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(54) **EXHAUST GAS AFTER TREATMENT SYSTEM FOR A DIESEL CYCLE INTERNAL COMBUSTION ENGINE**

(57) An exhaust gas after treatment system (ATS) for a diesel cycle internal combustion engine (E) has a first and a second particulate filter (F1,F2) arranged in series along an exhaust line (EP), which channels exhaust gas from the engine (E) to an external environment;

the first particulate filter (F1) is a soot filter, and the second particulate filter (F2) is an ash filter, which is arranged downstream of the soot filter, considering the exhaust gas direction in the exhaust line (EP), and is suitable to be serviced to allow for removal of collected ash.

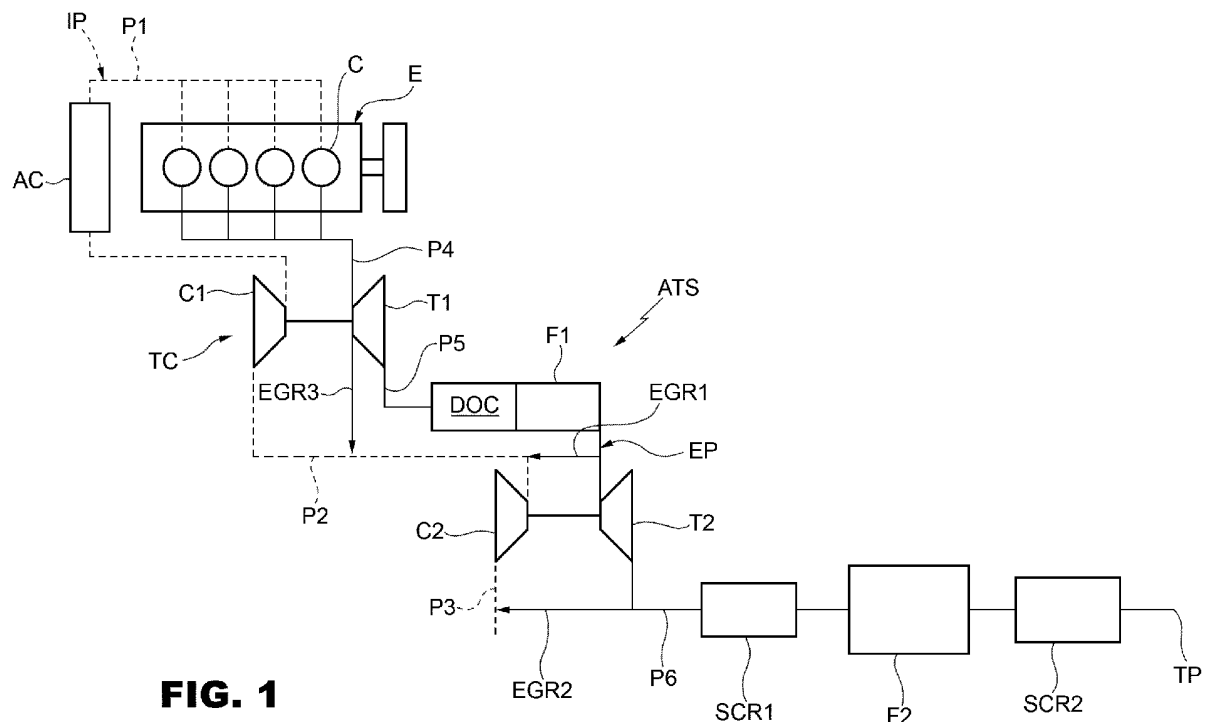


FIG. 1

Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This patent application claims priority from Italian patent application no. 102019000014304 filed on 07/08/2019.

Field of the invention

[0002] The present invention relates to an exhaust gas after treatment system for a diesel cycle internal combustion engine.

Description of the prior art

[0003] As it is known, an after treatment system (ATS) receives the exhaust gas from an internal combustion engine and, according to the implemented cycle in such engine, e.g. a gasoline or diesel cycle, it comprises a number of devices to reduce/eliminate pollutants contained in the exhaust gas, such as NO_x, HC, particulate, etc.

