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(54) **Title**: METHOD TO DETERMINE LEVEL OF REDUCTANT IN A TANK

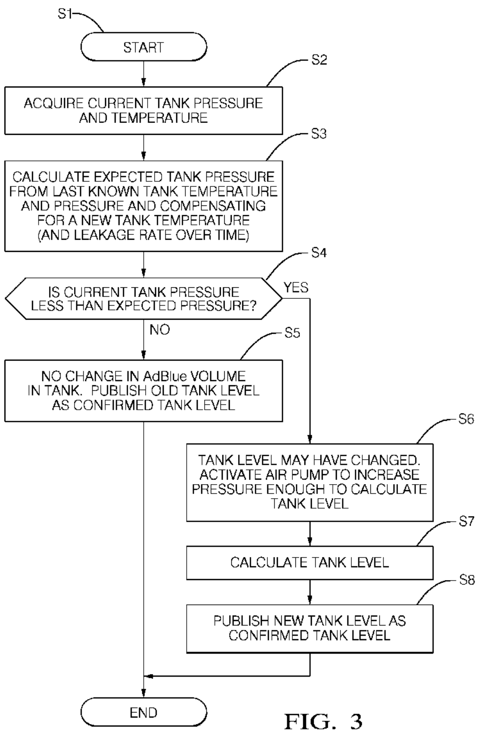

FIG. 3

(57) **Abstract**: A method of determining the level of reductant in a storage tank of a Selective Catalytic Reduction dosing system comprising: a) determining the initial air pressure within said tank P1; b) pressurizing the tank; c) determining the added mass of air during said pressurization, m added; d) measuring the pressure of the tank subsequent to pressurization, P2; e) determining the volume of air in the tank from P1, P2 and m added; f) determining the level of reductant in the tank form the determined volume of air in the tank from step e) and the assumed or determined volume of the tank before and/or after pressurization.

WO 2017/016779 A1

Method to Determine Level of Reductant in a Tank

Technical Field

The present invention relates to a reagent dosing system for dosing a reagent into the exhaust gas flow of an internal combustion engine, and specifically to a Selective Catalytic Reduction dosing system in a vehicle such as a Diesel vehicle. It has particular application in determining the volume of reagent such as urea in a storage tank.

Background of the Invention

Reagent dosing systems such as Selective Catalytic Reduction (SCR) dosing systems are used in vehicles to reduce emissions such as nitrogen oxide (NOx) in the exhaust gas flow, by converting the emissions into other substances.

A known SCR dosing system doses a reagent comprising urea into an exhaust gas flow. The system comprises a urea tank, a urea delivery module (UDM), a feed line, and a coolant system comprising a cooler and a temperature sensor. The UDM may be adjacent, or fitted to, the urea tank. The UDM may integrate three sensors, for filtering and tank heating, temperature and concentration, and urea level. Urea is delivered from the urea tank, via the UDM and the feed line to a dosing injector module comprising a water-cooled pump injector. A flow of engine coolant, which runs at too high a temperature to be used directly for cooling urea, is further cooled by the cooler. The subsequent flow of coolant to the injector module prevents the urea from reaching boiling point during hot vehicle running conditions.

In a further known SCR dosing system, pressurised urea is supplied to a dosing injector module comprising a water-cooled solenoid injector. A pressuring means comprising a pump and a pressure sensor directly pressurises the urea, within part of the feed line, after is has left the urea tank. The boiling point of the urea is increased by the pressurisation, and therefore the system can operate with a coolant system supplied with normal engine coolant at 90 – 110°C, without the requirement for an additional cooler. However, the pump required to directly pressurise the urea is complex and expensive, and must be sufficiently robust to the accommodate the pressures of frozen urea.

In an enhanced known design the urea is pressurised by providing means to pressurise the air in the urea tank, thus pressurising the urea.

It is an object of the invention to reduce the cost of such systems by providing a system and method to determine the level of urea without the need for a level sensor or such like.

