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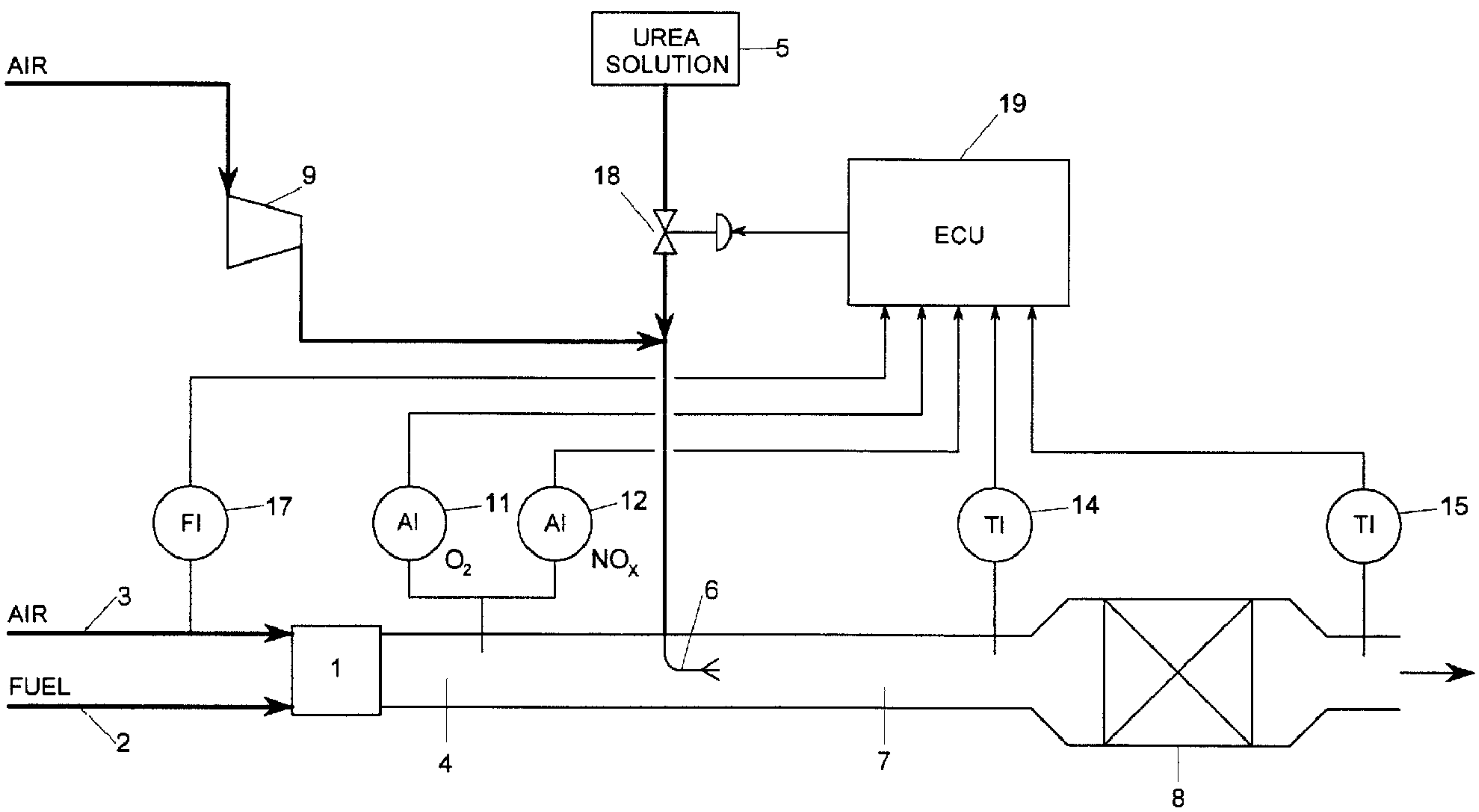
(54) Titre : METHODE DE REGULATION DE L'INJECTION D'UN AGENT REDUCTEUR DANS UN GAZ D'ECHAPPEMENT DE MOTEUR A COMBUSTION

