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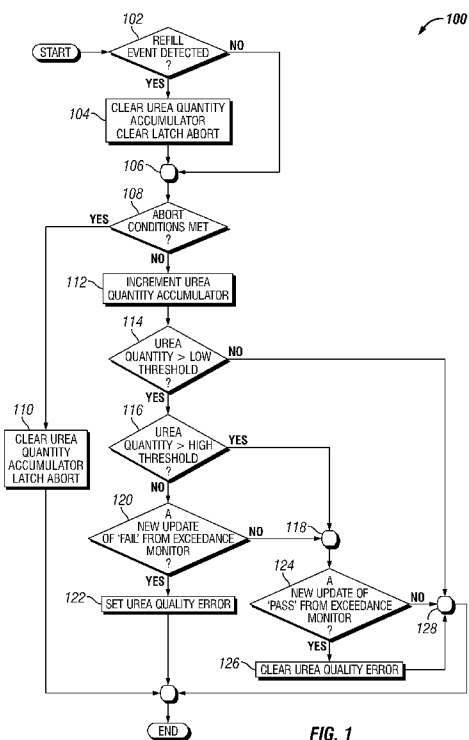
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(54) Title: SYSTEM, METHOD, AND APPARATUS FOR AFTERTREATMENT SYSTEM MONITORING



(57) Abstract: A method includes determining whether a urea refill event is detected, and clearing a quality accumulator value and clearing a latching abort command. The method includes determining whether urea fluid quality check abort conditions are met, and clearing the urea quality accumulator, latching the abort command, and exiting the reductant fluid quality check. In response to the abort conditions not being met, incrementing the urea quality accumulator according to an amount of urea being injected, and comparing the accumulated urea quantity to a low test threshold. The method includes, in response to the accumulated urea quantity being greater than the low test threshold, comparing the accumulated urea quantity to a high test threshold, and in response to the urea quantity being greater than the high test threshold, determining whether the a NO<sub>x</sub> exceedance is observed and clearing a urea quality error in response to the NO<sub>x</sub> exceedance not being observed.

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# SYSTEM, METHOD, AND APPARATUS FOR AFTERTREATMENT SYSTEM MONITORING

## BACKGROUND

The technical field generally relates to aftertreatment systems for internal combustion engines. The introduction of aftertreatment systems into the exhaust systems of internal combustion engines also introduces a number of related challenges and drawbacks.

In one example, a NO<sub>x</sub> reduction system provides a capability to reduce NO<sub>x</sub> emissions from the engine. However, it is desirable to detect whether the NO<sub>x</sub> reduction system is properly or sufficiently reducing NO<sub>x</sub> gases. One method to determine whether the NO<sub>x</sub> reduction system is operating properly is to put a NO<sub>x</sub> sensor downstream of the NO<sub>x</sub> reduction system. However, in certain engine operating conditions, the system will be operating properly, yet the engine will be producing enough NO<sub>x</sub> that the NO<sub>x</sub> sensor detects NO<sub>x</sub> output and the system may appear to be in a failed condition. At certain engine operating conditions, the engine may be producing a small amount of NO<sub>x</sub> such that even a failed NO<sub>x</sub> reduction system is capable of converting virtually all of the presented NO<sub>x</sub> and the system may appear to be operating properly.

Certain systems for aftertreatment rely upon an active component (e.g. a selective reduction catalyst (SCR) component), upon a reagent (e.g. urea to provide NH<sub>3</sub> to the SCR component), and/or upon a reagent delivery system (e.g. a reagent injector). Certain failures of these systems produce failures that are difficult to detect, and/or difficult to identify a source of the failure. For example, it is challenging to distinguish between a failed catalyst on the SCR component, a failed reagent (e.g. a urea reagent container erroneously or improperly filled with water), and a failed reagent delivery system.

Certain systems for aftertreatment rely upon having both upstream and downstream NO<sub>x</sub> measurement of the reduction catalyst to determine if the

catalyst NO<sub>x</sub> conversion has degraded. Certain systems for aftertreatment rely upon inlet NO<sub>x</sub> determinations and reductant injection rate determinations that have high accuracy and precision to determine if the catalyst NO<sub>x</sub> conversion efficiency has degraded.

Therefore, further technological developments are desirable in this area.

## SUMMARY

One embodiment is a unique method for determining a NO<sub>x</sub> reduction system failure. Other embodiments include unique methods and systems for distinguishing the failed component in the NO<sub>x</sub> reduction system. This summary is provided to introduce a selection of concepts that are further described below in the illustrative embodiments. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter. Further embodiments, forms, objects, features, advantages, aspects, and benefits shall become apparent from the following description and drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic flow diagram of a procedure for detecting a reductant fluid quality error.

Fig. 2A illustrates an exemplary timeline for detecting a reductant fluid refill event.

Fig. 2B illustrates a second exemplary timeline for detecting a reductant fluid refill event.

Fig. 3 illustrates a timeline for detecting a reductant fluid quality error.

Fig. 4 illustrates exemplary deNO<sub>x</sub> efficiency and deNH<sub>3</sub> efficiency values plotted against ANR for a NO<sub>x</sub> reduction system.

Fig. 5 illustrates an epsilon ( $\epsilon$ ) value plotted against ANR for a NO<sub>x</sub> reduction system.

Fig. 6 depicts an exemplary behavior table for a NO<sub>x</sub> reduction system diagnostic procedure.

Fig. 7 is a schematic flow diagram of a procedure for determining an average deNO<sub>x</sub> efficiency.

Fig. 8 is a schematic flow diagram of a procedure for determining an averaged  $\epsilon$  value.

Fig. 9 is a schematic flow diagram of a procedure for monitoring a NO<sub>x</sub> reduction system NO<sub>x</sub> conversion amount.

Fig. 10 provides an illustrative estimated NO<sub>x</sub>, high NO<sub>x</sub> threshold, and low NO<sub>x</sub> threshold value.

Fig. 11 provides an illustrative estimated NO<sub>x</sub>, high NO<sub>x</sub> threshold, and low NO<sub>x</sub> threshold value, with a NO<sub>x</sub> value plotted on a logarithmic axis.

Fig. 12 depicts an exemplary behavior table for a NO<sub>x</sub> reduction system monitoring procedure.

## DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended, any alterations and further modifications in the illustrated 5 embodiments, and any further applications of the principles of the invention as illustrated therein as would normally occur to one skilled in the art to which the invention relates are contemplated herein.

Referencing Fig. 1, an example procedure 100 for performing a 10 reductant fluid quality check is depicted. The procedure 100 includes an operation 102 to determine whether a refill event is detected. If the refill event is detected, at operation 104 a urea quality accumulator value is cleared (e.g. reset to zero) and a latching abort command is cleared, allowing the reductant fluid quality check to proceed. The latching abort command 15 indicates that, once the abort command is set, the abort command value is held at the same value until updated by another operation.

In response to the refill event not being detected, the procedure 100 bypasses operation 104 to continuation 106, and the procedure further includes an operation 108 to determine whether abort conditions are met. In 20 response to the abort conditions being met, the check includes an operation to clear the urea quality accumulator, latch the abort command, and exit the check. Example operations to determine whether the abort conditions are met include checking the latching abort command, and checking whether a fault is present. Example faults that cause the reductant fluid quality check to abort 25 include a temperature sensor fault, a NO<sub>x</sub> sensor fault, a reductant injector fault, and/or a reductant tank level fault. Additionally or alternatively, any fault in the system that renders an engine-out NO<sub>x</sub> estimate, a reduction catalyst NO<sub>x</sub> conversion efficiency estimate, and/or an injected amount of reductant (relative to a commanded amount of reductant) to be sufficiently

uncertain is a fault that can be utilized to abort the reductant fluid quality check.

The reductant fluid quality check continues, when no abort condition is met, by an operation 112 to increment a urea quality accumulator (or reductant quality accumulator) according to an amount of urea being injected. The procedure 100 includes an operation 112 to compare the output of the urea quality accumulator, the urea quantity, to a low test threshold, and if the urea quantity is less than the low test threshold the current execution cycle of the reductant fluid quality check is exited through continuation 128. If the urea quantity is greater than the low test threshold, the test is continued with an operation 116 to compare the urea quantity to a high test threshold.

In response to the urea quantity being greater than the high test threshold, the procedure 100 includes an operation 124 to determine whether the urea quality check can be determined to be a PASS value. The operation 124 is determined to be a PASS value when no NO<sub>x</sub> exceedance is observed. If the operation 124 is determined to be a PASS value, the procedure 100 includes an operation 126 to clear any urea quality error before proceeding to continuation 128 and exiting.

In response to the urea quantity being lower than the high test threshold, the procedure 100 includes an operation 120 to determine whether the check can be determined to be a FAIL value. If the check is determined to be a FAIL value, the procedure includes an operation 122 to set a urea quality error (or reductant fluid quality error), if present. An example operation 120 determines the check to be a FAIL value when a NO<sub>x</sub> exceedance is observed.

Referencing Figs. 2A and 2B, illustrative data demonstrating an operation to detect a refill event is depicted. The curve 202a illustrate the state of the key switch 208, with a high vertical position indicating an "ON" key switch and a low vertical position indicating an "OFF" key switch. The curve 204a indicates the output of the urea tank level 206 (or reductant tank level), for example from a urea tank level sensor.

The exemplary operation includes a detection in response to a fill-up during a key off event (or other controller shutdown event wherein, during the period of the shutdown, a signal from a reductant tank level sensor is unavailable) illustrated in the top timeline. At a first time 210 the urea tank level is shown to be low at a time when a key switch is turned off. In the example of the upper timeline, the signal from the urea tank level is unavailable while the keyswitch remains off. The signal is resumed at a second time 212, and when the urea tank level is determined to be high, a refill event is detected.

The difference between the low and the high tank levels that is required to determine that a refill event has occurred may be any amount, including any minimally significant amount up to an amount requiring that the tank be substantially filled with new reductant fluid before a refill event is detected. For example, the refill event may detect top-off events where a minor but significant amount of urea is added, only events from a threshold low level to ensure that most of the present urea is newly added urea, or events where a specified percentage of the entire capacity of the urea tank is added (e.g. 10%, 20%, 50%, or other value). One of skill in the art will recognize that requiring more complete refills improves the reliability of a given reductant fluid quality check to properly determine the NO<sub>x</sub> reduction capacity of the replacement reductant fluid, but it will also reduce the number of opportunities to perform a reductant fluid quality check, as partial fill-ups of insufficient size to trigger a refill detection will extend the time period between checks.

Referencing Fig. 2B illustrative data demonstrates an operation to detect a refill event. In the operations of the lower timeline, while the key switch remains on and the urea tank level signal remains active, a fill up event occurs at the time period 214. In certain embodiments, when a urea tank level increase is detected, an initial urea tank level and a final urea tank level are determined according to when the tank level rise begins and ends, and/or according to when the tank level rise begins and a tank level decrease begins.

According to the difference between the final and initial urea tank levels, a refill event may be detected. The amount of rise determined to be a refill event is determined under similar considerations for an embodiment utilizing Fig. 2B or Fig. 2A.

5           Referencing Fig. 3, example operations of a reductant fluid quality check procedure are shown on a timeline of illustrative data 300. The upper data timeline indicates the “DEF” tank level (diesel exhaust fluid), which may be a level of any reductant fluid. The lower timeline indicates an asterisk 318, 320 at each reductant fluid quality check result. Certain ones of the reductant  
10 fluid quality check results are utilized, and certain others of the reductant fluid quality check result are ignored. At the bounded times 302, 304 in the upper timeline, a refill event is detected due to the rise in the DEF tank level.

          Referencing the lower timeline, test data points occurring before the DEF tank refill event are ignored and the test results are not used to set or  
15 clear a reductant fluid quality error. After the DEF tank refill event, the test data points are likewise ignored until an amount of reductant is injected that exceeds the low test threshold – occurring at time 306 in the illustration. The test continues until the high test threshold amount of reductant is injected, occurring at time 308 in the illustration. The test point 318 that occurs  
20 between the times 306, 308 is utilized, and since a sufficient SCR conversion efficiency 322 is demonstrated reductant fluid quality error is cleared, reset, decremented, or other actions are taken consistent with a passed check on the NO<sub>x</sub> reduction system. In the example embodiment, test values occurring later than the high test threshold may be ignored, or may be utilized to clear or  
25 decrement a reductant fluid quality error. In one form, test values occurring later than the high test threshold are not utilized to increment or set the reductant fluid quality error.

          Further in Fig. 3, a second DEF tank refill event occurs between times 314, 316. The low test threshold amount of urea injected is passed at time 310  
30 in the example, and the high test threshold amount of urea injected is passed

at time 312 in the example. A test value 320 indicates that a NO<sub>x</sub> exceedance event occurred. The test value 320 occurs before the high test threshold is reached, and a reductant fluid quality error is set or incremented, or other actions are taken consistent with a failed check on the NO<sub>x</sub> reduction system.

5 In the example of Fig. 3, the two test values occurring after the high test threshold is reached are not utilized.

An example procedure for determining whether an aftertreatment deNO<sub>x</sub> system failure is present and for determining the source of the deNO<sub>x</sub> system failure is described following. The example procedure for determining  
10 the deNO<sub>x</sub> system failure and source may be combined with other procedures to eliminate potential causes for system failure and/or performance degradation.

