

[54] **APPARATUS AND METHODS FOR
TREATING EXHAUST GASES OF
COMBUSTION**

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 684,751, Nov. 11, 1967, abandoned.

[52] U.S. Cl. **55/73, 55/74, 55/84, 55/DIG. 30, 55/222, 60/30**

[51] Int. Cl. ... **B01d 53/14, B01d 53/04, F02b 13/10**

[58] Field of Search **23/211, 277 C; 55/DIG. 30, 55/83, 84, 222, 268, 269, 263, 68, 73; 60/30, 31; 261/141, 159, 160**

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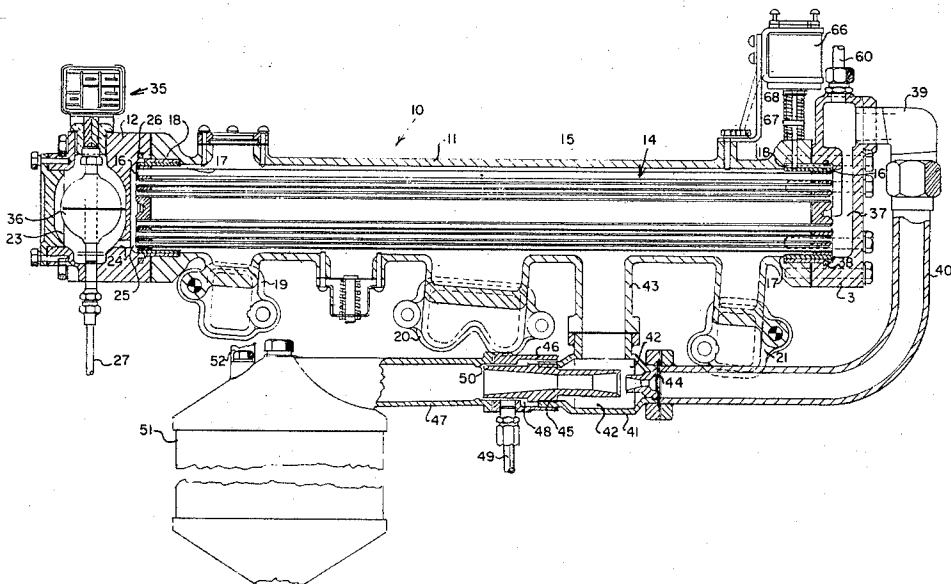
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[57]

ABSTRACT

Apparatus and methods for treating the hot, noxious exhaust gases of combustion emitted from an internal combustion engine or the like wherein fuel is burned at the optimum air/fuel ratio and the exhaust gases are subjected to cooling substantially instantaneously upon their exhaust from the combustion chamber, the heat of the exhaust gases being utilized to convert an aqueous liquid to steam which subsequently is mixed with the exhaust gases and then condensed to effect separation of the exhaust gases from the condensate. The exhaust gases may be filtered and recycled through the engine if desired. The cooling of the exhaust gases reduces their volume and velocity, thereby avoiding the imposition of back pressure on the engine and resulting in muffling or silencing of the engine noises without requiring a conventional muffler.

