Title: ENGINE AFTER-COOLING SYSTEM

Abstract: An engine after-cooling system (10) comprises a liquid-to-air after-cooler (11) for cooling compressed air which is output from a compressor for combustion by an internal-combustion engine, a radiator (19) for cooling a liquid coolant which is output from the after-cooler (11), a pump (21) for continuously pumping the coolant through the system (10), an outlet air temperature sensor (27) for sensing the temperature of the compressed air after being cooled by the after-cooler (11), a coolant temperature sensor for sensing the temperature of the coolant output from the after-cooler (11), and a controller (26) for controlling the flow-rate of coolant through the system (10) in response to the sensed air and coolant temperatures.
ENGINE AFTER-COOILING SYSTEM

Field of the Invention

The present invention relates generally to cooling systems and, in particular, to engine after-cooling systems for cooling the compressed air which is output from a compressor such as a turbocharger or supercharger for combustion by an internal-combustion engine.

Brief Discussion of the Prior Art

Diesel engines often include a compressor such as a turbocharger or supercharger for compressing inlet air prior to the air being mixed with diesel fuel and combusted. Compressing the inlet air allows more diesel fuel to be combusted during each cycle of a diesel engine and this consequently increases the amount of power which is output by the engine.

The power output and fuel consumption of many modern diesel engines are computer-controlled so that the engines comply with emission requirements. These types of engines are therefore often referred to as emission-controlled engines. If the ambient air temperature in the vicinity of such a diesel engine increases so that the temperature of the inlet air for the engine also rises, the engine is automatically de-rated by its controlling computer so that the power output of the engine is reduced.

The engine is de-rated because as the temperature of the inlet air rises the compressed air output by the compressor expands and becomes less dense by volume so that the amount of diesel which can be effectively combusted per unit volume of air is thus reduced. De-rating the engine causes less diesel fuel to be injected into the cylinder combustion chamber with the air so that the desired fuel-air ratio is maintained. This means that there is both less air and less diesel being combusted during each combustion cycle of the engine and the output power of the engine is consequently reduced. De-rating the engine reduces the quantity of pollutants which are emitted by the engine but can significantly diminish the power output of the engine, particularly under heavy load.

The temperature of the compressed inlet air for a diesel engine is not only dependent on the ambient air temperature in the vicinity of the engine. When the inlet air is being compressed by a compressor such as a turbocharger or supercharger, the
compression process increases the temperature of the inlet air by a significant amount. If the engine is a modern diesel engine which is able to be de-rated by its integrated computer management system, the increase in temperature caused by the compression process will usually cause the engine to de-rate so that the engine produces less power.

When diesel engines which rely on compressed inlet air are used in automotive and stationary applications the engines usually include an after-cooling system which cools the inlet air after it is compressed so as to improve engine performance. The after-cooling system includes an air-to-air after-cooler which is similar in design to a conventional water-to-air radiator and includes a plurality of cooling tubes through which the compressed inlet air passes and a plurality of cooling fins adjacent the cooling tubes so that heat from the compressed inlet air is able to be transferred to the cooling fins which in turn are able to transfer the heat to the surrounding air which flows past the cooling fins. In automotive and stationary applications the air-to-air after-cooler is typically positioned in front of the water-cooling radiator which is usually located in front of the engine.

Although after-cooling systems of the type which include an air-to-air after-cooler are effective in cooling compressed inlet air and increasing engine performance, they suffer from the deficiency that as the ambient air temperature increases the cooling efficiency of the air-to-air after-cooler decreases which results in an increase in the temperature of the compressed inlet air which is output from the after-cooler. This increase in temperature of the compressed inlet air reduces engine performance and can cause a de-rateable engine’s integrated computer management system to automatically de-rate the engine’s power output in response to the cooling inefficiency so that the engine will continue to meet emission requirements and regulations.

The reduction in cooling efficiency of air-to-air after-coolers as ambient air temperature increases can be overcome to a certain extent by increasing the size of such after-coolers so that greater cooling can be achieved in order to at least partially offset any increase in ambient air temperature. However, there are practical limitations to the amount by which the size of an air-to-air after-cooler can be increased. For example, the size of an air-to-air after-cooler may be limited by the
amount of space which is available to accommodate the after-cooler.

