

Translated from the French



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**METHOD AND DEVICE FOR RECUPERATING AMBIENT THERMAL ENERGY
FOR VEHICLE EQUIPPED WITH AN POLLUTION-FREE ENGINE
WITH SECONDARY COMPRESSED AIR**

The invention that is the subject of this patent concerns ground vehicles, particularly those equipped with pollution-free or pollution-reducing engine, with or without separate combustion chamber, operating with secondary compressed air injection, and incorporating a high-pressure compressed air reservoir.

In the patent application published under the number WO 96/27737, the author described a pollution elimination process for an engines equipped with separate external combustion chamber, operating according to a twin-mode principle with two types of energy, using either a conventional fuel such as petrol or diesel on open road (single-mode operation with air/fuel mixture) or at low speed, notably in urban and suburban zones, with an addition of compressed air (or of any other non-polluting gas) to the combustion chamber, excluding any other fuel (air-based single-mode operation, i.e. with the addition of compressed air). In patent application FR 9607714, the author described the installation of this type of engine for single-mode operation, with the addition of compressed air, on service vehicles such as urban buses.

In this type of engine, in air/fuel mixture mode, the air/fuel mixture is drawn in and compressed in a separate intake and compression chamber. This mixture is then transferred – still under pressure and at constant volume – to a separate combustion chamber, and is then burned in order to augment the temperature and pressure of the said mixture. After the opening of a transfer system connecting the said combustion or expansion chamber to a pressure relief and exhaust chamber, the mixture is decompressed in the latter chamber in order to produce work. The decompressed gases are then exhausted to the atmosphere via an exhaust pipe.

During operation with air plus secondary compressed air, which is more particularly subject of this invention, at low power, the fuel injection system is no longer controlled: in this case, after the admission into the combustion chamber of fuel-free compressed air – largely after the point of admission into the latter – from the intake and compression chamber, a small quantity of secondary compressed air is injected from an external reservoir, in which air is stored under high pressure – 200 bar for instance – and at ambient temperature. This small quantity of compressed air at ambient temperature will heat-up on coming into contact with the mass of high-temperature air contained in the combustion or expansion chamber, and will dilate and thereby augment the pressure in the chamber, so as to enable engine work to be delivered during the pressure relief.

This type of twin-mode or twin-energy engine (air and petrol, or air and secondary compressed air) can also be modified for preferential use – in urban zones, for instance – on all vehicles, particularly urban buses or other service vehicles (taxis, garbage trucks, etc) in air/secondary compressed air single mode, by eliminating all operation of the engine with conventional fuel.

The engine will only run in single mode with the injection of secondary compressed air into the combustion chamber, which will thereby become an expansion chamber. In addition, the air taken in by the engine can be filtered and purified through one or more carbon filters or by any other mechanical or chemical process, or through a molecular screen or through

5 other filters, so as to provide a pollution-free engine. The use of the term "air" in this text also includes "any non-polluting gas".

10 In this type of engine, the secondary compressed air is injected into the combustion or expansion chamber under an operating pressure established as a function of the pressure existing in the chamber, and at a pressure considerably higher than in the said chamber, in order to allow its transfer – at 30 bar for example. To achieve this, a conventional pressure relief system is used, which performs work-free pressure relief that does not absorb heat, and that therefore does not produce a temperature decrease, thereby allowing decompressed air (at approximately 30 bar in our example) at ambient temperature to be injected into the combustion or expansion chamber.

15 This process of injection of secondary compressed air can also be employed on conventional 2- or 4-stroke engines, in which the said injection of secondary compressed air will be taken into the engine combustion chamber roughly at top dead center of ignition.