Statement of the Invention

In one aspect is provided a method of determining the level of reductant in a storage tank of a Selective Catalytic Reduction dosing system comprising: a) determining the initial air pressure within said tank P1; b) pressurizing the tank; c) determining the added mass of air during said pressurization, $m_{added;}$ d) measuring the pressure of the tank subsequent to pressurization, P2;

e) determining the volume of air in the tank from P1, P2 and m added; and and f) determining the level of reductant in the tank form the determined volume of air in the tank from step e) and the assumed or determined volume of the tank before and/or after pressurization

Step f) may comprise determining the level of the reductant by subtracting the assumed or determined volume of the tank from the determined volume of step e) .

The method may include determining the volume of the tank before pressurization Vt1 and /or after pressurization Vt2 dependent on temperature and/or pressure P1 and/ or P2 and using the thus determined values of Vt1 and/or Vt2 in step f).

The method may include the steps of determining the volume of the tank before pressurization Vt1 and after pressurization Vt2, and taking any difference into consideration in the determination step f)

The method is preferably performed during routine pressurization of the reductant tank.

The method is preferably performed subsequent to the following steps: i) determining the current tank pressure and/or temperature: ii) calculating the expected tank pressure from a previously recorded tank temperature/and or pressure; iii) determining if the current tank pressure deviates from said expected tank pressure from ii) by more than a pre-set threshold, and performing the methods of claims 1 to 4 where it is determined that said deviation is more than said pre-set threshold.

In step ii) the method preferably includes compensating for any change in temperature and/or leakage rate and/or usage of reductant.

Detailed Description of Examples

Figure 1 shows a urea or reductant dispensing system with which the current method may be used. It shows a Selective Catalytic Reduction (SCR) dosing system 102, for supplying a reagent such as urea to a dosing injector module 122.

The system 102 comprises a urea tank 112, which in the present embodiment is pressure-resistant, a pressure sensor 132 for sensing air pressure within the urea tank 112, a reagent delivery module comprising a Urea Delivery Module (UDM) 110, and a feed line 104.

The UDM 110 comprises a filter, an electrical heater, and a temperature sensor. The tank 112 contains a volume of urea 128, and a volume of air 162. The feed line 104, which comprises a first freeze-resistant section 118 and a second freeze resistant, high temperature section 120, supplies urea from a volume of the urea 128 in the urea tank 112, via the UDM 110, to an injector module 122 comprising a dosing injector such as a pump-injector, which is water-cooled by coolant provided from a coolant supply line 124.

The urea tank 112 is pressurised, by a source of air pressure. In, the source of air pressure is an air pump assembly 114, comprising an electric air pump and a filter. In alternative embodiments, the urea tank 112 could be pressurised by compressed air from a vehicle brake system (i.e. in heavy duty applications), compressed air from a mechanical air pump on a cam shaft/alternator etc., compressed air from an air suspension system, boosted air pressure from an inlet manifold, or by a combination of suitable sources of air pressure.

Detailed Description of Invention

In one aspect the method calculates the volume of urea/reductant in a storage tank by determining the volume of air in the tank. The volume of liquid urea or reductant is determined as the tank volume minus the volume of air. The volume of the tank may be assumed fixed or variable with temperature and/or pressure.

The volume of air in the tank according to an example is determined by measuring the pressure of the tank before and after a pressurization process where e.g. air is pumped into the tank to pressurize it. The change in pressure is a function of the volume of air in the tank (i.e. tank volume minus urea volume, the latter may be assumed to be incompressible) and the mass of air pumped in.

Typically with the systems described above, a pressure sensor is already present which can detect the tank pressure. If not a pressure sensor can be provided which is cheaper in some instances that a level sensor.

This allows the removal of a complex level sensor from the system or replacement of the level sensor with a simpler more cost effective one.

Methodology of examples involves in examples using relationships between parameters such as the pressure, volume, optionally temperature, and the mass of air pumped into the tank, plus optionally estimation of the impact of pressure and temperature on tank volume, as well as optionally modelling of mass flow delivery from an air pump and optionally the observance of any leakages from the system with additional logic to check the validity of previous level calculations.

Figure 2a to d shows the effect of operation of the air pump to achieve for example a pre-defined pressure increase. The tank is operated between times t1 and t2 and the urea volume may be calculated after pressurization at time t2. Preferably the tank level is determined when the air pump has been turned on for a certain time; e.g. minimum threshold time or when the air pressure has risen by a certain amount e.g. above a threshold.

