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(54) METHOD OF REGENERATING A PARTICULATE FILTER

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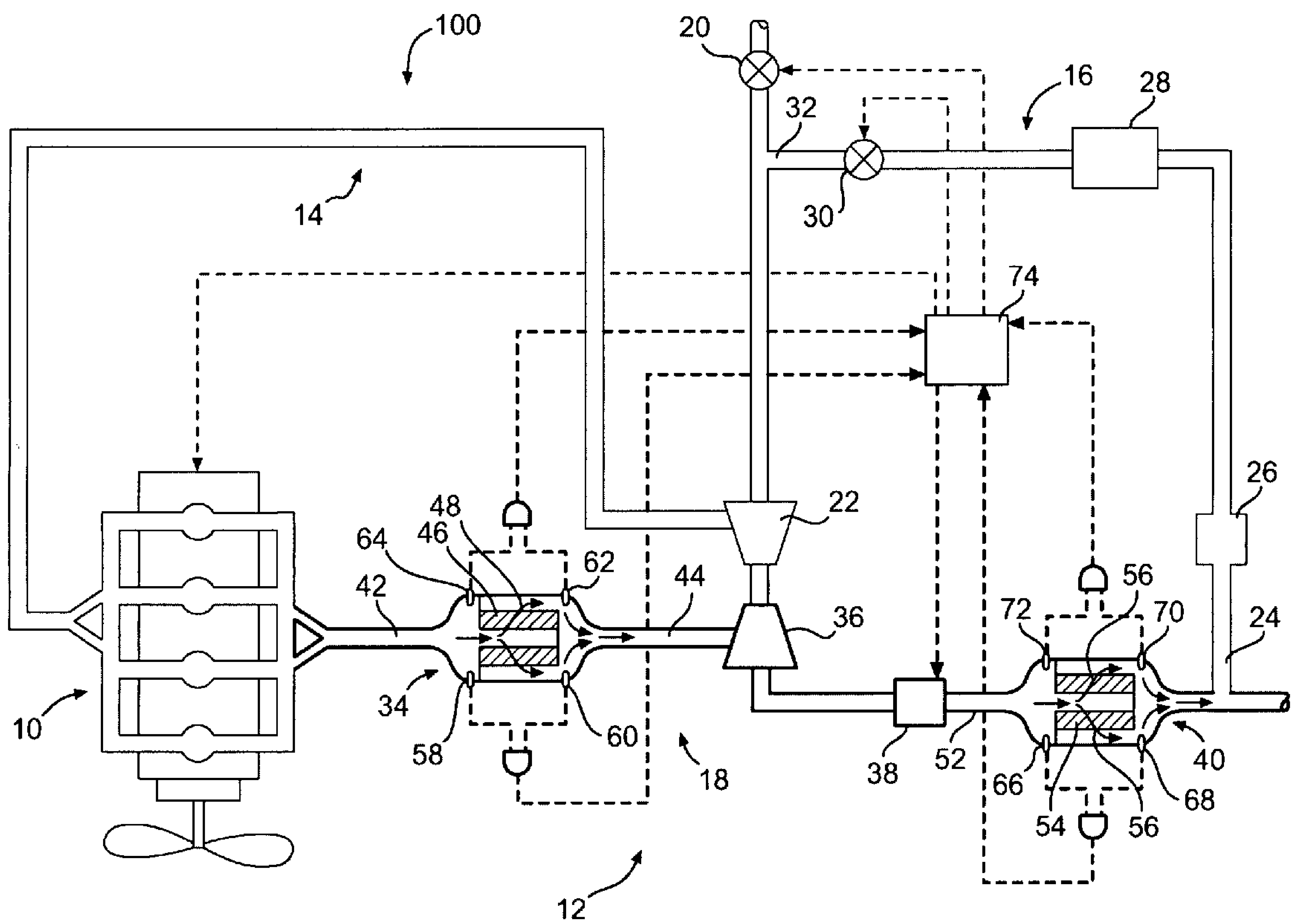
(57) **ABSTRACT**

A method of regenerating a particulate filter is disclosed. The method involves heating the particulate filter to an intermediate temperature, and maintaining the particulate filter at the intermediate temperature until substantial temperature equilibrium is reached. The particulate filter is then heated to a regeneration temperature higher than the intermediate temperature.