[0004] In particular, EGR is a strategy consisting in recirculating exhaust gas in order to limit NO_x production.

[0005] In the meantime, in the field of diesel cycle engines, the ATS is usually provided with one filter, e.g. a Diesel particulate filter (DPF), so as to trap and collect the particulate contained in the exhaust gas. The particulate mainly includes soot, i.e. particles derived by incomplete combustion of hydrocarbons. Soot filters are usually regenerated so as to automatically convert the accumulated soot. The regeneration is carried out either passively (at normal operating temperatures by NO₂, e.g. 200-550 °C) or actively (by generating additional heat in case of predetermined operating conditions, so as to reach relatively high temperatures, e.g. 550-650 °C, and also by O₂).

[0006] Preferably, techniques usually called as "forced passive regeneration" can be implemented: passive regeneration is assisted by adjustment of the higher exhaust gas temperatures thanks to management of the engine combustion.

[0007] During regeneration, the collected soot is burnt off in the filter, by oxidation by NO₂ and O₂. Filters are usually combined with a catalytic coating, so as to lower the activation temperature of such oxidation and therefore promote regeneration.

[0008] In addition, filters and NO_x catalyst can be implemented together with EGR lines.

[0009] In this field, a need is felt to provide an early NO_x oxidation and early soot filtering along the exhaust line of the ATS, in particular for improving the regeneration capability and for protecting a possible downstream EGR line from soot particulate, in order to avoid engine corrosion and wear due at the engine intake because of this EGR line.

[0010] A further need is felt to provide filters having a

small size, so as to use the after treatment system ATS in restricted spaces, but without compromising the high level of efficiency requested during particulate treatment.

[0011] An aim of the present invention is to satisfy the above mentioned needs.

Summary of the invention

[0012] The aforementioned aim is reached by an exhaust gas after treatment system for a diesel cycle internal combustion engine, as defined in the appended set of claims.

[0013] The main principle of the invention is to provide an after treatment system wherein the particulate filtering function in the after treatment system is split into two filters, i.e. in a first filter defined by a soot filter and in a second filter arranged downstream of the first filter and defined by an ash collection filter, wherein this second filter can be serviced so as to periodically remove the collected ash.

[0014] Preferably, the after treatment system is associated with a one-stage or a two-stage turbocharging system to compress air supplied to the internal combustion engine, wherein the first soot filter is arranged upstream of a turbine of such turbocharging system, so as to operate at higher pressures and higher temperatures, and the second filter is arranged downstream of the turbine, or turbines, of the turbocharged system.

Brief description of the drawings

[0015] For a better understanding of the present invention, a preferred embodiment is described in the following, by way of a non-limiting example, and with reference to the attached drawings, in which

- figure 1 diagrammatically shows an exhaust gas after treatment system for a diesel cycle internal combustion engine according to the present invention; and
- figure 2 shows an exemplary diagram about the filtration efficiency of some kinds of filters during use.

Detailed description of the preferred embodiment

[0016] In figure 1, the acronym ATS indicate, as a whole, an exhaust gas after treatment system, for a diesel cycle internal combustion engine E, preferably a four-stroke type engine.

[0017] Engine E comprises a plurality of cylinders C, which communicate with an intake line IP through respective intake valves (not shown) for receiving an air flow, in particular a flow of compressed air. The air aspirated by, or compressed into, the cylinders C is mixed with Diesel fuel, dosed into such cylinders C by respective injectors (not shown). In the meantime, the cylinders C communicate with the system ATS through respective exhaust valves (not shown) .

[0018] The system ATS delivers the exhaust gas into the external environment and is designed to reduce the pollutants contained in the exhaust gas.

