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(54) **INTERNAL-COMBUSTION ENGINE ASSOCIATED WITH A RANKINE CYCLE CLOSED LOOP AND WITH A CIRCUIT FOR WATER INJECTION INTO THE ENGINE INTAKE SYSTEM**

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(57) **ABSTRACT**

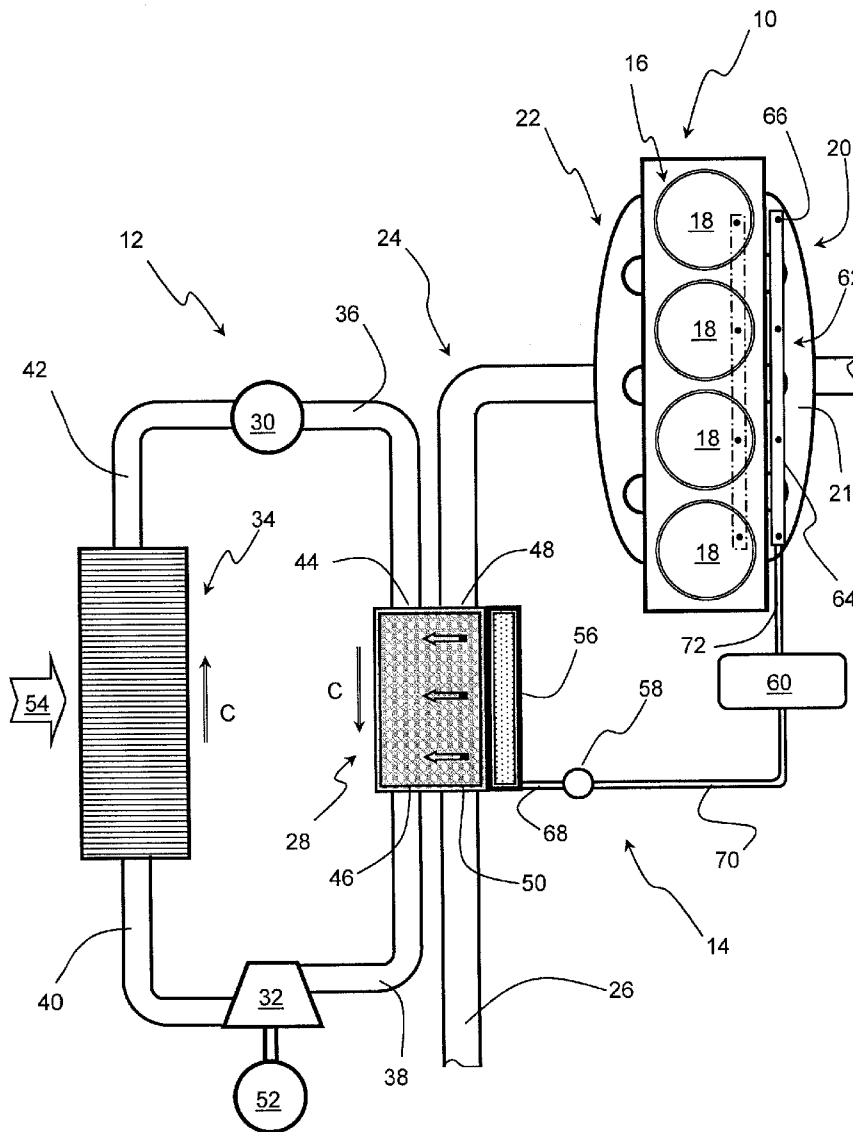
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The present invention is an internal-combustion engine, for a motor vehicle, comprising at least one cylinder (16) with a combustion chamber (18), an air intake (20) and a burnt gas exhaust (22). The engine comprises a heat exchanger (28) having a Rankine cycle closed loop (12) and a circuit (14) for injecting water into the engine intake system.