20 The process according to the invention provides a system that allows the quantity of useable and available energy to be increased. It is characterised by the means used and, more particularly, by the fact that the compressed air contained in the reservoir at very high pressure (200 bar for example) and at ambient temperature (20 degrees for instance) prior to its final use at a lower pressure (at 30 bar for example) is decompressed to a pressure close to the pressure necessary for its final use, within a variable-volume system (such as a piston in a cylinder), producing work that can be recovered and used by any known means (mechanical, electrical, hydraulic, or other). This decompression with work has the consequence of chilling the compressed air to a very low temperature (-100 °C for example) at a pressure close to that required for its use. This compressed air that has been decompressed to its pressure of use and that is at very low temperature is then transferred to a heat exchanger with ambient air, and will heat up to a temperature approaching the ambient temperature, and will thereby increase its pressure and/or volume by recovering the thermal energy drawn from the atmosphere.

35 The advantages of the process according to the invention are considerable: firstly, work is produced during the decompression and can be used either directly by the engine primary shaft or indirectly, for instance, by driving mechanical, electrical or other subassemblies; secondly, free thermal energy is obtained by using the atmospheric temperature, which gives rise to an increase in pressure and/or volume of the air and, consequently, increases the operational range.

40 A person suitably qualified in the subject can calculate the quantity of very high-pressure air to be supplied to the pressure relief system with work, as well as the characteristics and volume of the latter, in order to obtain – at the end of this pressure relief with work – the final chosen operating pressure and the coldest temperature possible, as a function of the engine usage. An electronic system for managing these parameters allows the quantities of compressed air used and recovered to be optimized at all times. A person suitably qualified in the subject can also calculate the sizing and characteristics of the heat exchanger, which can employ all concepts known in the field without changing the process of the invention.

45 It is also possible according to the process of the invention to use, partially or otherwise, all or part of the air that has been decompressed and is at low temperature at all the hot areas of the engine, for example in the cylinder and/or cylinder head cooling system,

or elsewhere.

5 According to another characteristic of the invention, the work performed by the pressure relief is used to provide pneumatic assistance to a gas pressure booster system in the combustion or expansion chamber.

10 According to another characteristic of the process, the system of pressure relief with work can be used to generate electricity by means of, for instance, a core moving within a coil, advantageously replacing the vehicle's alternator.

 According to another characteristic of the process of the invention, the air/air heat exchanger can be designed to provide air conditioning for the vehicle during the summertime, through induction and distribution (within the vehicle) of the heating air that cools when it passes through the radiator and transfers its calories to the decompressed air.

15 In addition, the particular characteristics of operation of the invention described above can be combined without changing the principle; for example, the heating of the decompressed cold air can be performed in two stages with, on the one hand, atmospheric air followed by cooling or vice versa; similarly, it is possible at the beginning of travel to recover electrical power and then, at the end of travel, to recover mechanical energy for assistance.

20 It is also possible to perform the operation of pressure relief with work in two or more operations, such as pressure relief with work (used by all known systems) at intermediate pressure followed by re-heating in an air/air heat exchanger, prior to further pressure relief with work (also used by all known systems) and re-heating.

25 Other purposes, advantages and characteristics of the invention will come to the fore during perusal of the description - which is not exhaustive - of several special implementations described with reference to the appended drawings:

- Figure 1 is a schematic side projection of a pollution-free engine equipped with a device for pneumatic assistance with the control of a pressure booster piston;
- 30 • Figure 2 shows the same device at the beginning of engine decompression;
- Figure 3 shows the same device at the end of engine decompression;
- Figure 4 shows a pneumatic device for electrical power generation;
- Figure 5 shows a pneumatic device that generates both electrical and mechanical power.
- 35 • Figure 6 shows a schematic side projection of a device for the recovery of surrounding thermal energy used directly on the engine primary shaft;
- Figure 7 shows a schematic representation of a device using the heat exchanger that provides air conditioning for the vehicle;
- 40 • Figure 1 shows a schematic side projection of a pollution-free engine and its compressed air supply system, incorporating an intake and compression chamber (1), a constant-volume combustion or expansion chamber (2), installed in which is

- an additional air injector (22) fed with compressed air from a very high-pressure reservoir (23) and a pressure relief and exhaust chamber (4). The intake and compression chamber (1) is connected to the combustion or expansion chamber (2) by a pipeline (5) of which the opening and closing are controlled by a sealing flap valve (6). The combustion or expansion chamber (2) is connected to the pressure relief and exhaust chamber (4) by a pipeline or transfer system (7) of which the opening and closure are controlled by a sealing flap valve (8). The intake and compression chamber (1) is supplied with air via an intake pipeline (13) of which the opening is controlled by a valve (14) and upstream of which a pollution-free carbon filter (24) is installed.

