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(54) ENGINE COOLING SYSTEM

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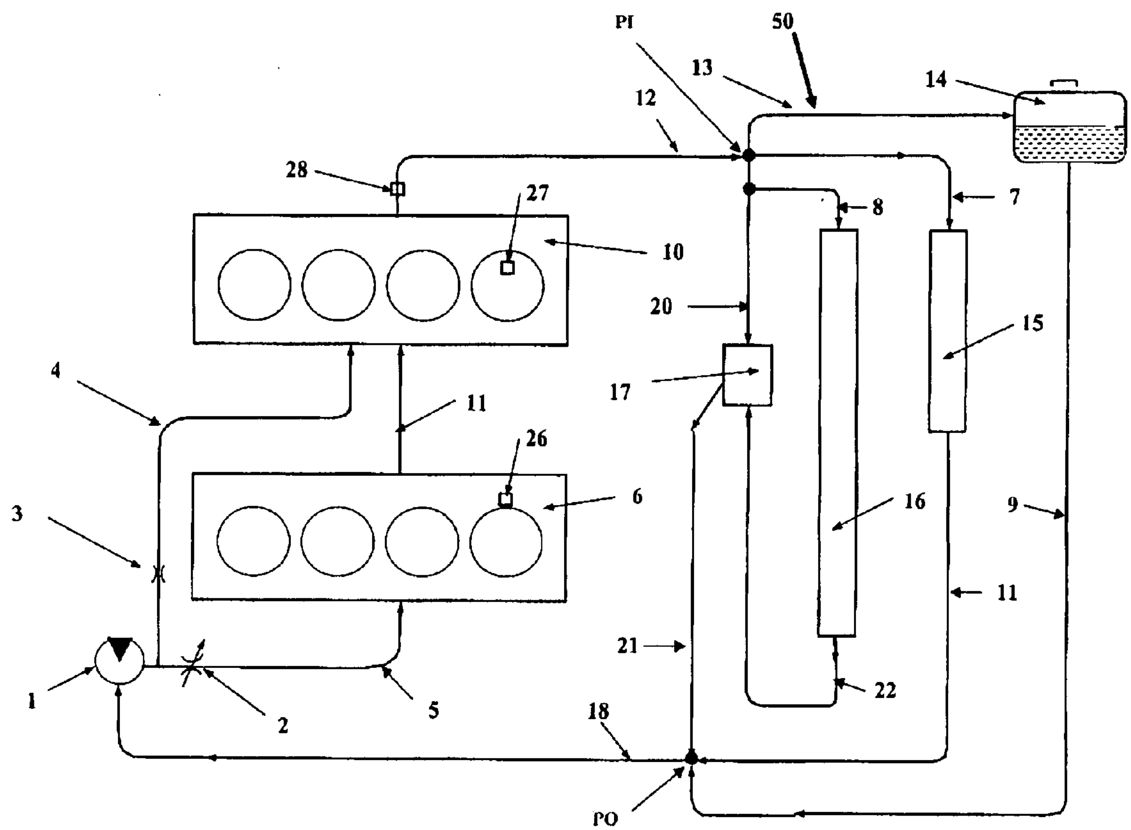
(57) ABSTRACT

A cooling system for an internal combustion engine is disclosed in which the supply of coolant to a cylinder block **6** is controlled independently of the coolant supply to a cylinder head **10** so that the temperatures of the cylinder block **6** and the cylinder head **10** can be optimised to produce improved performance and economy.



