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(71) Applicant (for all designated States except US): **CATERPILLAR INC.** [US/US]; 100 N.E. Adams Street, Peoria, IL 61629-9510 (US).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **CHAVANNAVAR, Praveen** [IN/US]; 1700 W Hickory Grove Rd, A109, Dunlap, IL 61526 (US).

(74) Agents: **FAHLBERG, Robin, S.** et al.; 100 N. E. Adams Street, Peoria, IL 61629-9510 (US).

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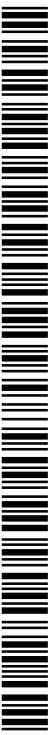
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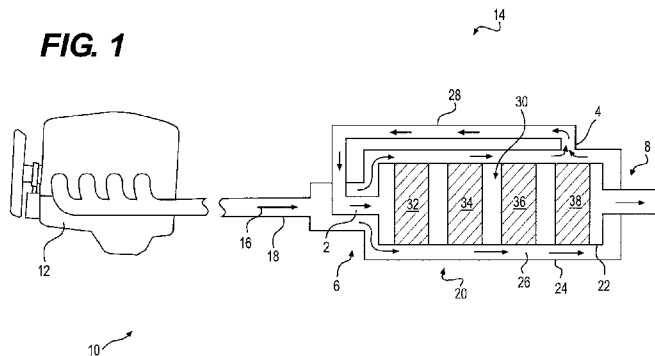
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(54) Title: EXHAUST TREATMENT SYSTEM

FIG. 1



(57) Abstract: An exhaust treatment system (14) for a power system (10) is disclosed. The exhaust treatment system includes an exhaust conduit (18) directing exhaust gas (16) produced by the power system towards at least one exhaust treatment device (32). The exhaust treatment system may also include a substrate (42) positioned within an enclosure (20) of the at least one exhaust treatment device. The exhaust conduit may be configured to preheat the substrate with the exhaust gas prior to directing the exhaust gas into the enclosure.

EXHAUST TREATMENT SYSTEM

Description

Technical Field

5 The present disclosure relates generally to an exhaust treatment system for a power system, and more particularly, to an exhaust treatment system to reduce phosphorous aging.

Background

10 The composition of exhaust produced by the combustion of hydrocarbon fuels includes a mixture of particulate matter (soot), oxide gases (such as, for example, NO_x, SO_x, etc.), and unburned hydrocarbons. To comply with emission standards, engine manufactures have developed and implemented a variety of exhaust treatment devices to reduce pollutants in exhaust gas prior to the exhaust gas being released into the atmosphere. These exhaust treatment devices may include, for example, a diesel particulate filter (DPF), a selective
15 catalytic reduction (SCR) device, a diesel oxidation catalyst (DOC), an ammonia oxidation catalyst (AMOX) and other similar components. These devices capture or convert undesirable constituents in exhaust gas into less harmful products as the exhaust gas flows therethrough.

20 The long-term durability of the exhaust treatment devices is essential for efficient emission control. The durability of these devices can be affected by a variety of factors including engine lubricating oil consumption. During normal engine operation, some of the lubricating oil is combusted. The deposition of combustion products from phosphorus containing lubricant additives can adversely affect the durability of exhaust treatment devices (called
25 “phosphorous aging” or “phosphorous poisoning”). To minimize this adverse impact, engines are designed to reduce lubricant consumption, and lubricants are

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formulated with lower concentrations of phosphorus containing compounds. However, phosphorus containing lubricant additives (such as, ZDDP - Zinc Dialkyl Dithiophosphate) protect the engine from excessive wear and assist in increasing engine durability. Historically, techniques such as oversizing an exhaust treatment device, and regenerating an exhaust treatment device with the addition of a scavenging additives have been used to account for phosphorous aging of exhaust treatments devices.

U.S. Patent No. 7,341,447 issued to Guinther et al. (the '447 patent) discloses the inclusion of manganese in a lubricant to improve the durability of a catalytic converter. In the '447 patent, the manganese acts as a scavenging agent to interact with and remove the phosphorous deposited in the catalytic converter. While the method of the '447 patent may improve the durability of a catalytic converter, it may have drawbacks. For instance, inclusion of manganese may increase cost.

The disclosed exhaust treatment systems are directed at overcoming these and/or other shortcomings in existing technology.

Summary

In one aspect, an exhaust treatment system for a power system is disclosed. The exhaust treatment system includes an exhaust conduit directing exhaust gas produced by the power system towards at least one exhaust treatment device. The exhaust treatment system may also include a substrate positioned within an enclosure of the at least one exhaust treatment device. The exhaust conduit may be configured to preheat the substrate with the exhaust gas prior to directing the exhaust gas into the enclosure.