The intake and compression chamber (1) operates like a piston-based compressor assembly in which a piston (9) sliding within a cylinder (10) is controlled by a conrod (11) and a crankshaft (12). The pressure relief and exhaust chamber (4) controls a conventional piston engine with a piston (15) sliding within a cylinder (16), that drives the rotation of a crankshaft (18) via a conrod (17). The decompressed air is exhausted through an exhaust pipeline (19) of which the opening is controlled by a valve (20). The rotation of the crankshaft (12) of the intake and compression chamber (1) is controlled, via a mechanical linkage (21), by the engine crankshaft (18) of the pressure relief and exhaust chamber (4).

According to the invention, the combustion chamber (2) incorporates a pressure booster chamber consisting of a cylinder (25) within which a piston (26) moves; the movement of this piston is controlled by a pressure lever (27 and 28). Between the pressure lever and its control cam (29), of which the rotation is driven by the engine and in phase with the engine, there is an assistance system. This assistance system consists of: a piston (30) sliding within a cylinder (31) closed at both ends; the piston (30) is connected by a rod (32) to a bearing (33) that acts on the control cam (29); and of a rod and conrod system (34) that links it to the pressure lever (27 and 28) controlling the pressure booster piston (26). The piston (30) governs access to two sealed chambers (35 and 36) within the cylinder: one pressure relief and work chamber (35) at the cam end (29); and one back-pressure chamber (36) at the pressure lever end. A high-pressure air intake pipeline (37) opens into the pressure relief and work chamber (35); the opening and closure of this pipeline is controlled by an electrovalve (38). An exhaust pipeline (39) also opens into the pressure relief and work chamber (35); the opening and closure of this pipeline is controlled by an electrovalve (40). The exhaust line (39) is also connected to an air/air heat exchanger or radiator (41), which itself is connected via a pipeline (42) to a buffer system of storage (43) at practically-constant final-usage pressure. The back-pressure chamber (36) is connected via a pipeline (44) to the buffer reservoir (43), which also supplies the additional air injector (22) via a pipeline (45).

When the engine is running in air/secondary compressed air mode (see Figure 1), the compression piston delivers high-temperature compressed air into the expansion chamber (2), when the pressure booster piston (26) is at its bottom dead centre; the additional air injector (2) is then switched so that it injects into the chamber a small quantity of additional air at ambient temperature and at a pressure slightly higher than that in the expansion chamber (2). A first pressure increase can then be observed in the expansion chamber (2). The electrovalve (38), controlled by a computer, opens in order to admit a small quantity of air at very high pressure and ambient temperature – supplied from the reservoir (23) – and then closes as, simultaneously, the cam (29) starts to push back the assistance piston (30). The very high-pressure compressed air that has been admitted into the pressure relief

5 and work chamber (35) pushes back the assistance piston (30) which itself, via the rod and conrod system (34) and the pressure lever (27 and 28), pushes back the pressure booster piston (26) to its top dead centre, further increasing the pressure in the expansion chamber (2).

10 During the travel of the assistance piston (30), the compressed air contained in the assistance chamber (35) decompresses, producing work and causing a large temperature drop; its pressure at the end of travel is roughly equal to the pressure of the air contained in the back-pressure chamber (36). During these operations, the engine piston (15) -- which controls the pressure relief chamber (4) -- arrives at its top dead centre (see Figure 2), and the sealing shutter flap (8) is opened so as to allow decompression of the compressed air contained in the expansion chamber (2) and produce engine work. During this pressure relief, the cam (29) maintains the pressure booster piston (26) at its top dead centre; 15 Because of the pressure lever, the forces due to the pressure in the chamber (2) are not transmitted to the cam (29), and the pressures in the assistance chamber (35) and the back-pressure chamber (36), which are roughly equal, apply no torque to the said cam.

