(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
20 November 2008 (20.11.2008)

PCT

(10) International Publication Number
WO 2008/138146 A1

(51) International Patent Classification:
F01N 3/023 (2006.01) *B01D 53/92* (2006.01)
B01D 46/00 (2006.01) *F01N 3/025* (2006.01)

(21) International Application Number: PCT/CA2008/000945

(22) International Filing Date: 15 May 2008 (15.05.2008)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/938,106 15 May 2007 (15.05.2007) US
60/953,856 3 August 2007 (03.08.2007) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL,

[Continued on next page]

(54) Title: SEGMENTED PARTICULATE FILTER FOR AN ENGINE EXHAUST STREAM

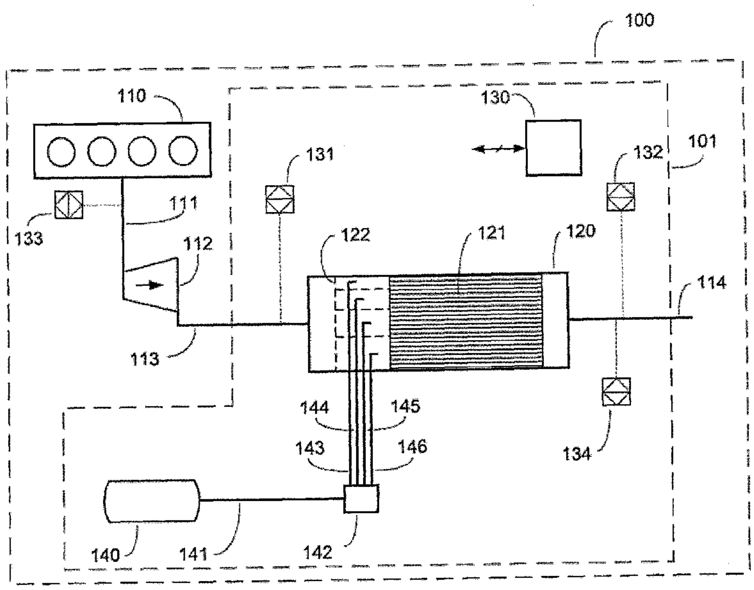


FIG. 8

(57) **Abstract:** A particulate filter is fluidly connected to and disposed downstream from a diesel engine exhaust stream outlet. The filter has a plurality of filter segments that have differing physical properties or structural characteristics such that the engine exhaust stream to fuel stream ratio is maintained substantially consistent among segments during their regeneration. A method for regenerating a segmented filter comprises maintaining the engine exhaust stream to fuel stream ratio substantially consistent among segments during their regeneration.

WO 2008/138146 A1

NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

SEGMENTED PARTICULATE FILTER FOR AN ENGINE EXHAUST STREAM

Field of the Invention

[0001] The present invention relates to engine exhaust stream particulate filters and, more particularly, to diesel engine exhaust stream particulate filters. A diesel particulate filter (sometimes abbreviated herein as a "DPF") is a device designed to remove diesel particulate matter or soot from the exhaust gas stream of a diesel engine.

Background of the Invention

[0002] Diesel engines, during combustion of the fuel/air mixture, produce a variety of particles, generically classified as diesel particulate matter, due to incomplete combustion. The composition of the particles varies widely depending upon engine type, age and the emissions specification that the engine was designed to meet.

[0003] Historically, diesel engine emissions were not regulated until 1987 when the first California Heavy Truck rule was introduced capping particulate emissions at 0.60 g/BHP hour. Since then, progressively stricter standards have been introduced for diesel engine particulate emissions. While particulate emissions from diesel engines were first regulated in the United

States, similar regulations have also been adopted by the European Union, most Asian countries, and the rest of North and South America.

[0004] A DPF cleans an exhaust gas stream by forcing the gas stream to flow through the filter. There are a variety of diesel particulate filter technologies on the market. Each is designed around similar requirements:

[0005] (a) fine filtration;

[0006] (b) minimal pressure drop;

[0007] (c) low cost;

[0008] (d) mass production suitability; and

[0009] (e) product durability.

[0010] Filters generally require more maintenance than catalytic converters. Particulates trapped by the filter will eventually clog the pores. This increases the pressure drop across the filter which, when it reaches or exceeds a critical value, is capable of reducing the efficiency of the engine. Regular filter maintenance or regeneration therefore becomes necessary.

[0011] Regeneration is the process of removing accumulated particulates from a filter. This is done either passively or actively by intentionally increasing the temperature of the trapped particulates. On-board active filter management can employ a variety of strategies, for example:

[0012] (1) Engine management to increase the exhaust gas temperature.

[0013] (2) A fuel burner to increase the exhaust gas temperature.

[0014] (3) A catalytic oxidizer to increase the exhaust gas temperature.

[0015] (4) Resistive heating coils to increase the exhaust gas temperature.

[0016] (5) Microwave energy to increase the particulate temperature.

[0017] On-board active regeneration systems consume extra fuel, whether through burning the fuel to heat the DPF or providing extra power to the associated electrical system. Typically a computer monitors one or more sensors that measure back-pressure and/or temperature and, based on pre-programmed set points, makes decisions on when to activate and end the regeneration cycle. Running the regeneration cycle too often, although keeping the back-pressure in the exhaust system low will use extra fuel. Not regenerating the DPF sufficiently frequently can increase the risk of engine damage, can reduce engine efficiency due to high back pressure, and can result in excessive regeneration temperatures and possible DPF failure.

[0018] Typically without the use of catalysts, diesel particulate matter combusts when temperatures around 600°C and above are attained. The start of combustion causes a further increase in temperature. In some cases the combustion of particulate matter can raise the temperature of the DPF above a threshold temperature that can cause damage to the DPF. Unlike spark-ignited engines, which typically have less than 0.5% oxygen in the exhaust gas stream upstream from the emission control device(s), many diesel engines typically have 8% to 18% oxygen in the exhaust stream pre-filter. While the amount of available oxygen makes fast regeneration of a filter possible, it can also contribute to runaway regeneration problems.

[0019] The particulate filter can be divided into segments which can be regenerated at different times by the selective introduction of a fuel into the particular segment(s) being regenerated, while the engine exhaust stream continues to flow though all segments of the filter including those that are being regenerated. Regenerating a segment or portion of the filter at a given time, compared to the entire filter, reduces the required mass flow rate of the fuel used for regeneration. If, for example, syngas is used as the fuel, this approach can offer the advantage of reducing the size and cost of a syngas generator required by the system. Furthermore, there are advantages to regenerating segments of the filter sequentially in a continuous cycle, so that syngas is being directed into at least one filter segment at a given time during operation of said particulate filter. This enables an essentially continuous requirement for the syngas stream and can offer the advantage of reducing the fluctuations in demand for the syngas stream.

[0020] If a DPF is segmented into equal segments of the substantially same dimensions and structure, when all segments are equally loaded with soot the flow rate of exhaust gas passing through each of the segments will be about the same. For example, if the DPF is segmented into four quadrants then about 25% of the exhaust gas flow will pass through each segment when all segments are equally loaded with soot.

[0021] If only one segment has been regenerated, then more than 25% of the exhaust gas stream will pass through the “clean” segment, thereby leaving less exhaust gas to pass through each of the other segments when they are being regenerated. If a fixed mass flow rate of fuel is supplied during regeneration, the result is that the fuel-to-exhaust gas ratio will be higher in the next segment to be regenerated, and the temperature associated with combusting a fixed amount of fuel, for example syngas (a mixture of hydrogen and carbon monoxide), will be higher and thus potentially damaging to the DPF’s catalyst, washcoat and/or substrate.

[0022] As progressively more and more segments are regenerated, the ratio of syngas to exhaust gas will increase further, thereby resulting in higher temperatures and more of a chance of damage to the DPF. The present approach utilizes the benefits of a segmented particulate filter while addressing this issue.

Summary of the Invention

[0023] In a preferred method for regenerating a segmented engine exhaust stream particulate filter, the heat value ratio of the engine exhaust stream to the fuel stream introduced into each individual segment during regeneration is maintained substantially consistent among segments. This offers the advantages of reducing the risk of thermal damage to the filter during regeneration (by decreasing the variation in the maximum regeneration temperatures reached in each segment), increased regeneration consistency between the segments, and reduced fuel consumption.

