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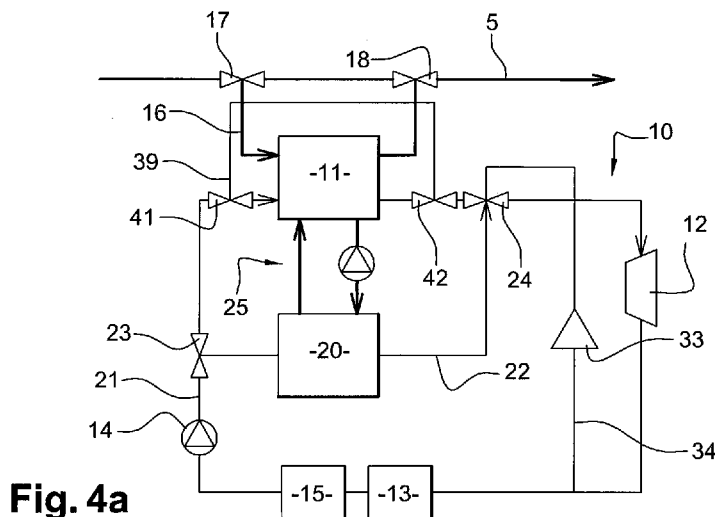
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(54) Title: ENGINE ARRANGEMENT COMPRISING A SEPARATE HEAT STORAGE DEVICE



(57) Abstract: The engine arrangement (1) comprises: - an internal combustion engine (2); - a waste heat recovery system (10) in which a working fluid is successively pumped by a pump (14), heated in a heat exchanger (11) by means of a heat source produced by the engine operation, and expanded in an expander (12). The waste heat recovery system (10) further comprises a heat storage device (20) which is arranged outside from the heat exchanger (11), downstream from the pump (14) and upstream from the expander (12), said heat storage device (20) comprising a heat storage material (30) which is in thermal contact with the working fluid (31) through a partition wall (32) and being arranged so as to be capable of storing heat from the heat source and of releasing previously stored heat in order to heat the working fluid.

## ENGINE ARRANGEMENT COMPRISING A SEPARATE HEAT STORAGE DEVICE

### Field of the invention

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The present invention relates to an engine arrangement comprising a waste heat recovery system, especially in a vehicle.

### Technological background

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For many years, attempts have been made to improve the efficiency of internal combustion engines, which has a direct impact on fuel consumption.

For this purpose, an engine can be equipped with a waste heat recovery system, i.e. a system making use of a heat source produced by the vehicle operation, such as the hot exhaust gases which contain a lot of thermal energy that would otherwise be lost.

One example of a waste heat recovery system is a circuit in which a working fluid undergoes the following successive processes:

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- the working fluid is pumped from low to high pressure;
- the high pressure working fluid is heated in at least one heat exchanger by means of said heat source;
- the working fluid is expanded in an expander.

As a result, at least part of the thermal energy of the heat source used to heat – and possibly evaporate – the working fluid is recovered in the expander, for example into mechanical energy or electricity.

One weakness of the current engine arrangements comprising a waste heat recovery system is that it is not always possible to immediately use the mechanical energy or electricity so recovered, typically because it may exceed the vehicle needs at the time it is produced by the waste heat recovery system. As a consequence, the energy which could potentially be recovered from the heat source is not always fully used.

Besides, in some operating conditions, the working fluid temperature may greatly increase. With organic fluids (such as ethanol or a refrigerant), which are commonly used as working fluids in such systems, this

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could lead to thermal stability problems and ultimately to the deterioration of the working fluid.

Another problem may exist when the waste heat recovery system is a closed loop system, for example operating according to the Rankine cycle.

5 In such a system, the working fluid flows in a closed loop and undergoes successive processes according to the Rankine thermodynamic cycle:

- the working fluid, which is a liquid at this stage, is pumped from low to high pressure;
- the high pressure liquid is evaporated into a gas by a hot fluid
- 10 flowing in another circuit of the engine arrangement;
- the gas is expanded in an expander;
- finally, the gas is condensed in a condenser.

Said condenser is arranged at the front part of the vehicle, so that the working fluid can be condensed by means of the ambient air moving

15 through the condenser due to the vehicle motion.

However, in some operating conditions, the cold provided by ambient air moving through the condenser is not enough to cool and condense the working fluid. This can typically happen at high loads, and/or when outside air temperature is fairly high. In other words, one of the key bottlenecks of the

20 closed loop cycles such as the Rankine cycle is the increased need of cooling capacity to allow condensing of the working fluid. At high engine loads or relatively high external temperatures, the free cooling capacity of the vehicle cooling package is not sufficient to cool both the engine and to condensate the working fluid.

As a consequence, the activation of the Rankine circuit would lead to an activation of the vehicle fan in order to provide additional cold to the condenser. This would have negative consequences on the overall energy consumption of the vehicle. Alternatively, if the vehicle fan has already been activated to cool down the engine, its cooling capacity may not be sufficient for

30 cooling down both the engine cooling circuit and the waste heat recovery system. This may result in a working fluid overheating.

Moreover, for high variations in load and engine speed – like for example in urban environments – the necessary changes of cycle conditions lead to variations in components working conditions far away from optimal

35 working points.

It therefore appears that engine arrangements comprising a waste heat recovery system are not fully satisfactory and could be improved.

### Summary

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It is an object of the present invention to provide an improved engine arrangement comprising a waste heat recovery system which can overcome the drawbacks of the prior art engine arrangements.

10 It is another object of the invention to provide such an engine arrangement which makes it possible to more efficiently use the thermal energy from the heat source without impairing the engine arrangement overall efficiency nor damaging the working fluid.

According to the invention such an engine arrangement comprises:

- an internal combustion engine;
- 15 - a waste heat recovery system in which a working fluid is successively pumped by a pump, heated in at least one heat exchanger by means of a heat source produced by the engine operation, and expanded in an expander;

20 the waste heat recovery system further comprising a heat storage device which is arranged outside from the heat exchanger, downstream from the pump and upstream from the expander, said heat storage device comprising a heat storage material which is in thermal contact with the working fluid through a partition wall and which is arranged so as to be capable of storing heat from the heat source and of releasing previously stored heat in  
25 order to heat the working fluid.

Thus, in an engine arrangement according to the invention, the thermal energy coming – directly or indirectly – from the heat source can be stored at times when it cannot be used, or when its use could have negative consequences on the overall engine arrangement performance, especially in  
30 terms of fuel consumption. Additionally, said stored energy can be used at a later time, when the operating conditions of the engine arrangement, and more generally of the vehicle, are more favourable for an efficient use of the energy previously stored in the waste heat recovery system.

35 Furthermore, the invention makes it possible to protect the working fluid from overheating, which increases the service life of the waste heat

recovery system and avoids the need to change the working fluid, which can be fairly expensive.

Moreover, the fan activation due to the operation of the waste heat recovery system can be avoided, which makes it possible not to impair the engine arrangement efficiency.

Owing to the heat storage device, the invention enables to take better advantage of the heat source, insofar as its thermal energy can be used over a wider range of operating conditions, either immediately or later, when the operating conditions allow heat to be released by the heat storage device. As a result, the engine arrangement overall efficiency can be increased on average over a given duty cycle.

Besides, by providing a heat storage device located outside from the heat exchanger, the invention allows using said device only when necessary, which further improves the system efficiency.

In practice, the partition wall separates the heat storage material and the working fluid, preventing them from being mixed. In a possible embodiment, the heat storage material could be the same material as the working fluid; however the heat storage material and the working fluid remain separate. In other words, in this implementation, the heat storage material cannot flow through the pump, heat exchanger and expander.

These and other features and advantages will become apparent upon reading the following description in view of the drawing attached hereto representing, as non-limiting examples, embodiments of an engine arrangement according to the invention.

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### **Brief description of the drawings**

The following detailed description of several embodiments of the invention is better understood when read in conjunction with the appended drawings, it being however understood that the invention is not limited to the specific embodiments disclosed.

