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(54) **METHOD AND SYSTEM FOR LOWERING VEHICLE EMISSIONS USING ACTIVE PRE-CHAMBER IGNITION**

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F02D 41/38	(2006.01)
F02B 19/10	(2006.01)
F02B 19/12	(2006.01)

(52) **U.S. Cl.**
CPC ***F02D 41/0042*** (2013.01); ***F02B 19/1023*** (2013.01); ***F02B 19/12*** (2013.01); ***F02D 41/38*** (2013.01); *F02D 2041/389* (2013.01); *F02D 2200/06* (2013.01)

(58) **Field of Classification Search**
CPC F02D 41/0042; F02D 41/38; F02D 2041/389; F02D 2200/06; F02B 19/1023; F02B 19/12
See application file for complete search history.

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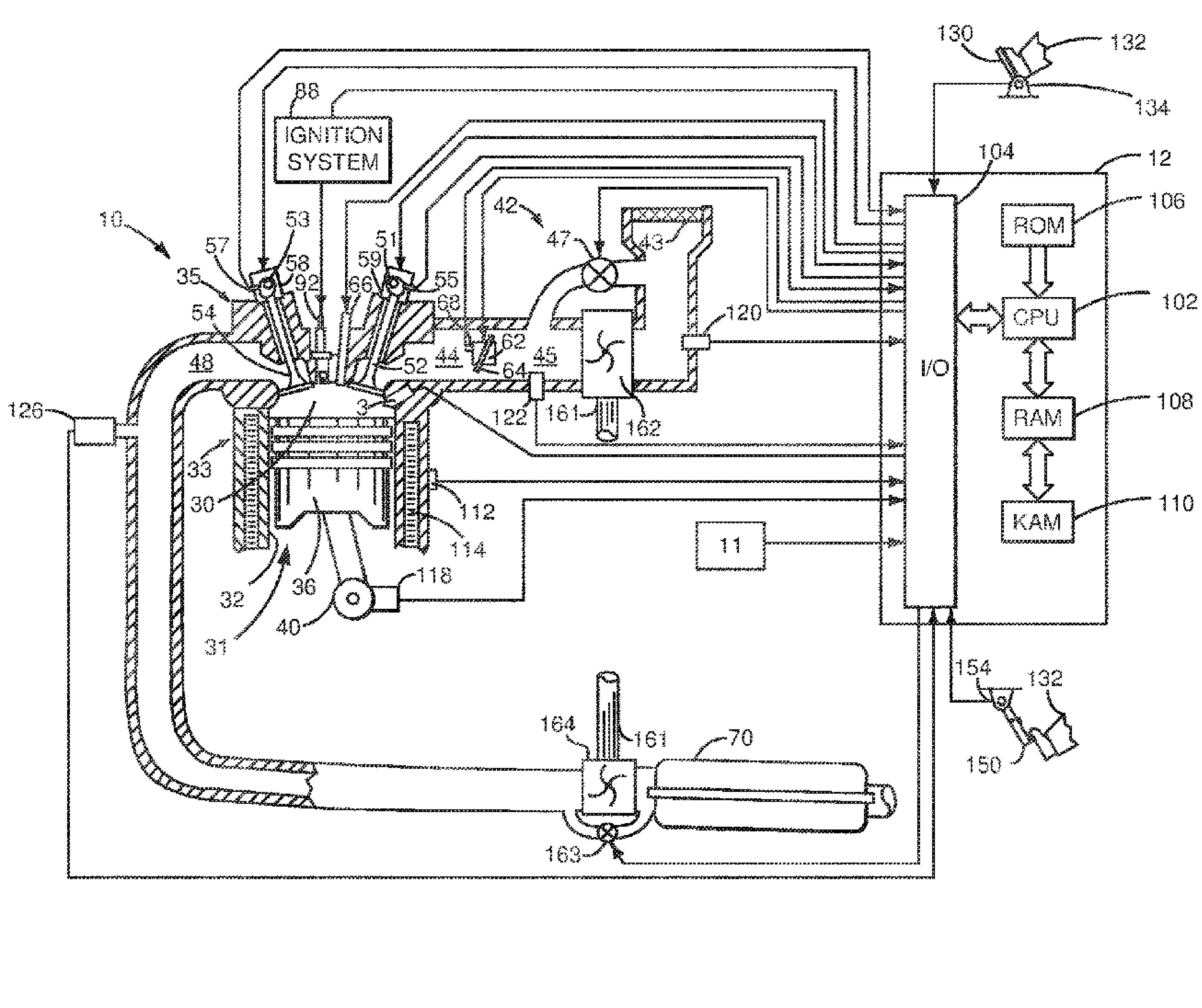
(57) **ABSTRACT**

Methods and systems are presented for improving operation of an engine that includes an evaporative emissions system. In one example, the methods and systems adjust an amount of fuel that is delivered to a pre-chamber of an igniter in response to purging fuel vapors and/or an indication of hydrocarbon breakthrough of a carbon filled fuel vapor storage canister.