The cooling efficiency of after-cooling systems can be significantly increased by using a water-to-air after-cooler to condense the compressed air instead of an air-to-air after-cooler. Water-to-air after-coolers are used with diesel marine engines such that seawater is used instead of air to cool the after-coolers. These marine after-cooling systems continuously pump fresh seawater through their after-coolers and heat exchangers instead of continuously pumping the same seawater through the after-coolers. Marine engines are able to output much more power when they employ seawater-cooled after-cooling systems instead of air-cooled after-cooling systems.

Seawater-cooled after-cooling systems are obviously not suitable for use with land-based engines. Although attempts have been made to modify existing water-to-air after-cooling systems so that they can be used with land-based engines, to the inventor's knowledge such attempts have not to date been particularly successful.

An example of a prior art water-to-air after-cooling system is disclosed in United States Patent No. 4,697,551 (Larsen et al.). Larsen et al. discloses a method and apparatus for quickly adjusting the coolant flow in a tuned, low-flow coolant system to maintain the temperature of air leaving an after-cooler at a desired temperature and for maintaining the temperature of an engine block within a predetermined range during various engine loads and ambient temperatures. In particular, Larsen et al. discloses a quick-acting, proportional radiator shuttle valve for mixing hot coolant from an inlet of a radiator with cooled coolant from an outlet of the radiator for application to an after-cooler, and a quick-acting after-cooler shuttle valve for mixing cooled coolant from the outlet of the radiator with coolant from the after-cooler for application to an engine block. The operation of the radiator shuttle valve is controlled by a valve-actuating controller which controls the shuttle valve in response to the temperature of the air which is output from the after-cooler as measured by an air temperature sensor. The operation of the after-cooler shuttle valve is controlled by a valve-actuating controller which controls the after-cooler shuttle in response to the temperature of the coolant in the engine block. A pump is used to pump coolant through the radiator, after-cooler, and the engine block.

Another example of a prior art water-to-air after-cooling system is disclosed
in United States Patent No. 5,201,285 (McTaggart). McTaggart discloses a controlled cooling system for a turbocharged internal combustion engine having a heat exchange radiator, liquid coolant to absorb heat from the engine, a pump to circulate coolant through the system, a fan to force air in heat exchange with the engine coolant radiator, and another radiator for the charge-air after-cooler coolant. The cooling and turbo charge system for the engine includes a temperature control valve to direct a portion of the liquid coolant discharged from the engine to the radiator and to direct a portion of the liquid coolant to bypass the radiator in response to the temperature of the liquid coolant after discharge from the engine. A liquid sub-cooler heat exchanger lowers the temperature of the liquid coolant by passing the coolant in heat exchange with forced air from the fan. A flow control valve directs a portion of the liquid coolant discharged from the radiator to the sub-cooler heat exchanger and the remainder of the liquid coolant to the engine. An after-cooler heat exchanger lowers the temperature of the combustion air discharged from the turbo compressor by passing the combustion air charge in heat exchange with the liquid coolant from the sub-cooler heat exchanger.

Yet another example of a prior art water-to-air after cooling system is disclosed in United States Patent No. 4,977,862 (Aihara et al.). The Aihara et al. patent discloses an engine room-cooling control system for an engine which includes an after-cooling system. The after-cooling system includes a liquid-to-air after-cooler or intercooler for cooling compressed air which is output from a compressor (which is in the form of a turbocharger) for combustion by the engine. The disclosed after-cooling system also includes a radiator for cooling a liquid coolant which is output from the after-cooler, a pump for pumping coolant through the system, an air temperature sensor for sensing the temperature of the compressed air after being cooled by the after-cooler, a coolant temperature sensor for sensing the temperature of the coolant output from the after-cooler, and a controller for controlling the flow-rate of coolant through the system in response to the sensed air and coolant temperatures. The cooling circuit of the Aihara et al. patent not only cools the after-cooler but also cools the compressor.