The exemplary procedure includes determining a deNO<sub>x</sub> efficiency within a temperature and exhaust flow range where the deNO<sub>x</sub> efficiency has a  
15 reduced sensitivity to variation and uncertainty in the sensing values. The procedure includes determining a normalized deNO<sub>x</sub> efficiency, which includes a ratio between measured deNO<sub>x</sub> efficiency and expected deNO<sub>x</sub> efficiency, such as shown in Equation 1. The normalized deNO<sub>x</sub> efficiency is calculated for the data points with an ammonia to NO<sub>x</sub> ratio (ANR) higher than a  
20 stoichiometric ANR ( $\beta$ ).

$$\eta_{Normalized} = \frac{\eta_{measured}}{\eta_{no\ min\ al}} = \frac{(NO_{x\_in} - NO_{x\_out}) / NO_{x\_in}}{\eta_{no\ min\ al}} \quad (\text{Equation 1})$$

It has been found that at ANR values above the  $\beta$  value, the deNO<sub>x</sub> efficiency is not sensitive to ANR, which reduces the noise introduced from NO<sub>x</sub> reduction catalyst inlet NO<sub>x</sub> sensing error (or modeled inlet NO<sub>x</sub> error)  
25 and urea dosing error. Accordingly, the normalized deNO<sub>x</sub> efficiency can be more indicative of the effects of the NO<sub>x</sub> reduction catalyst and the reductant fluid quality, while helping decouple the effects of inlet NO<sub>x</sub> determination errors and reductant injection rate errors. Referencing Fig. 4, simulated illustrative data is shown illustrating the deNO<sub>x</sub> efficiency behavior of various

operating curves. The curves 416, 418, 420, and 424 illustrate example deNO<sub>x</sub> efficiency values as a function of the ANR, and illustrate that the deNO<sub>x</sub> efficiency rises linearly with the ANR over a period of operating points below the β value, begins a non-linear transition region around the β value, at  
 5 flattens at high ANR values to a value which is not responsive to the ANR at high ANR values. The values 422 represent a number of possible curves that may be determined for a given system, similar to the curves 416, 418, etc.

Referencing again Fig. 4, the curves 406, 408, 410, 414 illustrate example deNH<sub>3</sub> efficiency curves corresponding to the deNO<sub>x</sub> efficiency curves  
 10 416, 418, 420, 424. The curves for deNO<sub>x</sub> efficiency and deNH<sub>3</sub> efficiency meet at the β value, or at the stoichiometric point. The values 412 represent a number of possible curves that may be determined for a given system, similar to the curves 406, 408, etc. The curves 406, 408, 410, 414 are illustrated to provide a fuller understanding of the catalyst activity in the system.

15 For the data points with ANR less than β, the procedure includes determining an ε value. The ε value is defined as the ratio between dosing commands and NO<sub>x</sub> removed in the catalyst (*see* Equation 2). In the example of Equation 2, the ε value is a mass balance ratio. For example, as depicted in the illustrative data of Fig. 5, while the deNO<sub>x</sub> efficiency is insensitive to ANR  
 20 at high ANR values – specifically above β – the ε value becomes relatively insensitive to ANR at low values of ANR. The curves 504 depicts the ε value as a function of ANR. As depicted in the illustrative data of Fig. 4, the ε value becomes relatively insensitive to ANR at low values of ANR, specifically below β.

$$25 \quad \varepsilon = \frac{NH_3\_in}{NOx\_in - NOx\_out} = \frac{NH_3\_in / NOx\_in}{(NOx\_in - NOx\_out) / NOx\_in} = \frac{ANR}{DeNOx\_eff}$$

(Equation 2)

When evaluated in the regions where it is insensitive to ANR, the normalized deNO<sub>x</sub> efficiency is more sensitive to catalyst deNO<sub>x</sub> efficiency deterioration, and decouples engine-out NO<sub>x</sub> determinations and urea injector

errors. Generally, a deteriorated deNO<sub>x</sub> efficiency will move downward in the curves, for example from operating curve 416 to operating curve 418. When evaluated in the regions where it is insensitive to ANR, the  $\epsilon$  value is more sensitive to urea delivery, and decouples catalyst deNO<sub>x</sub> efficiency deterioration.

Referencing Fig. 6, an example logic description to utilize the normalized deNO<sub>x</sub> efficiency and the  $\epsilon$  value is illustrated. In the example of Fig. 6, where both the deNO<sub>x</sub> efficiency and the  $\epsilon$  value indicate a component failure, the failure is attributable to any of the deNO<sub>x</sub> catalyst, the reductant dosing system, or the reductant fluid quality. Where both of the deNO<sub>x</sub> efficiency and the  $\epsilon$  value indicate a PASS, then no component failure is indicated. Where the  $\epsilon$  value indicates a component failure and the deNO<sub>x</sub> efficiency indicates a PASS, the component failure is narrowed to the reductant dosing system or the reductant fluid quality. Where the  $\epsilon$  value indicates a PASS and the deNO<sub>x</sub> efficiency indicates a component failure, the component failure is narrowed to the deNO<sub>x</sub> catalyst or the reductant fluid quality.

Referencing Fig. 6, an illustrative component failure logic 600 is depicted. The component failure logic 600 is helpful to reduce maintenance costs and failure diagnostic time, as well as to separate coupled issues in diagnosing a failed component. Alternatively or additionally, the information from Fig. 6 can be utilized with other information available in the system to further determine which component is failed. For example, if a catalyst temperature excursion is observed immediately before a failure, it may be determined to be more likely to be a failed catalyst than a reductant fluid quality failure. A technician may manually check a reductant fluid quality or a reductant doser system. In one form, a fault present in the reductant doser system, a reductant tank level that is observed to drop as expected over time, results from an active diagnostic performed on the reductant dosing system, and/or any other information available in the system may be utilized with the

information from Fig. 6 to determine which component of a NO<sub>x</sub> reduction aftertreatment system has failed.

In the example component failure logic 600 of Fig. 6, a first column 602 depicts an  $\epsilon$  based failure determination, for example according to Equation 2 and the nominal operations depicted in Fig. 5 or similar information calibrated for a particular system. A second column 604 depicts a normalized deNO<sub>x</sub> efficiency based failure determination, for example according to Equation 1 and the deNO<sub>x</sub> efficiency curves depicted in Fig. 4 or similar information calibrated for a particular system. In the example logic 600, where the  $\epsilon$  indicates a failure and the normalized deNO<sub>x</sub> efficiency indicates a failure, the failure is determined to be one of the catalyst, the dosing injector, or the reductant quality, although the diagnostic differences of the  $\epsilon$  and normalized deNO<sub>x</sub> efficiency do not separate these component failures. Where the  $\epsilon$  indicates a failure, but the normalized deNO<sub>x</sub> efficiency does not indicate a failure, the catalyst is understood to be working properly and the component failure is narrowed to a dosing injector or the reductant quality. Where the  $\epsilon$  indicates a pass and the normalized deNO<sub>x</sub> efficiency indicates a failure, the component failure is understood to be either the catalyst or the reductant quality. Where both the  $\epsilon$  and the normalized deNO<sub>x</sub> efficiency indicate a pass, the system is understood to be working correctly. The output of the logic 600 can be combined with other information, for example a reductant quality check such as depicted in Fig. 1, to further narrow the diagnosis of any failure.

Another example procedure is described for diagnosing whether reductant fluid is proper, diluted, replaced, or otherwise improper. The procedure includes an operation to determine whether a tank refill event is detected. An example operation includes interpreting a reductant tank level value, for example from a tank level sensor, and in response to the reductant tank level value determining the reductant tank is recently filled. The procedure further includes determining a tank refill event in response to the reductant tank level value. In response to the tank refill event, the procedure

includes an operation to clear a reductant accumulator value and proceeding with a reductant fluid quality check. The operation also clears an abort latch, such that a check at operation will indicate that abort conditions are not met for the purpose of checking a new urea tank, although other abort conditions  
5 may be otherwise met.

The procedure further includes determining a NO<sub>x</sub> emissions amount, for example determined from reductant dosing commands, inlet and outlet NO<sub>x</sub> levels for a reductant catalyst, an estimated temperature for the reductant catalyst, and an exhaust flow rate for an engine providing the  
10 exhaust treated by the reductant catalyst. The inlet and outlet NO<sub>x</sub> level values may be determined from a sensor, and the inlet NO<sub>x</sub> level may alternatively or additionally be determined from a model. The reductant catalyst temperature may be determined from an inlet sensor, outlet sensor, a mid-brick sensor, and/or from a weighted average of available sensors or a  
15 modeled value based upon exhaust and/or turbine outlet temperatures.

The exemplary procedure further includes determining a NO<sub>x</sub> exceedance event in response to the NO<sub>x</sub> emissions amount. In response to the NO<sub>x</sub> exceedance event occurring within a predetermined period after the tank refill event, a reductant fluid quality failure is detected. In certain  
20 embodiments, determining the NO<sub>x</sub> exceedance event includes accumulating a reductant injected amount during a period of the reductant fluid quality check. In response to the reductant injected amount being lower than a low test threshold, the reductant fluid quality check is exited without conclusion. In response to the reductant injected amount being greater than a high test  
25 threshold, the procedure includes an operation to clear any reductant fluid quality error if a NO<sub>x</sub> exceedance is not detected. In response to the reductant injected amount being greater than the low test threshold but less than the high test threshold, the procedure includes an operation to set a reductant fluid quality error if a NO<sub>x</sub> exceedance is detected, and to clear a reductant fluid  
30 quality error if the NO<sub>x</sub> exceedance is not detected.

The detection of the NO<sub>x</sub> exceedance includes determining that a threshold amount of NO<sub>x</sub> is being emitted from the system, where the threshold amount of NO<sub>x</sub> is a selected amount of NO<sub>x</sub>. Exemplary and non-limiting threshold amounts of NO<sub>x</sub> include an amount exceeding an emissions target, an amount exceeding a short-term emissions target, an amount exceeding any other NO<sub>x</sub> target value, and/or an amount exceeding any selected target with an added or subtracted estimated margin of error. The margin of error may be added, for example, to ensure that a given NO<sub>x</sub> emissions level is actually greater than the NO<sub>x</sub> target value. The margin of error may be subtracted, for example, to ensure that a given NO<sub>x</sub> emissions level does not exceed the NO<sub>x</sub> target value before a reductant fluid quality error is set. The margin of error is a value that may be updated over time, for example to the uncertainty of a NO<sub>x</sub> estimate at current operating conditions of the system.

Referencing Fig. 7, an example procedure 700 for monitoring an aftertreatment system is illustrated. The procedure 700 includes an operation 702 to check whether abort conditions for the procedure are met. Exemplary abort conditions include a fault in a hardware component and/or sensor related to the aftertreatment system, a transient operating condition being present, and a reductant dosing system that is presently available to dose (e.g. no conditions are present that prevent the dosing system from providing reductant during the monitoring procedure). The transient operating condition can be a transient exhaust temperature, exhaust flow, and/or engine-out NO<sub>x</sub> level value. In certain embodiments, the presence of steady state operating conditions, or the lack of transient operating conditions, allows the monitoring procedure to proceed. Where abort conditions are present, the procedure includes an operation 704 to reset a counter (a samples taken counter) and an efficiency accumulator.

The procedure 700 further includes an operation 706 to determine whether screening conditions are present. Example screening conditions

include determining that an SCR catalyst temperature is within an operating range, determining that an exhaust flow value or a catalyst space velocity is in an operating range, determining that a dosing command is not presently restricted or limited, and/or that a NO<sub>x</sub> sensor output is operating within a high confidence regime. Example conditions for the NO<sub>x</sub> sensor output to operate in a high confidence regime include the NO<sub>x</sub> sensor output value being within a rational range, the NO<sub>x</sub> sensor value being lower than a threshold value (e.g. not near the top of the operating range such that it might become unreliable during the test), that ambient air pressure is within a normal range, that an NH<sub>3</sub> slip estimate is within a normal range, and/or that an NO<sub>2</sub> slip estimate is within a normal range. In certain embodiments, some test screening or testing abort conditions may be characterized as an abort condition or a screening condition. Generally, where a condition should be absent it is characterized as an abort condition for the test to proceed, and where a condition should be present it is characterized as a screening condition for the test to proceed, but such characterizations are not limiting to any particular embodiment, and certain conditions may be an abort condition in certain embodiments and a screening condition in certain embodiments.

The procedure 700 includes an operation 708 to determine whether the present ANR is greater than the  $\beta$  value. The  $\beta$  value is a stoichiometric value of ANR, or a value near stoichiometric wherein the variability in the deNO<sub>x</sub> efficiency as a function of the ANR is acceptably low. Where the ANR is below the  $\beta$  value, the procedure 700 exits the current execution cycle through continuations 712, 716. Where the ANR is above the  $\beta$  value, the procedure 700 continues with an operation 710 to calculate and accumulate a normalized efficiency value, for example as in Equation 1. The operation 700 to accumulate the normalized efficiency value includes any operation enabling the averaging of a number of normalized efficiency values, including storing a number of efficiency values in a memory buffer, utilizing a filtered or weighted averaged efficiency value that captures historical efficiency value information

over a number of efficiency value points, and similar operations understood in the art.

The procedure 700 further includes an operation 714 to determine whether a sufficient number of efficiency value samples have been taken. The operation 714 to determine whether a sufficient number of samples have been taken includes determining whether a predetermined number of samples have been taken, determining whether enough samples have been taken to provide a given statistical confidence in the average of the samples, and/or may further include weighting of the confidence increment provided by each of the samples in response to the particular reliability of a given sample and determining whether the accumulated confidence exceeds a threshold value.

Where the procedure 700 has not resulted in a sufficient number of samples, the procedure 700 exits the current execution cycle through the continuation 716. Where the procedure 700 has provided sufficient samples, the procedure 700 includes an operation 718 to calculate an averaged efficiency. The operation 718 to calculate the averaged efficiency includes an operation to determine a statistically significant average – for example a mean or median average, an operation to utilize a moving average as the average, and/or an operation to utilize a filtered value as an average. Any other averaging operations understood in the art are contemplated herein. The procedure includes an operation 720 to clear the efficiency accumulator, which may further include resetting any filters, moving averages, or other information history parameters.

Referencing Fig. 8, an exemplary procedure 800 for monitoring an aftertreatment system is illustrated. The procedure 800 includes an operation 802 to check whether abort conditions for the procedure are met. Exemplary abort conditions include a fault in a hardware component and/or sensor related to the aftertreatment system, a transient operating condition being present, and a reductant dosing system that is presently available to dose (e.g. no conditions are present that prevent the dosing system from providing

reductant during the monitoring procedure). The transient operating condition can be a transient exhaust temperature, exhaust flow, and/or engine-out NO<sub>x</sub> level value. In certain embodiments, the presence of steady state operating conditions, or the lack of transient operating conditions, allows the monitoring procedure to proceed. Where abort conditions are present, the procedure includes an operation to reset a counter (a samples taken counter) and an  $\epsilon$  accumulator.

