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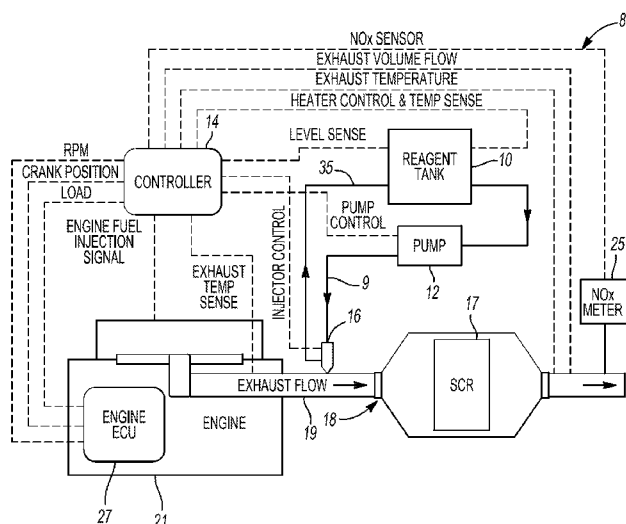
Declarations under Rule 4.17:

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(54) **Title:** EXHAUST AFTERTREATMENT CONTROL SYSTEM AND METHOD FOR MAXIMIZING FUEL EFFICIENCY WHILE REDUCING EMISSIONS

**Fig-1**

(57) **Abstract:** An engine exhaust treatment and fuel efficiency improvement system includes a NOx module that determines a quantity of NOx emitted from an engine. A selective catalytic reduction (SCR) efficiency module determines a SCR efficiency to reduce the determined NOx quantity below a predetermined threshold. A reagent dosing module determines a quantity of reagent required to reduce the NOx quantity below the predetermined threshold. An injection optimization module determines whether an increase in system operating efficiency may be obtained by changing an injected reagent quantity and an engine operating parameter in cooperation with each other while maintaining the NOx quantity below the threshold, the system being operable to change the reagent injection quantity and engine operating parameter to increase system efficiency.

EXHAUST AFTERTREATMENT CONTROL SYSTEM AND METHOD FOR MAXIMIZING FUEL EFFICIENCY WHILE REDUCING EMISSIONS

FIELD

5 **[0001]** The present disclosure relates to exhaust treatment systems and, more particularly, relates to a system for controlling injection of a reagent, such as an aqueous urea solution, into an exhaust stream to reduce oxides of nitrogen (NO_x) emissions from internal combustion engine exhaust while maximizing engine fuel efficiency.

10 BACKGROUND

[0002] This section provides background information related to the present disclosure which is not necessarily prior art. Lean burn engines provide improved fuel efficiency by operating with an excess of oxygen, that is, a quantity of oxygen that is greater than the amount necessary for complete combustion of the available fuel. Such engines are said to run "lean" or on a "lean mixture." However, this improved or increase in fuel economy, as opposed to non-lean burn combustion, is offset by undesired pollution emissions, specifically in the form of oxides of nitrogen (NO_x).

[0003] One method used to reduce NO_x emissions from lean burn internal combustion engines is known as selective catalytic reduction (SCR). SCR, when used, for example, to reduce NO_x emissions from a diesel engine, involves injecting an atomized reagent into the exhaust stream of the engine in relation to one or more selected engine operational parameters, such as exhaust gas temperature, engine rpm or engine load as measured by engine fuel flow, turbo boost pressure or exhaust NO_x mass flow. The reagent/exhaust gas mixture is passed through a reactor containing a catalyst, such as, for example, activated carbon, or metals, such as platinum, vanadium or tungsten, which are capable of reducing the NO_x concentration in the presence of the reagent.

[0004] An aqueous urea solution is known to be an effective reagent in SCR systems for diesel engines. However, use of such an aqueous urea solution may involve many disadvantages. Urea is highly corrosive and may adversely affect mechanical components of the SCR system, such as the

injectors used to inject the urea mixture into the exhaust gas stream. Urea also may solidify upon prolonged exposure to high temperatures, such as temperatures encountered in diesel exhaust systems. Solidified urea will accumulate in the narrow passageways and exit orifice openings typically found in injectors. Solidified urea may also cause fouling of moving parts of the injector and clog any openings or urea flow passageways, thereby rendering the injector unusable.

[0005] During vehicle operation, both internal combustion engine fuel and aqueous urea are consumed. At the present time, vehicle engine control and reductant injection control are substantially autonomous where the exhaust treatment system is tasked with only reducing undesirable emissions. To reduce the overall cost of vehicle operation, it may be beneficial to provide a system that maximizes engine fuel efficiency while providing exhaust treatment.

