United States Patent **5,640,845**
Ng, et al. **June 24, 1997**

NITROGEN SPARK DENOXER

Abstract

A NOx control system for an internal combustion engine includes an oxygen-enrichment device that produces oxygen- and nitrogen-enriched air. The nitrogen-enriched air contains molecular nitrogen that is provided to a spark plug that is mounted in an exhaust outlet of an internal combustion engine. As the nitrogen-enriched air is expelled at the spark gap of the spark plug, the nitrogen-enriched air is exposed to a pulsating spark that is generated across the spark gap of the spark plug. The spark gap is elongated so that a sufficient amount of atomic nitrogen is produced and is injected into the exhaust of the internal combustion engine. The injection of the atomic nitrogen into the exhaust of the internal combustion engine causes the oxides of nitrogen (NOx) to be reduced into nitrogen and oxygen such that the emissions from the engine will have acceptable levels of NOx. The oxygen-enrichment device that produces both the oxygen- and nitrogen-enriched air can include a selectively permeable membrane.

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Description

Background of the Invention

1. Field of the Invention

This invention relates to a method and apparatus for reducing oxides of nitrogen (NOx) in the exhaust emissions of an internal combustion engine, and more particularly, to a new and improved spark discharge device for forming atomic (monatomic) nitrogen from molecular nitrogen so that the atomic nitrogen can be injected into the exhaust of an internal combustion engine to reduce NOx in the exhaust to nitrogen and oxygen.

2. Background of the Invention

If oxygen-enriched air is used as part of the intake of an internal combustion engine, the engine's power density tends to be increased and the particulate emissions from the engine tend to be reduced. On the other hand, the use of such oxygen-enriched air tends to increase the amount of NOx present in the engine's exhaust. This increase in the amount of NOx in the engine's exhaust has concerned developers and manufacturers of internal combustion engines because legal regulations dealing with emissions from an internal combustion engine include specifications limiting the amount of NOx that may be present in such emissions. Consequently, the developers and manufacturers of internal combustion engines would like to obtain the advantages of using oxygen-enriched air in the intake of an internal combustion engine, but at the same time would like to reduce the amount of NOx that is present in the engine's emissions.

One way of reducing NOx in any stream of gas is to inject atomic nitrogen into the stream of gas. For example, an article entitled "Effect of nitrogen-containing plasmas on stability, NO formation and sooting of flames" by J. C. Hilliard and F. J. Weinberg appearing in *Nature*, Vol. 259, page 556 (Feb. 19, 1976) indicates that nitrogen atoms from a plasma can be injected into a fast flowing stream of nitric oxide in argon and synthetic exhaust gas mixes. The article further states (page 557) that "[r]eductions in nitric oxide from 3,000 ppm to a residual 80 ppm were readily obtained in flows up to 250 l min.sup.-1." In German Patent Application No. DE 34 09 859 A1, which was filed Mar. 17, 1984, was published Sep. 19, 1985, and is entitled "Denitration of Waste Gases," the NOx in the waste gases from combustion engines and plants is formed into nitrogen and oxygen by introducing nitrogen atoms into the flow of such waste gases. In that German patent application, the amount of nitrogen atoms introduced into the waste gas stream is dependent on the NO concentration measured upstream and downstream of the generator of the nitrogen atoms.

One problem associated with the injecting of atomic nitrogen into the exhaust of an automobile engine is providing a source of nitrogen from which the atomic nitrogen can be formed. One of the most common sources from which atomic nitrogen can be formed is ammonia (NH3), but at the present time, it is not practical to store ammonia in an automobile. Even if a source of molecular nitrogen is available, an additional problem associated with the injection of atomic nitrogen into the exhaust of an automobile engine is the forming of the atomic nitrogen. A sufficient quantity of atomic nitrogen has to be produced in order to reduce the NOx in the exhaust of an automobile engine to nitrogen and oxygen. However, the atomic nitrogen needs to be produced in or in close proximity of the exhaust stream because atomic nitrogen tends to be unstable.