The procedure 800 further includes an operation 806 to determine whether screening conditions are met. The abort conditions and screening conditions of the procedure 800 are similar to but need not be the same as the abort conditions and screening conditions of the procedure 700. For example, procedure 800 utilizes values of ANR below  $\beta$ , and determines values of  $\epsilon$  rather than normalized deNO<sub>x</sub> efficiency. The criteria, operating ranges of sensors, and operating margin within the operating range of sensors and hardware components, to determine whether  $\epsilon$  can be reliably determined and an  $\epsilon$ -based test successfully completed can differ from the same parameters for a deNO<sub>x</sub> efficiency based test.

The procedure 800 includes an operation 808 to determine whether the present ANR is less than the  $\beta$  value. The  $\beta$  value is a stoichiometric value of ANR, or a value near stoichiometric wherein below the  $\beta$  value the variability in the  $\epsilon$  as a function of the ANR is acceptably low. Where the ANR is above the  $\beta$  value, the procedure exits the current execution cycle through the continuations 816, 818. Where the ANR is below the  $\beta$  value, the procedure 800 continues with an operation 810 to calculate and accumulate an  $\epsilon$  value, for example as in Equation 2. The operation 810 to accumulate the  $\epsilon$  value includes any operation enabling the averaging of a number of  $\epsilon$  values, including storing a number of  $\epsilon$  values in a memory buffer, utilizing a filtered or weighted averaged  $\epsilon$  value that captures historical  $\epsilon$  value information over a number of  $\epsilon$  value points, and similar operations understood in the art.

The procedure 800 further includes an operation 812 to determine whether a sufficient number of  $\epsilon$  value samples have been taken. The operation to determine whether a sufficient number of samples have been taken includes determining whether a predetermined number of samples have been taken, determining whether enough samples have been taken to provide a given statistical confidence in the average of the samples, and/or may further include weighting of the confidence increment provided by each of the samples in response to the particular reliability of a given sample.

Where the procedure 800 has not resulted in a sufficient number of samples, the procedure exits the current execution cycle. Where the procedure 800 has provided sufficient samples, the procedure 800 includes an operation 814 to calculate an averaged  $\epsilon$  value. The operation 814 to calculate the averaged  $\epsilon$  value includes an operation to determine a statistically significant average – for example a mean or median average, an operation to utilize a moving average as the average, and/or an operation to utilize a filtered value as an average. Any other averaging operations understood in the art are contemplated herein. The procedure includes an operation 820 to clear the  $\epsilon$  accumulator, which may further include resetting any filters, moving averages, or other information history parameters.

Another exemplary set of embodiments includes a procedure for monitoring a  $\text{NO}_x$  reduction catalyst conversion capability. In certain embodiments, the procedure is operable with a  $\text{NO}_x$  sensor downstream of the  $\text{NO}_x$  reduction catalyst, and no  $\text{NO}_x$  sensor upstream of the  $\text{NO}_x$  reductions catalyst. The procedure may be useful in a system having an upstream  $\text{NO}_x$  sensor, for example as a backup diagnostic for the  $\text{NO}_x$  reduction catalyst if the upstream  $\text{NO}_x$  sensor is failed or suspect. The procedure includes an operation to determine an expected  $\text{NO}_x$  emissions value – the  $\text{NO}_x$  emissions value being a  $\text{NO}_x$  emissions value downstream of the  $\text{NO}_x$  reduction catalyst (e.g. “tailpipe”  $\text{NO}_x$ ). An exemplary expected  $\text{NO}_x$  emissions value is described with

reference to Figs. 10 and 11 following, wherein the diagonal line 1010, 1110 is utilized as the expected NO<sub>x</sub> emissions value.

The procedure further includes determining that a present engine out NO<sub>x</sub> amount is lower than a NO<sub>x</sub> catalyst threshold capability value and greater than a failed NO<sub>x</sub> catalyst threshold capability value. The NO<sub>x</sub> catalyst threshold capability value is a NO<sub>x</sub> amount where a fully capable NO<sub>x</sub> catalyst experiences a decreasing NO<sub>x</sub> conversion capability due to high quantity of NO<sub>x</sub> passing through the catalyst. The failed NO<sub>x</sub> catalyst threshold capability value is a NO<sub>x</sub> amount where a severely degraded NO<sub>x</sub> catalyst will nevertheless exhibit a very high NO<sub>x</sub> conversion due to the low quantity of NO<sub>x</sub> passing through the catalyst. Additionally or alternatively, the high and low NO<sub>x</sub> threshold values are further bounded by a region wherein a NO<sub>x</sub> model is determined to be reliable. Exemplary high and low NO<sub>x</sub> threshold values are described with reference to Figs. 10 and 11 following. Fig. 10 depicts test cell data 1000 taken for a particular system run through a predetermined load schedule, and Fig. 11 depicts test cell data 1100 for a similar system run through a different predetermined load schedule. The data includes the engine out NO<sub>x</sub> output 1002, 1102 as a function of the fuel mass over charge mass 1004. The left vertical line 1006 is selected according to the low NO<sub>x</sub> threshold value, and the right vertical line 1008 is selected according to the high NO<sub>x</sub> threshold value. The example thresholds 1006, 1008 are non-limiting.

The procedure includes determining the present engine out NO<sub>x</sub> amount in response to engine fueling, engine torque, and/or a present engine speed. Additionally or alternatively, the procedure includes determining the present engine out NO<sub>x</sub> amount in response to an intake manifold pressure and one or more timing values of injected fuel (or spark timing for a spark-ignition engine). Any engine out NO<sub>x</sub> model understood in the art is contemplated herein.

In one example, the low NO<sub>x</sub> value 1006 (e.g. the failed NO<sub>x</sub> catalyst threshold capability value) is determined at a low value of a fuel mass-flow to charge mass-flow ratio, and the high NO<sub>x</sub> value 1008 (e.g. the NO<sub>x</sub> catalyst threshold capability value) is determined at a high value of the fuel mass-flow to charge mass-flow ratio. When the observed fuel mass-flow to charge mass-flow ratio is between the low value and the high value, the procedure to monitor the NO<sub>x</sub> reduction catalyst proceeds. In a further embodiment, an estimated NO<sub>x</sub> value for the engine is determined from a calibration line 1010, 1110 between the low value and the high value that bounds an observed engine out NO<sub>x</sub> amount, or that bounds a majority of observed engine out NO<sub>x</sub> amount data points.

Referencing Fig. 10, a plot 1000 of engine-out NO<sub>x</sub> amounts as a function of fuel mass-flow to charge mass-flow ratios are illustrated. The data points in Fig. 10 are taken from a test cell for a particular engine, and are representative of the type of data that an operator can readily determine for a given system. In the embodiment of Fig. 10, the left vertical line 1006 is taken as the low value of a fuel mass-flow to charge mass-flow ratio, and the right vertical line 1008 is taken as the high value of a fuel mass-flow to charge mass-flow ratio. The low and high values may be determined according to the quality of the model, for example selecting logical bounding points for reliable data, and/or according to the engine-out NO<sub>x</sub> amounts that are treatable by a properly functioning NO<sub>x</sub> reduction catalyst (for the high value) and the engine-out NO<sub>x</sub> amounts that would be treatable even for a failed or degraded NO<sub>x</sub> reduction catalyst (for the low value). The diagonal line 1010 between the high and low values, in one form, is the engine-out NO<sub>x</sub> amount estimate to be utilized in a procedure such as the procedure described in the section referencing Fig. 9.

The procedure further includes an operation to perform a screening step, wherein a number of screening parameters are checked, and the operation to monitor the NO<sub>x</sub> reduction catalyst NO<sub>x</sub> conversion capability is

continued if the screening parameters pass. Exemplary and non-limiting screening parameters include the NO<sub>x</sub> reduction catalyst within a proper operational temperature, an exhaust flow of the engine being within a specified range, a rate of change of the NO<sub>x</sub> reduction catalyst temperature  
5 being lower than a threshold value, a reductant injection command value not being limited by a system constraint (i.e. the control system for the reductant injection determination is commanding a reductant injection amount that is estimated to be sufficient to convert a designed amount of NO<sub>x</sub>), the downstream NO<sub>x</sub> sensor value is reading within a specified range and does not  
10 have a fault, the rate of change of the NO<sub>x</sub> sensor value is below a threshold value, an ambient pressure is within a specified range, an estimated NH<sub>3</sub> slip amount is within a range or below a threshold, and an estimated NO<sub>2</sub> slip amount is within a range or below a threshold value. Additional screening parameters include a determination that the engine is at steady state  
15 operation, that an engine speed rate of change is below a threshold value, and/or that an engine fueling or torque value rate of change is below a threshold value.

The determination of ranges for each screening parameter depends upon the hardware present in the system, the NO<sub>x</sub> amount that is considered for the  
20 system (e.g. due to relevant emissions limits, etc.), and is a mechanical step for one of skill in the art having the benefit of the disclosures herein. Each range and limit for the screening parameters is selected to ensure that the NO<sub>x</sub> reduction catalyst is operating under nominal conditions wherein a properly operating catalyst should be expected to succeed and a sufficiently degraded or  
25 failed catalyst should be expected to provide insufficient NO<sub>x</sub> reduction.

An exemplary procedure includes determining an averaged expected NO<sub>x</sub> value and an averaged measured NO<sub>x</sub> value from the NO<sub>x</sub> sensor downstream of the NO<sub>x</sub> reduction catalyst, and determining whether the NO<sub>x</sub>  
reduction capability is failed in response to the averaged measured NO<sub>x</sub>  
30 values. The averaged NO<sub>x</sub> values may be averages of a number of values

stored in a buffer, a filtered value of each parameter (with the same or distinct time constants), moving averages of the NO<sub>x</sub> values, or values determined from other averaging mechanisms known in the art. The threshold to determine a failed NO<sub>x</sub> conversion capability is selectable according to the specific parameters of the contemplated system, and may be a difference of 20%, 30%, 50%, or greater NO<sub>x</sub> amounts. In certain embodiments, the difference may be a ratio difference of observed:expected NO<sub>x</sub> (e.g. 1.2:1), an absolute value of NO<sub>x</sub> (e.g. 10 g/hr), and/or a difference in selected units (e.g. 0.5 g/hp-hr difference).

Another exemplary procedure includes determining whether an engine-out NO<sub>x</sub> regime is in a low, nominal, or high output region. For example, referencing Fig. 10, the low region may be left of the left vertical line 1006, the nominal region may be between the vertical lines 1006, 1008, and the high region may be to the right of the right vertical line 1008. The exemplary procedure further includes determining whether the observed NO<sub>x</sub> amount is higher or lower than the expected NO<sub>x</sub> amount. Referencing Fig. 12, an exemplary response table 1200 is illustrated for the exemplary procedure.

In response to the observed tailpipe NO<sub>x</sub> amount being lower than the expected NO<sub>x</sub> amount, in the low engine-out NO<sub>x</sub> regime the procedure in region 1212 includes blocking the monitor from passing the NO<sub>x</sub> reduction capability, or blocks the monitor from clearing a NO<sub>x</sub> reduction capability fault. In the region 1212, an example procedure in certain embodiments does not determine the NO<sub>x</sub> reduction capability is failed. In response to the observed tailpipe NO<sub>x</sub> amount being lower than the expected NO<sub>x</sub> amount, in the nominal engine-out NO<sub>x</sub> regime the procedure in region 1214 determines the NO<sub>x</sub> reduction capability is passed or allows the monitor to clear a NO<sub>x</sub> reduction capability fault. In response observed tailpipe NO<sub>x</sub> amount being lower than the expected NO<sub>x</sub> amount, in the high engine out NO<sub>x</sub> region 1206, the example procedure in the

region 1216 determines the NO<sub>x</sub> sensor to be in error or to fail a sensor rationality check.

In response to the observed tailpipe NO<sub>x</sub> amount being higher 1210 than the expected NO<sub>x</sub> amount, in the low engine-out NO<sub>x</sub> regime 1202 the procedure in region 1218 determines the NO<sub>x</sub> sensor to be in error or to fail a sensor rationality check. In response to the observed tailpipe NO<sub>x</sub> amount being higher 1210 than the expected NO<sub>x</sub> amount, in the nominal engine-out NO<sub>x</sub> regime 1204, the procedure in region 1220 determines the NO<sub>x</sub> reduction capability is failed or allows the monitor to set a NO<sub>x</sub> reduction capability fault. In response observed tailpipe NO<sub>x</sub> amount being higher 1210 than the expected NO<sub>x</sub> amount, in the high engine out NO<sub>x</sub> region 1206, the example procedure in the region 1222 excludes the operations from affecting any sensor or system failures, and/or from allowing faults to be set or cleared.

Referencing Fig. 9, a schematic flow diagram illustrates a procedure 900 for monitoring a NO<sub>x</sub> reduction system. The procedure 900 includes an operation 916 to determine whether an engine fuel flow 902 and an engine mass flow 904 are below threshold values to perform a monitoring check of the NO<sub>x</sub> reduction system. The procedure 900 further includes an operation 918 to determine whether the rate of change of the engine fuel flow 902 and the engine mass flow 904 are below threshold values to perform the monitoring check of the NO<sub>x</sub> reduction system. The threshold values for the engine fuel flow 902 and engine mass flow 904, and the rates of change thereof, may be set for any reason, including without limitation controlling the test to occur within certain power or emissions limits, within certain catalyst space velocity limits, and/or within certain exhaust temperature limits. The outputs of the operations 916, 918 are input as logical values to an AND block 926. The procedure 900 further includes an operation 922 to determine whether a value of a  $\frac{FuelFlow}{ChargeFlow}$  is between a high and low threshold. The value  $\frac{FuelFlow}{ChargeFlow}$  may be determined according to any method; a lookup table utilizing fuel

massflow 902 and charge massflow 904 is consistent with the depiction in the example. The procedure 900 further includes operations to determine whether data screening parameters 920 have values indicating the monitor should be performed.