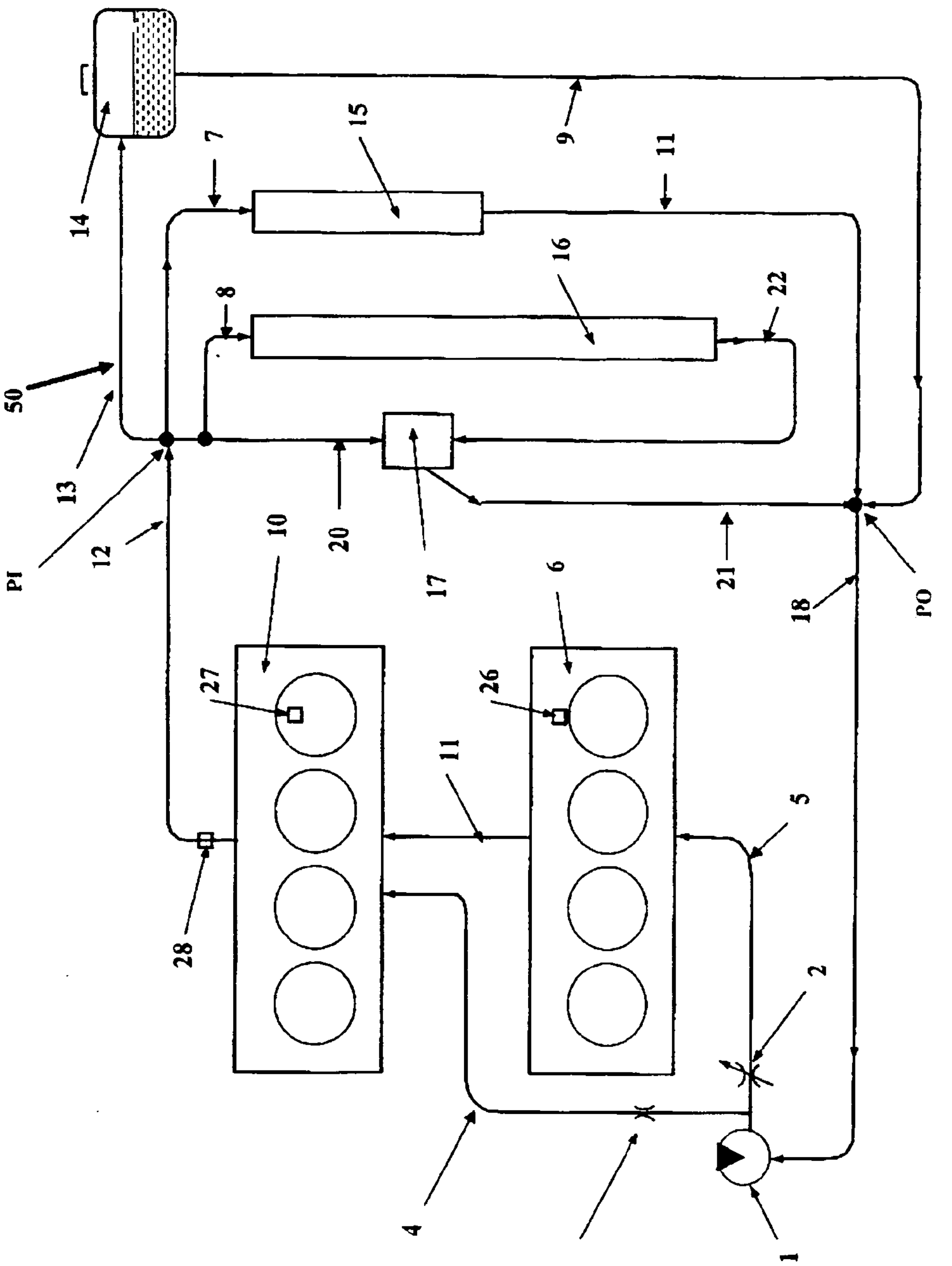


Fig. 1

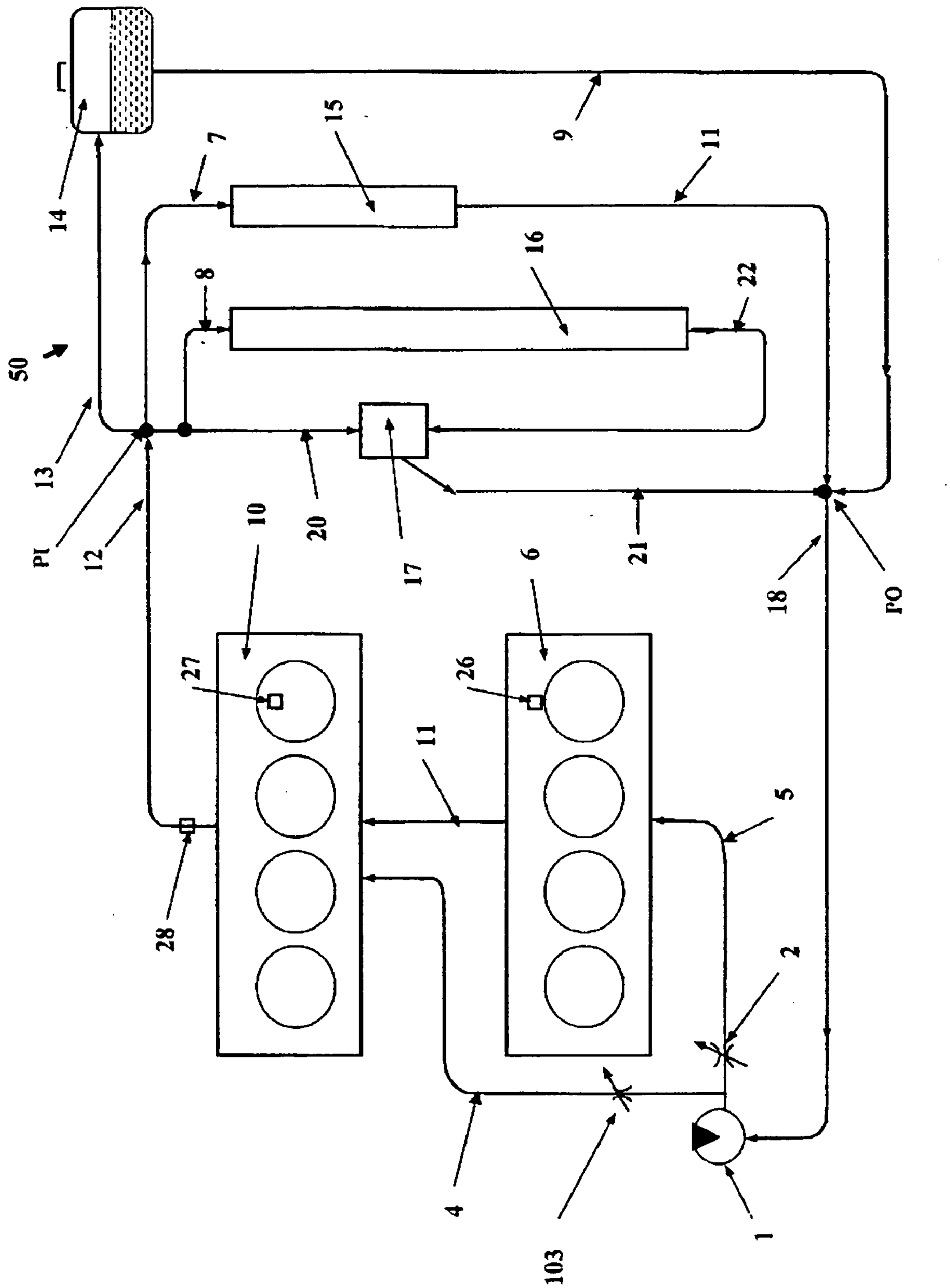


Fig. 2

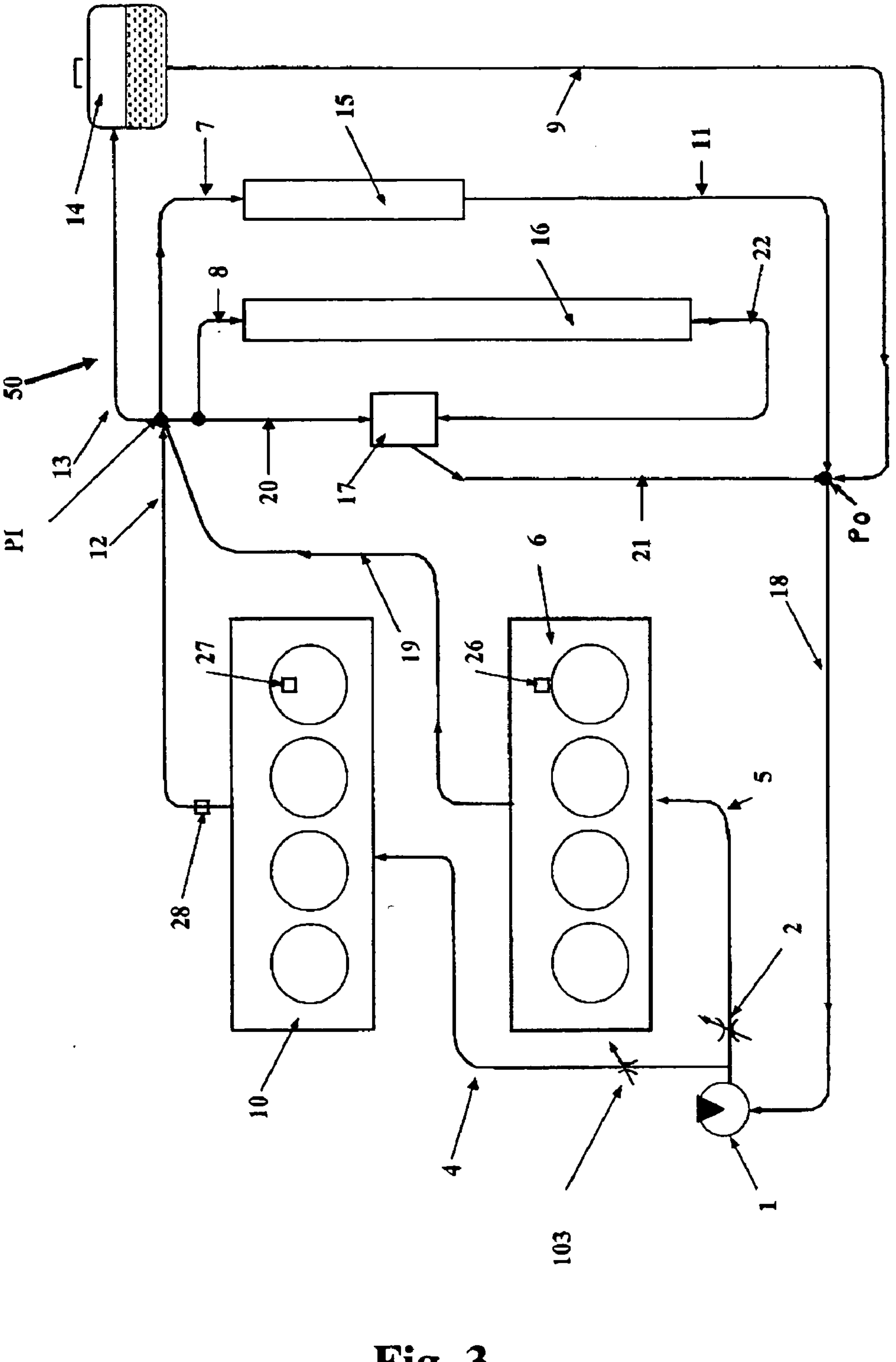


Fig. 3

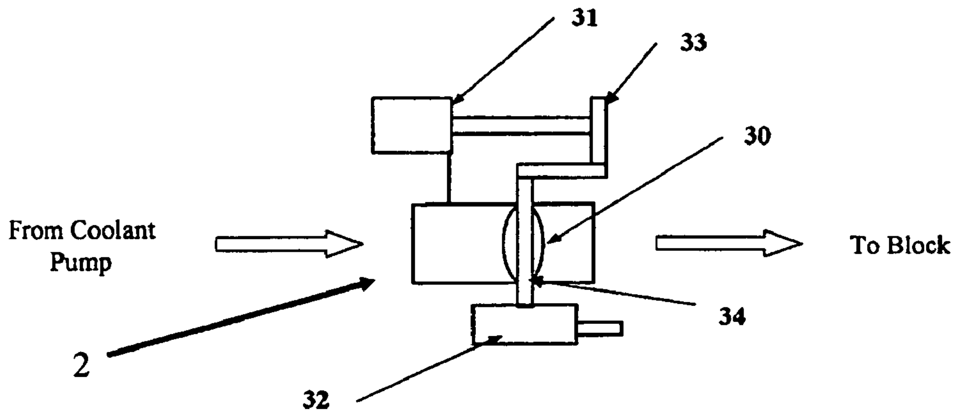


Fig. 4

ENGINE COOLING SYSTEM

[0001] This invention relates to internal combustion engines and in particular to a cooling system for an internal combustion engine.

[0002] It is well known to provide an internal combustion engine with a cooling system in which coolant is circulated through a cylinder block and cylinder head of the engine and through a radiator before being returned to the engine by a pump.

[0003] Such a cooling system provides adequate cooling for the engine but cannot accommodate different cooling requirements during different operating conditions nor provide optimised cooling for the cylinder head and the cylinder block.

[0004] For example, internal combustion engine emissions of CO and HC are relatively high after a cold start particularly in the case of high speed direct injection diesel engines for passenger cars and light duty trucks. The problem is compounded by any catalyst fitted to the engine being below its light-off temperature and so unable to actively reduce emissions. In addition, engine fuel economy is worse when the engine is cold due to lower thermal efficiency, poor combustion and higher friction.

[0005] A second problem is that NOx emissions need to be reduced from I.C. engines which can be achieved via lower engine metal temperatures but this has the disadvantage with a conventional cooling system of lower general metal temperatures which will tend to increase friction.

[0006] With a conventional cooling system it is difficult to cool sufficiently the cylinder head valve bridges without over cooling other parts of the engine and power ratings of an engine are often restricted due to excessive temperatures in the valve bridge region. Therefore effective cooling of this region would allow higher thermal loadings without the need to increase the coolant bulk flow rate and therefore increased thermal inertia and slower warm-up rates which would result in increased CO & HC emissions and reduced fuel economy during warm-up.

[0007] For a high speed direct injection (HSDI) diesel engine a lower cylinder head temperature would give lower NOx and a hotter cylinder bore will produce lower friction leading to lower fuel consumption. Hotter cylinder heads however give lower CO, especially during warm-up.

[0008] The inventors have realised that what is required is a cooling system that will allow the cylinder head flame face to warm-up quicker especially under light load running from a cold start, whilst being able to cool the cylinder head or at least portions of it such that it runs colder after the exhaust system temperature has risen. This would then allow a better CO to NOx trade-off.