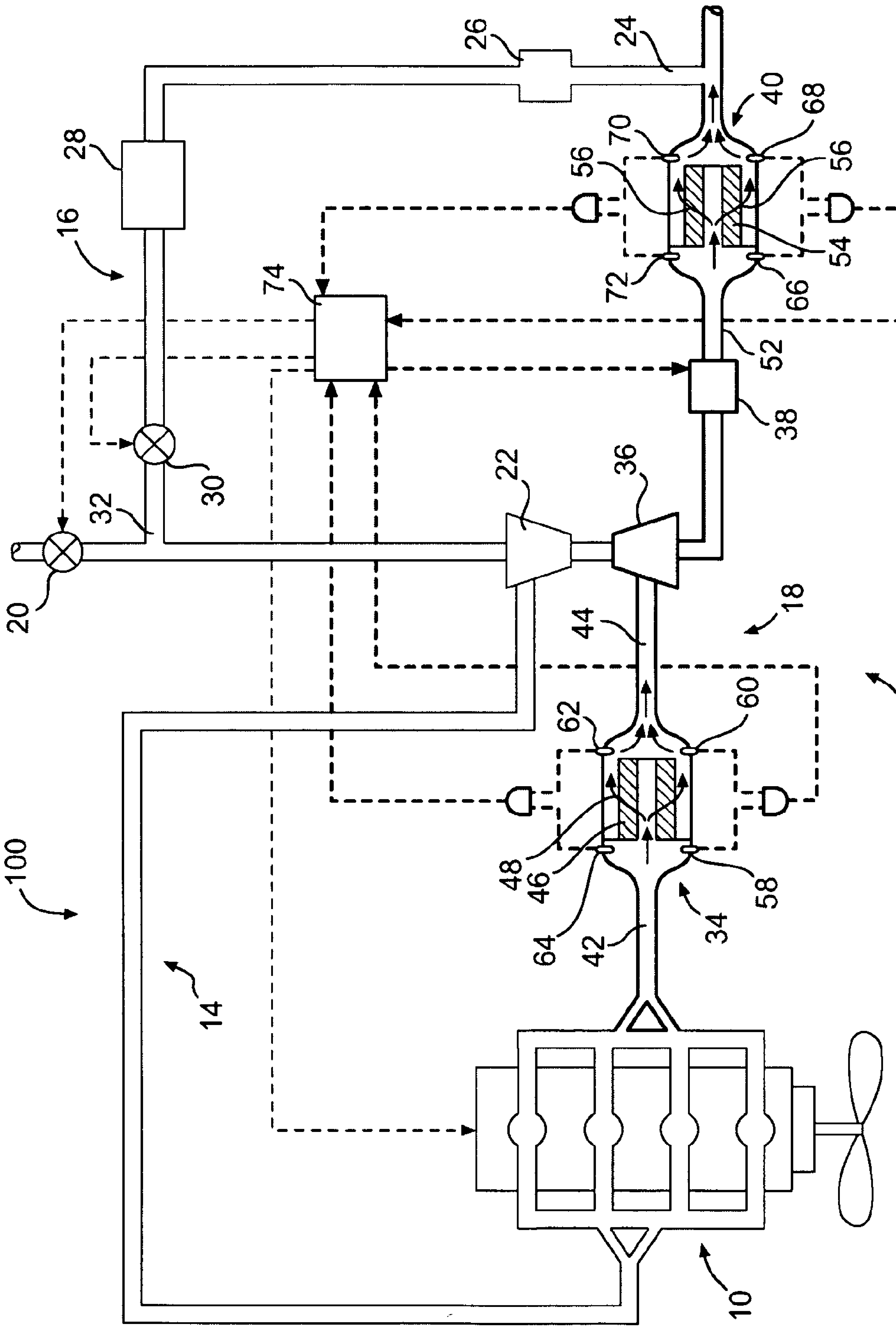

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FIG. 1

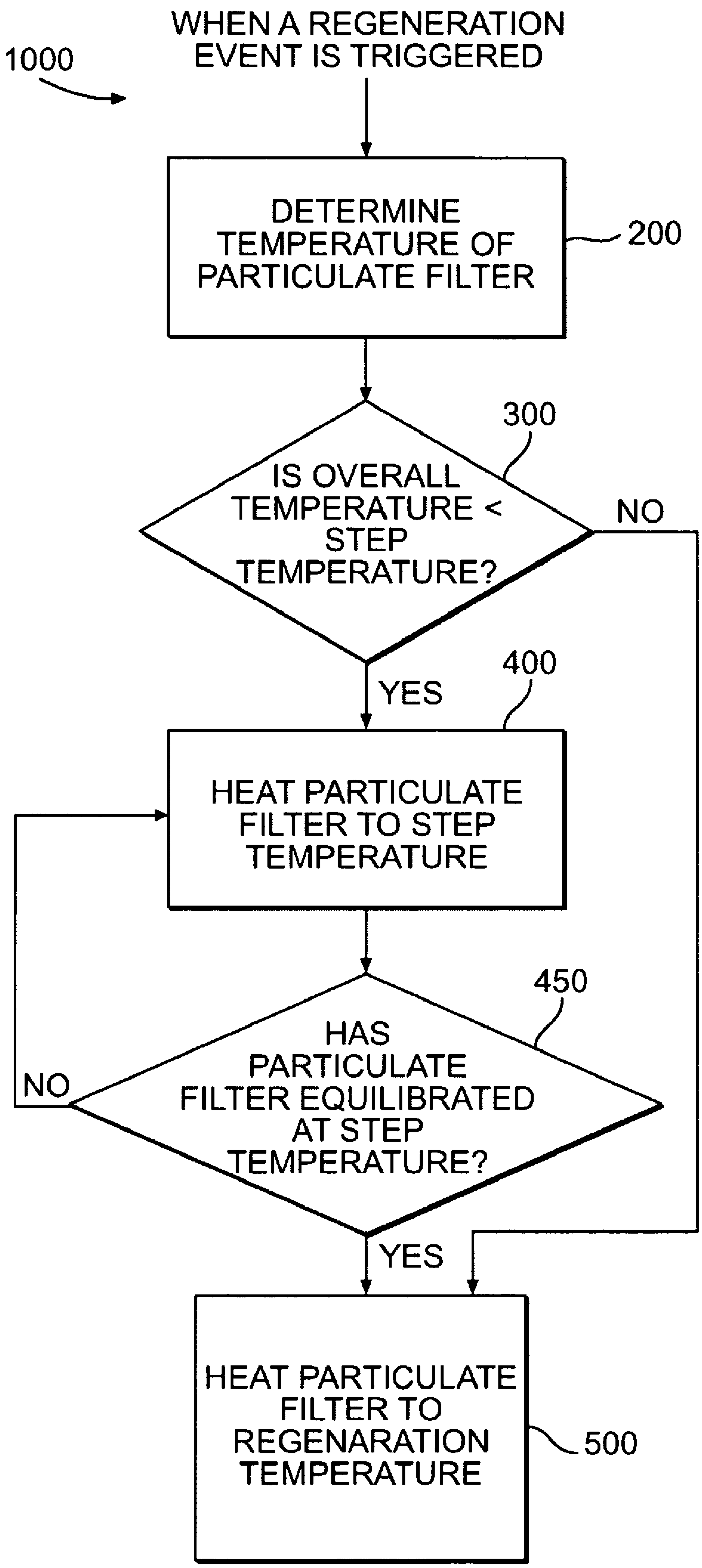
WHEN A REGENERATION EVENT IS TRIGGERED
1000
DETERMINE TEMPERATURE OF PARTICULATE FILTER
200
IS OVERALL TEMPERATURE < STEP TEMPERATURE?
300
NO
YES
400
HEAT PARTICULATE FILTER TO STEP TEMPERATURE
HAS PARTICULATE FILTER EQUILIBRATED AT STEP TEMPERATURE?
450
NO
YES
HEAT PARTICULATE FILTER TO REGENARATION TEMPERATURE
500