5           In response to all of the logical values for the determining operations entering the AND block 926 being TRUE, the procedure 900 includes an enable operation 928 for each of the operations 932, 934. The procedure 900 further includes an operation 912 to determine an expected NO<sub>x</sub> emissions value 914. The example operation 912 utilizes an engine speed 916, an engine  
10 torque 918, and a weighting factor 910. The weighting factor 910 may be determined in response to various engine operation conditions, including at least an EGR fraction, a charge temperature, the timing of fueling, and/or a fuel rail pressure. Additionally or alternatively, any NO<sub>x</sub> model to determine an expected NO<sub>x</sub> emissions value is contemplated herein.

15           The procedure 900 further includes, in response to the enabling operation 928, calculating an average value of the expected NO<sub>x</sub> tailpipe a first operation 932 to calculate an average of a number of values of an expected NO<sub>x</sub> calculation over a period of time or execution cycles, and a second operation  
20 934 to calculate an average of a number of values of a NO<sub>x</sub> sensor reading 930 over the period of time or execution cycles. The NO<sub>x</sub> sensor reading is interpreted from a NO<sub>x</sub> sensor positioned downstream of the NO<sub>x</sub> reduction catalyst of the NO<sub>x</sub> reduction system. The procedure 900 further includes an operation 936 to compare the averaged values, and an operation 938 to  
25 determine a fault value (increment, set, decrement, and/or clear) in response to the comparison.

          An example set of embodiments is a method including determining whether a urea refill event is detected, and in response to the refill event being detected, clearing a urea quality accumulator value and clearing a latching  
30 check abort conditions are met, and in response to the abort conditions being

met, clearing the urea quality accumulator, latching the abort command, and exiting the reductant fluid quality check. The method further includes, in response to the abort conditions not being met, incrementing the urea quality accumulator according to an amount of urea being injected. The method  
5 further includes comparing the accumulated urea quantity to a low test threshold, and in response to the accumulated urea quantity being less than the low test threshold, exiting the current execution cycle of the reductant fluid quality check. The method further includes, in response to the accumulated urea quantity being greater than the low test threshold,  
10 comparing the accumulated urea quantity to a high test threshold, and in response to the urea quantity being greater than the high test threshold, determining whether the a  $\text{NO}_x$  exceedance is observed and clearing a urea quality error in response to the  $\text{NO}_x$  exceedance not being observed.

Certain further embodiments of the example method are described  
15 following. An example method includes in response to the accumulated urea quantity being less than the high test threshold, determining whether the a  $\text{NO}_x$  exceedance is observed and setting a urea quality error in response to the  $\text{NO}_x$  exceedance being observed and clearing the urea quality error in response to the  $\text{NO}_x$  exceedance not being observed. An example method includes  
20 determining an averaged  $\varepsilon$  value including ANR/de $\text{NO}_x$   $\eta$  values taken at ammonia-to- $\text{NO}_x$  ratio (ANR) values below a  $\beta$  value, wherein  $\beta$  is approximately a stoichiometric ANR value, determining an averaged de $\text{NO}_x$   $\eta$  value comprising de $\text{NO}_x$   $\eta$  values taken above the  $\beta$  value, and in response to the averaged  $\varepsilon$  value and the averaged de $\text{NO}_x$   $\eta$  value, determining whether a  
25  $\text{NO}_x$  reduction system is in a PASS or FAIL state. An example method further includes determining the state of the  $\text{NO}_x$  reduction system in response to the averaged  $\varepsilon$  value and the averaged de $\text{NO}_x$   $\eta$  value comprises determining the  $\text{NO}_x$  reduction system is in a PASS state in response to the averaged  $\varepsilon$  value and the averaged de $\text{NO}_x$   $\eta$  value both indicating a passing value. Additionally  
30 or alternatively, the method includes determining the state of the  $\text{NO}_x$

reduction system in response to the averaged  $\varepsilon$  value and the averaged deNO<sub>x</sub>  $\eta$  value by determining the NO<sub>x</sub> reduction system is in a failed state, with the failure being at least one of a urea injector and the urea in response to the averaged  $\varepsilon$  value indicating a failing value and the averaged deNO<sub>x</sub>  $\eta$  value indicating a passing value. In certain embodiments, the method includes determining the failure to be a urea injector in response to the urea fluid quality error being one of cleared and not set.

An example method includes determining the state of the NO<sub>x</sub> reduction system in response to the averaged  $\varepsilon$  value and the averaged deNO<sub>x</sub>  $\eta$  value by determining the NO<sub>x</sub> reduction system is in a failed state, with the failure being at least one of a NO<sub>x</sub> reduction catalyst and the urea in response to the averaged  $\varepsilon$  value indicating a failing value and the averaged deNO<sub>x</sub>  $\eta$  value indicating a passing value. In certain embodiments, the method further includes determining the failure to be a NO<sub>x</sub> reduction catalyst in response to the urea fluid quality error being one of cleared and not set. In certain embodiments, the averaged deNO<sub>x</sub>  $\eta$  value includes a normalized deNO<sub>x</sub>  $\eta$  value. An example method includes each  $\varepsilon$  value determined for the averaged  $\varepsilon$  value being determined according any one of the terms selected from the equation:

$$\varepsilon = \frac{NH_3\_in}{NOx\_in - NOx\_out} = \frac{NH_3\_in / NOx\_in}{(NOx\_in - NOx\_out) / NOx\_in} = \frac{ANR}{DeNOx\_eff};$$

where NH<sub>3,in</sub> is the NH<sub>3</sub> concentration into the deNO<sub>x</sub> catalyst, wherein NO<sub>x,in</sub> is the NO<sub>x</sub> concentration into the deNO<sub>x</sub> catalyst, wherein the NO<sub>x,out</sub> is the NO<sub>x</sub> concentration out of the deNO<sub>x</sub> catalyst.

An example method includes each deNO<sub>x</sub>  $\eta$  value determined for the averaged deNO<sub>x</sub>  $\eta$  value being determined according to the equation:

$$\eta_{Normalized} = \frac{\eta_{measured}}{\eta_{nominal}} = \frac{(NO_{x\_in} - NO_{x\_out}) / NO_{x\_in}}{\eta_{nominal}}$$

where  $\eta_{Normalized}$  is the deNO<sub>x</sub>  $\eta$  value, and wherein  $\eta_{nominal}$  is an expected deNO<sub>x</sub> efficiency.

Another example set of embodiments is a method including determining whether an engine fuel massflow and an engine charge massflow have values below threshold values, determining whether the engine fuel massflow and an engine charge massflow have rates of change below threshold values,

5 determining whether a number of data screening parameters have values indicating that a NO<sub>x</sub> reduction system monitor operation can be performed, and determining whether a value of  $\frac{FuelFlow}{ChargeFlow}$  is between a high and low

threshold. The method further includes, in response to all of the logical values for the determining operations being TRUE, calculating an average of a  
 10 number of values of an expected NO<sub>x</sub> calculation over a period of time or execution cycles, and calculating an average of a number of values of a NO<sub>x</sub> sensor reading over the period of time or execution cycles. The method includes comparing the averaged values and determining a fault value for a NO<sub>x</sub> reduction system NO<sub>x</sub> conversion capability in response to the comparing.

15 Certain further embodiments of the method are described following. An example method includes calculating an average of a number of values of an expected NO<sub>x</sub> calculation over a period of time or execution cycles by operating a NO<sub>x</sub> reduction model of the NO<sub>x</sub> reduction system. an example method includes calculating an average of a number of values of an expected NO<sub>x</sub>  
 20 calculation over a period of time comprises using lookup values from a predetermined function of engine out NO<sub>x</sub> values as a function of

$\frac{FuelFlow}{ChargeFlow}$  values. In certain further embodiments, the method includes the

high and low thresholds of the  $\frac{FuelFlow}{ChargeFlow}$  being validated operating ranges

for the predetermined function, and/or the predetermined function being a

25 linear increasing function with  $\frac{FuelFlow}{ChargeFlow}$ .

Yet another example set of embodiments is a method including determining an averaged  $\epsilon$  value comprising ANR/deNO<sub>x</sub>  $\eta$  values taken at ammonia-to-NO<sub>x</sub> ratio (ANR) values below a  $\beta$  value, where  $\beta$  is approximately a stoichiometric ANR value for a NO<sub>x</sub> reduction system fluidly coupled to the exhaust of an internal combustion engine, determining an averaged deNO<sub>x</sub>  $\eta$  value being deNO<sub>x</sub>  $\eta$  values taken above the  $\beta$  value, and in response to the averaged  $\epsilon$  value and the averaged deNO<sub>x</sub>  $\eta$  value, determining whether the NO<sub>x</sub> reduction system is in a PASS or FAIL state. In certain embodiments, the method includes determining the state of the NO<sub>x</sub> reduction system in response to the averaged  $\epsilon$  value and the averaged deNO<sub>x</sub>  $\eta$  value by determining that the NO<sub>x</sub> reduction system is in a PASS state in response to the averaged  $\epsilon$  value and the averaged deNO<sub>x</sub>  $\eta$  value both indicating a passing value. Additionally or alternatively, the method includes determining the state of the NO<sub>x</sub> reduction system in response to the averaged  $\epsilon$  value and the averaged deNO<sub>x</sub>  $\eta$  value by determining the NO<sub>x</sub> reduction system is in a failed state, with the failure being at least one of a urea injector and a urea fluid quality, in response to the averaged  $\epsilon$  value indicating a failing value and the averaged deNO<sub>x</sub>  $\eta$  value indicating a passing value, where the urea is a reductant fluid for the NO<sub>x</sub> reduction system and the urea injector is operationally coupled to the exhaust at a position upstream of a selective reduction catalyst. In certain further embodiments, the method includes determining the failure to be the urea injector in response to a urea fluid quality check passing the urea fluid quality.

In certain embodiments, the method includes determining the state of the NO<sub>x</sub> reduction system in response to the averaged  $\epsilon$  value and the averaged deNO<sub>x</sub>  $\eta$  value by determining the NO<sub>x</sub> reduction system is in a failed state, with the failure being at least one of a NO<sub>x</sub> reduction catalyst and the urea, in response to the averaged  $\epsilon$  value indicating a failing value and the averaged deNO<sub>x</sub>  $\eta$  value indicating a passing value. In certain embodiments, the method includes determining the failure to be a NO<sub>x</sub> reduction catalyst in

response to the urea fluid quality check passing the urea fluid quality. Additionally or alternatively, the averaged deNO<sub>x</sub> η value is a normalized deNO<sub>x</sub> η value.

In certain embodiments, the method includes each ε value determined for the averaged ε value to be determined according any one of the terms selected from the equation:

$$\varepsilon = \frac{NH_3\_in}{NOx\_in - NOx\_out} = \frac{NH_3\_in / NOx\_in}{(NOx\_in - NOx\_out) / NOx\_in} = \frac{ANR}{DeNOx\_eff};$$

where NH<sub>3</sub><sub>in</sub> is the NH<sub>3</sub> concentration into the deNO<sub>x</sub> catalyst, wherein NO<sub>x</sub><sub>in</sub> is the NO<sub>x</sub> concentration into the deNO<sub>x</sub> catalyst, wherein the NO<sub>x</sub><sub>out</sub> is the NO<sub>x</sub> concentration out of the deNO<sub>x</sub> catalyst. In certain embodiments, the method includes each deNO<sub>x</sub> η value determined for the averaged deNO<sub>x</sub> η value to be determined according to the equation:

$$\eta_{Normalized} = \frac{\eta_{measured}}{\eta_{nominal}} = \frac{(NO_{x\_in} - NO_{x\_out}) / NO_{x\_in}}{\eta_{nominal}}$$

where η<sub>Normalized</sub> is the deNO<sub>x</sub> η value, and wherein η<sub>nominal</sub> is an expected deNO<sub>x</sub> efficiency.

Still another example set of embodiments is a system including an internal combustion engine having an exhaust, a NO<sub>x</sub> reduction system having a selective catalytic reduction (SCR) catalyst, and a reductant injector operationally coupled to the exhaust at a position upstream of the SCR catalyst and receiving reductant from a reductant source. The system includes a means for determining a failure in one of the reductant injector, the SCR catalyst, and the reductant. In certain embodiments, the system includes the means for determining a failure further including a means for distinguishing a failure source between the reductant injector, the SCR catalyst, and the reductant. In still further embodiments, the system includes the means for determining a reductant failure including means for detecting a reductant source refill event, and accumulating an amount of reductant injected over a period of time following the reductant source refill event. In certain further

embodiments, the system includes the means for determining a failure of the reductant injector in response to: a failed  $\epsilon$  value, a passed normalized deNO<sub>x</sub> efficiency value, and the determining the failure of the reductant determines that the reductant is not failed. Additionally or alternatively, the system  
5 includes a means for determining a failure of the SCR catalyst in response to: a passed  $\epsilon$  value, a failed normalized deNO<sub>x</sub> efficiency value, and the determining the failure of the reductant determines that the reductant is not failed.