20 Claims, 5 Drawing Sheets



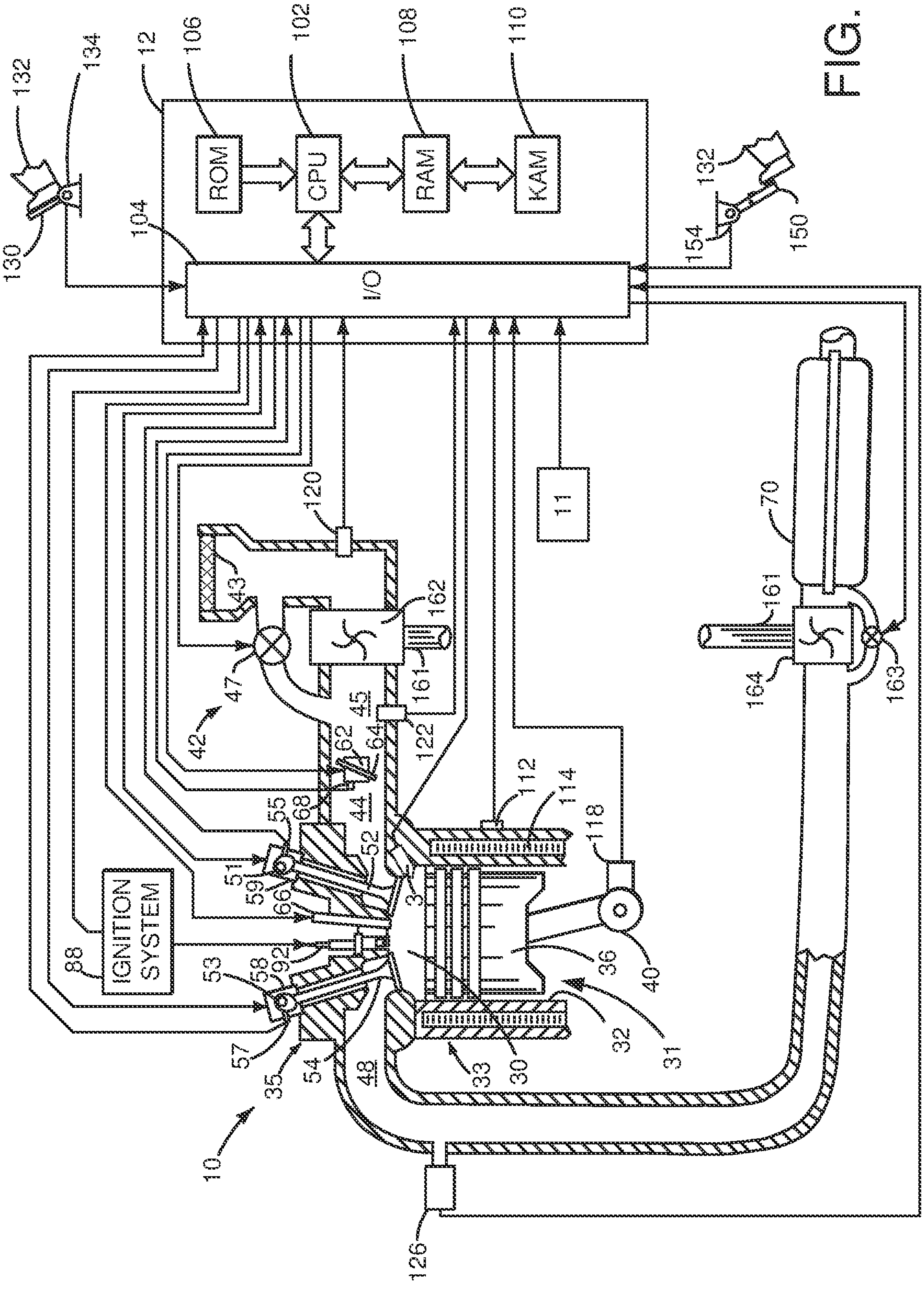


FIG. 1

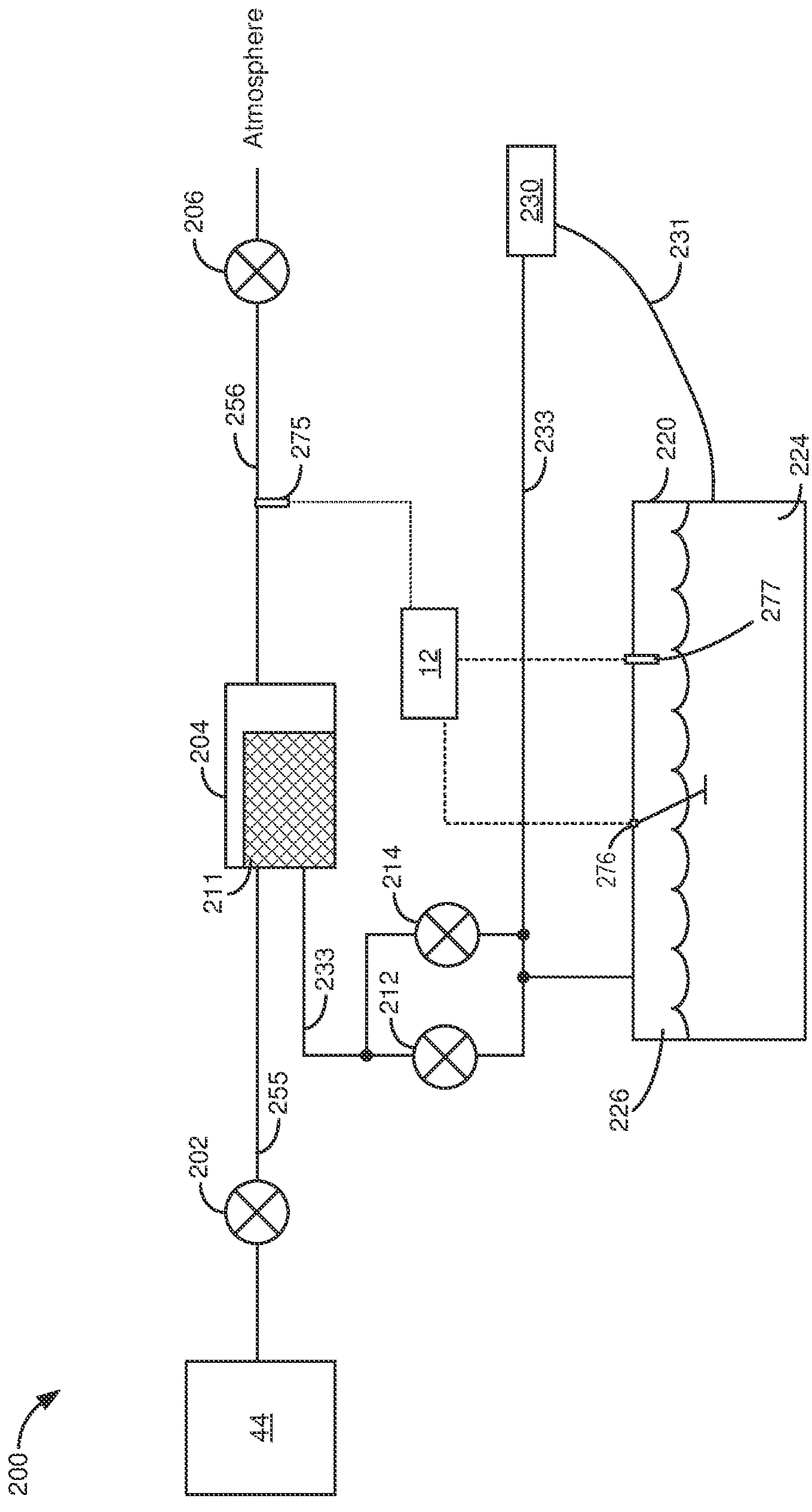

Atmosphere
206
256
275
230
231
233
220
224
277
12
204
211
214
276
233
212
255
202
226
44
200