Accordingly, it is an object of the present invention to provide a new and improved method and apparatus for forming atomic nitrogen from molecular nitrogen so that the atomic nitrogen can be injected into the exhaust of an internal combustion engine to thereby reduce NOx in the exhaust to nitrogen and oxygen.

It is another object of the present invention to provide a new and improved spark discharge device for producing atomic nitrogen in or near the exhaust of an internal combustion engine so that the NOx present in that exhaust will be reduced to nitrogen and oxygen as the atomic nitrogen is so introduced into the exhaust.

It is yet another object of the present invention to provide a new and improved method and apparatus for reducing the amount of NOx in the emissions from an internal combustion engine by utilizing a modified automotive spark plug to produce a pulsating spark in a spark gap that forms atomic nitrogen from nitrogen-enriched air that is produced by a selectively permeable membrane and is introduced into the spark gap so that the atomic nitrogen can be introduced into the exhaust of an internal combustion engine.

Summary of the Invention

In accordance with these and many other objects of the present invention, a NOx control system for an internal combustion engine embodying the present invention includes an oxygen-enrichment device that produces oxygen-enriched air and nitrogen-enriched air. The oxygen-enriched air may be provided to the intake of the internal combustion engine for combustion of the fuel. In order to reduce the amount of NOx in the exhaust of the internal combustion engine, the molecular nitrogen in the nitrogen-enriched air produced by the oxygen-enrichment device is supplied to a spark plug that is mounted in exhaust outlet of an internal combustion engine. The spark plug includes a channel that extends from an inlet adjacent the top, positive electrode of the spark plug, through a central portion of the positive electrode that extends through the body of the spark plug to an opening adjacent the spark gap formed between a lower tip of the positive electrode and a ground electrode of the spark plug. The spark gap is elongated as compared to a standard automotive spark plug and insulators about a portion of the ground electrode and the spark gap protect the spark gap from the flow of exhaust gases.

As the nitrogen-enriched air is expelled at the spark gap of the spark plug, the nitrogen-enriched air is exposed to a pulsating spark that is generated across the spark gap of the spark plug by a high DC potential. As a result, a sufficient amount of atomic nitrogen is produced and is injected into the exhaust of the internal combustion engine. The injection of the atomic nitrogen into the exhaust of the internal combustion engine causes the NOx to be reduced into nitrogen and oxygen such that the emissions from the engine will have acceptable levels of NOx. In one embodiment of the present invention, the oxygen-enrichment device that produces both the oxygen- and nitrogen-enriched air can include a selectively permeable membrane as for example disclosed in U.S. Pat. No. 5,051,114 issued on Sep. 24, 1991.

Brief Description of the Drawings

These and many other objects and advantages of the present invention will become readily apparent from consideration of the following detailed description of the embodiment of the invention shown in the accompanying drawing wherein:

FIG. 1 is a diagrammatic illustration of an internal combustion engine having a NOx control system embodying the present invention;

FIG. 2 is an enlarged diagrammatic view of a portion an internal combustion engine illustrating the positioning of a spark plug used in the NOx control system of FIG. 1 in the exhaust of the internal combustion engine; and

FIG. 3 is a cross-sectional view of the spark plug shown in FIG. 2 and used in the NOx control system of FIG. 1.

Detailed Description of the Preferred Embodiment

Referring now more specifically to FIG. 1, therein is disclosed a diagrammatic representation of an internal combustion engine (10) having an intake line (12) for receiving air that is combined with fuel in the engine (10) and an exhaust line (14) through which is expelled the exhaust gases produced in the engine (10). The exhaust gases contain pollutants including NOx. In order to control the amount of NOx present in the exhaust gases expelled from the engine (10) through the exhaust line (14), the engine (10) is provided with a NOx control system that is generally designated by the reference numeral (16) and that embodies the present invention. The NOx control system 16 includes an oxygen-enrichment device (18) that produces oxygen-enriched air and nitrogen-enriched air. The oxygen-enriched air is used as at least a portion of the air that is supplied to the intake line (12) of the engine (10). The nitrogen-enriched air is supplied to a spark discharge or generating device (20) that extends into the exhaust line (14) so that the molecular nitrogen in the nitrogen-enriched air being supplied to the spark discharge device (20) can be converted to atomic nitrogen and injected into the exhaust gases being expelled from the engine (10) through the exhaust line (14). As a result of the injection of the atomic nitrogen into the exhaust gases, the NOx in those exhaust gases are reduced to nitrogen and oxygen thereby decreasing to an acceptable level the amount of NOx in the exhaust gases being expelled from the engine (10).