The Aihara et al. after-cooling system has several deficiencies, the most serious of which is that the controller of the system is able to stop the pump from
supplying coolant to the after-cooler. Stopping the flow of coolant through the after-cooler would likely cause a failure of the after-cooler itself. The inlet and outlet of the after-cooler assembly of the Aihara et al. after-cooling system includes a cowl or duct so as to distribute the pressurised air on the inlet side of the after-cooler over the larger internal surface of the cores of the after-cooler. Even so, there is a hot-spot where the air blast of the compressed air hits the centre of the first after-cooler core. If the coolant is not moving through the core then no heat is able to be removed from the central area receiving the hot air blast. This central area will expand as it is heated. Because the surrounding structure of the after-cooler core is not subject to this hot-spot effect and no coolant is flowing, buckling and structural failure of the after-cooler core is likely to result. It is well known that the portion of any after-cooler core subject to the initial air blast from the compressor is the area which erodes or fails first during service. Also, coolant will boil in the area of the hot-spot. Once this happens all cooling ability is lost, as air is induced into the system through boiling of the coolant and thus greatly reducing the ability of the coolant pump to operate properly. Air can become trapped within the system on the suction side of the pump and this can cause problems with the flow of coolant.

It would therefore be desirable to have a water-to-air after-cooling system which is suitable for use with land-based engines such as land-based diesel engines.

Summary of the Invention

It is an object of the present invention to overcome, or at least ameliorate, one or more of the deficiencies of the prior art mentioned above, or to provide the consumer with a useful or commercial choice.

Other objects and advantages of the present invention will become apparent from the following description, taken in connection with the accompanying illustrations, wherein, by way of illustration and example, a preferred embodiment of the present invention is disclosed.

According to an aspect of the present invention there is provided an engine after-cooling system comprising a liquid-to-air after-cooler for cooling compressed air which is output from a compressor for combustion by an internal-combustion engine, a radiator for cooling a liquid coolant which is output from the after-cooler, a
pump for continuously pumping the coolant through the system, an outlet air temperature sensor for sensing the temperature of the compressed air after being cooled by the after-cooler, a coolant temperature sensor for sensing the temperature of the coolant output from the after-cooler, and a controller for controlling the flow-rate of coolant through the system in response to the sensed air and coolant temperatures.

The after-cooling system may be employed with any suitable internal-combustion engine which may or may not be a de-rateable emission-controlled engine and which may or may not be installed on a vehicle. However, it is preferred that the after-cooling system is used with a de-rateable emission-controlled engine such as, for example, de-rateable emission-controlled diesel engine.

The engine after-cooling system enables a de-rateable emission-controlled engine, such as, for example, a de-rateable emission-controlled diesel engine which uses the system, to maintain high power output levels in relatively high ambient temperatures without de-rating. The system also assists in decreasing the fuel consumption of such engines.

The after-cooling system may be used with any suitable internal-combustion engine such as, for example, a diesel, petrol, or gas-powered internal-combustion engine which employs any suitable compressor such as, for example, a turbocharger or a supercharger to compress inlet air prior to the air being combusted by the engine.

The after-cooling system according to the present invention has superior performance when compared with other engine after-cooling systems which are of a similar size. This makes the after-cooling system according to the present invention particularly suitable for use in situations where the space available to accommodate an engine after-cooling system is at a premium.

The after-cooling system is preferably independent of any other cooling systems such as engine cooling systems.

The liquid-to-air after-cooler of the system may be of any suitable type. In a preferred form the liquid-to-air after-cooler includes a pipe through which compressed inlet air from the compressor passes, and a plurality of cooling tubes located adjacent to the pipe so that heat is able to be transferred from the compressed inlet air to the liquid coolant which passes through the cooling tubes. In a particular preferred form the liquid-to-air after-cooler includes three cooling sections each
containing a plurality of cooling tubes. Each cooling section has respective inlet and outlet ports.

Any suitable liquid-to-air cooling radiator may be used in the system. For example, the liquid-to-air cooling radiator may be of the type which includes any suitable number of vertically extending cooling tubes. In a preferred form, particularly useful in high temperature and/or high load applications, the radiator may be a triple-pass radiator having three sections that each include a plurality of horizontal cooling tubes.