FIG. 2

METHOD OF REGENERATING A PARTICULATE FILTER

TECHNICAL FIELD

[0001] The present disclosure relates generally to particulate filter regeneration, and more particularly to a method to regenerate particulate filters.

BACKGROUND

[0002] Diesel engines and other engines known in the art may exhaust a complex mixture of air pollutants. The air pollutants may be composed of gaseous compounds and solid particulate matter, which may include unburned carbon particles called soot. Exhaust emission standards regulate the amount of particulate matter emitted from an engine. One method used by engine manufacturers to comply with these emission standards is to remove particulate matter from the exhaust flow of an engine using a particulate filter. Most particulate filters operate by a similar process of forcing engine exhaust through filter elements in the particulate filter that are designed to block particulate matter while allowing the gases to flow through. Periodically the accumulated particulate matter in the filter elements are burned off, to reduce the pressure drop within the filter (commonly referred to as backpressure). Filter regeneration is the process of burning the accumulated particulate matter in the filter elements. When filter regeneration is desired, the temperature of the exhaust gas is increased to raise the temperature of the accumulated soot in the filter to its combustion temperature. A catalyst is sometimes used to lower the regeneration temperature.

[0003] Filter regeneration causes different regions of the filter element to heat up at different rates causing a thermal gradient between these different regions. The thermal expansion mismatch between the different regions resulting from these thermal gradients induce thermo-mechanical stresses in the filter element. When the magnitude of these stresses exceed the strength of the filter element, the filter element cracks. In addition to reducing the useful lifetime of the particulate filter, cracks in the filter element create a leakage path for particulate to escape, thereby reducing filtration efficiency.

[0004] U.S. Pat. No. 5,701,735 (the '735 patent) to Kawaguchi describes a method of regenerating a particulate filter to reduce the likelihood of the filter "melting" or "cracking" due to high-temperature thermal stress. When regeneration of the particulate filter is desired, the method of the '735 patent allows a regenerative gas to flow through a particulate filter. While flowing through the upstream side, the regenerative gas cools the upstream side of the filter to below the regeneration temperature. Because of the transfer of heat from the upstream side, the temperature of the regenerative gas increases, reducing the cooling of the downstream side. This preferential cooling of the upstream side of the filter causes combustion to initiate on the downstream side of the filter during a regeneration event. The combustion flame then propagates to the upstream side of the filter. In the method of the '735 patent, propagation of the combustion flame within the filter is opposite to the direction of flow of the regenerative gas. Therefore, a part of the combustion heat is transferred upstream by the combustion flame and the remaining part is transferred downstream by the regenerative gas. This transfer of heat to both the upstream and downstream regions prevents overheating of the filter in any one region, thereby preventing the melting or cracking of the filter due to thermal stress.

[0005] Although the regeneration method of the '735 patent may reduce the component of thermal stress due to high temperature, it may introduce thermal stresses in the filter by intentionally inducing a thermal gradient in the filter. By selectively heating the down stream side of the filter and cooling the upstream side, a thermal gradient is created within the filter. This thermal gradient will cause the upstream side of the filter to expand by a different amount than the downstream side. This differential expansion of the filter caused by the thermal gradient induces thermal stresses in the filter. Further, additional parts, such as valves, pipes and other components associated with the regenerative gas, may have to be added to the exhaust system to practice the method of regeneration of the '735 patent. These additional parts may increase the cost of the exhaust system.