Example 1

The following equation is utilized in the determination of urea volume,

Equation 1: Urea Volume = Tank Volume – Air Volume

If the tank volume is known, the urea volume can be determined if the air volume is known/determined. Thus according to a simple embodiment the air volume is estimated and used to determine the urea volume from the equation above.

The Ideal Gas Equation is as follows:

Equation 2 $PV = mRT$

According to the basic example, the initial pressure of the tank is determined P1 and the tank is then pressurized e.g. by pumping means which adds an additional mass of air to the tank, madded to the existing or initial mass of air mo. The pressure P2 after pressurization is determined.

Equation 3 $$P_1V = m_oRT1$$

Where V is the air volume (tank volume) minus the reductant volume, and assumed to be constant.

After pressurization:

Equation 4 $$P_2V = (m_o + m_{added})RT_2.$$

Assuming T1 and T2 are the same, equations 3 and 4 this gives the volume V:

Equation 5 $$V = m_{added} RT/(P2 - P1)$$

where P2 and P1 are the air pressure before and after the pumping operation.

Preferably the air mass added to pressurize the tank is determined form the following equation :

Equation 6 $$m_{added} = \text{Sum (Air Mass Flow * deltaTime)}$$

Where deltaTime is the duration of a pumping operation and AirMassFLow is the flow mass of air through/from the pump.

Thus if the air mass can be determined after the pumping operation by integrating air flow with respect to time.

In examples, the Air Mass Flow can be determined by modelling the characteristics of the air pump as a function of air pressure supply , supply voltage etc. Alternatively the air flow could be measured by a simple air flow meter in series with the air pump.

In a simple embodiment, the tank temperature is assumed constant during the pressure increase

In preferred aspect, the tank volume is not assumed to be constant but varies according to the tank pressure and/or temperature. Variation in physical tank volume due to pressure and temperature will generally be small but depends on tank construction. Thus the tank volume can be determined from:

Equation 7: Tank Volume = f (Tank Pressure, Tank Temperature)

The above methodology may be performed during normal pressurisation periods of the tank. Periodic pressurisation is necessary to ensure adequate injection of urea.

Further Examples

With a urea delivery system with no air leaks the pump may not be activated for several drive cycles. Thus in enhanced embodiment, the following may be used to infer knowledge of the tank state in between pump operations. So alternatively, the process including pressurisation may be determined at times outside the normal operational pressurisation times.

Preferably any application of the methodology above outside normal pressurisation periods is only performed if diagnostics suggest it may be necessary, e.g. if there may be a leak or the tank is getting below a critical value. In the following examples, it is determine when, i,e. under what circumstances it is preferable to perform the method.

Example 1

Figure 3 illustrates an example of the invention and show a flow chart of the operation. The method starts at step S1. At step S2 the tank pressure and temperature are measured.

At step S3 the expected tank pressure is determined from the last known tank temperature and pressure and compensating for the new tank temperature, as well as optionally any leakage or usage rate over time.

In step S4, the current tank pressure is compared with the expected tank pressure from step S3. If it is less than the expected tank pressure the procedure proceed to step S5

At S5 it is assumed that there is no change in the urea volume.

If at step 4 the current tank pressure is less than expected tank level may have changed. The process proceeds to step S6 where the air pump is activated to increase the pressure and the tank level determined as described above at step S7. This may involve the procedure described above. At S8 the new tank level is confirmed as correct.

Refined Example 2

Figure 4 shows a flow chart of methodology when the tank is running.

At vehicle start-up the tank level logic is as following: The current tank pressure and temperature is acquired at step S11. As step S12 this is determined if the current tank pressure is less than the expected demanded tank pressure. If so at step S13 the pump is activated to increase pressure. At step S14 the tank level is determined. Again steps S13 and S14 may be performed as described above.

If not at step S15 the calculated expected tank pressure is determined form the last known tank temperature and pressure compensating optionally with new tank temperature/any urea consumption over time/leakage rate over time.

At step S16 it is determined if the tank pressure is less than expected tank pressure. If not at step S17 there is assumed to be no change in the volume of urea. If so however the process proceeds to step S18 where it is assumed the tank level has changed or there is an air leak. The air pump is activated and the process proceeds to step S14 where the new tank level is computed. Therefore steps S18 and S14 perform the methodology as described in the figure 3 example.