FIG. 2

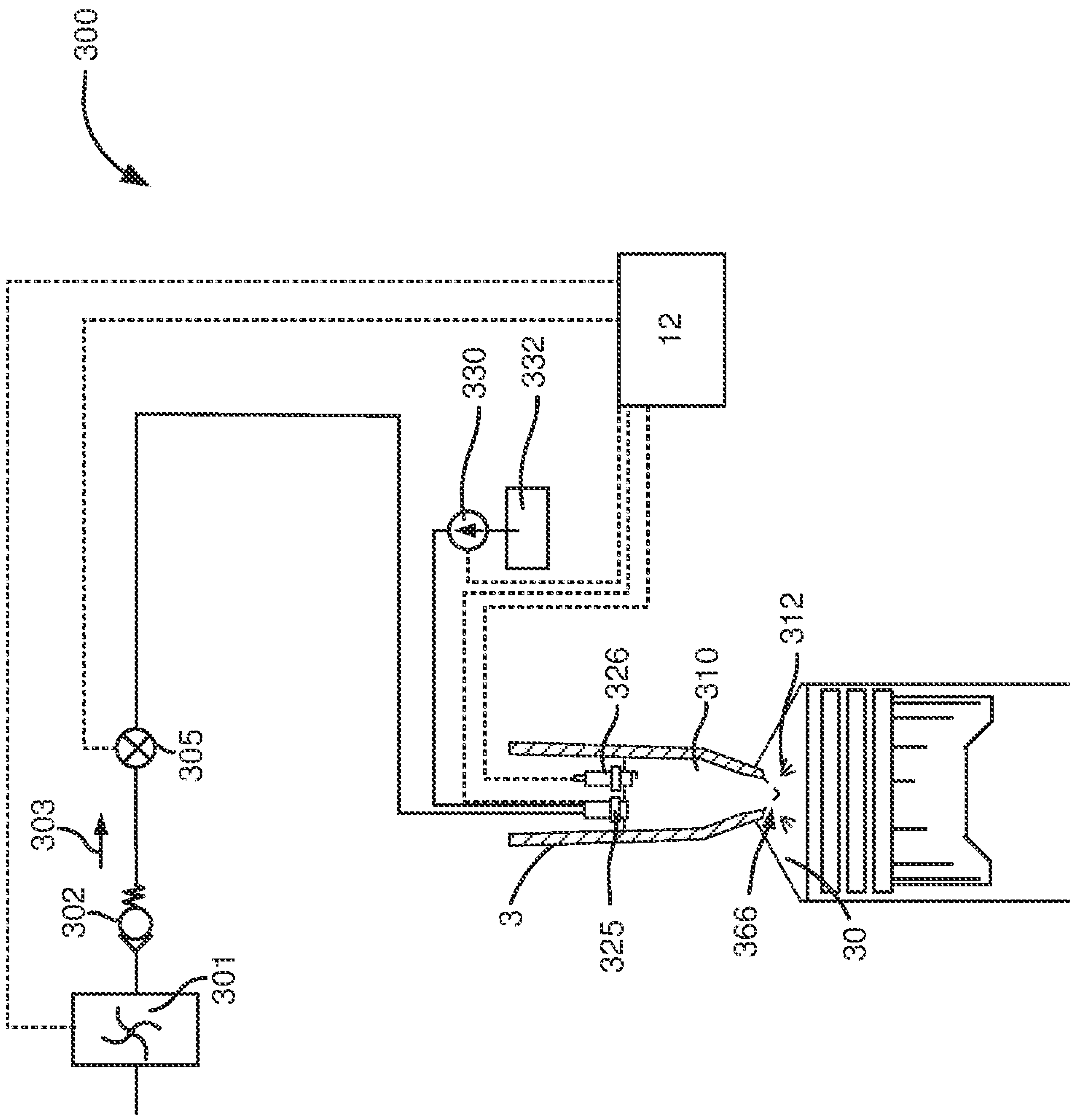


FIG. 3

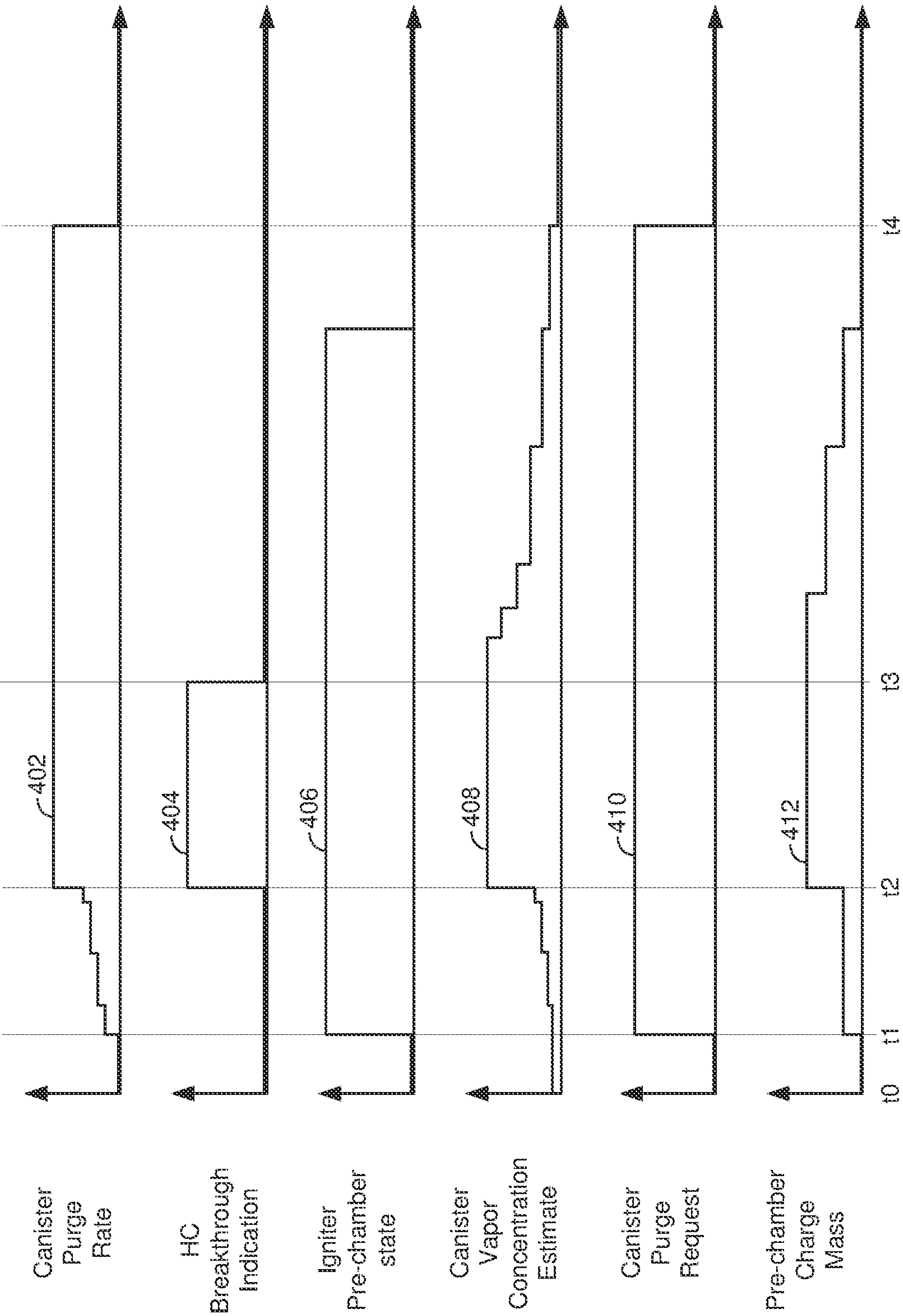

Canister Purge Rate
HC Breakthrough Indication
Igniter Pre-chamber state
Canister Vapor Concentration Estimate
Canister Purge Request
Pre-charge Charge Mass
402
404
406
408
410
412
t0
t1
t2
t3
t4