[0024] In one aspect, the filter comprises a plurality of filter segments that have differing physical properties or structural characteristics such that the engine exhaust stream to fuel stream ratio is maintained substantially consistent among segments during their regeneration. The segments can be designed and constructed so that if they were each supplied with a gas stream under the same conditions, the mass flow of that gas stream through each of them would be different. Such filters are described herein as "unequally segmented filters".

[0025] In another aspect, the mass flow rate of the fuel stream or syngas stream introduced to each individual segment can be varied to enable a substantially consistent heat value ratio of the streams introduced into each segment during regeneration.

[0026] Thus, in preferred embodiments an engine exhaust stream particulate filter comprises at least two filter segments wherein the segments are structured so that if they were each supplied with a gas stream under identical conditions, the gas stream mass flow through each of the segments would be different. For example, the segments can differ from each other in at least one structural characteristic selected from the group consisting of cross-sectional area, longitudinal filter length, filter porosity and filter cell density. Preferably, the segments differ from each other in at least one structural characteristic such that the engine exhaust stream mass flow rate through each segment during their regeneration is approximately equal. In compact designs, the filter segments can be housed in a common enclosure.

[0027] In embodiments of a method for operating a particulate filter comprising a plurality of filter segments, the method comprises:

[0028] (a) directing an exhaust stream from a combustion engine through the plurality of filter segments;

[0029] (b) selectively introducing a hydrogen-containing gas stream at least periodically into each of the filter segments to regenerate the segment;

[0030] (c) maintaining the engine exhaust stream to hydrogen-containing gas stream heat value ratio used for regeneration of each segment substantially consistent among the plurality of segments.

[0031] In some embodiments of the above method, the engine exhaust stream mass flow rate through each segment is different so that the heat value ratio is maintained substantially consistent among segments during their regeneration. The segments can be structured as described above, so that if they were supplied with a gas stream under identical conditions, the gas stream mass flow through each one of the plurality segments would be different.

[0032] In other embodiments of the above method, the heat value ratio is maintained substantially consistent among segments during their regeneration by varying the mass flow rate of the hydrogen-containing gas stream that is introduced to regenerate each segment. For example, the mass flow rate of the hydrogen-containing gas stream that is introduced to regenerate each segment can depend upon its position in a regeneration sequence

[0033] In the above-described methods, the hydrogen-containing gas stream can be introduced into the plurality of segments sequentially in a regeneration sequence.

[0034] In the above-described methods, the duration of regeneration of each segment can be substantially the same.

[0035] The above-described methods can be employed in a non-continuous regeneration cycle or in a continuous regeneration cycle in which the hydrogen-containing gas stream is being introduced into at least one filter segment at a given time, so that at least one filter segment is undergoing regeneration during operation of the particulate filter.

[0036] In embodiments of an engine and exhaust after-treatment system, the system comprises:

[0037] (a) a combustion engine;

[0038] (b) a particulate filter connected to receive an exhaust gas stream from the engine via an exhaust stream conduit, the particulate filter comprising a plurality of filter segments with different structural characteristics from one another, wherein during operation of the particulate filter the exhaust gas stream is directed through the segments in parallel;

[0039] (c) a syngas generator for producing a syngas stream;

[0040] (d) a controller configured to selectively direct the syngas stream to each of the segments in sequence to regenerate the segment.

[0041] Preferably the filter segments are structured so that if they were each supplied with a gas stream under identical conditions, the gas stream mass flow through each of the segments would be different.

Brief Description of the Drawing(s)

[0042] FIG. 1 is a photographic image showing an end view of a diesel particulate filter with one of four equal segments regenerated.

[0043] FIG. 2a is a simplified end view of a diesel particulate filter divided into four equal segments. FIG. 2b is a simplified end view of a diesel particulate filter divided into four unequal segments.

[0044] FIG. 3 is a table that summarizes the exhaust gas flow splits, temperature and pressure drop history at various phases in a regeneration cycle of a four-segment, equally divided diesel particulate filter.

[0045] FIG. 4 is a plot of exhaust gas flow splits over a DPF regeneration test cycle, at the various phases in the regeneration cycle that is tabulated in FIG. 3.

[0046] FIG. 5 is a plot of exhaust gas outlet temperatures from the various segments of a diesel particulate filter at the various phases in the regeneration cycle that is tabulated in FIG. 3.

[0047] FIG. 6 is a table that summarizes the exhaust gas flow splits, temperature and pressure drop history at various phases in a regeneration cycle of a four-segment, unequally divided diesel particulate filter.

[0048] FIG. 7 is a plot of exhaust gas outlet temperatures from the various segments of a diesel particulate filter at the various phases in the regeneration cycle that is tabulated in FIG. 6.

[0049] FIG. 8 illustrates a schematic view of a combustion engine system comprising a segmented diesel particulate filter.

Detailed Description of Preferred Embodiment(s)

[0050] A diesel particulate filter (DPF) can be segmented into at least two segments, for example, by providing a baffle on the upstream side of the filter monolith, or by having separate filter segments housed in a common enclosure or not. This enables the introduction of a fuel, for example, a syngas stream, selectively into different portions or segments of the filter and the regeneration of each segment separately or independently from another. With this type of filter regeneration of the segments can be conducted sequentially and in a continuous cycle. In another variation the segments can be regenerated in sequence, one after the other, and then the DPF can be operated for a period without any segments being regenerated, with the regeneration sequence repeated only when regeneration is required. The engine exhaust stream flows through all segments of the DPF, whether the segment is being regenerated or not. As each segment is regenerated, the mass flow of the engine exhaust stream through the segment being regenerated tends to change as a result of the removal of particulate matter. This in turn can alter the heat value ratio of the engine exhaust stream to the fuel stream during the regeneration of subsequent segments.

[0051] The following discussion describes a shortcoming of an "equally" segmented DPF, in which the segments are regenerated sequentially in a continuous or non-continuous cycle. For example, if a DPF is loaded with soot and there are four equally divided segments the total engine exhaust stream flow will be equally split with about 25% of the total engine exhaust stream flowing through each segment. After regeneration of the first segment, the first segment which now has less soot will have a lower resistance to the flow of the engine exhaust stream. FIG. 1 is a photographic image showing an end view of a diesel particulate filter with one of four equal segments regenerated. Significantly more that 25% of the total engine exhaust stream flow will pass through the first regenerated (cleaned) segment, while less than 25% of the total engine exhaust stream flow will flow through each of the remaining segments. This type of flow behavior will continue as each segment is regenerated. When the fourth or last segment in the regeneration sequence is regenerated, only a small fraction of the total engine exhaust stream flow will pass through the fourth segment (about 12% in an example described below). The lower flow rate in the final segment is a result of the lower resistance to flow in the other segments that have been previously regenerated. If the flow rate of the fuel or syngas stream supplied is substantially consistent among segments during the regeneration process, the segments regenerated later in the sequence will receive more fuel relative to engine exhaust (that is, an increased heat value ratio), with the potential to over-heat and thermally damage the segment.

[0052] The present approach reduces the variation in the heat value ratio of the streams flowing through the various segments during regeneration, by factoring into the filter design and/or regeneration technique the change in the engine exhaust stream flow rate through the segments that occurs as they are regenerated or cleaned.

[0053] In one embodiment of an improved segmented filter design, a diesel particulate filter is divided into at least two segments having different cross-sectional areas. FIG. 2a (prior art) is a simplified end view of a diesel particulate filter that has a substantially circular or round cross-sectional profile, and that is divided into four equal segments, A, B, C and D. FIG. 2b is a simplified end view of an improved diesel particulate filter divided into four unequal segments with differing cross-sectional areas where the smallest segment AA would be regenerated first, followed in sequence by the progressively larger segments BB, CC and then DD. The appropriate relative cross-sectional area of the segments will be dependent upon the operating parameters of the

DPF and/or the engine exhaust gas after-treatment system, including the regeneration control strategy and sequence. The segments are preferably sized so that there is a substantially consistent heat value ratio during regeneration, if the rate of fuel flow supplied for regeneration is consistent among segments (for example, so that the ratio is consistent at the start of regeneration of each segment, or on average over the regeneration of each segment).