(30) **Foreign Application Priority Data**

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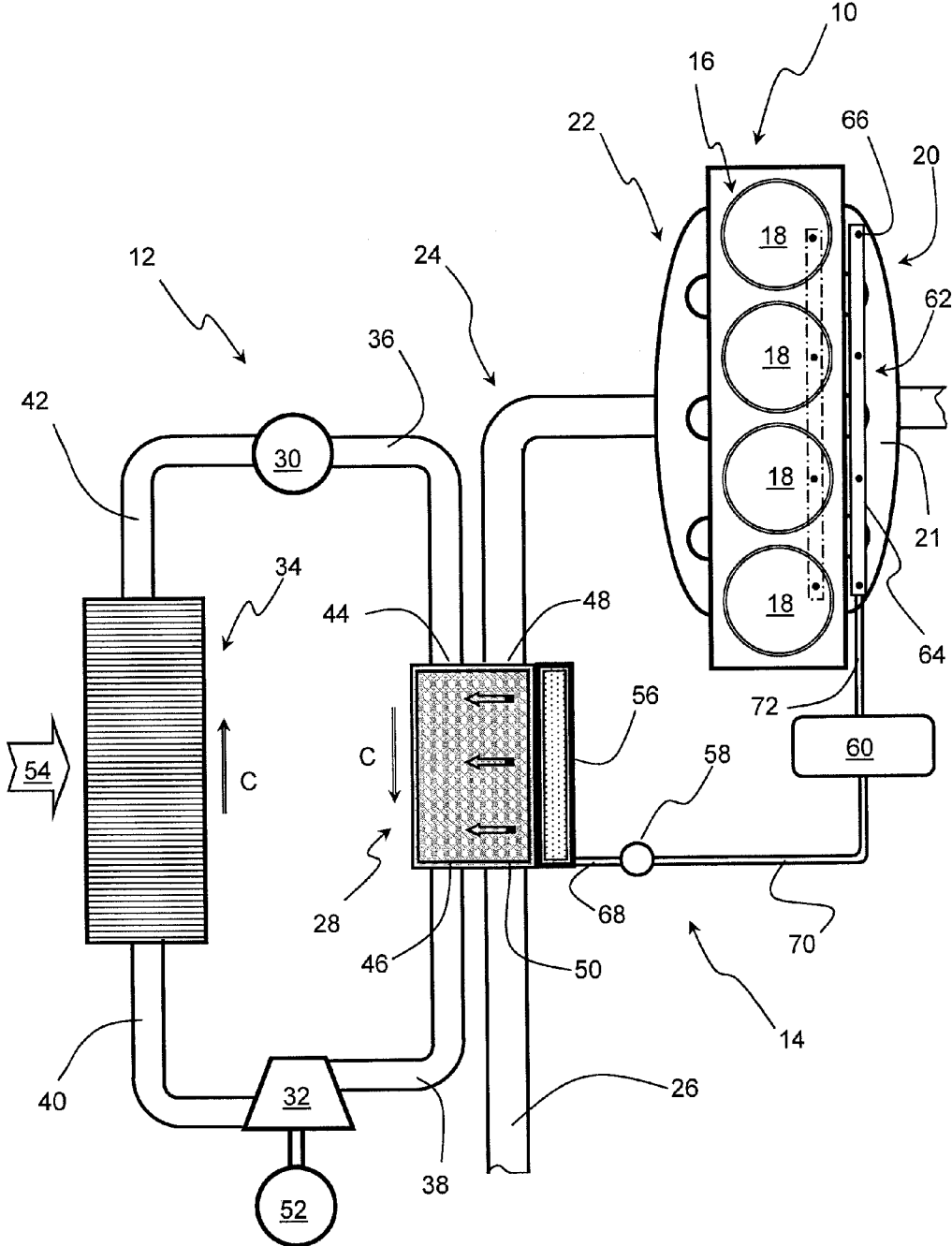


Figure unique

**INTERNAL-COMBUSTION ENGINE
ASSOCIATED WITHA RANKINE CYCLE
CLOSED LOOP AND WITH A CIRCUIT FOR
WATER INJECTION INTO THE ENGINE
INTAKE SYSTEM**

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to an internal-combustion engine associated with a Rankine cycle closed loop and a circuit for injecting water into the engine intake system and, more particularly, relates to a gasoline motor vehicle internal-combustion engine for motor vehicles.