This is confirmed at step S20. The leakage rate is also calculated at step S19 and used in the calculation of expected tank pressure/step S15.

Additionally

In the case when the system starts and the pressure in the tank is already greater than the demand. A plausibility check can be made if the temperature of the tank has changed from the last know condition.

Using

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2} \therefore V_2 = \frac{P_1 \times V_1 \times T_2}{P_2 \times T_1}$$

Where

P_1 = Pressure in tank at vehicle key off or shutdown

T_1 = Temperature in tank at vehicle key off or shutdown

V_1 = Volume in tank at vehicle key off or shutdown

P_2 = Pressure in tank at vehicle key on or startup

T_2 = Temperature in tank at vehicle key on or startup

V_2 = Calculated Volume in tank at vehicle key on or startup

Claims

1. A method of determining the level of reductant in a storage tank (112) of a Selective Catalytic Reduction dosing system (102) comprising:

a) determining the initial air pressure within said tank P1 (S2);

b) pressurizing the tank (S6);

c) determining the added mass of air during said pressurization, m added;

d) measuring the pressure of the tank subsequent to pressurization, P2;

e) determining the volume of air in the tank from P1, P2 and m added; and;

f) determining the level of reductant in the tank form the determined volume of air in the tank from step e) and the assumed or determined volume of the tank before and/or after pressurization

2. A method as claimed in claim 1 where step f) comprises determining the level of the reductant by subtracting the assumed or determined volume of the tank from the determined volume of step e).

3. A method as claimed in claim 1 including determining the volume of the tank before pressurization Vt1 and /or after pressurization Vt2 dependent on temperature and/or pressure P1 and/ or P2 (S3) and using the thus determined values of Vt1 and/or Vt2 in step f).

4. As claimed in claim 2 including the steps of determining the volume of the tank before pressurization Vt1 and after pressurization Vt2, and taking any difference into consideration in the determination step f)

5. A method as claimed in any preceding claim where said method is performed during routine pressurization of the reductant tank (112).

6. A method as claimed in claim 1to 4 wherein said method is performed subsequent to the following steps:

i) determining the current tank pressure and/or temperature (S11):

ii) calculating the expected tank pressure from a previously recorded tank temperature/and or pressure (S15) ;

iii) determining if the current tank pressure deviates from said expected tank pressure from ii) by more than a pre-set threshold (S16); and performing the methods of claims 1 to 4 where it is determined that said deviation is more than said pre-set threshold.

7. A method as claimed in claim 6 wherein step ii) includes compensating for any change in temperature and/or leakage rate and/or usage of reductant.