Preferably, the cooling tubes of the first section extend from an inlet port of the radiator so that coolant can flow into the tubes of the first section through the inlet port. The cooling tubes of the second section are preferably located below the first section and are preferably connected to an opposite end of the first section to the inlet port so that coolant is able to flow from the tubes of the first section into the tubes of the second section in the opposite direction to the flow of coolant through the tubes of the first section. The cooling tubes of the third section are preferably located below the second section and are preferably connected to an opposite end of the second section to that which the tubes of the first section are connected to so that coolant can flow from the tubes of the second section into the tubes of the third section in the opposite direction to the flow of coolant through the tubes of the second section. The ends of the cooling tubes of the third section which are not connected to the tubes of the second section are preferably connected to an outlet of the radiator so that coolant can flow from the tubes of the third section and through the outlet. It is preferred that the radiator has horizontally extending cooling tubes because it has been found that such radiators are able to cool the coolant which flows through them more efficiently than radiators with vertical cooling tubes. It has also been found that a radiator with horizontally extending cooling tubes is less likely to have undesirable high temperature regions or "hot spots" formed therein. The radiator may be of any suitable size and shape, and may be fabricated from any suitable material.

A plurality of vertical cooling fins is preferably located adjacent the cooling tubes of the various sections of the radiator so that heat is able to be transferred from the coolant in the cooling tubes to the cooling fins, and then transferred to the air which flows past the cooling fins.
The radiator preferably has header tanks on the sides thereof. It is also preferred that the radiator includes a plurality of directional baffle plates in the header tanks for directing the flow of coolant into the various sections of the radiator.

Preferably, the radiator is fabricated from aluminium alloy.

It is preferred that the radiator and the after-cooler are similar to each other.

The pump may be of any suitable type. For example, the pump may be a variable or constant flow-rate pump. If the pump is a variable flow-rate pump any suitable variable flow-rate pump, such as, for example, a vane-type pump having a positive displacement, may be used. In a particular preferred form, the flow-rate of the pump may be varied between 1 and 250 litres or 30 to 180 litres of coolant per minute. If the pump is a constant flow-rate pump any suitable constant flow-rate pump, such as, for example, a centrifugal pump may be employed. The pump is preferably driven by a hydraulic motor or an electric motor whose speed may or may not be varied.

It is preferred that the pump continuously pumps the coolant through the system while the engine is operating. It is particularly preferred that the pump continuously pumps the coolant through the system only while the engine is operating.

The engine after-cooling system preferably also includes an inlet air temperature sensor for sensing the temperature of the compressed air before the compressed air is cooled by the after-cooler. The inlet air temperature sensor may be provided by any air temperature sensor which is suitable for sensing the temperature of the compressed air prior to the compressed air being cooled by the after-cooler. In a preferred form, the inlet air temperature sensor is in the form of an air temperature probe. The inlet air temperature sensor may be a remote sensor such as, for example, an infra-red sensor. The inlet air temperature sensor is preferably located immediately adjacent the inlet of the after-cooler to which the compressed air is input.

The outlet air temperature sensor may be provided by any air temperature sensor which is suitable for sensing the temperature of the compressed air after the compressed air is cooled by the after-cooler. In a preferred form, the outlet air temperature sensor is in the form of an air temperature probe. The outlet air temperature sensor may be a remote sensor such as, for example, an infra-red sensor.
The outlet air temperature sensor is preferably located immediately adjacent the outlet of the after-cooler from which the cooled compressed inlet air is output.

The coolant temperature sensor may be of any type which is suitable for sensing the temperature of the coolant which is output from the after-cooler. In a preferred form, the coolant temperature sensor is in the form of a water temperature probe. The coolant temperature sensor may be a remote sensor such as, for example, an infra-red sensor.

The controller may be of any type which is suitable for controlling the flow-rate of coolant through the system in response to the air and coolant temperatures which are sensed by the air and coolant sensors. In a preferred form the controller includes a hydraulic controller or an electronic controller for controlling the speed of the pump to thereby control the flow-rate of the pump, and a programmable logic controller (PLC) or a computer for controlling the hydraulic controller or electronic controller in response to the sensed air and coolant temperatures.