Figure 1 is a schematic representation of an engine arrangement comprising a waste heat recovery system according to an embodiment the invention;

Figure 2a is a schematic representation of a waste heat recovery system according to a second embodiment of the invention;

Figures 2b-2f show the waste heat recovery system of Figure 2a in different operating phases;

Figure 3 is a schematic representation of a waste heat recovery system according to a third embodiment of the invention;

5 Figure 4a is a schematic representation of a waste heat recovery system according to a fourth embodiment of the invention;

Figures 4b-4e show the waste heat recovery system of Figure 4a in different operating phases;

10 Figure 5a is a schematic representation of a waste heat recovery system according to a fifth embodiment of the invention;

Figures 5b-5e show the waste heat recovery system of Figure 5a in different operating phases.

### **Detailed description of the invention**

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The internal combustion engine arrangement 1 according to the invention comprises an internal combustion engine 2, which can be a diesel engine or a spark ignition engine. The invention relates in particular, but not exclusively, to industrial vehicles. The arrangement may comprise a turbocharger 40 including a turbine 41 and a compressor 42.

20 Intake air is carried by an air intake line 3, it is compressed by the compressor 42 of the turbocharger 40 and passes through a charge air cooler 4 before it enters the engine 2. An exhaust line 5 is provided for collecting exhaust gases from said engine 2 and for directing them through the turbine 41 of the turbocharger 40, then towards various exhaust gases after treatment devices 6 before they are released into the atmosphere.

In order to cool the engine 2, there is further provided a coolant circuit 7 carrying an engine coolant and including a radiator 8.

30 A fan 9 can be mounted on the engine shaft and may create an air flow in a channel through which outside air can be sucked rearwards from the front of the vehicle, the charge air cooler 4 and radiator 8 being arranged in said channel.

The engine arrangement 1 also comprises a waste heat recovery system 10 carrying a working fluid which is successively pumped to a high pressure, heated in a heat exchanger by means of a heat source produced by the engine 2 operation, and expanded in an expander to a low pressure. As a

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result, at least part of the thermal energy of the heat source used to heat or evaporate the working fluid is recovered in the expander in the form of mechanical work which may be used as such and/or may be for example transformed into electricity by a generator driven by the expander.

5 In the illustrated embodiment, the waste heat recovery system 10 is of the closed loop type, for example of the Rankine type or of the Kalinka type. However, other types of waste heat recovery systems are possible, such as, for example, systems of the Brayton, Stirling or Ericsson type.

10 Thus, in this embodiment, the working fluid flows in a loop and undergoes successive processes according to the Rankine thermodynamic cycle. In the shown embodiment, the working fluid is distinct from the engine fluids such as the fuel, oil, coolant, etc. In the case of a Rankine cycle, the working fluid can be water or an organic fluid such as ethanol or such as Chloro-Fluoro-Carbons (CFCs), Hydro-Chloro-Fluoro-Carbons (HCFCs),  
15 Hydro-Fluoro-Carbons (HFCs) or hydro-carbons (HCs).

The waste heat recovery system 10 comprises a heat exchanger 11 in which the working fluid can be heated by means of the heat source. The heat source may be constituted by a hot fluid flowing in a pipe. In the embodiments shown in the figures, the heat source comprises the exhaust  
20 gases flowing from the engine 2 in the exhaust line 5; for example, the heat exchanger 11 can be located downstream from the exhaust gases after treatment devices 6. However, other implementations could be envisaged.

The system could comprise several heat exchangers, provided in series and/or in parallel, for heating the working fluid using the heat of a  
25 common heat source or of different heat sources. The heat source(s) can derive their heat from the internal combustion engine or from another heat generating device in the engine arrangement.

For example, the working fluid can be directly heated by said exhaust gases passing through the heat exchanger 11. This heat exchanger 11  
30 can be a boiler in which the working fluid flowing in the system 10 is at least partly but preferably totally evaporated by the hot exhaust gases.

Downstream from the heat exchanger 11, the working fluid flows through an expander 12. The expander 12 is capable of recovering part of the energy of the hot working fluid and of transforming it into mechanical energy. It  
35 can be for example a turbine, or a screw expander or a piston expander.

In the case of a Rankine circuit, downstream from the expander 12, the working fluid, which has been expanded and thereby partially cooled, can flow towards a condenser 13 in which it becomes a liquid again. It has to be noted that the engine arrangement 1 is schematically depicted in Figure 1 and may not show the concrete implementation of the various components of the arrangement 1. More precisely, the condenser 13 may be a direct air cooled condenser and would then preferably be located at the front part of the vehicle, in the air channel that can be created by the fan 9 and/or by the vehicle displacement. As a variant, the condenser 13 could be an indirectly cooled condenser where an intermediate fluid circuit is used to cool the condenser.

Downstream from the condenser 13, the working fluid – as a liquid – will be pumped by a pump 14 before entering the heat exchanger 11. In the pump 14, the working fluid is pumped from low to high pressure, and then directed towards the heat exchanger 11.

A reservoir 15 for the working fluid can further be provided, for example between the condenser 13 and the pump 14.

According to the invention, the waste heat recovery system 10 further comprises a heat storage device 20.

The heat storage device 20 is arranged outside of the heat exchanger 11, downstream from the pump 14 and upstream of the expander 12.

The heat storage device 20 is arranged so as to be capable of storing heat from the heat source and of releasing previously stored heat in order to heat the working fluid. It therefore makes it possible to use more energy from the heat source than in the prior art, either immediately or later, depending on the needs and on the engine arrangement operating conditions.

Moreover, when the waste heat recovery system 10 is activated, which in particular means that the working fluid is heated by the heat source in the heat exchanger 11, the heat storage device 20 may be used or not, depending on the needs, insofar as it is located externally of the heat exchanger 11. The heat storage device 20 can therefore be used only when necessary, e.g. under highly transient engine work conditions, or when heat recuperation and mechanical energy recovery by the Rankine cycle is not possible due to high heat rejection demands of the engine, or when the vehicle cannot make use of the energy recovered by the Rankine cycle, for driveability or general control reasons.

The heat storage device 20 can be arranged so as to be capable of storing heat directly from the heat source. In other words, the heat storage device 20 can be directly thermally connected to the heat source, without any intermediate heat transfer fluid. For example, when the heat source is  
5 constituted by a hot fluid, such as exhaust gases, said hot fluid can flow through the heat storage device 20.

Alternatively or additionally, the heat storage device 20 can be arranged so as to be capable of storing heat indirectly from the heat source, via at least one intermediate fluid.

10 For example, as this is schematically illustrated in Figure 1, the heat storage device 20 can draw heat:

- directly from the heat source, here the hot exhaust gases;
- and/or from the working fluid, with said working fluid flowing successively through the heat exchanger 11, where it receives heat from the  
15 heat source, and then through the heat storage device 20. As a result, the heat storage device 20 through which flows the working fluid can, in a first operating period, store heat from the working fluid which has been heated by the heat source, and, during a second operating period, can directly release heat to the working fluid;

- 20 - and/or from an intermediate thermal loop.

Furthermore, the heat storage device 20 comprises a heat storage material 30 which is in thermal contact with the working fluid 31 through a partition wall 32, as this is schematically illustrated in figure 1.

In other words, the working fluid flowing in the circuit – for example  
25 the Rankine circuit – is not in physical contact with the heat storage material and cannot be mixed with it. Although the working fluid 31 and the heat storage material 30 could be the same material, they remain separate by means of the partition wall 32 which acts as a wall for transferring heat from the working fluid 31 to the heat storage material 30 and vice versa.

30 In practice, several types of heat storage devices can be used, either alone or in combination.

In an implementation, hereafter referred to as “sensible heat storage”, the heat storage device 20 can comprise a container containing a heat storage material which does not undergo a phase change when heat is  
35 transferred from the heat source to said heat storage material or when said heat storage material transfers heat to the working fluid. In other words, in the

different operating conditions, said heat storage material can store heat by being heated, or release heat to the working fluid, without changing phase by storing heat in an amount proportional to the material's heat capacity.

For example, said heat storage material 30 can be a liquid or a gas, and the working fluid 31 can flow through the container inside a pipe the peripheral wall of which forms said partition wall 32. Preferably, the container is also insulated. With this implementation, heat transfer rates can be high, leading to a high recovery efficiency.