[0003] 2. Description of the Prior Art

[0004] A Rankine cycle is a thermodynamic cycle in which heat from an external heat source is transmitted to a closed loop that contains a working fluid. The Rankine cycle generally has a stage in which the working fluid is compressed in an isentropic manner, followed by a stage where the compressed liquid fluid is heated and vaporized on contact with a source of heat. The vapor is then expanded, in another stage, in an isentropic manner in an expansion machine, then, in a last stage, the expanded vapor is cooled and condensed on contact with a cold source.

[0005] To carry these stages, the loop comprises a compressor pump for circulating and compressing the fluid in liquid form, an evaporator that is swept by a hot fluid for at least partial vaporization of the compressed fluid, an expansion machine for expanding the vapor by converting the energy of the vapor to another energy such as a mechanical or electric energy, and a condenser in which the heat contained in the vapor is provided to a cold source, which is generally the outside air that sweeps this condenser, to convert the vapor to a fluid in liquid form.

[0006] To provide heating and vaporization of the fluid flowing through the evaporator, it is known to use as the hot source the calorific energy conveyed by the exhaust gas of the internal-combustion engine by placing the evaporator on the engine exhaust line, as described in French Patent 2,884,555. This layout improves the energy efficiency of the engine by recovering a large part of the energy lost in the exhaust by converting it to an energy that can be re-used in mechanical or electric form by the engine, its accessories or the vehicle accessories.

[0007] It is also known to inject water into the intake system of an engine in order to lower the combustion temperature of the fuel mixture in the combustion chamber of the engine, which improves the fuel consumption of the engine and limits the discharge of pollutants such as nitrogen oxides (NOx), etc., which increases the engine efficiency by extending the limits of engine knock and the enrichment zone.

[0008] One solution for injecting water is to provide a tank for storing water and a device for supplying water using a pump and one or more injectors for feeding the water in liquid or vaporized form either into the intake manifold of the engine (indirect injection engine) or into the combustion chamber of the cylinder of this engine (direct injection).

[0009] The drawback of this configuration is that it requires a tank of great capacity (ten of liters) which occupies a large volume, which is not often available in motor vehicles. Furthermore, the user of the vehicle is obliged to fill the tank before it is totally empty to prevent engine malfunction due to the absence of water injection into the intake system.

[0010] It has been observed that, for a gasoline engine operating at a richness of 1, the exhaust gas contains a large amount of water which is about 7 mass %, essentially in vapor form, and that it is possible to condense about 80% of this water using a cooling power of approximately 20 kW.

[0011] A heat exchanger providing condensation of a very large part of the water vapor present in this exhaust gas is therefore provided on the exhaust gas circulation path, as described in WO-01/92,710.

[0012] The condensed water is then collected in a storage vessel prior to being sent through a distribution system to a system for injecting water into the engine intake system.

[0013] Increasing the energy efficiency and the engine efficiency of gasoline engines while limiting emissions is an ongoing concern for engine and car manufacturers.

[0014] Manufacturers could therefore provide an internal-combustion engine with a Rankine cycle closed loop and a circuit for injecting water into the intake system of the engine.

[0015] Such a layout is however difficult to achieve due to the installation, at the engine exhaust, and more particularly on the exhaust line, of an evaporator for heating and vaporizing the working fluid of the Rankine cycle loop and of a condenser for converting the water vapor contained in the gas to water.

[0016] Indeed, the exhaust line already comprises a multiplicity of devices for exhaust gas treatment, such as depollution catalysts, particle filters for particle trapping, lambda type sondes, expansion boxes, etc.

[0017] The space available for an evaporator and a condenser is therefore very limited. To allow installation thereof, the size of the evaporator and/or of the condenser has to be limited, which can only reduce their performances and thus degrade the operation of the Rankine cycle loop and/or of the water injection circuit.

[0018] The present invention overcomes the aforementioned drawbacks by a simple and inexpensive layout for the Rankine cycle closed loop and the water injection circuit on the engine.

