreciated that the third and fourth three-way valves 26, 27 may be actuated selectively to connect the second heat exchanging means 20 to the second cooling circuit 11. In order to connect the first and second cooling circuits 10, 11, the fifth and sixth three-way valves 35, 36 are actuated to by-pass the first and second heat exchanging means 16, 20. The liquid coolant is typically at different temperatures in the first and second cooling circuits 10, 11 but is allowed to mix under certain controlled circumstances. Since the first and second heat exchanging means 16, 20 are by-passed this configuration has particular application during a warm-up procedure for the internal combustion engine 2.

The controller 29 is provided for controlling operation of the cooling apparatus 1. The controller 29 is configured to control operation of the circuit connecting means 33 in dependence on first and second temperature signals ST1, ST2 received from the first and second temperature sensors T1, T2. The first temperature signal ST1 provides an indication of a first temperature in the first cooling circuit 10; and the second temperature signal ST2 provides an indication of a second temperature in the second cooling circuit 11.

In this embodiment the electronic processor 30 is configured to control the cooling apparatus 1 to connect the first cooling circuit 10 to the second cooling circuit 11 in order to expedite heating of the cylinder head 4. The electronic processor 30 checks that the first temperature is higher than the second temperature. If the second temperature is below the second cooling circuit lower temperature threshold, the electronic processor 30 is configured to connect the first and second cooling circuits 10, 11. The electronic processor 30 actuates the first and fifth three-way valves 23, 35 to connect the first coolant outlet 14 to the second coolant inlet 18 (thereby by-passing the first heat exchanging means 16); and actuates the second and sixth three-way valves 24, 36 to connect the second coolant outlet 19 to the first coolant inlet 13 (thereby by-passing the second heat exchanging means 20).

It will be appreciated that various changes and modifications may be made to the cooling apparatus 1 described herein without departing from the scope of the present invention.

The control of the first and second cooling circuits 10, 11 has been described herein with reference to first cooling circuit upper and lower temperature thresholds and second cooling circuit upper and lower temperature thresholds. It will be understood that additional

temperature thresholds may be defined for the first cooling circuit and/or the second cooling circuit.

## CLAIMS:

1. A cooling apparatus for an internal combustion engine having an exhaust manifold; the cooling apparatus comprising:
  - 5 a first cooling circuit comprising an exhaust manifold cooling line for cooling the exhaust manifold;  
first heat exchanging means for rejecting heat from the first cooling circuit;  
a second cooling circuit comprising an engine cooling line for cooling the internal combustion engine;
  - 10 second heat exchanging means for rejecting heat from the second cooling circuit; and  
third heat exchanging means for transferring heat from the first cooling circuit to the second cooling circuit.
- 15 2. A cooling apparatus as claimed in claim 1 comprising first valve means for connecting the exhaust manifold cooling line either to the first heat exchanging means or to the third heat exchanging means.
- 20 3. A cooling apparatus as claimed in claim 2, wherein the first valve means comprises first and second valves operable to connect the exhaust manifold cooling line to the first heat exchanging means; or to connect the exhaust manifold cooling line to the third heat exchanging means.
- 25 4. A cooling apparatus as claimed in claim 3, wherein the first valve is a first three-way valve for connecting an outlet of the exhaust manifold cooling line either to the first heat exchanging means or to the third heat exchanging means; and the second valve is a second three-way valve for connecting either the first heat exchanging means or the third heat exchanging means to an inlet of the exhaust manifold cooling line.
- 30 5. A cooling apparatus as claimed in any one of claims 1 to 4, wherein the second heat exchanging means and the third heat exchanging means are arranged in series.
- 35 6. A cooling apparatus as claimed in any one of the preceding claims comprising second valve means for selectively connecting the engine cooling line to the second heat exchanging means.

7. A cooling apparatus as claimed in claim 6, wherein the second valve means comprises a third three-way valve for connecting an outlet of the engine cooling line either to the second heat exchanging means or to a bypass line for bypassing the second heat exchanging means; and a fourth three-way valve for connecting either the second heat exchanging means or the bypass line to an inlet of the engine cooling line.