In another implementation, hereafter referred to as "latent heat storage, the heat storage device 20 can comprise a container containing a phase-change material, i.e. a heat storage material 30 which can undergo a phase change when heat is transferred from the heat source to said heat storage material 30 or when said heat storage material 30 transfers heat to the working fluid 31. In practice, said heat storage material 30 is chosen to ensure its melting or solidifying temperature is reached in the operative conditions of the engine arrangement 1.

Such a material stores or releases thermal energy when melting or solidifying. The corresponding amount of energy is large because the device makes use of the latent heat of fusion, which is generally much greater than the specific heat capacity of a material. The main advantages of this implementation are therefore the high thermal efficiency and also the high heat transfer rate during phase change.

Examples of phase-change materials contain paraffins, and/or inorganic salts like NaOH, KOH, LiOH, NaNO<sub>2</sub> and/or some metals like Sn or Pb. For example, the melting temperature can be around 200°C. The highest possible latent heat would make it possible to gain weight.

The partition wall 32 can be the wall of a pipe inside which the working fluid 31 can flow through the container, thereby being in thermal contact with the heat storage material 30. Preferably, the container is insulated.

In still another implementation, hereafter referred to as "chemical heat storage", the heat storage device 20 can comprise a unit including a sorbent and a gas or liquid which can be absorbed or adsorbed by said sorbent, the desorption being endothermic and the absorption or adsorption being exothermic. Here, the sorbent is the heat storage material 30, and the partition wall 30 can be formed by a wall of the unit or of a pipe inside which the working fluid 31 can flow through the unit.

The unit can typically comprise a first chamber including the sorbent and a second chamber, distinct from the first one, for storing the gas or liquid. The chambers can be connected or not, depending on the operating phase.

5 For example, the sorbent can be a salt, which is capable of absorbing or adsorbing water. Providing heat to the device leads to the desorption of water from the sorbent. The water steam can then be recovered in the second chamber, where it is separated from the sorbent. In this second chamber, water changes phase and pressure by condensation while  
10 condensation heat is rejected. When heat release is required, the condensed water is contacted with the salt again, which entails heat rejection.

Alternatively, the sorbent can be a zeolite, a silicon gel or a metal hydride, the material which can be absorbed or adsorbed by said sorbent then being H<sub>2</sub>.

15 Such a device is advantageous in that it has a high heat storage capacity and further allows a longer storage period. Moreover, this device has a good performance under steady state conditions. Furthermore, no insulation of the unit is necessary.

It has to be noted that the arrangement of the heat storage device 20 of Figure 1 is schematic and meant to illustrate the invention in a  
20 general way, and shall not be considered as limitative.

Thus, in the implementation shown in Figure 1, the heat storage device 20 is arranged on the main line 21 of the waste heat recovery system 10, i.e. the line in which the working fluid is successively pumped,  
25 heated and expanded. However, the heat storage device 20 could be arranged in a derivation line, so as to be by-passed when needed.

Besides, the heat storage device 20 is shown as being arranged downstream from the heat exchanger 11. However, it could be arranged in parallel with the heat exchanger 11, this implementation being advantageous in  
30 that the heat storage device 20 could thus be used as a further heat exchanger for heating/evaporating the working fluid.

The heat recovery system may further comprise an expansion valve 33 arranged in parallel with the expander 12 in an expander by-pass line 34 which can branch from the main line 21 of the waste heat recovery  
35 system 10 downstream from the heat storage device 20. A valve 35 is arranged at the connecting point between the main line 21 and the expander by-pass

line 34, or in the by-pass line itself, to control the flow of working fluid in said expander by-pass line 34.

In practice, several implementations of the engine arrangement 1 – and more specifically of the waste heat recovery system 10 – could be envisaged, in particular the three embodiments which will now be described with reference to Figures 2a to 5e. It has to be noted that, in the Figures, the heat source comprises the exhaust gases flowing from the engine 2 in the exhaust line 5. However, this implementation shall not be considered as limitative, and other heat sources produced by the engine operation could be used, alone or in combination, including EGR gases, engine oil, engine cooling fluid or any other heat carrying fluid of the engine arrangement. Besides, the waste heat recovery system 10 which is shown on Figures 2a to 5e can be a Brayton cycle, a partially illustrated Rankine cycle, or any other appropriate cycle.

Reference is first made to Figure 2a which shows a second embodiment of the invention.

In this embodiment, the heat exchanger 11 is arranged both on an exhaust derivation line 16 of the exhaust line 5 and on the main line 21 of the waste heat recovery system 10, meaning that it is designed to promote heat transfer between the fluids circulating respectively in the exhaust derivation line 16 and in the main line 21. A first valve 17 and a second valve 18 are arranged at the connecting points between the exhaust line 5 and the derivation line 16 so as to adjust the exhaust gases flow rate through the heat exchanger 11 according to the needs. A single valve arrangement could be provided, either at one of the connecting points or in the exhaust line 5.

Besides, the heat storage device 20 is arranged in a line of the waste heat recovery system 10 so as to be capable of storing heat indirectly from the heat source, by means of the working fluid heated by the heat source in the heat exchanger 11. More precisely, the heat storage device 20 is arranged on a derivation line 22 of the waste heat recovery system 10, downstream from the heat exchanger 11. A first three-way valve 23 and a second three-way valve 24 may be arranged at the connecting points between the main line and the derivation line, so that the sub flow rate of working fluid flowing through the heat storage device 20 may be varied compared to the whole working fluid flow rate in the main line 21, For example, the sub flow rate of working fluid flowing through the heat storage device 20 may be controlled

between 0% and 100% of the whole working fluid flow rate in the main line 21. The second valve 24 can also be used as the valve 35 at the connection point with the expander by-pass line 34. Alternatively, a single valve arrangement could be provided for directing the flow either in the main line 15 and/or in the derivation line 22, for example with a three way valve at either of the connecting points or with a two way throttle valve in the main line between the connecting points.

Therefore, the working fluid can flow through the heat storage device 20 when valve 23 allows it. The flow rate in the derivation line 22 can be the full flow rate of working fluid, or part of it, or can be null (the heat storage device 20 then being by-passed), depending on the needs and on the engine operating conditions.

Since the heat storage device is located in a derivation of the main line, it can be at least partially, preferably totally, by-passed by the working fluid under some operating conditions. Therefore, it is possible, for those operating conditions, to avoid at least partially, preferably totally, any interference of the heat storage device on the waste heat recovery cycle.

In concrete terms, the working fluid can be heated – or even evaporated – by the exhaust gases in the heat exchanger 11.

Depending on the engine arrangement operating conditions, heat storage can be activated or not, and the waste heat recovery system 10 can work or not, with the meaning that the waste heat recovery system 10 can effectively deliver mechanical work from its expander 12, or not.

Different operating phases of the arrangement of Figure 2a will now be described with reference to figures 2b – 2f. A cross drawn on a line means that no fluid can flow in said line.

If the waste heat recovery system 10 can work, part of the exhaust gases flows in the derivation line 16 of the exhaust line 5 through the heat exchanger 11, thereby evaporating the working fluid. The working fluid is subsequently expanded in the expander 12, thereby enabling energy recovery, before continuing the cycle until entering again the heat exchanger 11. The valve 24 is preferably set so that no working fluid flows in the expander by-pass line 34.

In case the heat storage device 20 has not reached its maximum heat storage capacity and the working fluid temperature or enthalpy at the heat exchanger outlet is high enough, especially higher than within the heat storage

device, the waste heat recovery system 10 may be operated as shown in figure 2b. In this operating phase, part of the working fluid may be directed to the derivation line 22 and may therefore flow through the heat storage device 20. As a result, the heat storage device 20 can store heat from the working fluid which has been previously heated by the exhaust gases in the heat exchanger 11. Thus, in this embodiment, the heat storage device 20 is capable of storing heat indirectly from the heat source, via at least one intermediate fluid, namely the working fluid. As the working fluid is cooled down when passing through the heat storage device 20, this operating phase can be used preferably if the working fluid temperature at the heat exchanger outlet is high enough, otherwise, the working fluid at the expander inlet may not have enough energy to ensure the expander 12 operates efficiently.

Alternatively, if the working fluid temperature at the heat exchanger outlet is too low to allow heat to be stored in the heat storage device 20, and if heat has been stored in the heat storage device 20, the waste heat recovery system 10 may be operated as shown in figure 2c. In this operating phase, all the working fluid flow can be directed towards the heat storage device 20. Thus, the working fluid recovers heat from both the heat exchanger 11 and, subsequently, the heat storage device 20, before it enters the expander 12.