In another aspect, a method of operating an exhaust treatment device of an engine is disclosed. The method includes directing exhaust gas produced by the engine towards the exhaust treatment device. The exhaust treatment device including a substrate positioned within an enclosure. The method also includes heating the substrate to a temperature higher than a

temperature of the exhaust gas prior to directing the exhaust gas past the substrate. The method further includes directing the exhaust gas into the enclosure and past the substrate after the heating.

In yet another aspect, a method of reducing phosphorous aging of an exhaust treatment device of an engine is disclosed. The method includes directing exhaust gas produced by the engine into an enclosure of the exhaust treatment device. The exhaust treatment device may include a substrate positioned within the enclosure. The method may also include transferring heat from the exhaust gas to the substrate prior to directing the exhaust gas into the enclosure. The method may further include directing the exhaust gas in the enclosure past the substrate.

Brief Description of the Drawings

FIG. 1 is an illustration of a power system with an exemplary exhaust treatment system;

FIG. 2 is an illustration of the flow of exhaust through a Diesel Oxidation Catalyst of the exhaust treatment system of FIG. 1;

FIG. 3 is an illustration of the flow of exhaust through a prior art Diesel Oxidation Catalyst; and

FIG. 4 is a flow chart illustrating a method of operating an exemplary disclosed exhaust treatment system.

Detailed Description

FIG. 1 illustrates a power system 10 which includes an engine 12 and an exhaust treatment system 14 to treat an exhaust stream 16 produced by the engine 12. The power system 10 and engine 12 may include other features and components not shown, such as controllers, fuel systems, air systems, cooling systems, drive train components, turbochargers, exhaust gas recirculation systems, etc. The engine 12 may be any type of internal combustion engine (gasoline, diesel, gaseous fuel, natural gas, propane, etc.), may be of any size,

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with any number of cylinders, and in any configuration ("V," in-line, radial, etc.). The engine 12 may be used to power any machine or other device, including on-highway trucks or vehicles, off-highway trucks or machines, earth moving equipment, generators, aerospace applications, locomotive applications, marine applications, pumps, and/or stationary equipment.

The exhaust treatment system 14 includes an exhaust conduit 18 fluidly coupled to a can 20 that includes one or more exhaust treatment devices 30 positioned therein. These exhaust treatment devices 30 may include a DOC 32, a DPF 34, an SCR device (SCR 36), and an AMOX device (AMOX 38). Can 20 includes an inner chamber 22 that encloses the exhaust treatment devices 30 and an outer chamber 24 that is disposed around the inner chamber 22 to define an annular space 26 between the inner and outer chambers 22, 24. A conduit 28 fluidly couples an outlet 4 at the downstream end 8 of the outer chamber 24 to an inlet 2 at the upstream end 6 of the inner chamber 22. Conduit 18 directs the exhaust stream 16 through the annular space 26 along the length of can 20 before directing the exhaust stream 16 through conduit 28, and into the inner chamber 22 through inlet 2. Within the inner chamber 22, the exhaust stream 16 flows through the exhaust treatment devices 30 before exiting can 20. That is, as illustrated in FIG. 1, the exhaust stream 16 is directed around the exhaust treatment devices 30 before being directed through these devices. As the exhaust stream 16 flows through the annular space 26 around the exhaust treatment devices 30, heat transfer occurs between the exhaust stream 16 and the walls of the inner and the outer chambers 22, 24. A portion of this heat may heat the exhaust treatment devices 30 contained within inner chamber 22. Directing the exhaust stream 16 around an exhaust treatment device 30 prior to directing the exhaust stream 16 through the device may heat the device and cool the exhaust stream 16 such that, the exhaust stream 16 flowing through a device may be cooler than the device. In some embodiments, the exhaust treatment system 14 may be configured to increase the heat transferred from the exhaust stream 16 to

the exhaust treatment devices 30. For instance, in some embodiments, the outer walls of the outer chamber 24 may be insulated (such as, for example, include a wrap around insulating sheath) or may be fabricated from a thermally non-conductive material to increase the heat transferred to the heat treatment devices 30. In some embodiments, heat transfer enhancement features (such as, for example, fins, pins, etc.) coupled to the outer wall of the inner chamber 22 may extend into the annular space 26 to increase the heat transferred from the exhaust stream 16 to the inner chamber 22.

As the exhaust stream 16 flows through the exhaust treatment devices 30, one or more constituents in the exhaust may be separated and/or be converted into more benign compounds. The relatively cleaner exhaust stream 16 may then be directed out of can 20. Although FIG. 1 illustrates the exhaust stream 16 as travelling through the annular space 26 along substantially the entire length of inner chamber 22 before being directed to inlet 2 of inner chamber 22, this is only exemplary. In some embodiments, the outer chamber 24 may extend only along portions of the length of can 20, and the exhaust stream 16 may preheat only some exhaust treatment components 30. In some embodiments, the conduits (and/or the outer chamber 24) may be configured to direct the exhaust stream 16 selectively around selected exhaust treatment devices 30 (such as, for example, DPF 34 but DOC 32) before being directed to inlet 2. In such an embodiment, heat may be transferred from the exhaust stream 16 to DPF 34, and, the exhaust stream 16 passing through the DPF 34 may be cooler than the DPF 34. In these embodiments, the exhaust stream 16 passing through another exhaust treatment device (such as, for example, the DOC 32) may not necessarily be cooler than the respective device.