[0019] Preferably, the air flow in the intake line IP is compressed by means of a turbocharging system, in particular a two-stage turbocharging system TC. System TC comprises two compressors C1 and C2 arranged in series along the intake line IP to compress the air supplied to the cylinders C, and two turbines T1 and T2 arranged along an exhaust line EP of the system ATS and coupled respectively to the compressors C1 and C2, e.g. by respective shafts, to operate such compressors C1 and C2. According to figure 1, the compressor C1 is arranged downstream of the compressor C2, considering the air flow direction in the intake line IP; and the turbine T1 is arranged upstream of the turbine T2, considering the exhaust gas direction in the exhaust line EP.

[0020] According to a variant, not shown, a one-stage turbocharging system is provided, i.e. with a single compressor arranged along the intake line IP and a single turbine arranged along the exhaust line EP.

[0021] According to another variant, at least one of the turbines T1 and T2 operates an electric generator, so as to supply electric energy to a motor that, in turn, is controlled to operate the corresponding compressor.

[0022] As shown in figure 1, the intake line IP comprises a portion P1, which is connected to an outlet port of the compressor C1 to direct the compressed air flow towards the intake valves and is, therefore, at a high pressure. An intercooler or air cooler AC is preferably provided along portion P1. The intake line IP further comprises a portion P2, which connects an outlet port of the compressor C2 to an inlet port of the compressors C1 and, therefore, is at an intermediate pressure; and a portion P3, which is connected to an inlet port of the compressor C2 and receives air from the external environment.

[0023] In the meantime, the exhaust line EP comprises: a portion P4, which is connected to an inlet port of the turbine T1 and is, therefore, at high pressure and temperature; a portion P5, which connects an outlet port of the turbine T1 to an inlet port of the turbine T2 and, therefore, is at intermediate pressure and temperature; and a portion P6, which is connected to an outlet port of the turbine T2 and channels the exhaust gas from the turbine T2 to an exhaust tail pipe TP, discharging the exhaust gas into an external environment.

[0024] The exhaust line EP preferably also comprises a muffler or silencer, not shown.

[0025] Preferably, an EGR system is provided so as to recirculate a part of the exhaust gas from the exhaust line EP into the intake line IP, e.g. under the control of valves and/or devices that are not shown and are generally known in the art. Preferably, the EGR system comprises a recirculation line EGR1 connecting the portion P5 to the portion P2 and a recirculation line EGR2 connecting the portion P6 to the portion P3, to draw respective flows of exhaust gas from the exhaust line EP. According to a variant, not shown, only one of the recircu-

lation lines EGR1 and EGR2 is provided. More preferably, the EGR system further comprises an additional recirculation line EGR3 connecting the portion P4 (or the inlet port of the turbine T1) to the portion P2, to draw an additional flow of exhaust gas from the exhaust line EP.

[0026] The EGR system may optionally comprise one or more coolers (not shown) to cool the exhaust gas flow or flows drawn from the exhaust line EP, before mixing such flows with the air in the intake line IP.

[0027] According to an aspect of the present invention, the system ATS comprises a filter F1 configured to trap and collect soot from the exhaust gas flowing along the exhaust line EP, and to let the ash flowing downstream of the filter F1. In other words, the porosity and/or the dimensions of the pores in the filter F1 are sufficient to trap most of the soot, but they are too high to trap and collect nanoparticles, as ash.

[0028] Preferably, filter F1 is arranged upstream of at least one of the turbines T1 and T2 (considering the exhaust gas direction), so as to be relatively near to the engine E. In other words, the filter F1 operates at higher pressures and higher temperatures, for a more efficient regeneration (indeed, higher temperatures and pressure improve the passive regeneration capability). Therefore, materials (ceramic or metallic) of the filter F1 need to be chosen on the basis of such temperatures and pressures.

[0029] In particular, the filter F1 is arranged along portion P5, i.e. between the turbines T1 and T2. More preferably, the line EGR1 starts from a point that is arranged downstream of the filter F1, so that the exhaust gas drawn and recirculated by the lines EGR1 and EGR 2 is already filtered from soot, in order to protect the engine.