[0054] Unequal segmentation of the diesel particulate filter can reduce the variation in the heat value ratio, and thus the variation in temperature of the regeneration process, among individual segments as they are regenerated. It can also substantially reduce the overall fuel consumption associated with filter regeneration. For example, if the first segment AA was at approximately 65° compared to an equally segmented filter segment at 90°, the mass flow rate of the engine exhaust stream flowing through the first segment would be 65/90 or approximately 72% of the amount it would be in an equally segmented filter segment. Therefore, the required flow rate of the fuel stream or syngas stream would be about 72% of the amount required for an equally segmented filter, in order to maintain a similar heat value ratio. In the foregoing example the overall fuel saving would be about 28%.

[0055] The table in FIG. 3 summarizes modeled data from a DPF regeneration test cycle of a four segment, equally divided DPF (of the type illustrated in FIG. 2a), at various phases of a test cycle. The test starts off with a clean DPF (phase 1) which then becomes loaded with soot (phase 2). Data is provided for subsequent phases as and after each of the four segments (seg.) is regenerated in sequence by supplying syngas at about the same flow rate. FIG. 4 illustrates the mass flow rate of the engine exhaust gas stream (EG) through the four DPF segments during the various phases of the test cycle that are tabulated in FIG. 3, as well as the overall pressure drop across the DPF at the various phases. This data is included in FIG. 3. FIG. 4 shows that, as would be expected, the overall pressure drop decreases as each segment is regenerated. When all segments are clean or all segments of the DPF are loaded with soot, the EG flow is split about equally among the four segments (as at phase 1, 2, 3 and 10 where approximately 25% of the EG flow passes through each segment). Once one segment has been regenerated, a larger proportion (about 45%) of the EG passes through the cleaned segment with only about 18% passing through each of the three loaded segments (see phase 4 data points). Similarly, once two more segments have been regenerated (phases 6 and 8) the proportion of EG passing through the remaining loaded segment(s) drops even further to about 12%. FIG. 5 illustrates the temperatures of the various segments during the various phases of the test cycle that are tabulated in FIG. 3. The outlet temperature for the segment being regenerated gets hotter for each of the four segments. This is because the ratio of fuel (syngas) to EG is lowest in the first segment to be regenerated but increases with regeneration of each of the remaining three segments, because proportionately less of the EG is passing through the remaining loaded segments, but the supply of fuel (syngas) is the same.

[0056] The data shown in FIGS. 6 and 7 illustrates how an unequally divided DPF (of the type illustrated in FIG. 2b) can be used to reduce the variation in outlet temperature from the segments as they are regenerated in sequence. FIG. 6 summarizes data modeled for a similar DPF regeneration test cycle of a four segment, unequally divided DPF. The test starts off with a clean DPF (phase 1) which then becomes loaded with soot (phase 2). The EG mass flow rate through the four DPF segments during the various phases of the test cycle is shown in FIG. 6, as well as the overall pressure drop across the DPF at the various phases. When the DPF is clean or all segments are loaded with soot, the EG flow is split unequally among the four segments (approximately 19%, 22% 27% and 32% at phases 1, 2 and 10). Once one segment has been regenerated, a larger proportion of the EG (about 33%) passes through that first segment (see phase 4 data points). However, the proportion of EG passing through a segment during regeneration of that segment is consistently about 14% for all four segments (see phases 3, 5, 7 and 9). FIG. 6 shows that, as would be expected, the overall pressure drop decreases as each segment is regenerated. Temperature data is also provided for the various phases as and after each of the four segments is regenerated in sequence by supplying syngas at about the same flow rate. FIG. 7 illustrates the outlet temperatures (date also shown in FIG. 6) from the various segments during the various phases of the test cycle that are tabulated in FIG. 6. Unlike for the equally divided DPF (data in FIG. 5), the outlet temperature for the segment being regenerated is substantially the same for each of the four segments as they are regenerated. This is because the ratio of fuel to EG is substantially the same for each of the four segments during regeneration because of the variation in cross-sectional area of the segments.

[0057] In other embodiments of improved segmented filter designs, other physical properties or structural characteristics of the filter segments can be different from one another, besides or in addition to their cross-sectional area. For example, the mass flow of the engine exhaust stream can be made more consistent among the different segments during regeneration by having segments with differing filter cell density, differing filter porosity and/or differing longitudinal filter lengths or volumes.

[0058] Ceramic wall-flow monoliths used for DPFs can be manufactured by extruding a large unitary section or by cementing or bonding together multiple smaller sections or “bricks” to form one complete larger section. The DPF in FIG. 1 is constructed of multiple bricks; the joints between the bricks are visible in FIG. 1. If the DPF is constructed of smaller bricks rather than being one complete extrusion, preferably the divisions between the segments do not coincide with the area or joints where individual bricks are joined to form the DPF, or at least care is taken to reduce the degree of overlap. This reduces the thermal gradient and thermal stress across the adhesive or cement that joins the individual bricks of a DPF together.

[0059] In embodiments of a regeneration technique for a segmented particulate filter, the heat value ratio during the regeneration of an individual segment can be held substantially consistent among segments by controlling and varying the mass flow rate of the fuel stream introduced to each individual segment. The mass flow rate of the fuel stream can be adjusted depending on the mass flow rate of the engine exhaust stream flowing through an individual segment during regeneration to maintain the desired heat value ratio. This technique can reduce the overall fuel consumption associated with filter regeneration, but can cause a fluctuating demand for fuel (for example, syngas) for regeneration purposes, and requires a more complex control system. The technique can be used with an equally segmented particulate filter to reduce the variation in the heat value ratio, and thus the variation in temperature of the regeneration process, among individual segments as they are regenerated. It can also be used with unequally segmented particulate filters of the types described herein, to provide further non-passive control of the heat value ratio.

[0060] The present segmented filter designs and regeneration techniques can provide some or all of the following advantages over those used in conventional DPFs:

[0061] (A) Reduced potential of thermal damage to the filter substrate and catalyst during regeneration.

[0062] (B) Reduced fuel penalty associated with filter regeneration due to reducing the amount of fuel (for example syngas or diesel fuel) required to heat the individual filter segments during regeneration.

[0063] (C) If syngas is used for regeneration, reduced syngas generator size and cost due to the reduced mass flow rate of the engine exhaust stream flowing through an individual segment, which reduces the amount of syngas required to heat the individual filter segments during regeneration.

[0064] In the above described embodiments the segments can be regenerated by various methods, for example, conducted sequentially until all segments have been regenerated, conducted in a specific order, conducted in a continuous cycle, conducted in a non-continuous cycle, and/or conducted only when regeneration is of the filter required. The regeneration process can be controlled through an open-loop control method and/or a closed loop control method employing sensors and/or pre-determined regeneration algorithms.

[0065] FIG. 8 illustrates a schematic view of a combustion engine system 100 comprising an exhaust after-treatment sub-system 101. Engine 110 produces an engine exhaust stream which travels through conduit 111, through an optional turbo-compressor 112, and through conduit 113 to DPF assembly 120 where the engine exhaust stream is filtered by a filter 121 to reduce the level of regulated particulate emissions therein. The filtered engine exhaust stream is then released to the atmosphere via an exhaust conduit 114. Conduit 113 and exhaust conduit 114 can comprise additional exhaust after-treatment devices, not shown in FIG. 8.

[0066] As particulates collect in filter 121, the flow of the engine exhaust stream is impeded, increasing the backpressure of the engine exhaust stream upstream of filter 121. An optional sensor can be employed to monitor the temperature of the engine exhaust stream and can be located near the engine outlet, for example, sensor 133. An optional pressure sensor 131 monitors the pressure of the engine exhaust stream upstream of filter 121 and can be located along conduits 111 or 113. An optional pressure sensor 132 monitors the pressure of the engine exhaust stream downstream of filter 121 and can be located along conduits 114 or other optional conduits located downstream of filter 121 (not shown in FIG. 8). Alternatively, a pair of pressure sensors 131 and/or 132 can be located within DPF assembly 120 upstream and downstream of filter 121. Alternatively a differential pressure sensor (not shown in FIG. 8) can be employed to monitor the pressure of the exhaust stream upstream and downstream of filter 121. Alternatively, an optional sensor can be employed to monitor the temperature of the engine exhaust stream near the DPF outlet, for example, sensor 134, or at other locations along conduits 113 or 114 or within DPF assembly 120. A controller 130 receives signals from optional pressure sensors 131 and 132, and optional temperature sensors 133 and 134.