Yet another example set of embodiments is a system including an  
10 internal combustion engine having an exhaust, a NO<sub>x</sub> reduction system having a selective catalytic reduction (SCR) catalyst, a reductant injector operationally coupled to the exhaust at a position upstream of the SCR catalyst and receiving reductant from a reductant source, and a means for determining a failure in the NO<sub>x</sub> reduction system in response to an engine-out  
15 NO<sub>x</sub> amount and a NO<sub>x</sub> measurement at a position downstream of the SCR catalyst. In certain embodiments, the means for determining a failure in the NO<sub>x</sub> reduction system determines the NO<sub>x</sub> reduction system is passed in response to the engine-out NO<sub>x</sub> amount in a middle range and the NO<sub>x</sub> measurement in a low range. Additionally or alternatively, the means for  
20 determining a failure in the NO<sub>x</sub> reduction system determines the NO<sub>x</sub> reduction system is failed in response to the engine-out NO<sub>x</sub> amount in a middle range and the NO<sub>x</sub> measurement in a high range. In certain embodiments, the means for determining a failure in the NO<sub>x</sub> reduction system determines a NO<sub>x</sub> sensor providing the NO<sub>x</sub> measurement is failed in  
25 response to the engine-out NO<sub>x</sub> amount in a high range and the NO<sub>x</sub> measurement in a low range. In certain embodiments, the means for determining a failure in the NO<sub>x</sub> reduction system determines a NO<sub>x</sub> sensor providing the NO<sub>x</sub> measurement is failed in response to the engine-out NO<sub>x</sub> amount in a low range and the NO<sub>x</sub> measurement in a high range.

While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only certain exemplary embodiments have been shown and described and that all changes and modifications that come within the spirit of the inventions are desired to  
5 be protected. In reading the claims, it is intended that when words such as “a,” “an,” “at least one,” or “at least one portion” are used there is no intention to limit the claim to only one item unless specifically stated to the contrary in the claim. When the language “at least a portion” and/or “a portion” is used  
10 the item can include a portion and/or the entire item unless specifically stated to the contrary.

## WHAT IS CLAIMED IS:

1. A method, comprising: determining whether a urea refill event is detected, in response to the refill event being detected, clearing a urea quality accumulator value and clearing a latching abort command;

determining whether urea fluid quality check abort conditions are met;

5 in response to the abort conditions being met, clearing the urea quality accumulator, latching the abort command, and exiting the reductant fluid quality check;

in response to the abort conditions not being met, incrementing the urea quality accumulator according to an amount of urea being injected;

10 comparing the accumulated urea quantity to a low test threshold, and in response to the accumulated urea quantity being less than the low test threshold, exiting the current execution cycle of the reductant fluid quality check;

in response to the accumulated urea quantity being greater than the low test threshold, comparing the accumulated urea quantity to a high test threshold, in response to the urea quantity being greater than the high test threshold, determining whether the a  $\text{NO}_x$  exceedance is observed and clearing a urea quality error in response to the  $\text{NO}_x$  exceedance not being observed.

20 2. The method of claim 1, further comprising, in response to the accumulated urea quantity being less than the high test threshold, determining whether the a  $\text{NO}_x$  exceedance is observed and setting a urea quality error in response to the  $\text{NO}_x$  exceedance being observed and clearing the urea quality error in response to the  $\text{NO}_x$  exceedance not being observed.

25 3. A method according to any one of claims 1 and 2, the method further comprising determining an averaged  $\varepsilon$  value comprising  $\text{ANR}/\text{deNO}_x$   $\eta$  values taken at ammonia-to- $\text{NO}_x$  ratio (ANR) values below a  $\beta$  value, wherein  $\beta$  is approximately a stoichiometric ANR value;

determining an averaged  $\text{deNO}_x$   $\eta$  value comprising  $\text{deNO}_x$   $\eta$  values taken above the  $\beta$  value; and

in response to the averaged  $\varepsilon$  value and the averaged deNO<sub>x</sub>  $\eta$  value, determining whether a NO<sub>x</sub> reduction system is in a PASS or FAIL state.

4. The method of claim 3, wherein determining the state of the NO<sub>x</sub> reduction system in response to the averaged  $\varepsilon$  value and the averaged deNO<sub>x</sub>  $\eta$  value comprises determining the NO<sub>x</sub> reduction system is in a PASS state in response to the averaged  $\varepsilon$  value and the averaged deNO<sub>x</sub>  $\eta$  value both indicating a passing value.

5. The method of any one of claims 3 and 4, wherein determining the state of the NO<sub>x</sub> reduction system in response to the averaged  $\varepsilon$  value and the averaged deNO<sub>x</sub>  $\eta$  value comprises determining the NO<sub>x</sub> reduction system is in a failed state, with the failure being at least one of a urea injector and the urea in response to the averaged  $\varepsilon$  value indicating a failing value and the averaged deNO<sub>x</sub>  $\eta$  value indicating a passing value.

6. The method of claim 5, further comprising determining the failure to be a urea injector in response to the urea fluid quality error being one of cleared and not set.

7. The method of any one of claims 3 through 6, wherein determining the state of the NO<sub>x</sub> reduction system in response to the averaged  $\varepsilon$  value and the averaged deNO<sub>x</sub>  $\eta$  value comprises determining the NO<sub>x</sub> reduction system is in a failed state, with the failure being at least one of a NO<sub>x</sub> reduction catalyst and the urea in response to the averaged  $\varepsilon$  value indicating a failing value and the averaged deNO<sub>x</sub>  $\eta$  value indicating a passing value.

8. The method of claim 7, further comprising determining the failure to be a NO<sub>x</sub> reduction catalyst in response to the urea fluid quality error being one of cleared and not set.

9. The method of any one of claims 3 through 8, wherein the averaged deNO<sub>x</sub>  $\eta$  value comprises a normalized deNO<sub>x</sub>  $\eta$  value.

10. The method of any one of claims 3 through 9, wherein each  $\varepsilon$  value determined for the averaged  $\varepsilon$  value is determined according any one of the terms selected from the equation:

$$\varepsilon = \frac{NH_3\_in}{NOx\_in - NOx\_out} = \frac{NH_3\_in / NOx\_in}{(NOx\_in - NOx\_out) / NOx\_in} = \frac{ANR}{DeNOx\_eff};$$

wherein  $NH_3\_in$  is the  $NH_3$  concentration into the  $deNO_x$  catalyst,  
 wherein  $NO_{x\_in}$  is the  $NO_x$  concentration into the  $deNO_x$  catalyst, wherein the  
 $NO_{x\_out}$  is the  $NO_x$  concentration out of the  $deNO_x$  catalyst.

5 11. The method of any one of claims 9 and 10, wherein each  $deNO_x \eta$   
 value determined for the averaged  $deNO_x \eta$  value is determined according to  
 the equation:

$$\eta_{Normalized} = \frac{\eta_{measured}}{\eta_{nominal}} = \frac{(NO_{x\_in} - NO_{x\_out}) / NO_{x\_in}}{\eta_{nominal}}$$

10 wherein  $\eta_{Normalized}$  is the  $deNO_x \eta$  value, and wherein  $\eta_{nominal}$  is an  
 expected  $deNO_x$  efficiency.

12. A method, comprising:

determining whether an engine fuel massflow and an engine charge  
 massflow have values below threshold values;

15 determining whether the engine fuel massflow and an engine charge  
 massflow have rates of change below threshold values;

determining whether a plurality of data screening parameters have  
 values indicating that a  $NO_x$  reduction system monitor operation can be  
 performed;

determining whether a value of  $\frac{FuelFlow}{ChargeFlow}$  is between a high and low

20 threshold; and

in response to all of the logical values for the determining operations  
 being TRUE, calculating an average of a number of values of an expected  $NO_x$   
 calculation over a period of time or execution cycles, and calculating an  
 average of a number of values of a  $NO_x$  sensor reading over the period of time  
 25 or execution cycles;

comparing the averaged values; and

determining a fault value for a NO<sub>x</sub> reduction system NO<sub>x</sub> conversion capability in response to the comparing.

13. The method of claim 12, wherein the calculating an average of a number of values of an expected NO<sub>x</sub> calculation over a period of time or execution cycles comprises operating a NO<sub>x</sub> reduction model of the NO<sub>x</sub> reduction system.

14. The method of claim 12, wherein the calculating an average of a number of values of an expected NO<sub>x</sub> calculation over a period of time comprises using lookup values from a predetermined function of engine out NO<sub>x</sub> values as a function of  $\frac{FuelFlow}{ChargeFlow}$  values.

15. The method of claim 14, wherein the high and low thresholds of the  $\frac{FuelFlow}{ChargeFlow}$  comprise validated operating ranges for the predetermined function.

16. The method of any one of claims 14 and 15, wherein the predetermined function comprises a linear increasing function with  $\frac{FuelFlow}{ChargeFlow}$ .

17. A method, comprising:

determining an averaged  $\varepsilon$  value comprising ANR/deNO<sub>x</sub>  $\eta$  values taken at ammonia-to-NO<sub>x</sub> ratio (ANR) values below a  $\beta$  value, wherein  $\beta$  is approximately a stoichiometric ANR value for a NO<sub>x</sub> reduction system fluidly coupled to the exhaust of an internal combustion engine;

determining an averaged deNO<sub>x</sub>  $\eta$  value comprising deNO<sub>x</sub>  $\eta$  values taken above the  $\beta$  value; and

in response to the averaged  $\varepsilon$  value and the averaged deNO<sub>x</sub>  $\eta$  value, determining whether the NO<sub>x</sub> reduction system is in a PASS or FAIL state.

18. The method of claim 17, wherein determining the state of the NO<sub>x</sub> reduction system in response to the averaged  $\varepsilon$  value and the averaged deNO<sub>x</sub>

$\eta$  value comprises determining the  $\text{NO}_x$  reduction system is in a PASS state in response to the averaged  $\varepsilon$  value and the averaged  $\text{deNO}_x \eta$  value both indicating a passing value.

19. The method of any one of claims 17 and 18, wherein determining  
5 the state of the  $\text{NO}_x$  reduction system in response to the averaged  $\varepsilon$  value and the averaged  $\text{deNO}_x \eta$  value comprises determining the  $\text{NO}_x$  reduction system is in a failed state, with the failure being at least one of a urea injector and a urea fluid quality in response to the averaged  $\varepsilon$  value indicating a failing value and the averaged  $\text{deNO}_x \eta$  value indicating a passing value, the urea  
10 comprising a reductant fluid for the  $\text{NO}_x$  reduction system and the urea injector operationally coupled to the exhaust at a position upstream of a selective reduction catalyst.

20. The method of claim 19, further comprising determining the failure  
15 to be the urea injector in response to a urea fluid quality check passing the urea fluid quality.

21. The method of any one of claims 17 through 20, wherein  
determining the state of the  $\text{NO}_x$  reduction system in response to the averaged  $\varepsilon$  value and the averaged  $\text{deNO}_x \eta$  value comprises determining the  $\text{NO}_x$   
20 reduction system is in a failed state, with the failure being at least one of a  $\text{NO}_x$  reduction catalyst and the urea in response to the averaged  $\varepsilon$  value indicating a failing value and the averaged  $\text{deNO}_x \eta$  value indicating a passing value.

22. The method of claim 21, further comprising determining the failure  
25 to be a  $\text{NO}_x$  reduction catalyst in response to the urea fluid quality check passing the urea fluid quality.

23. The method of any one of claims 17 through 22, wherein the averaged  $\text{deNO}_x \eta$  value comprises a normalized  $\text{deNO}_x \eta$  value.

24. The method of any one of claims 17 through 23, wherein each  $\varepsilon$   
value determined for the averaged  $\varepsilon$  value is determined according any one of  
30 the terms selected from the equation:

$$\varepsilon = \frac{NH_3\_in}{NOx\_in - NOx\_out} = \frac{NH_3\_in / NOx\_in}{(NOx\_in - NOx\_out) / NOx\_in} = \frac{ANR}{DeNOx\_eff};$$

wherein  $NH_3\_in$  is the  $NH_3$  concentration into the de $NO_x$  catalyst,  
 wherein  $NO_x\_in$  is the  $NO_x$  concentration into the de $NO_x$  catalyst, wherein the  
 $NO_x\_out$  is the  $NO_x$  concentration out of the de $NO_x$  catalyst.

5           25. The method of any one of claims 23 and 24, wherein each de $NO_x$   $\eta$   
 value determined for the averaged de $NO_x$   $\eta$  value is determined according to  
 the equation:

$$\eta_{Normalized} = \frac{\eta_{measured}}{\eta_{nominal}} = \frac{(NO_{x\_in} - NO_{x\_out}) / NO_{x\_in}}{\eta_{nominal}}$$

10           wherein  $\eta_{Normalized}$  is the de $NO_x$   $\eta$  value, and wherein  $\eta_{nominal}$  is an  
 expected de $NO_x$  efficiency.

26. A system, comprising:

an internal combustion engine having an exhaust;

15           a  $NO_x$  reduction system comprising a selective catalytic reduction (SCR)  
 catalyst, a reductant injector operationally coupled to the exhaust at a position  
 upstream of the SCR catalyst and receiving reductant from a reductant source;

            a means for determining a failure in one of the reductant injector, the  
 SCR catalyst, and the reductant.

20           27. The system of claim 26, wherein the means for determining a  
 failure further comprises a means for distinguishing a failure source between  
 the reductant injector, the SCR catalyst, and the reductant.

28. The system of claim 27, further comprising determining a failure of  
 the reductant in response to detecting a reductant source refill event, and  
 accumulating an amount of reductant injected over a period of time following  
 the reductant source refill event.

25           29. The system of any claim 28, further comprising determining a  
 failure of the reductant injector in response to:

a failed  $\varepsilon$  value;

a passed normalized de $NO_x$  efficiency value; and

the determining the failure of the reductant determines that the reductant is not failed.

30. The system of any one of claims 28 and 29, further comprising determining a failure of the SCR catalyst in response to:

5 a passed  $\varepsilon$  value;

a failed normalized deNO<sub>x</sub> efficiency value; and

the determining the failure of the reductant determines that the reductant is not failed.

31. A system, comprising:

10 an internal combustion engine having an exhaust;

a NO<sub>x</sub> reduction system comprising a selective catalytic reduction (SCR) catalyst, a reductant injector operationally coupled to the exhaust at a position upstream of the SCR catalyst and receiving reductant from a reductant source; and

15 a means for determining a failure in the NO<sub>x</sub> reduction system in response to an engine-out NO<sub>x</sub> amount and a NO<sub>x</sub> measurement at a position downstream of the SCR catalyst.