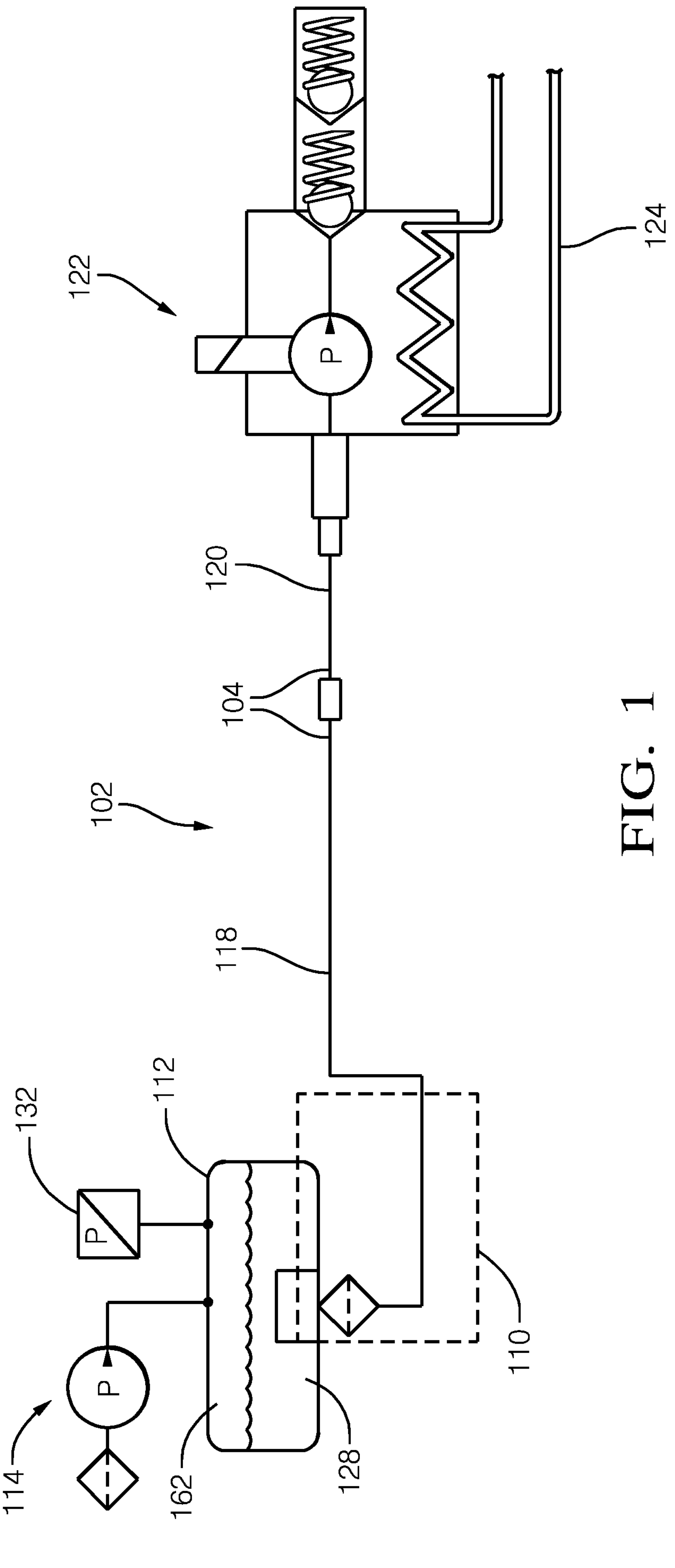

FIG. 1

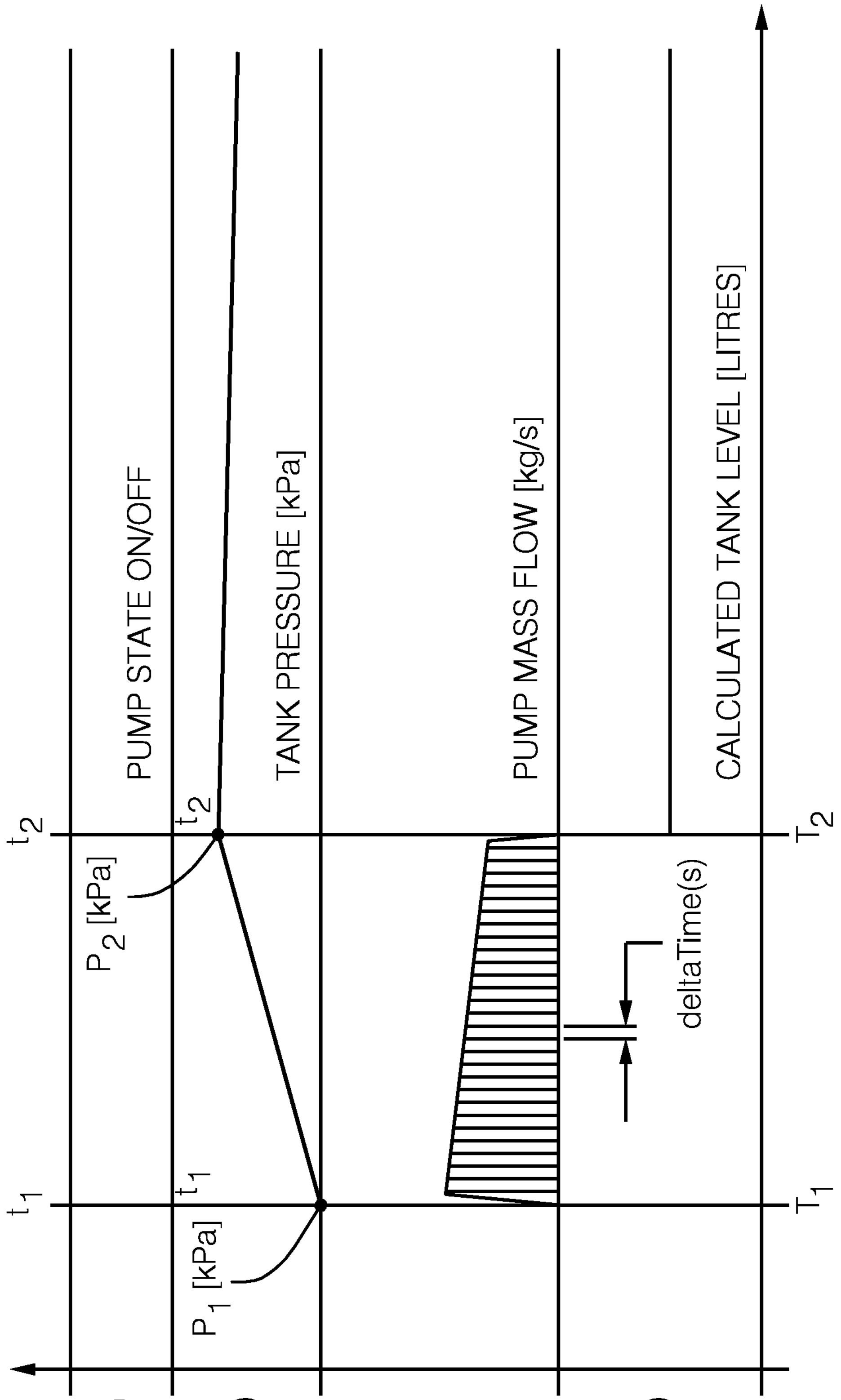
a)
b)
c)
d)
t_1
t_2
P_1 [kPa]
P_2 [kPa]
PUMP STATE ON/OFF
TANK PRESSURE [kPa]
PUMP MASS FLOW [kg/s]
CALCULATED TANK LEVEL [LITRES]
deltaTime(s)
T_1
T_2