It should be noted that the exhaust treatment devices 30 illustrated in FIG. 1 are exemplary only, and other embodiments of the exhaust treatment system 14 may include less, more, or other exhaust treatment devices 30. In some embodiments, a heat source (for example, a burner) may be included

upstream of can 20 to provide the heat necessary for regeneration of the DPF 34. And in some embodiments, a reductant dosing system may be positioned upstream of SCR 36 to inject a reductant into the exhaust stream 16. It should also be noted that the order of the exhaust treatment devices 30 illustrated in FIG. 1 is only exemplary, and in other embodiments, these devices may be positioned in a different order in can 20. In some embodiments, multiple cans may be used in place of the single can 20 illustrated in FIG. 1, and in other embodiments, can 20 may be eliminated and the various exhaust treatment devices may be positioned at different locations within the exhaust conduit 18.

10 Since exhaust treatment devices 30, such as DOC 32, DPF 34, SCR 36, and an AMOX 38 are well known in the art, these devices will only be briefly described herein. DOC 32 may include a flow-through substrate having, for example, a honey comb structure with many parallel channels for the exhaust stream 16 to flow through. A catalytic coating (for example, of a platinum group metal) may be applied to the surface of the substrate to promote oxidation of
15 some constituents (such as, for example, hydrocarbons, oxides of sulphur, etc.) of the exhaust stream 16 as it flows therethrough. The honeycomb structure of the substrate increases the contact area of the substrate to the exhaust stream 16 and therefore allows more of the undesirable constituents in the exhaust stream 16 to
20 be oxidized as it flows therethrough.

 DPF 34 is a device used to physically separate soot or particulate matter from exhaust stream 16. DPF 34 may include a wall flow substrate. The exhaust stream 16 passes through the walls of the wall flow substrate leaving the larger particulate matter accumulated on the walls. As is known in the art, DPF
25 34 may be regenerated periodically to clear the accumulated particulate matter. In some embodiments, regeneration of DPF 34 may be accomplished by heating the exhaust stream 16 to a regeneration temperature upstream of the DPF 34. Although not depicted in FIG. 1, in embodiments employing such a regeneration

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technique, exhaust treatment system 14 may include a heating device (electric heater, microwave device, burner, etc.) positioned upstream of can 20.

SCR 36 may include one or more catalyzed substrates that convert oxides of nitrogen (NO_x) in exhaust stream 16 into relatively benign components, such as, nitrogen gas and water. A reagent (such as, for example, urea, AdBlue[®], etc.) may be injected into the exhaust stream 16 to enable the oxidation reaction in SCR 36. Although not illustrated in FIG. 1, SCR 36 may include a dosing system that injects the reagent into the exhaust stream. AMOX 38 may convert the excess ammonia in the exhaust stream 16 to benign compounds.

10 In the exhaust stream 16, phosphorous may exist in an oxide or an acid form (collectively referred to herein as “phosphorous”). These phosphorous containing compounds in the exhaust stream 16 may deposit on the exhaust treatment devices 30, as they flow through the device. Over time, this deposited phosphorous may negatively affect the performance of the exhaust treatment
15 devices 30. Although the phosphorous in the exhaust stream 16 may deposit on, and affect the performance of, all the exhaust treatment devices of FIG. 1, for the sake or brevity, only its impact on DOC 32 will be described herein.

FIG. 2 illustrates the flow of the exhaust stream 16 through one of the channels 44 of a honeycomb substrate 42 of DOC 32. As the exhaust stream
20 16 flows through the channel 44, the hydrocarbons, oxides of nitrogen, and sulphur containing compounds (collectively referred to herein as “hydrocarbons”) in the exhaust stream 16 gets chemically bonded to the catalyzed surfaces 46 of the substrate 42. These chemically bonded hydrocarbons undergoes an oxidation reaction, and the resulting products leave the surface 46 along with the exhaust
25 stream 16. The catalyzed surfaces 46 of the substrate 42 are now ready to chemically bond with, and oxidize, more hydrocarbons in the exhaust stream 16. Meanwhile, the phosphorous in the exhaust stream 16 gets physically deposited on the catalyzed surfaces 46 of substrate 42. This physically deposited phosphorous will cover (or mask) regions of the surface 46 that they deposit on,

and prevent hydrocarbons from chemically bonding with these covered regions. Deposition of the phosphorous on the substrate 42 thus reduces the chemical activity of substrate 42, and thereby reduces the effectiveness of DOC 32. Although not described herein, the phosphorous will affect the other exhaust
5 treatment devices 30 of exhaust treatment system 14 in a similar manner.