[0006] The disclosed method of regeneration of a particulate filter is directed to overcoming one or more of the problems set forth above.

SUMMARY OF THE INVENTION

[0007] In accordance with one aspect, the present disclosure is directed towards a method of regenerating a particulate filter. The method involves triggering a regeneration process and determining a value indicative of an initial temperature of the particulate filter. The initial temperature is then compared to an intermediate temperature, and the particulate filter is preheated to the intermediate temperature. The particulate filter is then maintained at the intermediate temperature for a predetermined period of time, and the particulate filter is heated to a regeneration temperature.

[0008] According to another aspect, the present disclosure is directed to a method of regenerating a diesel particulate filter. The method involves heating the particulate filter to an intermediate temperature, and maintaining the particulate filter at the intermediate temperature until substantial temperature equilibrium is reached. The particulate filter is then heated to a regeneration temperature higher than the intermediate temperature.

[0009] In yet another aspect, the present disclosure is directed to an exhaust system of an engine. The exhaust system includes a particulate filter through which exhaust gas flows, one or more temperature sensors attached to the particulate filter, and a control system electrically connected to the sensors. The sensors are configured to measure a value indicative of a temperature of the particulate filter. The control system is configured to heat the particulate filter to an intermediate temperature that is higher than the overall temperature, maintain the particulate filter at the intermediate temperature until a substantial temperature equilibrium is reached, and heat the particulate filter to a regeneration temperature that is higher than the intermediate temperature.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1** is a diagrammatic illustration of an engine system having an exhaust treatment system with particulate filters according to an exemplary embodiment of the present disclosure;

[0011] FIG. 2 is an exemplary method of regenerating a particulate filter of FIG. 1.

DETAILED DESCRIPTION

[0012] FIG. 1 illustrates an engine system 100 having a power source 10 having an exemplary exhaust treatment system 12. Power source 10 may include an engine such as, for example, a diesel engine, a gasoline engine, a natural gas engine, or any other engine apparent to one skilled in the art. Power source 10 may alternately include another source of power such as a furnace or any other source of power known in the art. Exhaust treatment system 12 may include an air induction system 14, a recirculation system 16, and an exhaust system 18.

[0013] Air induction system 14 may be configured to introduce charged air into a combustion chamber (not shown) of power source 10. Air induction system 14 may include an induction valve 20, compressor 22, and other components known in the art such as, one or more air coolers, additional valving, one or more air cleaners, one or more waste gates, a control system, etc.

[0014] Recirculation system 16 may be configured to redirect a portion of the exhaust flow of power source 10 from exhaust system 18 into air induction system 14. Recirculation system 16 may include components such as, an inlet port 24, a recirculation particulate filter 26, a cooler 28, a recirculation valve 30, and a discharge port 32. Inlet port 24 may be connected to exhaust system 18 and configured to receive at least a portion of the exhaust flow from power source 10. Specifically, inlet port 24 may be disposed downstream of a particulate filter 40. It is contemplated that inlet port 24 may be located elsewhere within exhaust system 16.

[0015] Exhaust system 18 may be configured to direct exhaust flow out of power source 10. Exhaust system 18 may include a first particulate filter 34, a turbine 36, a regeneration assist system 38, and a second particulate filter 40. It is contemplated that additional emission controlling devices may be included within exhaust system 18.

[0016] First particulate filter 34 may be connected to power source 10 via a fluid passageway 42 and to turbine 36 via a fluid passageway 44. First particulate filter 34 may include a first filter element 46 configured to filter particulate matter from the exhaust flow. First particulate filter 34 may also be fitted with sensors to measure different parameters pertaining to the operating condition of the filter.

[0017] The first filter element 46 may be of any type known in the art, such as, for example, ceramic cordierite, ceramic foam, other ceramic, sintered metal, or metal foam type filter. The first filter element 46 assists in removing particulate matter, such as soot, from the exhaust flow. The first filter element 46 may be situated horizontally, vertically, radially, or in any other configuration that allows for proper filtration. The first filter element 46 may of a honeycomb, mesh, mat, or any other construction that allows for proper filtering of particulate matter. The first filter element 46 may contain pores, cavities or spaces of a size that allows exhaust gas to flow through while substantially restricting the passage of particulate matter. The flow of exhaust through the pores of the first filter element 46 is illustrated by the arrows 48. In some applications, the first filter element 46 may contain heating elements configured to heat the first filter element 46 and the exhaust flow during a regeneration event. First particulate filter 34 may also include a catalyst to catalyze the particulate matter filtered by the first particulate filter 34. The catalyst may include, for example, a base metal oxide, a molten salt, and/or a precious metal that assists in reducing the combustion temperature of particulate matter.