FIG. 4

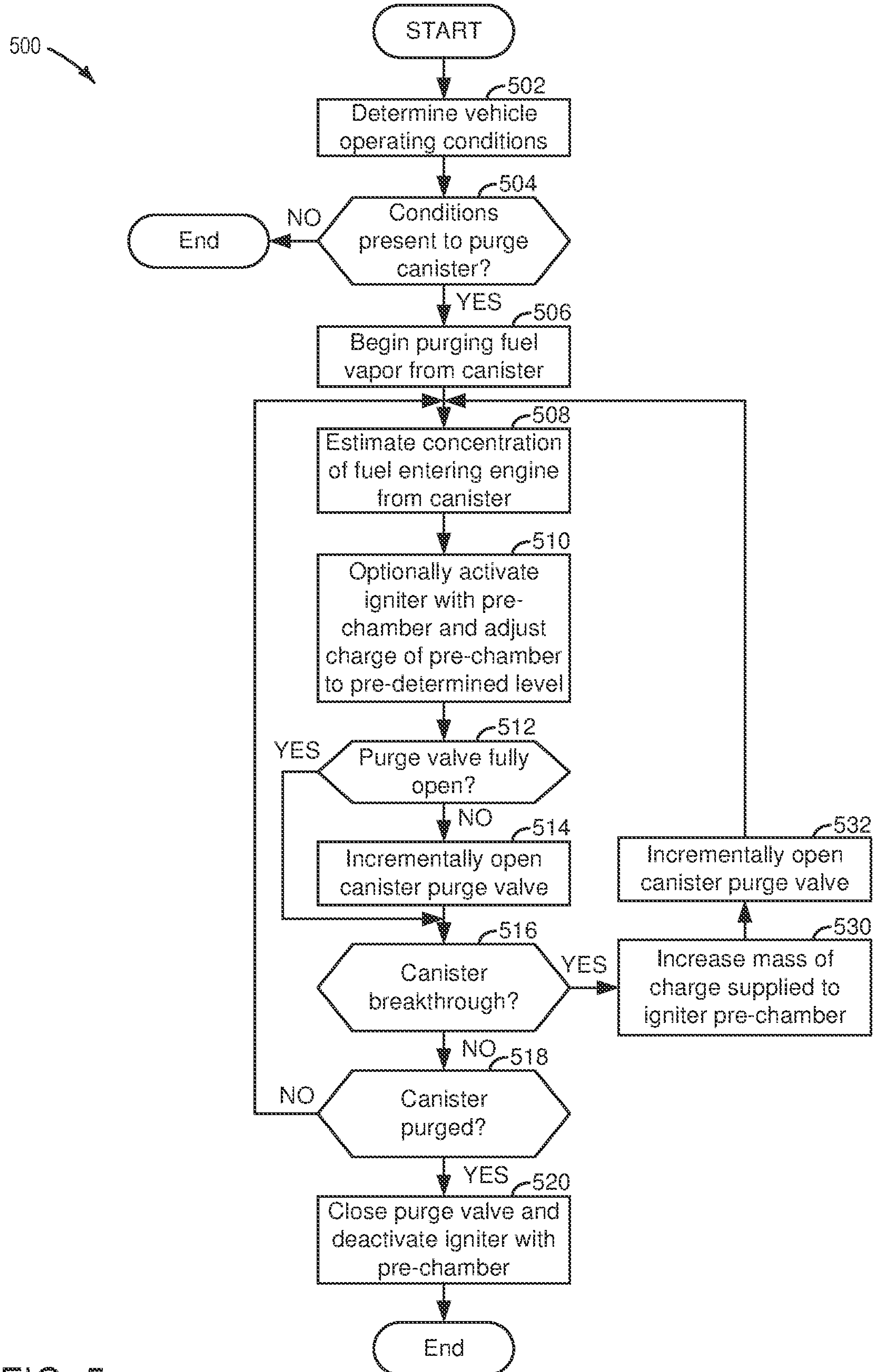

500
START
502
Determine vehicle operating conditions
504
Conditions present to purge canister?
NO
End
YES
506
Begin purging fuel vapor from canister
508
Estimate concentration of fuel entering engine from canister
510
Optionally activate igniter with pre-chamber and adjust charge of pre-chamber to pre-determined level
512
Purge valve fully open?
YES
NO
514
Incrementally open canister purge valve
516
Canister breakthrough?
YES
530
Increase mass of charge supplied to igniter pre-chamber
532
Incrementally open canister purge valve
NO
518
Canister purged?
NO
YES
520
Close purge valve and deactivate igniter with pre-chamber
End

FIG. 5

METHOD AND SYSTEM FOR LOWERING VEHICLE EMISSIONS USING ACTIVE PRE-CHAMBER IGNITION

FIELD

The present description relates generally to methods and systems for lowering emissions of an internal combustion engine.

BACKGROUND/SUMMARY

A vehicle may include a fuel vapor emissions control system that utilizes a carbon filled fuel vapor storage canister. The carbon filled fuel vapor storage canister may store fuel vapors when liquid fuel in a fuel tank is heated via diurnal heating. The carbon filled fuel vapor storage canister may also store fuel vapors when the fuel tank is being filled so that the fuel vapors do not escape to atmosphere. The carbon filled fuel vapor storage canister may be purged of fuel vapors from time to time so that the fuel vapors do not overflow the carbon filled fuel vapor storage canister. The fuel vapors may be purged from the carbon filled fuel vapor storage canister by opening a valve and drawing the fuel vapors into an engine where they may be combusted. However, if a rate at which fuel vapors are generated and supplied to the carbon filled fuel vapor storage canister exceeds the rate that fuel vapors are purged from the carbon filled canister, fuel vapor may be released to atmosphere.

The inventors herein have recognized the above-mentioned issue and have developed a method for operating a vehicle, comprising: via a controller, increasing an amount of fuel that is supplied via an igniter in response to purging fuel vapors from a carbon filled canister, and where the igniter includes a pre-chamber.

By increasing an amount of fuel that is supplied to an igniter that includes a pre-chamber in response to purging of fuel vapors from a carbon filled canister, it may be possible to provide the technical result of improving combustion stability while purging an evaporative emissions system so that flow through a carbon filled canister may be increased. In particular, the igniter may increase a range of air-fuel ratios at which combustion stability may be acceptable. Further, it may be possible to increase flow rates of hydrocarbons from a carbon filled canister during canister purging so that a canister may be emptied sooner than if the amount of fuel that is supplied to the igniter is not increased.

The present description may provide several advantages. In particular, the approach may reduce an amount of time it takes to purge a carbon filled canister of fuel vapors. Additionally, the approach may improve combustion stability during purging of fuel vapors. Further, the approach may reduce evaporative emissions by increasing fuel vapor flow during conditions of hydrocarbon breakthrough of the carbon filled canister.

The above advantages and other advantages, and features of the present description will be readily apparent from the following Detailed Description when taken alone or in connection with the accompanying drawings.

It should be understood that the summary above is provided to introduce in simplified form a selection of concepts that are further described in the detailed description. It is not meant to identify key or essential features of the claimed subject matter, the scope of which is defined uniquely by the claims that follow the detailed description. Furthermore, the claimed subject matter is not limited to implementations that solve any disadvantages noted above or in any part of this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows an example engine to which an evaporative emissions system may be coupled;

FIG. **2** shows an example evaporative emissions system;

FIG. **3** shows an example igniter that may be supplied with fuel and air;

FIG. **4** shows an example vehicle operating sequence according to the method of FIG. **5**; and

FIG. **5** shows an example method for operating a vehicle and its evaporative emissions system.

DETAILED DESCRIPTION

The following description relates to systems and methods for operating a vehicle and an evaporative emissions system. The vehicle may be a hybrid vehicle or a non-hybrid vehicle. The vehicle may include an engine of the type that is shown in FIG. **1**. An evaporative emissions system of the type shown in FIG. **2** may be coupled to the engine. An example igniter of the type that may be operated to improve combustion stability during purging of fuel vapors from a carbon filled fuel vapor storage canister is shown in FIG. **3**. An engine and fuel vapor emissions control system may be operated as shown in FIG. **4** to reduce hydrocarbon emissions and improve combustion stability. Finally, a method for operating a vehicle is shown in FIG. **5**. The method may improve combustion stability during purging of fuel vapors from a carbon filled canister.

Referring to FIG. **1**, internal combustion engine **10**, comprising a plurality of cylinders, one cylinder of which is shown in FIG. **1**, is controlled by electronic engine controller **12**. The controller **12** receives signals from the various sensors shown in FIGS. **1** and **2**. The controller may employ the actuators shown in FIGS. **1** and **2** to adjust engine operation based on the received signals and instructions stored in memory of controller **12**.

Engine **10** is comprised of cylinder head **35** and block **33**, which include combustion chamber **30** and cylinder walls **32**. Piston **36** is positioned therein and reciprocates via a connection to crankshaft **40**. Combustion chamber **30** is shown communicating with intake manifold **44** and exhaust manifold **48** via respective intake valve **52** and exhaust valve **54**. Each intake and exhaust valve may be operated by an intake cam **51** and an exhaust cam **53**. The position of intake cam **51** may be determined by intake cam sensor **55**. The position of exhaust cam **53** may be determined by exhaust cam sensor **57**. Intake valve **52** may be selectively activated and deactivated by valve activation device **59**. Exhaust valve **54** may be selectively activated and deactivated by valve activation device **58**. The intake and exhaust valves may be deactivated in a closed position so that the intake and exhaust valves do not open during a cycle of the engine (e.g., four strokes). Valve activation devices **58** and **59** may be electro-mechanical devices.

Igniter **3** is shown extending into combustion chamber **30** and it may receive air and fuel. Igniter **3** also includes a spark plug (not shown) for generating spark and combusting air-fuel mixtures formed in a pre-chamber of igniter **3**. In some examples, igniter **3** may be incorporated into cylinder head **35**. A more detailed view of igniter **3** is shown in FIG. **3**.

Fuel injector **66** is shown protruding into combustion chamber **30** and it is positioned to inject fuel directly into cylinder **31**, which is known to those skilled in the art as direct injection. Fuel injector **66** delivers liquid fuel in proportion to the pulse width from controller **12**. Fuel is delivered to fuel injector **66** by a fuel system (not shown) including a fuel tank, fuel pump, and fuel rail (not shown). In one example, a high pressure, dual stage, fuel system may be used to generate higher fuel pressures.

