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(54) **METHOD OF TREATING GASOLINE EXHAUST GASES**

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(57) **ABSTRACT**

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A method of treating exhaust gases from a gasoline engine after cold-start using an exhaust gas aftertreatment system comprises adsorbing unburnt hydrocarbons (HC) from the engine exhaust gas with an HC trap, supplying heated ambient air to the exhaust gas stream downstream of the HC trap when the temperature of the HC trap is sufficient that trapped HC are desorbed therefrom and passing the air-enriched gas stream over a three-way catalyst (TWC). An exhaust gas aftertreatment system for a gasoline-fuelled engine (1) for performing the method according to the invention comprises a HC trap (5), a downstream secondary air injection point (8), means for supplying heated ambient air to the secondary air injection point (9), a TWC (7) downstream of the point of secondary air injection, and means in use for operating the heated air supply means when the temperature of the HC trap is sufficient that HC trapped thereon are desorbed therefrom.

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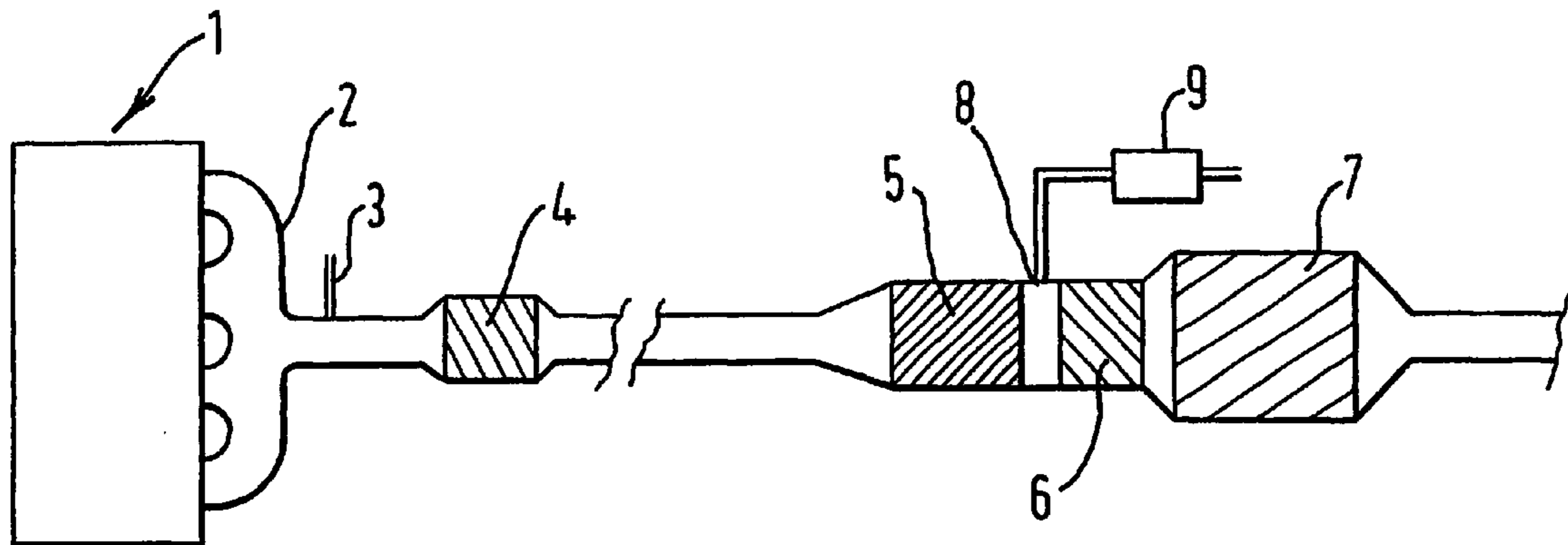
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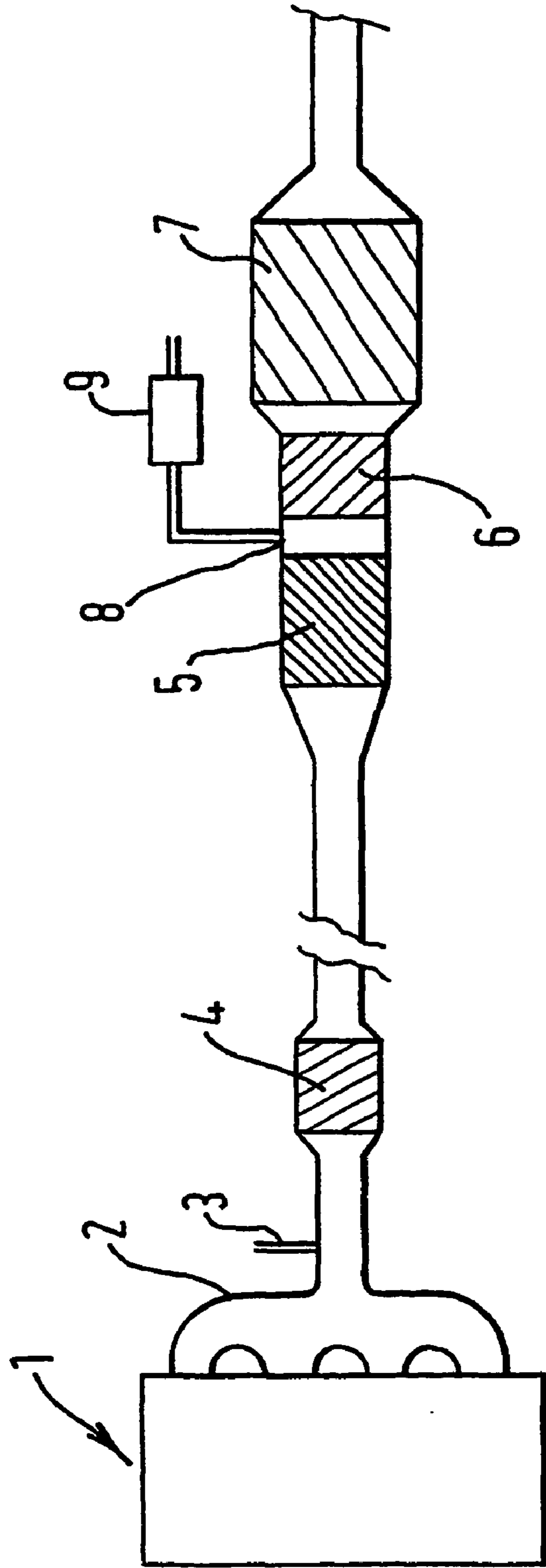