[0067] The following paragraphs describe control strategies that can be used to initiate and terminate regeneration of filter 121. These strategies are applicable to unsegmented filters, and equally divided segmented filters or unequally divided segmented filters of the type described herein.

[0068] In preferred control strategies, controller 130 initiates a regeneration process for filter 121 based on employing one of equations (1), (2), (3) or (4).

[0069] Initiate DPF regeneration when:

$$n < [(P_1-P_2)/P_3], \qquad (1)$$

$$n < [(P_1-P_2)/P_3] \text{ and } t_1 > x_1 \qquad (2)$$

$$n < [(P_1-P_2)/P_3] \text{ and } T_1 > y_1 \qquad (3)$$

$$n < [(P_1-P_2)/P_3] \text{ and } t_1 > x_1 \text{ and } T_1 > y_1 \qquad (4)$$

where n = predetermined value

P_1 = pressure of engine exhaust stream upstream of the DPF filter

P_2 = pressure of engine exhaust stream downstream of the DPF filter

P_3 = predetermined first pressure value, which represents a pressure differential between the inlet and outlet of a clean DPF (without trapped particulates or a regenerated DPF) during the present operating condition of the engine. This value can be pre-programmed or stored in a look-up table, or calculated (as a function of the mass flow of exhaust stream or mass flow of the inlet air steam of the engine, temperature of exhaust stream at the inlet to DPF, cross-sectional area of DPF, and a constant).

t_1 = time since last regeneration

x_1 = predetermined first time value

T_1 = temperature of engine exhaust stream at, for example: engine outlet, DPF outlet, or other position along engine exhaust stream conduits

y_1 = predetermined first temperature value.

[0070] Alternatively, in equations (1), (2), (3) or (4), P_1 can be employed in place of P_3.

[0071] In other embodiments of a control strategy, controller 130 initiates a regeneration process for filter 121 based on employing one of equations (5), (6), (7) or (8).

$$n < P_1 \quad (5)$$

$$n < P_1 \text{ and } t_1 > x_1 \quad (6)$$

$$n < P_1 \text{ and } T_1 > y_1 \quad (7)$$

$$n < P_1 \text{ and } t_1 > x_1 \text{ and } T_1 > y_1 \quad (8)$$

[0072] Alternatively, in equations (5), (6), (7) or (8), $P_1 - P_2$ can be employed in place of P_1.

[0073] In yet other embodiments of a control strategy, controller 130 initiates a regeneration process for filter 121 based on employing one of equations (9), (10), (11) and (12).

$$n < [(P_1\text{-}P_2)/m_1], \quad (9)$$

$$n < [(P_1\text{-}P_2)/m_1] \text{ and } t_1 > x_1 \quad (10)$$

$$n < [(P_1\text{-}P_2)/m_1] \text{ and } T_1 > y_1 \quad (11)$$

$$n < [(P_1\text{-}P_2)/m_1] \text{ and } t_1 > x_1 \text{ and } T_1 > y_1 \quad (12)$$

where $m_1 =$ mass flow of engine exhaust stream.

[0074] Alternatively, in equations (9), (10), (11) or (12), P_1 can be employed in place of $P_1 - P_2$.

[0075] Alternatively, in equations (9), (10), (11) or (12), m_2 can be employed in place of m_1

where m_2 = mass flow of engine intake air stream.

[0076] In equations (1) through (12) the parameters that are actually monitored and associated signals sent to the controller can be indicative of another parameter, for example, in equation (9) a pressure sensor can be employed to monitor the engine exhaust stream in order to indicate the mass flow rate of the engine exhaust stream.

[0077] In further embodiments of a control strategy, controller 130 initiates a regeneration process for filter 121 based on employing at least one of equations (1) through (12) and at least one of equations (13) (14).

$$T_1 < y_2, \tag{13}$$

$$\lambda > [O_2], \tag{14}$$

where y_2 = predetermined second temperature value

λ = oxygen concentration of engine exhaust stream

$[O_2]$ = predetermined oxygen concentration value.

[0078] In preferred embodiments of a control strategy for terminating regeneration, controller 130 terminates a regeneration process for filter 121 based on at least one of equations (15), (16), (17) or (18).

[0079] Terminate DPF regeneration when:

$$T_2 > y_3, \quad (15)$$

$$dT_2 > z \quad (16)$$

$$t_2 > x_2 \quad (17)$$

$$P_4 \ (P_1\text{-}P_2) \quad (18)$$

$$P_4 < P_3 \quad (19)$$

where T_2 = temperature of engine exhaust stream at, for example: DPF outlet, or other position along engine exhaust stream conduit downstream of DPF outlet

y_3 = predetermined third temperature value, which can be the same as y_2 or different.

dT_2= rate of change to T_2

z = predetermined rate of change value

t_2 = time since initiation of regeneration

x_2 = predetermined second time value

P_4 = predetermined second pressure value.

[0080] Preferably in the above described control strategies, DPF assembly 120 is divided into equally or unequally divided segments which enables the regeneration of at least one segment or portion of filter 121 at a given time. In FIG. 8, DPF assembly 120 comprises a baffle 122 which is a means to divide and channel the flow of the syngas stream through a segment within filter 121, while allowing the engine exhaust stream to flow though all segments of filter 121 including those that are being regenerated. Alternatively or in addition, DPF assembly 120 comprises a baffle downstream (not shown in FIG. 8) of filter 121 in order to divide and channel the engine exhaust stream as it exits a segment within filter 121. This allows the engine exhaust stream exiting each individual segment to be monitored. For example, the temperature of the engine exhaust stream exiting each segment can be monitored and regeneration of individual segments can be triggered depending on the monitored value for that segment.

[0081] In FIG. 8, syngas generator assembly 140 can be operated essentially continuously when engine system 100 is in operation. A fuel and oxidant reactant supply and control system (not shown in FIG. 8) supplies the necessary reactants to syngas generator assembly 140. The syngas stream produced by syngas generator assembly 140 flows through conduit 141 to valve 142 where it is diverted to flow selectively through at least one of conduits 143, 144, 145 or 146 and the respective segments within DPF assembly 120. Alternatively syngas can be directed to DPF assembly 120 via a single conduit and the selective flow of syngas to the different segment accomplished by flow diverters or other devices within DPF assembly 120. Valve 142 is controlled by controller 130.

[0082] Various algorithms can be used for controlling regeneration of a segmented DPF. The algorithm can include factors such as:

[0083] (a) the regeneration cycle of DPF. This can be, for example, continuous, periodic or only as required;

[0084] (b) the order of regenerating the different segments. This can be, for example, sequential (for example, for an unequally segmented filter) or non-sequential (for example, done as required as determined by monitoring of individual segments);

[0085] (c) the component to be monitored in order to control the regeneration. This can be, for example, individual segment or overall DPF assembly;

[0086] (d) the control system employed for regeneration. This can be, for example, closed-loop or open-loop systems or some combination; and

[0087] (e) the operating parameter(s) to be monitored for the regeneration control system. This can be, for example, duration of regeneration or temperature of exhaust gas stream for DPF assembly or filter or an individual segment thereof; or pressure drop across the filter or DPF assembly.

[0088] Table 1 illustrates examples of various regimes that can be used to control the regeneration of an equally or unequally segmented DPF assembly. One or more of these regimes can be used.