(54) Title: METHOD FOR CONTROLLING INJECTION OF REDUCING AGENT IN EXHAUST GAS FROM A COMBUSTION ENGINE



(57) Abrégé/Abstract:
The invention relates to a method for controlling injection of a reductant into a NO_x containing exhaust gas stream from a combustion engine, where combustion of a known fuel takes place and where the NO_x is reduced by selective catalytic reduction, SCR, in the presence of a SCR catalyst, comprising establishing signals related to exhaust gas flow, NO_x concentration in the exhaust gas stream upstream of the catalyst, exhaust gas temperature upstream of the SCR catalyst, exhaust gas temperature

(57) **Abrégé(suite)/Abstract(continued)**:
downstream of the SCR catalyst and to input data for catalyst characteristics. From the signals an adjusted amount of the reductant is calculated by using a calculated amount of reductant and a value d(E*T)/dt, where E is the exhaust gas flow, T is the exhaust gas temperature upstream of the catalyst and t is time.

ABSTRACT

The invention relates to a method for controlling injection of a reductant into a NO_x containing exhaust gas stream from a combustion engine, where combustion of a known fuel takes place and where the NO_x is reduced by selective catalytic reduction, SCR, in the presence of a SCR catalyst, comprising establishing signals related to exhaust gas flow, NO_x concentration in the exhaust gas stream upstream of the catalyst, exhaust gas temperature upstream of the SCR catalyst, exhaust gas temperature downstream of the SCR catalyst and to input data for catalyst characteristics. From the signals an adjusted amount of the reductant is calculated by using a calculated amount of reductant and a value d(E*T)/dt, where E is the exhaust gas flow, T is the exhaust gas temperature upstream of the catalyst and t is time.

METHOD FOR CONTROLLING INJECTION OF REDUCING AGENT IN EXHAUST GAS FROM A COMBUSTION ENGINE

BACKGROUND OF THE INVENTION

1 Field of the Invention

The invention relates to a method for controlling a stream containing a component, which takes part in a catalytic reaction and which adsorbes on the catalyst.

The invention is in particular directed to control of injection of a reductant to an exhaust gas, where formed nitrogen oxides are selectively, catalytically reduced and where the reducing component is adsorbed on or desorbed from the surface of the catalyst. Both reducing component and nitrogen oxides must be avoided in the catalyst effluent.

The invention is especially useful in purifying an exhaust gas from combustion engines in vehicles, where nitrogen oxides are reduced by ammonia possibly injected as an aqueous solution of ammonia or urea.

2 Description of Related Art

Purification of an exhaust gas is already performed in many ways. One way is disclosed in US patent No. 6,427,439, where purification of exhaust gas is carried out by catalytically reducing the nitrogen oxides, NO_x. The addition of the reducing agent is controlled by an electronic engine controller, EEC, which determines the amount of reductant to be added as proportional to the NO_x concentration, when this concentration is above a predetermined value. When the NO_x concentration is lower and the amount of adsorbed ammonia is less than the ammonia capacity of the catalyst, the amount of added reductant is a predetermined amount. The EEC uses signals from measurements of NO_x concentration, NH_3 concentration, temperature, engine speed and engine load for calculation of the amount of adsorbed NH_3 on the catalyst surface and of reductant addition at the time of the calculation. However, this means many different measurements and calculations are involved in a vehicle where load of the engine increases and decreases frequently and quickly.

In US patent No. 5,628,186 a further method for addition of a reducing agent is described. The addition is controlled by detecting operation parameters of the engine and catalyst in the exhaust gas and then determining from NO_x measurement the required amount of NH_3 and then adjusting this from the catalyst performance. The temperature is calculated from the performance of the engine. This requires several computing steps.

The injection strategy for reductant addition of the process of US patent No. 6,119,448 uses similar measurements, furthermore, a reference engine is included in the calculations.

Also patent number US patent No. 5,950,422 discloses an exhaust gas purification method. The similar calculations of amount of reductant to be added is performed by dividing the catalyst volume into several sub-regions, where after calculations for each sub-region are performed.

Though a great number of methods to control addition of reductant into exhaust gas are known in the art, there is still need to improve NO_x conversion by controlled addition of a reductant in order to prevent detrimental leakage of the reductant into the environment.