In some cases, the heat storage device 20 has to be by-passed, as shown in figure 2d. This operating phase may be used for example if the exhaust gases temperature is not high enough to both heat the working fluid in the heat exchanger 11 and allow heat to be stored in the heat storage device 20. It can also be used if the heat storage 20 device has reached its maximum thermal capacity, or if the heat from the heat storage device 20 cannot be used, for example because it would lead to the working fluid being overheated.

If the waste heat recovery system 10 cannot work, for example for lack of available cooling power at the condenser 13, the expander 12 can be by-passed, all the working fluid, when circulating, flowing in the expander by-pass line 34 through the expansion valve 33.

If the heat storage 20 device has not reached its maximum capacity, the waste heat recovery system 10 may be operated as shown in figure 2e. In this operating phase, heat is recuperated from the exhaust gases by the working fluid in the heat exchanger 11 and, at least in part, transferred to the heat storage device 20 where the working fluid is ideally cooled down and condensates at high pressure. The working fluid is then redirected to the

reservoir 15 by passing the expansion valve 33 and the condenser 13 which can re-condensate the rest of the working fluid.

When the heat storage device 20 cannot store any additional heat, the waste heat recovery system 10 may be operated as shown in figure 2f: no  
5 exhaust gases flow through the heat exchanger 11, in order to avoid a further increase in the working fluid temperature; the heat storage device 20 is bypassed, and the pump is turned off.

Reference is now made to Figure 3 which shows a third embodiment of the invention.

10 The embodiment of Figure 3 is similar to the embodiment of Figure 2a, the exhaust line 5 being further provided with an additional derivation line 36 equipped with a first valve 37 and a second valve 38. In this second third embodiment, the heat storage device 20 is arranged both on the derivation line 22 of the waste heat recovery system 10 and on said additional  
15 derivation line 36 of the exhaust line 5. The heat storage device 20 can therefore store heat (i) directly from the heat source and/or (ii) indirectly from the previously heated working fluid, as explained with respect to the first embodiment.

Reference is now made to Figure 4a which shows a fourth  
20 embodiment of the invention.

In this embodiment also, the heat storage device 20 is arranged so as to be capable of storing heat indirectly from the heat source, via at least one intermediate fluid. Besides, the waste heat recovery system 10 is designed so that the working fluid can flow through the heat storage device 20. As a result,  
25 the heat storage device 20 can directly release heat to the working fluid.

The embodiment of Figure 4a differs from the embodiment of Figure 2a by essentially two features.

First of all, the heat storage device 20 is not arranged downstream from the heat exchanger 11 but in parallel with said heat exchanger 11. More  
30 precisely, the heat storage device 20 is arranged on derivation line 22 of the waste heat recovery system 10, with an upstream connecting point being located on the main line 21 between the pump 14 and the heat exchanger 11 and the downstream connecting point being located on the main line 21 between the heat exchanger 11 and the expander 12. In the shown  
35 embodiment, each connecting point is equipped with a respective three way valve 23, 24, but, as explained with respect to other embodiments, a single

valve arrangement could be provided for directing the flow either in the main line 15 and/or in the derivation line 22. The heat storage device 20 can act as an additional heat exchanger capable of heating – or evaporating – the working fluid in conjunction with the heat exchanger 11.

5           Moreover, in this fourth embodiment, the waste heat recovery system 10 further comprises a thermal loop 25 including the heat exchanger 11 and the heat storage device 20 and in which a thermal fluid flows, so that the heat storage device 20 is capable of storing heat indirectly from the heat source, by means of the thermal fluid heated by the heat source and/or the  
10           working fluid in the heat exchanger 11.

          Also, since the heat storage device is located in a derivation of the main line, it can be at least partially, preferably totally, by-passed by the working fluid under some operating conditions. Therefore, it is possible, for those operating conditions, to avoid at least partially, preferably totally, any  
15           interference of the heat storage device on the waste heat recovery cycle.

          In Figure 4a is also illustrated a by-pass line 39 of the heat exchanger 11 in which the working fluid can flow, said by-pass line 39 being equipped with a first valve 41 and a second valve 42.

          Different operating phases of the arrangement of Figure 4a will now  
20           be described with reference to figures 4b – 4d. A cross drawn on a line means that no fluid can flow in said line.

          If the waste heat recovery system 10 can work, part of the exhaust gases flows in the derivation line 16 of the exhaust line 5 through the heat exchanger 11, thereby evaporating the working fluid. The working fluid is  
25           subsequently expanded in the expander 12, thereby enabling energy recovery, before continuing the cycle until entering again the heat exchanger 11. The valve 24 ensures that no working fluid flows in the expander by-pass line 34.

          During the operating phase illustrated in Figure 4b, the working fluid is heated in the heat exchanger 11 by the exhaust gases and flow in the  
30           main line 21 to enable energy recovery in the expander 12. By means of the thermal loop 25, heat can be stored in the heat storage device 20. Furthermore, the heat stored in the heat storage device 20 can be transferred to the working fluid flowing in the derivation line 22.

          When heat from the heat storage device 20 cannot be recuperated,  
35           as shown in Figure 4c, no working fluid is made to flow in the derivation line 22. Heat can however still be transferred to the heat storage device 20 by means of

the thermal loop 25. Said heat is stored in the heat storage device and can be later retransmitted to the working fluid when possible and useful.

If the waste heat recovery system 10 cannot work, the expander 12 can be by-passed, in which case the working fluid, when circulating, flows in the expander by-pass line 34 through the expansion valve 33.

In the operating phase illustrated in Figure 4d, the thermal fluid can continue collecting heat from the exhaust gases and storing it in the heat storage device 20, which will subsequently release said heat to the working fluid. Furthermore, the heat exchanger 11 is by-passed, the working fluid thus being prevented from overheating.

When the heat storage device 20 cannot store any additional heat, the waste heat recovery system 10 is operated as shown in figure 4e: no exhaust gases flow through the heat exchanger 11, in order to avoid a further increase in the working fluid temperature. In the working fluid circuit, both the heat exchanger 11 and the heat storage device 20 are by-passed by the working fluid, and the thermal loop is not working either.

Finally, reference is made to Figure 5a which shows a fifth embodiment of the invention.

This fifth embodiment differs from the fourth embodiment in that there is not provided a thermal loop between the heat exchanger 11 and the heat storage device 20.

In this embodiment, where the heat source is constituted by a hot fluid flowing in a pipe, namely the hot exhaust gases flowing in the exhaust line 5, the heat storage device 20 is arranged in a derivation line 26 of said pipe 5 so as to be capable of directly storing heat from the heat source. This embodiment is advantageous in that it allows more heat to be stored in the heat storage device 20, insofar as the thermal energy contained in exhaust gases is higher than the thermal energy contained in the working fluid.

Valves 27 and 28 may be provided on said derivation line 26 in order to direct part of the exhaust gases towards the heat exchanger 11 and/or towards the heat storage device 20. As with previous embodiments, a single valve arrangement could be provided.

Different operating phases of the arrangement of Figure 5a will now be described with reference to figures 5b – 5d. A cross drawn on a line means that no fluid can flow in said line.

If the waste heat recovery system 10 can work, at least part of the exhaust gases can flow in the derivation line 16 of the exhaust line 5 through the heat exchanger 11, thereby evaporating the working fluid. The working fluid is subsequently expanded in the expander 12, thereby enabling energy recovery, before continuing the cycle until entering again the heat exchanger 11. A dedicated by-pass control valve ensures that no working fluid flows in the expander by-pass line 34.

In the operating conditions shown in Figure 5b, the exhaust gases flow through the heat exchanger 11, thereby heating and evaporating the working fluid passing through the heat exchanger 11. In addition, part of the working fluid may be controlled to pass through the heat storage device 20 and can either store heat in the heat storage device 20 or recover previously stored heat, depending on the operating conditions. No exhaust gases flow in the derivation line 26 of pipe 5, which means that, in this operating phase, the heat storage device 20 cannot directly store heat from the heat source. As the working fluid can flow through both the heat exchanger 11 and the heat storage device 20, it can thus be heated/evaporated at the same time by these two devices.