20 Once the pressure relief supplying engine work in the pressure relief and exhaust chamber (4) has taken place (see Figure 3), the sealing shutter flap (8) is closed again. The rotation of the cam (29) allows further movement of the assistance piston, and the sealing shutter flap (6) opens so as to admit another quantity of gas into the combustion and expansion chamber (2); the electrovalve (40) opens; impelled by the return spring (46) and the pressure in the chamber (2), the assistance piston (30) returns to its initial position, 25 delivering air that is compressed but that has undergone partial decompression, and that is at low temperature, into the air/air heat exchanger or radiator (41), from the assistance chamber (35). By virtue of the heat exchanger, this air will heat-up to a temperature close to ambient temperature, and will increase in volume while returning to the buffer reservoir (43), having recovered a considerable quantity of energy from the atmosphere.

30 According to a characteristic of the process of the invention, the pressure relief with work can be used to supply electrical power to the vehicle. An example of a device implementing this process is shown in Figure 4, in which you can see a device that is very similar to the assistance device described above, and that has many points in common with the aforesaid assistance device; it consists of a piston (30) sliding within a cylinder (31) that is closed at both ends. The piston (30) is integral with a rod (34) that bears a ferrite core (49) that passes within a coil (50), and of which the extremity is connected to a return spring (46). 35 The piston (30) governs access within the cylinder to two sealed chambers (35 and 36): one pressure relief and work chamber (35); and one back-pressure chamber (36) at the rod end (34). A high-pressure air intake pipeline (57) opens into the pressure relief and work chamber (35); the opening and closing of this pipeline are controlled by an electrovalve (38). An exhaust pipeline (39) also opens into the pressure relief and work chamber (35); the opening and closing of this pipeline are controlled by an electrovalve (40). The exhaust pipeline (39) is also connected to an air/air heat exchanger or radiator (41), the which is itself connected -- via a pipeline -- to a buffer reservoir (43) at practically-constant final-usage pressure. The 40 back-pressure chamber (36) is connected via a pipeline (44) to the buffer reservoir (43), which also feeds the additional air injector (22) via a pipeline (45).

During operation of the engine in compressed air mode, according to the invention of the process, and as a function of the compressed air consumed by the additional air injector (22), the electrovalve (38) is opened and then closed to give admission to a quantity of very

high-pressure compressed air into the chamber (35). Impelled by the difference in pressure
5 between the chambers (35) and (36), the piston (30) moves, compressing the spring (46)
and causing the rod (34) to move the ferrite core (49) within the coil (50), thus producing
electrical current. The pressure relief (with work) of the ambient-temperature high-pressure
compressed air charge causes a temperature decrease. When the pressure – or, rather, the
10 effort between the two chambers – reaches equilibrium, the electrovalve (40) is opened and,
impelled by the return spring (46), the piston (30) and the ferrite core (49) return to their initial
position, delivering air that is compressed but that has been partially decompressed and that
is at extremely low temperature, contained in the pressure and pressure relief chamber (35),
into the air/air heat exchanger or the radiator (41). Because of the heat exchanger, this air is
15 heated to a temperature approaching ambient temperature and thereby augments in volume;
it enters the buffer reservoir (43) having recovered a considerable quantity of energy from the
atmosphere.

According to a characteristic of the invention, the two devices described above can
also be combined advantageously: the pressure is highest right at the beginning of travel of
the piston (30), whereas the effort required to cause the pressure lever to operate is smaller.
20 This device thus combined is illustrated in Figure 5, in which one can see a ferrite core (49)
sliding within a copper-wire coil (50) – similar to those shown in Figure 4 – located on the
control rod (34), between the assistance system and pressure lever as illustrated in Figures 1
to 3. During operation, it therefore becomes possible to recover electrical energy at the
beginning of travel within the coils (50) provided for the purpose, and then for operation to
25 take place in the manner described for Figures 1 to 3.