SUMMARY OF THE INVENTION

It is desirable to provide a method and a system for controlling injection of a reductant into a combustion engine exhaust gas. The method is based on simple and reliable measurements to obtain a signal for solution flow regulation of reducing agent, which always quickly is corrected to correspond to changes in operation of the combustion engine.

The invention relates to a method for controlling injection of a reductant into a NO_x containing exhaust gas stream from a combustion engine, where the NO_x is reduced by selective catalytic reduction, SCR, in the presence of a SCR catalyst.

In one aspect, the method comprises steps of establishing signals related to exhaust gas flow, to NO_x concentration in the exhaust gas stream upstream of the SCR catalyst and to exhaust gas temperature upstream and downstream of the SCR catalyst.

The method may further comprise the steps of calculating a molar NO_x flow in the exhaust gas stream upstream of the SCR catalyst, a NO_x conversion in the catalyst, a required amount of reductant and of adjusting the required amount of reductant responsive to the signals.

The method may still further comprise the steps of establishing signals related to the molar NO_x flow, the NO_x conversion, the required amount of reductant and to an adjusted amount of reductant.

The required amount of reductant is by the method of the invention adjusted by calculating a value d(E*T)/dt, where
t is time,
E is the exhaust gas flow, and
T is the exhaust gas temperature upstream of the SCR catalyst and by establishing a signal related to the value d(E*T)/dt. This signal and the signal responsive to the required amount of reductant are used for calculation of the adjusted amount of reductant.

The signal related to the adjusted amount of reductant is used for metering the adjusted amount of reductant, which is injected into the exhaust gas.

The invention is further related to an exhaust gas system using the control method, where the system contains an SCR catalyst, an injection nozzle upstream of the catalyst and sensor devices, wherein the sensor devises consist of a sensor for measuring NO_x concentration upstream of the catalyst; sensors for measuring two of combustion air mass flow, fuel mass flow and O_2 concentration in exhaust gas or a sensor for measuring exhaust gas mass flow upstream of the catalyst, and further a sensor for measuring temperature of the exhaust gas upstream of the catalyst and a sensor for measuring temperature of the exhaust gas downstream of the catalyst.

The advantage is that by using only five instrument signals and a parameter describing the rate of the change of the product of exhaust gas flow and catalyst temperature, very quick and reliable corrections of the signal for reductant injection is obtained. This ensures maximum NO_x conversion and simultaneously avoiding NH_3 slip outlet the catalyst.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic drawing of a combustion engine exhaust system with injection of a solution of a reactant into an exhaust gas stream upstream of a catalyst.

Fig. 2 is a block diagram showing the measurements and principles for calculation of the amount of reactant to be injected into an exhaust gas stream.

DETAILED DESCRIPTION OF THE INVENTION

A complete combustion of a fuel CH_x in combustion engines would be:

$$CH_x + (1+x/4)O_2 \rightarrow CO_2 + x/2\ H_2O \qquad (1)$$

where O_2 is oxygen in combustion air.

In diesel engine driven vehicles combustion takes place with a certain amount of excess air. This results in formation of nitrogen oxides, NO_x in the exhaust gas, which is a serious pollution for the environment.

NO_x can be reduced by ammonia, NH_3, which however is difficult to store in vehicles, and an aqueous solution of ammonia or urea, H_2NCONH_2, is therefore preferred as a reducing agent.

The ammonia is formed when urea decomposes as it is sprayed into the hot exhaust gas according to the following reaction:

$$H_2NCONH_2 + H_2O \rightarrow 2\ NH_3 + CO_2 \qquad (2)$$

The mixture of exhaust gas and reductant, ammonia, then passes over a catalyst where the nitrogen oxides, nitrogen monoxide, NO and nitrogen dioxide, NO_2, react with the ammonia to form nitrogen and water according to at least the following reactions:

$$4\ NO + 4\ NH_3 + O_2 \rightleftarrows 4\ N_2 + 6\ H_2O \qquad (3)$$

and

$$6\ NO_2 + 8\ NH_3 \rightleftarrows 7\ N_2 + 12\ H_2O \qquad (4)$$

The reduction processes are equilibrium reactions and the equilibrium is dependent of temperature, catalyst volume, catalyst activity and concentration of the present components. Thereby, it is not possible to convert all the NO_x, only a theoretical maximal amount can be converted.