SUMMARY

[0006] This section provides a general summary of the disclosure, and is not a comprehensive disclosure of its full scope or all of its features.

[0007] An engine exhaust treatment and fuel efficiency improvement system includes a NO_x module that determines a quantity of NO_x emitted from an engine. A selective catalytic reduction (SCR) efficiency module determines a SCR efficiency to reduce the determined NO_x quantity below a predetermined threshold. A reagent dosing module determines a quantity of reagent required to reduce the NO_x quantity below the predetermined threshold. An injection optimization module determines whether an increase in system operating efficiency may be obtained by changing an injected reagent quantity and an engine operating parameter in cooperation with each other while maintaining the NO_x quantity below the threshold, the system being operable to change the reagent injection quantity and engine operating parameter to increase system efficiency.

[0008] A method includes determining an engine operating parameter, calculating an exhaust NO_x and calculating a selective catalytic reduction (SCR) conversion efficiency required to reduce the engine exhaust NO_x below a predetermined threshold. A quantity of reagent to inject into the exhaust to

reduce the engine exhaust NO_x below the threshold is determined. The method also includes determining whether an operating efficiency of the system may be increased by changing both the reagent quantity and the engine operating parameter while maintaining exhaust NO_x below the threshold. The reagent
5 quantity and the operating parameter are changed to reduce the engine fuel consumption.

[0009] Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purposes of illustration only and are not intended to
10 limit the scope of the present disclosure.

DRAWINGS

[0010] The drawings described herein are for illustrative purposes only of selected embodiments and not all possible implementations, and are not intended to limit the scope of the present disclosure.

15 **[0011]** Figure 1 is a schematic depicting an exemplary exhaust aftertreatment system constructed in accordance with the teachings of the present disclosure;

[0012] Figure 2 is a functional block diagram of a controller according to the present disclosure;

20 **[0013]** Figure 3 is a functional block diagram illustrating an alternate controller arrangement according to the present disclosure; and

[0014] Figure 4 is flow diagram that illustrates the steps of a method for improving the operating efficiency of an engine exhaust treatment and fuel efficiency improvement system.

25 **[0015]** Corresponding reference numerals indicate corresponding parts throughout the several views of the drawings.

DETAILED DESCRIPTION

[0016] Example embodiments will now be described more fully with
30 reference to the accompanying drawings.

[0017] It should be understood that although the present teachings may be described in connection with diesel engines and the reduction of NO_x

emissions, the present teachings may be used in connection with any one of a number of exhaust streams, such as, by way of non-limiting example, those from diesel, gasoline, turbine, fuel cell, jet or any other power source outputting a discharge stream. Moreover, the present teachings may be used in connection
5 with the reduction of any one of a number of undesired emissions. For example, injection of hydrocarbons as a NO_x reducing agent or for the regeneration of diesel particulate filters is also within the scope of the present disclosure. For additional description, attention should be directed to commonly-assigned U.S. Patent No. 8,047,452, entitled "Method And Apparatus For Injecting Atomized
10 Fluids", which is incorporated herein by reference.

[0018] With reference to the Figures, a pollution control system 8 for reducing NO_x emissions from the exhaust of an internal combustion engine 21 is provided. In Figure 1, solid lines between the elements of the system denote fluid lines for reagent and dashed lines denote electrical connections. The
15 system of the present teachings may include a reagent tank 10 for holding the reagent and a delivery module 12 for delivering the reagent from the tank 10. The reagent may be a urea solution, a hydrocarbon, an alkyl ester, alcohol, an organic compound, water, or the like and can be a blend or combination thereof. It should also be appreciated that one or more reagents may be available in the
20 system and may be used singly or in combination. The tank 10 and delivery module 12 may form an integrated reagent tank/delivery module. Also provided as part of system 8 is a controller 14, a reagent injector 16, and an exhaust system 18. Exhaust system 18 includes an exhaust conduit 19 providing an exhaust stream to at least one catalyst bed 17.

[0019] The delivery module 12 may comprise a pump that supplies reagent from the tank 10 via a supply line 9. The reagent tank 10 may be polypropylene, epoxy coated carbon steel, PVC, or stainless steel and sized according to the application (e.g., vehicle size, intended use of the vehicle, and the like). A pressure regulator (not shown) may be provided to maintain the
30 system at predetermined pressure setpoint (e.g., relatively low pressures of approximately 60-80 psi, or in some embodiments a pressure of approximately 60-150 psi) and may be located in the return line 35 from the reagent injector 16.