The engine (10) may be any type of internal combustion engine in which air supplied through the intake line (12) is combined with a combustible fuel. One example of such an engine (10) is a diesel engine. As is the case with all such internal combustion engines, exhaust gases are produced and are expelled through the exhaust line (14).

The exhaust gases flowing through the exhaust line (14) pass through a turbocharger (22) and an optional turbocompressor (24) to an exhaust outlet (26) from which the exhaust gases are discharged into the atmosphere. The movement of the exhaust gases through the turbocompressor (24) drives a pump within the turbocompressor (24) so that air drawn into an air inlet (28) is compressed and supplied under pressure to an inlet (30) of the oxygen-enrichment device (18). The oxygen-enrichment device (18) is adapted to separate the oxygen and nitrogen present in the air being supplied from the turbocompressor (24) so as to produce oxygen-enriched air at an outlet (32) and nitrogen-enriched air at another outlet (34). The oxygen-enrichment device (18) can be of the type having a selectively permeable membrane that can separate or enrich gaseous mixtures. A membrane of this type is disclosed in U.S. Pat. No. 5,051,114 issued on Sep. 24, 1991. As indicated in that patent, the membrane disclosed in that patent can be used to produce oxygen-enriched air by separating oxygen and nitrogen present in the air.

The oxygen-enriched air flowing from the outlet (32) is supplied to an inlet (36) of an air-mixing device (38). The air mixing device (38) blends the oxygen-enriched air supplied to the inlet (36) with air drawn into another inlet (40) so that air that is-enriched with a certain amount of oxygen is supplied from an outlet (42) to the turbocharger (22). The turbocharger (22) is driven by the flow of exhaust gases through the exhaust line (14) of the engine (10) and enables a greater amount of air being supplied from the air mixing device (38) to be injected into the engine (10) through the air intake line (12).

As previously indicated, the oxygen-enrichment device (18) separates oxygen from the air supplied to its inlet (30), resulting in oxygen-enriched air being supplied to its outlet (32). Consequently, the air being expelled from the other outlet (34) of the oxygen-enrichment device (18) is nitrogen-enriched air. Depending on the membrane used in the oxygen-enrichment device (18), the air being expelled from the outlet (34) of the oxygen-enrichment device (18) may contain as much as 99% molecular nitrogen.

The nitrogen-enriched air being expelled from the outlet (34) is supplied to an inlet (44) of the spark discharge device (20). As shown in FIG. 3, the spark discharge device (20) can be a modified automotive spark plug that is configured so that the molecular nitrogen present in the air being expelled from the outlet (34) can be converted into atomic nitrogen that is injected into the exhaust (14).

More specifically, the spark plug (20) has a center, positive electrode (50) having a high-voltage terminal (52) extending from a top end (54) of the spark plug (20) that is adapted to be coupled to a source of high-voltage, DC potential. The center electrode (50) extends from the top end (54) through a body portion (56) made of an insulating porcelain type of material such as high resistance Alumina. The body portion (56) has a ribbed, outer upper portion (58) and a lower insulating portion (60). A central channel (62) extends from the top end (54) through the upper portion (58) and the lower portion (60) of the spark plug (20) to a lower or spark gap end (64). The center electrode (50) extends through the channel (62) and is received therein. A metal collar (66) is disposed about the lower body portion (60) and includes screw threads (68) that are normally used to secure an automotive spark plug in a cylinder of an engine. In the case of the spark plug (20), the screw threads (68) are used to secure the lower, spark gap end (64) in the exhaust line (14) of the engine (10) as is for example illustrated in FIG. 2 and is discussed hereinafter. When so secured to the exhaust (14), the screw threads (68) and thereby the collar (66) are grounded to the engine (10).