When the waste heat recovery system 10 can only partially be used, as shown in Figure 5c, a part of the exhaust gas may be controlled to pass through the boiler 11 and a part through the HSD, thereby storing heat. The working fluid flow only passes through the boiler 11.

If the waste heat recovery system 10 cannot work, the expander 12 is by-passed, all the working fluid, when circulating, flowing in the expander by-pass line 34 through the expansion valve 33.

In the operating phase illustrated in Figure 5d, no exhaust gas flow through the heat exchanger 11 to prevent overheating of the working fluid. However, the exhaust gases are directed towards the heat storage device 20 so that heat can be stored. The working fluid is not flowing in the heat storing device, but only through the heat exchanger 11.

When the heat storage device 20 has reached its maximum capacity, no exhaust gases is directed towards said heat storage device 20, as shown in figure 5e, to prevent overheating of the working fluid.

Generally speaking, whatever the embodiment of the invention, when the waste heat recovery system 10 cannot be used, or can only be partially used, because this would lead to an activation of the fan 9 or the fan 9

would not be able to provide enough cooling effect for both the engine 2 and the condenser 13 of the waste heat recovery system 10, then heat storage is activated.

The invention therefore makes it possible both to prevent the  
5 working fluid from overheating and to store heat even if the waste heat recovery system 10 is not working. The thermal energy of the heat source can thus be recovered even if it is not used immediately. Preferably, the invention provides a short or medium term energy storage device. Typically, it is contemplated that the heat storage device should be able to store an amount of  
10 energy enough to run the expander 12 during a period of time of at least 10 seconds, preferably of at least 30 seconds and most preferably of at least one minute.

Another advantage of the invention lies in the fact that the admission conditions of the expander 12 can be regulated even for very  
15 transient heat source conditions. Besides, the waste heat recovery system control can be more efficient.

The invention is of course not limited to the embodiments described above as examples or depicted in the appended Figures, but encompasses all technical equivalents and alternatives of the means described  
20 as well as combinations thereof. For example, while many heat exchangers in the Figures are shown as parallel flow heat exchangers, some or all of the exchangers could be of the cross-flow or counter-flow type.

## CLAIMS

1. An engine arrangement comprising:
  - an internal combustion engine (2);
  - 5 - a waste heat recovery system (10) in which a working fluid is successively pumped by a pump (14), heated in at least one heat exchanger (11) by means of a heat source produced by the engine operation, and expanded in an expander (12);characterized in that the waste heat recovery system (10) further  
10 comprises a heat storage device (20) which is arranged outside from the heat exchanger (11), downstream from the pump (14) and upstream from the expander (12), said heat storage device (20) comprising a heat storage material (30) which is in thermal contact with the working fluid (31) through a partition wall (32) and which is arranged so as to be capable of storing heat  
15 from the heat source and of releasing previously stored heat in order to heat the working fluid.
2. The engine arrangement according to claim 1, characterized in that the heat storage device (20) is arranged so as to be capable of storing  
20 heat directly from the heat source, without any intermediate heat transfer fluid.
3. The engine arrangement according to claim 1 or claim 2, characterized in that the heat storage device (20) is arranged so as to be capable of storing heat indirectly from the heat source, via at least one  
25 intermediate heat transfer fluid.
4. The engine arrangement according to any one of claims 1 to 3, characterized in that the waste heat recovery system (10) is designed so that the working fluid can flow through the heat storage device (20).  
30
5. The engine arrangement according to any one of claims 1 to 4, characterized in that the waste heat recovery system (10) comprises a main line (21) in which the working fluid is successively pumped, heated and expanded, and a derivation line (22) including the heat storage device (20).  
35

6. The engine arrangement according to claim 5, characterized in that the waste heat recovery system (10) comprises a one valve (23, 24) to control the sub flow rate of working fluid flowing through the heat storage device (20).

5

7. The engine arrangement according to any one of claims 1 to 6, characterized in that the heat storage device (20) is arranged downstream from the heat exchanger (11).

10

8. The engine arrangement according to any one of claims 1 to 6, characterized in that the heat storage device (20) is arranged in parallel with the heat exchanger (11).

9. The engine arrangement according to any one of claims 1 to 8, characterized in that the heat storage device (20) is arranged in a line of the waste heat recovery system (10) so as to be capable of storing heat indirectly from the heat source, by means of the working fluid heated by the heat source in the heat exchanger (11).

20

10. The engine arrangement according to any one of claims 1 to 9, characterized in that the waste heat recovery system (10) further comprises a thermal loop (25) including the heat exchanger (11) and the heat storage device (20) and in which a thermal fluid flows, so that the heat storage device (20) is capable of storing heat indirectly from the heat source, by means of the thermal fluid heated by the heat source and/or the working fluid in the heat exchanger (11).

25

11. The engine arrangement according to any one of claims 1 to 10, characterized in that the heat source is constituted by a hot fluid flowing in a pipe (5) and in that the heat storage device (20) is arranged in a derivation line (26) of said pipe (5) so as to be capable of directly storing heat from the heat source.

30

12. The engine arrangement according to any one of claims 1 to 11, characterized in that the heat source comprises the exhaust gases flowing from the engine (2) in an exhaust line (5).

35

13. The engine arrangement according to any one of claims 1 to 12, characterized in that the waste heat recovery system (10) is a Rankine cycle in which the working fluid flows in a loop, a condenser (13) being further  
5 provided between the expander (12) and the pump (14) by which the working fluid is pumped.

14. The engine arrangement according to any one of claims 1 to 13, characterized in that the heat storage device (20) comprises a container  
10 containing a heat storage material which does not undergo a phase change when heat is transferred from the heat source to said heat storage material or when said heat storage material transfers heat to the working fluid.

15. The engine arrangement according to any one of claims 1 to 14, characterized in that the heat storage device (20) comprises a container  
15 containing a phase-change material, i.e. a heat storage material which can undergo a phase change when heat is transferred from the heat source to said heat storage material or when said heat storage material transfers heat to the working fluid.

20

16. The engine arrangement according to any one of claims 1 to 15, characterized in that the heat storage device (20) comprises a unit including  
25 a sorbent and a gas or liquid which can be absorbed or adsorbed by said sorbent, the desorption being endothermic and the absorption or adsorption being exothermic.