As it appears from reactions (3) and (4) it is important to inject the correct amount of ammonia or urea solution into the hot exhaust gas. Sufficient ammonia must be present to obtain as high conversion as possible.

On the other hand, surplus of ammonia, resulting in leakage of ammonia from the catalyst and into to the atmosphere, must be avoided.

During reaction, a certain amount of ammonia is adsorbed on the surface of the catalyst. When reaction conditions, especially exhaust gas flow and temperature, change due to change in load/operation conditions of the engine, desorption or increased adsorption will occur resulting in lack or surplus of ammonia. This will result in incomplete conversion of NO_x or in NH_3 slip out into the atmosphere. It is therefore very important to inject the correct amount of urea/ammonia to the exhaust gas and to adjust this amount very quickly and precisely during variations of operation of the engine.

The invention provides a method and a system for an accurate injection of urea solution into an exhaust gas. The method comprises five measurements and four steps for determining of main parameters and creating a correct, updated signal to a urea solution flow control valve, dosing pump or other control device.

The first step is calculation of NO_x flow in the exhaust gas, the second step is a calculation of NO_x conversion, the third step is a determination of theoretical required amount of reductant and the fourth step is a determination of the actual requirement of the amount of reductant by use of an event based filter. The involved calculations are carried out with a frequency of between 5 and 30 Hz, i.e. one calculation loop is carried out in between 33 and 200 ms.

An example of a specific use of the invention is shown on Fig 1. Combustion takes place in diesel motor 1 of fuel 2 and with air 3 forming an exhaust gas stream 4, which contains a certain amount of NO_x and O_2 due to added excess air. Reducing agent, preferably an aqueous solution of urea 5 is stored in a tank and injected to the exhaust gas stream through nozzle 6. Urea solution in the hot exhaust gas stream is immediately decomposed to NH_3 and CO_2 according to reaction (2) resulting in exhaust gas stream 7, which is passed through a catalyst 8, where a selective catalytic reduction of NO_x by NH_3 to N_2 takes place.

The air from air compressor 9 to urea is used for pushing the urea solution through nozzle 6 and for obtaining a good atomisation of the solution.

The O_2 content in stream 4 is measured by analyser 11 and the NO_x content by analyser 12, while temperatures inlet and outlet of the catalyst are measured by temperature instruments 14 and 15, respectively.

The flow of air 3 to motor 1 is measured by flow instrument 17 and the urea solution flow is regulated by valve 18. The signals from the measuring instruments are received by an electronic control unit, ECU, 19, which creates an up-dated accurate signal for the control valve 18.

A specific embodiment of the invention is shown on Fig. 2. Step 1 is a stoichiometric calculation of the amount of NO_x created by the combustion and calculated as moles/hours. The calculation is based on measurement of air to combustion measured as kg/h, measurement of O_2 content in exhaust gas measured as volumetric % and NO_x content measured as ppm by volume.

The NO_x flow calculation can be carried out using different methods. One method is as above based on using the air mass flow into the engine, the oxygen content of the exhaust gas and the NO_x, i.e. the NO and NO_2 concentrations in the exhaust gas. These can be given either by a sensor or by engine maps. The stoichiometric calculation is based on the assumption of a complete combustion of a fuel with the general formula CH_x with air to form CO_2 and H_2O according to reaction 1. With the fuel composition known, the oxygen content of the exhaust gas and one of either air mass flow or fuel flow to the engine known, the exhaust gas flow can be calculated. The exhaust gas flow may also be based on measurement of fuel and combustion air flow or on measurement of pressure drop across the catalyst. Further, the mass flow of the exhaust gas may be directly measured by a sensor, which then is installed in a gas with high temperature. Alternatively, the NO_x concentration can be given directly to step 1 of engine control system.

Step 2 calculates the maximum possible or wanted NO_x conversion based on the same three measurements as step 1 plus measurement of temperature of the exhaust gas inlet and outlet of the catalyst. Set points for parameters as catalyst data and reaction kinetic are given, optionally, a desired maximum conversion as well.