Table 1

Example of Regeneration Regimes for a Segmented DPF

Regime	DPF Regeneration Cycle	Segment Regeneration Order	Component to be Monitored	Control System	Operating Parameter
A	as required	sequential	DPF assembly	closed-loop	differential pressure across DPF assembly or its rate of change
B	as required	sequential	segment	closed-loop	temperature or its rate of change downstream of segment
C	as required	sequential	segment	open-loop	duration of flow of syngas stream to each segment
D	as required	sequential	DPF assembly	open-loop	duration of flow of syngas stream to DPF assembly
E	continuous	sequential	segment	closed-loop	temperature downstream of segment
F	continuous	sequential	segment	open-loop	duration of flow of syngas stream to each segment
G	periodic	sequential	segment	open-loop	duration of flow of syngas stream to each segment
H	periodic	sequential	DPF assembly	open-loop	duration of flow of syngas stream to DPF assembly
I	as required	sequential	DPF assembly	closed-loop	mass flow rate of engine exhaust stream

[0089] As the syngas stream exits conduit 143, 144, 145 or 146, and enters a respective chamber created by baffle 122, the syngas stream mixes with and is carried by a portion of the engine exhaust stream through the respective segment of filter 121. The remaining portion of the engine exhaust stream flows through the remaining segments of filter 121, where particulates are trapped, exits DPF assembly 120 and is then released to the atmosphere via exhaust conduit 114. As the syngas stream and engine exhaust stream mixture flows through a segment of filter 121 it undergoes combustion reactions and heats the segment of filter 121, enhancing the regeneration process. The combustion reactions can be promoted by a catalyst (not shown in FIG. 8) within DPF assembly 120, for example, on filter 121 or on a substrate upstream of filter 121. Alternatively, the combustion reactions can occur without the use of a catalyst, for example, through flame combustion by employing a fuel burner and/or ignition source. A suitable mass flow rate and volume of syngas is required to heat the segment to the desired temperature for a predetermined period. During the regeneration process, the particulates trapped in the segment of filter 121 are oxidized and carried away from filter 121 and DPF assembly 120 via conduit 114 to the atmosphere by the portion of the engine exhaust stream. Controller 130 employing at least one programmed control regime and/or signals received from various sensors, determines when to terminate the regeneration process for the particular segment(s) of filter 121 and sends a signal to valve 142. The controller that controls regeneration of the filter can be dedicated for that purpose or can be part of another controller, for example, an overall engine control module.

[0090] In FIG. 8, exhaust after-treatment sub-system 101 can optionally comprise one or more additional exhaust after-treatment devices which at least periodically utilize a syngas stream (for example, for regeneration and/or heating), The controller can determine where the syngas is to be directed, and may need to assign different priorities to the various devices and their requirements or demands for syngas. For example, in a system with a DPF and a lean NOx trap (LNT) the syngas stream can be preferably directed by the controller in order of priority for:

[0091] (1) Regeneration process of DPF;

[0092] (2) De-sulfation process of LNT;

[0093] (3) Regeneration process of LNT.

[0094] Furthermore, syngas generator assembly 140 can from time to time require a regeneration process which would be a higher priority over the above stated processes.

[0095] The present filter segmentation designs and techniques have the following potential commercial applications, end-uses and/or markets (present and future):

[0096] (1) Diesel engine retrofit markets.

[0097] (2) Diesel engine original equipment manufacturer (OEM) markets.

[0098] (3) Segmentation of lean NOx traps during desulfation heating processes.

[0100] The fuel employed to regenerate the DPF can be another fuel (other than syngas) for example diesel, gasoline, natural gas, propane, ethanol, methanol or kerosene can be used.

[0101] The engine can be a lean burn combustion engine fueled by suitable fuels, for example, diesel, fuel oil, kerosene, natural gas, propane, liquefied petroleum gas (LPG), methanol, ethanol or gasoline. The engine system can comprise additional devices which utilize a syngas stream for example, a lean NOx trap, selective catalytic reactor (SCR), diesel oxidation catalyst (DOC) and or a fuel cell. A diverter valve can be used to selectively direct the flow of syngas stream to such additional devices.

[0102] While particular elements, embodiments and applications of the present invention have been shown and described, it will be understood, that the invention is not limited thereto since modifications can be made by those skilled in the art without departing from the scope of the present disclosure, particularly in light of the foregoing teachings.

What is claimed is:

1. An engine exhaust stream particulate filter comprising at least two filter segments wherein said segments are structured so that if they were each supplied with a gas stream under identical conditions, the gas stream mass flow through each of said segments would be different.

2. The engine exhaust stream particulate filter of claim 1 wherein said segments differ from each other in at least one structural characteristic selected from the group consisting of cross-sectional area, longitudinal filter length, filter porosity and filter cell density.

3. The engine exhaust stream particulate filter of claim 1 wherein said at least two filter segments are unequal in their in cross-sectional area.

4. The engine exhaust stream particulate filter of claim 1 having a longitudinal axis, wherein said at least two filter segments are unequal in length in the longitudinal direction.

5. The engine exhaust stream particulate filter of claim 1 wherein said segments differ from each other in at least one structural characteristic such that the engine exhaust stream mass flow rate through each segment during their sequential regeneration is approximately equal.

6. The engine exhaust stream particulate filter of claim 1 wherein said at least two filter segments are housed in a common enclosure.

7. A method for operating a particulate filter comprising a plurality of filter segments, the method comprising:

(a) directing an exhaust stream from a combustion engine through said plurality of filter segments;
(b) selectively introducing a hydrogen-containing gas stream at least periodically into each of said filter segments to regenerate said segment;
(c) maintaining the engine exhaust stream to hydrogen-containing gas stream heat value ratio used for regeneration of each segment substantially consistent among said plurality of segments.

8. The method of claim 7 wherein said hydrogen-containing gas stream is introduced into said plurality of segments sequentially in a regeneration sequence.

9. The method of claim 8 wherein the engine exhaust stream mass flow rate through each segment is different so that said heat value ratio is maintained substantially consistent among segments during their regeneration.

10. The method of claim 9 wherein said segments are structured so that if they were supplied with a gas stream under

identical conditions, the gas stream mass flow through each one of said plurality segments would be different.

11. The method of claim 7 wherein said heat value ratio is maintained substantially consistent among segments during their regeneration by varying the mass flow rate of said hydrogen-containing gas stream that is introduced to regenerate each segment.

12. The method of claim 11 wherein said hydrogen-containing gas stream is introduced into said plurality of segments sequentially in a regeneration sequence.

13. The method of claim 12 wherein the mass flow rate of said hydrogen-containing gas stream that is introduced to regenerate each segment depends upon its position in the regeneration sequence.

14. The method of claim 7 wherein the duration of regeneration of each segment is substantially the same.

15. The method of claim 7 where said hydrogen-containing gas stream is being introduced into at least one filter segment at a given time so that at least one filter segment is undergoing regeneration during operation of said particulate filter.

16. The method of claim 8 further comprising

(d) monitoring at least one of a pressure P_1 of said engine exhaust stream upstream of said particulate filter, a temperature T_1 of said engine exhaust stream, and a time interval t_1 related to operation of said particulate filter, and initiating said regeneration sequence by selectively introducing a hydrogen-containing gas stream into a first segment in said sequence when at least one of P_1, T_1 or t_1 is greater than a predetermined threshold value.

17. The method of claim 8 further comprising:

(d) monitoring at least one of pressure differential ΔP across said particulate filter, a temperature T_1 of said engine exhaust stream, and a time interval t_1 related to operation of said particulate filter and initiating said regeneration sequence by selectively introducing a hydrogen-containing gas stream into a first segment in said sequence when at least one of ΔP, T_1 or t_1 is greater than a predetermined threshold value.

18. The method of claim 17 further comprising:

(e) ceasing regeneration of said first filter segment and each subsequent segment in said regeneration sequence when ΔP falls below a predetermined threshold value.

19. The method of claim 17 further comprising:

(e) ceasing regeneration of said first filter segment and each subsequent segment in said regeneration sequence when the rate-of-decrease in ΔP falls below a predetermined threshold value.

20. The method of claim 8 wherein the flow of said hydrogen-containing gas stream to each segment in said regeneration sequence is ceased after a predetermined segment regeneration time.

21. The method of claim 8 further comprising

(d) monitoring a temperature T_2 of said exhaust stream downstream of said particulate filter and the flow of said hydrogen-containing gas stream to a particular segment is ceased when said temperature T_2 exceeds a predetermined third threshold value.

22. The method of claim 7 wherein said hydrogen-containing gas stream is selectively introduced into each of said plurality of segments depending on a monitored operating parameter of each said segment.

23. The method of claim 22 wherein said operating parameter is a temperature of said engine exhaust stream passing through each segment.

24. An engine and exhaust after-treatment system comprising:

(a) a combustion engine;

(b) a particulate filter connected to receive an exhaust gas stream from said engine via an exhaust stream conduit, said particulate filter comprising a plurality of filter segments with different structural characteristics from one another, wherein during operation of said particulate filter said exhaust gas stream is directed through said segments in parallel;

(c) a syngas generator for producing a syngas stream;

(d) a controller configured to selectively direct said syngas stream to each of said segments in sequence to regenerate said segment.