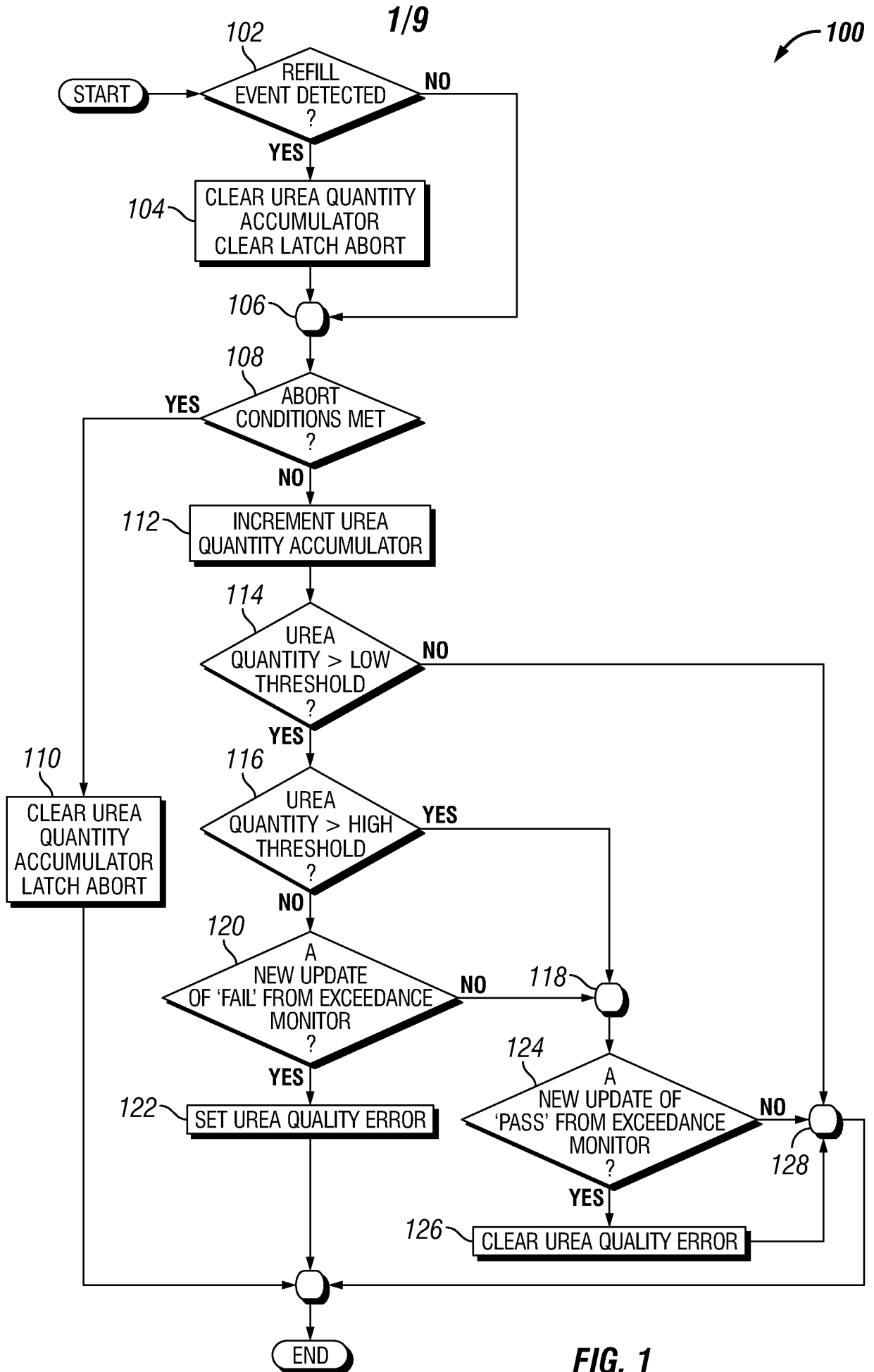
32. The system of claim 31, wherein the means for determining a failure in the NO<sub>x</sub> reduction system determines the NO<sub>x</sub> reduction system is passed in response to the engine-out NO<sub>x</sub> amount in a middle range and the NO<sub>x</sub> measurement in a low range.

33. The system of any one of claims 31 and 32, wherein the means for determining a failure in the NO<sub>x</sub> reduction system determines the NO<sub>x</sub> reduction system is failed in response to the engine-out NO<sub>x</sub> amount in a middle range and the NO<sub>x</sub> measurement in a high range.

34. The system of any one of claims 31 through 33, wherein the means for determining a failure in the NO<sub>x</sub> reduction system determines a NO<sub>x</sub> sensor providing the NO<sub>x</sub> measurement is failed in response to the engine-out NO<sub>x</sub> amount in a high range and the NO<sub>x</sub> measurement in a low range.

35. The system of any one of claims 31 through 34, wherein the means for determining a failure in the NO<sub>x</sub> reduction system determines a NO<sub>x</sub> sensor providing the NO<sub>x</sub> measurement is failed in response to the engine-out NO<sub>x</sub> amount in a low range and the NO<sub>x</sub> measurement in a high range.

5



**FIG. 1**

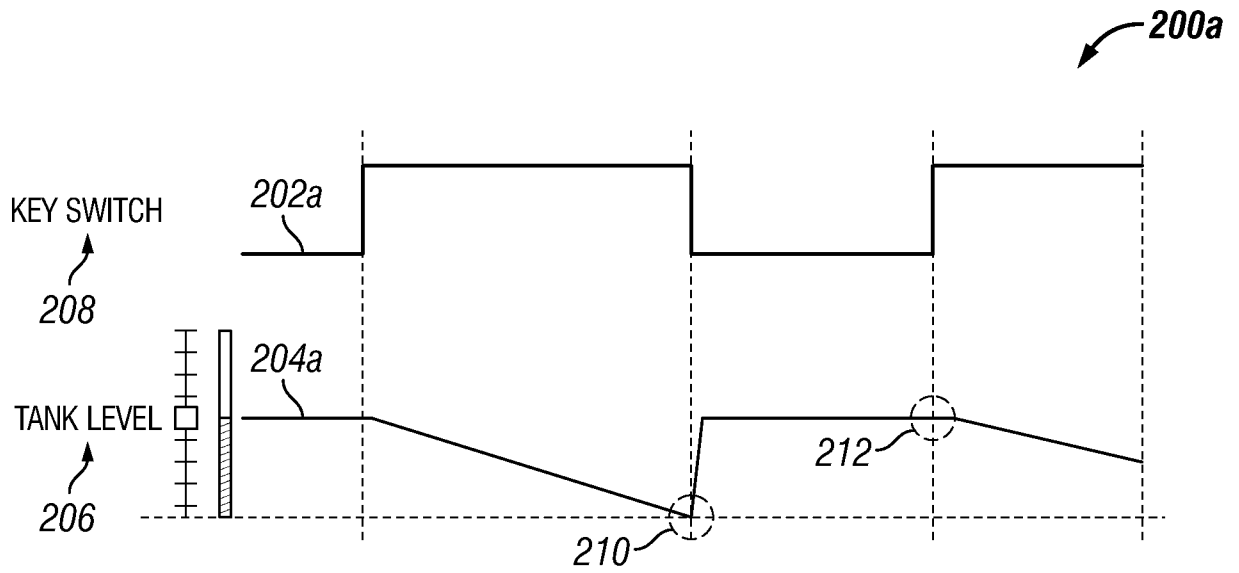


FIG. 2A

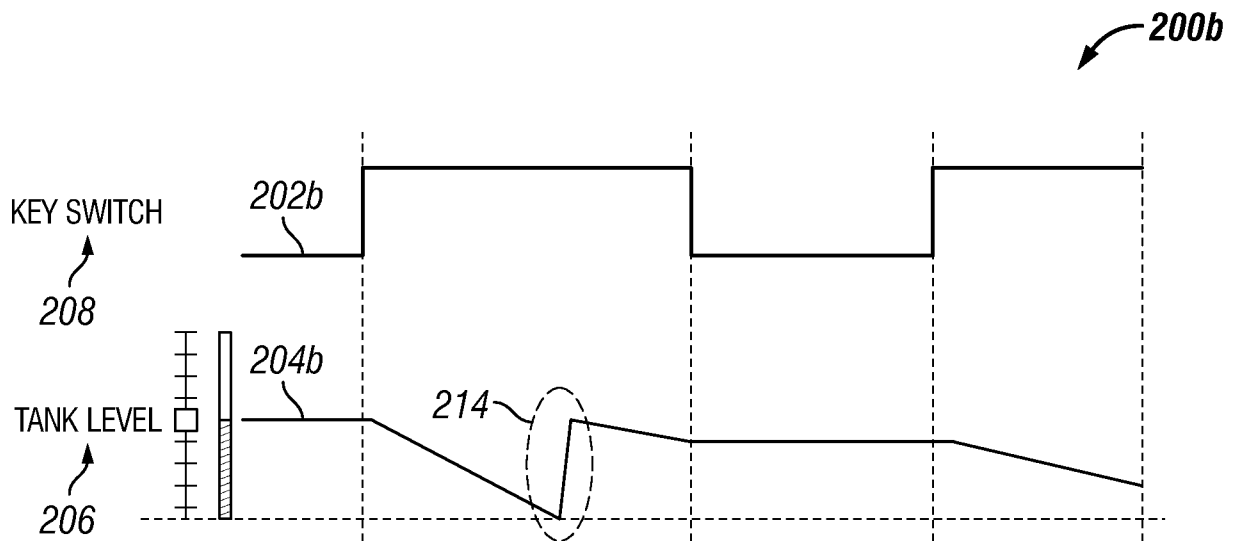
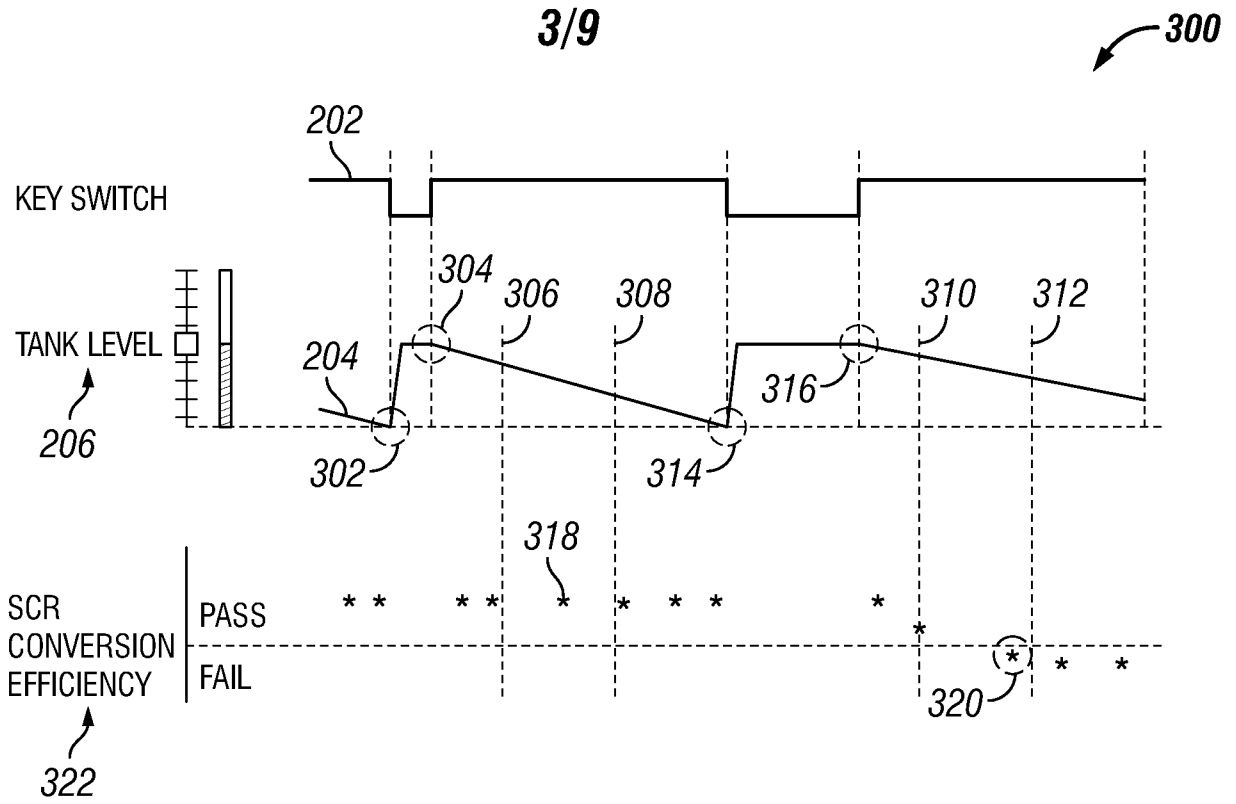
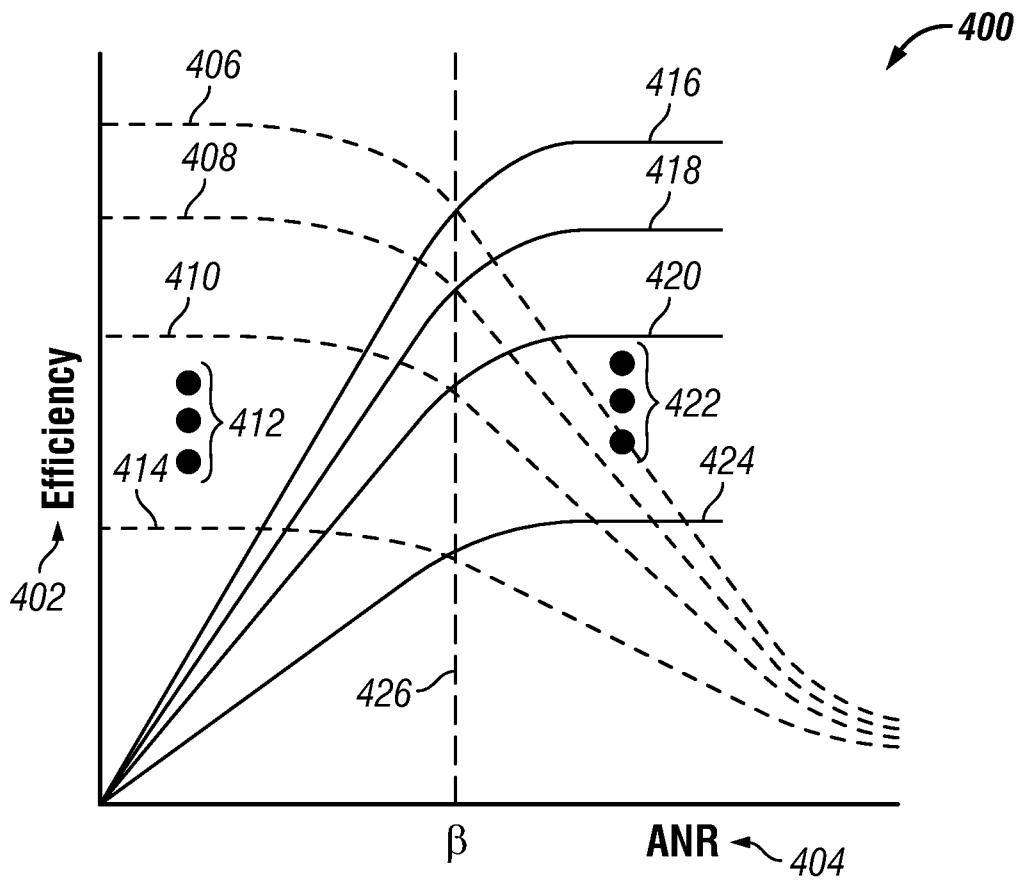