The kinetic calculation of the injection strategy is based on a tubular reactor model, which besides the chemical reaction calculation also includes calculations for outer mass transfer (film transfer) and pore diffusion within the catalyst. The kinetic reactor model calculates the maximum possible NO_x conversion over the catalyst that can be achieved for a given point of engine operation. The inputs for the calculation are the exhaust gas flow, NO_x flow, the O_2 concentration, the temperatures and a predetermined NH_3 slip. The exhaust gas flow and the NO_x flow are obtained in the same way as in step 1, as the exhaust gas flow is determined during step 1. The NH_3 slip is set together with catalyst data, such as catalyst volume, length, void, hydraulic diameter, catalyst activity and the kinetic parameters for the above mentioned reactions. In the kinetic part a maximum allowed conversion could be set as part of the injection strategy.

The maximum allowed conversion may be used to tune the system for engines where different NO_x reductions are required to reach a legislative target. Alternatively, a reduced NO_x reduction efficiency can be accomplished with the system by fictively reducing the catalyst volume in the data set for the calculations.

Results from steps 1 and 2 are used in step 3 to obtain the theoretically required amount of urea solution to be injected at a certain moment.

This theoretical amount is further adjusted in the event based filter, step 4, based on measurement of exhaust gas temperature inlet of catalyst, air flow measurement and O_2 measurement and on determination of exhaust gas flow as in step 2 in order to avoid leakage of ammonia or NO_x during transient conditions.

The amount of ammonia adsorbed on the catalyst surface changes especially with changes in exhaust gas flow and temperature. The filter takes into consideration the historical data of the catalyst in order to foresee the NH_3 adsorption/desorption capacity of the catalyst. If the conditions of the catalyst are such that a large desorption of ammonia can occur, then part of the calculated (step 3) urea injection is retained and stored in the memory of the injection algorithm. On the other hand, if the conditions are favourable for the adsorption of NH_3 on the catalyst, then the actual urea injection can be increased until the amount of urea as stored in the memory is used up. This is to assure that the mass balance over time is correct.

The filter determines at any time changes in the product of exhaust gas flow and temperature, d(E*T)/dt, where
E is exhaust gas flow,
T is temperature, and
t is time.

If d(E*T)/dt is positive, flow and/or temperature are increasing making desorption of ammonia from the catalyst favourable, then a part of the calculated urea is retained and stored for later use. The retained urea is re-injected when the change in the product is negative, i.e. flow and/or temperature are decreasing, thus making adsorption of ammonia on the catalyst favourable.

The mentioned measurements are performed by sensors, which are commercially available.

By the method of the invention, the amount of injected urea solution is immediately adjusted, NH_3 leakage from the catalyst is avoided and simultaneously maximum NO_x conversion is obtained at any and varying load of the motor.

The injection strategy can be tuned to obtain an improved transient operation by adjusting the parameters of the event based filter.

In principal, the same injection algorithm can be used for any type of engine, the compliance with the emission regulations is controlled by the determination of the catalytic volume, which depends on the mass flow of exhaust gas from the specific engine.

The invention is particular useful in cars, vans, lorries, trains, ships or generators, which are driven by diesel combustion engines, and where the exhaust gas system is equipped with a selective catalytic reduction system. The invention will secure a very low degree of emission of poisonous NH_3 and NO_x to the atmosphere, even at big and/or frequent changes in load of engine.

CLAIMS

1. A method for controlling injection of a reductant into an NO_x containing exhaust gas stream from a combustion engine, where the NO_x is reduced by selective catalytic reduction (SCR) in the presence of a SCR catalyst, comprising the steps of

establishing a signal related to exhaust gas flow;

establishing a signal related to NO_x concentration in the exhaust gas stream upstream of the SCR catalyst;

establishing a signal related to exhaust gas temperature upstream of the SCR catalyst;

establishing a signal related to exhaust gas temperature downstream of the SCR catalyst;

calculating a molar NO_x flow in the exhaust gas stream upstream of the SCR catalyst and establishing a signal related to the molar NO_x flow;

calculating an NO_x conversion in the catalyst and establishing a signal related to the NO_x conversion;

calculation of a required amount of reductant and establishing a signal related to the required amount of reductant;

adjusting the required amount of reductant;

establishing a signal related to an adjusted amount of reductant;

using the signal related to the adjusted amount of reductant for metering the adjusted amount of reductant; and

injecting the adjusted amount of reductant into the exhaust gas;

wherein,

the required amount of reductant is adjusted by calculation of a value d(E*T)/dt, where
t is time,
E is the exhaust gas flow, and
T is the exhaust gas temperature upstream of the SCR catalyst and establishing a signal related to the value d(E*T)/dt; and

calculation of the adjusted amount of reductant by means of the signals responsive to the required amount of reductant and of the value d(E*T)/dt.