A pressure sensor may be provided in the supply line 9 leading to the reagent injector 16. The system may also incorporate various freeze protection strategies to thaw frozen reagent or to prevent the reagent from freezing. During system operation, regardless of whether or not the injector is releasing reagent into the exhaust gases, reagent may be circulated continuously between the tank 10 and the reagent injector 16 to cool the injector and minimize the dwell time of the reagent in the injector so that the reagent remains cool. Continuous reagent circulation may be necessary for temperature-sensitive reagents, such as aqueous urea, which tend to solidify upon exposure to elevated temperatures of 300°C to 650°C as would be experienced in an engine exhaust system.

[0020] Furthermore, it may be desirable to keep the reagent mixture below 140°C and preferably in a lower operating range between 5°C and 95°C to ensure that solidification of the reagent is prevented. Solidified reagent, if allowed to form, may foul the moving parts and openings of the injector.

[0021] The amount of reagent required may vary with load, exhaust gas temperature, exhaust gas flow, engine fuel injection timing, desired NO_x reduction, barometric pressure, relative humidity, EGR rate and engine coolant temperature. A NO_x sensor or meter 25 may or may not be positioned downstream from catalyst bed 17. NO_x sensor 25, if provided, is operable to output a signal indicative of the exhaust NO_x content to controller 14 and/or an engine control unit 27.

[0022] Referring to Figures 1 and 2, controller 14 is in communication with engine control unit 27 and is in receipt of signals representative of measured exhaust parameters as provided by exhaust sensors 50. The measured exhaust parameters may include exhaust temperature at a location proximate engine 21 and/or at a location proximate an inlet to SCR 17. The exhaust temperature downstream from SCR 17 may also be measured. Other relevant exhaust information that may be collected by exhaust sensors 50 includes exhaust pressure, exhaust flow rate and NO_x, if a NO_x sensor is provided.

[0023] Controller 14 includes a NO_x module 52, an SCR efficiency module 54, a dosing module 56, an injection optimization module 58, a fuel

combustion control module 60 and a reagent injection control module 62. Controller 14 may receive input signals from engine control unit 27 indicative of a number of engine operating conditions including engine speed, engine load, fuel injection timing, exhaust gas recirculation system flow, fuel flow rate, coolant
5 temperature, engine inlet air temperature, barometric pressure, air flow rate, manifold pressure, and crankshaft position. Other information may also be provided from ECU 27 or exhaust system sensors 50. Controller 14 commands an engine fuel injection system 66 and reagent injector 16.

[0024] NO_x module 52 calculates the NO_x content emitted by engine 21
10 based on either the signal output from the NO_x sensor or one or more of the signals previously discussed including engine speed, fuel flow rate, intake air temperature, injection timing and/or coolant temperature. NO_x module 52 may be programmed with a map generated from empirical test data obtained from a similar engine operating under like circumstances. Other purely analytical
15 techniques may be used to calculate a quantity of engine NO_x, if desired. NO_x module 52 may determine NO flow, NO₂ flow, and/or a NO_x ratio = NO₂ : NO_x.

[0025] SCR efficiency module 54 is in receipt of the calculated engine NO_x provided by NO_x module 52. SCR efficiency module 54 calculates a required SCR conversion efficiency to assure that the NO_x content entering the
20 atmosphere is at or below a predetermined threshold based on the calculated quantity of engine NO_x. Once the quantity of NO_x has been determined and the required SCR efficiency to appropriately reduce the NO_x has been calculated, this information is forwarded to dosing module 56.

[0026] Dosing module 56 calculates the amount of ammonia to provide
25 to the engine exhaust to reduce the NO_x content below the predetermined threshold. Several different methods may be used to calculate the requisite quantity of ammonia. For example, one method includes executing an ammonia storage model to determine a target amount of ammonia to be stored in SCR 17. The ammonia storage model may include a map correlating the required
30 quantities of ammonia to be dosed to exhaust containing NO_x. The map may account for reductant type, selective catalytic reduction device type, SCR temperature, and exhaust mass flow rate, among other factors. SCR dosing

module 56 may alternatively calculate the amount of ammonia required using purely theoretical models without the use of a map. The purely analytical and theoretical approach may incorporate a chemistry and physics based model. Use of this type of model may significantly reduce the need for prototype
5 construction and data collection. Some of the models, however, may have limited applicability.