[0009] In addition the inventors have realised that if the cylinder bore temperature could be separately controlled then an optimum friction to wear ratio could be achieved. That is to say, if the local oil film temperature that the piston rings and skirt see can be managed better without a major impact on the emissions the friction could be reduced without compromising wear or emissions and so the fuel economy could be influenced largely independently from the emissions. For example, if the oil film temperature could be maintained during normal engine running in the range of approx. 110 to 130° C., this will give low friction and keep the oil in good condition for a long period of time.

[0010] It is known from GB-A-2,377,253 to provide a cooling system for an engine in which the flow of coolant through the engine can be controlled by the use of an electronically controlled flow control valve independently of the flow being produced by the system pump. Although this system is able to provide improved performance with respect to a conventional cooling system no provision is made for independently cooling the cylinder head and the cylinder block and so the flow of coolant to the engine always has to be a compromise and, particularly at high engine loads and speeds, the cylinder block may be overcooled in order to prevent critical areas in the cylinder head becoming too hot.

[0011] It is further known from EP-A-0894953 to provide a cooling system in which separate flow paths are provide to the cylinder head and cylinder block of an engine. However, this system has the disadvantages that the pump is positioned downstream from the cylinder head and the cylinder block and so is likely to suffer from cavitation in use and the two flow paths are not totally independent because the flow to the cylinder block is diverted from the flow from the cylinder head. With such an arrangement it would not be possible to control the temperature of the cylinder block independently from the temperature of the cylinder head because the two flow paths are interlinked and so the flow through the two flow paths would need to be a compromise to account for the often different requirements of the cylinder head and cylinder block.

[0012] It is an object of the invention to provide an improved cooling system for an internal combustion engine.

[0013] According to a first aspect of the invention there is provided a cooling system for an internal combustion engine comprising a cooling circuit including passages formed in a cylinder head of the engine and in a cylinder block of the engine and at least one conduit connecting the passages in the cylinder head and cylinder block to an inlet to a pump used to circulate the coolant through the cooling circuit wherein the pump is a variable flow rate pump controlled by an electronic control unit, the coolant passages in the cylinder block are connected by a first coolant supply conduit to an outlet from the pump, the coolant passages in the cylinder head are connected by a second coolant supply conduit to an outlet from the pump, the flow through at least one of the first and second coolant supply passages is controlled by an electronically controlled flow control valve operably connected to an electronic controller used to control the opening and closing of the electronically controlled flow control valve and the flow through the other of the first and second coolant supply passages has a predetermined flow restriction to prevent unlimited flow therethrough.