In addition, intake manifold **44** is shown communicating with turbocharger compressor **162** and engine air intake **42**. In other examples, compressor **162** may be a supercharger compressor. Shaft **161** mechanically couples turbocharger turbine **164** to turbocharger compressor **162**. Optional electronic throttle **62** adjusts a position of throttle plate **64** to control air flow from compressor **162** to intake manifold **44**. Pressure in boost chamber **45** may be referred to a throttle inlet pressure since the inlet of throttle **62** is within boost chamber **45**. The throttle outlet is in intake manifold **44**. In some examples, throttle **62** and throttle plate **64** may be positioned between intake valve **52** and intake manifold **44** such that throttle **62** is a port throttle. Compressor recirculation valve **47** may be selectively adjusted to a plurality of positions between fully open and fully closed. Waste gate **163** may be adjusted via controller **12** to allow exhaust gases to selectively bypass turbine **164** to control the speed of compressor **162**. Air filter **43** cleans air entering engine air intake **42**.

Distributorless ignition system **88** provides an ignition spark to combustion chamber **30** via spark plug **92** in response to controller **12**. Universal Exhaust Gas Oxygen (UEGO) sensor **126** is shown coupled to exhaust manifold **48** upstream of catalytic converter **70**. Alternatively, a two-state exhaust gas oxygen sensor may be substituted for UEGO sensor **126**.

Converter **70** can include multiple catalyst bricks, in one example. In another example, multiple emission control devices, each with multiple bricks, can be used. Converter **70** can be a three-way type catalyst in one example.

Controller **12** is shown in FIG. **1** as a conventional microcomputer including: microprocessor unit **102**, input/output ports **104**, read-only memory **106** (e.g., non-transitory memory), random access memory **108**, keep alive memory **110**, and a conventional data bus. Controller **12** is shown receiving various signals from sensors coupled to engine **10**, in addition to those signals previously discussed, including: engine coolant temperature (ECT) from temperature sensor **112** coupled to cooling sleeve **114**; a position sensor **134** coupled to a driver demand pedal **130** for sensing a demand (e.g., torque or power) applied by human driver **132**; a position sensor **154** coupled to brake pedal **150** for sensing a braking demand (e.g., torque) applied by human driver **132**, a measurement of engine manifold pressure (MAP) from pressure sensor **122** coupled to intake manifold **44**; an engine position sensor from an engine position sensor **118** sensing crankshaft **40** position; a measurement of air mass entering the engine from sensor **120**; and a measurement of throttle position from sensor **68**. Barometric pressure may also be sensed (sensor not shown) for processing by controller **12**. In a preferred aspect of the present description, engine position sensor **118** produces a predetermined number of equally spaced pulses every revolution of the crankshaft from which engine speed (RPM) can be determined.

Controller **12** may also receive input from human/machine interface **11**. A request to start the engine or vehicle may be generated via a human and input to the human/machine interface **11**. The human/machine interface may be a touch screen display, pushbutton, key switch or other known device. Controller **12** may also automatically start engine **10** in response to vehicle and engine operating conditions. Automatic engine starting may include starting engine **10** without input from human **132** to a device that is dedicated to receive input from human **132** for the sole purpose of starting and/or stopping rotation of engine **10** (e.g., a key switch or pushbutton). For example, engine **10** may be automatically stopped in response to driver demand torque being less than a threshold and vehicle speed being less than a threshold.

During operation, each cylinder within engine **10** typically undergoes a four stroke cycle: the cycle includes the intake stroke, compression stroke, expansion stroke, and exhaust stroke. During the intake stroke, generally, the exhaust valve **54** closes and intake valve **52** opens. Air is introduced into combustion chamber **30** via intake manifold **44**, and piston **36** moves to the bottom of the cylinder so as to increase the volume within combustion chamber **30**. The position at which piston **36** is near the bottom of the cylinder and at the end of its stroke (e.g. when combustion chamber **30** is at its largest volume) is typically referred to by those of skill in the art as bottom dead center (BDC).

During the compression stroke, intake valve **52** and exhaust valve **54** are closed. Piston **36** moves toward the cylinder head so as to compress the air within combustion chamber **30**. The point at which piston **36** is at the end of its stroke and closest to the cylinder head (e.g. when combustion chamber **30** is at its smallest volume) is typically referred to by those of skill in the art as top dead center (TDC). In a process hereinafter referred to as injection, fuel is introduced into the combustion chamber. In a process hereinafter referred to as ignition, the injected fuel is ignited by known ignition means such as spark plug **92**, resulting in combustion.

During the expansion stroke, the expanding gases push piston **36** back to BDC. Crankshaft **40** converts piston movement into a rotational torque of the rotary shaft. Finally, during the exhaust stroke, the exhaust valve **54** opens to release the combusted air-fuel mixture to exhaust manifold **48** and the piston returns to TDC. Note that the above is shown merely as an example, and that intake and exhaust valve opening and/or closing timings may vary, such as to provide positive or negative valve overlap, late intake valve closing, or various other examples.

Referring now to FIG. **2**, a block diagram of an example evaporative emissions system **200** is shown. Evaporative emissions system **200** includes a canister purge valve **202**, a carbon filled fuel vapor storage canister **204**, a canister vent valve **206**, a fuel tank pressure sensor **277**, a fuel tank level sensor **276**, a fuel cap **230**, a fuel tank pressure control valve **212**, a hydrocarbon sensor **275**, and a refueling valve **214**. In some examples, a leak detection module including a pump and change over valve may replace vent valve **206**. Carbon filled fuel vapor storage canister **204** may include activated carbon **211** to store fuel vapors. Fuel tank pressure control valve **212** and refueling valve **214** are shown in fluidic communication with carbon filled fuel vapor storage canister **204** and fuel tank **220** via conduit **233**. Fuel may flow from fuel cap **230** to fuel tank **220** via filler neck pipe **231**. Carbon filled fuel vapor storage canister **204** may be in selective fluidic communication with intake manifold **44** via conduit **255** and canister purge valve **202**.

During refilling of fuel tank **220**, the refueling valve **214** and the canister vent valve **206** may be opened so that fuel vapors may exit fuel tank **220**, pass though conduit **233**, and be stored in carbon filled fuel vapor storage canister **204**. Air that has been stripped of hydrocarbons may flow from carbon filled fuel vapor storage canister **204** to atmosphere via conduit or passage **256** and vent valve **206**.

Carbon filled fuel vapor storage canister **204** may be purged of fuel vapors by opening canister purge valve **202**, fully closing fuel tank pressure control valve **212**, fully closing refueling valve **214**, and opening canister vent valve **206**. In particular, low pressure in engine intake manifold **44** may draw fuel vapors from carbon filled canister when canister purge valve **202** and canister vent valve are opened. Fresh air drawn in from atmosphere may cause fuel vapors to desorb from the carbon filled fuel vapor storage canister.

Referring now to FIG. **3**, a schematic view of an igniter system **300** is shown. An igniter **3** for one cylinder of engine **10** is shown, but it should be appreciated that igniter system **300** may include one igniter **3** for each cylinder of engine **10**.

Igniter system **300** may include an air compressor **301** that is configured to deliver pressurized air to injector **325** that is included in igniter **3** via check valve **302** and control valve **303**. Igniter system **300** also includes a fuel tank **332** and a fuel pump **330** that may deliver fuel to injector **325**. In this example, injector **325** injects air and fuel. However, in other examples, separate injectors may be provided for air and fuel. Igniter **3** also includes an ignition source **326** (e.g., a spark plug) for initiating combustion of an air-fuel mixture within pre-chamber **310**. Combustion that is initiated in pre-chamber **310** may provide flame jets **312** that improve combustion stability for cylinder **31** when cylinder **31** combusts either rich or lean mixtures. For example, during purging of a fuel vapor storage canister, igniter **3** may be activated to initiate combustion of air-fuel mixtures in cylinder **31**. If fuel vapors from purging the carbon filled canister enrichen the air-fuel mixture in cylinder **31**, igniter **3** may operate to improve combustion in cylinder **31** via igniting the air-fuel mixture in cylinder **31** at multiple ignition cites that are generated from the flame jets that may emanate from orifices **366**.