The collar (66) is secured to the lower body portion (60) by a sealing compound (70) and has a gasket or conical seat (72). A sealing compound (74) also is used to secure the center electrode (50) in the channel (62). A tip portion (76) of the center electrode (50) projects from the lower extremity of the lower body portion (60) such that the tip (76) defines one end of a spark gap (78) formed at the lower end (64) of the lower body portion (60). The other end of the spark gap (78) is defined by a side, ground electrode (80). The side electrode (80) is generally L-shaped with an downwardly extending leg portion (82) that extends angularly from the lower end (64) of the lower body portion (60) of the spark plug (20) and a leg portion (84) that extends generally transverse to the tip (76) of the center electrode (50) in order to define the other end of the spark gap (78).

The side electrode (80) can be made of a nickel alloy and is coupled to the collar (66) such that when the spark plug (20) is secured in the exhaust line (14) by the screw threads (68), the side electrode (80) also will be grounded to the engine (10). In order to insulate the leg portion (82) of the side electrode (80), the leg portion (82) is encased in a ceramic insulator material 86 such as Alumina. A ceramic insulator (88) also is provided about the tip (76) of the center electrode (50). In order to deliver the nitrogen-enriched air that is being supplied to the inlet (44) of the spark plug (20) to the spark gap (78), a channel (90) is formed in the center electrode (50) and extends from the inlet (44) to a small opening (92) in the tip (76).

The spark gap (78) needs to be significantly greater in length between the tip (76) and the leg portion (84) of the side electrode (80) than a normal automotive spark plug in order to provide a sufficient amount of discharge area for the spark that is generated from the tip (76) to the leg portion (84) of the side electrode (80) to transform into atomic nitrogen the molecular nitrogen in the nitrogen-enriched air being supplied through the inlet (44) and the opening (92). For example, a spark gap (78) of about 3/4 inch, and possibly as much as 1 inch, between the tip (76) and the leg portion (84) is sufficient to provide the necessary spark gap area. The ceramic insulator 86 on the leg portion (82) of the side electrode (80) and the ceramic insulator (88) about the tip (76) provide protection around the spark gap (78) and to the spark that is produced across the spark gap (78). In addition, the protection afforded by the insulators (86 and 88) allows the molecular nitrogen to flow out from the small opening (92) without drawing into the spark gap (78) exhaust gases flowing in the exhaust line (14).

As previously indicated, the molecular nitrogen in the-enriched nitrogen air being supplied to the inlet (44) of the spark plug (20) flows through the channel (90) to the spark gap (78). In order to transform the molecular nitrogen into atomic nitrogen, a spark needs to be generated across the spark gap (20) from the tip (76) to the leg 84 of the ground electrode (80). Such a spark is generated by supplying a pulsed, relatively high DC potential to the electrode terminal (52) that is coupled via the center electrode (50) to the tip (76). The DC potential so supplied to the terminal (52) is at a minimum of 35-40 kV and preferable about 50 kV. This potential can be provided by modifying a typical ignition system in an automobile including the battery, induction coil, condenser and distributor cap to deliver such a potential. The amount of atomic nitrogen that needs to be produced is in part dependent on the amount of NOx in the exhaust gases in the exhaust (14) while the amount of atomic nitrogen actually produced is in part dependent on the frequency of the spark being produced across the spark gap (78) which in turn is dependent on the frequency at which the DC potential supplied to the terminal (52) is pulsed. In general the potential being supplied to the terminal (52) should be pulsed at a frequency in the range of 20-100 Hz with a frequency of 60 Hz being considered adequate for producing a sufficient amount of atomic nitrogen in the spark gap (78) to reduce the NOx in the exhaust to an acceptable level. In fact, it has been experimentally found that the amount of NOx in the exhaust gases in the exhaust (14) generally decreases as the frequency of the spark in the spark gap (78) is increased to at least to 60 Hz.