FIG.1

FIG.2

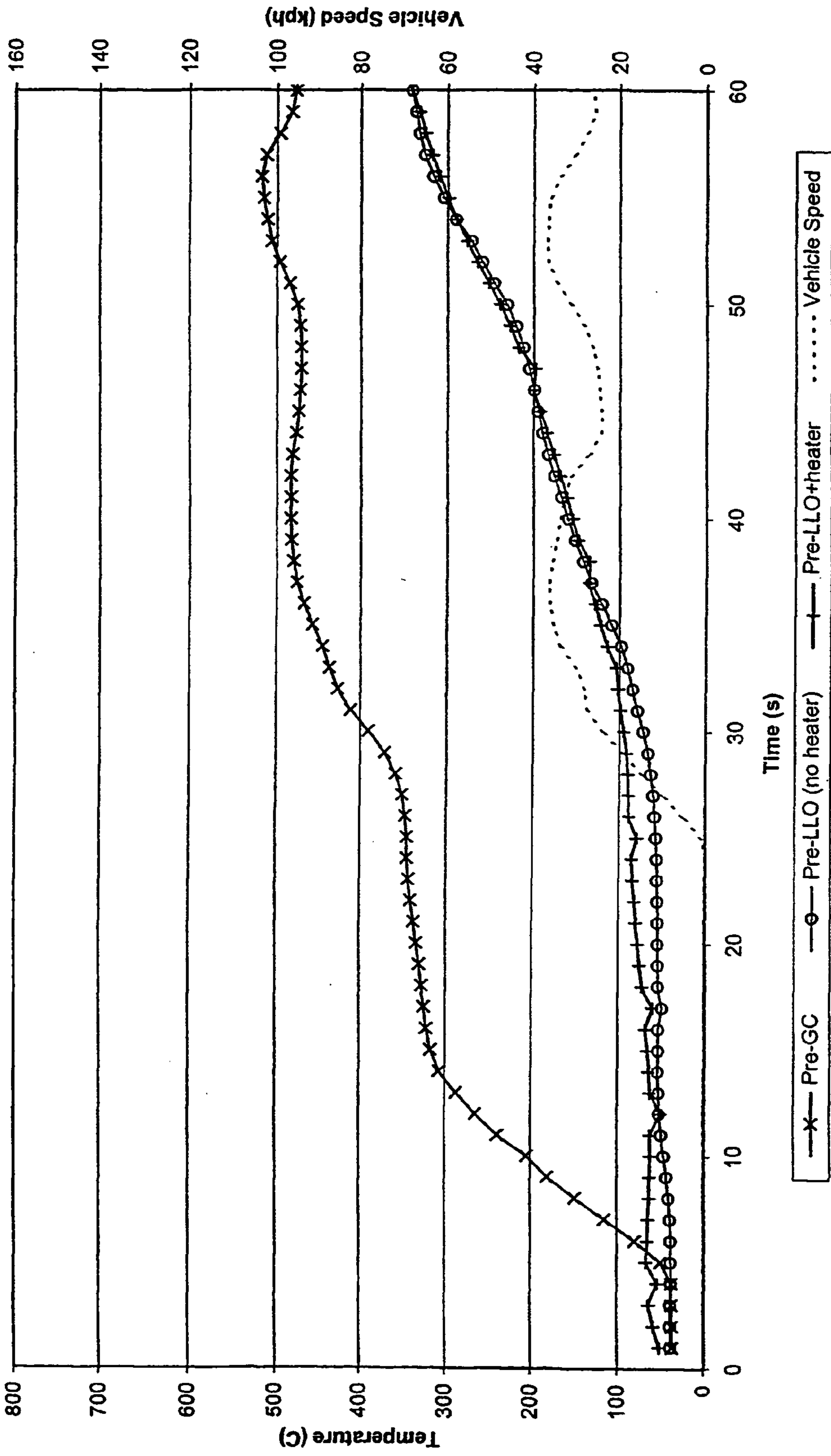