SUMMARY OF THE INVENTION

[0019] The present invention therefore relates to an internal-combustion engine, notably for a motor vehicle, comprising at least one cylinder with a combustion chamber, an air intake and a burnt gas exhaust, comprising a heat exchanger shared with a Rankine cycle closed loop and a circuit for injecting water into the engine intake system.

[0020] The shared heat exchanger can be arranged on the exhaust.

[0021] In cases where the exhaust means comprises an exhaust manifold (23) and an exhaust line (24), the shared heat exchanger can be arranged on the exhaust line.

[0022] The shared heat exchanger can be a dual-mode exchanger with an evaporator for vaporizing the working fluid of the Rankine cycle loop and with a condenser for converting to water the water vapor of the exhaust gas for the water injection circuit.

[0023] The shared heat exchanger can comprise an inlet and an outlet for the working fluid of the Rankine cycle loop, as well as an inlet and an outlet for the exhaust gas.

BRIEF DESCRIPTION OF THE DRAWING

[0024] Other features and advantages of the invention will be clear from reading the description hereafter, given by way

of non imitative example, with reference to the sole FIGURE showing an internal-combustion engine with a Rankine cycle closed loop and a water injection circuit.

DETAILED DESCRIPTION OF THE INVENTION

[0025] In the FIGURE, an internal-combustion engine **10** is associated with a Rankine cycle closed loop **12** and a circuit **14** for injecting water into the engine intake system.

[0026] The internal-combustion engine comprises at least one cylinder **16** with a combustion chamber **18** where the combustion of a fuel mixture occurs, an air intake **20**, here in form of an air intake manifold **21**, and a burnt gas exhaust **22** which conveys burnt gas resulting from the fuel mixture combustion for discharge to the atmosphere.

[0027] As can be seen, the exhaust comprises, by way of example, an exhaust manifold **23** connected to an exhaust line **24** in which the exhaust gas coming from manifold **23** circulates, only a part of exhaust pipe **26** intended for discharge to the atmosphere of the burnt gas resulting from the fuel mixture combustion illustrated.

[0028] This exhaust line carries, advantageously as close as possible to the exhaust manifold, a dual-mode heat exchanger **28** whose purpose is explained more in detail in the description below.

[0029] Rankine cycle closed loop **12** comprises a positive-displacement pump **30** for compressing and circulating a working fluid, such as water, circulating clockwise as shown by arrows C, dual-mode heat exchanger **28**, a receiving expansion machine **32** and a cooling exchanger **34**.

[0030] The various elements of the loop are connected to one another by fluid circulation lines **36**, **38**, **40** and **42** for connecting successively the pump to the dual-mode exchanger (line **36**), the dual-mode exchanger to the expansion machine (line **38**), the expansion machine to the cooling exchanger (line **40**) and the cooling exchanger to the pump (line **42**) so that the working fluid, in liquid or vapor form, circulates in the direction shown by arrows C.

[0031] Pump **30** compresses the water between the pump inlet and its outlet where the water, still in liquid form, is at high pressure.

[0032] This pump is advantageously driven in rotation by any known means such as an electric motor (not shown).

[0033] The compressed water is carried through line **36** to inlet **44** of dual-mode exchanger **28** and then it leaves through outlet **46** in form of hot compressed vapor.

[0034] Dual-mode exchanger **28** thus provides an operating mode (evaporator mode) with the phase change of the working fluid of the Rankine cycle loop from the liquid phase to the vapor phase.

[0035] To achieve this change, the dual-mode exchanger uses the heat coming from the exhaust gas circulating in exhaust line **24**.

[0036] By way of example, this exchanger can be a cross-flow exchanger with a flow circulating between water inlet **44** and water vapor outlet **46**, and another flow with a hot exhaust gas inlet **48** and an exhaust gas outlet **50**, from where the exhaust gas is discharged to the atmosphere through the rest of the exhaust line.

[0037] The water vapor coming from outlet **46** of exchanger **28** is then sent through line **38** to expansion machine **32**.