The controller may control the flow-rate of coolant through the system in any suitable manner. Preferably, the controller controls the flow-rate of coolant through the system by controlling the rate at which coolant is pumped through the system by the pump, or in other words, by controlling the flow-rate of the pump. In another preferred form, the controller does not control the flow-rate of coolant through the system by controlling the flow-rate of the pump. For example, the pump may be a constant flow-rate pump which continuously pumps the coolant through the system at a constant rate, and the system may include one or more bleed valves which are able to be controlled by the controller so as to decrease or increase the amount of coolant flowing through the system and thereby control the flow-rate of coolant through the system.

The pump preferably pumps coolant which has been cooled by the radiator from the radiator to the after-cooler.

The after-cooling system preferably includes an ambient air temperature sensor for sensing the ambient temperature of the air in the vicinity of the system. The ambient air temperature sensor may be provided by any air temperature sensor which is suitable for sensing the temperature of the air in the vicinity of the system. In a preferred form, the ambient air temperature sensor is in the form of an air
temperature probe. The ambient air temperature sensor may be a remote sensor such as, for example, an infra-red sensor. The ambient air temperature sensor is preferably located immediately adjacent the after-cooling system.

The after-cooling system preferably includes a fan for forcing air through the radiator to thereby assist the radiator in cooling the coolant which passes through the radiator. The fan may be of any suitable type and may be a variable speed fan or a constant speed fan. The direction of rotation of the fan is preferably able to be varied. Preferably, the controller is able to control the speed or direction of rotation of the fan.

In a preferred form, the controller determines the difference between the ambient air temperature sensed by the ambient air temperature sensor and the temperature sensed by the inlet air temperature sensor of the compressed air from the compressor (e.g. turbocharger or supercharger) which is input into the after-cooler prior to being cooled or condensed by the after-cooler. The controller also preferably determines the difference between the ambient air temperature sensed by the ambient air temperature sensor and the temperature sensed by the outlet air temperature sensor of the compressed air output from the after-cooler. The controller preferably uses the difference between the ambient air temperature and the temperature of the compressed inlet air prior to being cooled by the after-cooler, the difference between the ambient air temperature and the temperature of the compressed inlet air output from the after-cooler, and the temperature of the coolant as sensed by the coolant temperature sensor to determine the flow-rate of the coolant through the system and the speed of the fan which will maintain the coolant temperature and thus the temperature of the compressed inlet air which is output from the after-cooler at an optimum temperature.

Preferably, the controller controls the fan so that the speed thereof corresponds to the fan speed which the controller determines will cause the coolant temperature to contribute to maintaining the compressed inlet air which is output from the after-cooler at an optimum temperature. Preferably, the controller controls the rate at which the coolant is pumped through the system by the pump (i.e. the flow-rate of the pump) so that the flow-rate of the coolant through the system corresponds to the flow-rate which the controller determines will cause the coolant temperature to
contribute to maintaining the compressed inlet air which is output from the after-cooler at an optimum temperature.

The optimum temperature may be any suitable temperature. If the engine is a de-rateable engine, the optimum temperature of the compressed inlet air which is output from the after-cooler is preferably a temperature which prevents the engine from de-rating or a temperature which minimises the amount by which the engine de-rates its output.

The after-cooling system preferably includes a manifold tank. The manifold tank may be of any suitable size and shape, and may be fabricated from any suitable material. The manifold tank is preferably connected to an output of the pump and to an inlet of the after-cooler.

The after-cooling system preferably includes a header tank. The header tank may be of any suitable size and shape, and may be fabricated from any suitable material. The header tank is preferably connected to the manifold tank.

It is preferred that the after-cooling system includes a coolant level sensor. The coolant level sensor may be of any suitable type. In a preferred form, the coolant level sensor senses the coolant level in the header tank.

The after-cooling system preferably includes an expansion tank. The expansion tank may be of any suitable size and shape, and may be fabricated from any suitable material. The expansion tank is preferably connected to the header tank.