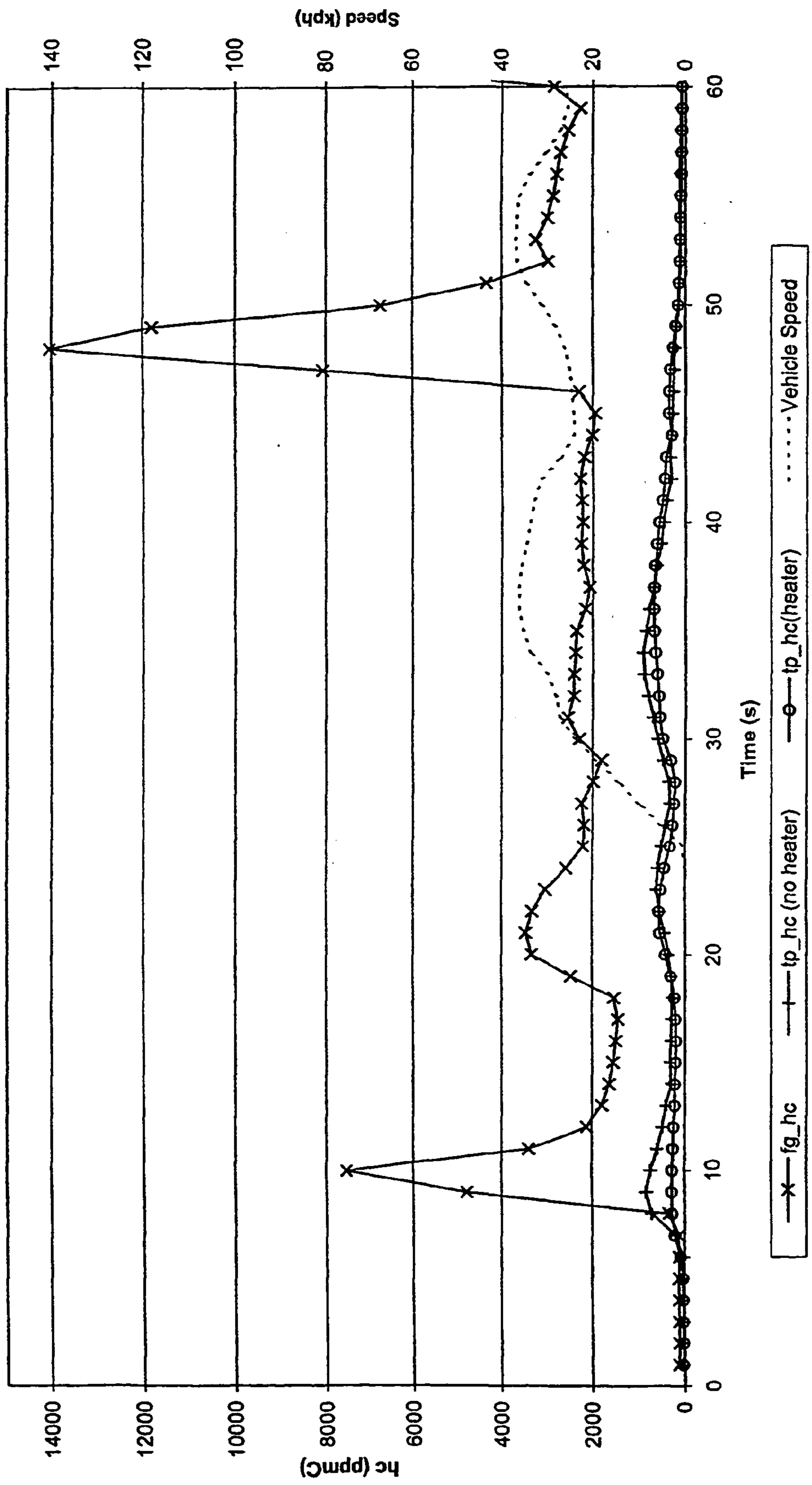