[0030] Preferably, filter F1 is regenerated only passively, i.e. active regeneration of the soot is not provided in the system ATS and in the engine E.

[0031] In particular, the filter F1 is associated with a catalyst to promote oxidation of NO_x and, therefore, to lower the activation temperature of the regeneration in the filter F1. This arrangement also enables an early NO_x oxidation along the system ATS.

[0032] More in particular, such catalyst can be defined by catalytic material directly in the filter F1, e.g. the filtering walls of the filter F1 are manufactured so as to include such catalytic material. By way of example, filter F1 is defined by a so-called catalyzed soot filter (CSF).

[0033] In combination or as an alternative, the catalyst can be defined by a dedicated catalytic converter, e.g. a so-called Diesel oxidation catalyst (DOC), arranged upstream of the filter F1. The DOC has the task to oxidize hydrocarbons and to generate NO₂, for both NO_x-reduction (fast reaction) and passive soot oxidation in the filter. In this approach, the main aim can be filtering the exhaust gas for the EGR. Therefore, a DOC/filter combination could be preferred.

[0034] In any case, any kind of soot filter can be chosen as filter F1, among the ones available on the market.

[0035] At present, the soot filters (bare or catalyzed) usually have a mean pore size between 15 and 20 mi-

crons and wall thicknesses of about 10 milli-inch. By way of example, substrate materials are SiC or Cordierite. Cell densities are between 300 and 400 cpsi (cells per square inch), and preferably are partially asymmetric to increase ash capacity.

[0036] Advantageously, the filter F1 could be designed in a specialized manner, so as to oxidize soot and HC in a manner not to pollute the engine intake system and not to cause cylinder wear, at minimum backpressure losses and soot regeneration requirements. This allows a certain ash migration downstream, relatively low pressure losses and relatively high filtration efficiency.

[0037] According to another aspect of the present invention, the system ATS further comprises a filter F2, which is arranged downstream of the filter F1 (considering the exhaust gas direction) and is configured to trap and collect ash. In other words, the porosity and/or the dimensions of the pores in the filter F2 are enough small to trap and collect ash and other nanoparticles. In the meantime, the filter F2 is configured so as to be serviced, in order to allow maintenance personnel for periodically removing the collected ash from the system ATS. By way of example, the filter F2 is temporarily removed from the exhaust line EP by such personnel and is treated in a known manner so as to discharge and dispose the ash.

[0038] Also this kind of filter can be chosen from the ones commonly available on the market.

[0039] Advantageously, this downstream filter F2 could be designed in a specialized manner, to better comply with requirements about ash retaining (and ash cleaning service) and about reduction of emissions of nanoparticles, to fulfil requirements of PN emissions down to 10 nm.

[0040] In other words, the filter F2 allows for reaching a layout achieving very high filtration efficiency, so as to reduce PN (particle number) also for particle size in the range between 10 and 23 nm (and not only higher than 23 nm).

[0041] According to a preferred embodiment, the filter F1 is designed to be dedicated to trap as much soot as possible, flowing out from the combustion engine E, and to leave nanoparticles (e.g. ash) flowing through the filter F1, as much as possible. In this regard, an appropriate filtration efficiency can be chosen for the filter F1 to reach this desired dedicated design. In particular, the filtration efficiency of the filter F1 is chosen so as to be preferably between 95% and 99%. The right values of filtration efficiency can be chosen in view of appropriate tests, to be carried out on the basis of different engines, different filtering technologies, etc.

[0042] In this contest, the word "soot" is considered, in more general terms, to define solid particles in the exhaust gas having size above 23 nm (e.g. up to 10 μm). In the meantime, the word "ash" is meant to define solid particles having size between 10 and 23 nm, as mentioned above, that is within the range of the nanoparticles according to the general classification given to Diesel Exhaust Particle Sizes (<https://dieselnet.com/tech/dpm>

[size.php](#)).