26 Claims, 9 Drawing Figures



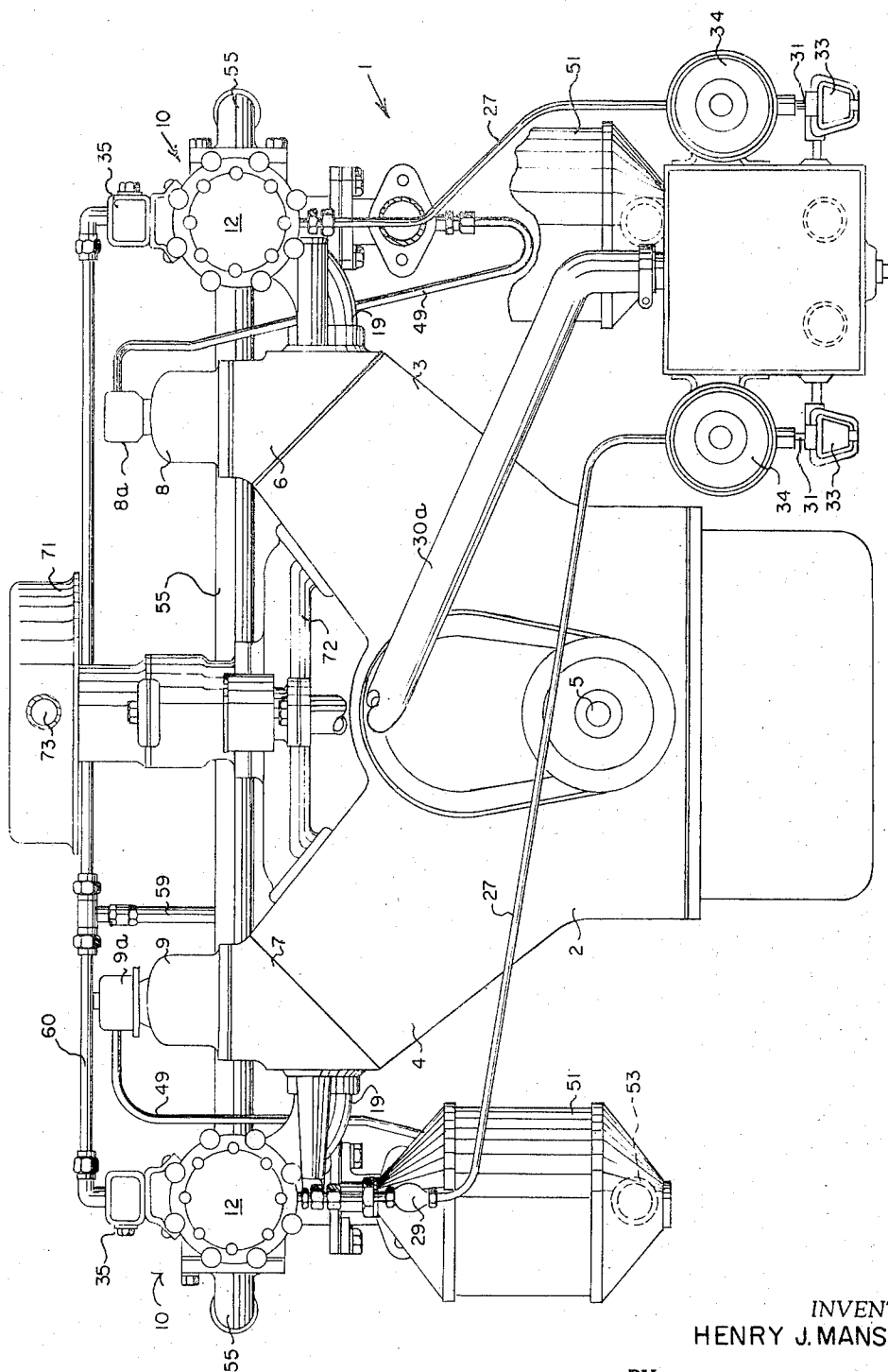


FIG. 1