[0018] The sensors attached to the first particulate filter 34 may include among others, pressure sensors 58, 60 and temperature sensors 62, 64. These sensors may be located proximate to the inlet and the outlet of the first particulate filter 34. The pressure sensors 58, 60 may measure the pressure drop of the exhaust flow across the filter, and the temperature sensors 62, 64 may measure the temperature of the exhaust entering and exiting the first particulate filter 34. The temperature sensor data may be used to calculate an overall temperature of the first particulate filter 34. The overall temperature may be a temperature value calculated from the temperature sensor data based upon a mathematical model. In some cases, the overall temperature may represent the average temperature of a particulate filter. It is contemplated that these sensors may be located at other locations within the first particulate filter 34. For instance, one or more temperature sensors may be located at different locations of the first filter element 46 to measure the temperature variation between the different locations. The temperature sensor data may also be used to determine the temperature gradient across the first filter element 46 or any other thermal characteristic related to the measured temperatures. It is also contemplated that other sensors, such as flow rate sensors, mass sensors, etc. may be used to measure other operating characteristic of the first particulate filter 34. The pressure sensors 58, 60 and temperature sensors 62, 64 along with other sensor of the first particulate filter 34 may be electrically connected to a control system 74.

[0019] As noted above, the first particulate filter 34 may be fluidly connected a turbine 36. The turbine 36 may be located downstream of the first particulate filter 34 and may be mechanically coupled to drive the compressor 22 of the air induction system 14 to form a turbocharger. In particular, as the hot exhaust gases exiting power source 10 expand against the blades of turbine 36, the shaft of turbine 36 may rotate and drive the connected compressor 22. It is contemplated that more than one turbine 36 may be included within exhaust system 18 and disposed in parallel or series relationship. It is also contemplated that turbine 36 may, alternately, be omitted and compressor 22 be driven by power source 10 mechanically, hydraulically, electrically, or in any other manner known in the art.

[0020] Downstream to the turbine 36, may be located a regeneration assist system 38. The exhaust flow exiting the turbine 36 may flow through the regeneration assist system 38. The regeneration assist system 38 may include systems, such as a fuel driven burner or an oxidation catalyst system. The regeneration assist system 38 may assist in the regeneration of the second particulate filter 40, and may be configured to increase the temperature of the exhaust flowing through it. For instance, fuel may be sprayed by the fuel driven burner and ignited within the regeneration assist system 38 to heat the exhaust flow. The regeneration assist system 38 may include components, such as spark plugs, spray nozzles, fuel lines, burners, and any other means that assists in heating the exhaust flow. In some applications, the regeneration assist system 38 may heat the exhaust flow electrically and may include electrical resistive heaters. The regeneration assist system may also include instrumentation to communicate with and execute instructions from a control system **74**. These instructions may include commands from the controls system **74** instructing the regeneration assist system **38** begin heating the exhaust flow. The regeneration assist system **38** may also be fitted with sensors (not shown) to measure different operating conditions, such as temperature, pressure, flow rate, etc. of the regeneration assist system **38**.

[0021] Although the regeneration assist system **38** is depicted as located between the between the turbine **36** and the second particulate filter **40** to assist in regeneration of the second particulate filter **40**. The regeneration assist system **38** may also be located upstream of the first particulate filter **34** to assist in regeneration of the first particulate filter **34**. In some applications, multiple regeneration assist systems **38** may be located upstream of different particulate filters to assist in regeneration of the respective filters. In some applications the regeneration assist system **38** may not be located upstream of some particulate filters, and the heat to regenerate those filters may be provided by other means. For instance, the heat to regenerate the first particulate filter **34** may be provided by the power source **10**, or by heating elements located in first particulate filter element **34**. In some applications, the exhaust flow may be heated by electromagnetic radiation, such as microwaves. Using a regeneration assist system **38** to heat the exhaust flow may make the heating of the exhaust flow more controllable. For example, by using only the correct amount of fuel necessary to heat the exhaust flow to the required temperature, good control over the exhaust gas temperature may be achieved.

[0022] The second particulate filter **40** may be disposed downstream of the regeneration assist system **38**. Specifically, second particulate filter **40** may be fluidly connected to regeneration assist system **38** via a fluid passageway **52**. The second particulate filter **40** may include a second filter element **54** to filter particulate matter from the exhaust flow. Similar to the first filter element **46**, the second filter element **54** may also be of any type known in the art, may be situated in any configuration, and may be of any construction that allows for proper filtering of particulate matter. The flow of exhaust through the pores of the second filter element **54** is illustrated by the arrows **56**. In some applications, the pore size of the second filter element **54** may be different than the pore size of the first filter element **46** to filter a different size of particulate matter particles. Similar to first particulate filter **34**, the second particulate filter **40** may also include a catalyst to reduce the ignition temperature of particulate matter trapped by second particulate filter **40**, and heating elements to heat the accumulated particulate matter. Similar to the first particulate filter **34**, the second particulate filter **40** may also include pressure sensors **66**, **68** and temperature sensors **70**, **72** to measure the pressure drop across the second particulate filter **40** and temperatures at different locations within the filter. These sensors may also be electrically connected to the control system **74**.