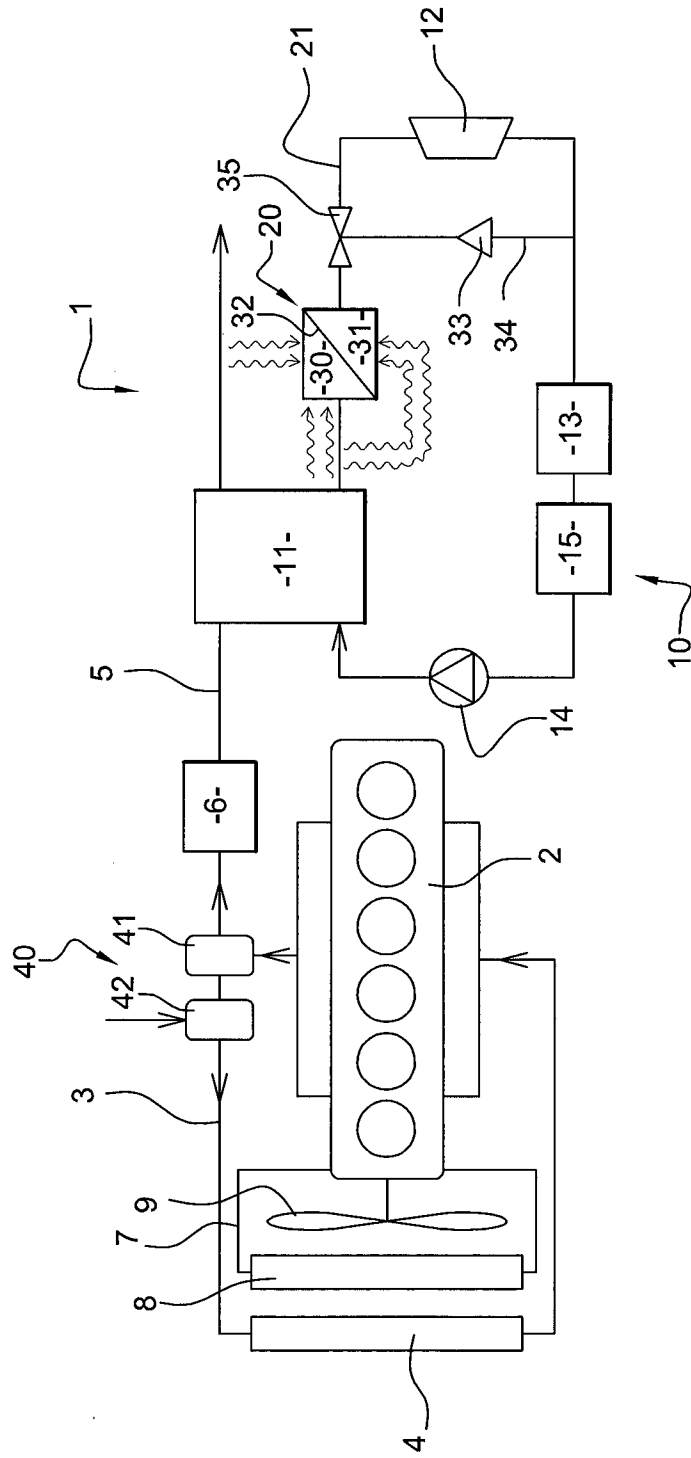


Fig. 1

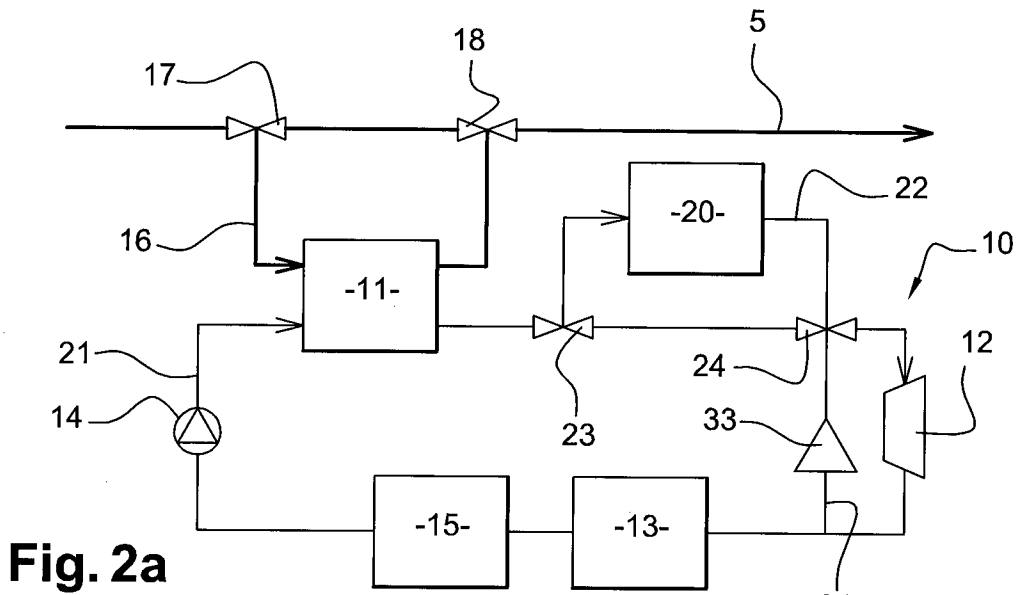


Fig. 2a

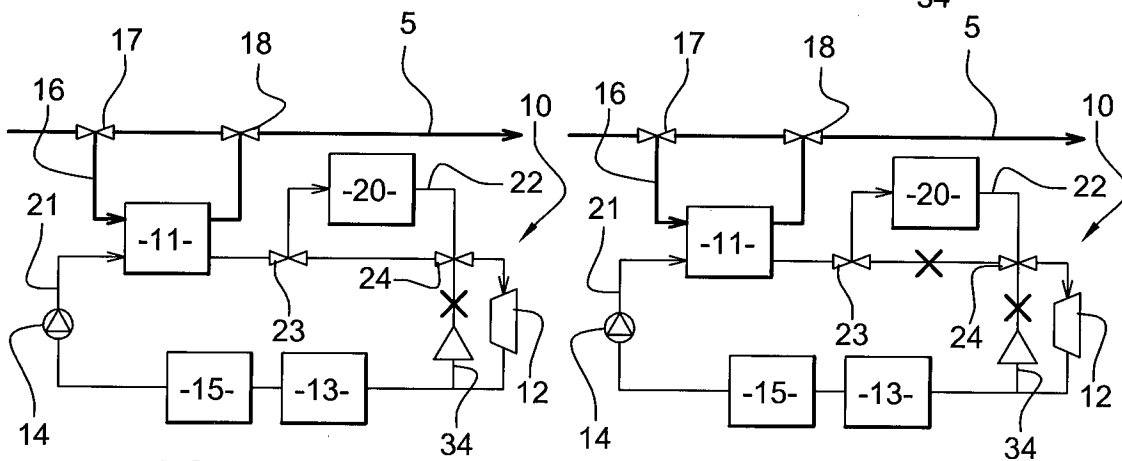


Fig. 2b

Fig. 2c

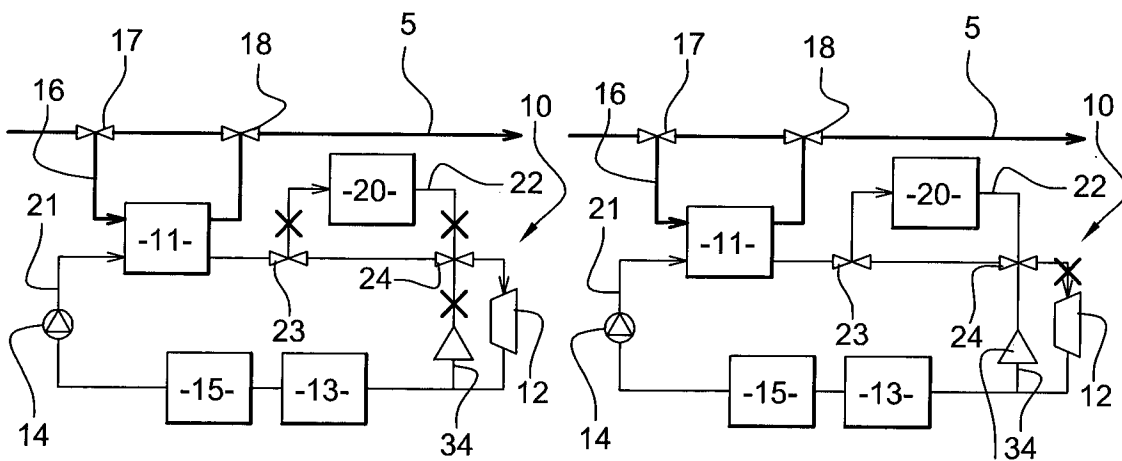
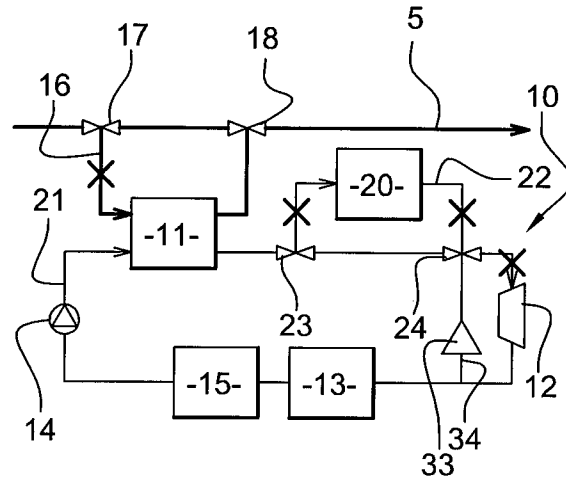
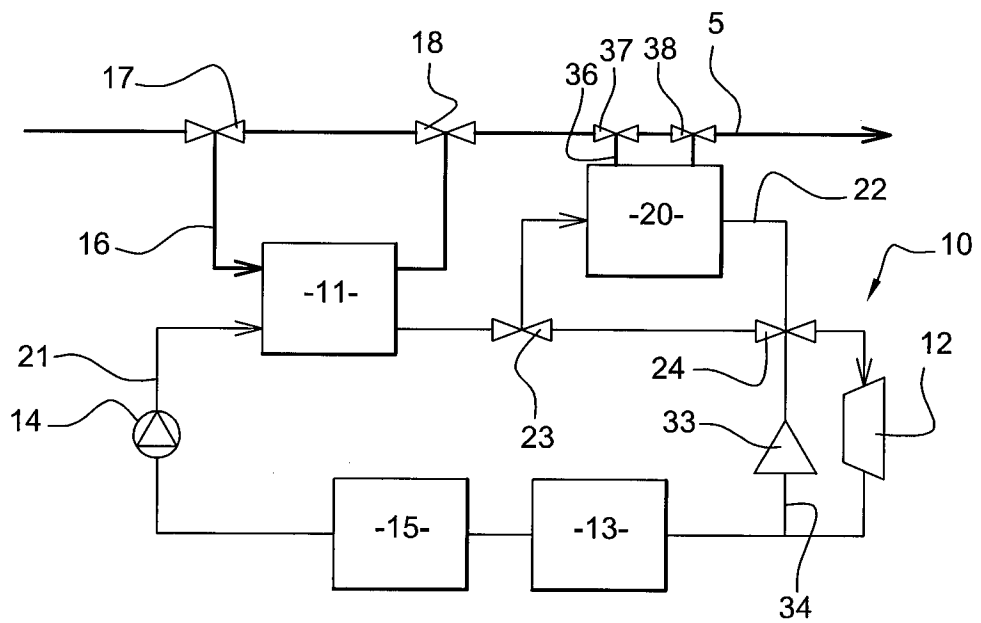