The system of FIGS. **1-3** provides for a vehicle system, comprising: an engine including an igniter that includes a pre-chamber; a fuel tank; a carbon filled fuel vapor storage canister in selective fluidic communication with the fuel tank; a canister purge valve; and a controller including executable instructions stored in non-transitory memory that cause the controller to increase an amount of fuel supplied via the igniter in response to purging fuel vapors from the carbon filled fuel vapor storage canister. In a first example, the vehicle system includes where purging fuel vapors includes opening the canister purge valve. In a second example that may include the first example, the vehicle system further comprises additional instructions that cause an amount of fuel supplied via the igniter to increase as a function of an amount of fuel vapor that is purged from the carbon filled fuel vapor storage canister. In a third example that may include one or both of the first and second examples, the vehicle system further comprises additional instructions to increase an amount of fuel delivered via the igniter in response to an indication of hydrocarbon breakthrough from the carbon filled fuel vapor storage canister. In a fourth example that may include one or more of the first through third examples, the vehicle system includes where the amount of fuel supplied via the igniter is supplied to the pre-chamber. In a fifth example that may include one or more of the first through fourth examples, the vehicle system further comprises additional executable instructions to supply air to the pre-chamber.

Referring now to FIG. **4**, an example vehicle operating sequence according to the method of FIG. **5** is shown. The sequence of FIG. **4** may be provided via the system of FIGS. **1-3** according to the method of FIG. **5**.

The first plot from the top of FIG. **4** is a plot of a carbon filled fuel vapor storage canister purge rate (e.g., grams/second) versus time. The vertical axis represents the purge rate of the carbon filled fuel vapor storage canister and the purge rate of the carbon filled fuel vapor storage canister increases in the direction of the vertical axis arrow. The horizontal axis represents time and time increases from the left side of the plot to the right side of the plot. Trace **402** represents the purge rate of the carbon filled fuel vapor storage canister.

The second plot from the top of FIG. **4** is a plot of a hydrocarbon breakthrough state indication versus time. The vertical axis represents the hydrocarbon breakthrough state indication for when hydrocarbons exit the carbon filled fuel vapor storage canister and move toward atmosphere. The hydrocarbons may exit the carbon filled fuel vapor storage canister when the carbon filled fuel vapor storage canister lacks capacity to store additional hydrocarbons and hydrocarbons are flowing into the carbon filled fuel vapor storage canister or are being liberated from the carbon filled fuel vapor storage canister. These hydrocarbons may be detected via a hydrocarbon sensor. The horizontal axis represents time and time increases from the left side of the plot to the right side of the plot. Trace **404** represents the hydrocarbon breakthrough state indication. Hydrocarbons are indicated as breaking through the carbon filled fuel vapor storage canister when trace **404** is at a higher level near the vertical axis arrow head. Hydrocarbons are not indicated as breaking through the carbon filled fuel vapor storage canister when trace **404** is at a lower level near the horizontal axis.

The third plot from the top of FIG. **4** is a plot of an igniter pre-chamber state indication versus time. The vertical axis represents the igniter pre-chamber state and the igniter is activated (e.g., operating as an ignition source) when trace **406** is at a higher level near the vertical axis arrow. The igniter is not activated when trace **406** is at a lower level near the horizontal axis. The horizontal axis represents time and time increases from the left side of the plot to the right side of the plot. Trace **406** represents the igniter pre-chamber state indication.

The fourth plot from the top of FIG. **4** is a plot of a carbon filled fuel vapor storage canister vapor concentration amount estimate (e.g., a concentration of hydrocarbons stored in the canister) versus time. The vertical axis represents the carbon filled fuel vapor storage canister vapor concentration amount estimate and the carbon filled fuel vapor storage canister vapor concentration amount estimate increases in the direction of the vertical axis arrow. The horizontal axis represents time and time increases from the left side of the plot to the right side of the plot. Trace **408** represents the carbon filled fuel vapor storage canister vapor concentration amount estimate.

The fifth plot from the top of FIG. **4** is a plot of a canister purge request (e.g., a request to purge or remove fuel vapors from the carbon filled fuel vapor storage canister) versus time. The vertical axis represents the canister purge request state and the canister purge request is asserted when trace **410** is at a higher level near the vertical axis arrow. The canister purge request is not asserted when trace **410** is at a lower level near the horizontal axis. The horizontal axis represents time and time increases from the left side of the plot to the right side of the plot. Trace **410** represents the canister purge request.

The sixth plot from the top of FIG. **4** is a plot of a pre-chamber charge mass (e.g., a mass of air and fuel introduced to the pre-chamber of an igniter) versus time. The vertical axis represents the pre-chamber charge mass and the pre-chamber charge mass increases in the direction of the vertical axis arrow. The horizontal axis represents time and time increases from the left side of the plot to the right side of the plot. Trace **412** represents the pre-chamber charge mass.

At time t**0**, hydrocarbons are not being purged from the carbon filled fuel vapor storage canister nor is there a request to do the same. Hydrocarbons are not breaking through the carbon filled fuel vapor storage canister and the igniters are not activated. The vehicle's engine is running (e.g., rotating and combusting fuel and air) (not shown) and the pre-chamber charge mass is zero. The carbon filled fuel vapor storage canister fuel vapor concentration level is low.

At time t**1**, a request to purge the carbon filled fuel vapor storage canister is generated. The request may be generated based on an amount of time since a last most recent purge of fuel vapors from the canister completed. Further, the request may be generated based on an estimate of fuel vapor stored in the canister and/or other conditions. The request to purge the carbon filled fuel vapor storage canister causes the engine's igniters to be activated to promote more robust combustion stability in the engine's cylinders. Hydrocarbon (HC) breakthrough is not indicated and the canister purge rate begins to increase. The pre-chamber charge mass is increased to a small amount to support activation of the igniters.

At time t**2**, hydrocarbon breakthrough occurs and the pre-chamber charge mass is increased so that a greater canister purge rate may be supported, thereby increasing the possibility of a higher level of combustion stability during purging of fuel vapors from the carbon filled fuel vapor storage canister. The canister purge flow rate is increased to reduce a possibility of additional hydrocarbon vapors being released to the atmosphere. The carbon filled fuel vapor storage canister hydrocarbon concentration has increased to a higher level and purging remains active.

At time t**3**, the hydrocarbon breakthrough ceases, but the carbon filled fuel vapor storage canister continues to be purged of fuel vapors. The canister purge flow rate remains high and the canister purge request remains active. The igniters remain activated and the pre-chamber charge mass remains at a higher level. Between time t**3** and time t**4**, the carbon filled fuel vapor storage concentration falls and the engine's igniters are deactivated when the fuel vapor storage fuel vapor concentration falls below a threshold level. The canister purge level remains activated and the pre-chamber charge mass is reduced in response to the concentration of fuel vapor stored in the carbon filled canister being reduced.

At time t**4**, the request to purge the carbon filled fuel vapor storage canister of fuel vapors is withdrawn and the canister purge rate is reduced to zero in response to withdrawing the purging request. There is no hydrocarbon breakthrough and the igniters are deactivated. The carbon filled fuel vapor storage canister vapor concentration is low and the pre-chamber charge mass is zero.

In this way, the pre-chamber charge mass may be adjusted as a function of carbon filled fuel vapor storage canister flow rate and concentration of fuel vapor in the carbon filled fuel vapor storage canister. Further, the igniters may be activated and deactivated in response to hydrocarbon breakthrough of the carbon filled fuel vapor storage canister to improve combustion stability and reduce engine emissions.

Referring now to FIG. **5**, an example method **500** for operating a vehicle that includes an evaporative emissions system is shown. At least portions of method **500** may be included in and cooperate with a system as shown in FIGS. **1-3** as executable instructions stored in non-transitory memory. The method of FIG. **5** may cause the controller to actuate the actuators in the real world and receive data and signals from sensors described herein when the method is realized as executable instructions stored in controller memory.

At **502**, method **500** determines vehicle operating conditions. Vehicle operating conditions may include but are not limited to an estimate of fuel vapors stored in a carbon filled fuel vapor storage canister, ambient temperature, ambient pressure, engine speed, engine load, and engine operating state. Method **500** proceeds to **504**.