According to one of the key characteristics of the invention, another device for
application and implementation of the process of the invention is shown in Figure 6, in which
the pressure relief produces work that can be used directly at the engine primary shaft,
where a conrod assembly (53) and working piston (54) are connected directly to the engine
30 primary shaft (18). This piston (54) slides within a cylinder closed at one end (55) and
governs entry to a work chamber (35) into which open: firstly, a high-pressure air intake
pipeline (37) of which opening and closing are controlled by an electrovalve (38); and,
secondly, an exhaust pipeline (39) connected to the air/air heat exchanger or radiator (41),
which itself is connected by a pipeline (42) to a buffer system of storage at practically-
35 constant final usage pressure (43). During operation, when the working piston (54) is at its
top dead centre, the electrovalve (38) is opened and then closed in order to admit a quantity
of compressed air at very high pressure; this air then decompresses in pushing the piston
(54) to its bottom dead centre and drives the engine crankshaft (18) via the conrod (53).
During the upward journey of the piston (54), the exhaust electrovalve (40) is then opened
40 and the compressed air (which has partially decompressed and is at very low temperature)
contained in the work chamber is delivered into the air/air heat exchanger or radiator (41).
This air thus heats up to a temperature approaching ambient temperature and augments in
volume while travelling to the buffer reservoir (43), having recovered a considerable quantity
of energy from the atmosphere.

Figure 7 is a view in perspective of an air/air heat exchanger (41) such as described
45 for the preceding Figures, equipped as per the device for implementation of the process of
the invention described below, in order to provide air conditioning for the vehicle via a
pipeline feeding air at very low temperature (39) and an extraction pipeline carrying away air
after heating (42) for its final use; the atmospheric air intended to re-heat it is collected via a
50 pipeline (55) and blown across the radiator by a fan (56). By transferring its calories to the

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- 5 compressed air in the radiator, the atmospheric air cools and is collected in a pipeline (56) on which a moving shutter flap (57) allows all of part of the said air to be directed to the vehicle's passenger compartment in order to provide air conditioning, according to the extent to which the said shutter flap is open. The flow of refrigerated air can be regulated by means of any means known in the field, such as a cache on the radiator, shutter flaps, addition of hot air, etc, without changing the principle of this characteristic of the invention. This system can be
- 10 used in combination with the other devices described previously, without changing the principle of the invention described above.



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CLAIMS

- 5 1. Process for recovering surrounding thermal energy for engines or vehicles equipped with pollution-free or pollution-reducing engines operating with the injection of additional air into the combustion or expansion chamber and having a system of storage of high-pressure compressed air, characterised by the fact that the compressed air contained in the high-pressure reservoir is, before its final use at lower pressure, decompressed to a pressure
10 close to that necessary for its final use, within a variable-volume system such as a piston in a cylinder, producing work that has the consequence of cooling the thus partially-decompressed compressed air to low temperature, and characterised by the fact that this compressed air – which has been partially decompressed to its usage pressure – is transferred to a heat exchanger, in order to heat it and augment its pressure and/or volume
15 by recovering a quantity of thermal energy.
2. Process according to claim 1 characterised by the fact that the compressed air, which is partially decompressed and is at low temperature, is transferred to a heat exchanger with surrounding air at ambient temperature, in order to be heated to a temperature that is roughly equal to the said ambient temperature, and that its temperature and/or volume are thereby
20 increased in having recovered a quantity of thermal energy from the atmosphere.
3. Process according to claim 1 or claim 2, characterised by the fact that all or part of the very low-temperature decompressed air is heated on the hot areas of the engine, which thereby acts as a complement to the engine cooling system, whether or not in combination with its passage through the heat exchanger.
- 25 4. Application of the process according to claims 1 to 3, characterised by the fact that the work produced during pressure relief within the variable-volume system is recovered and used by mechanical, electrical, pneumatic or hydraulic systems to complement the engine power.
- 30 5. Application of the process according to claim 2, characterised by the fact that the ambient air that passes through the air/air heat exchanger, and which is thereby cooled, is used to provide air conditioning for the vehicle.
- 35 6. Device for application of the process of the invention according to claim 4, characterised by the fact that: the variable-volume system is composed of a piston (30) fitted with control and/or movement transmission rods (32 and 34) that slide within a cylinder (31) closed at both ends; at one end, the said cylinder governs entry into a pressure relief and work chamber (35), into which a high-pressure air intake pipeline (37) opens; an electrovalve (38) controls opening and closure of this pipeline, so as to permit or interdict the admission of a quantity of high-pressure compressed air; the said air decompresses in pushing the piston, producing work and cooling the air to low temperature; when the piston (30) returns to the
40 appropriate position, an exhaust pipeline (39), of which the opening and closure are controlled by an electrovalve (40), propels the low-temperature partially-decompressed compressed air into the heat exchanger (41), where it heats to a temperature close to ambient temperature, thereby increasing in volume, and is subsequently directed out of the radiator to a practically constant-pressure reservoir (43), that is itself connected, firstly, to
45 the secondary compressed air injector (22) and, secondly, to the back-pressure chamber (36), allowing regulation of the pressure obtained at the end of pressure relief and balancing the pressures on either side of the latter, so that the piston can be pushed to its starting point