[0043] As far as the filtration efficiency of the filter F2 is concerned, it can be chosen so as to be dedicated for trapping and collecting ash and other nanoparticles flowing along portion P6 of the exhaust line EP, so as to fulfill recent legal requirements. In this regard, the filter F2 is chosen/designed so as to have a filtration efficiency higher than 99,5%, and preferably higher than 99,9.

[0044] In particular, recent filtering technologies (e.g. the so-called "membrane" technology, or the so-called "overcoat" technology, or the so-called "Narrow Mean pore Size", or "NPS", technology) are able to achieve filtration efficiencies of 99.99%: thanks to these new technologies it is possible to reach ultra low PN limits.

[0045] In indicating the above values for the ranges of the filtration efficiencies of the filters F1 and F2, for some filtering technologies, such filtration efficiency is considered and/or estimated and/or detected when the filter has been used at least for a period of time, e.g. for about 50-100 hours.

[0046] Indeed, when some kinds of filters are brand new, they have a filtration efficiency that is still rather low, and such filtration efficiency suddenly increases during the first period of usage, so as to reach an average level of the filtration efficiency in the following period. This behavior is shown by way of example in figure 2. In view of this diagram, the values of the "filtration efficiency" indicated in the above ranges are given and considered as the average level reached after the first period of usage, e.g. after a relatively small accumulation of particulate.

[0047] On the other hand, for other filtering technologies, like the above mentioned "membrane" and "overcoat" technologies, the required average filtration efficiency is given from the very beginning of the filter usage.

[0048] As shown in figure 1, filter F2 is arranged downstream of the turbines T1 and T2, i.e. along the portion P6, where temperatures and pressures are relatively low.

[0049] Preferably, the system ATS further comprises at least one SCR device arranged along the portion P6, to add an urea-based liquid or an ammonia-based liquid into the exhaust gas in order to perform a Selective Catalytic Reduction process and, therefore, convert the NOx. In particular, the system ATS comprises two SCR devices arranged in series, i.e. a device SCR1 arranged upstream of the filter F2 and a device SCR2 arranged downstream of the filter F2. The device SCR1 helps in converting a possible part of the soot that has passed through the filter F1, without being trapped and burnt off. On the other hand, the device SCR2 is controlled so as to reach given targets in the emissions/pollutants at the tail pipe TP, if the device SCR1 alone is not sufficient to reach such targets.

[0050] According to a variant, not shown, the device SCR2 is not provided.

[0051] Thanks to the ability of filtering ash, the filter F2 is able to trap and collect and other nanoparticles, e.g. also particles defined by urea-based deposits, if an urea-based additive is injected at the device SCR1, and other

nanoparticles coming out from the filter F1 during regeneration of the latter.

[0052] According to a preferred aspect, possible passive regeneration operations on filter F2 (to burn off possible remaining soot) are carried out occasionally, at very long time intervals from each other, e.g. 3-500 hours, during longer high load operations and/or a programmed heat treatment by engine thermal management.

[0053] From the above description it is clear that the filtering function of the system ATS is split into the two filters F1 and F2.

[0054] Thanks to this feature, it is possible to reach a high efficiency in the particulate conversion and removal, by using a solution having a relatively small size and causing a relatively low pressure loss along the system ATS.

[0055] In the meantime, only the filter F2 needs to be serviced, for ash removal and/or cleaning. Therefore, the proposed solution is relatively cost-effective.

[0056] Besides, if an EGR system is provided, the engine E is more effectively protected from corrosion and wear, as the main part of the soot is converted by the filter F1, upstream of the lines EGR1 and EGR2, so that these lines recirculate gas having a small amount of particulate, and also lower NO_x (forming nitric acid) if such lines start from a point downstream of the SCR device.

[0057] A minor part of the soot could be still present in the exhaust gas flowing into the portion P6, i.e. towards the filter F2, but such part is trapped by the same filter F2, together with the ash, and is partially converted by the Selective Catalytic Reduction process carried out by the device SCR1. In the meantime, efficiency of the SCR devices is higher thanks to the early NO_x oxidation carried out by the catalyst that is associated to the filter F1.