[0014] The predetermined flow restriction may be formed by one of an orifice and the use of a coolant supply passage having a relatively small cross-sectional flow area representing a restriction to flow for at least a portion of the length of the other coolant supply passage.

[0015] Preferably, the electronic control unit may be formed as part of the electronic controller used to control opening and closing of the first electronically controlled flow control valve.

[0016] The cooling system may further comprise at least one temperature sensor operably connected to the electronic controller to sense the temperature of a part of the cylinder head and to supply a signal indicative of the sensed temperature to the electronic controller, at least one temperature sensor operably connected to the electronic controller to sense the temperature of a part of the cylinder block and to supply a signal indicative of the sensed temperature to the electronic controller, the electronic controller is operable, at least during normal engine running, to control the opening and closing of the electronically controlled flow control valve based upon at least one of the signals received from the cylinder head and cylinder block temperature sensors and the electronic control unit is operable, at least during normal engine running, to control the flow rate from the variable flow rate pump based upon at least one of the signals received from the cylinder head and cylinder block temperature sensors.

[0017] During normal engine running the flow from the variable flow rate pump may be controlled to provide the minimum required flow based upon at least one of the signals received from the cylinder head and cylinder block temperature sensors.

[0018] The cooling system may further comprise at least one coolant temperature sensor operably connected to the electronic controller for sensing the temperature of the coolant exiting the cylinder head and the electronic controller is operable to control the opening and closing of the electronically controlled flow control valve based upon the signals received from at least one of the cylinder head and cylinder block temperature sensors and from the coolant temperature sensor.

[0019] The cooling system may further comprise at least one coolant temperature sensor operably connected to the electronic controller for sensing the temperature of the coolant exiting at least one of the cylinder block and the cylinder head and the electronic control unit is operable to control the flow from the variable flow rate pump based upon the signals received from at least one of the cylinder head and cylinder block temperature sensors and from the coolant temperature sensor.

[0020] The electronically controlled flow control valve may control the flow of coolant through the first coolant supply conduit to the cylinder block, at least one cylinder head temperature sensor may be operably connected to the electronic controller to sense the temperature of a part of the cylinder head and to supply a signal indicative of the sensed temperature to the electronic controller and the temperature of the cylinder head may be controlled by the electronic control unit, at least during normal engine running, by varying the flow from the variable flow rate pump to maintain the temperature as sensed by the or each cylinder head sensor within a predetermined desired range based upon the sensed temperature of the cylinder head and at least one cylinder block temperature sensor may be operably connected to the electronic controller to sense the temperature of a part of the cylinder block and to supply a signal indicative of the sensed temperature to the electronic controller and the temperature of the cylinder block may be controlled, at least during normal engine running, by the electronic controller opening and closing the electronically controlled flow control valve to maintain the temperature of the cylinder block within a predetermined desired temperature range based upon the sensed temperature of the cylinder block.

[0021] Alternatively, the electronically controlled flow control valve may control the flow of coolant through the second coolant supply conduit to the cylinder head, at least one cylinder head temperature sensor may be operably connected to the electronic controller to sense the temperature of a part of the cylinder head and to supply a signal indicative of the sensed temperature to the electronic controller and the temperature of the cylinder head may be controlled, at least during normal engine running, by the electronic controller opening and closing the electronically controlled flow control valve to maintain the temperature of the cylinder head within a predetermined desired temperature range based upon the sensed temperature of the cylinder head and at least one cylinder block temperature sensor is operably connected to the electronic controller to sense the temperature of a part of the cylinder block and to supply a signal indicative of the sensed temperature to the electronic controller and the temperature of the cylinder block is controlled by the electronic control unit, at least during normal engine running, by varying the flow from the variable flow rate pump to maintain the temperature as sensed by the or each cylinder block sensor within a predetermined desired range based upon the sensed temperature of the cylinder block.

[0022] Preferably, the temperature of the coolant exiting the cylinder head may be sensed.

[0023] When the temperature of the coolant exiting the cylinder head is above a predetermined maximum thermostat operating temperature the flow from the pump is increased from the normal low flow rate in order to reduce the coolant temperature.

[0024] Advantageously, the passages formed in the cylinder head and the passages formed in the cylinder block may be connected in parallel by separate conduits to a return circuit used to return coolant to the inlet to the pump so as to provide totally independent control of the temperature of the cylinder head and the cylinder block.

[0025] Alternatively, the passages formed in the cylinder head and the passages formed in the cylinder block are connected by a common conduit to a return circuit used to return coolant to the inlet to the pump such that the coolant from the cylinder block passes through at least one of the passages in the cylinder head to the common conduit.

[0026] A radiator may be connected in the return circuit between the cooling passages in the cylinder block and the cylinder head and the inlet to the pump.

[0027] A vehicle compartment heater may be connected in the return circuit between the cooling passages in the cylinder block and the cylinder head and the inlet to the pump.

[0028] A degas reservoir may be connected in the return circuit between the cooling passages in the cylinder block and the cylinder head and the inlet to the pump.

[0029] The radiator, compartment heater and degas reservoir may be connected in parallel between two common points of the return circuit.

[0030] A valve controlled bypass circuit may be connected in parallel to the radiator to allow coolant to bypass the radiator when the temperature of the coolant is below a predetermined minimum temperature.

[0031] The first coolant supply passage may provide at least a general coolant flow through the cylinder block.

[0032] The first coolant supply passage may provide a directed coolant flow to the cylinder block to cool specific regions of the cylinder block.

[0033] The second coolant supply passage may provide at least a general coolant flow through the cylinder head.

[0034] The second coolant supply passage may provide a directed coolant flow to the cylinder head to cool specific regions of the cylinder head.

[0035] The coolant from the cylinder block may be used to provide a general coolant flow to the cylinder head and the flow through the second coolant supply passage may be used to provide a directed coolant flow to the cylinder head to cool specific regions of the cylinder head.

[0036] According to a second aspect of the invention there is provided a method for cooling an internal combustion engine having a cylinder head, a cylinder block, a first coolant supply conduit to supply coolant from a an electronically controlled variable flow rate pump to passages formed in the cylinder block, a second coolant supply conduit for independently supplying coolant from the pump to passages formed in the cylinder head, an electronically controlled flow control valve to control the flow of coolant though one of the first and second coolant supply conduits, a predetermined flow restriction to prevent unlimited flow through the other of the first and second coolant supply conduits wherein the method comprises opening and closing the or each electronically controlled flow control valve and changing the flow rate from the variable flow rate pump to maintain, at least during normal engine running, the temperature of the cylinder block within a desired temperature range and the temperature of the cylinder head within a desired temperature range.