As the exhaust stream 16 flows through channel 44 of substrate 42, phosphorous in the exhaust stream 16 proximate surface 46 (such as, for example, region marked "b" in FIG. 2) gets deposited on the surface 46. This deposition of phosphorous from regions proximate the surface 46 decreases the
10 concentration of phosphorous in this region as compared to regions away from the surface 46 (such as, for example, region marked "a" in FIG. 2). That is, as the exhaust stream 16 flows through channel 44, the concentration of phosphorous in a region a away from the surface 46 is higher than the concentration of phosphorous in a region b proximate the surface 46. Thus, the
15 physical deposition of phosphorous on surface 46 introduces a concentration gradient of phosphorous across the width of channel 44. This concentration gradient induces diffusion forces F_d that act from a to b, and causes the phosphorous to diffuse from the regions away from surface 46 towards the surface 46. Although FIG. 1 illustrates the diffusion force F_d as acting
20 substantially perpendicular to the direction of exhaust flow, this is only illustrative. In general, the diffusion force F_d may act in any direction towards surface 46. Further, although the direction of phosphorous migration due to diffusion will be towards surface 46, this direction may not necessarily be the same as the direction of the diffusion force F_d . Advection forces cause the
25 phosphorous in the exhaust to flow with the exhaust stream 16. And, the path of a phosphorous particle towards surface 46 may, among others, depend on a vector sum of the diffusion and advection forces.

In addition to the diffusion forces F_d , thermophoresis forces F_t resulting from temperature gradients in the exhaust stream 16 act on phosphorous

particles in the exhaust stream 16. Thermophoresis force is a force resulting from a temperature gradient in a gas medium. Due to the temperature gradient, fine suspended particles (such as phosphorous) in the gas experience thermophoresis forces in the direction of decreasing temperature. Because of the heat transfer

5 from the exhaust stream 16 to the DOC 32 prior to the exhaust stream 16 entering the DOC 32, the substrate 42 temperature (T_1) will be higher than the temperature (T_2) of the exhaust stream 16 flowing through channel 44. Due to physical contact, heat transfer will occur between the relatively hotter substrate surface 46 and the relatively cooler exhaust stream 16 proximate this surface 46 (region b).

10 Because of this heat transfer with surface 46, the peripheral regions (region b) of the exhaust stream 16 will be hotter than the center regions (region a). This temperature differential across the width of the exhaust stream 16 introduces thermophoresis forces F_t directed from the peripheral regions towards the center regions (from a to b). These thermophoresis forces F_t tend to push phosphorous

15 away from the surface 46. Therefore, while the diffusion forces F_d tend to push phosphorous in the exhaust stream 16 towards surface 46, the thermophoresis forces F_t tend to push the phosphorous away from the surface 46. The net effect of both these forces will be to reduce the amount of phosphorous deposited on the surface 46.

20 In typical exhaust treatment systems of the prior art, the temperature of the exhaust is higher than the temperature of the after treatment devices. Therefore, as illustrated in FIG. 3, in exhaust treatment systems of the prior art, the exhaust stream 16 passing through the DOC 32 is at a higher temperature than the substrate 42 of the DOC 32 (that is, $T_2 > T_1$). Because of

25 heat transfer with the cooler surface 46, the peripheral regions of the exhaust stream 16 will be cooler than the center regions. Therefore, the thermophoresis forces, that act in the direction of a lower temperature gradient, tend to push the phosphorous from the center towards the surface 46. Thus, in typical prior art exhaust treatment systems, both diffusion forces F_d and thermophoresis forces F_t

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act to push phosphorous towards the surface 46, thereby increasing the amount of deposited phosphorous. In contrast, in exhaust treatment systems of the current disclosure the thermophoresis forces F_t tend to counteract the effect of the diffusion forces F_d .

5 In preferred embodiments of the exhaust treatment system, the substrate 42 will be at a higher temperature than the exhaust stream 16 flowing through it, since such a temperature differential will induce thermophoresis forces that tends to push phosphorous away from surface 46. However, such a temperature differential is not a requirement. In general, the temperature
10 differential between the substrate 42 and the exhaust stream 16 may be such that the forces that tend to deposit phosphorous on surface 46 (that is, a force towards surface 46) is lower than that in the prior art. For instance, in some embodiments, the substrate 42 may have substantially the same temperature as the exhaust stream 16. In these embodiments, thermophoresis forces may be
15 substantially eliminated. In these embodiments, only the diffusion forces will drive the phosphorous towards the surface 46. Thus, elimination of the thermophoresis forces decreases the forces that tend to deposit phosphorous on surface 46 as compared to a prior art system where both diffusion and thermophoresis forces act towards the surface 46. It is also contemplated that, in
20 some embodiments, the temperature of the substrate 42 may in fact be lower than the exhaust stream 16. In these embodiments, the temperature differential between the substrate 42 and the exhaust stream 16 may be minimized to decrease the thermophoresis forces acting towards the substrate 42.