FIG.3



METHOD OF TREATING GASOLINE EXHAUST GASES

[0001] The present invention relates to a method of treating exhaust gases from a gasoline engine after cold-start using an exhaust gas aftertreatment system and more particularly to a method of operating an exhaust gas aftertreatment system comprising a hydrocarbon trap, a downstream secondary air injection point, means for supplying heated ambient air to the secondary air injection point and a three-way catalyst downstream of the point of secondary air injection.

[0002] The regulated emissions from gasoline-fuelled internal combustion engines are reduced by a variety of exhaust gas aftertreatment devices, including frequently, a hydrocarbon trap (e.g. effective to trap unburnt hydrocarbons ("HC") in the exhaust gas in a zeolite below a certain temperature, and desorb the HC above that temperature), and a three-way catalyst ("TWC") downstream of the trap. The TWC is effective, once it reaches the appropriate light-off temperature, to cause oxidation of HC, oxidation of CO and simultaneous reduction of NO_x to N₂. Known TWC's have a relatively high light-off temperature for HC oxidation, so the purpose of the HC trap is to delay the HC reaching the TWC until it has reached light-off temperature. This has not been wholly successful in many systems causing HC to pass through the TWC unreacted in the period immediately following start-up.

[0003] A variety of prior art methods have been suggested (and some, adopted) to assist the TWC to reach HC light-off temperature, including improved CO oxidation on the TWC thereby to use the exotherm to heat the catalyst to the HC light-off temperature, "EGI" (Exhaust Gas Ignition) and hydrogen-initiated light-off. Many systems use the addition of supplementary or secondary air into the exhaust gas downstream of the HC trap to provide improved oxidation conditions to speed TWC HC light-off.

[0004] Another system, is the Electrically Heated Catalyst ("EHC"), which can provide electric resistive heating to a catalyst in an exhaust gas treatment system. For example, the TWC can include an EHC to increase the temperature of the catalysts in order to achieve rapid HC light-off. However, in practice, EHC's have not been favoured by the automobile industry because they require too much power and this puts heavy demands on the vehicle battery. For example, if ambient temperatures fall below about 10° C. (and winter temperatures well below this are met with regularly in parts of Europe and North America), the battery may be incapable of providing the necessary power to heat the catalyst sufficiently, with the result that the EHC is switched off. Another reason why EHC's have not been widely adopted is that complicated heavy-duty connections to exhaust treatment components are required to cope with the high current. Furthermore, doubts have been raised about the durability of EHC's because they can be exposed to temperatures of about 1000° C., especially when there is a lot of exothermic reaction taking place on the TWC.

[0005] A prior art arrangement including secondary injection of heated air between an upstream HC trap and a downstream catalyst is described in WO 96/24756. In particular at FIG. 2C there is shown an HC trap 28 and a catalysts 30 comprising a catalyst composition effective at least for the conversion of HC, an air pump 32, an air

injection line 42' and an independently powered catalyst heating member 62. The catalyst-heating element 62 may comprise, for example, electric heating coils powered from the battery. From the above description it will be seen that this system suffers similar drawbacks to those of EHC's mentioned above.

[0006] An alternative to using battery power is described in U.S. Pat. No. 5,459,999. This discloses an exhaust gas cleaner system for an automotive internal combustion engine including an air introduction pipe for introducing secondary air, heated initially by a heater, to a catalytic converter unit mounted on the exhaust pipe. The document teaches that powering the heater from the engine alternator is undesirable because this puts a heavy load on the internal combustion engine which in turn leads to higher engine emissions.

[0007] We have now found that, very surprisingly, it is possible to obtain the benefit from heating the TWC with heated secondary air, without suffering from problems caused by excessive engine or battery load. In particular we have discovered that in one embodiment 1 hp, i.e. 750 W for about a minute is adequate to increase the temperature of the exhaust gas in an exhaust system by from 30 to 60° C.

[0008] According to one aspect, the invention provides a method of treating exhaust gases from a gasoline engine after cold-start using an exhaust gas aftertreatment system, which method comprising adsorbing unburnt hydrocarbons (HC) from the engine exhaust gas with an HC trap, supplying heated ambient air to the exhaust gas stream downstream of the HC trap when the temperature of the HC trap is sufficient that trapped HC are desorbed therefrom and passing the air-enriched gas stream over a three-way catalyst (TWC).

[0009] According to a second aspect the invention provides an exhaust gas aftertreatment system for a gasoline-fuelled engine, which system comprising a HC trap, a downstream secondary air injection point, means for supplying heated ambient air to the secondary air injection point, a TWC downstream of the point of secondary air injection, and means in use for operating the heated air supply means when the temperature of the HC trap is sufficient that HC trapped thereon are desorbed therefrom.

[0010] Suitably, the pre-heating means for the secondary air is a small electric resistance heater, which may provide from 500 to 1000 W of power. The actual form of the heater is not critical. Alternatives to electric heating may be used. Conveniently, only a relatively small temperature rise in the secondary air has been found to be necessary, sufficient to increase the reduced-HC gas stream temperature by about 30 to 60° C. The actual temperature and volume of the secondary air can be chosen by routine experiment, depending upon the actual engine, the specific aftertreatment system and, any specific low light-off catalyst.