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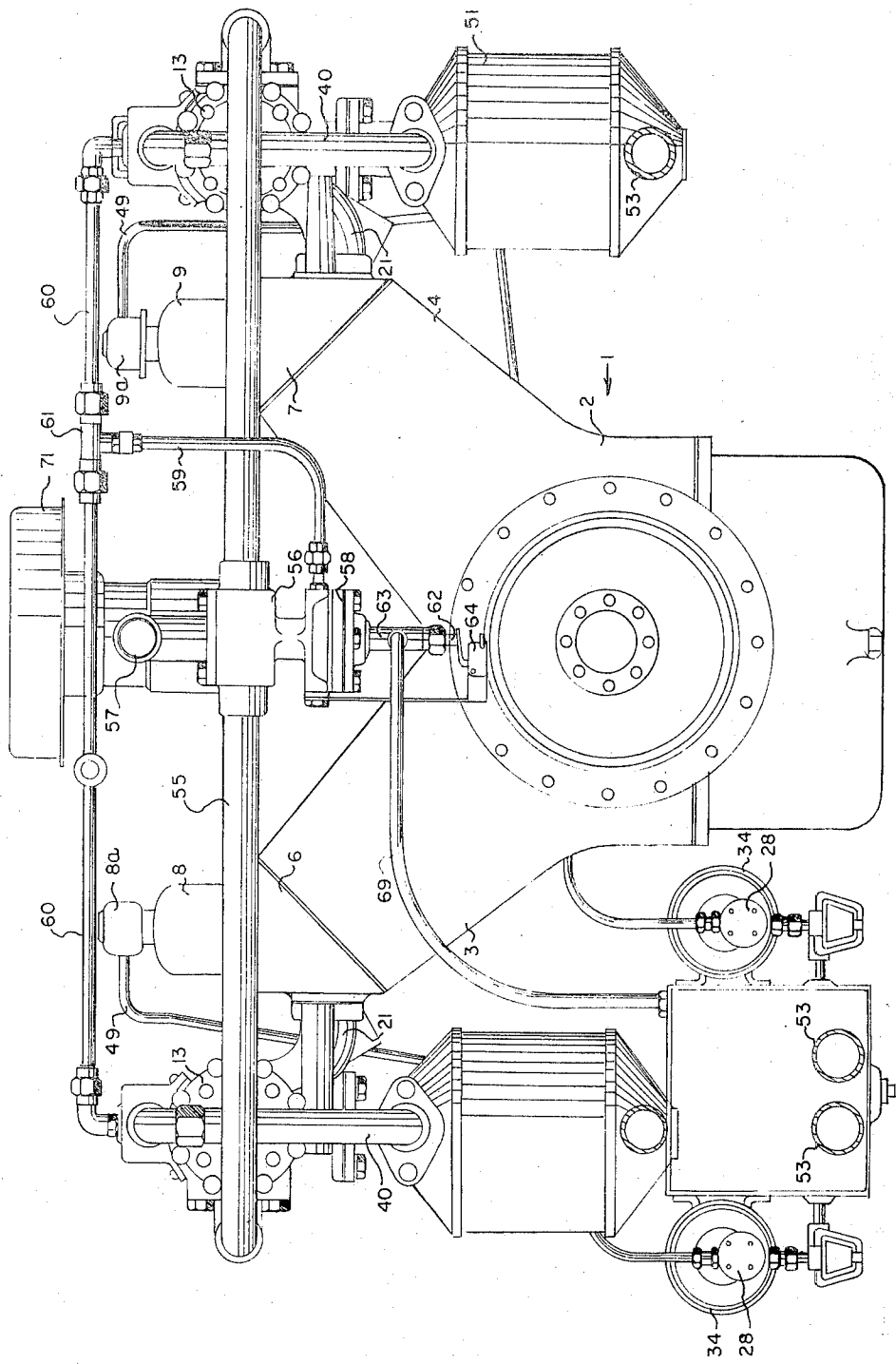