 Although FIG. 1 illustrates an embodiment of exhaust treatment
25 system 14 where the exhaust stream 16 is used to heat the exhaust treatment devices 30, this is not a requirement. In general, any technique to heat one or more of the exhaust treatment devices 30 relative to the exhaust stream 16 may be employed. For instance, in some embodiments, heaters wrapped around an exhaust treatment device (such as, DOC 32) or heaters embedded on a substrate

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(such as, substrate 42) may be used to heat the substrate 42 relative to the exhaust stream 16. These heaters may be activated constantly, or may be selectively activated to increase the temperature of substrate 42 based on a measured reading or at a desired time. For instance, thermocouples and/or other sensors (such as, sensors that detect the concentration of a constituent in exhaust stream 16) coupled to different regions of the exhaust treatment system 14 may measure different parameters of the exhaust treatment system 14. And, a control system may selectively activate the heaters based on readings from one or more of these sensors.

10 Industrial Applicability

The exhaust treatment system of the current disclosure may be applied to any application where it is desired to decrease phosphorous aging of exhaust treatment devices. In an exemplary embodiment, the exhaust treatment system of the current disclosure may be used in a power system. To illustrate some exemplary features of the disclosed exhaust treatment system, an exemplary application will now be described.

With reference to FIG. 1, an engine 12 may be fluidly coupled to an exhaust treatment system 14. An exhaust stream 16 from the engine 12 may be directed through the exhaust treatment system 14 to the atmosphere. The exhaust treatment system 14 may include a DOC 32 including a catalyzed honeycomb substrate 32. As the exhaust stream 16 flows through the DOC 32, hydrocarbons in the exhaust stream 16 may chemically bond with a catalyzed surface 46 of the substrate 42 and get oxidized. Additionally, phosphorous in the exhaust stream 16 may also get physically deposited on the surface 46 and mask regions of the surface 46 from the hydrocarbons. The phosphorous deposition may decrease the chemical activity of the substrate 42. The disclosed exhaust treatment system 14 is configured to increase the temperature of the substrate surface 46 relative to the exhaust stream 16, and thereby, minimize the deposition of phosphorous on the substrate 42.

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FIG. 4 shows a flow chart illustrating an exemplary method of using a disclosed exhaust treatment system. The method includes producing an exhaust stream 16 (step 50) from engine 12. The exhaust stream 16 may be directed towards DOC 32. The substrate 42 of the DOC 32 may be heated (step 5
60) to increase the temperature of the substrate 42 relative to the exhaust stream 16. The substrate 42 may be heated by any means. In one embodiment, the substrate 42 may be heated by directing the exhaust stream 16 around the DOC 32 prior to the exhaust stream 16 entering the DOC 32. Alternatively or additionally, the substrate 42 may be heated by activating a heater wrapped
10 around the DOC 32 or embedded in the substrate 42. In some embodiments, heating the substrate 42 (step 60) may increase the temperature of the substrate 42 above the temperature of the exhaust stream 16, while in other embodiments, heating the substrate 42 may not increase the temperature of the substrate 42 above the exhaust stream 16 temperature, but may only decrease a temperature
15 differential between the exhaust stream 16 and the substrate 42. The exhaust stream 16 may be directed into the DOC 32 (step 70), and directed past the substrate. As the exhaust stream 16 flows past the substrate 42, hydrocarbons in the exhaust stream 16 gets chemically bonded to the substrate 42, while phosphorous in the exhaust stream 16 gets physically deposited on the substrate
20 42. Because of the heating, the temperature differential between the substrate 42 and the exhaust stream 16 is such that the induced forces, that tend to deposit the phosphorous on the substrate 42, are decreased (step 80). Due to a concentration gradient of the phosphorous in the exhaust stream 16, diffusion forces F_d may act to move the phosphorous in the exhaust stream 16 towards the substrate 42. In
25 embodiments where the temperature of the substrate 42 is higher than the exhaust stream 16, thermophoresis forces F_t that act to push phosphorous in a direction away from the substrate 42 are induced. These thermophoresis forces F_t act to decrease the amount of phosphorous deposited on the substrate 42. In embodiments where the temperature difference of substrate 42 and exhaust

stream 16 is reduced but the temperature of the substrate 42 is not higher than the exhaust stream 16 temperature, the reduced temperature gradient decreases the phosphorous deposition on the substrate 42.