[0023] The control system **74** may include all the components to manage the exhaust treatment system **12** such as, for example, a memory, a secondary storage device, and a processor. Various circuits may be associated with control system **74** such as, for example, power supply circuitry, signal conditioning circuitry, and other appropriate circuitry. The control system **74** may be connected to different components of the exhaust treatment system **12** and may be configured to send and receive signals to and from the different components. These signals may include data from different sensors and commands instructing a component to perform a particular task. For instance, the control system **74** may be configured to receive temperature and pressure data signals from the first and second particulate filters **34**, and **40**, and send instructions to the regeneration assist system **38**. Signals from other sensors which may indicate different parameters related to the operating condition of the exhaust treatment system **12** may also be input to the control system **74**.

[0024] The control system **74** may be configured to store different parameter values. These stored parameters may include user specified values and values calculated by the control system **74**. For instance, the stored parameters may include a regeneration temperature, a step temperature, a limit pressure drop, and a limit time.

[0025] The regeneration temperature may be an average temperature at which collected particulate matter in a particular filter burns. The regeneration temperature may also be the lower limit of a range of temperatures at which the accumulated particulate matter in a particulate filter burns. It may be a user-defined value or may be a value that the control system **74** computes from sensor inputs.

[0026] The step temperature may be a temperature value to which a particulate filter **34**, **40** may be heated prior to regeneration. The step temperature may be a user-specified constant temperature value lower than a regeneration temperature of the filter. It may also be a value that is calculated by the control system **74** based upon the sensor signals. For instance, based upon the temperature sensors **70**, **72** the control system **74** may compute an overall temperature of the second particulate filter **40**. The control system **74** may further compute the step temperature based on a mathematical model. For instance, the step temperature may be calculated based upon the thermo-mechanical stresses induced in a filter element **46**, **54**. Specifically, the step temperature may be calculated such that the stresses generated in the filter element **46**, **54** due to a change of temperature from the step temperature to the regeneration temperature does not exceed the strength of the filter element **46**, **54**. The step temperature may be a temperature value which is higher than the overall temperature and lower than the regeneration temperature of the filter. The step temperature may be also be calculated based upon the temperature gradient in a filter element **46**, **54**.

[0027] The limit pressure drop may be a user specified value or a value calculated by the control system **74**. For instance, the limit pressure drop may be specified by a user based upon the maximum permissible pressure drop across a particulate filter. It may also be calculated by the control system based upon sensor inputs.

[0028] The time limit may indicate a time duration between filter regenerations. It may be a constant value specified by a user, or it may be calculated by the control system **74** based upon sensor inputs. In some cases, it may be a user-defined value based on prior experience.

[0029] The control system **74** may be configured to perform different mathematical and logical operations and compare the results with other calculated results and stored parameters. For instance, based on signals from the pressure sensors **66**, **68** the control system **74** may calculate the pressure drop across the second particulate filter **40**. The control system **74** may then compare this calculated pressure drop with the stored limit pressure drop. The control system **74** may also calculate an overall temperature of the second particulate filter **40** based on signals from the temperature sensors **70**, **72** and compare the result with the stored step temperature. The control system **74** may also do a model based calculation based on some or all of the sensor data, and may compare the result with other stored or calculated values. The results of the comparisons and calculations by the control system **74** may be used to control different components of the exhaust treatment system **12**. For instance, the control system **74** may trigger the regeneration assist system **38** to begin heating the exhaust flow through it when the pressure drop across the second particulate filter **40** reaches or exceeds the limit pressure drop, when the overall temperature of the second particulate filter **40** is lower than the step temperature, or when the time between regenerations of the second particulate filter **40** exceed the stored time limit. It is also contemplated that in some applications, the control system **74** may trigger the regeneration assist system **38** to begin heating the exhaust flow based on other comparisons, calculations or sensor inputs. For instance, the control system **74** may use a mathematical model to determine the particulate matter loading in a filter, and use these results trigger the regeneration assist system. In some cases, a sensor signal indicating a mass flow rate through the fluid passageway **52** below a preset value may also trigger regeneration of the second particulate filter **40**. The control system **74** may also signal the regeneration assist system **38** to stop heating the exhaust flow based upon results of the comparisons, calculations or sensor inputs. For example, when the overall temperature of the second particulate filter **40** reaches or exceeds the step temperature, the control system **74** may signal the regeneration assist system **38** to stop heating the exhaust flow. The control system **74** may also control the operation of other components of the exhaust treatment system **12**. For instance, the control system may control the operation of the induction valve **20** and the recirculation valve **30** based upon signal inputs or calculated values. In some applications, the control system **74** may be part of the engine computer system. In these applications, the control system **74** may also control the operation of other components of the engine system **100**.

INDUSTRIAL APPLICABILITY

[0030] The disclosed method of regenerating a particulate filter **34**, **40** may be used with any type of engine system **100** that exhausts exhaust gases containing particulate matter. The engine system **100** may include diesel engines, gasoline engines, gaseous fuel driven engines, or any other engine known in the art. The engine system **100** may also be a part of a mobile or a stationary machine. Some of the particulate matter exhausted by the engine system **100** gets filtered by filter elements **46**, **54** within the particulate filters **34**, **40**. These particulate filters **34**, **40** are regenerated periodically to prevent the accumulated particulate matter from restricting exhaust flow through the filters. During regeneration, large temperature gradients are introduced between different sections of the filter elements **46**, **54**. The thermo-mechanical stresses resulting from these temperature gradients induce micro-cracks in the filter elements **46**, **54**. These micro-cracks deteriorate the filtering efficiency and the durability of the particulate filters **34**, **40**. The disclosed method of regeneration of particulate filters preserves the filtering efficiency and increases the durability of the particulate filters **34**, **40** by reducing the thermal gradients induced in the filter elements **46**, **54** during regeneration.