[0011] It can readily be seen that according to the invention, the heating means is not included in the main exhaust system, with the result that it is not exposed to excessive temperatures and thus improved durability can be expected. Also, the invention requires only low quantities of power, with the result that electric heating is simple and inexpensive and can readily be incorporated without major redesign of the vehicle components. Such a heater unit can be compact and inexpensive and may be easily serviced or replaced.

[0012] Desirably, the heating means is controlled by a control system to switch on and off only when there is a requirement, as predetermined or, optionally, in response to sensed conditions.

[0013] An extremely significant feature of the present invention is that, unlike a "traditional" EHC concept, heating of the secondary air is not required before engine start-up. This completely removes the danger of discharging or damaging the battery and since power for heating is actually required only after engine start-up, the on-board generator (usually an alternator) is completely capable of providing adequate power. Thus, according to the invention, a preferred method of operation is to begin to supply heated secondary air only when the HC trap begins to desorb HCs; this will vary according to the engine and exhaust system design and characteristics, the engine start-up conditions as determined by the engine management unit and the size and characteristics of the trap material, and may be determined by routine experiment in each case. Generally, however, it can be expected that most benefits from the present invention may be obtained by beginning to supply heated secondary air about 10 sec. after cranking the engine, and terminating the supply up to about a minute after cranking. Of course, such secondary air, whether or not heated, may be supplied at other times during engine operation, for example in response to operating conditions.

[0014] Desirably, the exhaust gas aftertreatment system of the invention is used with a close-coupled gas conversion ("GC") catalyst in conjunction with a first secondary air injection, for example into the exhaust manifold itself. Such GC catalysts and air injection are themselves known, although it is preferred that the GC catalyst is a high loading Pt catalyst, e.g. 300 g/ft³ Pt, carried on a metallic substrate. The GC catalyst provides a first reduction of cold start emissions.

[0015] In a preferred embodiment, the TWC is preceded by a low-light-off catalyst which is conveniently a Pd containing catalyst carried on a metallic support. The low-light-off catalyst is suitably designed to exploit the chemical species generated by the GC catalyst, to light-off before there is any significant desorption of HC from the HC trap. For example, it may comprise 150 g/ft³Pd on a 600 cell per sq. (cpsi) in metallic substrate.

[0016] The TWC is suitably a conventional TWC. It may, for example, comprise a Pd/Rh catalyst carried at a loading of 150 g/ft³ on an 800 cells per sq. in metallic or ceramic substrate.

[0017] Desirably, the GC catalyst, low-light-off catalyst and TWC are supported on thin metal foil through-flow substrates. Suitable cell densities are in the range 400 to 1600 cpsi, preferably 600-1000 cpsi. These substrates, and the technology for coating the substrates with catalytic coatings, are themselves known.

[0018] Desirably, the engine management unit is adjusted or programmed to optimise the performance of the catalyst system according to the invention. Preferably, the engine includes a pre-catalyst HEGO (heated exhaust gas oxygen) sensor which feeds signals to the engine management unit to trim fuel supply, and preferably also includes an engine-out HEGO sensor located downstream of the first secondary air injection point.

[0019] Desirably, the system of the invention is optimised for the specific engine and exhaust system, and the engine management may suitably utilise a rich start strategy, for example to generate H₂ and/or CO to assist in early light-off. If necessary, H₂ output can be boosted by using a catalyst that promotes the water gas shift reaction. In general, it is recommended to use excess fuel upon start up, combined with secondary air addition into the exhaust manifold and with spark retard.

[0020] In general, an effort should be made to avoid heat loss from the exhaust gases to the ambient, and it is preferred to insulate the exhaust pipes.