At **504**, method **500** judges if conditions are present for purging the carbon filled fuel vapor storage canister of fuel vapors. Conditions may include but are not limited to the amount of fuel vapor being stored in the canister exceeding a threshold amount, an amount of time since a last most recent time that fuel vapors where purged from the fuel vapor storage canister exceeding a threshold amount of time, a concentration of fuel vapors stored in the carbon filled fuel vapor storage canister, and a manual request to purge the carbon filled fuel vapor storage canister. The concentration of fuel vapors in the carbon filled fuel vapor storage canister may be based on an amount of fuel that is added to a fuel tank. If method **500** judges that conditions are present for purging the carbon filled fuel vapor storage canister, the answer is yes and method **500** proceeds to **506**. Otherwise, the answer is no and method **500** proceeds to exit.

At **506**, method **500** begins to purge fuel vapors from the carbon filled fuel vapor storage canister. The carbon filled fuel vapor storage canister may be purged by opening the canister purge valve and the canister vent valve while the vehicle's engine is running (e.g., rotating and combusting air and fuel). Method **500** proceeds to **508**.

At **508**, estimates a concentration of fuel entering the engine via the carbon filled fuel vapor storage canister. In one example, method **700** includes a closed loop proportional and integral (PI) controller to adjust an equivalence ratio of the engine (e.g., Lambda) based on feedback from an oxygen sensor such that the equivalence ratio oscillates about a stoichiometric air-fuel ratio (e.g., $\lambda=1$) during nominal engine operating conditions (e.g., the engine is at operating temperature and operating within a predetermined speed and load range). The PI controller outputs a variable Lambse that represents the engine's desired Lambda value. Method **500** determines a desired engine fuel amount (Fd), or alternatively, a desired engine air amount (MAF) based on a driver demand torque or power. The desired engine fuel amount or desired engine air amount may be determined via functions or via look-up tables and the other of the two values (e.g., the air amount or the fuel amount) may be determined via the following equation:

$$F_d = \frac{MAF}{Lambse \cdot AFd} \qquad \text{eq. (1)}$$

where Fd is the engine fuel amount or desired engine fuel amount, MAF is the engine air amount or desired engine air amount, Lambse is the output of the PI controller, and AFd is the desired engine air-fuel ratio. Method **500** supplies fuel to the engine via the carbon filled fuel vapor storage canister and method **500** adjusts the amount of fuel injected in response to the concentration of fuel vapors stored in the carbon filled fuel vapor storage canister. In particular, method **500** may determine the concentration of fuel entering the engine via the following equation:

$$\text{p\_comp} = \frac{(Lambse(k)-1)+(Lambse(k+1)-1)}{2}\cdot dt + \text{p\_comp\_old} \quad \text{eq. (2)}$$

where p_comp is the learned concentration of fuel entering the engine via the carbon filled fuel vapor storage canister, Lambse is the requested engine equivalence ratio, k is the k^{th} Lambse value, k+1 is the $k^{th}+1$ Lambse value, dt is the amount of time between Lambse samples, and p_comp_old is the last most recent value of p_comp. Equation 2 may be determined each time method **500** is executed so that p_comp is the integrated value of Lambse −1. Initially, the value of p_comp_old may be set to zero or an inferred value. The variable p_comp_old is set equal to the value of p_comp once the value of p_comp has been determined. The amount of fuel delivered to the engine may be determined via the following equation:

$$F_{dmod}=F_d-p\_comp \quad \text{eq. (3)}$$

where F_{dmod} is the desired modified fuel amount that is to be delivered to the engine, Fa is the desired amount of fuel to be supplied to the engine, and p_comp is the concentration of fuel entering the engine from the carbon filled fuel vapor storage canister. The amount of fuel injected to the engine may be adjusted via adjusting the engine's fuel injectors to deliver the amount of fuel F_{dmod}. Thus, the amount of fuel injected to engine cylinders may decrease as the value of p_comp increases. Method **500** proceeds to **510**.

At **510**, method **500** activates the engine's igniters. The igniters may be activated by suppling one or more of fuel, air, and spark to a pre-chamber of each igniter. In one example, an amount of charge (e.g., air and fuel mass) delivered to the pre-chamber of an igniter may be a predetermined fixed amount value, or alternatively, an amount value that varies with engine speed and engine load. For example, at higher engine speeds and loads, a greater amount of charge may be supplied to the pre-chamber of the igniter as compared to when the engine is operated at a lower speed and lower load. By activating the igniters, combustion stability of engine cylinders may be improved, especially when a cylinder is operating lean or rich. In still other examples, the amount of fuel that is injected to the pre-chamber of igniters may be a function of a concentration and flow rate of fuel vapors that are entering the engine. Method **500** proceeds to **512**.

At **512**, method **500** judges whether or not the canister purge valve (e.g., **202** of FIG. **2**) is fully open. If so, the answer is yes and method **500** proceeds to **516**. Otherwise, the answer is no and method **500** proceeds to **514**.

At **514**, method **500** incrementally opens the canister purge valve from its present position. For example, if the canister purge valve is open zero percent, method **500** may open the canister purge value to five percent of the canister purge valves fully open position. Alternatively, if the canister purge valve is a pulse width modulated valve, it may be commanded to be open for five percent of a predetermined amount of time. For example, the canister purge valve may be opened for 50 milliseconds for every second the canister purge valve is operated. Method **500** proceeds to **516** after incrementally opening the canister purge valve.

At **516**, method **500** judges whether or not there is hydrocarbon breakthrough from the carbon filled fuel vapor storage canister. In other words, method **500** judges whether or not hydrocarbons are flowing from the carbon filled fuel vapor canister toward atmosphere via the canister vent valve (e.g., **206** of FIG. **2**). In one example, method **500** may judge that there is hydrocarbon breakthrough when a concentration of hydrocarbons in conduit or passage **256** is greater than a threshold concentration. If so, the answer is yes and method **500** proceeds to **530**. Otherwise, the answer is no and method **500** proceeds to **518**.

At **518**, method **500** judges whether or not the carbon filled fuel vapor canister is purged of fuel vapors. In one example, method **500** judges that the carbon filled fuel vapor canister is purged when the value of p_comp is zero or when an amount of hydrocarbons entering the engine is less than a threshold amount. The hydrocarbon concentration may be determined via a hydrocarbon sensor. If method **500** judges that the carbon filled fuel vapor canister is purged of fuel vapors, then the answer is yes and method **500** proceeds to **520**. Otherwise, the answer is no and method **500** returns to **508**.

At **520**, method **500** fully closes the canister purge valve and deactivates the engine's igniters. The igniters may be deactivated by ceasing to supply the igniters with spark, fuel, and air. Additionally, method **500** may fully open the canister vent valve to allow fuel vapors to be stored in the carbon filled fuel vapor storage canister. Method **500** proceeds to exit.

At **530**, method **500** increases a mass of fuel and/or air entering the pre-chamber of the engine's igniters. In one example, method **500** may increase the fuel mass and the air mass entering the pre-chamber of each igniter via the following equations:

$$\text{Ignitam}=f(fvc,fvf,\text{load},n) \quad \text{eq. (4)}$$

$$\text{Ignitfm}=g(fvc,fvf,\text{load},n) \quad \text{eq. (5)}$$

where Ignitam is the igniter air mass (e.g., the mass of air injected to the igniter pre-chamber), f is a function that returns the igniter air mass, fvc is the concentration of fuel vapors exiting the carbon filled fuel vapor storage canister, fvf is the flow rate of gases from the carbon filled fuel vapor storage canister, load is engine load, n is engine speed, Ignitfm is the igniter fuel mass (e.g., a mass of fuel injected to the igniter pre-chamber), and g is a function that returns the igniter fuel mass. The functions f and g may reference tables or functions to determine values for Ignitam and Ignitfm. In one example, the fuel mass and air mass injected to the pre-chambers of igniters increases with increased flow rates and concentrations of fuel leaving the carbon filled fuel vapor storage canister and entering the engine. This may provide increased combustion stability and lower emissions by increasing the fraction of fuel that is combusted in engine cylinders during purging of the carbon filled canister. The fuel and air are combusted in the pre-chamber by providing a spark to the pre-chamber. Method **500** proceeds to **532**.