5 Since deposition of phosphorous on the substrate 42 is decreased, phosphorous aging of the DOC 32 is mitigated. Thus, the durability of DOC 32 is increased. Since this durability increase is accomplished without the addition of chemical compounds (such as, scavenging agents), cost is decreased. Further, since no scavenging agents are added, any undesirable effects of these scavenging agents on components of the power system is eliminated.

10 It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed exhaust treatment system. Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the disclosed exhaust treatment system. It is intended that the specification and examples be considered as
15 exemplary only, with a true scope being indicated by the following claims and their equivalents.

Claims

1. An exhaust treatment system (14) for a power system (10), comprising:
an exhaust conduit (18) directing exhaust gas (16) produced by the
5 power system towards at least one exhaust treatment device (32); and
a substrate (42) positioned within an enclosure (20) of the at least
one exhaust treatment device, wherein the exhaust conduit is configured to
preheat the substrate with the exhaust gas prior to directing the exhaust gas into
the enclosure.
10
2. The exhaust treatment system of claim 1, wherein the
exhaust conduit is configured to preheat the substrate such that a temperature of a
surface of the substrate that contacts the exhaust gas is higher than a temperature
of the exhaust gas within the enclosure.
15
3. The exhaust treatment system of claim 1, wherein the
enclosure includes an inner chamber (22) which encloses the substrate, and an
outer chamber (24) positioned around the inner chamber with an annular space
(26) defined therebetween, the exhaust conduit being configured to direct the
20 exhaust gas through the annular space prior to directing the exhaust gas into the
inner chamber.
4. The exhaust gas treatment system of claim 4, further
including a fluid flow passage (28) that fluidly couples a downstream end of the
25 annular space to an inlet (2) positioned at an upstream end of the inner chamber.
5. The exhaust gas treatment system of claim 1, wherein the
at least one exhaust treatment device includes a first exhaust treatment device
(32) positioned upstream of a second exhaust treatment device (34).

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6. The exhaust treatment system of claim 5, wherein said substrate is a first substrate of the first exhaust treatment device and the second exhaust treatment device includes a second substrate positioned within the enclosure and the exhaust conduit is configured to preheat both the first and the second substrate with the exhaust gas prior to directing the exhaust gas into the enclosure.

7. A method of operating an exhaust treatment device (32) of an engine (12), comprising:

directing exhaust gas (16) produced by the engine towards the exhaust treatment device, the exhaust treatment device including a substrate (42) positioned within an enclosure (20);

heating (60) the substrate to a temperature higher than a temperature of the exhaust gas prior to directing the exhaust gas past the substrate; and

directing (70) the exhaust gas into the enclosure and past the substrate after the heating.

8. The method of claim 7, wherein the heating includes heating the substrate using the exhaust gas prior to directing the exhaust gas into the enclosure.

9. The method of claim 7, wherein directing the exhaust gas into the enclosure includes directing the exhaust gas into the enclosure after passing the exhaust gas along an external surface of the enclosure.