In the actual construction of the NOx control system (16), it is preferable that the spark plug (20) be located in as close proximity as possible to the exhaust line (14) because atomic nitrogen produced at the spark gap (78) tends to be somewhat unstable and should be combined with the exhaust gases in the exhaust line (14) as soon as possible after being formed. Accordingly as shown in FIG. 2 of the drawings, the spark gap (78) of the spark plug (20) is preferably positioned in the exhaust line (14).

More specifically, FIG. 2 shows a portion of the engine (10) and in particular one of the cylinders (94) having a piston (96). A mixture of combustible fuel and oxygen-enriched air supplied through the intake (12) of the engine (10) flows through an intake valve (98) when the valve is opened so that the mixture is injected into the cylinder (94) on top of the piston (96). After the mixture of air and fuel is ignited in the cylinder (94), exhaust gases are allowed to escape from the cylinder (94) through a then opened exhaust valve 100 illustrated in FIG. 2. The exhaust gases which contain NOx flow through the exhaust line (14) and past the lower spark gap end (64) of the spark plug (20) that is threadedly mounted in the exhaust line (14). As is discussed above, the nitrogen-enriched air from the outlet (34) of the oxygen-enrichment device (18) is supplied through the inlet (44) adjacent the top terminal (52) of the spark plug (20), through the center electrode (50) and out of the opening (92) in the tip (76) of the center electrode (50) to the spark gap (78). As the high DC potential supplied to the terminal (52) is pulsed, a spark of high potential is generated across the spark gap (78) between the tip (76) of the positive center electrode (50) and the leg (84) of the ground-side electrode (80). This spark results in molecular nitrogen in the nitrogen-enriched air flowing out from the small opening (92) in the tip (76) to be converted to atomic nitrogen. The so-formed atomic nitrogen is thereby injected into the flow of exhaust gases being emitted through the exhaust (14) from the engine (10), and in particular, the cylinder (94). When such atomic nitrogen is so injected in the exhaust gases in the exhaust (14), the atomic nitrogen combines with NOx contained in those exhaust gases to form nitrogen and oxygen. For example, the following equation would apply with respect to nitric oxide contained in the exhaust gases when such nitric oxide is exposed to the atomic nitrogen formed in the spark gap (78) of the spark plug (20):

2NO+2N.fwdarw.2N.sub.2 +O.sub.2

Accordingly, the injection of atomic nitrogen into the exhaust gases containing NOx will result in the reduction of the NOx to nitrogen and oxygen. As a result, the amount of NOx in the exhaust gases being expelled from the exhaust outlet (26) into the atmosphere will tend to be at acceptable levels.

Obviously, many modifications and variations of the present invention are possible in light of the above teachings. In this regard, the engine (10) described in connection with the above preferred embodiment has a turbocharger (22) for forcing a greater amount of air into the engine (10) through the intake line (12) and a turbocompressor (24) for supplying a greater quantity of air to the oxygen-enrichment device (18). On the other hand, the NOx control system (16) can be used with an engine that does not include any such turbocharger (22) or turbocompressor (24). If the turbocompressor (24) is not utilized, the oxygen-enrichment device (18) may have to be increased in size to provide the necessary amount of nitrogen-enriched air to the inlet (44) of the spark discharge device (20). The NOx control system (16) also can be used to reduce the level of NOx in the exhaust of the engine (10) even though the air that is supplied to the engine (10) through the intake line (12) is not oxygen-enriched air. All that is necessary is for nitrogen-enriched air to be supplied to the spark discharge device (20) in order that molecular nitrogen is transformed into atomic nitrogen which is in turn injected into the exhaust gases being emitted from the engine (10). In fact, more than one spark plug (for example, four spark plugs) can be used to generate a sufficient amount of atomic nitrogen. Thus, it is to be understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically described above.