The after-cooling system including the heat circuit thereof which includes the after-cooler, radiator, and pump, together with any piping or other conduit which may connect the various components together may be fabricated from any suitable material. In a preferred form, the heat circuit is fabricated from aluminium or aluminium alloy. The excellent thermal conductivity of aluminium and aluminium alloys enables temperature variations in the system to be relatively quickly detected by the controller so that the controller is able to respond to the detected variations shortly after they are established. This enables the controller to effectively control the system in real-time.

**Brief Description of the Illustrations**

In order that the invention may be more fully understood and put into
practice, a preferred embodiment thereof will now be described with reference to figure 1 of the accompanying illustrations which depicts a schematic diagram of the preferred embodiment.

**Detailed Description of the Illustrations**

Referring to figure 1, there is depicted an engine after-cooling system 10 according to a preferred embodiment of the present invention which is for use with a de-ratable emission-controlled diesel engine.

System 10 includes a liquid-to-air after-cooler 11 for cooling compressed air which is output from a compressor such as a turbocharger or supercharger for combustion by an internal-combustion engine. After-cooler 11 includes a pipe 12 which is connected to the output of a compressor such as, for example, a turbocharger or supercharger so that compressed inlet air which is output by the compressor passes through the pipe 12. After-cooler 11 also includes a plurality of sections 13 that each include a plurality of cooling tubes. The sections 13 are located adjacent the pipe 12 so that heat from the compressed air which passes through the pipe 12 is able to be transferred to a liquid coolant such as water which passes through the plurality of tubes in each section 13. Each section 13 has a respective inlet port 14 and a respective outlet port 15 so that coolant is able to flow into the sections 13 through their inlet ports 14 and out of the sections 13 through their outlet ports 15.

Each inlet port 14 of the after-cooler 11 is connected to a manifold tank 16 so that coolant is able to flow from the manifold tank 16 and into the sections 13 through the inlet ports 14.

Each outlet port 15 of the after-cooler 11 is connected to a coolant temperature sensor 17 so that coolant is able to flow from the sections 13 through the outlet ports 15 and pass through the temperature sensor 17 so that the sensor 17 is able to sense the temperature of the coolant which passes through it.

The water temperature sensor 17 is connected to an inlet port 18 of a radiator 19 so that coolant which passes through the sensor 17 enters the core of the radiator 19 through the inlet port 18. Radiator 19 is a three-pass radiator which includes horizontal cooling tubes and an outlet port 20 as well as the inlet port 18 which is located at the top of the radiator 19 and diagonally opposite the outlet port 20.
Coolant which enters the radiator 19 through the inlet port 18 passes through the horizontal cooling tubes of the radiator 19 so that heat from the coolant is transferred to the air which surrounds the tubes and is thereby removed from the coolant. The cooled coolant then flows out of the radiator 19 through an outlet port 20 which is located at the bottom of the radiator 19.

The outlet port 20 of the radiator 19 is connected to an inlet port of a coolant pump 21 which is driven by a hydraulic or electric motor 22. Pump 21 is of a type which is able to continuously pump 1 to 250 litres or 30 to 180 litres of coolant per minute. An outlet port of the pump 21 is connected to the manifold tank 16, and the manifold tank 16 is connected to a header tank 23 so that coolant which is pumped out of the outlet port of the pump 21 accumulates in the manifold tank 16 and the header tank 23.

Header tank 23 is located adjacent to an expansion tank 24, and a coolant level sensor 25 senses the level of the coolant inside the header tank 23 for a management system. The coolant circulating within the system 10 can be replenished by topping-up the header and expansion tanks 23, 24.

The radiator 19 is fitted with a variable-speed fan 30 which is able to force air through the core of the radiator 19 so that heat is transferred from the coolant passing through the radiator 19 to the air which is forced through the radiator 19 by the fan 30 so as to thereby cool the coolant.