by a spring (46).

7. Device for the application according to claim 4, characterised by the fact that the pressure relief system producing work allows one to provide assistance with the control of a pressure booster piston (26) sliding within a cylinder (28) opening into the combustion or expansion chamber (2), allowing boosting of the pressure of the air contained in the combustion chamber while phase control is provided by a cam (29), while the decompression of the quantity of high-pressure compressed air admitted into the pressure relief and work chamber (35) pushes the piston (30), which – by means of its control rod (34) – acts on a pressure lever (27 and 28), which pushes back the pressure booster piston (26), thereby augmenting the pressure in the combustion or expansion chamber (2) and consequently enhancing the performance of the engine.

8. Device for the application according to claim 4, characterised by the fact that the pressure relief system producing work is used to supply electrical energy: the control rod (34) is equipped with a ferrite core (49) moving within a coil (50), and the assembly is returned to its starting position by a spring (46).

9. Device according to claims 7 and 8, characterised by the fact that the pressure relief system producing work is used both to produce electricity via a ferrite core and a coil (49) and to boost the pressure of the air contained in the combustion or expansion chamber (2) as described in claim 6.

10. Device for the application and implementation of the process according to any one of claims 1 to 4, characterised by the fact that: the high-pressure compressed air contained in the reservoir (23) is decompressed within a variable-volume system, consisting of a piston (54) that is connected by a conrod (53) to the engine crankshaft (18) and that slides within a cylinder closed at one end (55), governing entry to a chamber above the said piston; a high-pressure air intake pipeline (37) opens into the said chamber, and the opening and closure of the pipeline are controlled by an electrovalve (38) that allows or interdicts the admission of a quantity of high-pressure compressed air; this air decompresses while pushing the piston (54), producing work directly recovered at the engine primary shaft (18), and thereby cools to a very low temperature; when the piston (54) returns to its top dead centre, an exhaust pipeline (39) – of which the opening and closure are controlled by an electrovalve (40) – allows decompressed and low-temperature compressed air to be delivered into the heat exchanger (41), where it heats up to a temperature close to ambient temperature, thus augmenting in volume; on leaving the radiator, the said air is subsequently directed to a practically constant-pressure reservoir (43), the which is itself connected to the secondary compressed air injector (22).

11. Device for the application according to claim 5, characterised by the fact that the ambient air is channelled and blown by a fan (56) to a manifold (55) in order to chill and transfer its calories to the compressed air that passes through the radiator and is then directed via a pipeline (56) into the vehicle's passenger compartment in order to provide air conditioning; a moving shutter flap (57) enables one to control the quantity of air admitted and thus to regulate the said air conditioning.