[0058] Preferably, it is possible to separate soot filtration from ash filtration, e.g. by choosing an appropriate filtration efficiency for the filter F1.

[0059] In other words, the soot filtration is carried out as far as possible only at the filter F1, that is associated with higher temperatures, enabling to convert soot into CO₂ by appropriate combustion strategies (preferably by passive regeneration). At least ideally, all the soot is trapped and stored in the filter F1, and not on the downstream filter F2.

[0060] During regeneration of filter F1, nanoparticles can/will be emitted and go downstream, to filter F2.

[0061] In particular, in the filter F1, the filtration technology and/or the pore size are designed only for soot filtration, and possibly to reduce backpressure to a minimum. In this regard, there is also an advantage in controlling the filter F1, as the back pressure increases only due to soot loading, and not because of ash loading.

[0062] Also the EGR cleanliness is improved by trapping as much soot as possible in the filter F1.

[0063] As a consequence, the filter F2 traps and collects ash, without receiving soot, or receiving a negligible part of the soot.

[0064] The filter F2 needs only a periodical maintenance, e.g. for ash cleaning or for replacing the filter F2.

In the meantime, it is possible to foresee in a relatively precise manner the need for such maintenance, as the back pressure at the filter F2 increases only because of ash loading (and not because of soot loading).

[0065] From the above it should be clear that modifications can be made to the above described system ATS, without departing from the scope of protection defined by the appended claims.

[0066] In particular, as mentioned above, any kind of soot filter can be chosen as filter F1 and any kind of ash filter can be chosen as filter F2.

Claims

1. Exhaust gas after treatment system (ATS) for a diesel cycle internal combustion engine (E), the after treatment system comprising:

- an exhaust line (EP) to channel exhaust gas from said engine (E) to an external environment;
- a first particulate filter (F1) and a second particulate filter (F2) arranged in series along said exhaust line (EP) ;

wherein the first particulate filter (F1) is configured to trap and collect soot and to let ash pass through the first particulate filter (F1), and wherein the second particulate filter (F2) is configured to trap and collect ash, is arranged downstream of said first particulate filter (F1), considering the exhaust gas direction in said exhaust line (EP), and is configured to be serviced, so as to allow for removal of collected ash.

2. After treatment system according to claim 1, **characterized in that** said first particulate filter (F1) is associated with a catalyst.

3. After treatment system according to claim 2, **characterized in that** said catalyst comprises catalytic material in said first particulate filter (F1).

4. After treatment system according to claim 2 or 3, **characterized in that** said catalyst comprises a catalytic converter (DOC) arranged upstream of said first particulate filter (F1).

5. After treatment system according to anyone of the previous claims, **characterized in that** said first particulate filter (F1) is a passively regenerated filter.

6. After treatment system according to anyone of the previous claims, **characterized by** comprising at least one turbine (T1,T2) suitable to operate, directly or indirectly, an air compressor and arranged along said exhaust line (EP) downstream of said first particulate filter (F1); said second particulate filter (F2)

being arranged downstream of said turbine (T1,T2).

7. After treatment system according to anyone of the previous claims, **characterized by** comprising at least one EGR line (EGR1,EGR2) to recirculate a part of the exhaust gas into an intake line (IP) for said internal combustion engine (E); said EGR line (EGR1,EGR2) starting from a point of the exhaust line (EP) downstream of said first particulate filter (F1).

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8. After treatment system according to anyone of the previous claims, **characterized by** comprising at least one SCR device (SCR1) arranged along said the exhaust line (EP) between said first particulate filter (F1) and second particulate filter (F2).

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9. After treatment system according to anyone of the previous claims, wherein the first particulate filter (F1) has a filtration efficiency and/or a pore size chosen so as to trap soot flowing out of the combustion engine (E) and allowing ash to flow downstream through the first particulate filter (F1).