A controller 26 controls the flow-rate of the pump 21 by controlling the speed of the hydraulic motor 22 in response to the coolant temperature sensed by the coolant temperature sensor 17, the temperature of the compressed inlet air output from the after-cooler 11 as sensed by an outlet air temperature sensor 27, the temperature of the compressed inlet air prior to being cooled by the after-cooler 11 as sensed by an inlet air temperature 28, and the ambient air temperature sensed by an ambient air temperature sensor 29. In particular, the controller 26 controls the rate at which the pump 21 pumps (i.e. the flow-rate of the pump 21) coolant through the system 10 in response to the sensed coolant and air temperatures to maintain the cooled compressed inlet air which is output from the after-cooler 11 at an optimum temperature. The optimum temperature of the compressed air output from the after-cooler 11 may, for example, be a temperature which prevents the engine from de-
rating or which minimises the amount by which the engine de-rates it’s output.

Controller 26 includes a programmable logic controller (PLC) or computer and a hydraulic or electronic controller. The outputs of the coolant temperature sensor 17 and air temperature sensors 27 to 29 are connected to inputs of the PLC or computer. The PLC or computer then processes the air and coolant temperatures that are sensed by the sensors 17, 27, 28, and 29 and outputs a control signal for controlling the hydraulic or electronic controller. As part of the processing of the engine inlet air and coolant temperatures sensed by the sensors 17, 27, 28, and 29, the PLC or computer calculates the difference between the ambient air temperature sensed by the air temperature sensor 29 and the temperature of the inlet air to the after-cooler 11 as sensed by the air temperature sensor 28. Also, the PLC or computer calculates the difference between the ambient air temperature sensed by the inlet air temperature sensor 29 and the temperature of the outlet air from the after-cooler 11 as sensed by the inlet air temperature sensor 27. The PLC or computer uses these calculated temperature differentials and the coolant temperature sensed by the coolant temperature sensor 17 to determine the flow-rate of the pump 21 and the speed of the fan 30 which will maintain the compressed inlet air which is output from the after-cooler 11 at or near the optimum temperature. The PLC or computer outputs control signals to the fan 30 and the hydraulic or electronic controller for the pump 21 so that the flow-rate of the pump 21 and the speed of the fan 30 are maintained at the flow-rate and speed as calculated by the PLC or computer. The hydraulic or electronic controller controls the speed of the hydraulic or electric motor 22 in response to the flow-rate control signal from the PLC or computer so that the flow-rate of the pump 21 (and therefore the flow-rate of coolant through the system 10) is maintained at the flow-rate calculated by the PLC or computer.

The PLC or computer is not only able to control the speed of the fan 30, it is also able to control the direction of rotation of the fan 30. The direction of rotation of the fan 30 is determined by parameters which are set in the PLC or computer of the controller 26.

All of the components in the heat circuit including the after-cooler 11, radiator 19, pump 21, and piping which connects the various components together are fabricated from aluminium or aluminium alloys. The excellent thermal conductivity
of aluminium and aluminium alloys enables temperature variations in the system 10 to be relatively quickly detected by the controller 26 so that the controller 26 is able to respond to the detected variations shortly after they are established. This enables the controller 26 to effectively control the system 10 in real-time.

Throughout the specification and the claims, unless the context requires otherwise, the term "comprise", or variations such as "comprises" or "comprising", will be understood to apply the inclusion of the stated integer or group of integers but not the exclusion of any other integer or group of integers.

Throughout the specification and claims, unless the context requires otherwise, the term "substantially" or "about" will be understood to not be limited to the value for the range qualified by the terms.

It will be appreciated by those skilled in the art that variations and modifications to the invention described herein will be apparent without departing from the spirit and scope thereof. The variations and modifications as would be apparent to persons skilled in the art are deemed to fall within the broad scope and ambit of the invention as herein set forth.

It will be clearly understood that, if a prior art publication is referred to herein, that reference does not constitute an admission that the publication forms part of the common general knowledge in the art in Australia or in any other country.
CLAIMS:

1. An engine after-cooling system comprising a liquid-to-air after-cooler for cooling compressed air which is output from a compressor for combustion by an internal-combustion engine, a radiator for cooling a liquid coolant which is output from the after-cooler, a pump for continuously pumping the coolant through the system, an outlet air temperature sensor for sensing the temperature of the compressed air after being cooled by the after-cooler, a coolant temperature sensor for sensing the temperature of the coolant output from the after-cooler, and a controller for controlling the flow-rate of coolant through the system in response to the sensed air and coolant temperatures.