FIG. 2

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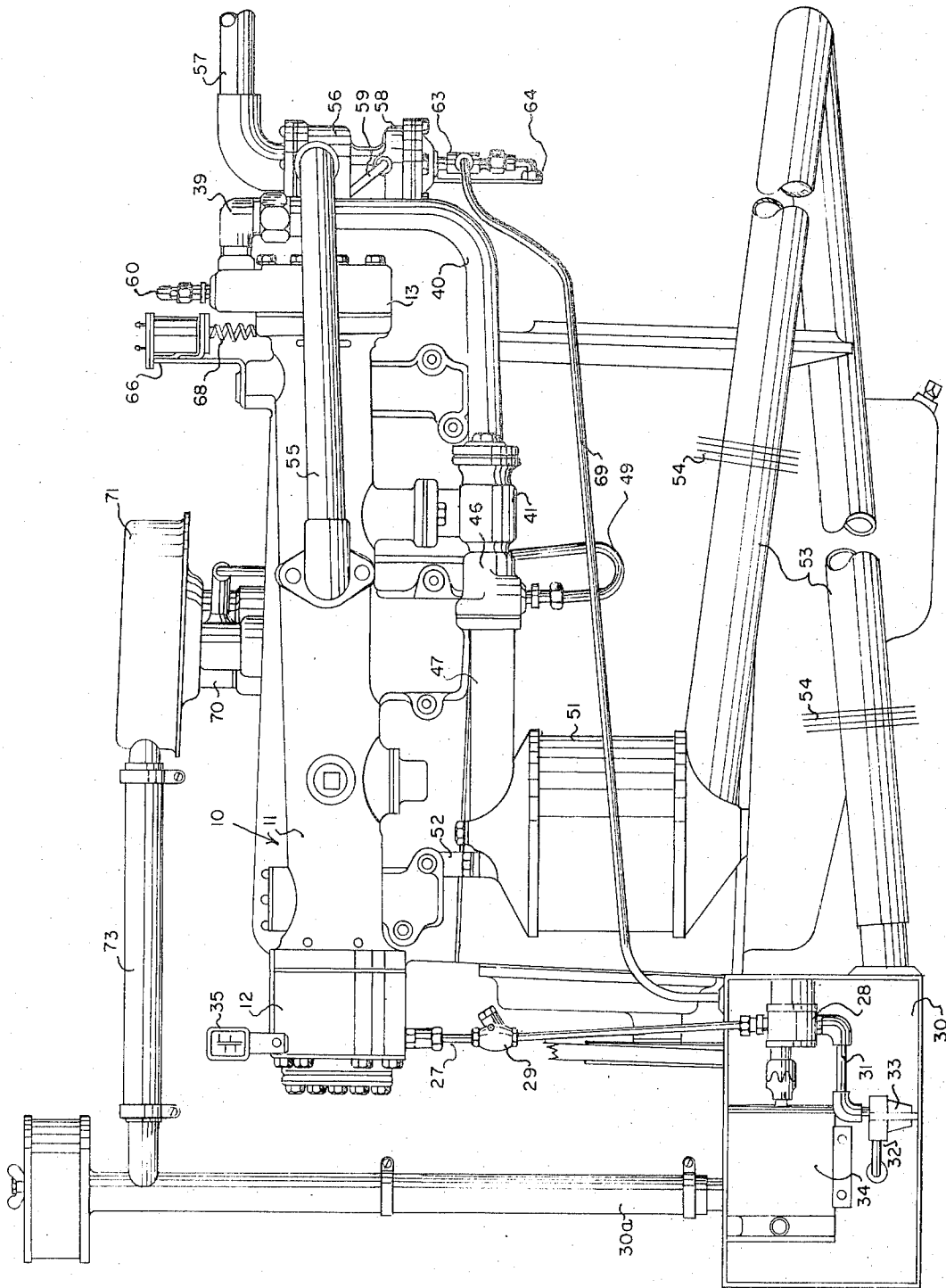