[0027] Dosing module 56 may also calculate a dosing rate of reductant to be injected into the exhaust. Dosing module 56 may account for the particular ammonia storage mechanism employed. For example, the reductant may be
10 carried on a vehicle as an aqueous urea solution or as a solid urea. The physical characteristics of injector 16 may also be considered at this time to define an energization sequence to the particular injector being used to supply the reductant to the exhaust.

[0028] Injection optimization module 58 determines whether an
15 increase in vehicle operation efficiency may be gained by varying the reductant dosing rate and the rate of engine fuel consumption. Injection optimization module 58 calculates the extent to which engine exhaust NO_x may be increased up to the predetermined NO_x threshold. A further calculation is made regarding the opportunity to operate engine 21 in a further lean mode by reducing the
20 quantity of fuel injected into the combustion chambers of the engine. When the engine operating conditions are further leaned out to reduce fuel consumption, NO_x output from the engine typically increases. Injection optimization module 58 evaluates several combinations and permutations of possible reductant injection rates and fuel consumption rates that may be possible while maintaining the NO_x
25 output below the predetermined threshold.

[0029] At least one of the factors considered by injection optimization module 58 includes determining the upper limit of the NO_x reduction system. State another way, injection optimization module 58 determines the maximum NO_x increase over the present operating condition that may be counteracted by
30 an increase in reductant injection rate while maintaining a NO_x output below the threshold. Injection optimization module 58 also accounts for the possibility of varying other engine operating characteristics including air flow, fuel injection

timing, EGR flow and fuel flow rate. Once the optimized engine operating parameters and reductant injection rates have been determined to minimize vehicle operation costs, controller 14 recalculates the engine NO_x that will be emitted to atmosphere based on the projected changes to fuel injection rate, reagent injection rate, EGR flow, and any other parameters. Based on the previous calculations, injection optimization module 58 calculates whether the system operating efficiency may be increased. If so, the revised target engine operating conditions are provided to fuel combustion control module 60. Similarly, the revised reagent quantity is provided to reagent injection control module 62. Fuel combustion control module 60 outputs a signal to engine fuel injection system 66 to provide the new target fuel flow rate. This information may be provided to ECU 27. Fuel combustion control module 60 may account for the number and type of active fuel injectors associated with engine 21. Fuel combustion control module 60 may also output signals for controlling the EGR flow rate and the intake air flow rate.

[0030] Reagent injection control module 62 receives a signal from injection optimization module 58 relating to the quantity of ammonia to be injected to meet the target NO_x output. Reagent injection control module 62 outputs a signal to control the operation of reagent injector 16. The signal may account for the type of reagent being injected. For example, reagent injection control module 62 may consider the percentage of urea within an aqueous solution or some other parameter depending on the reductant storage system. After commands have been sent from controller 14 to engine fuel injection system 66 and reagent injector 16, controller 14 recalculates the engine NO_x at the exhaust system outlet based on confirmed changes to the engine management parameters. A reagent dosing quantity is calculated based on the recalculated NO_x content provided by NO_x module 52. The revised dosing quantity is provided to reagent injection control module 62 such that reagent injector 16 delivers the revised and optimized reagent quantity.

[0031] As depicted in Figure 3, some modules previously described as being executed within controller 14 may alternately be included as part of the engine control unit 27. In particular, it is contemplated that NO_x module 52, SCR

efficiency module 54 and injection optimization module 58 form a part of ECU 27. Controller 14 would continue to implement dosing module 56 and an input/output module 68. Input/output module 68 assists with the transfer of information between ECU 27 and controller 14.

5 **[0032]** In operation, and with reference to Figure 4, the exhaust treatment and fuel efficiency optimization system of the present disclosure collects information regarding the present operating conditions of the exhaust system and measures exhaust sensed parameters at step 80. Exhaust system sensors 50 provide controller 14 with signals indicative of the relevant exhaust
10 conditions. Similarly at step 82, controller 14 receives information from ECU 27 including signals indicative of engine speed, engine load, fuel injection timing, EGR flow, fuel flow rate, engine inlet air temperature, barometric pressure, engine coolant temperature, crankshaft position, exhaust manifold pressure and possibly several other signals indicative of the engine operating condition.

15 **[0033]** At step 84, control calculates the engine NO_x using a NO_x sensor signal or one or more of the methods previously described. Controller 14 next calculates the SCR conversion efficiency required to maintain the NO_x output to the atmosphere at or below a predetermined threshold at step 86. At
20 step 88, control determines the quantity of ammonia that is to be injected to reduce the NO_x magnitude to the threshold quantity. At step 90, a reagent dosing quantity or reagent dosing rate is calculated. The dosing rate will typically be determined in grams of urea per second.