2. Method of claim 1, wherein the establishing of the signal relating to the exhaust gas flow, comprises

establishing signals related to two of mass flow of combustion air, mass flow of fuel and related to O_2 concentration in the exhaust gas stream; and

calculation of the exhaust gas flow responsive to the signals.

3. Method of claim 1 or 2, wherein the calculation of NO_x conversion in the catalyst comprises

calculation of the NO_x conversion responsive to the signals related to the exhaust gas flow, the NO_x concentration in the exhaust gas stream and the temperatures upstream and downstream of the catalyst, and signals related to input data for catalyst dimensions, catalyst bed dimensions and kinetic data for the catalyst and NO_x conversion reaction.

4. A method for controlling injection of a reductant into a NO_x containing exhaust gas stream from a combustion engine, where the NO_x is reduced by selective catalytic reduction, SCR, in the presence of a SCR catalyst, comprising the steps of

(a) establishing a signal related to two of mass flow of combustion air, mass flow of fuel and O_2 concentration in the exhaust gas stream,
establishing a signal related to NO_x concentration in the exhaust gas stream upstream of the catalyst,
establishing a signal related to exhaust gas temperature upstream of the SCR catalyst, and
establishing a signal related to exhaust gas temperature downstream of the SCR catalyst;

(b) calculation of a molar NO_x flow in the exhaust gas stream responsive to the signals of two of the mass flow of combustion air, the mass flow of fuel and the O_2 concentration in the exhaust gas stream and of the NO_x concentration in the exhaust gas stream;

(c) calculation a of NO_x conversion in the catalyst responsive to NO_x concentration in the exhaust gas stream, the exhaust gas temperature upstream and downstream of the SCR catalyst, and of two of the signal of the mass flow of air to combustion, the mass flow of fuel and the O_2 concentration in the exhaust gas stream;

(d) calculation of a required amount of reductant responsive to signals of the molar NO_x flow in the exhaust gas stream and of the NO_x conversion in the catalyst;

(e) calculation of an adjusted amount of reductant responsive to signals of the required amount of reductant, the exhaust gas temperature, T, upstream of the SCR catalyst, and of two of the mass flow of air to combustion, the mass flow of fuel and the O_2 concentration in the exhaust gas stream, the calculation including calculation of a value d(E*T)/dt, where
t is time,
E is the exhaust gas flow, and
T is the exhaust gas temperature upstream of the SCR catalyst; and

(f) injection of the adjusted amount of reductant into the exhaust gas stream.

5. The method of any one of claims 1 to 4, wherein the reductant is ammonia, an aqueous solution of ammonia or an aqueous solution of urea.