[0037] At least one temperature sensor may be provided to sense the temperature of a part of the cylinder head and at least one temperature sensor may be provided to sense the temperature of a part of the cylinder block and the method may further comprises opening an closing the or each electronically controlled flow control valve and varying the flow rate from the pump based upon the signals received from cylinder head and cylinder block temperature sensors.

[0038] Preferably, the temperature of the coolant exiting the cylinder head may be sensed and the method may further comprises opening an closing the or each electronically controlled flow control valve and varying the flow rate from the pump based upon the signals received from cylinder head and cylinder block temperature sensors and from the coolant sensor.

[0039] The invention will now be described by way of example with reference to the accompanying drawing of which:—

[0040] **FIG. 1** is a schematic diagram of a cooling system for an internal combustion engine according to a first embodiment of the invention;

[0041] **FIG. 2** is a schematic diagram of a cooling system for an internal combustion engine according to a second embodiment of the invention;

[0042] **FIG. 3** is a schematic diagram of a cooling system for an internal combustion engine according to a third embodiment of the invention; and

[0043] **FIG. 4** is a schematic diagram of electronically controlled flow control valve for use in controlling the flow of coolant to a cylinder block or cylinder head of the internal combustion engine.

[0044] With particular reference to **FIG. 1** there is shown an internal combustion engine having a cylinder block **6** and a cylinder head **10** and a cooling system therefor.

[0045] The cooling system comprises of a pump **1** to circulate coolant from a pump outlet through a cooling circuit including respective passages (not shown) formed in the cylinder head **10** and in the cylinder block **6** through a return circuit **50** back to an inlet of the pump **1**.

[0046] The coolant is delivered to the cylinder block **6** through a first coolant supply conduit **5**. The flow through the first coolant supply conduit **5** is controlled by an electronically controlled flow control valve **2**. The electronically controlled flow control valve **2** is controlled by an electronic controller (not shown) and is shown in greater detail in **FIG. 4** from which it can be seen that the electronically controlled flow control valve **2** comprises of an electronically controlled vacuum actuator **31** connected by means of a linkage **33** to a shaft **34** upon which is mounted a flap valve **30**. A rotary potentiometer **32** is attached to one end of the shaft **34** to provide a feedback from the electronically controlled flow control valve **2** to the electronic controller of the position of the flap valve **30**.

[0047] The flap valve **30** is biased by a spring (not shown) into a fully open position so that in the event of an electrical or electronic failure the cylinder block **6** is not starved of coolant.

[0048] A micro-switch (not shown) is used to provide a signal indicative of the fully closed position which can be used to periodically update the calibration of the feedback from the potentiometer **32** and determine the fully closed position. However, it will be appreciated that calibration could be achieved in other ways such as by using a positive end stop.

[0049] In the fully closed position a small calibrated flow of coolant can still pass by the flap valve **2**.

[0050] It will be appreciated that other types of valve could be used and that the invention is not limited to the use of a flap valve.

[0051] The coolant is supplied to the cylinder head **10** through a second coolant supply conduit **4** which includes a predetermined flow restriction to prevent unlimited flow through the second coolant supply passage **4**. In this case the predetermined flow restriction is in the form of an orifice **3** but alternatively, at least a portion of the second coolant supply passage **4** could have a relatively small cross-sectional flow area so as to provide the predetermined flow restriction. It will be appreciated that if the internal diameter of any conduit, tube or pipe used to form the second coolant supply conduit **4** is relatively small it will provide an increased resistance to flow and so will act in a similar manner to an orifice. As yet another alternative the restriction to flow of the passages in the cylinder head could be used to prevent unlimited flow.

[0052] The coolant supplied to the cylinder block **6** from the first coolant supply conduit **5** passes through the internal passages formed in the cylinder block **6** and is transferred to the cylinder head **10** by a first return conduit **11** where it flows through the passages in the cylinder head **10** before flowing to a common inlet point 'PI' of the return circuit **50** through a common return conduit **12**.

[0053] The temperature of the coolant exiting the cylinder head **10** is sensed by a coolant sensor **28** which sends a signal to the electronic controller indicative of the temperature of the coolant exiting the cylinder head **10**.

[0054] A cylinder block sensor **26** is located on the cylinder block **6** at a position where it can provide an accurate indication of the temperature of the temperature of the wall of one of the cylinders of the engine. It will be appreciated that in practice there may be a cylinder block temperature sensor associated with each of the cylinders of the engine but for the purposes of this description only one temperature sensor **26** is shown and described.

[0055] A cylinder head temperature sensor **27** is located on the cylinder head **10** at a position where it can accurately sense the temperature of the cylinder head in a critical region such as for example in the region of a cylinder head valve bridge. The cylinder head sensor **27** provides a signal indicative of the sensed temperature to the electronic controller. It will be appreciated that in practice there may be a cylinder head temperature sensor associated with each of the cylinders of the engine but for the purposes of this description only one temperature sensor **27** is shown and described.

[0056] The pump **1** is driven by a belt from the engine but is a variable flow rate pump **1** that is to say it is a variable displacement pump and the flow rate from the pump **1** can be controlled independently of the rotational speed of the engine. It will be appreciated that the pump could alternatively be driven independently of the engine by an electric or hydraulic motor and in this case either a fixed displacement pump or a variable displacement pump could be used because the speed of the pump could be controlled independently of engine speed. The term 'variable flow rate pump' is used in this document to refer to any such pump.

[0057] The flow from the variable flow rate pump **1** is controlled by an electronic control unit (not shown) which in this case is formed as part of the electronic controller used to control the electronically controlled flow control valve **2** but could be a separate electronic control unit.

[0058] The return circuit **50** has a common outlet point 'PO' connected to the inlet to the variable flow rate pump **1** by a supply conduit **18**.

[0059] The return circuit **50** comprises of a degas supply conduit **13** connected from the common inlet point 'PI' to a degas reservoir **14** which is connected by a degas return conduit **9** to the common outlet point 'PO', a cabin heater supply conduit **7** connected between the common inlet point 'PI' and a cabin heater **15** which is connected to the common outlet point 'PO' by a cabin heater return conduit **11**, a radiator supply conduit **8** which is connected to the common inlet point 'PI' by a bypass conduit **20** and supplies coolant to a radiator **16** which is connected to a bypass thermostat **17** by a radiator return conduit **22** and a bypass thermostat return conduit **21** connecting the bypass thermostat **17** to the common outlet point 'PO'.

[0060] It will be appreciated that the invention is not limited to a return circuit configured as shown or to the use of a radiator, cabin heater, bypass thermostat or degas reservoir.