[0031] FIG. **2** illustrates the method **1000** of regeneration of the particulate filter in accordance with an embodiment of the current disclosure. To describe the operation of the disclosed method, an illustration describing the regeneration of the second particulate filter **40** is used. When the control system **74** triggers a regeneration process of the second particulate filter **40**, any of the above mentioned methods to regenerate the particulate filter may be executed. In this disclosure, triggering a regeneration process is used to indicate an initiation of the regeneration process. For example, initiation of the regeneration process may include commands from the control system **74** to begin heating the exhaust flow. The term regeneration process is used broadly to encompass all the heating and holding steps that eventually culminates in the combustion of particulate matter accumulated in the filter. For example, the regeneration process may include the steps of heating the exhaust flow to the step temperature, holding the temperature of the exhaust flow at the step temperature until the filter media equilibrates at that temperature, and heating the exhaust flow to the regeneration temperature.

[0032] The control system **74** may trigger a regeneration event when the pressure drop across a filter reaches or exceeds the pressure limit, when the time duration between successive regeneration events reaches or exceeds the time limit, or based upon a model based calculation. In some applications a regeneration event will be triggered at the first occurrence of one of the above listed events. In other applications, a regeneration event may only be triggered at the occurrence of more than one of the above listed events. It is also contemplated that the control system **74** may trigger a regeneration event based upon some other condition. For example, a regeneration may be triggered when a user initiates a regeneration event by activating a switch or a button.

[0033] When a regeneration event is triggered, the first step in the method **1000** of regeneration of a particulate filter is to determine the overall temperature of the second particulate filter **40** (step **200**). Determination of the overall temperature may include measuring the temperature of the exhaust flow entering and exiting the second particulate filter **40** using temperature sensors **70** and **72**. These measured temperatures may then be used to determine the overall temperature of the second particulate filter **40** using a mathematical model. In some applications, the mathematical model may include averaging the temperature readings from the temperature sensors **70**, **72**. In some other applications, a more complex mathematical model that may use other sensor inputs in addition to the temperature sensor inputs may be used to calculate the overall temperature. It is also contemplated that the control system **74** may directly use a temperature sensor input as the overall temperature of the second particulate filter **40**.

[0034] After determining the overall temperature of the second particulate filter **40**, the control system may compare this overall temperature with the step temperature (step **300**). If the overall temperature of the second particulate filter **40** is lower than the step temperature, the second particulate filter **40** may be heated to the step temperature (step **400**). To heat the second particulate filter **40** to the step temperature, the control system **74** may instruct the regeneration assist system **38** to start heating the exhaust flow through it. The heated exhaust flow may in turn heat the second particulate filter **40** while flowing through it. In some applications, the control system **74** may instruct the regeneration assist system **38** to heat the exhaust flow such that the second particulate filter **40** is heated and maintained at the step temperature. In some other applications, the control system **74** may use sensor inputs from temperature sensors **70**, **72** or other sensor inputs to maintain the second particulate filter **40** at the step temperature. In the comparison of step **300**, if the overall temperature of the second particulate filter **40** is at or above the step temperature, step **400** will not be executed, and the method will proceed directly to step **500**.

[0035] When the overall temperature of the second particulate filter **40** reach or exceed the step temperature (that is, when the condition of step **300** is satisfied), the particulate filter may be maintained at the step temperature until the particulate filter equilibrates at the step temperature (step **450**). Equilibrating the second particulate filter **40** at the step temperature may involve holding the second particulate filter **40** at the step temperature for a predetermined amount of time until substantially all regions of the second filter element **54** reaches the step temperature. This predetermined amount of time may be a user-specified time delay that may be stored in the control system **74**. The predetermined amount of time may provide sufficient time to allow the second filter element **54** of the second particulate filter **40** to substantially equilibrate to the step temperature. The predetermined amount of time may be determined from prior experience, experimental studies, analytical calculations or numerical computations (such as, for example, finite element analysis). When the second filter element **54** equilibrates at the step temperature, different sections of the filter element **54** are at substantially uniform temperature. In some applications, in place of a preset time delay, the control system **74** may maintain the second particulate filter **40** at the step temperature until inputs from temperature sensors indicate that the filter element **54** has substantially equilibrated at the step temperature.

[0036] After the particulate filter equilibrates at the step temperature (step **450**), the control system **74** may instruct the regeneration assist system **38** to further heat the exhaust flow to the regeneration temperature (step **500**). The regeneration temperature may be a user specified value of temperature stored in the control system **74** indicating the temperature at which the accumulated particulate matter in the second particulate filter **40** burns.