[0021] The invention is more particularly described with reference to the following working example. Reference is made also to the accompanying drawings, in which

[0022] FIG. 1 is a schematic diagram of an engine and exhaust system according to the invention,

[0023] FIG. 2 is a chart of exhaust gas temperature at various points in the system, and

[0024] FIG. 3 is a chart of HC concentrations at various points.

[0025] Referring to FIG. 1, a modern 2-litre, 4-cylinder normally aspirated gasoline engine is shown generally by 1. The exhaust manifold, 2, has a first air injection point, 3, and a close-coupled GC catalyst, 4, mounted close to the manifold. The GC catalyst is in this example, a 0.6 litre volume metal support of 600 cells per sq. in ("cpsi") carrying 300 g/ft³ Pt catalyst. In the conventional underfloor position is mounted a conventional HC trap, 5, in close proximity to, and desirably in the same packaging or "can" as a low-light-off ("LLO") catalyst, 6, and a conventional TWC, 7. The HC trap is a 0.57 litre volume metal support of 400 cpsi cell density, carrying a conventional zeolite trap material. The LLO catalyst is a 0.3 litre volume support of 600 cpsi cell density and carrying 150 g/ft³ Pd catalyst. The TWC is a 0.96 litre volume metal support of 800 cpsi cell density, carrying 150 g/ft³ of a Pd/Rh catalyst. A second secondary air injection point, 8, is located between the HC trap and the inlet of the LLO catalyst. Ambient air is taken by a conventional air pump (not shown) and passed through a canister, 9, containing a 700 W wound-wire resistance controlled by the engine management unit (not shown) to start immediately upon engine start-up and to stop once light-off of the TWC has been achieved. Suitably air flow rates for the heated secondary air are of the order of 30 litres per min, for this engine. Conventional silencers etc. (not shown) may be attached to the exhaust pipe, downstream of the catalyst system, as required.

[0026] The engine was operated according to the US Federal FTP75 drive cycle. Reference is made to FIGS. 2 and 3 and especially the plots showing values without the secondary air heater operating. The rapid heating strategy causes a peak in engine-out hydrocarbons. The GC catalyst lights off in ten seconds and this causes a rapid decrease in the pre-HC trap HC concentrations. The HC trap itself absorbs most of the HC emissions during this time and hence the concentrations at the tail pipe are very low. The low-light-off catalyst also starts to operate early in the drive cycle, but the increase in tail pip HC emissions show that some slippage occurring as the HC trap desorbs accumulated HC. This is due to the higher exhaust gas flow rates

occurring in this section of the drive cycle, which stretches the performance of the low-light-off catalyst.

[0027] Reference is now made to the plots on **FIG. 3** showing values for HC concentration both with and without the secondary air heater operational. In the key to the plots, fg-hc refers to engine-out hydrocarbons (ppmC); tp-hc (no heater) and tp-hc (heater) refer to tailpipe hydrocarbons without the secondary air heater operating, and with the secondary heater operating, respectively. The most dramatic effect is during the peak in post-trap levels that occurs 10 seconds into the drive cycle, where the use of the heater assists the achievement of light-off of the low-light-off catalyst, greatly reducing tail pipe emissions. A smaller benefit is observed during the HC trap desorption peak at about 20 seconds. These two reductions are sufficient to reduce the tail pipe non-methane HC emissions from 0.011 g/mile to 0.008 g/mile, which achieves the SULEV (Super Ultra Low Emission Vehicle) standard.

[0028] It should be appreciated that the invention may be carried out in other ways than those specifically described above, whilst still retaining the benefits of the invention.