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10. After treatment system according to anyone of the previous claims, wherein the first particulate filter (F1) has a filtration efficiency that is, at least after a given period of usage, between 95% and 99%.

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11. After treatment system according to anyone of the previous claims, wherein the second particulate filter (F2) has a filtration efficiency that is, at least after a given period of usage, higher than 99,5%.

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12. After treatment system according to claim 11, wherein said filtration efficiency of the second particulate filter (F2) is higher than 99,9%.

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13. Assembly comprising:

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 - a Diesel cycle internal combustion engine and
 - an exhaust gas after treatment system according to anyone of the previous claims.

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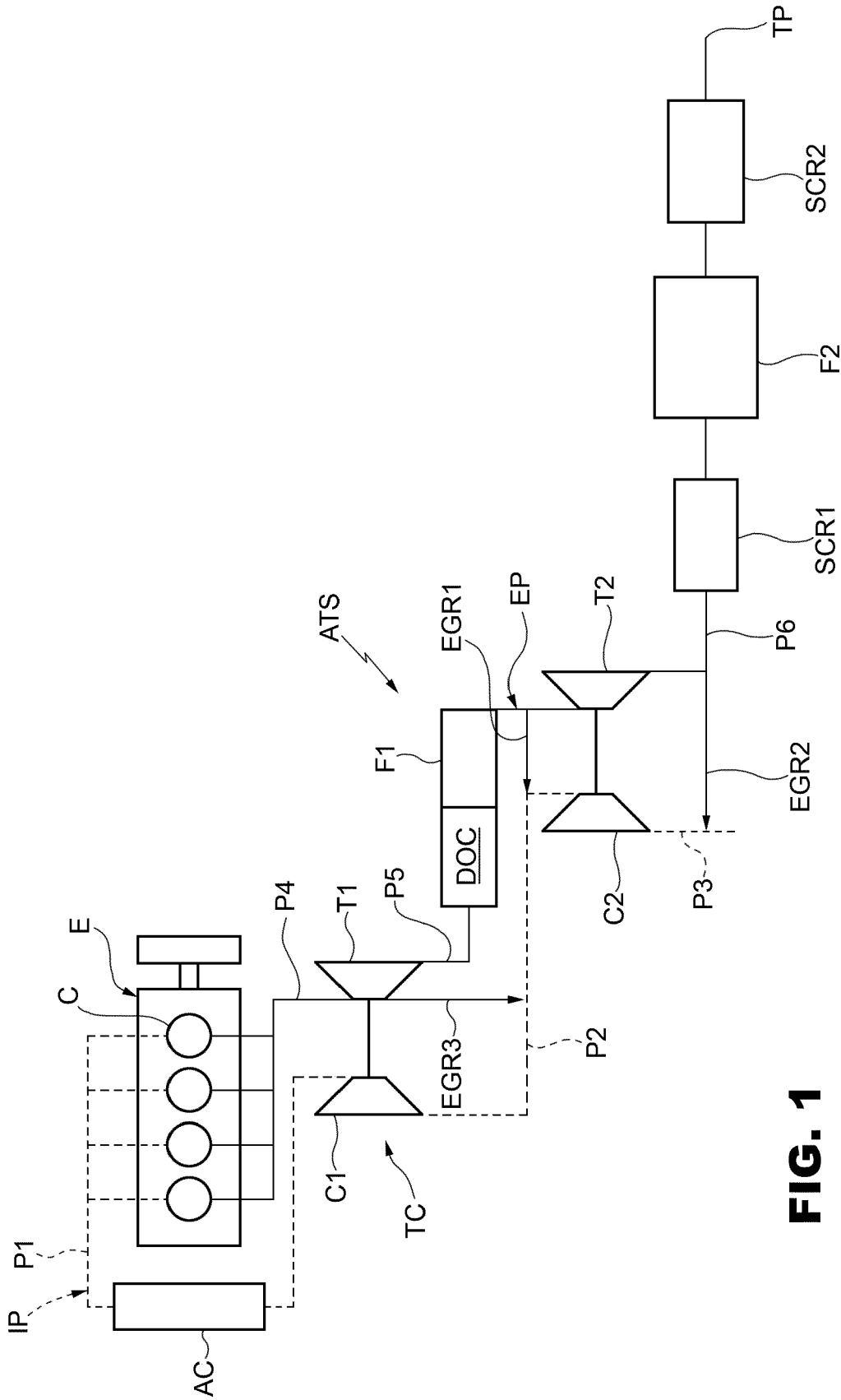
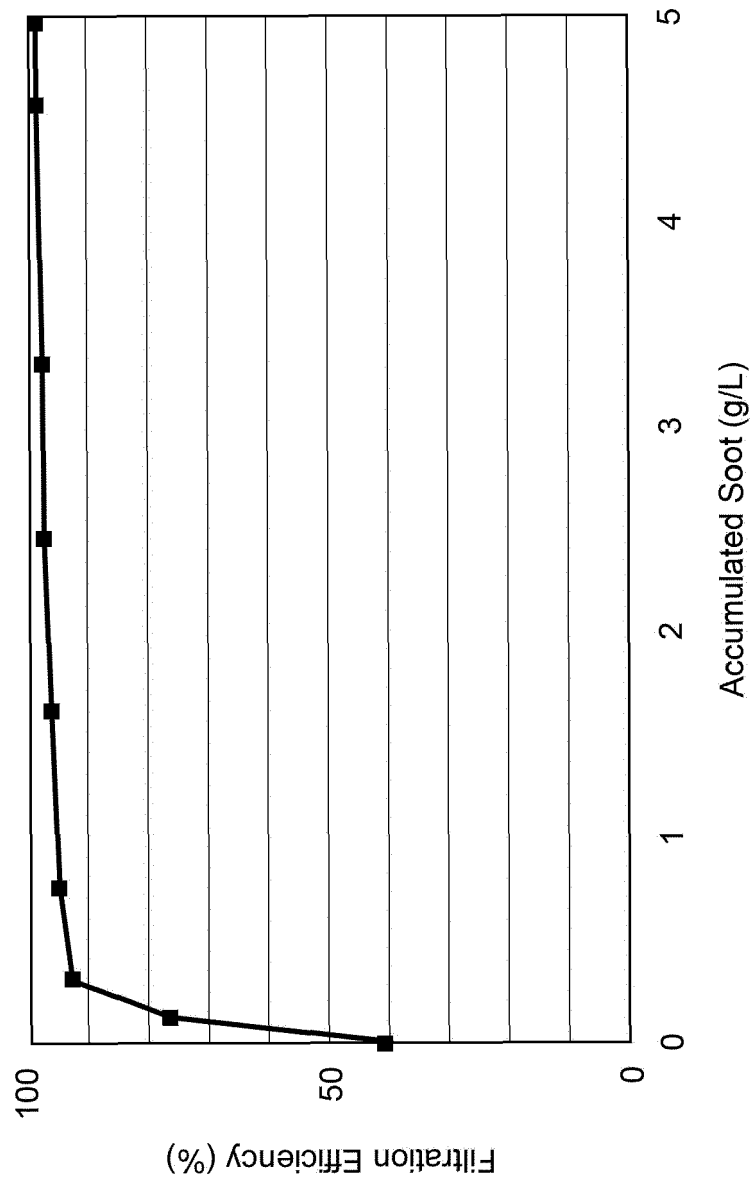


FIG. 1

**FIG. 2**



EUROPEAN SEARCH REPORT

 Application Number
 EP 20 18 9886

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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A	* paragraphs [0020] - [0024]; figure 1a * -----	4,7,8	F01N3/035 F01N13/00 F01N3/022
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			TECHNICAL FIELDS SEARCHED (IPC)
			F01N
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 8 September 2020	Examiner Kolland, Ulrich
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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REFERENCES CITED IN THE DESCRIPTION

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