25. The engine and exhaust after-treatment system of claim 24 wherein said filter segments are structured so that if they were each supplied with a gas stream under identical conditions, the gas stream mass flow through each of said segments would be different.

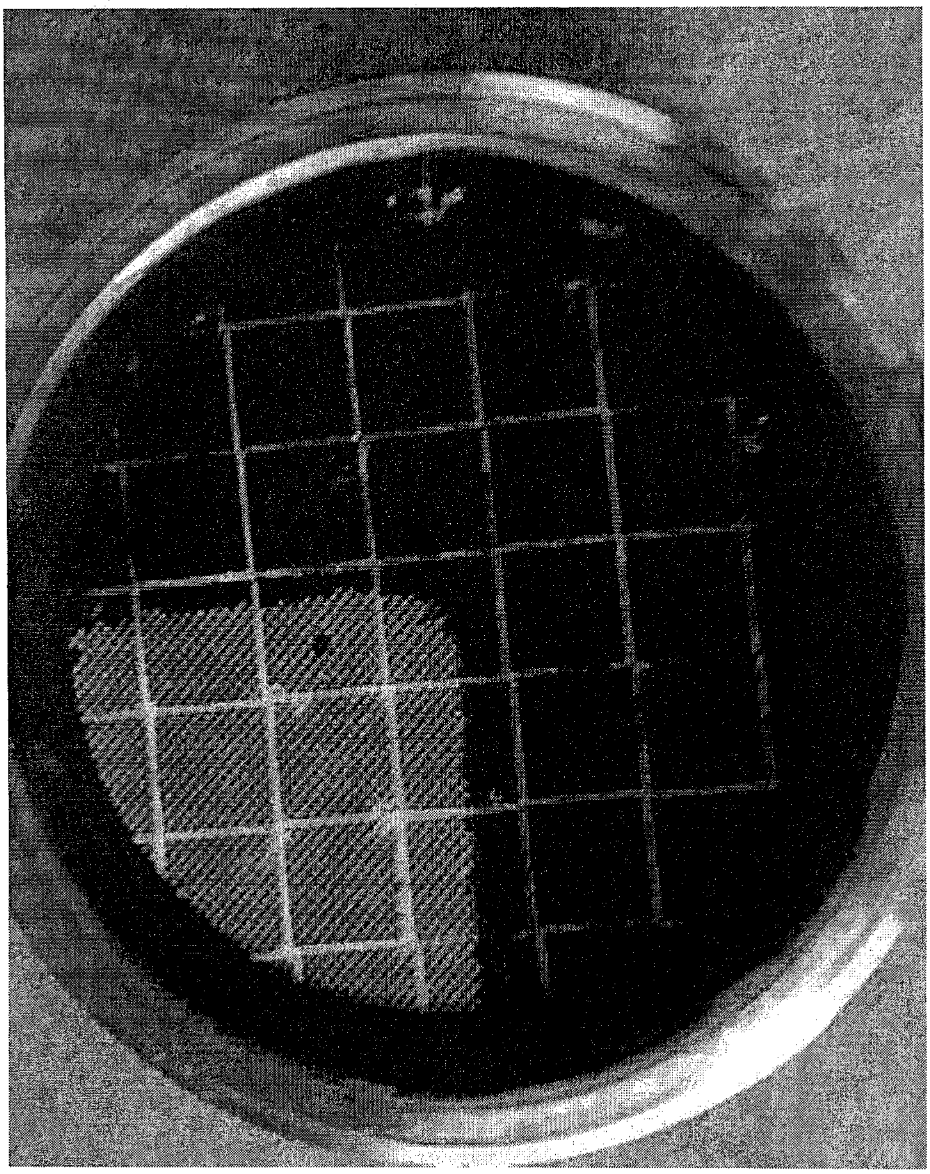


FIG. 1

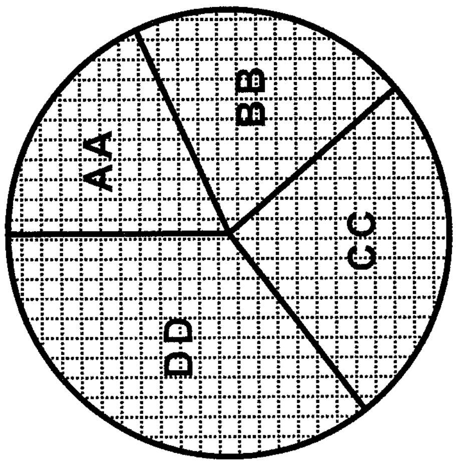
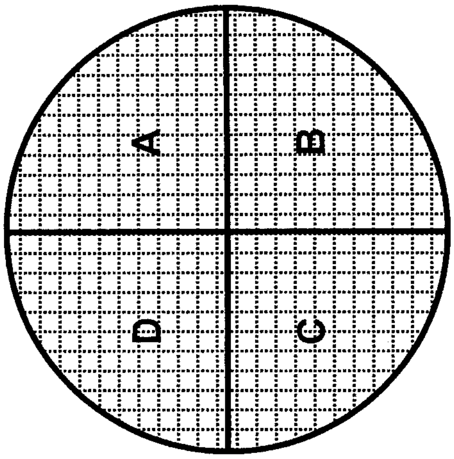


FIG. 2b



Prior Art

FIG. 2a

Regeneration of a DPF with Four Equal Segments

Phase	Description	SG supply	DPF pressure drop	EG split to seg. being heated	EG split in each cleaned seg.	EG split in each loaded seg.	Outlet T seg. being heated	Inlet T cleaned seg.	Outlet T cleaned seg.
(-)	(-)	(Y/N)	(kPa)	(-)	(-)	(-)	(°C)	(°C)	(°C)
1	Clean DPF	N	2.54		0.25		287	292	287
2	Loaded DPF	N	7.75			0.25	287	292	287
3	Seg. 1 being heated	Y	10.34	0.24		0.25	480	292	297
4	Seg. 1 cleaned	N	5.30		0.47	0.18	289	292	286
5	Seg. 2 being heated	Y	8.03	0.21	0.45	0.17	499	292	298
6	Seg. 1+2 cleaned	N	3.96		0.36	0.14	288	292	285
7	Seg. 3 being heated	Y	5.77	0.17	0.35	0.13	527	292	299
8	Seg. 1+2+3 cleaned	N	3.12		0.29	0.12	288	292	284
9	Seg. 4 being heated	Y	3.26	0.12	0.29		594	292	302
10	All segs cleaned	N	2.54		0.25		287	292	287