8. A cooling apparatus as claimed in any one of the preceding claims, wherein a first cooling liquid is provided in the first cooling circuit; and a second cooling liquid is provided in the second cooling circuit, the first and second cooling liquids being separated from each other.

9. A cooling apparatus as claimed in any one of the preceding claims, wherein the first cooling circuit is a high temperature cooling circuit and the second cooling circuit is a low temperature cooling circuit.

10. A cooling apparatus as claimed in any one of the preceding claims, wherein the first heat exchanging means comprises high temperature heat exchanging means; and the second heat exchanging means comprises low temperature heat exchanging means.

11. A cooling apparatus as claimed in any one of the preceding claims comprising a Thermo-Electric Generator (TEG) arranged in series or parallel to said first heat exchanging means and/or said second heat exchanging means.

12. A cooling apparatus as claimed in any one of the preceding claims, wherein the first heat exchanging means and/or the second heat exchanging means comprises an occupant heating system.

13. A cooling apparatus as claimed in any one of the preceding claims, wherein the exhaust manifold is formed integrally with a cylinder head; or the exhaust manifold is a separate component mounted to a cylinder head.

14. A controller for the cooling apparatus claimed in any one of the preceding claims, the controller comprising at least one processor as hereinbefore defined configured to control the cooling apparatus to bypass the first heat exchanging means and/or the second heat exchanging means when a temperature of the second cooling circuit is less than a predefined second cooling circuit lower temperature threshold.

15. A controller as claimed in claim 14 when dependent directly or indirectly on claim 2, wherein, when the temperature of the second cooling circuit is less than the predefined second cooling circuit lower temperature threshold, the at least one processor is configured to actuate the first valve means to connect the exhaust manifold cooling line to the third heat exchanging means.

16. A controller as claimed in claim 14 or claim 15 when dependent directly or indirectly on claim 2, wherein, when the temperature of the second cooling circuit is greater than the predefined second cooling circuit lower temperature threshold, the at least one processor is configured to actuate the first valve means to connect the exhaust manifold cooling line to the first heat exchanging means and to bypass the third heat exchanging means.

17. A cooling apparatus for an internal combustion engine having an exhaust manifold;  
a first cooling circuit comprising an exhaust manifold cooling line for cooling the exhaust manifold;  
first heat exchanging means for rejecting heat from the first cooling circuit;  
a second cooling circuit operationally separate from the first cooling circuit comprising an engine cooling line for cooling the internal combustion engine;  
second heat exchanging means for rejecting heat from the second cooling circuits;  
and  
circuit connecting means (33) for selectively connecting the first cooling circuit to the second cooling circuit.

18. A cooling apparatus as claimed in claim 17, wherein the circuit connecting means comprises:  
first valve means for selectively connecting an outlet of the exhaust manifold cooling line to an inlet of the engine cooling line; and  
second valve means for selectively connecting an outlet of the engine cooling line to an inlet of the exhaust manifold cooling line.

19. A cooling apparatus as claimed in claim 18, wherein the first valve means comprises a first three-way valve for connecting the outlet of the exhaust manifold cooling line either to the first heat exchanging means or to the inlet of the engine cooling line.

20. A cooling apparatus as claimed in claim 18 or claim 19, wherein the second valve means comprises a second three-way valve for connecting the outlet of the engine cooling line to the second heat exchanging means or to the inlet of the exhaust manifold cooling line.

21. A cooling apparatus as claimed in any one of claims 17 to 20, wherein the first cooling circuit is a high temperature cooling circuit and the second cooling circuit is a low temperature cooling circuit.

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22. A cooling apparatus as claimed in any one of claims 17 to 21, wherein the first heat exchanging means comprises high temperature heat exchanging means; and the second heat exchanging means comprises low temperature heat exchanging means.

10 23. A cooling apparatus as claimed in any one of claims 17 to 22, comprising a Thermo-Electric Generator device (TEG) arranged in series or parallel to said first heat exchanging means and/or said second heat exchanging means.