[0061] Operation of the return circuit **50** is in most respects conventional in that when the temperature of the coolant is low the bypass thermostat is operational to allow coolant to flow between the common inlet point 'PI' and the common outlet point 'PO' through the bypass conduit **20** and the bypass return conduit **21** without passing through the radiator **16** to speed up engine warm up and to improve cold start cabin heater performance. During this period any flow through the degas reservoir **14** will be detrimental to engine warm up as it will cause cold fluid stored in the degas reservoir **14** to be displaced via the degas return conduit **9** to merge with the coolant flowing through the bypass return conduit **21** thereby lowering the temperature of the coolant supplied to the variable flow rate pump **1** through the supply conduit **18**. After the engine has warmed up sufficiently, the bypass thermostat **17** will open and coolant will begin to flow through the radiator **16**.

[0062] During 'normal engine running' the electronic controller is operable to monitor the outputs from the cylinder block temperature sensor **26** and from the cylinder head temperature sensor **27** and control the cooling system accordingly. The term 'normal engine running' as meant herein means when the engine is operating normally with the temperature of the coolant being at a normal (hot) temperature so that the thermostat **17** is within its normal operating range which in this case is 85 to 105° C. and excludes any period of running when the thermostat is closed or the temperature of the coolant exceeds the maximum temperature of the thermostat **17**.

[0063] Therefore during normal engine running the variable flow rate pump **1** is operated at the minimum possible flow rate to reduce the power requirements for the variable flow rate pump **1** and the signal from the cylinder block temperature sensor **26** is used by the electronic controller to open and close the electronically controlled flow control valve **2** so as to maintain the temperature of the cylinder block **6** or to be more precise the part of the cylinder block **6** being monitored within a predetermined temperature range such as for example between 110 and 130° C. Therefore if the temperature of the sensed part rises above the upper temperature limit of the predetermined temperature range then the electronically controlled flow control valve **2** will be opened slightly so as to reduce the temperature by allowing more coolant to flow through the passages in the cylinder block **6**. Conversely, if the temperature of the sensed part falls below the lower temperature limit of the predetermined temperature range then the electronically controlled flow control valve **2** will be closed slightly so as to increase the temperature by allowing less coolant to flow through the passages in the cylinder block **6**. In practice the electronically controlled flow control valve **2** may be arranged to continuously adjust its position to try and maintain the temperature at a specific temperature such as for example 120° C. with a small plus and minus range such as plus or minus 1° C., this small plus or minus range is also a predetermined desired temperature range as meant herein. It will be understood that the movement of the valve can be controlled in many ways and the invention is not limited to the specific control technique employed.

[0064] During normal engine running the signal from the cylinder head sensor **27** is used by the electronic controller to maintain the temperature of the cylinder head **10** or to be more precise the temperature of the part of the cylinder head **10** which is being sensed within a predetermined range of temperatures. If the temperature exceeds the upper limit for this range then the electronic controller will increase the flow rate from the variable flow rate pump **1** and if the temperature falls below the minimum temperature then the flow rate from the variable flow rate pump **1** will be reduced. At all times the flow from the variable flow rate pump **1** will be maintained at the lowest level possible. In this way the temperature of the cylinder head **10** is controlled independently from the temperature of the cylinder block **6** while minimising the power requirements of the variable flow rate pump **1**.

[0065] It will be appreciated that in practice the control of the variable flow rate pump **1** may be more complex than that described to prevent sudden changes in temperature. For example the desired temperature range may include a mid-point or set point and the flow from the pump **1** may be increased or decreased proportionally based upon the difference in measured temperature from the set-point.

[0066] The cooling system is arranged to function differently when the engine is operating with a coolant temperature greater than the upper temperature limit at which the thermostat **17** can operate. Under these conditions it is desirable to maintain control over the coolant temperature and reduce it to a temperature within the normal temperature range of the thermostat **17**. Therefore, when the signal from the coolant sensor **28** indicates that the temperature of the coolant exiting the cylinder head **10** is above a predetermined maximum temperature, the electronic controller is operable to increase the flow rate through at least one of the cylinder head **10** and the cylinder block **6** by either temporarily increasing the flow rate from the pump **1** to a higher flow rate or opening further the electronically controlled flow control valve **2** or doing both of these actions. This will help to reduce the temperature of the coolant and, during this period, primary control is based upon the signal received from the coolant sensor **28**. This period of control will be maintained until the temperature of the coolant has dropped to a lower level well within the normal operating range of the thermostat **17**. When this lower temperature is reached control will revert back to that based primarily on the measured cylinder block **6** and cylinder head **10** temperatures.

[0067] One of the benefits of this cooling system is that because the variable flow rate pump **1** is always operated at the lowest possible flow rate then a low flow rate of coolant is returning to the return circuit **50** from the engine. The volume of coolant passing through the degas reservoir **14** is therefore reduced thereby reducing the volume of cold coolant flowing from the degas reservoir **14** back to the variable flow rate pump **1**. This alleviates the need to have a separate control valve preventing the flow of coolant to the degas reservoir during cold start-up conditions and hence reduces the cost and complexity of the cooling system.

[0068] With particular reference to **FIG. 2** there is shown an internal combustion engine having a cylinder block **6** and a cylinder head **10** and a cooling system which in many respects is the same as that previously described with reference to **FIG. 1** and so will not be described further in great detail.

[0069] The primary difference between the system shown in **FIG. 1** and that shown in **FIG. 2** is that an orifice **102** or other flow restriction is used to control the flow of coolant to the cylinder block **6** and an electronically controlled flow control valve **103** is used to control the flow of coolant to the cylinder head **10**.

[0070] The return circuit **50** is as previously described and operates as described above.

[0071] As before, the temperature of the coolant exiting the cylinder head **10** is sensed by a coolant sensor **28** which sends a signal to the electronic controller indicative of the temperature of the coolant exiting the cylinder head **10**, a cylinder block sensor **26** is located on the cylinder block **6** at a position where it can provide an accurate indication of the temperature of the temperature of the wall of one of the cylinders of the engine and a cylinder head temperature sensor **27** is located on the cylinder head **10** at a position where it can accurately sense the temperature of the cylinder head in a critical region such as for example in the region of a cylinder head valve bridge.

[0072] The pump **1** is driven by a belt from the engine and is a variable flow rate pump **1**.

[0073] An electronic controller (not shown) is used to control the electronically controlled flow control valve **103**.

[0074] During 'normal engine running' the electronic controller is operable to monitor the outputs from the cylinder block temperature sensor **26** and from the cylinder head temperature sensor **27** and control the cooling system accordingly. As before normal engine running means when the engine is operating normally with the temperature of the coolant being at a normal (hot) temperature so that the thermostat **17** is within its normal operating range which in this case is 85 to 105° C. and excludes any period of running when the thermostat is closed or the temperature of the coolant exceeds the maximum temperature of the thermostat **17**.

[0075] Therefore during normal engine running the signal from the cylinder block temperature sensor **26** is used by the electronic controller to control the flow from the pump **1** so as to maintain the temperature of the cylinder block **6** or to be more precise the part of the cylinder block **6** being monitored within a predetermined temperature range and the signal from the cylinder head sensor **27** is used by the electronic controller to maintain the temperature of the cylinder head **10** or to be more precise the temperature of the part of the cylinder head **10** which is being sensed within a predetermined range of temperatures by opening and closing the electronically controlled flow control valve **103**.