6. The method of any one of claims 1 to 5, wherein the engine is a diesel engine.

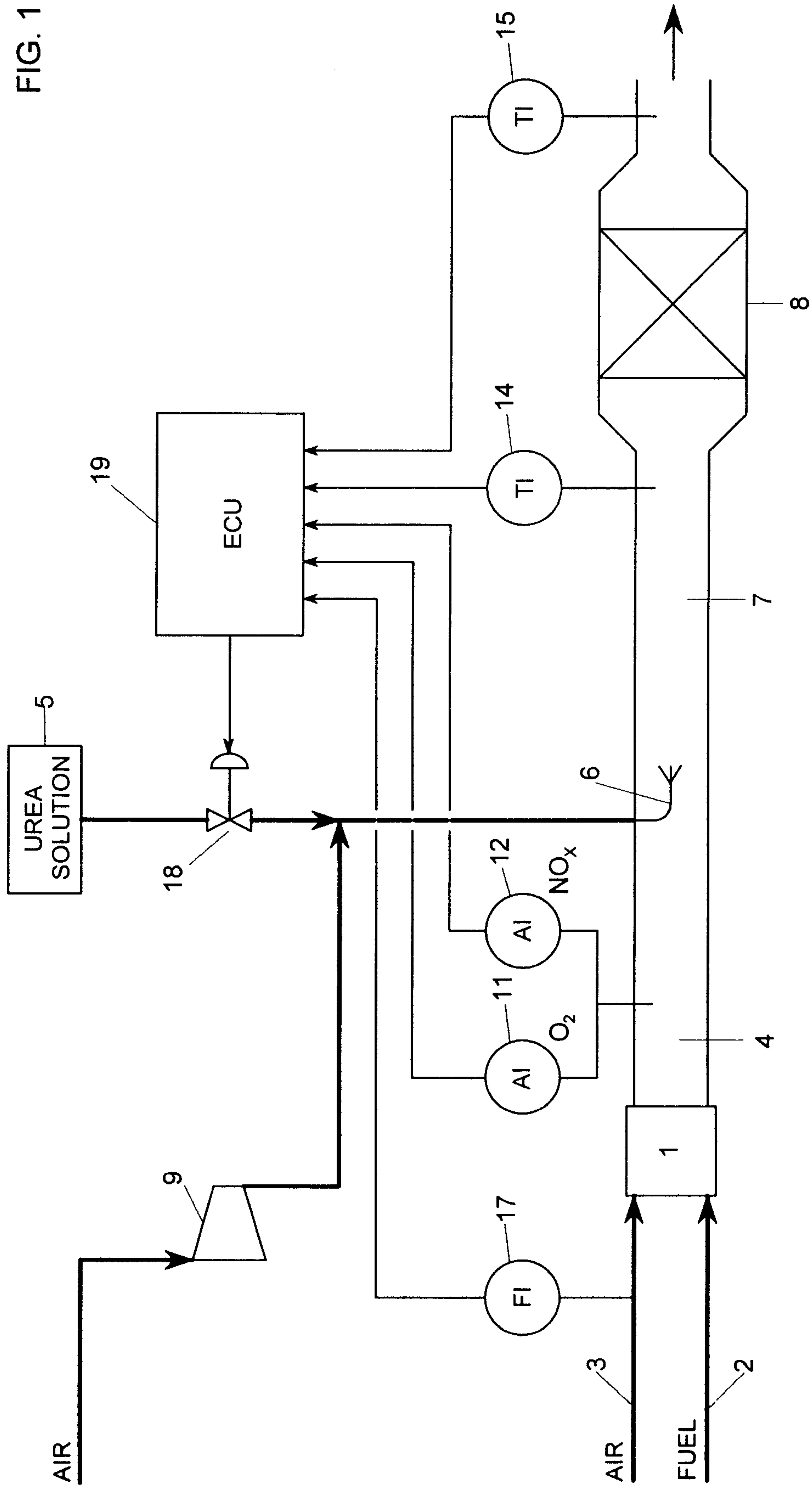
7. An exhaust gas system for use in the method of any one of claims 1 to 6, for controlling injection of a reductant into a NO_x containing exhaust gas stream from a combustion engine, where a selective catalytic reduction, SCR, system is installed, containing

an SCR catalyst,
an injection nozzle upstream of the catalyst,
an electronic control unit, and
a sensor for measuring NO_x concentration upstream of the catalyst;
sensors for measuring two of mass flow of air to combustion, mass flow of fuel and O_2 concentration or a sensor for measuring exhaust gas mass flow upstream of the catalyst;
a sensor for measuring temperature of the exhaust gas upstream of the catalyst; and
a sensor for measuring temperature of the exhaust gas downstream of the catalyst;

wherein,

the electronic control unit calculates an amount of reductant to be injected by a procedure comprising calculation of a value $d(E*T)/dt$, where
t is time,
E is the exhaust gas flow, and
T is the exhaust gas temperature upstream of the SCR catalyst.