Fig. 2d

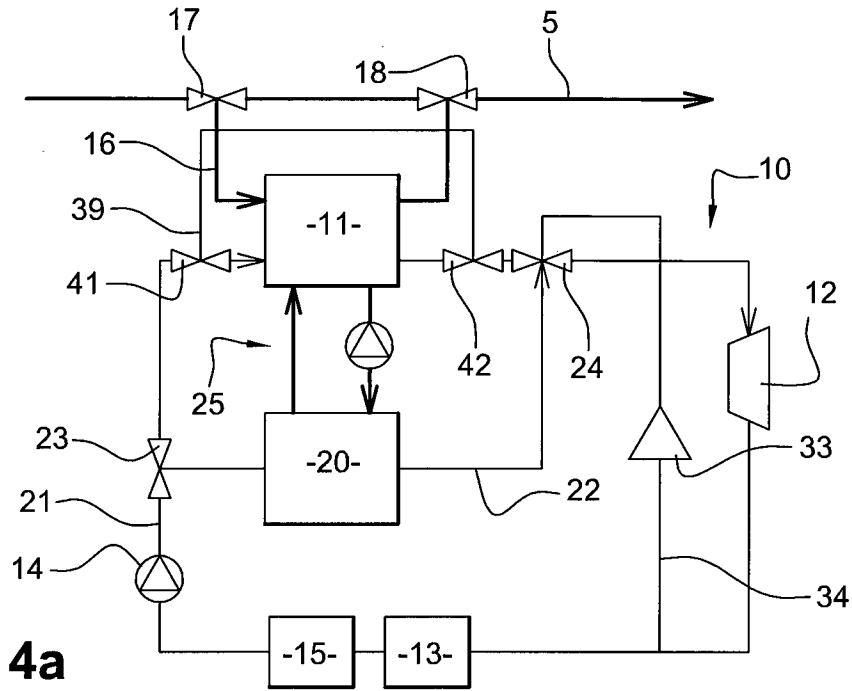
Fig. 2e



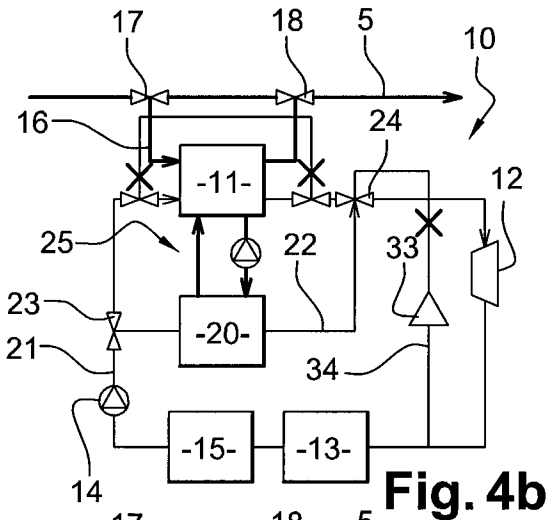
**Fig. 2f**



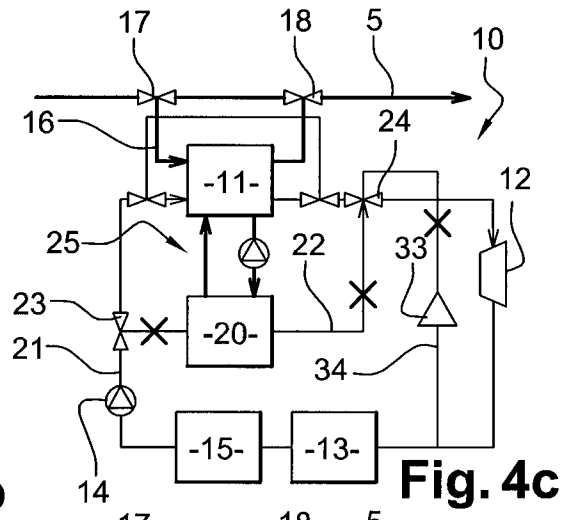
**Fig. 3**



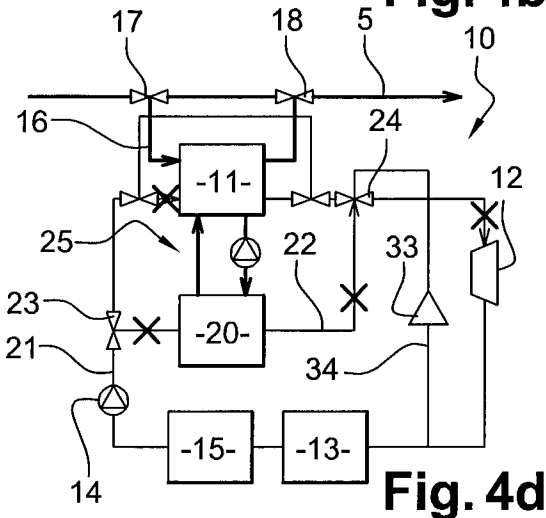
**Fig. 4a**



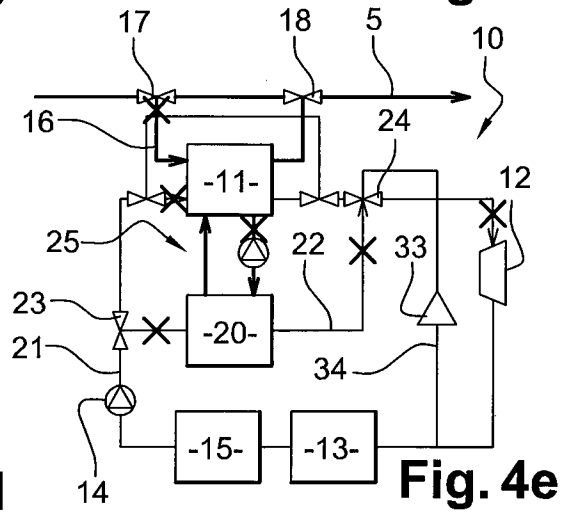
**Fig. 4b**



**Fig. 4c**



**Fig. 4d**



**Fig. 4e**

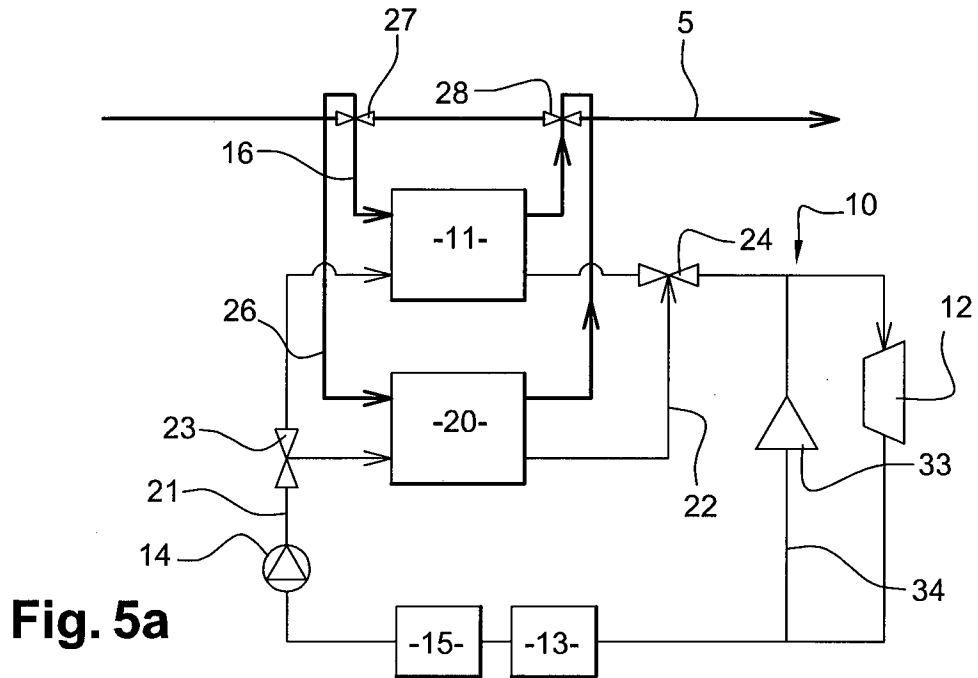


Fig. 5a

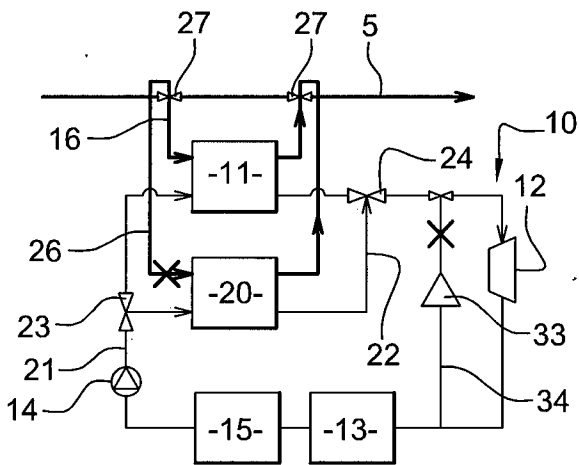


Fig. 5b

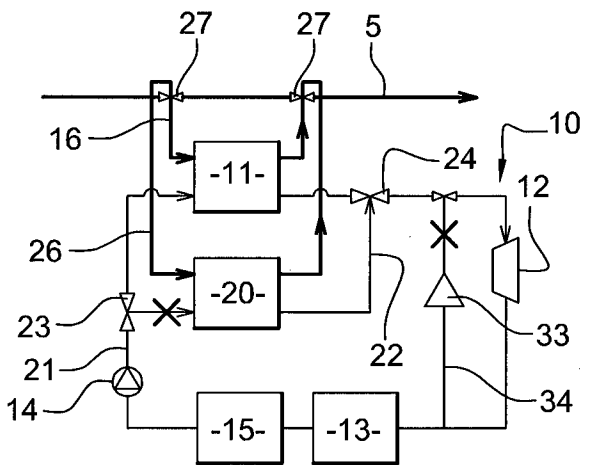


Fig. 5c

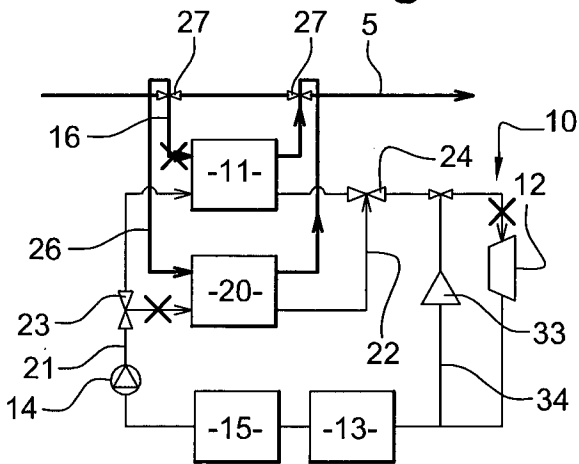


Fig. 5d

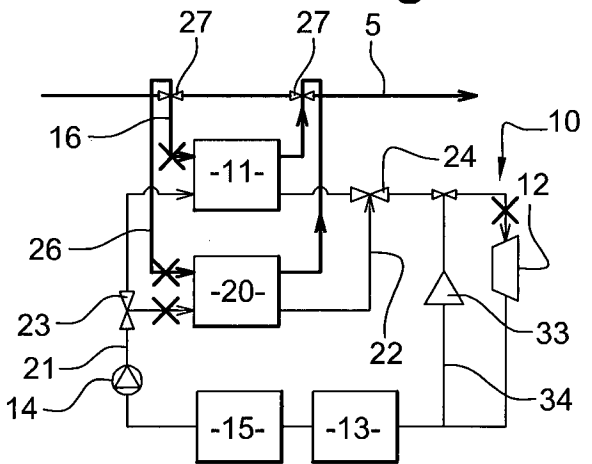


Fig. 5e

**INTERNATIONAL SEARCH REPORT**

International application No  
PCT/IB2012/003042

**A. CLASSIFICATION OF SUBJECT MATTER**  
 INV. F01N5/02 F01K23/06  
 ADD.

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

**B. FIELDS SEARCHED**  
 Minimum documentation searched (classification system followed by classification symbols)  
 F01N F01K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
 EPO-Internal, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2008/037980 A2 (UNIV SUSSEX [GB]; STOBART RICHARD KEITH [GB]; WEERASINGHE WEERASINGHE) 3 April 2008 (2008-04-03)	1,3-5, 7-10, 12-14
Y	page 25, line 20 - page 26, line 4; figure 1	2,6,11, 15,16
Y	----- DE 10 2004 052107 A1 (EBERSPAECHER J GMBH & CO [DE]) 4 May 2006 (2006-05-04)	2,6,11, 15,16
A	paragraphs [0021] - [0028]; figure 1	1
X	----- DE 10 2010 042401 A1 (BOSCH GMBH ROBERT [DE]) 19 April 2012 (2012-04-19)	1,3-9, 11-14