FIG. 3

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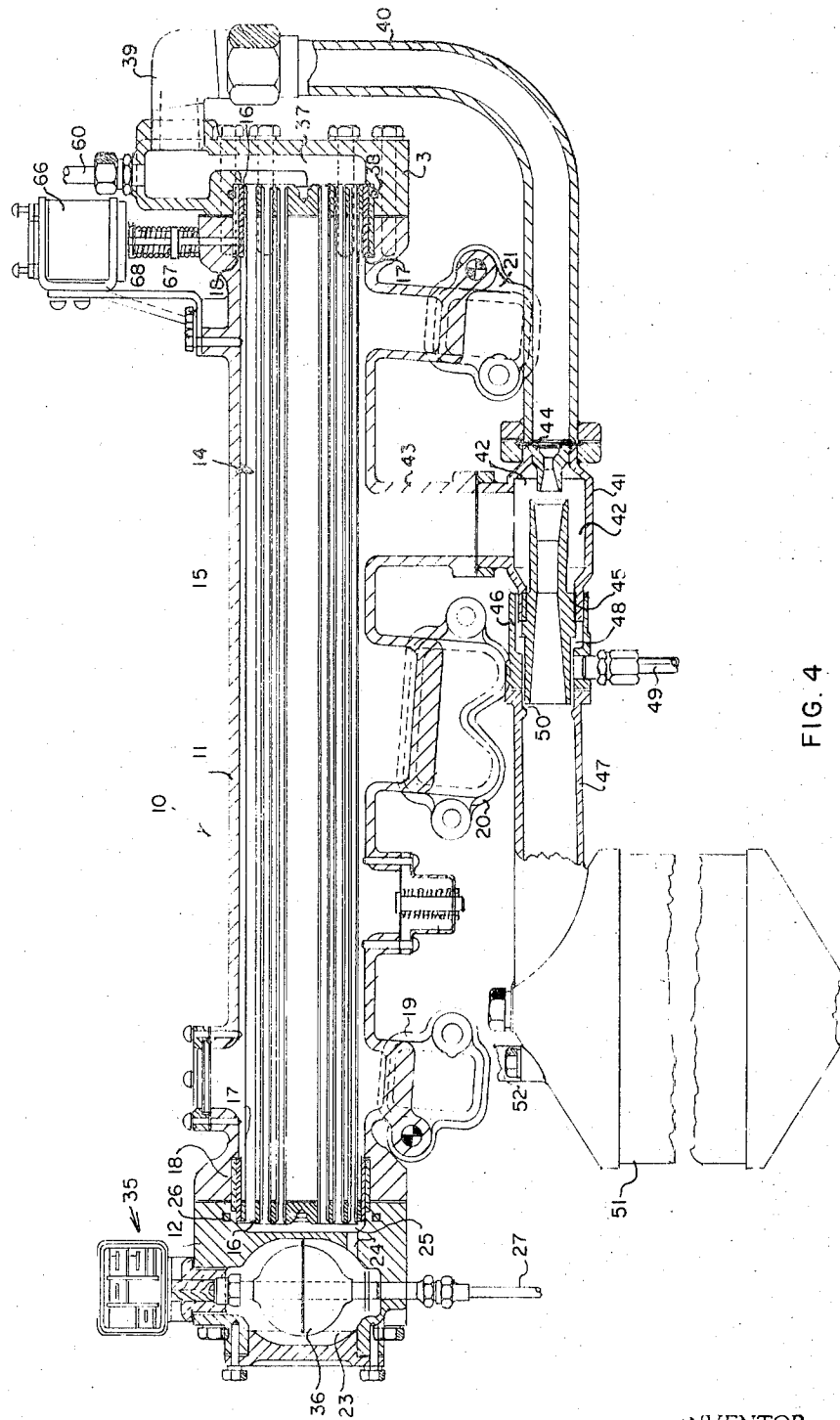


FIG. 4

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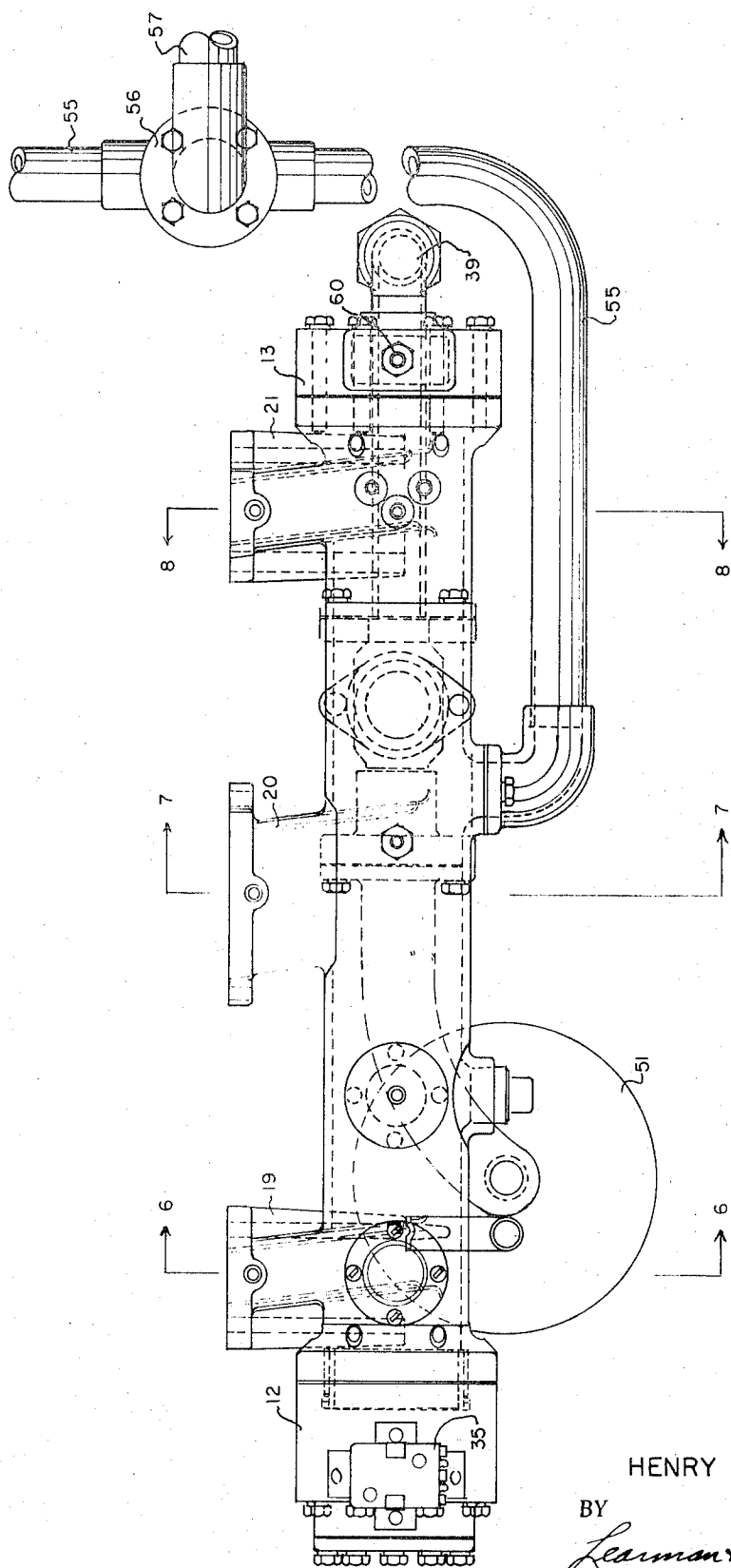