10. The method of claim 9, wherein heating the substrate includes heating the substrate using an electric heater.

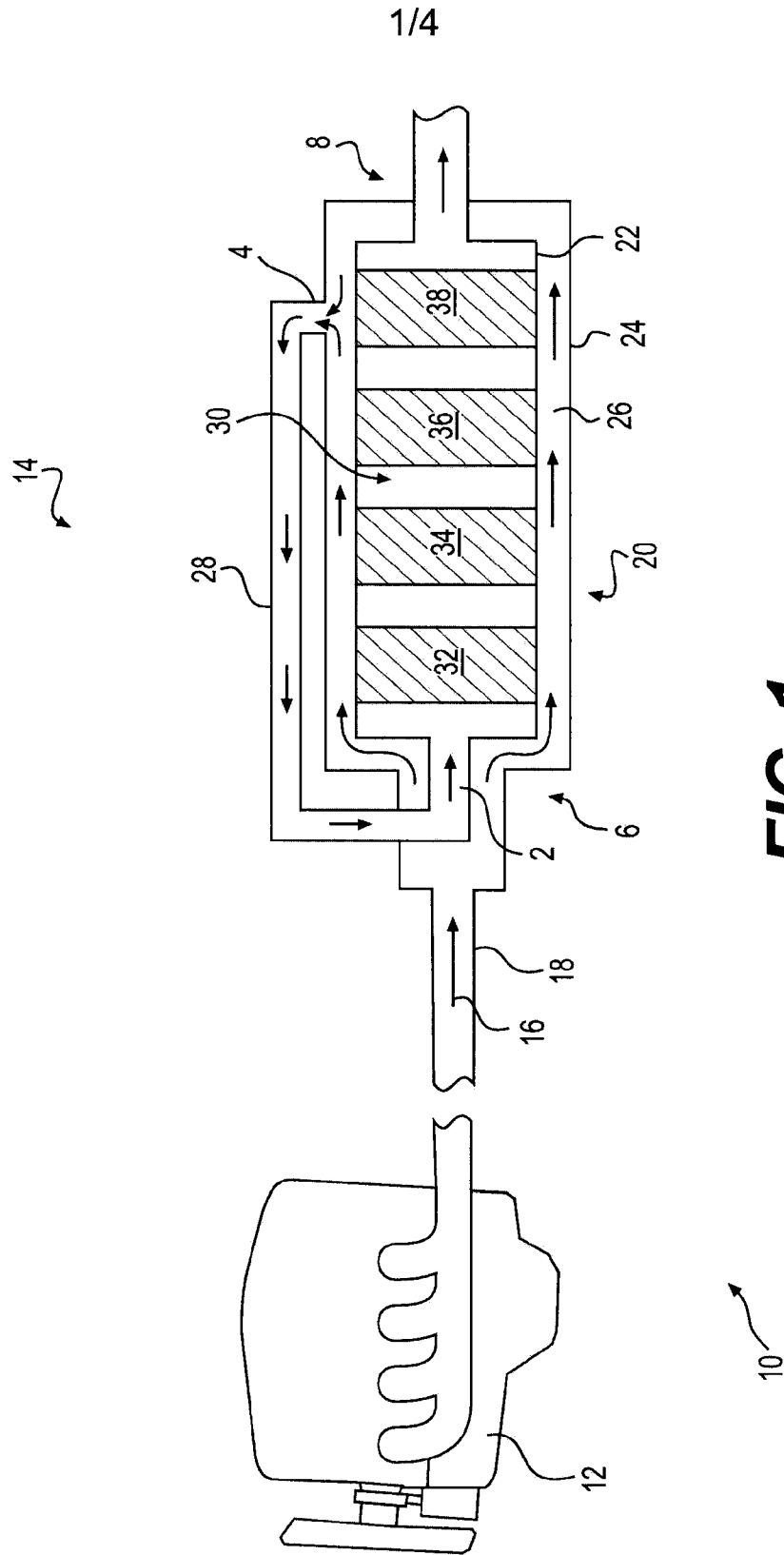


FIG. 1