A	paragraphs [0024] - [0034]; figures 1,2	15,16
A	----- WO 2012/027688 A1 (MODINE MFG CO [US]; YIN JIANMIN [US]; STEINBACK ERIC P [US]) 1 March 2012 (2012-03-01)	1-7,9-14
	paragraphs [0032] - [0037]; figure 1	
	----- -/--	

Further documents are listed in the continuation of Box C.

See patent family annex.

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Date of the actual completion of the international search

7 August 2013

Date of mailing of the international search report

06/09/2013

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Authorized officer

Kolland, Ulrich

# INTERNATIONAL SEARCH REPORT

International application No  
PCT/IB2012/003042

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2012/061812 A2 (MACK TRUCKS [US]; GIBBLE JOHN [US]; MCLAUGHLIN SAMUEL [US]) 10 May 2012 (2012-05-10) paragraphs [0027] - [0038]; figure 2 -----	1

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No PCT/IB2012/003042
---

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2008037980 A2	03-04-2008	CA 2681492 A1 EP 2071931 A2 JP 2010504462 A US 2010146949 A1 WO 2008037980 A2	03-04-2008 24-06-2009 12-02-2010 17-06-2010 03-04-2008
-----			
DE 102004052107 A1	04-05-2006	NONE	
-----			
DE 102010042401 A1	19-04-2012	CN 103154442 A DE 102010042401 A1 US 2013192225 A1 WO 2012048959 A1	12-06-2013 19-04-2012 01-08-2013 19-04-2012
-----			
WO 2012027688 A1	01-03-2012	NONE	
-----			
WO 2012061812 A2	10-05-2012	CA 2816782 A1 WO 2012061812 A2	10-05-2012 10-05-2012
-----			