1. A method of operating a gasoline-fuelled engine having exhaust gas treatment including a cold-start procedure comprising the steps of: (i) cranking the engine to self-propulsion; (ii) removing hydrocarbon (HC) adsorptively from the cool exhaust gas produced during initial self-propulsion; (iii) when, after initial self-propulsion, desorption of HC-begins, supplying hot air to the gas containing desorbed HC, whereby to heat the gas to a temperature at which a downstream three-way catalyst (TWC) will be active, and continuing the hot air supply until HC has become substantially desorbed; and (iv) feeding the resulting air-containing gas to a TWC, characterised by injecting air additionally into the exhaust gas shortly after leaving the engine and reacting the resulting mixture over a gas conversion catalyst; and between steps (iii) and (iv) contacting the gas with a low-light-off oxidation catalyst.

2. A method according to claim 1, wherein the supply of heated air is sufficient to increase the temperature of the exhaust gases contacting the TWC by from 30 to 600° C.

3. A method according to claim 1 or 2, further comprising stopping the supply of heated air when the TWC is at or above HC light-off temperature.

4. A method according to any preceding claim, further comprising beginning step (iii) about 10 seconds after cranking.

5. A method according to any preceding claim, further comprising ending step (iii) at up to one minute after cranking.

6. A method according to any preceding claim, further comprising starting the engine with excess fuel and spark retard and making the additional air injection into the engine exhaust manifold.

7. A method according to any one of the preceding claims wherein at least one of the catalysts and adsorbent is/are supported on a thin metal foil flowthrough substrate having cell density in the range 400-1600 cells per square inch (62-248 cells cm⁻²).

8. A method according to any preceding claim, wherein the oxidation catalyst comprises palladium.

9. A method according to any preceding claim, wherein the hot air is provided by way of an electric resistance heater powered by an engine alternator.

10. A method according to claim 9 under the control of engine management excluding, at the time of supplying hot air, feed of electricity to heavy current users such as a battery, air-conditioning, screen-heater and ventilation air blower.

11. An exhaust system for a gasoline-fuelled engine, which system comprising, in order: adsorptive trap means capable of removing HC from the gas; means for hot air injection downstream of the trap; and a TWC and having engine management programmed for a cold start procedure comprising (i) cranking the engine to self-propulsion; (ii) removing HC adsorptively from the cool exhaust gas produced during initial self-propulsion; (iii) when, after initial self-propulsion, desorption of HC takes place, supplying hot air by way of the air injection means, whereby to heat the gas to a temperature at which the TWC will be active, and continuing the hot air supply until HC has become substantially desorbed; and (iv) feeding the resulting air-containing gas to the TWC, wherein means for additional air injection into the exhaust gas shortly after leaving the engine and reaction of the mixture consisting of the gas and the additional injected air over a gas conversion catalyst; and a low-light-off oxidation catalyst between air-injection point (iii) and the TWC.

12. A system according to claim 11, wherein the means for operating the heated air supply is operably associated with means for sensing the temperature of the HC trap and/or the TWC.

13. A system according to claim 11 or 12, wherein the means for operating the heated air supply stops the supply of heated air when it is determined that the TWC is at or above HC light-off temperature.

14. A system according to any of claims 11 to 13, including control means for beginning step (iii) about 10 seconds after cranking.

15. A system according to any of claims 11 to 14, including control means for ending step (iii) at up to one minute after cranking.

16. A system according to any of claims 11 to 15, including control means for starting the engine with excess fuel and spark retard and making the additional air injection into the engine exhaust manifold.

17. A system according to any of claims 11 to 16, wherein at least one of the catalysts and adsorbent is/are supported on a thin metal foil flowthrough substrate having cell density in the range 400-1600 cpsi.

18. A system according to any of claims 11 to 17, wherein the oxidation catalyst comprises palladium.

19. A system according to any-of claims 11 to 18, wherein the hot air is provided by way of an electric resistance heater powered by an engine alternator.

20. A system according to claim 19, wherein the heater capacity is from 500 to 1000 W.

21. A system according to claim 19 or 20 under the control of engine management excluding, at the time of supplying hot air, feed of electricity to heavy current users such as a battery, air-conditioning, screen-heater and ventilation air blower.

22. An engine including an exhaust gas treatment system according to any of claims 11 to 21.