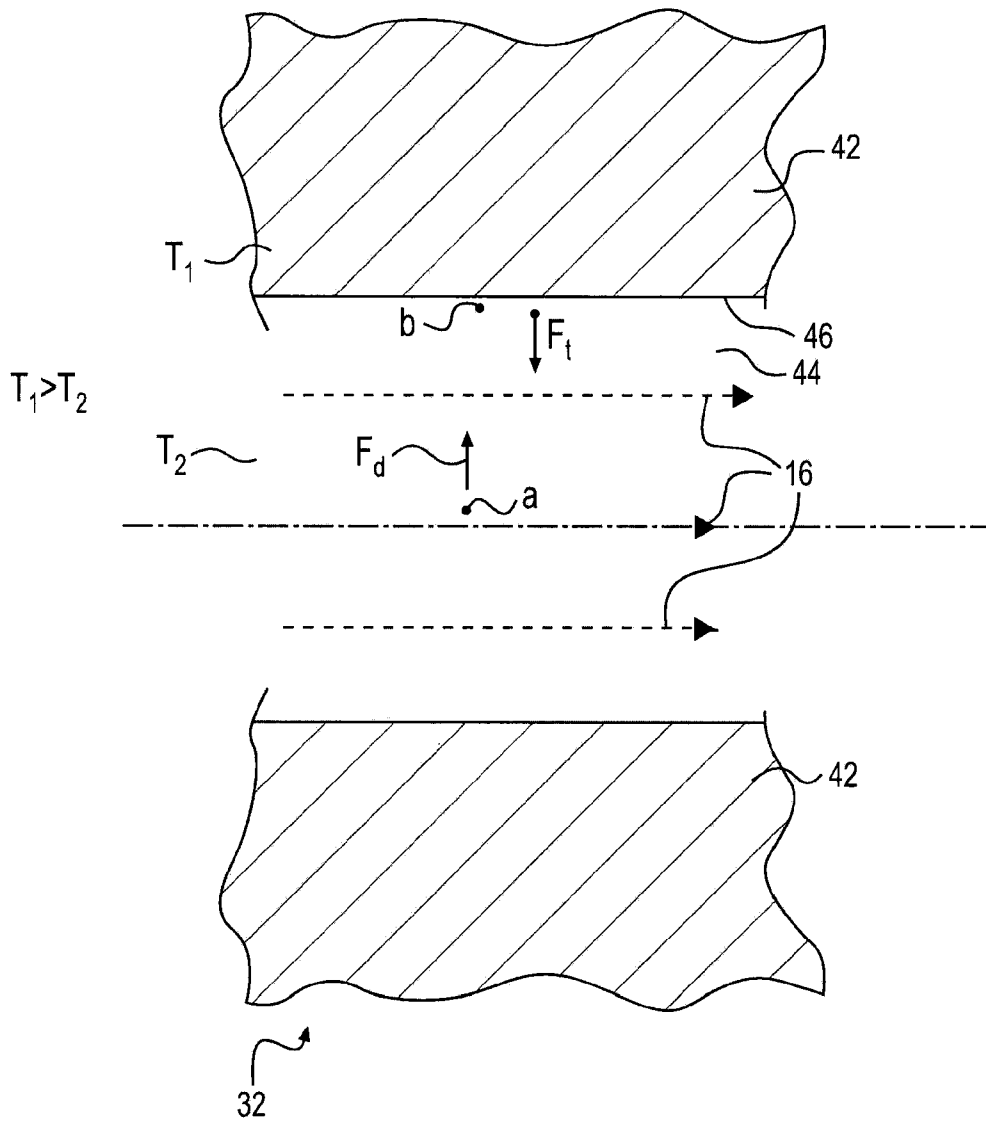


FIG. 2

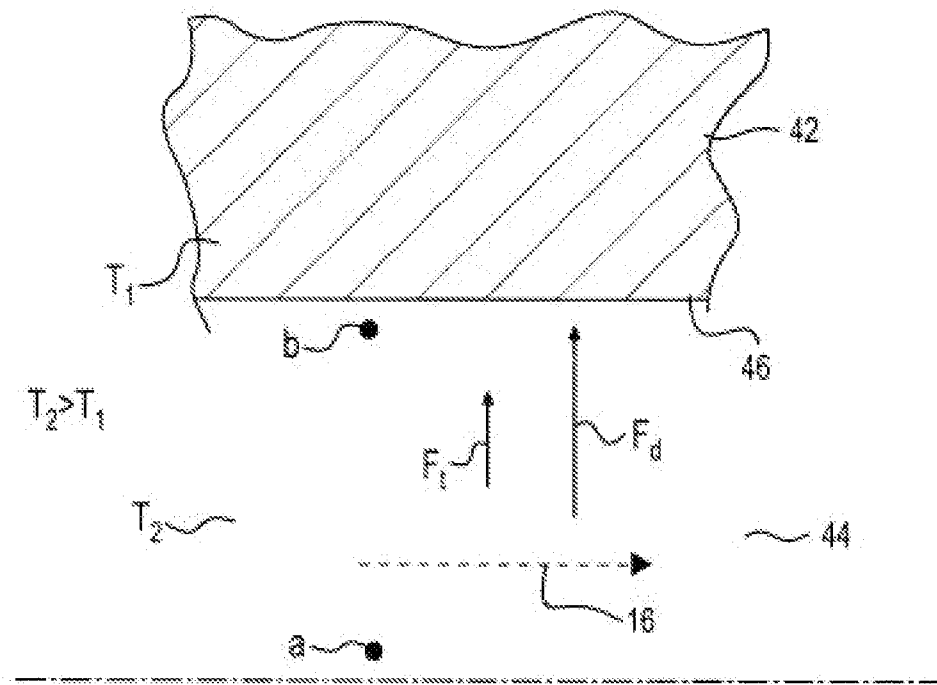
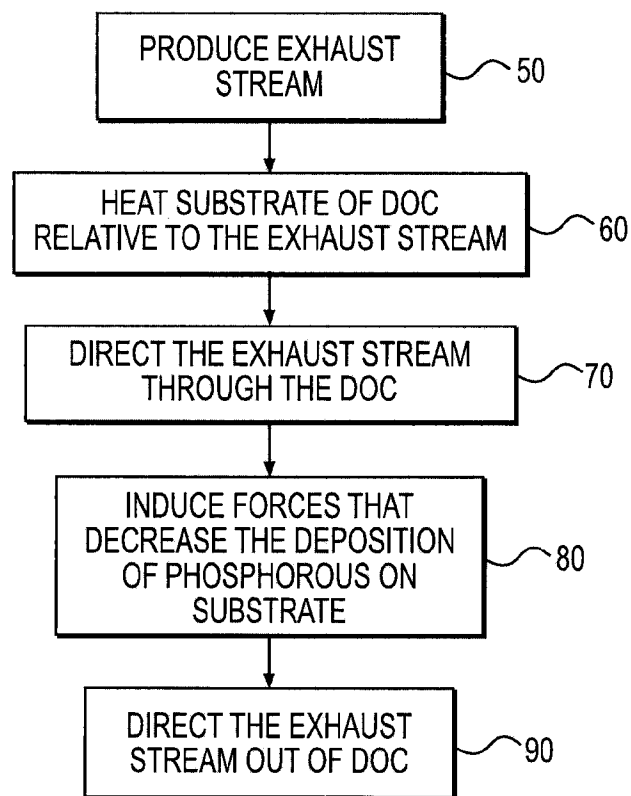


FIG. 3

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**FIG. 4**