[0034] Control, at step 92, calculates whether an increase in vehicle operation efficiency may be gained by varying the reductant dosing rate in
25 combination with changing the engine operating parameters. In one example, the rate of engine fuel consumption is reduced by adjusting the air/fuel mixture to be increasingly lean. Operating the engine at a further lean condition increases the NO_x output. To account for the increase in NO_x output, reductant dosing rate is increased. The cost of the increase in reductant dosing rate is less than the
30 cost savings realized by reducing the rate of engine fuel consumption. As such, the vehicle operating cost may be reduced by implementing the present teachings. In another example, the vehicle may operate more efficiently from a

cost analysis point of view if the rate of engine fuel consumption is increased, thereby reducing NO_x output and reducing the reductant dosing rate required to meet emission standards.

[0035] Once an optimized set of engine operating parameters and reductant injection rates have been determined, control recalculates the engine NO_x output based on the projected changes to engine control which may include injection timing and EGR flow. Recalculation occurs at step 94. At step 96, control determines whether the proposed optimized engine operating parameters and exhaust treatment system operating parameters may be met to improve the system efficiency based on changing the engine NO_x output. This determination may include evaluating the reagent injection system and ensuring that the system has the capability to reduce the increased quantity of NO_x to a magnitude at or below the predetermined threshold. If the projected changes to the engine operating conditions and the reductant injection system are not feasible, control continues to step 98 where reagent is dosed at the previously calculated rate at step 90 and not the proposed rate determined at step 92.

[0036] If control determines that system efficiency may be improved by changing the NO_x output of the engine, the information is sent to engine control unit 27 to vary the engine operating parameters at step 100. Control confirms that the engine operating parameters have been changed at step 102. Engine NO_x output is recalculated at step 104 based on the confirmed changes to the engine operating parameters that may include injection timing and EGR flow. A revised reagent dosing quantity is calculated at step 106 to account for recalculated engine NO_x quantity determined at step 104. At step 98, reagent is dosed at the recalculated rate determined at step 106.

[0037] As used herein, the term module refers to an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory that executes one or more software or
5 firmware program, a combinational logic circuit, and/or other suitable components that provide the described functionality.

[0038] Furthermore, the foregoing discussion discloses and describes merely exemplary embodiments of the present disclosure. One skilled in the art will readily recognize from such discussion, and from the accompanying
10 drawings and claims, that various changes, modifications and variations may be made therein without departing from the spirit and scope of the disclosure as defined in the following claims.

CLAIMS

What is claimed is:

1. An engine exhaust treatment and fuel efficiency improvement system, comprising:
 - 5 a NO_x module that determines a quantity of NO_x emitted from an engine;
 - a selective catalytic reduction (SCR) efficiency module that determines a SCR efficiency to reduce the determined NO_x quantity below a predetermined threshold;
 - a reagent dosing module that determines a quantity of reagent required to
10 reduce the NO_x quantity below the predetermined threshold; and
 - an injection optimization module that determines whether an increase in system operating efficiency may be obtained by changing both an injected reagent quantity and an engine operating parameter in cooperation with each other while maintaining the NO_x quantity below the threshold, wherein the
15 system injection optimization module outputs a signal to change the reagent injection quantity and the engine operating parameter to increase system efficiency.
2. The system of claim 1, wherein the engine operating parameter
20 includes fuel injection rate.
3. The system of claim 2, wherein the engine operating parameter includes exhaust gas recirculation flow rate.
- 25 4. The system of claim 1, wherein the reagent includes urea.
5. The system of claim 1, wherein the injection optimization module signals an increase in reagent injection quantity and a decrease in fuel injection rate.
30
6. The system of claim 1, wherein the injection optimization module determines whether the engine NO_x output at the changed engine operating

parameter may be reduced to the predetermined threshold by the exhaust treatment system and outputs a signal to change the engine parameter only when so determined.

5 7. The system of claim 1, wherein the NO_x module, the SCR efficiency module and the injection optimization module, are operable on a common control unit that controls the engine operating parameter.

10 8. A method of operating an engine exhaust treatment and fuel efficiency improvements system, the method comprising:

 determining an engine operating parameter;

 calculating engine exhaust NO_x;

 calculating a selective catalytic reduction (SCR) conversion efficiency required to reduce the engine exhaust NO_x below a predetermined threshold;

15 determining a quantity of reagent to inject into the exhaust to reduce the engine exhaust NO_x below the threshold;

 determining whether an operating efficiency of the system may be increased by changing both the reagent quantity and the engine operating parameter while maintaining exhaust NO_x below the threshold; and

20 changing the reagent quantity and the operating parameter to reduce engine fuel consumption.