FIG. 3

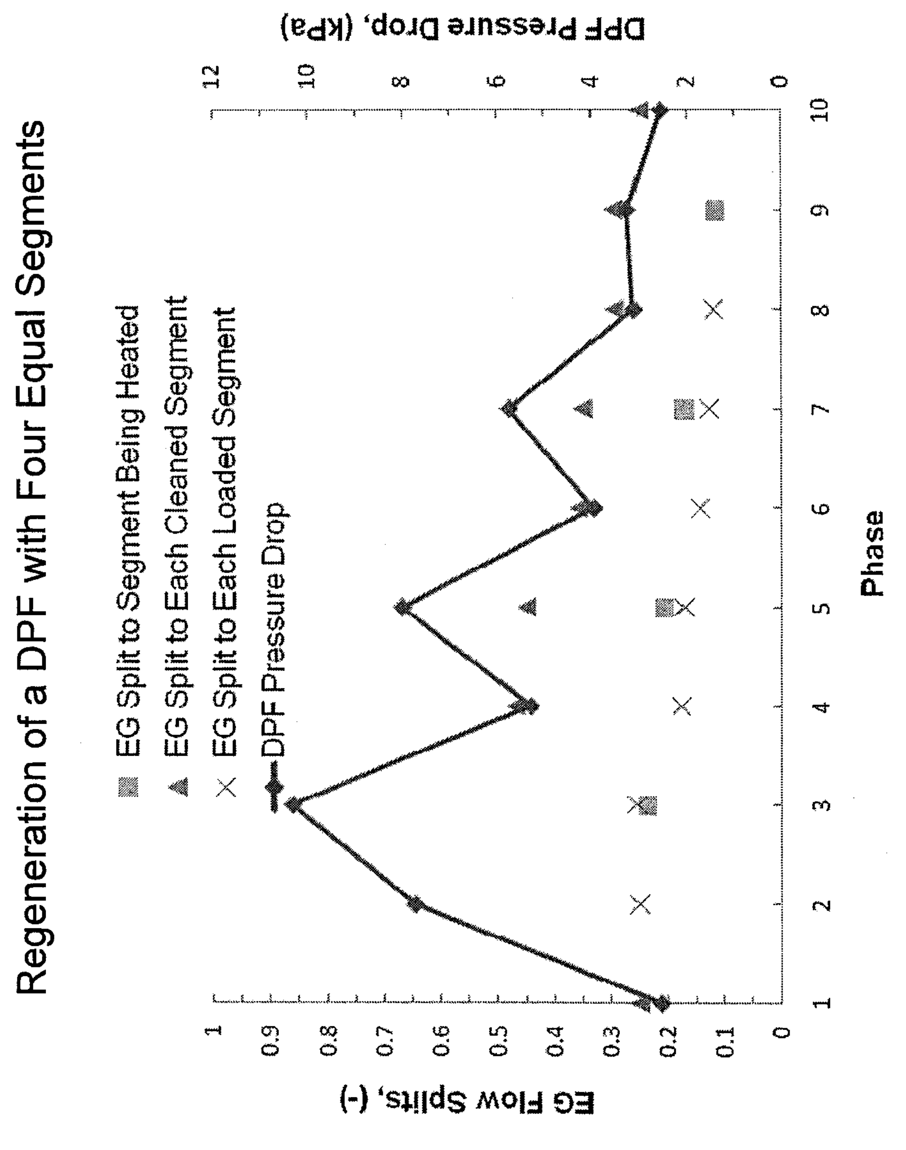
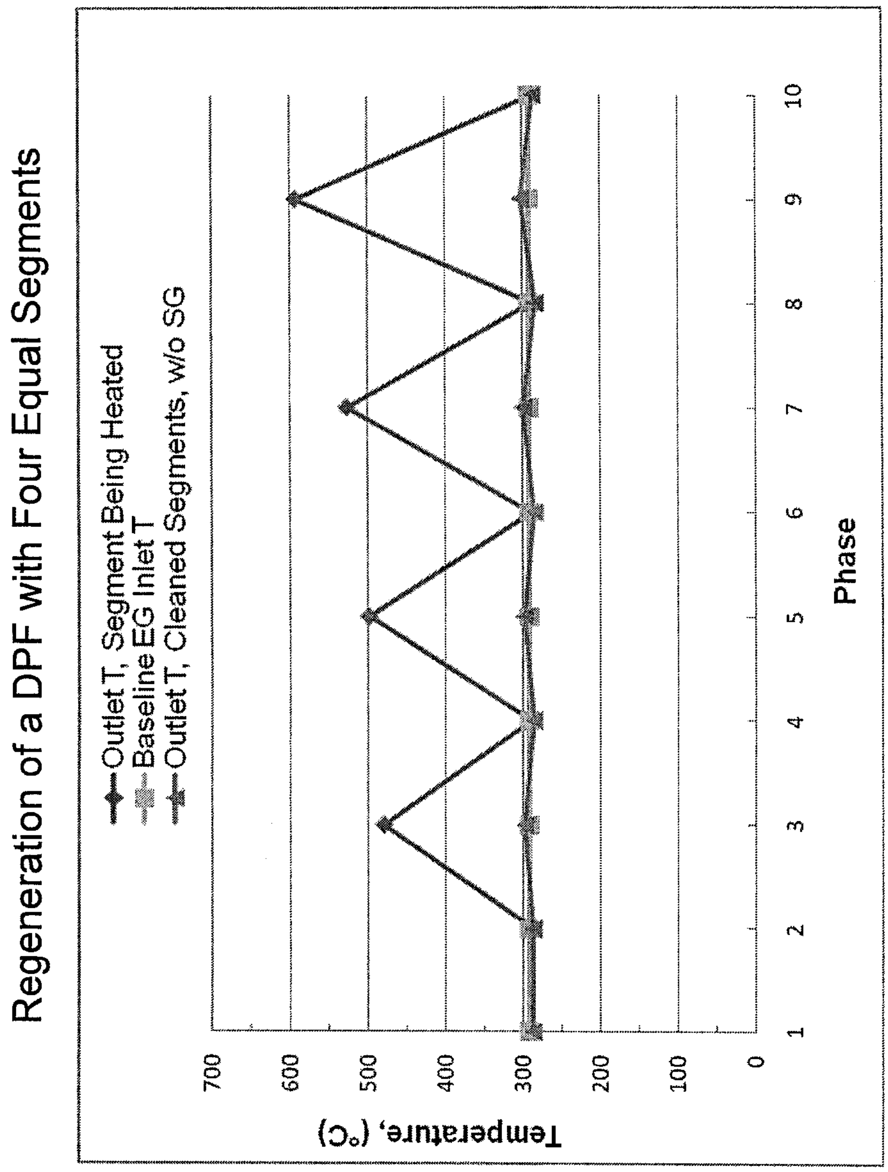

Regeneration of a DPF with Four Equal Segments
EG Split to Segment Being Heated
EG Split to Each Cleaned Segment
EG Split to Each Loaded Segment
DPF Pressure Drop
EG Flow Splits, (-)
DPF Pressure Drop, (kPa)
Phase
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
2
4
6
8
10
12
1
2
3
4
5
6
7
8
9
10

FIG. 4



Regeneration of a DPF with Four Equal Segments
Outlet T, Segment Being Heated
Baseline EG Inlet T
Outlet T, Cleaned Segments, w/o SG
Temperature, (°C)
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
Phase

FIG. 5

Regeneration of a DPF with Four Unequal Segments

Phase	Description	SG supply	DPF pressure drop	EG Split Seg. 1	EG Split Seg. 2	EG Split Seg. 3	EG Split Seg. 4	Outlet T Seg. 1	Outlet T Seg. 2	Outlet T Seg. 3	Outlet T Seg. 4
(-)	(-)	(Y/N)	(kPa)	(-)	(-)	(-)	(-)	(°C)	(°C)	(°C)	(°C)
1	Clean DPF	N	2.8	0.186	0.222	0.269	0.322	288	288	288	288
2	Loaded DPF	N	5.8	0.186	0.222	0.269	0.322	288	288	288	288
3	Seg. 1 being heated	Y	6.2	0.143	0.234	0.284	0.339	650	311	311	311
4	Seg. 1 cleaned	N	4.9	0.329	0.183	0.222	0.266	288	288	288	288
5	Seg. 2 being heated	Y	5.1	0.347	0.143	0.232	0.278	308	649	308	308
6	Seg. 1+2 cleaned	N	4.0	0.273	0.327	0.182	0.218	288	288	288	288
7	Seg. 3 being heated	Y	4.2	0.287	0.342	0.141	0.230	298	298	648	298
8	Seg. 1+2+3 cleaned	N	3.3	0.225	0.269	0.326	0.180	288	288	288	288
9	Seg. 4 being heated	Y	3.5	0.236	0.282	0.342	0.139	294	294	294	646
10	All segs cleaned	N	2.8	0.186	0.222	0.269	0.322	288	288	288	288