FIG. 2B



**FIG. 3**



**FIG. 4**

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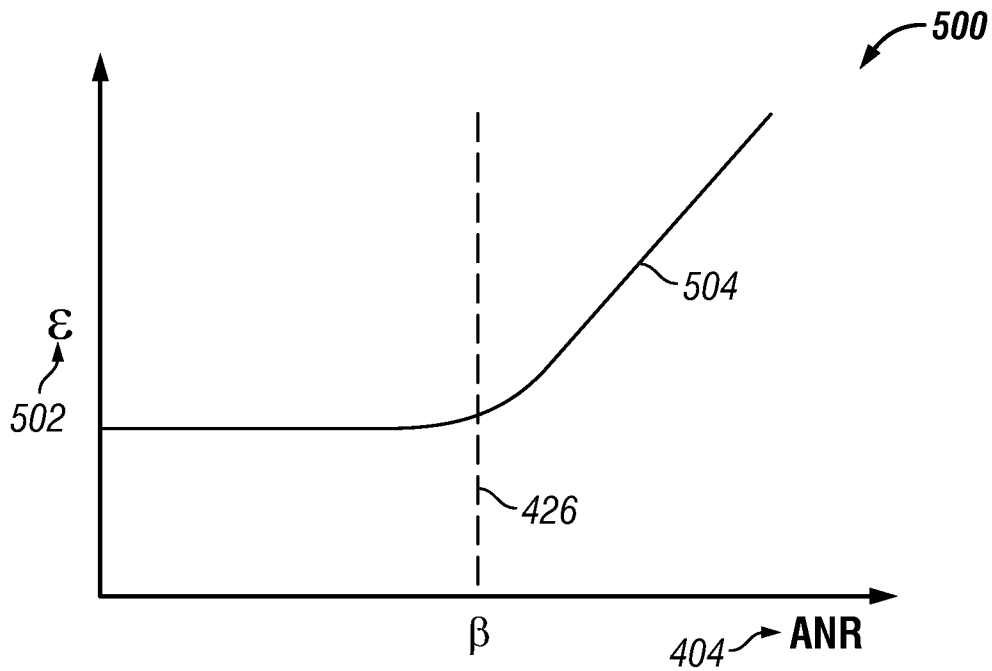


FIG. 5

$\epsilon$	NORMALIZED $\eta$	FAULT
FAIL	FAIL	COMPONENT FAILURE: CATALYST, DOSING, OR REDUCTANT
FAIL	PASS	COMPONENT FAILURE: DOSING OR REDUCTANT
PASS	FAIL	COMPONENT FAILURE: CATALYST OR REDUCTANT
PASS	PASS	PASS