2. The engine after-cooling system of claim 1, wherein the liquid-to-air after-cooler includes a pipe through which compressed inlet air from the compressor passes, and a plurality of cooling sections located adjacent to the pipe.

3. The engine after-cooling system of claim 1, wherein the radiator is a triple-pass radiator.

4. The engine after-cooling system of claim 1, wherein the pump is a variable flow-rate pump.

5. The engine after-cooling system of claim 1, wherein the pump includes a hydraulic motor or an electric motor.

6. The engine after-cooling system of claim 5, wherein the speed of the motor is able to be varied.

7. The engine after-cooling system of claim 1, wherein the pump operates continuously while the engine is operating.

8. The engine after-cooling system of claim 1, wherein the system also comprises an inlet air temperature sensor for sensing the temperature of the compressed air before the compressed air is cooled by the after-cooler.

9. The engine after-cooling system of claim 1, wherein the controller includes a hydraulic controller or an electronic controller for controlling the flow-rate of the pump.

10. The engine after-cooling system of claim 1, wherein the controller controls the flow-rate of coolant through the system by controlling the rate at which coolant is pumped through the system by the pump.
11. The engine after-cooling system of claim 1, wherein the pump pumps coolant which has been cooled by the radiator from the radiator to the after-cooler.

12. The engine after-cooling system of claim 8, wherein the system further comprises an ambient air temperature sensor for sensing the ambient temperature of the air in the vicinity of the system.

13. The engine after-cooling system of claim 1, wherein the system further comprises a fan for forcing air through the radiator.

14. The engine after-cooling system of claim 13, wherein the controller is able to control the speed of the fan.

15. The engine after-cooling system of claim 12, wherein the controller determines the difference between the ambient air temperature sensed by the ambient air temperature sensor and the temperature sensed by the inlet air temperature sensor of the compressed air from the compressor which is input into the after-cooler prior to being cooled or condensed by the after-cooler.

16. The engine after-cooling system of claim 15, wherein the controller determines the difference between the ambient air temperature sensed by the ambient air temperature sensor and the temperature sensed by the outlet air temperature sensor of the compressed air output from the after-cooler.

17. The engine after-cooling system of claim 16, wherein the controller uses the difference between the ambient air temperature and the temperature of the compressed inlet air prior to being cooled by the after-cooler, the difference between the ambient air temperature and the temperature of the compressed inlet air output from the after-cooler, and the temperature of the coolant as sensed by the coolant temperature sensor to determine the flow-rate of the coolant through the system which will maintain the coolant temperature and the temperature of the compressed air which is output from the after-cooler at an optimum temperature.

18. The engine after-cooling system of claim 14, wherein the controller controls the fan so that the speed of the fan corresponds to the fan speed which will contribute to maintaining the compressed inlet air which is output from the after-cooler at an optimum temperature.

19. The engine after-cooling system of claim 1, wherein the controller controls the rate at which the coolant is pumped through the system by the pump so that the
flow-rate of the coolant through the system corresponds to the flow-rate which will
cause the coolant temperature to contribute to maintaining the compressed inlet air
which is output from the after-cooler at an optimum temperature.
**INTERNATIONAL SEARCH REPORT**

**CLASSIFICATION OF SUBJECT MATTER**

*Int. Cl.*

**F02B 29/04** (2006.01)  **F01P 3/12** (2006.01)  **F02M 31/20** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

**FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

See below under "Electronic databases searched"

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)

(1) DWPI: IPC F02B, F02M, B60K with keywords: engine, turbocharge, cool, pump and similar terms
(2) DWPI: Keyword search: engine, turbocharge, cool, pump, sense and similar terms
(3) DWPI: IPC F02P 3/12 and keywords: turbocharge and similar terms
(4) USPTO: CCL/"123/41.31" and (turbo$ or super$) and (sen$)

**DOCUMENTS CONSIDERED TO BE RELEVANT**

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**Date of the actual completion of the international search**  18 May 2006

**Date of mailing of the international search report**  27 MAY 2006

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