 9. The method of claim 8, wherein calculating engine exhaust NO_x is accomplished without receiving a NO_x sensor signal.

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 10. The method of claim 8, wherein the engine operating parameter includes fuel injection rate.

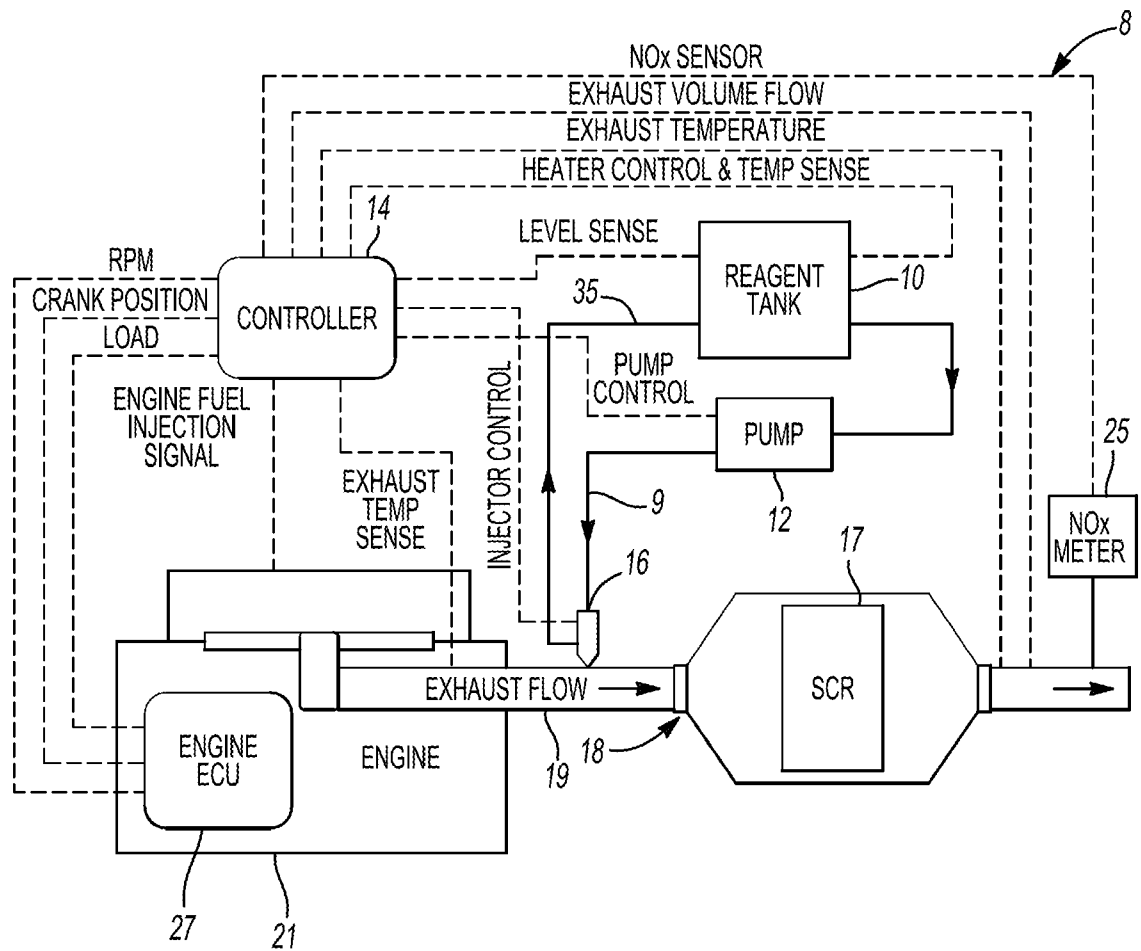
30 11. The method of claim 10, wherein changing the reagent quantity and the operating parameter includes increasing the reagent quantity and decreasing the fuel injection rate.

12. The method of claim 8, wherein the engine operating parameter includes exhaust gas recirculation flow rate.

13. The method of claim 8, wherein the reagent includes urea.

5

14. The method of claim 8, wherein determining whether an operating efficiency may be increased includes determining whether the system includes a capacity to reduce NO_x below the threshold.