FIG. 1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FUEL
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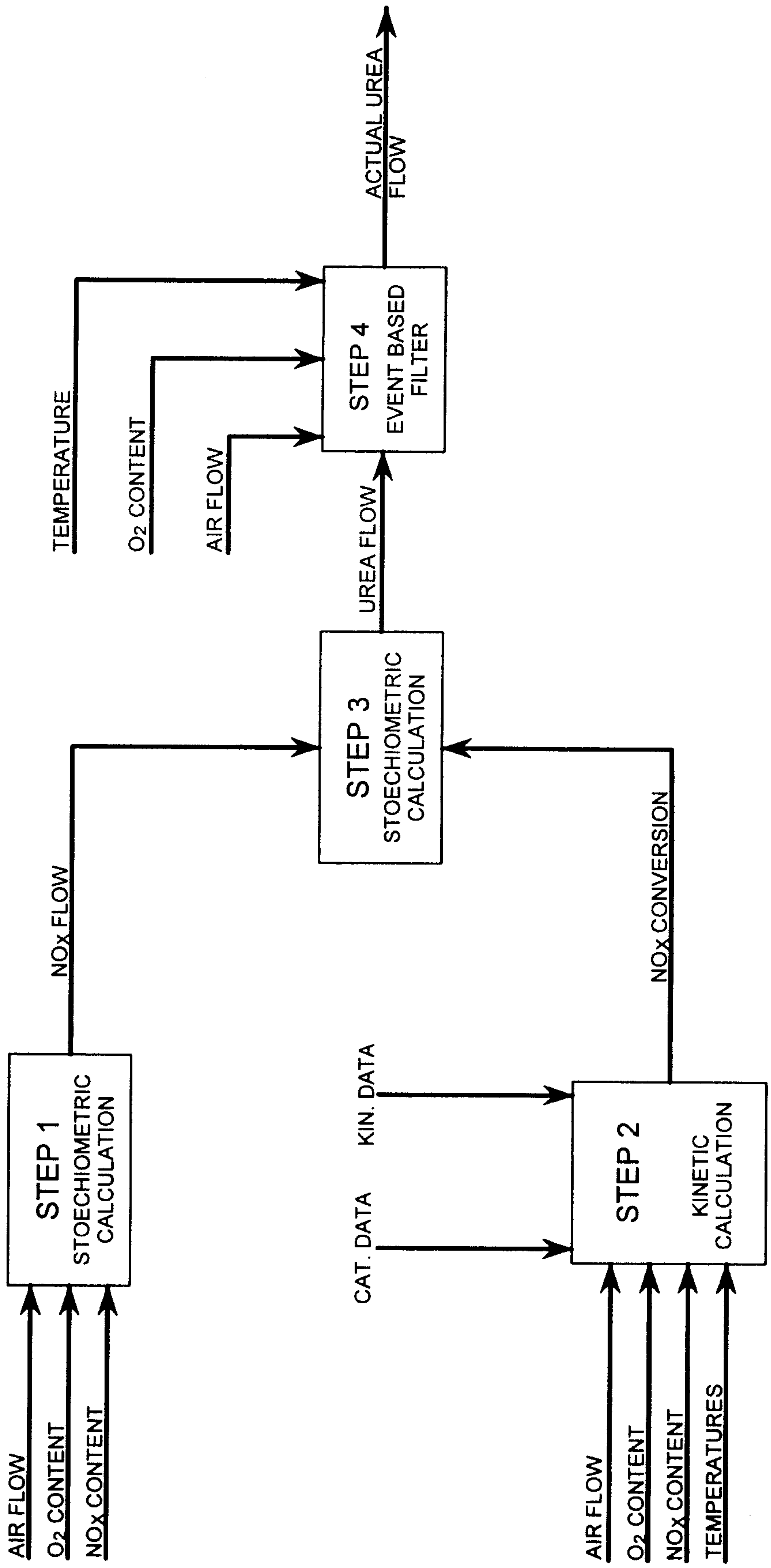
FIG. 2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O2 CONTENT
NOx CONTENT
STEP 1
STOECHIOMETRIC CALCULATION
NOx FLOW
CAT. DATA
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AIR FLOW
O2 CONTENT
NOx CONTENT
TEMPERATURES
STEP 2
KINETIC CALCULATION
NOx CONVERSION
STEP 3
STOECHIOMETRIC CALCULATION
UREA FLOW
TEMPERATURE
O2 CONTENT
AIR FLOW
STEP 4
EVENT BASED FILTER
ACTUAL UREA FLOW

AIR
UREA SOLUTION
5
19
9
18
ECU
FI
17
AI
11
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12
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8