At **532**, method **500** incrementally opens the canister purge valve so that the canister purge flow rate may be increased to hasten purging of the carbon filled fuel vapor storage canister. The canister purge flow rate may be increased even during hydrocarbon breakthrough of the carbon filled fuel vapor storage canister because increasing the flow rate of fuel and air into the igniter may increase combustion stability of the engine. Method **500** returns to **508**.

In this way, method **500** may improve combustion stability of an engine that is consuming fuel vapors that are purged from a carbon filled fuel vapor storage canister. The igniters may be activated in response to purging of fuel vapors or in response to hydrocarbon breakthrough of a carbon filled fuel vapor storage canister.

The method of FIG. **5** provides for a method for operating a vehicle, comprising: via a controller, increasing an amount of fuel that is supplied via an igniter in response to purging fuel vapors from a carbon filled canister, and where the igniter includes a pre-chamber. In a first example, the method further comprises increasing an amount of air that is supplied to the igniter that includes the pre-chamber in response to purging fuel vapors from the carbon filled canister. In a second example that may include the first example, the method includes where purging fuel vapors from the carbon filled canister is performed in response to a canister purge request. In a third example that may include one or both of the first and second examples, the method includes where the canister purge request is based on a concentration of fuel vapors stored in the carbon filled canister. In a fourth example that may include one or more of the first through third examples, the method includes where the concentration is estimated based on an amount of fuel added to a fuel tank. In a fifth example that may include one or more of the first through fourth examples, the method further comprises reducing an amount of fuel injected to an engine cylinder in response to purging fuel vapors from the carbon filled canister. In a sixth example that may include one or more of the first through fifth examples, the method further comprises opening a canister purge valve in response a request to purge fuel vapors from the carbon filled canister. In a seventh example that may include one or more of the first through sixth examples, the method further comprises combusting the amount of fuel that is supplied to the igniter via generating a spark within the igniter. In an eighth example that may include one or more of the first through seventh examples, the method further comprises ceasing combustion via the igniter in response to an indication of the carbon filled canister being purged of fuel vapors.

The method of FIG. **5** also provides for a method for operating a vehicle, comprising: via a controller, increasing an amount of fuel that is supplied via an igniter in response to an indication of hydrocarbon breakthrough of a carbon filled canister, and where the igniter includes a pre-chamber. In a first example, the method includes where the amount of fuel is delivered to the pre-chamber. In a second example that may include the first example, the method further comprises increasing an amount of air that is supplied via the igniter in response to the indication of hydrocarbon breakthrough. In a third example that may include one or both of the first and second examples, the method includes where the indication of hydrocarbon breakthrough is provided via a hydrocarbon sensor. In a fourth example that may include one or more of the first through third examples, the method further comprises igniting an air-fuel mixture in an engine cylinder via the igniter.

Note that the example control and estimation routines included herein can be used with various engine and/or vehicle system configurations. Further, the methods described herein may be a combination of actions taken by a controller in the physical world and instructions within the controller. The control methods and routines disclosed herein may be stored as executable instructions in non-transitory memory and may be carried out by the control system including the controller in combination with the various sensors, actuators, and other engine hardware. The specific routines described herein may represent one or more of any number of processing strategies such as event-driven, interrupt-driven, multi-tasking, multi-threading, and the like. As such, various actions, operations, and/or functions illustrated may be performed in the sequence illustrated, in parallel, or in some cases omitted. Likewise, the order of processing is not necessarily required to achieve the features and advantages of the example embodiments described herein, but is provided for ease of illustration and description. One or more of the illustrated actions, operations and/or functions may be repeatedly performed depending on the particular strategy being used. Further, the described actions, operations and/or functions may graphically represent code to be programmed into non-transitory memory of the computer readable storage medium in the engine control system, where the described actions are carried out by executing the instructions in a system including the various engine hardware components in combination with the electronic controller

This concludes the description. The reading of it by those skilled in the art would bring to mind many alterations and modifications without departing from the spirit and the scope of the description. For example, I3, I4, I5, V6, V8, V10, and V12 engines operating in natural gas, gasoline, diesel, or alternative fuel configurations could use the present description to advantage.

The following claims particularly point out certain combinations and sub-combinations regarded as novel and non-obvious. These claims may refer to "an" element or "a first" element or the equivalent thereof. Such claims should be understood to include incorporation of one or more such elements, neither requiring nor excluding two or more such elements. Other combinations and sub-combinations of the disclosed features, functions, elements, and/or properties may be claimed through amendment of the present claims or through presentation of new claims in this or a related application. Such claims, whether broader, narrower, equal, or different in scope to the original claims, also are regarded as included within the subject matter of the present disclosure.

The invention claimed is:

1. A method for operating a vehicle, comprising:

via a controller, increasing an amount of fuel that is supplied via an igniter in response to purging fuel vapors from a carbon filled canister, and where the igniter includes a pre-chamber.

2. The method of claim **1**, further comprising increasing an amount of air that is supplied to the igniter that includes the pre-chamber in response to purging fuel vapors from the carbon filled canister.

3. The method of claim **1**, where purging fuel vapors from the carbon filled canister is performed in response to a canister purge request.

4. The method of claim **3**, where the canister purge request is based on a concentration of fuel vapors stored in the carbon filled canister.

5. The method of claim **4**, where the concentration is estimated based on an amount of fuel added to a fuel tank.

6. The method of claim **1**, further comprising reducing an amount of fuel injected to an engine cylinder in response to purging fuel vapors from the carbon filled canister.

7. The method of claim **1**, further comprising opening a canister purge valve in response a request to purge fuel vapors from the carbon filled canister.

8. The method of claim **1**, further comprising combusting the amount of fuel that is supplied to the igniter via generating a spark within the igniter.

9. The method of claim 1, further comprising ceasing combustion via the igniter in response to an indication of the carbon filled canister being purged of fuel vapors.

10. A vehicle system, comprising:
- an engine including an igniter that includes a pre-chamber;
- a fuel tank;
- a carbon filled fuel vapor storage canister in selective fluidic communication with the fuel tank;
- a canister purge valve; and
- a controller including executable instructions stored in non-transitory memory that cause the controller to increase an amount of fuel supplied via the igniter in response to purging fuel vapors from the carbon filled fuel vapor storage canister.

11. The vehicle system of claim 10, where purging fuel vapors includes opening the canister purge valve.

12. The vehicle system of claim 10, further comprising additional instructions that cause an amount of fuel supplied via the igniter to increase as a function of a concentration of fuel vapor that is purged from the carbon filled fuel vapor storage canister.

13. The vehicle system of claim 10, further comprising additional instructions to increase an amount of fuel delivered via the igniter in response to an indication of hydrocarbon breakthrough from the carbon filled fuel vapor storage canister.

14. The vehicle system of claim 13, where the amount of fuel supplied via the igniter is supplied to the pre-chamber.

15. The vehicle system of claim 14, further comprising additional executable instructions to supply air to the pre-chamber.

16. A method for operating a vehicle, comprising:
- via a controller, increasing an amount of fuel that is supplied via an igniter in response to an indication of hydrocarbon breakthrough of a carbon filled canister, and where the igniter includes a pre-chamber.

17. The method of claim 16, where the amount of fuel is delivered to the pre-chamber.

18. The method of claim 17, further comprising increasing an amount of air that is supplied via the igniter in response to the indication of hydrocarbon breakthrough.

19. The method of claim 16, where the indication of hydrocarbon breakthrough is provided via a hydrocarbon sensor.

20. The method of claim 16, further comprising igniting an air-fuel mixture in an engine cylinder via the igniter.

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