FIG. 2

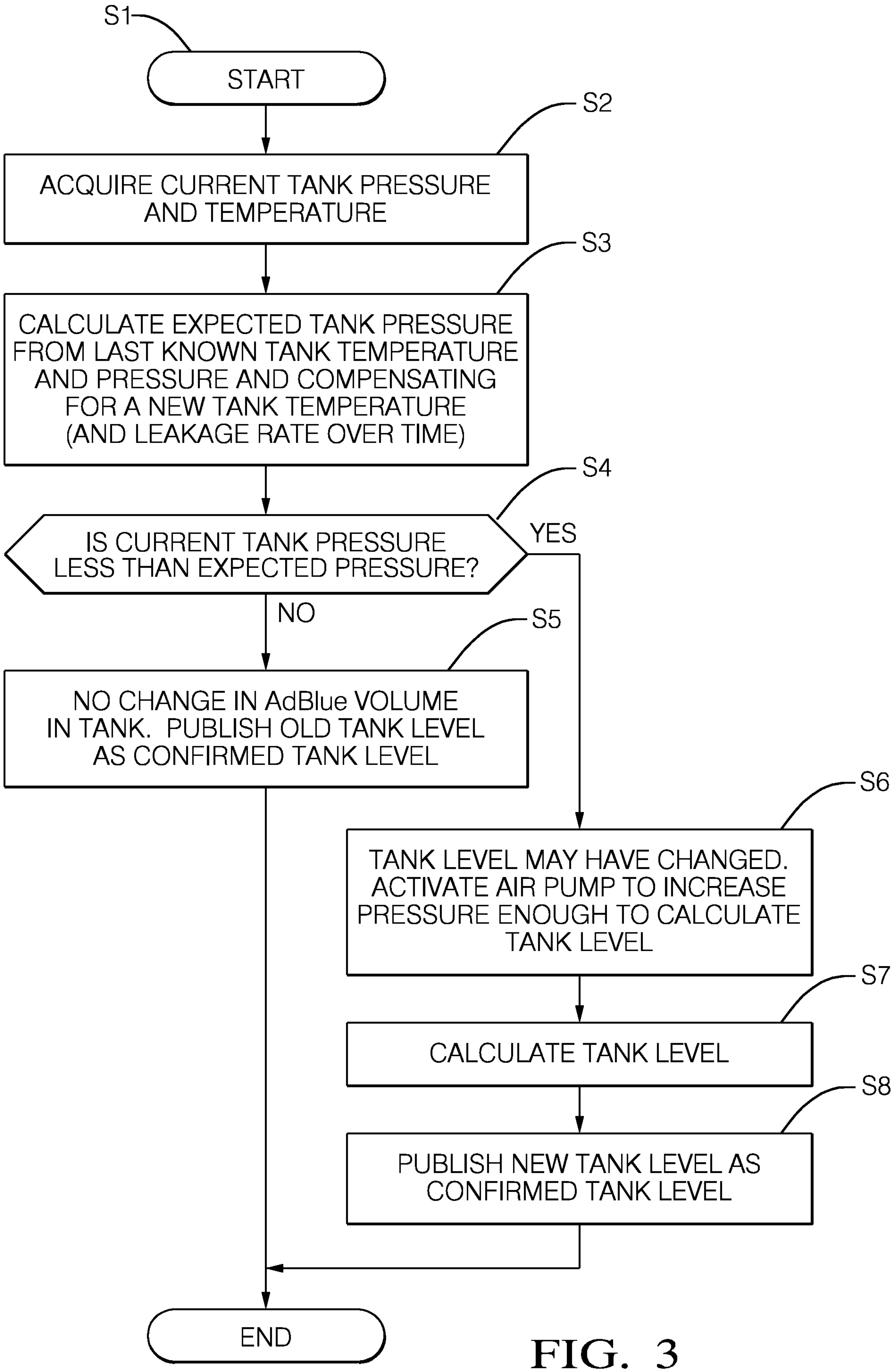
S1
START
S2
ACQUIRE CURRENT TANK PRESSURE AND TEMPERATURE
S3
CALCULATE EXPECTED TANK PRESSURE FROM LAST KNOWN TANK TEMPERATURE AND PRESSURE AND COMPENSATING FOR A NEW TANK TEMPERATURE (AND LEAKAGE RATE OVER TIME)
S4
IS CURRENT TANK PRESSURE LESS THAN EXPECTED PRESSURE?
YES
NO
S5
NO CHANGE IN AdBlue VOLUME IN TANK. PUBLISH OLD TANK LEVEL AS CONFIRMED TANK LEVEL
S6
TANK LEVEL MAY HAVE CHANGED. ACTIVATE AIR PUMP TO INCREASE PRESSURE ENOUGH TO CALCULATE TANK LEVEL
S7
CALCULATE TANK LEVEL
S8
PUBLISH NEW TANK LEVEL AS CONFIRMED TANK LEVEL
END