15 24. A cooling apparatus as claimed in any one of claims 17 to 23, wherein the first heat exchanging means and/or the second heat exchanging means comprises an occupant heating system.

20 25. A cooling apparatus as claimed in any one of claims 17 to 24, wherein the exhaust manifold is formed integrally with a cylinder head; or the exhaust manifold is a separate component mounted to a cylinder head.

26. A controller for the cooling apparatus claimed in any one of claims 17 to 25, the controller comprising at least one processor configured to control the cooling apparatus to connect the first cooling circuit to the second cooling circuit when a temperature of the  
25 second cooling circuit is less than a predefined second cooling circuit lower temperature threshold.

27. A controller as claimed in claim 26, wherein the at least one processor is configured to control the cooling apparatus to bypass the first heat exchanging means and/or the  
30 second heat exchanging means when the temperature at a point in the second cooling circuit is less than the predefined second cooling circuit lower temperature threshold.

28. A controller as claimed in claim 26 or claim 27, wherein the at least one processor is configured to disconnect the first cooling circuit from the second cooling circuit when the  
35 temperature of the second cooling circuit is greater than the predefined second cooling circuit lower temperature threshold.

29. A vehicle comprising a cooling apparatus as claimed in any one of claims 1 to 13 or any one of claims 17 to 25.

5 30. A cooling apparatus substantially as herein described with reference to the accompanying figures.

31. A controller for a cooling apparatus substantially as herein described with reference to the accompanying figures.

10 32. A vehicle substantially as herein described with reference to the accompanying figures.