FIG. 6

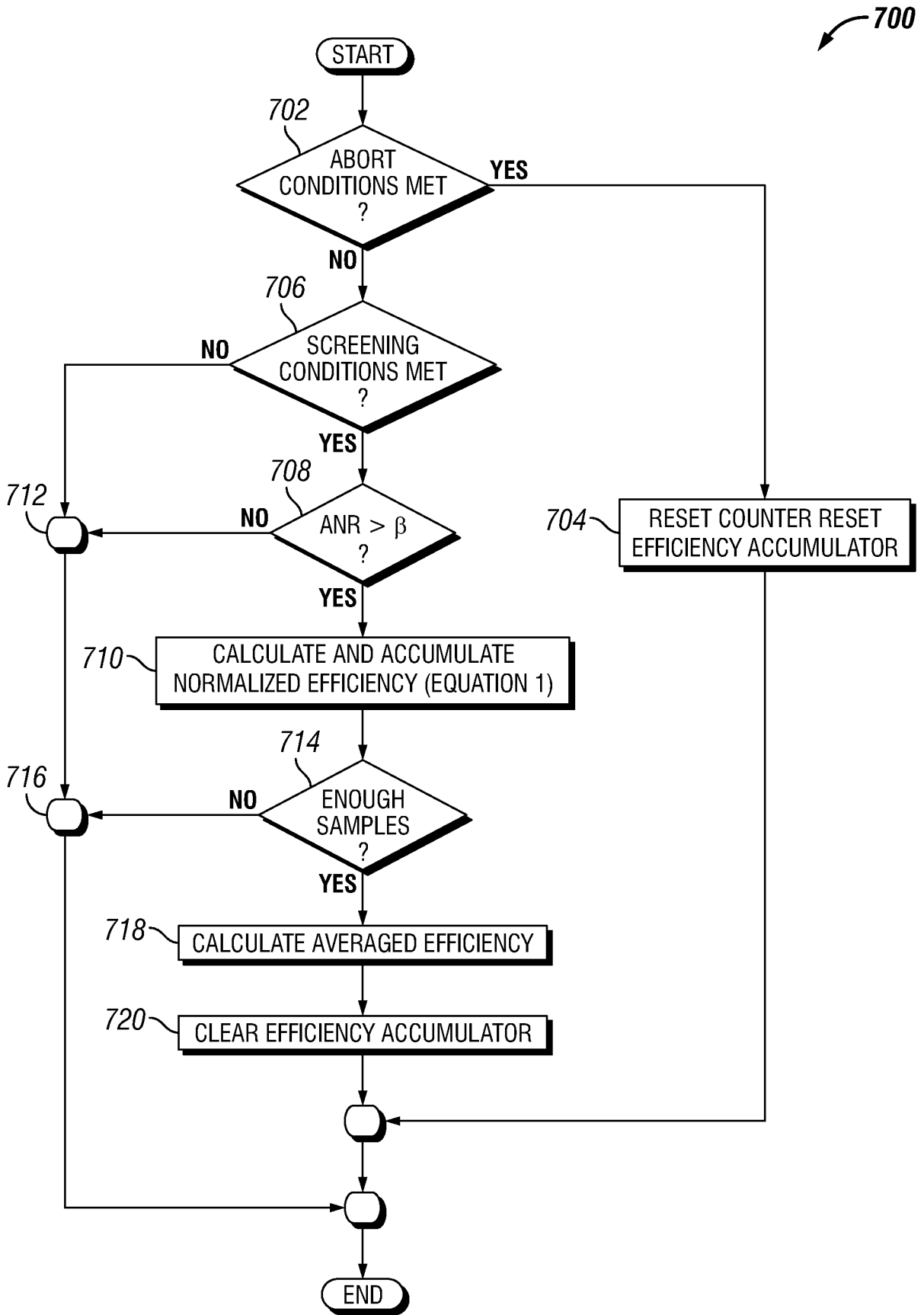


FIG. 7

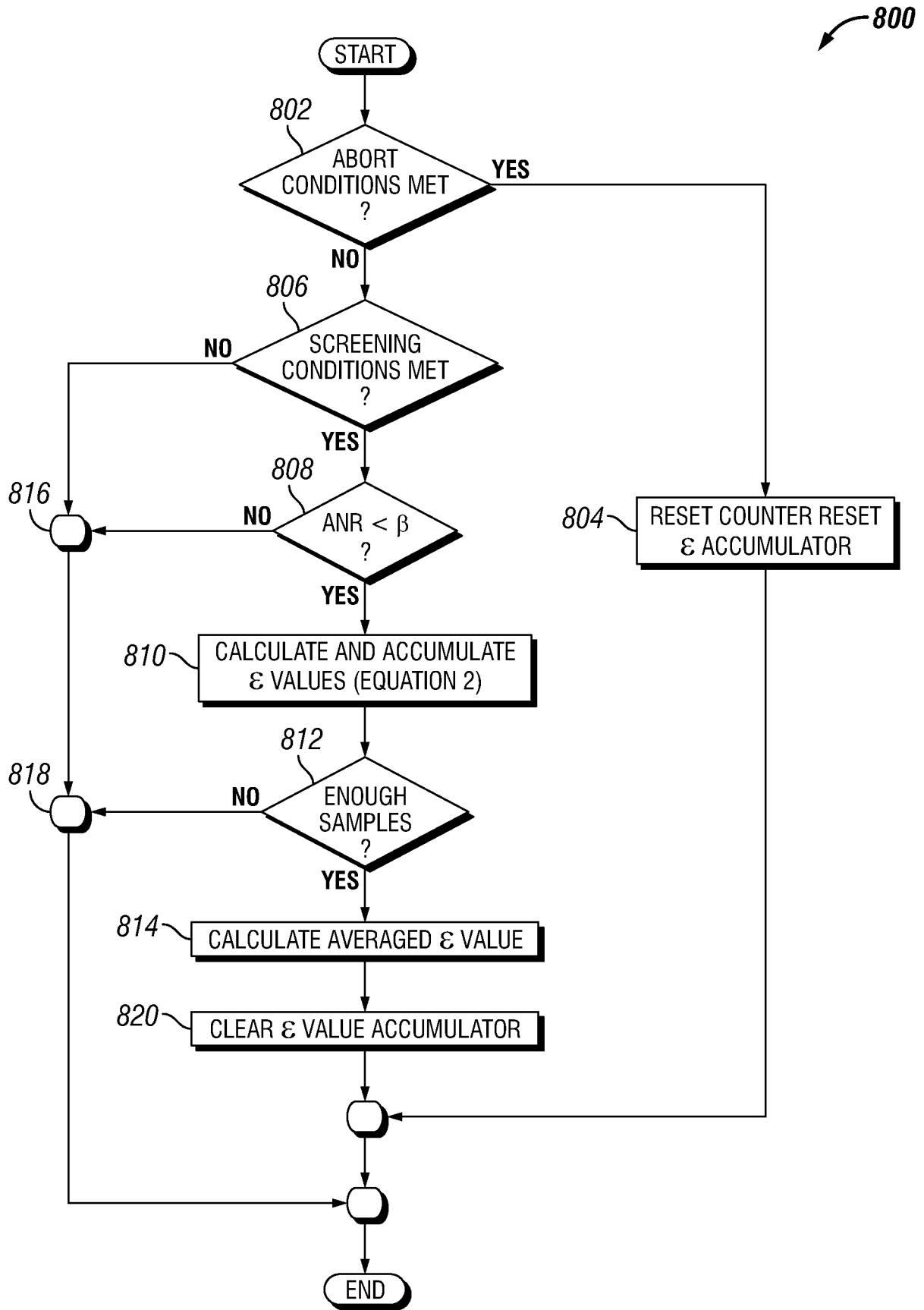


FIG. 8

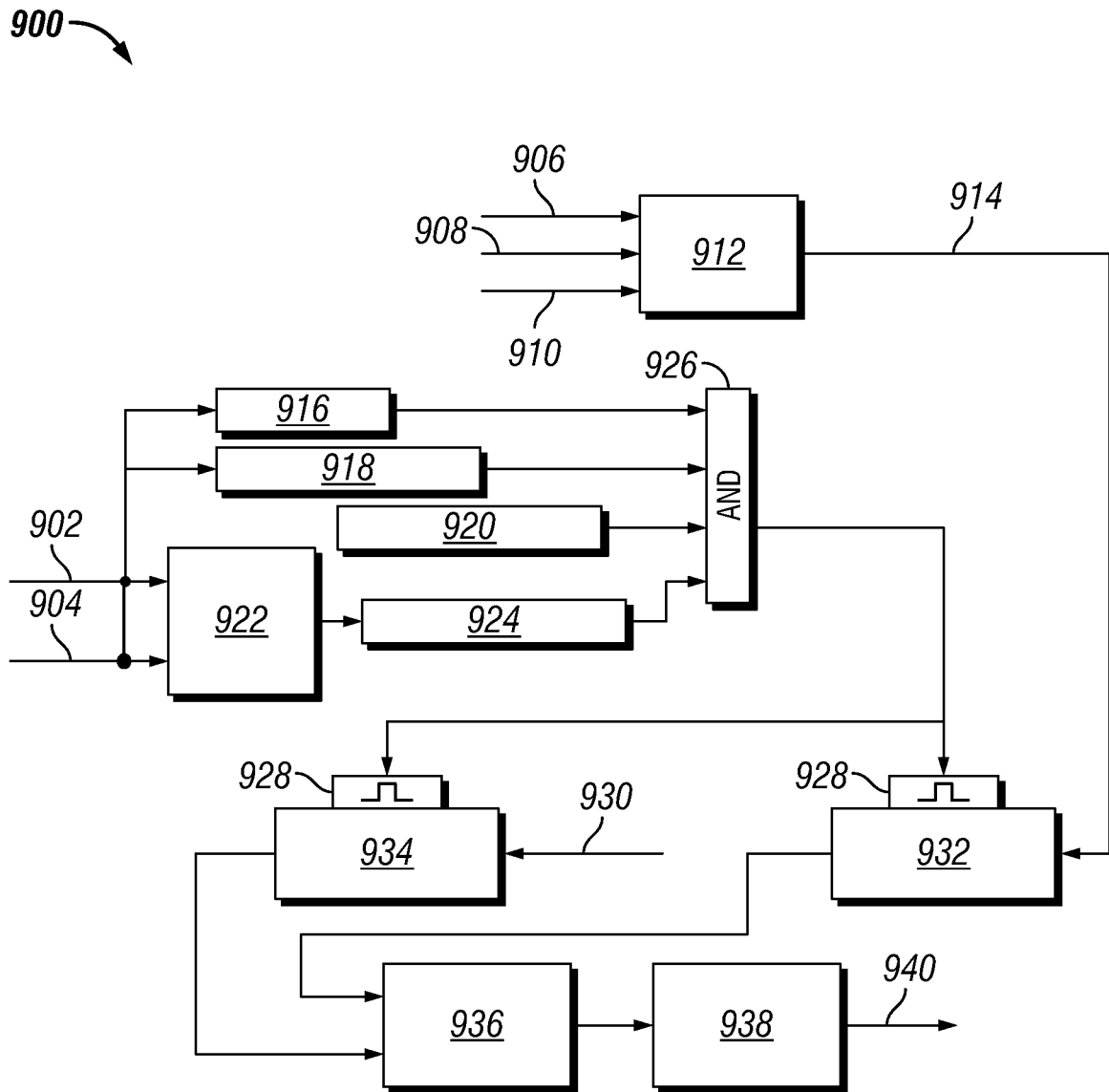


FIG. 9

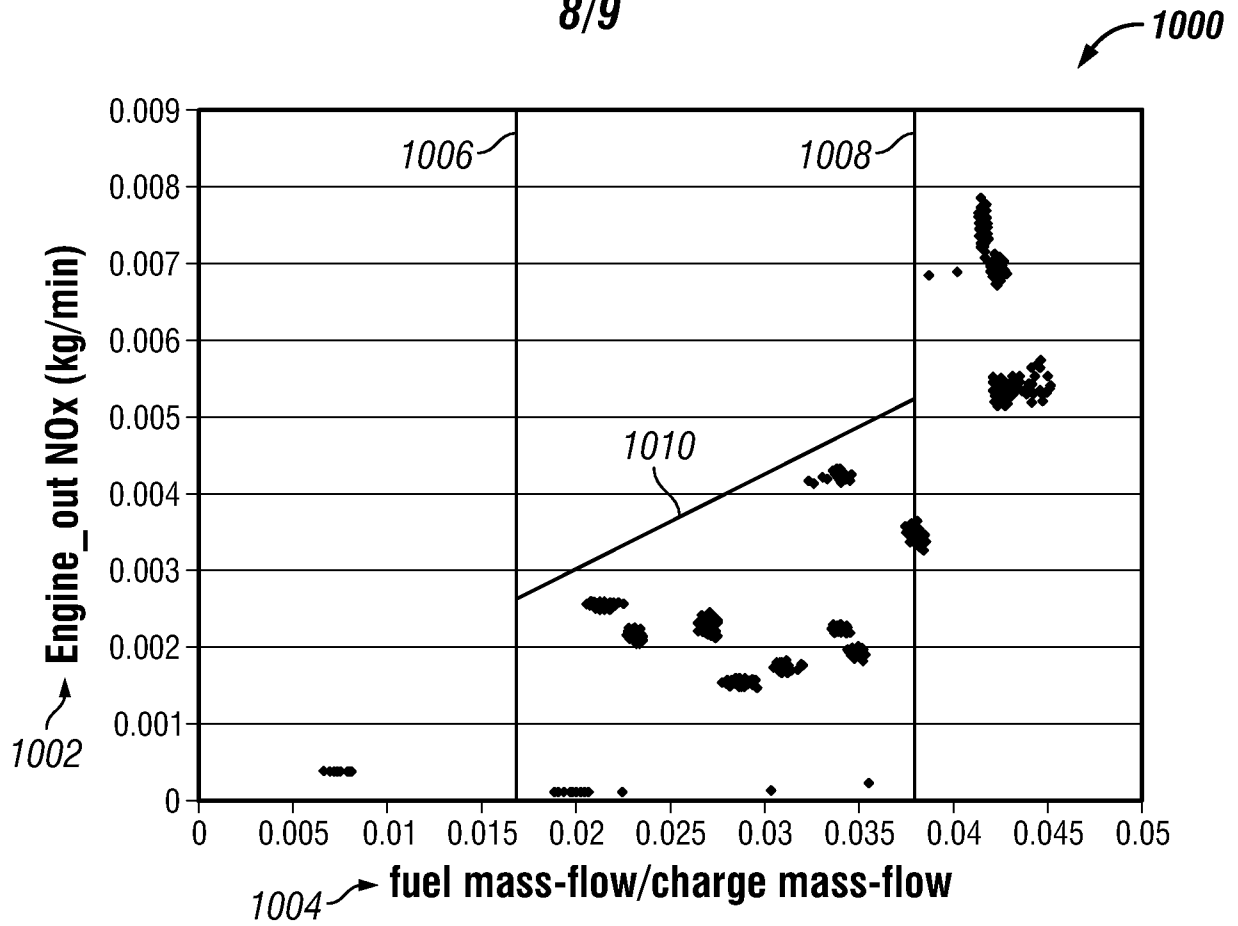


FIG. 10

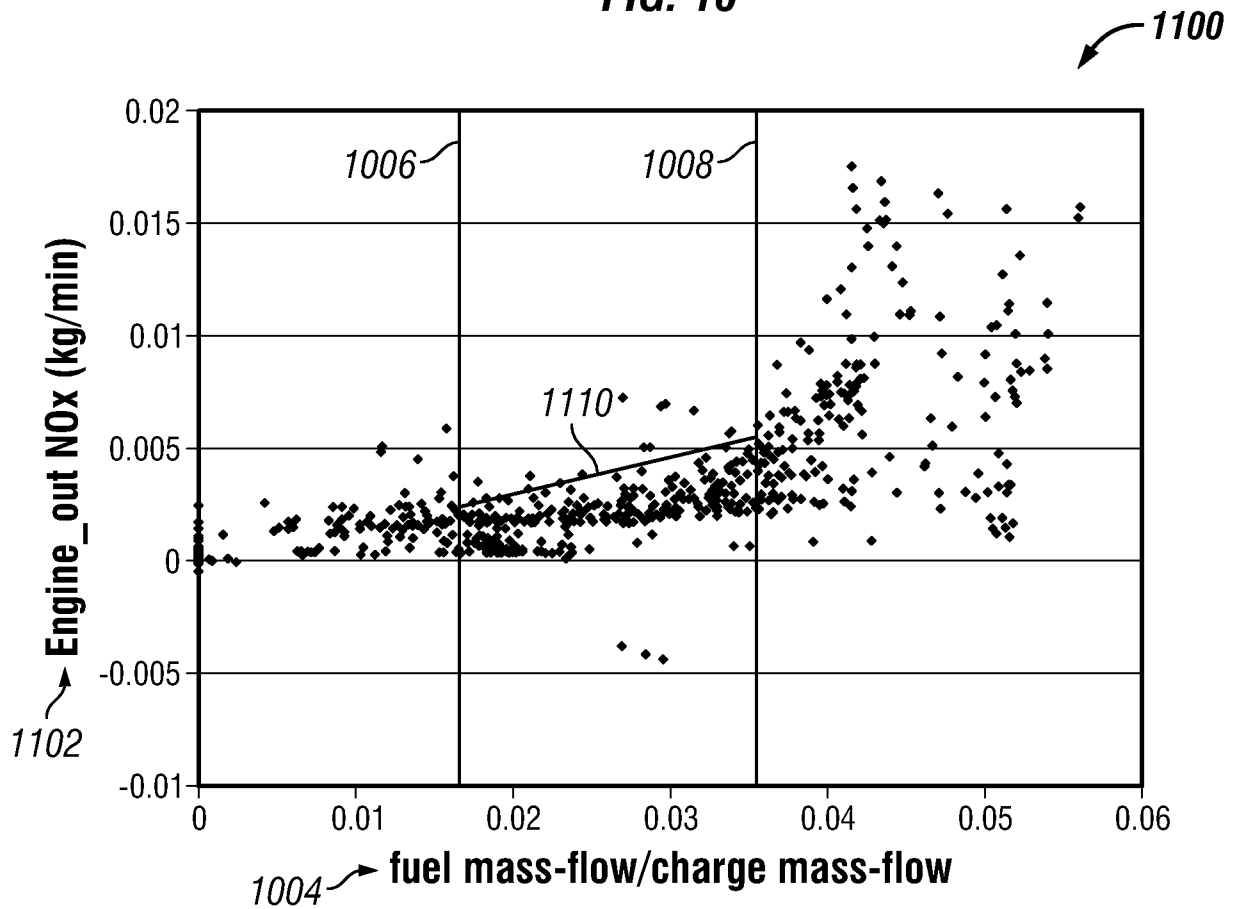


FIG. 11

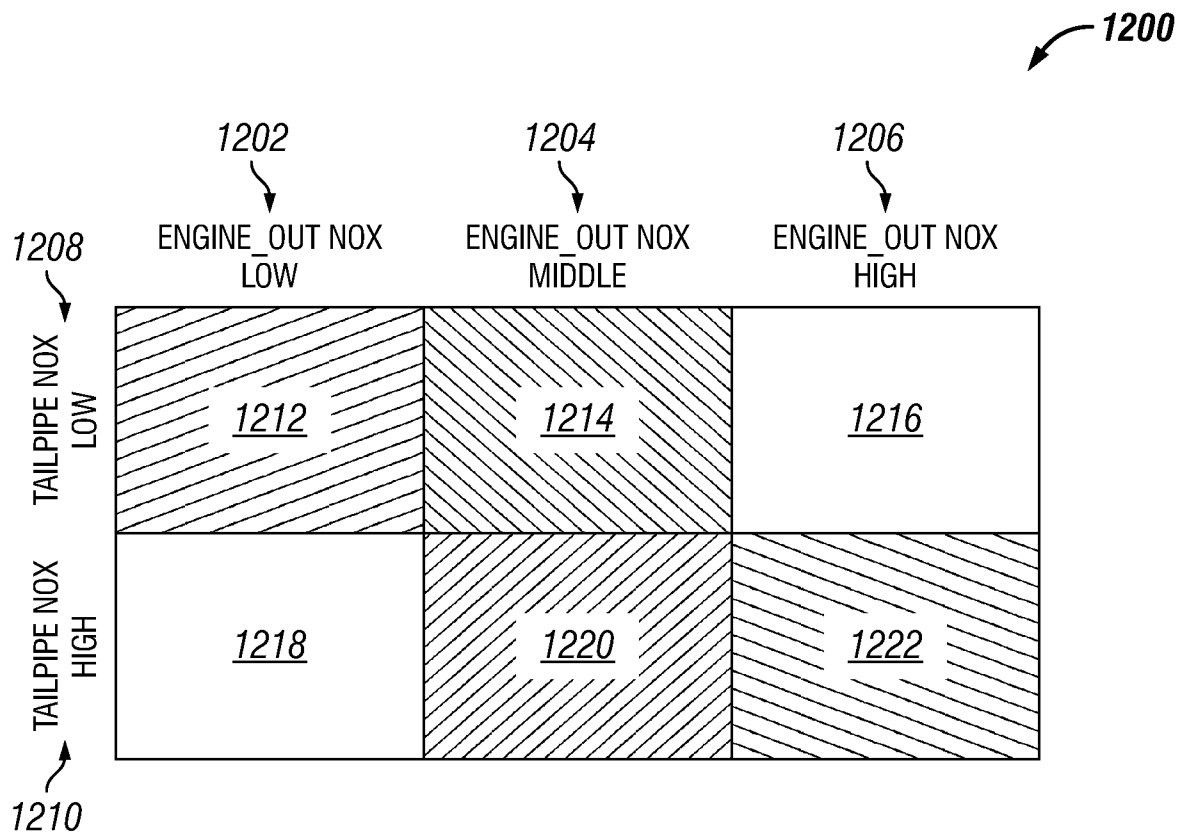


FIG. 12

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US2012/032436

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F01N 3/02 (2012.01)

USPC - 60/277

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(8) - F01N 3/00, 3/02, 3/029, 3/20, 3/24, 3/28 (2012.01)

USPC - 60/274, 277, 299, 605.2, 701/104, 108

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

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

MicroPatent, Google Patents

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2008/0178575 A1 (SHAIKH et al) 31 July 2008 (31.07.2008) entire document	31
Y	US 2010/0024401 A1 (ICHIKAWA) 04 February 2010 (04.02.2010) entire document	31
A	US 6,697,729 B2 (WRIGHT) 24 February 2004 (24.02.2004) entire document	1-4, 12-20, 26-33
A	US 2009/0185954 A1 (QI et al) 23 July 2009 (23.07.2009) entire document	1-4, 12-20, 26-33
A	US 7,776,265 B2 (BERRYHILL et al) 17 August 2010 (17.08.2010) entire document	1-4, 12-20, 26-33

 Further documents are listed in the continuation of Box C. 

\* 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

"&amp;" document member of the same patent family

Date of the actual completion of the international search

18 June 2012

Date of mailing of the international search report

29 JUN 2012

Name and mailing address of the ISA/US

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PCT OSP: 571-272-7774

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2012/032436

**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1.  Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
  
2.  Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
  
3.  Claims Nos.: 5-11, 21-25, 34, 35  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

1.  As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2.  As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3.  As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
  
4.  No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

**Remark on Protest**

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.