FIG. 3

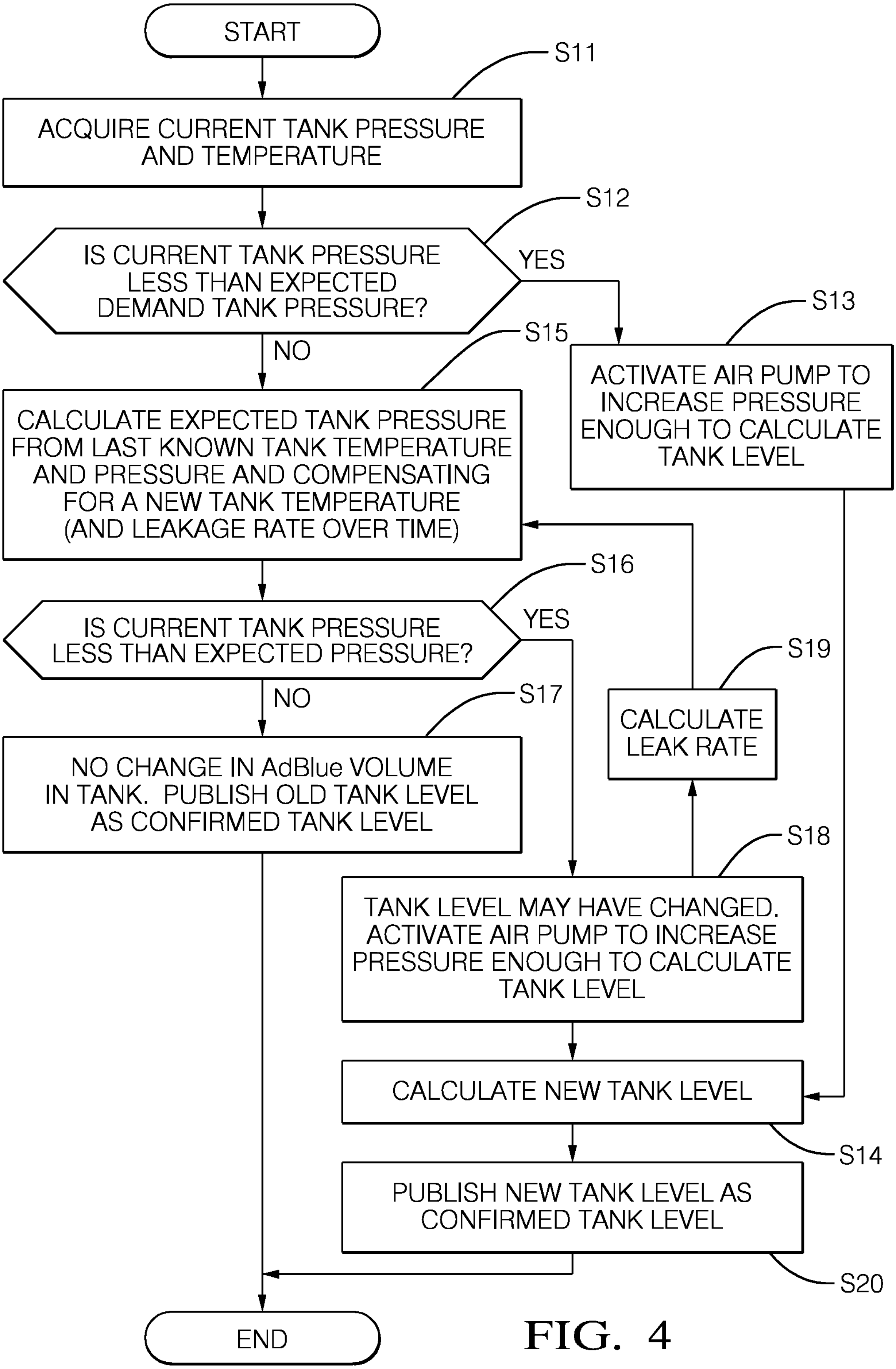
START
S11
ACQUIRE CURRENT TANK PRESSURE AND TEMPERATURE
S12
IS CURRENT TANK PRESSURE LESS THAN EXPECTED DEMAND TANK PRESSURE?
YES
NO
S13
ACTIVATE AIR PUMP TO INCREASE PRESSURE ENOUGH TO CALCULATE TANK LEVEL
S15
CALCULATE EXPECTED TANK PRESSURE FROM LAST KNOWN TANK TEMPERATURE AND PRESSURE AND COMPENSATING FOR A NEW TANK TEMPERATURE (AND LEAKAGE RATE OVER TIME)
S16
IS CURRENT TANK PRESSURE LESS THAN EXPECTED PRESSURE?
YES
NO
S19
CALCULATE LEAK RATE
S17
NO CHANGE IN AdBlue VOLUME IN TANK. PUBLISH OLD TANK LEVEL AS CONFIRMED TANK LEVEL
S18
TANK LEVEL MAY HAVE CHANGED. ACTIVATE AIR PUMP TO INCREASE PRESSURE ENOUGH TO CALCULATE TANK LEVEL
CALCULATE NEW TANK LEVEL
S14
PUBLISH NEW TANK LEVEL AS CONFIRMED TANK LEVEL
S20
END

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/065198

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01N3/20
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F01N

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2014/352280 A1 (QI BAOHUA [US] ET AL) 4 December 2014 (2014-12-04) figures 1,2a page 3, paragraph 42 page 3, paragraph 44 - page 4 page 4, paragraphs 45,46 -----	1-7
Y	WO 98/55840 A1 (APPLIED MATERIALS INC [US]) 10 December 1998 (1998-12-10) claims 1,2,4; figure 1 page 6, line 28 - page 8, line 10 -----	1-7
A	US 2008/050510 A1 (STEVENS RONALD [US] ET AL) 28 February 2008 (2008-02-28) claim 1; figures 1,2 page 4, paragraphs 35,36 -----	1-7

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 August 2016	22/08/2016

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1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2016/065198

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
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