FIG. 5

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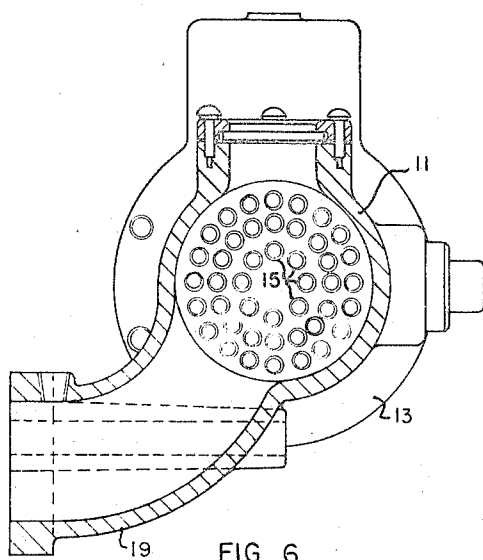


FIG. 6

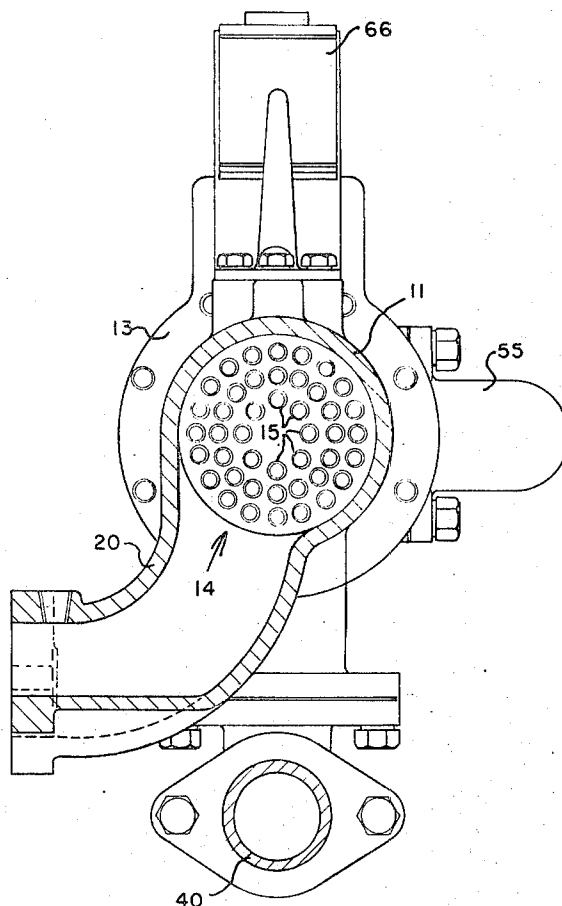