FIG. 1

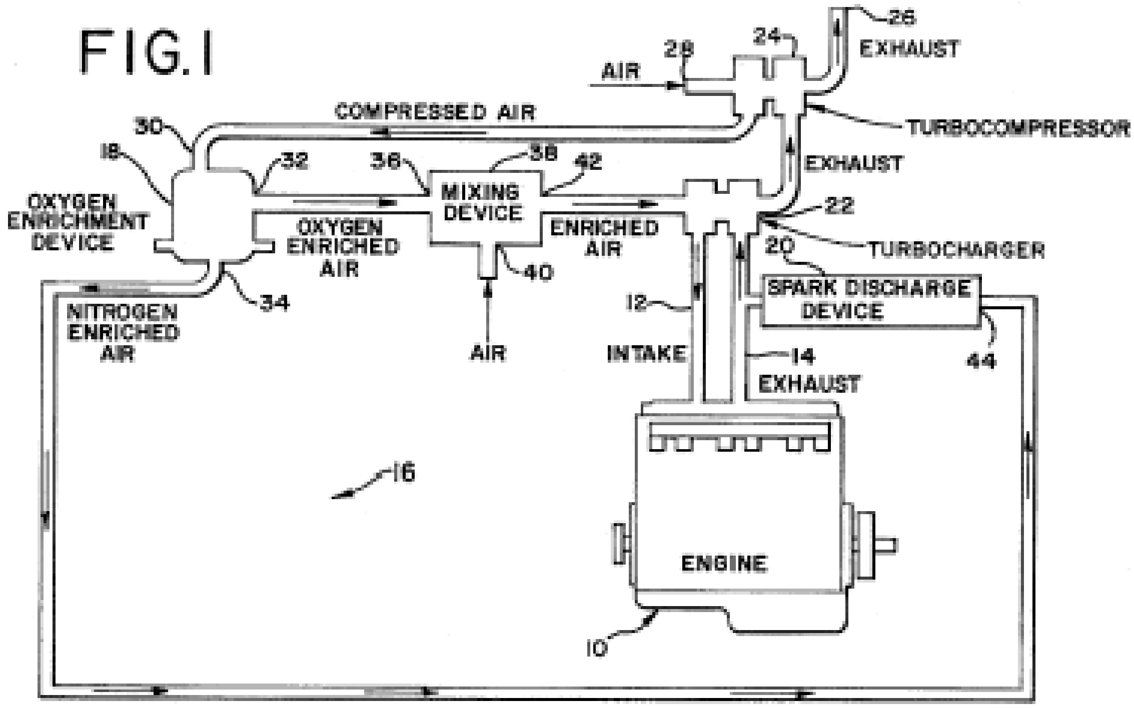
26
24
28
EXHAUST
AIR
COMPRESSED AIR
TURBOCOMPRESSOR
30
18
32
36
38
42
EXHAUST
22
OXYGEN ENRICHMENT DEVICE
MIXING DEVICE
OXYGEN ENRICHED AIR
ENRICHED AIR
20
TURBOCHARGER
40
SPARK DISCHARGE DEVICE
34
12
NITROGEN ENRICHED AIR
AIR
INTAKE
14
44
EXHAUST
16
ENGINE
10

FIG. 2

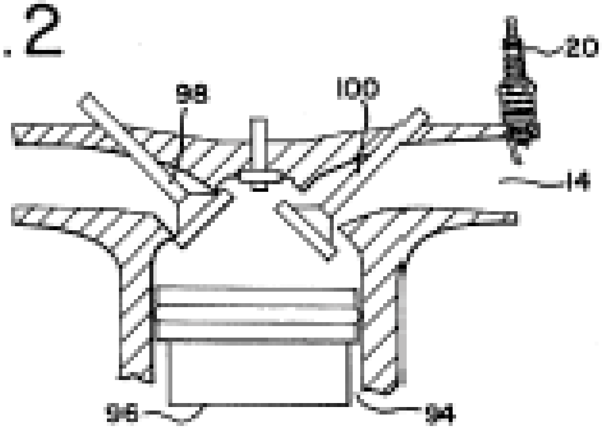
20
98
100
14
96
94

FIG.3