[0076] The temperature range in each case could be significant such as a difference of several tens of degrees centigrade or could be very small such as plus or minus 0.5° C. so that in practice the temperature is maintained at a constant predetermined temperature. The term opening and closing of a valve does not mean that a valve is moved from a fully open position to a fully closed position or vice-versa but means that, if more cooling is required, the valve is opened gradually until the required level of cooling is obtained and vice versa. This type of control reduces the risk of thermal stresses being set-up due to rapid changes in coolant temperature.

[0077] It will be appreciated that when the engine is started from cold it is desirable to warm up the engine as quickly as possible. However, because the temperatures of the cylinder block **6** and the cylinder head **10** will be much lower than those desired for efficient operation, the electronic controller will automatically fully close the electronically controlled flow control valve **103** and the pump **1** will be operated at its minimum flow rate. This will help with engine warm up and in particular will allow the cylinder head **10** to warm up quickly to reduce emissions. However, if more coolant flow is required for any reason such as to improve the output from the cabin heater or to help to reduce the temperature differential between various parts of the engine then the electronic controller is arranged to open the valve **103** and increase the flow of coolant from the pump **1** in order to meet these requirements.

[0078] A secondary benefit is that because a lower flow rate of coolant is returning to the return circuit **50** from the engine the volume of coolant passing through the degas reservoir **14** is reduced thereby reducing the volume of cold coolant flowing from the degas reservoir **14** back to the variable flow rate pump **1**. As before, this alleviates the need to have a separate control valve preventing the flow of coolant to the degas reservoir during cold start-up conditions and hence reduces the cost and complexity of the cooling system.

[0079] If the sensed temperature of the coolant exiting the cylinder exceeds the upper limit at which the thermostat **17** can operate that is to say the thermostat is already fully open then the electronic controller continues to monitor the signals from the cylinder block and head temperature sensors **26** and **27** but these are not used to control the electronically controlled flow control valve **103**. Instead, the electronic controller opens the electronically controlled flow control valve **103** to reduce the coolant temperature to a more acceptable lower level. As soon as the temperature of the coolant exiting the cylinder head **10** is sensed by the coolant sensor **28** to have fallen below a lower limit then control will revert to that in which the signals from the cylinder block and cylinder head temperature sensors **26** and **27** are used by the electronic controller to control the electronically controlled flow control valve **103**.

[0080] It will be appreciated that with this embodiment and that shown in **FIG. 1** the coolant returning from the cylinder block **6** to the return circuit can be used to provide a general cooling flow through the passages formed in the cylinder head **10** and the flow through the second coolant supply passages can be used to supply a directed flow to the cylinder head **10** by using a number of jets or nozzles aimed at specific parts of the cylinder head **10** such as the valve bridges. Alternatively, the flow from the second supply conduit can be used to provide a primary general flow through the passages in the cylinder head **10** and the flow from the cylinder block can be used to provide a supplementary general flow through the passages in the cylinder head or may be directed through different passages from the flow from the second coolant supply conduit **4**.

[0081] With particular reference to **FIG. 3** there is shown a further or third embodiment of the invention which in many respects is the same to the second embodiment shown in **FIG. 2** and for which only significant differences will be described in detail.

[0082] The primary difference between this embodiment and the embodiment shown in **FIG. 2** is that instead of the return conduit from the engine cylinder block **6** being connected to the cylinder head **10**, as it is in **FIG. 2**, the return conduit **19** is connected directly to the return circuit **50** and in this case is connected to the common input point 'PI' so as to form parallel flow paths.

[0083] As with the previously described embodiment the electronic controller is operable during normal engine running to vary the flow from the pump **1** and open and close the electronically controlled flow control valve **103** to control the temperature of the cylinder block **6** and the cylinder head **10** to maintain them at a predetermined temperature or within a predetermined range of temperatures. As before the electronically controlled flow control valve **103** is not moved in a step fashion from a fully closed position to fully open position or vice-versa but is moved in a controlled manner in the desired direction until the desired temperature is attained.

[0084] As before, during start-up from cold the electronically controlled flow control valve **103** is automatically maintained closed and the pump **1** is operated with minimum flow to speed up engine warm up. However, if more coolant flow is required for any reason such as to improve the output from the cabin heater or to help to reduce the temperature differential between various parts of the engine then the electronic controller is arranged to open the valve **103** and increase pump flow in order to meet these requirements.

[0085] The arrangement shown in **FIG. 3** has the advantage that the cooling of the cylinder head **10** is totally independent from the cooling of the cylinder block **6** but has the disadvantage that a larger capacity pump is required to support the separate parallel flow paths. That is to say with this arrangement the flow path from the pump **1** through the second coolant supply conduit **4**, the cylinder head **10** and the return conduit **11** from the cylinder head **10** to the common input point 'PI' of the return circuit **50** and the flow path from the pump **1** through the first coolant supply conduit **5**, the cylinder block **6** and the return conduit **19** to the common input point 'PI' of the return circuit are arranged in parallel. With such an arrangement the flow from the cylinder block **6** cannot be used to supplement the flow from the second coolant supply conduit **4** and so in practice a larger pump is likely to be required. For example, if for a particular point in time the cylinder head requires a flow of 5 litres per second and the cylinder block requires a flow rate of 4 litres per second the pump will only need to supply 5 litres per second if the cooling system is arranged as shown in **FIG. 2** but will need to supply 9 litres per second if the cooling system shown in **FIG. 3** is used.

[0086] It will be appreciated that with this parallel flow arrangement a coolant sensor could also be provided to monitor the temperature of the coolant leaving the cylinder block or the coolant sensor associated with the cylinder head coolant flow could be replaced by such a sensor.

[0087] It will be appreciated that such a parallel flow arrangement could also be applied to the situation shown in **FIG. 1** in which the flow to the cylinder head **10** is limited by an orifice **3** and the flow to the block **6** is controlled by a valve **2**.

[0088] Therefore in summary a number of different embodiments of the invention have been disclosed all of which use separate coolant supply passages to the cylinder block and the cylinder head and use a valve to control the flow of coolant to one of the coolant supply passages.

[0089] By using a cooling system according to the invention the cylinder head can be allowed to warm up quickly after a cold start and during normal engine running the cylinder block can be maintained at a temperature to produce low friction and minimal oil degradation while the cylinder head temperature is controlled to allow lower cylinder head temperatures and hence reduced NOx emissions while allowing the power rating for the components of the cylinder head to be increased by providing the required cooling thereto and in particular by providing focussed cooling of the critical components.

[0090] It will be appreciated that one of the advantages of the invention is that for all embodiments a single thermostat is used to control the temperature of the coolant during normal engine running. This minimises the cost of the system and prevents any problems that can occur if multiple thermostats are used such as thermostat fight.