FIG. 6

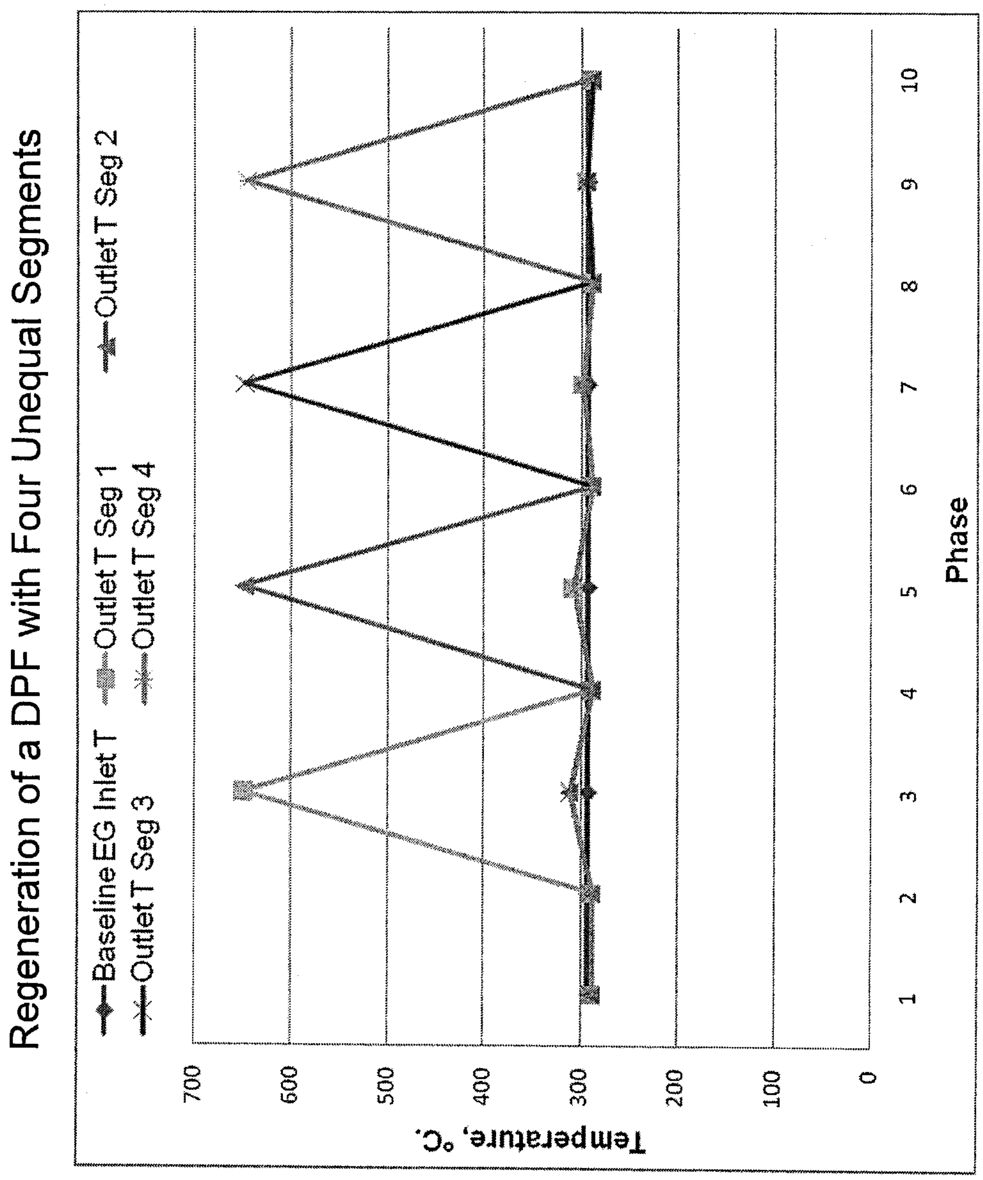

Regeneration of a DPF with Four Unequal Segments
Baseline EG Inlet T
Outlet T Seg 1
Outlet T Seg 2
Outlet T Seg 3
Outlet T Seg 4
Temperature, °C.
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
Phase

FIG. 7

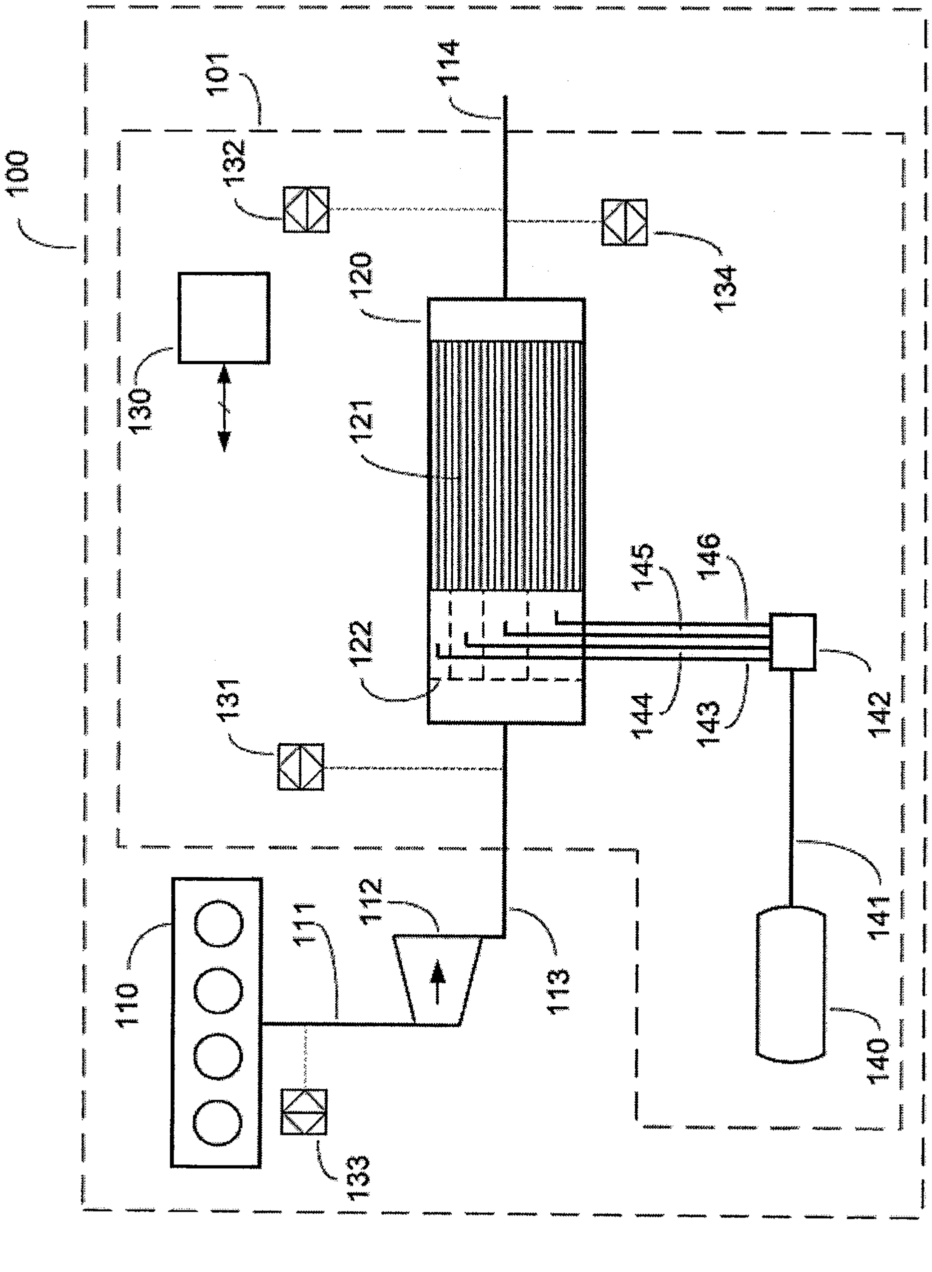

100
101
114
132
134
120
130
121
145
146
122
131
144
143
142
112
111
110
113
141
140
133

FIG. 8

INTERNATIONAL SEARCH REPORT	International application No. PCT/CA2008/000945

A. CLASSIFICATION OF SUBJECT MATTER

IPC: ***F01N 3/023*** (2006.01) , ***B01D 46/00*** (2006.01) , ***B01D 53/92*** (2006.01) , ***F01N 3/025*** (2006.01)

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: ***F01N 3/023*** (2006.01) , ***B01D 46/00*** (2006.01) , ***B01D 53/92*** (2006.01) , ***F01N 3/025*** (2006.01)

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)

Delphion, Esp@cenet, QPAT, Canadian Patent Database, Japan Patent Office (keywords used: filter, hydrogen, flow, rate, porosity, density, cross-sectional area, regenerate, syngas, segment)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 5655366 A (KAWAMURA, H.) 12 August 1997 (12-08-1997) * Entire document *	1-25
A	US 7179516 B2 (ICHIKAWA, S.) 20 February 2007 (20-02-2007) *Entire document *	1-25

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 July 2008 (28-07-2008)	27 August 2008 (27-08-2008)

Name and mailing address of the ISA/CA	Authorized officer
Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001-819-953-2476	Gregory Myslicki 819- 956-5824

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2008/000945

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 2005/0274104 A1 (BROMBERG, L. et al.) 15 December 2005 (15-12-2005) *Entire document *	1-25
A	US 2005/0126140 A1 (ITO, T. et al.) 16 June 2005 (16-06-2005) *Entire document *	1-25
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