[0037] Although the description above focuses on the method of regenerating the second particulate filter **40**, the disclosed method can also be used to regenerate any other particulate filter in the engine system **100**. In applications without a regeneration assist system **38**, heating the particulate filter to the step temperature and then to the regeneration temperature may be accomplished by other means. For example, heat to regenerate the first particulate filter **34** may be obtained by using the power source **10** to heat the exhaust flow to the required temperature or by using heaters installed in the first particulate filter **34**.

[0038] Heating and equilibrating a particulate filter at an intermediate temperature close to the regeneration temperature before further heating it to the regeneration temperature, decreases the temperature difference between different regions of the filter element during regeneration. This decrease in temperature difference will decrease the difference in thermal expansion between different regions of the filter element, thereby reducing the thermo-mechanical stresses in the filter element. This reduction of stresses in the filter element will decrease the likelihood of stress induced micro-cracks in the filter element, thereby increasing its durability. Since the increase in durability is achieved without the use of additional parts or processing treatments, the cost of the particulate filter is not impacted.

[0039] It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed method of regenerating a particulate filter. Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the disclosed regeneration method. It is intended that the specification and examples be considered as exemplary only, with a true scope being indicated by the following claims and their equivalents.

What is claimed is:

1. A method of regenerating a particulate filter comprising:
- triggering a regeneration process;
- determining a value indicative of an initial temperature of the particulate filter;
- comparing the initial temperature to an intermediate temperature;
- preheating the particulate filter to the intermediate temperature;
- maintaining the particulate filter at the intermediate temperature for a predetermined period of time; and
- heating the particulate filter to a regeneration temperature higher than the intermediate temperature.

2. The method of claim **1**, wherein the triggering of the regeneration process includes triggering regeneration of the particulate filter when a pressure drop across the particulate filter exceeds a threshold pressure drop.

3. The method of claim **1**, wherein the triggering of the regeneration process includes triggering regeneration of the particulate filter when a time between two successive regeneration events exceeds a threshold time duration.

4. The method of claim **1**, wherein the triggering of the regeneration process includes triggering regeneration of the particulate filter based upon a mathematical model estimating a particulate matter loading of the particulate filter.

5. The method of claim **1**, wherein the determination of the value includes measuring an inlet temperature and an outlet temperature of the particulate filter.

6. The method of claim **5**, wherein the determination of the value includes computing an overall temperature of the particulate filter based on the inlet temperature and the outlet temperature.

7. The method of claim **1**, wherein the determination of the value includes determining a temperature variation between different regions within the particulate filter.

8. The method of claim **7**, wherein the triggering of the regeneration process includes triggering regeneration of the particulate filter based on the temperature variation within the particulate filter.

9. The method of claim **1**, wherein the comparison of the initial temperature to the intermediate temperature includes computing the intermediate temperature.

10. The method of claim **9**, wherein the computation of the intermediate temperature includes determining the intermediate temperature such that the stresses in the particulate filter due to heating the particulate filter from intermediate temperature to the regeneration temperature is below the strength of the particulate filter.

11. The method of claim **1**, wherein the maintaining of the particulate filter at the intermediate temperature includes holding the particulate at the intermediate temperature until the particulate filter substantially equilibrates at the intermediate temperature.

12. The method of claim **11**, wherein the holding of the particulate filter at the intermediate temperature includes holding the particulate filter at the intermediate temperature until multiple temperature sensor readings indicate that the particulate filter has substantially equilibrated at the intermediate temperature.

13. The method of claim **1**, wherein the preheating of the particulate filter to the intermediate temperature, and the heating of the particulate filter to the regeneration temperature includes heating an exhaust gases supplied to the particulate filter using a fuel driven burner located upstream of the particulate filter.

14. The method of claim **1**, wherein heating the particulate filter to a regeneration temperature includes heating the particulate filter to a temperature at which an accumulated particulate matter in the particulate filter begins burning.

15. A method of regenerating a diesel particulate filter comprising:

heating the particulate filter to an intermediate temperature;

maintaining the particulate filter at the intermediate temperature until substantial temperature equilibrium is reached; and

heating the particulate filter to a regeneration temperature higher than the intermediate temperature.

16. The method of claim **15**, wherein the heating of the particulate filter to the intermediate temperature and the heating of the particulate filter to the regeneration temperature includes heating exhaust gases supplied to the particulate filter.

17. The method of claim **16**, wherein the heating of the exhaust gases includes heating the exhaust gases using a fuel driven burner located upstream of the particulate filter.

18. An exhaust system of an engine comprising;

a particulate filter through which exhaust gas flows;

one or more temperature sensors attached to the particulate filter, wherein the sensors are configured to measure a value indicative of a temperature of the particulate filter; and

a control system electrically connected to the sensors, wherein the control system is configured to:

heat the particulate filter to an intermediate temperature that is higher than the overall temperature,

maintain the particulate filter at the intermediate temperature until a substantial temperature equilibrium is reached, and

heat the particulate filter to a regeneration temperature that is higher than the intermediate temperature.

19. The system of claim **18**, further including a fuel driven burner located upstream of the particulate filter.

20. The system of claim **19** wherein the fuel driven burner is configured to heat the exhaust gas supplied to the particulate filter such that the particulate filter is heated to the intermediate temperature, maintained at the intermediate temperature, and heated to the regeneration temperature, in response to one or more commands from the control system.

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