[0091] A further advantage of a cooling system according to this invention is that only one degas connection point is required, this simplifies the system and produces a very cost efficient system as no additional piping or control valves are required. As previously mentioned because a cooling system according to the invention uses a low flow of coolant during cold start-up conditions, no additional valves are required to prevent cold coolant from being purged from the degas reservoir during these conditions. Such a cooling system is therefore less expensive to produce and will have good warm up properties.

[0092] It will be appreciated by those skilled in the art that although the invention has been described by way of example with reference to a number of specific embodiments it is not limited to these embodiments and that various alternative embodiments or modifications to the disclosed embodiments could be made without departing from the scope of the invention.

1. A cooling system for an internal combustion engine comprising a cooling circuit including passages formed in a cylinder head of the engine and in a cylinder block of the engine and at least one conduit connecting the passages in the cylinder head and cylinder block to an inlet to a pump used to circulate the coolant through the cooling circuit wherein the pump is a variable flow rate pump controlled by an electronic control unit, the coolant passages in the cylinder block are connected by a first coolant supply conduit to an outlet from the pump, the coolant passages in the cylinder head are connected by a second coolant supply conduit to an outlet from the pump, the flow through at least one of the first and second coolant supply passages is controlled by an electronically controlled flow control valve operably connected to an electronic controller used to control the opening and closing of the electronically controlled flow control valve and the flow through the other of the first and second coolant supply passages has a predetermined flow restriction to prevent unlimited flow therethrough.

2. A cooling system as claimed in **1** wherein the predetermined flow restriction is formed by one of an orifice and the use of a coolant supply passage having a relatively small cross-sectional flow area representing a restriction to flow for at least a portion of the length of the other coolant supply passage.

3. A cooling system as claimed in claim 1 or in claim 2 wherein the electronic control unit is formed as part of the electronic controller used to control opening and closing of the first electronically controlled flow control valve.

4. A cooling system as claimed in any of claims 1 to 3 wherein the cooling system further comprises at least one temperature sensor operably connected to the electronic controller to sense the temperature of a part of the cylinder head and to supply a signal indicative of the sensed temperature to the electronic controller, at least one temperature sensor operably connected to the electronic controller to sense the temperature of a part of the cylinder block and to supply a signal indicative of the sensed temperature to the electronic controller, the electronic controller is operable, at least during normal engine running, to control the opening and closing of the electronically controlled flow control valve based upon at least one of the signals received from the cylinder head and cylinder block temperature sensors and the electronic control unit is operable, at least during normal engine running, to control the flow rate from the variable flow rate pump based upon at least one of the signals received from the cylinder head and cylinder block temperature sensors.

5. A cooling system as claimed in claim 4 wherein, during normal engine running, the flow from the variable flow rate pump is controlled to provide the minimum required flow based upon at least one of the signals received from the cylinder head and cylinder block temperature sensors.

6. A cooling system as claimed in claim 4 or in claim 5 wherein the cooling system further comprises at least one coolant temperature sensor operably connected to the electronic controller for sensing the temperature of the coolant exiting the cylinder head and the electronic controller is operable to control the opening and closing of the electronically controlled flow control valve based upon the signals received from at least one of the cylinder head and cylinder block temperature sensors and from the coolant temperature sensor.

7. A cooling system as claimed in claim 4 in claim 5 wherein the cooling system further comprises at least one coolant temperature sensor operably connected to the electronic controller for sensing the temperature of the coolant exiting at least one of the cylinder block and the cylinder head and the electronic control unit is operable to control the flow from the variable flow rate pump based upon the signals received from at least one of the cylinder head and cylinder block temperature sensors and from the coolant temperature sensor.

8. A cooling system as claimed in any of claims 1 to 7 wherein the electronically controlled flow control valve controls the flow of coolant through the first coolant supply conduit to the cylinder block, at least one cylinder head

temperature sensor is operably connected to the electronic controller to sense the temperature of a part of the cylinder head and to supply a signal indicative of the sensed temperature to the electronic controller and the temperature of the cylinder head is controlled by the electronic control unit, at least during normal engine running, by varying the flow from the variable flow rate pump to maintain the temperature as sensed by the or each cylinder head sensor within a predetermined desired range based upon the sensed temperature of the cylinder head and at least one cylinder block temperature sensor is operably connected to the electronic controller to sense the temperature of a part of the cylinder block and to supply a signal indicative of the sensed temperature to the electronic controller and the temperature of the cylinder block is controlled, at least during normal engine running, by the electronic controller opening and closing the electronically controlled flow control valve to maintain the temperature of the cylinder block within a predetermined desired temperature range based upon the sensed temperature of the cylinder block.

9. A cooling system as claimed in any of claims 1 to 7 wherein the electronically controlled flow control valve controls the flow of coolant through the second coolant supply conduit to the cylinder head, at least one cylinder head temperature sensor is operably connected to the electronic controller to sense the temperature of a part of the cylinder head and to supply a signal indicative of the sensed temperature to the electronic controller and the temperature of the cylinder head is controlled, at least during normal engine running, by the electronic controller opening and closing the electronically controlled flow control valve to maintain the temperature of the cylinder head within a predetermined desired temperature range based upon the sensed temperature of the cylinder head and at least one cylinder block temperature sensor is operably connected to the electronic controller to sense the temperature of a part of the cylinder block and to supply a signal indicative of the sensed temperature to the electronic controller and the temperature of the cylinder block is controlled by the electronic control unit, at least during normal engine running, by varying the flow from the variable flow rate pump to maintain the temperature as sensed by the or each cylinder block sensor within a predetermined desired range based upon the sensed temperature of the cylinder block.

10. A method for cooling an internal combustion engine having a cylinder head, a cylinder block, a first coolant supply conduit to supply coolant from a an electronically controlled variable flow rate pump to passages formed in the cylinder block, a second coolant supply conduit for independently supplying coolant from the pump to passages formed in the cylinder head, an electronically controlled flow control valve to control the flow of coolant though one of the first and second coolant supply conduits, a predetermined flow restriction to prevent unlimited flow through the other of the first and second coolant supply conduits wherein the method comprises opening and closing the or each electronically controlled flow control valve and changing the flow rate from the variable flow rate pump to maintain, at least during normal engine running, the temperature of the cylinder block within a desired temperature range and the temperature of the cylinder head within a desired temperature range.

11. A method as claimed in claim 10 wherein at least one temperature sensor is provided to sense the temperature of a part of the cylinder head and at least one temperature sensor is provided to sense the temperature of a part of the cylinder block and the method further comprises opening an closing the or each electronically controlled flow control valve and varying the flow rate from the pump based upon the signals received from cylinder head and cylinder block temperature sensors.

12. A cooling system substantially as described herein with reference to the accompanying drawing.

13. A method for cooling an internal combustion engine substantially as described herein with reference to the accompanying drawing.

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