**Fig-1**

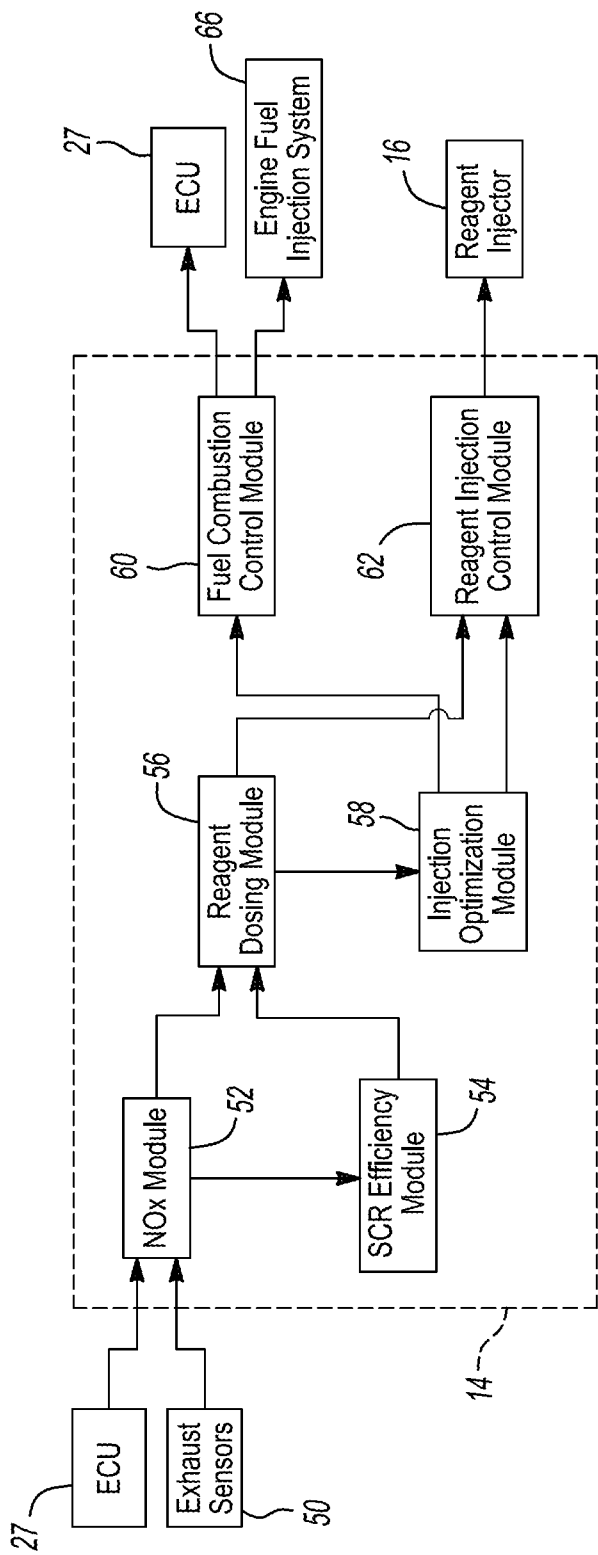


Fig-2

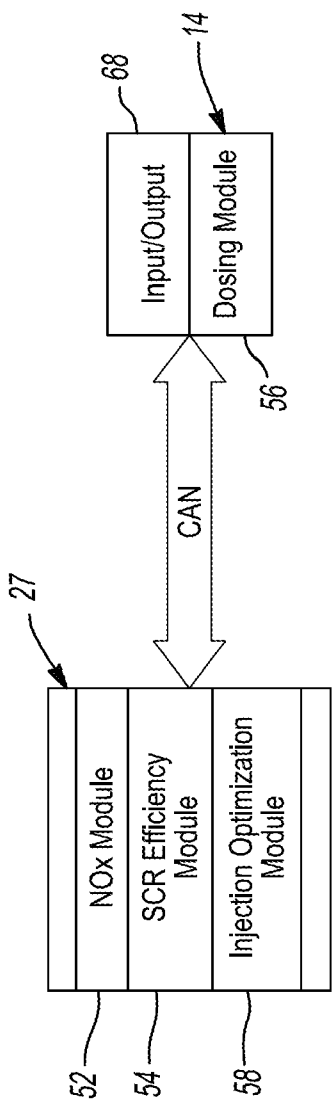
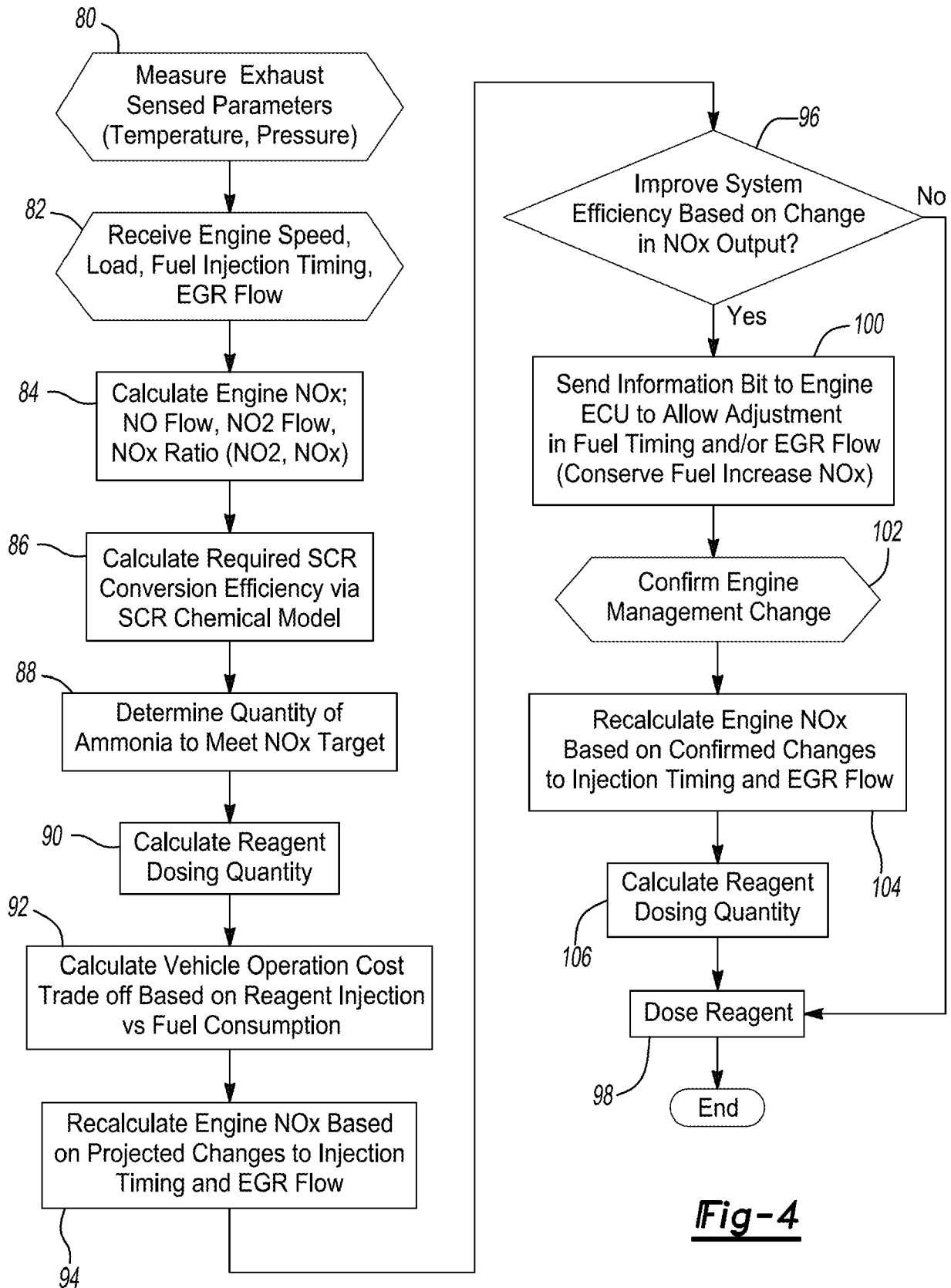


Fig-3

***Fig-4***

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/021651**A. CLASSIFICATION OF SUBJECT MATTER****F01N 3/20(2006.01)i, F01N 9/00(2006.01)i**

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)

F01N 3/20; F04B 49/06; F01N 3/00; F01N 3/10; F01N 9/00

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: NOx, reagent, SCR, treatment, and optimization

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2009-0301067 A1 (DINGLE et al.) 10 December 2009 See paragraphs [0013], [0102]–[0146] and claim 1.	1–14
A	US 2009-0013671 A1 (COOKE et al.) 15 January 2009 See paragraphs [0009]–[0029] and claim 1.	1–14
A	US 2009-0019835 A1 (DINGLE, PHILIP J. G.) 22 January 2009 See paragraphs [0010]–[0032] and figure 1.	1–14
A	US 2008-0087008 A1 (REBA et al.) 17 April 2008 See paragraphs [0010]–[0017] and claim 1.	1–14
A	US 2007-0163232 A1 (UENO, HIROKI) 19 July 2007 See claims 1,4.	1–14



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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