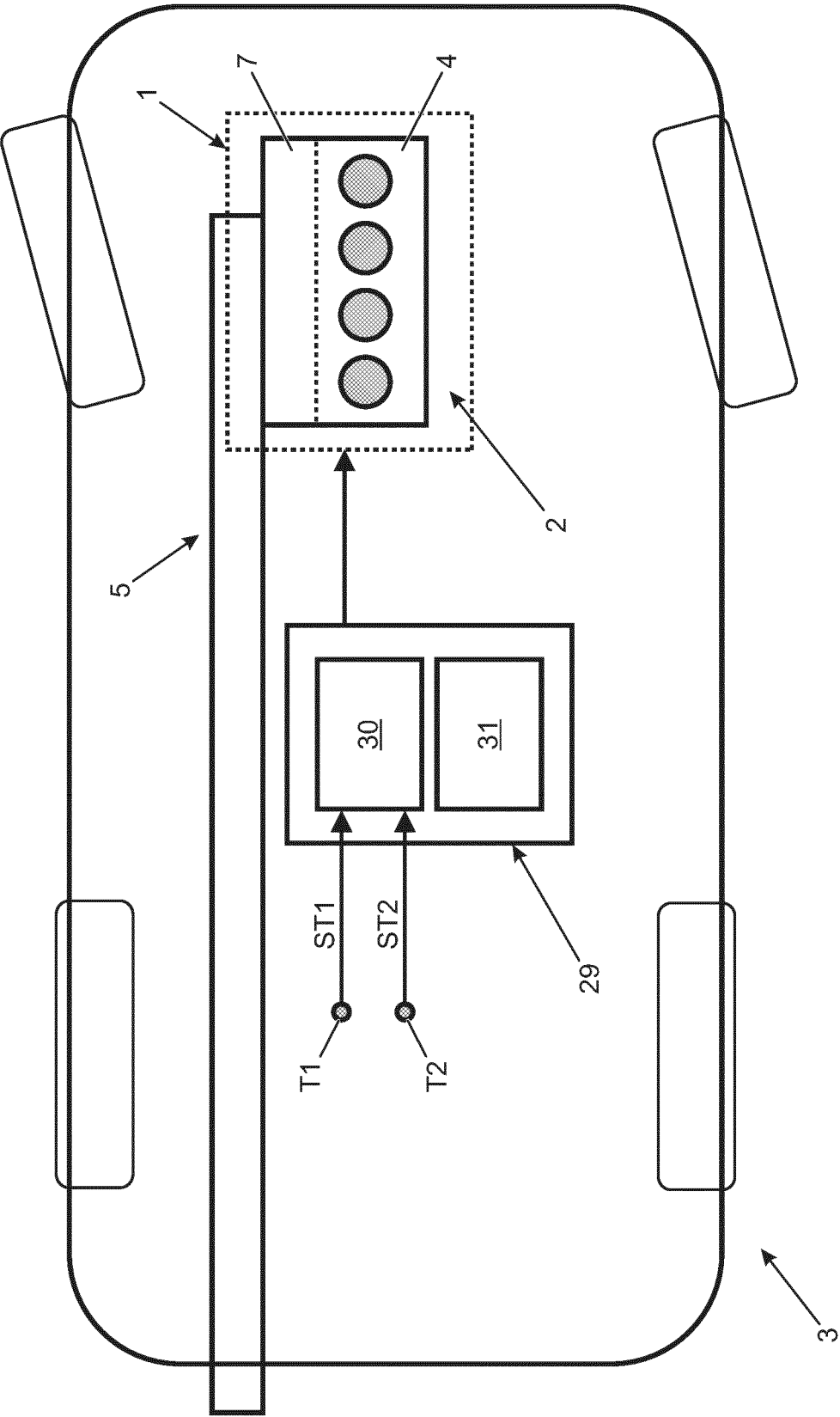


FIG. 1

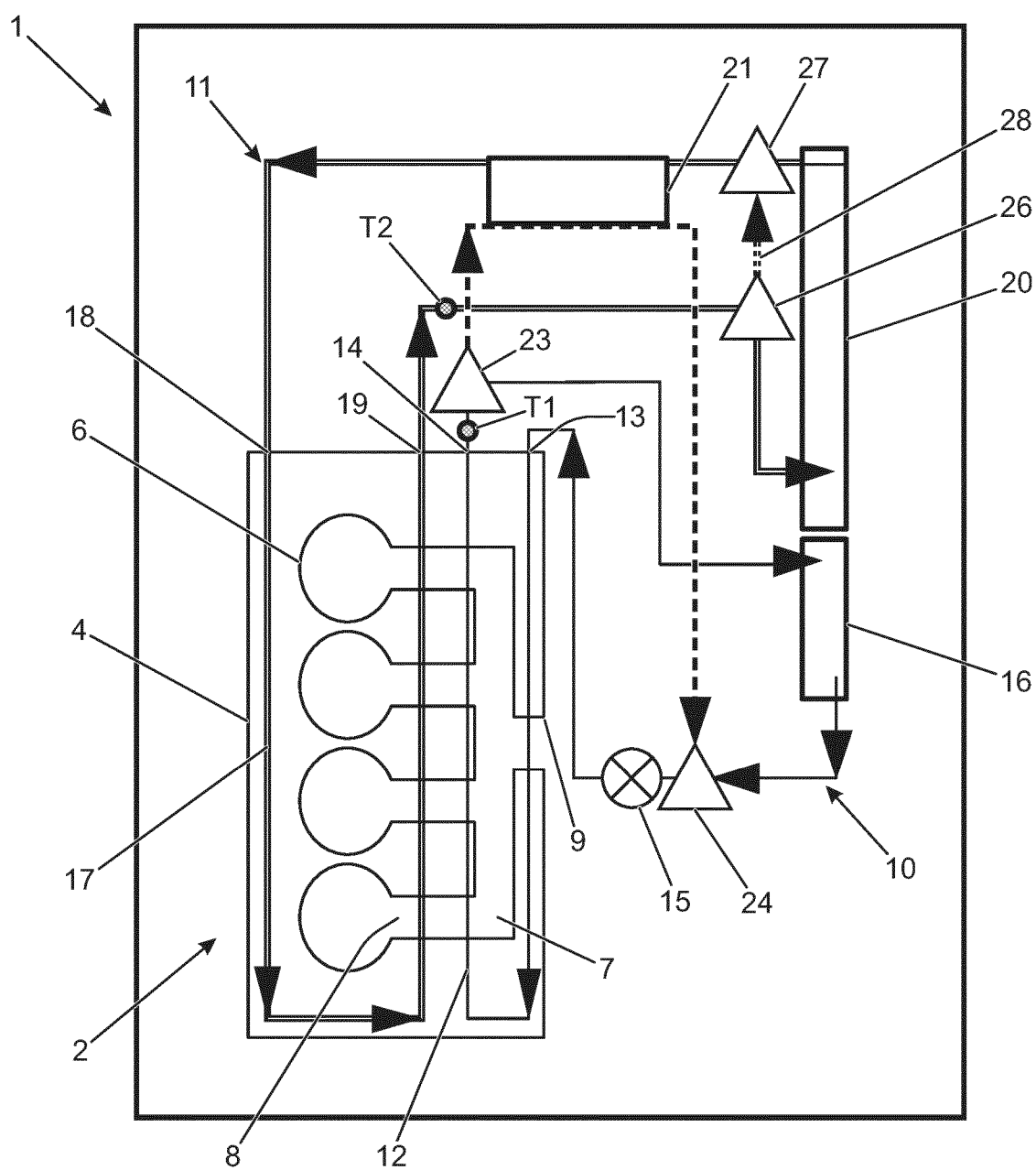


FIG. 2

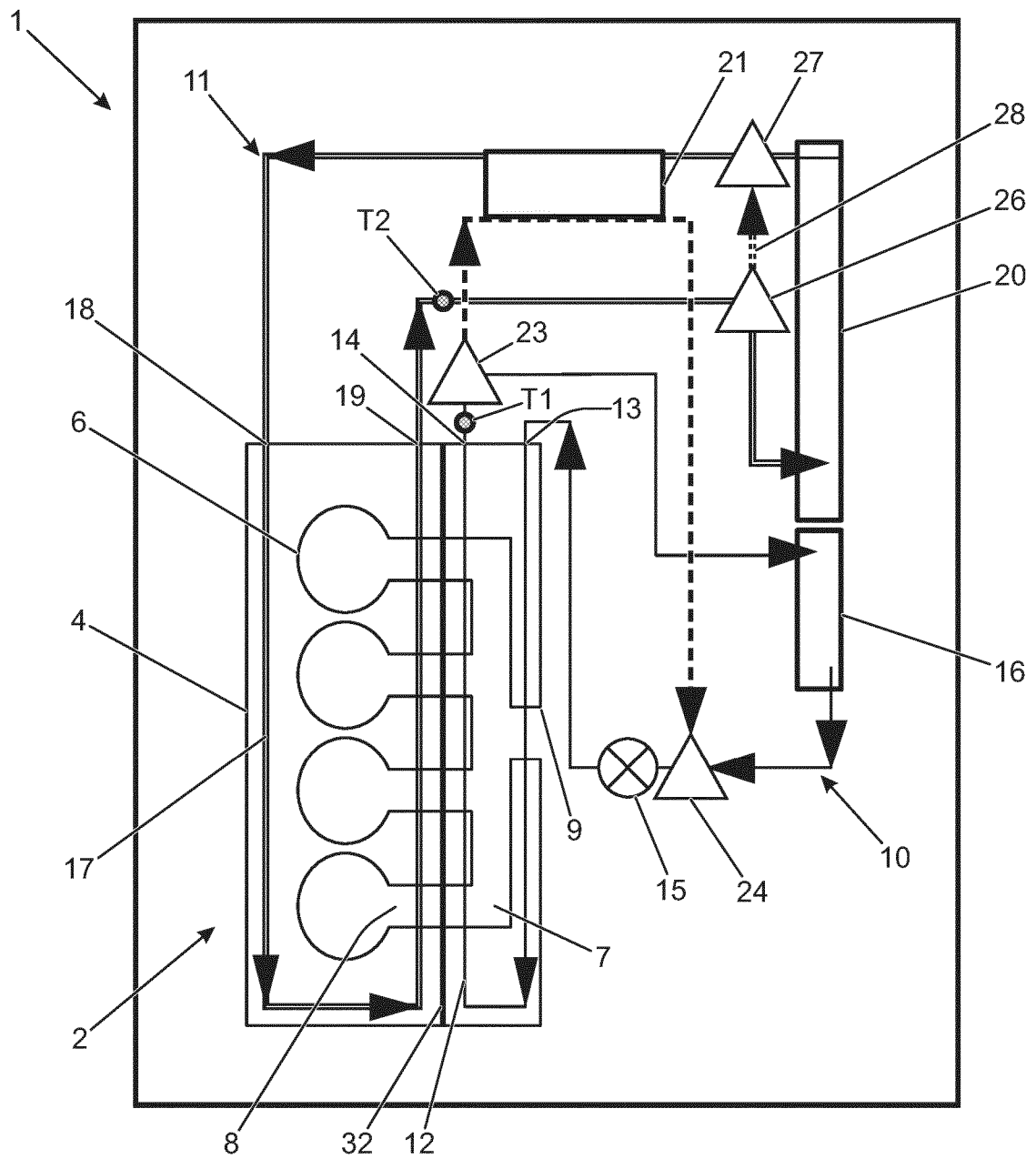


FIG. 3

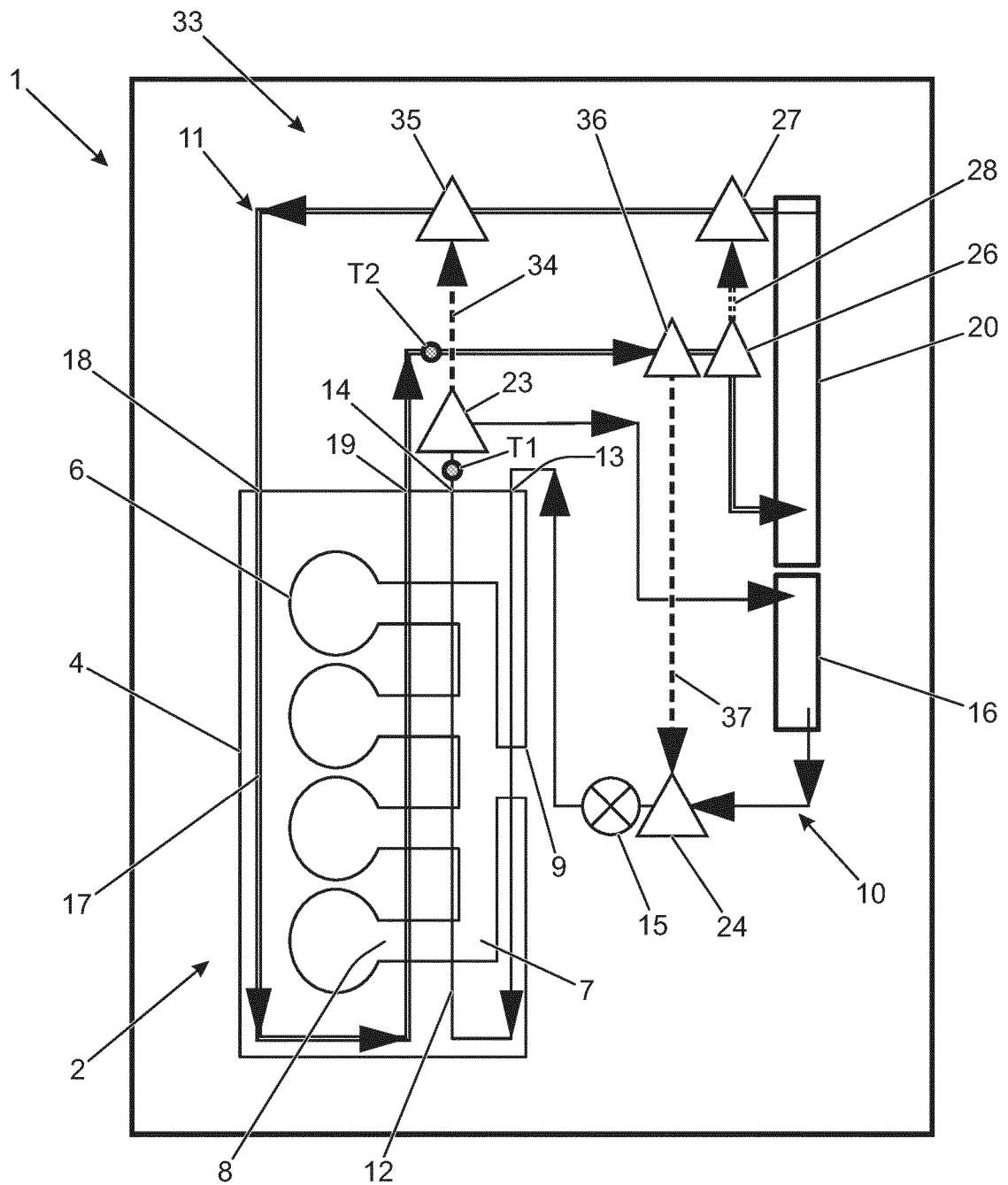


FIG. 4

## INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2016/082177

A. CLASSIFICATION OF SUBJECT MATTER  
 INV. F01P7/16 F01P3/20  
 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)  
 F01P F01N

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<br>Y<br>A | GB 1 600 033 A (METRO CAMMELL WEYMANN LTD)<br>14 October 1981 (1981-10-14)<br>pages 1-3<br>figure 1<br>-----                              | 1-4,8,<br>12-15,29<br>11<br>16 |
| X<br>A      | WO 2010/000284 A2 (FEV MOTORENTECH GMBH<br>[DE]; HABERMANN KNUT [DE])<br>7 January 2010 (2010-01-07)<br>pages 1-7<br>figures 1-2<br>----- | 1,5-10,<br>12-15,29<br>16      |
| Y           | US 2012/204557 A1 (JEBASINSKI ROLF [DE] ET<br>AL) 16 August 2012 (2012-08-16)<br>paragraphs [0045] - [0055]<br>figures 1-5<br>-----       | 11                             |



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents :

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

17 March 2017

Date of mailing of the international search report

26/05/2017

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

Schwaller, Vincent

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/EP2016/082177

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

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

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claims Nos.: 30-32  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:  
see FURTHER INFORMATION sheet PCT/ISA/210
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:  
1-16(completely); 29(partially)

### Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

**FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210**

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

1. claims: 1-16(completely); 29(partially)

A cooling apparatus for an internal combustion engine and an associated controller, the apparatus comprising a first cooling circuit for cooling an exhaust manifold and a second cooling circuit for cooling the internal combustion engine, wherein a heat exchanger for transferring heat from the first circuit to the second circuit is provided and wherein there is no fluid communication between both cooling circuits.

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2. claims: 17-28(completely); 29(partially)

A cooling apparatus for an internal combustion engine and an associated controller, the apparatus comprising a first cooling circuit for cooling an exhaust manifold and a second cooling circuit for cooling the internal combustion engine, wherein the first circuit is selectively connectable to the second circuit through circuit connecting means.

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**FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210**

Continuation of Box II.2

Claims Nos.: 30-32

Each of the claims 30-32 only contains a (very broad reference) to "the accompanying figures", without specifying any precise combination of technical features. The subject-matter of these claims is therefore unclear (Art. 6 PCT). Except where absolutely necessary, claims shall not rely on references to the drawings in specifying the technical features of the invention. Such a reference is not considered absolutely necessary in the present application. Moreover in the present application, "the accompanying figures" cover different inventions, since the subject-matter of the other claims 1-29 is non unitary. Furthermore claims 1-29 on file appear to cover (at least a large part of) the features shown in "the accompanying figures" in a clearer manner than claims 30-32. No meaningful search of the subject-matter of claims 30-32 could therefore be carried out.

Note that the search carried out nevertheless covers the entire subject-matter to which the claims are directed or to which they might reasonably be expected to be directed after they have been amended.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guidelines C-IV, 7.2), should the problems which led to the Article 17(2) declaration be overcome.

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2016/082177

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date           |
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