FIG. 7

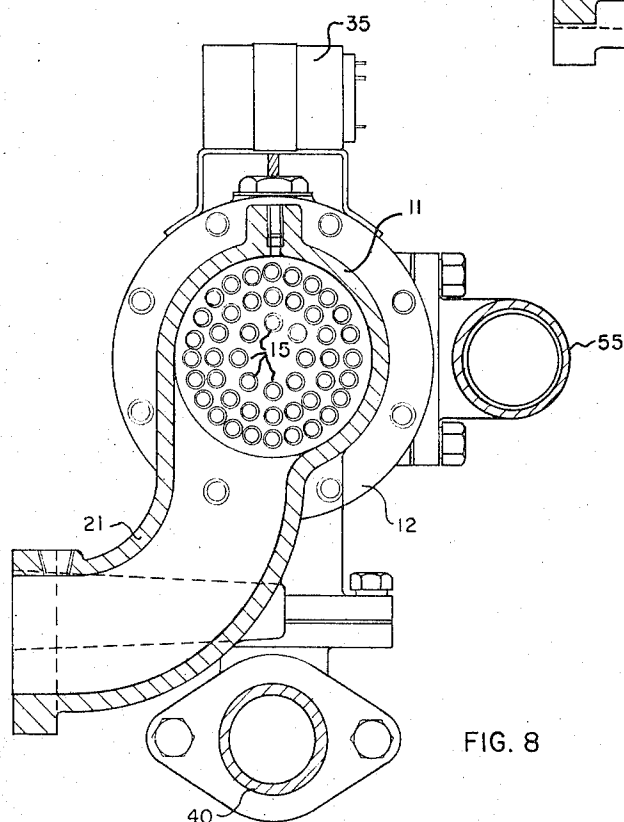


FIG. 8

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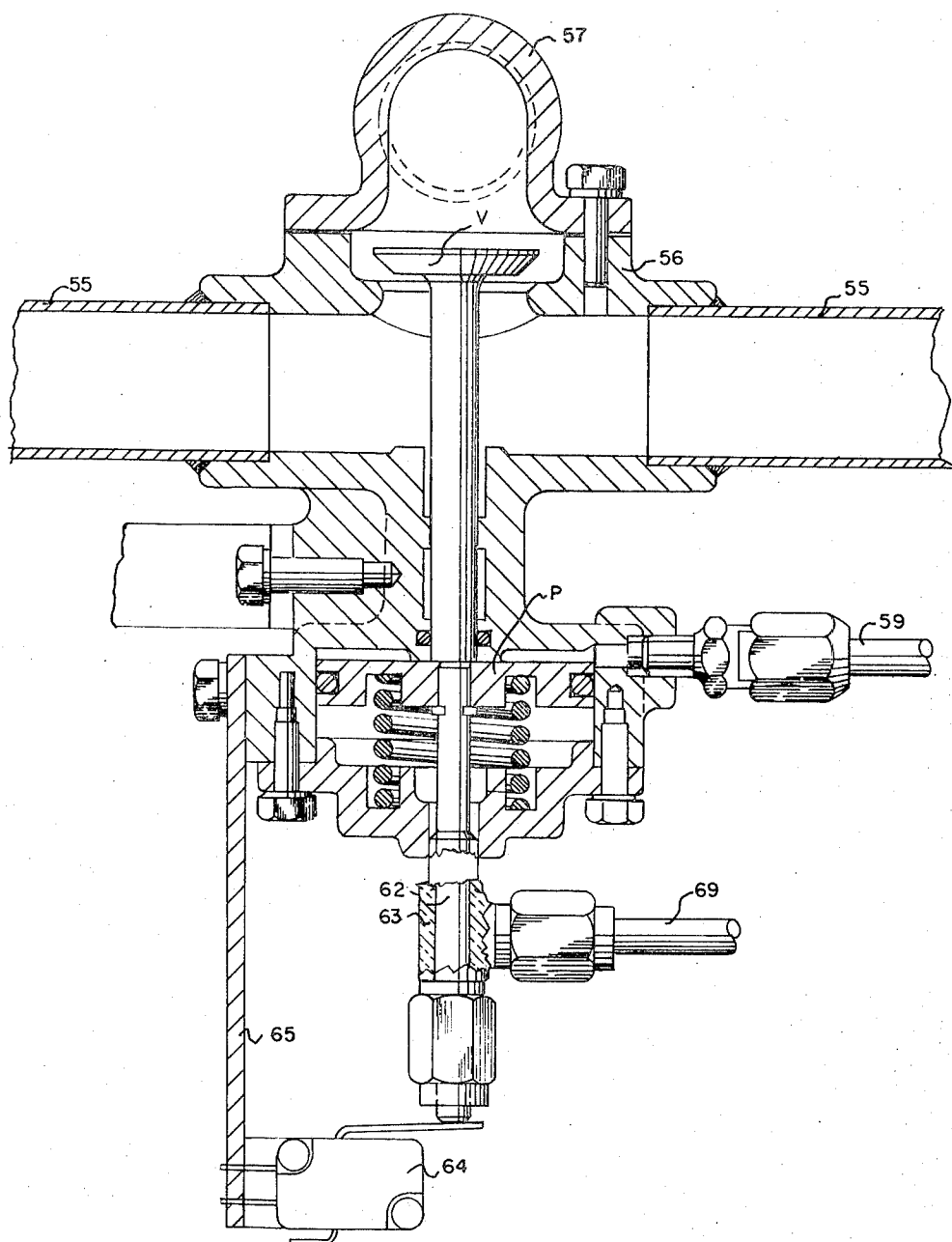