[0038] By way of example, this expansion machine is an expansion turbine whose rotor (not shown) is driven in rotation by the water vapor. This rotor is advantageously con-

nected to any known device allowing use of the recovered mechanical energy, for example a transmission system of a vehicle driving the wheels, or to convert the mechanical energy recovered to another energy, such as an electric generator **52** for example.

[0039] The vapor expanded to a low pressure and leaving expansion machine **32** is carried through line **40** to cooling exchanger **34**. This cooling exchanger (or condenser) allows conversion of the expanded low-pressure vapor coming from the turbine to water in liquid form after passing through this condenser.

[0040] By way of example, this condenser is an assembly of cooling tubes and fins swept by a cooling fluid **54** that flows through the condenser between its inlet face and its outlet face while cooling and condensing the expanded vapor.

[0041] This cooling fluid is here outside air at ambient temperature, but any other cooling fluid such as water can be used for condensing the vapor.

[0042] The water in liquid form leaving the condenser is then sent through line **42** to pump **30**.

[0043] Water injection circuit **14** comprises a water recovery vessel **56**, a water circulation and compression pump **58**, a recovered water buffer tank **60** and a device **62** for injecting the recovered water into the engine intake system.

[0044] As illustrated in the FIGURE, by way of example, the device is in the form of a distribution ramp **64** connected to a multiplicity of injectors **66** for injecting the recovered water into intake manifold **21** or, as shown in dot-and-dash line in the FIGURE, directly into combustion chambers **18**.

[0045] Connecting lines **68**, **70** and **72** are respectively provided between the recovery vessel and the pump, between the pump and the buffer tank, and between the buffer tank and the injection device.

[0046] In order to achieve this water injection into the intake system, vessel **56** recovers the condensed water coming from dual-mode exchanger **28**.

[0047] Indeed, during the heat exchange between the exhaust gas and the working fluid of the Rankine cycle loop, the gas is cooled and the water vapor contained in the gas condenses as droplets. Once these droplets have reached a sufficiently significant mass, they fall into vessel **56** due to gravity.

[0048] Dual-mode heat exchanger **28** thus provides another operating mode (condensation mode) with the conversion through condensation of the water vapor contained in the exhaust gas to water.

[0049] Thus, the dual-mode exchanger shared by the two circuits operates according to an evaporation mode for Rankine cycle loop **12** and according to a condensation mode for water injection circuit **14**.

[0050] This condensed water contained in vessel **56** then circulates, under the effect of pump **58**, in lines **68**, **70** prior to reaching buffer tank **60** (approximately 0.2 to 2 liters), from where it is sent to injection device **62** and injected into the engine intake system.

[0051] Buffer tank **60** is thus constantly supplied with water for injection circuit **14**, without requiring any outside manual intervention.

[0052] Advantageously, a water purification device (not shown) allowing to store, in tank **60**, water freed of the major part of the impurities it contained can be provided on line **68** or on line **70**.

1-30. (canceled)

31. An internal-combustion engine, comprising at least one cylinder with a combustion chamber, an engine air intake and a burnt gas exhaust, including a heat exchanger shared by a Rankine cycle closed loop and a circuit for injecting water into the engine air intake.

32. An internal-combustion engine as claimed in claim **31**, wherein the shared heat exchanger is disposed on the burnt gas exhaust to absorb heat from burnt gas exhaust.

33. An internal-combustion engine as claimed in claim **31**, wherein the burnt gas exhaust comprises an exhaust manifold and an exhaust line.

34. An internal-combustion engine as claimed in claim **32**, wherein the burnt gas exhaust comprises an exhaust manifold and an exhaust line.

35. An internal-combustion engine as claimed in claim **31**, wherein the shared heat exchanger is a dual-mode exchanger with an evaporator for vaporizing the working fluid of the Rankine cycle loop and a condenser for converting water vapor in the burnt exhaust gas into water for water injection by the water injection circuit into the engine air intake.

36. An internal-combustion engine as claimed in claim **32**, wherein the shared heat exchanger is a dual-mode exchanger with an evaporator for vaporizing the working fluid of the Rankine cycle loop and a condenser for converting water vapor in the burnt exhaust gas into water for water injection by the water injection circuit into the engine air intake.

37. An internal-combustion engine as claimed in claim **33**, wherein the shared heat exchanger is a dual-mode exchanger with an evaporator for vaporizing the working fluid of the Rankine cycle loop and a condenser for converting water vapor in the burnt exhaust gas into water for water injection by the water injection circuit into the engine air intake.

38. An internal-combustion engine as claimed in claim **34**, wherein the shared heat exchanger is a dual-mode exchanger with an evaporator for vaporizing the working fluid of the Rankine cycle loop and a condenser for converting water vapor in the burnt exhaust gas into water for water injection by the water injection circuit into the engine air intake.

39. An internal-combustion engine as claimed in claim **31**, wherein the shared heat exchanger comprises an inlet and an outlet for the working fluid of the Rankine cycle loop and an inlet and an outlet for the burnt exhaust gas.

40. An internal-combustion engine as claimed in claim **32**, wherein the shared heat exchanger comprises an inlet and an outlet for the working fluid of the Rankine cycle loop and an inlet and an outlet for the burnt exhaust gas.

41. An internal-combustion engine as claimed in claim **33**, wherein the shared heat exchanger comprises an inlet and an outlet for the working fluid of the Rankine cycle loop and an inlet and an outlet for the burnt exhaust gas.

42. An internal-combustion engine as claimed in claim **34**, wherein the shared heat exchanger comprises an inlet and an outlet for the working fluid of the Rankine cycle loop and an inlet and an outlet for the burnt exhaust gas.

43. An internal-combustion engine as claimed in claim **35**, wherein the shared heat exchanger comprises an inlet and an outlet for the working fluid of the Rankine cycle loop and an inlet and an outlet for the burnt exhaust gas.

44. An internal-combustion engine as claimed in claim **36**, wherein the shared heat exchanger comprises an inlet and an outlet for the working fluid of the Rankine cycle loop and an inlet and an outlet for the burnt exhaust gas.

45. An internal-combustion engine as claimed in claim **37**, wherein the shared heat exchanger comprises an inlet and an outlet for the working fluid of the Rankine cycle loop and an inlet and an outlet for the burnt exhaust gas.

46. An internal-combustion engine as claimed in claim **38**, wherein the shared heat exchanger comprises an inlet and an outlet for the working fluid of the Rankine cycle loop and an inlet and an outlet for the burnt exhaust gas.

47. An internal-combustion engine as claimed in claim **39**, wherein the inlet for the working fluid of the shared heat exchanger is connected to a compressor and circulation pump of the Rankine cycle loop

48. An internal-combustion engine as claimed in claim **40**, wherein the inlet for the working fluid of the shared heat exchanger is connected to a compressor and circulation pump of the Rankine cycle loop

49. An internal-combustion engine as claimed in claim **41**, wherein the inlet for the working fluid of the shared heat exchanger is connected to a compressor and circulation pump of the Rankine cycle loop

50. An internal-combustion engine as claimed in claim **42**, wherein the inlet for the working fluid of the shared heat exchanger is connected to a compressor and circulation pump of the Rankine cycle loop

51. An internal-combustion engine as claimed in claim **43**, wherein the inlet for the working fluid of the shared heat exchanger is connected to a compressor and circulation pump of the Rankine cycle loop

52. An internal-combustion engine as claimed in claim **44**, wherein the inlet for the working fluid of the shared heat exchanger is connected to a compressor and circulation pump of the Rankine cycle loop

53. An internal-combustion engine as claimed in claim **45**, wherein the inlet for the working fluid of the shared heat exchanger is connected to a compressor and circulation pump of the Rankine cycle loop

54. An internal-combustion engine as claimed in claim **46**, wherein the inlet for the working fluid of the shared heat exchanger is connected to a compressor and circulation pump of the Rankine cycle loop/

55. An internal-combustion engine, comprising at least one cylinder with a combustion chamber, an engine air intake and a burnt gas exhaust, including a heat exchanger shared by a Rankine cycle closed loop and a circuit for injecting water into the engine air intake; and wherein
the internal-combustion engine is part of a motor vehicle.

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