FIG. 9

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APPARATUS AND METHODS FOR TREATING EXHAUST GASES OF COMBUSTION

RELATED APPLICATION

This application is a continuation-in-part of application Ser. No. 684,751, filed Nov. 11, 1967 and now abandoned.

The invention disclosed herein relates to methods and apparatus particularly well adapted for use in treating exhaust gases emitted by internal combustion engines, but the methods and apparatus also are adapted for use in treating the exhaust of products of combustion from sources other than such engines.

The manufacturers of automotive vehicles have been striving for several years to provide an economical and effective solution to the problems caused by the exhausting to atmosphere of the products of combustion of internal combustion engines. The most noxious by-products of combustion are hydrocarbons, carbon monoxide and oxides of nitrogen. At the present time, four systems are in use for reducing exhaust hydrocarbons and carbon monoxide. The first system involves engine modifications which incorporate leaner and more precisely controlled carburetor air-fuel ratios. The second system involves the pumping of air into the exhaust manifold directly into the exhaust gases in the immediate vicinity of the exhaust valves. The third system involves redesign of cylinder heads and combustion chambers in an effort to obtain more complete combustion of the fuel so as to reduce the quantity of unburned hydrocarbons discharged. The fourth system involves recycling of blowby gases from the engine crank case to the carburetor for reburning.

Investigations currently are being conducted on the four systems referred to above, and in addition, in connection with post-cylinder exhaust treatment of reactive pollutant emissions prior to their exit from the tail pipe, recycling of a portion of the exhaust gas to the engine intake to lower the temperature of engine combustion and reduce the production of nitrogen oxides, and systems to prevent evaporation of gasoline from the carburetor and fuel tank.

It is known that emissions of hydrocarbons and carbon monoxide can be minimized by high temperature combustion of fuel and that high temperature combustion can be achieved by supplying sufficient oxygen or air to the combustion chamber to secure substantially complete combustion of the fuel. Thus, a lean air-fuel mixture, i.e., one containing more air than fuel, is utilized. However, high temperature combustion increases the emission of oxides of nitrogen. Conversely, relatively low temperature combustion, resulting from relatively fuel rich air-fuel mixtures, reduces the emission of oxides of nitrogen, but increases the emission of carbon monoxide and hydrocarbons.

Combustion temperatures vary over wide ranges according to the air-fuel mixture. In general, the richer the mixture, the lower the temperature, and vice versa. At combustion temperatures below about 1,450°F. the emission of carbon monoxide and hydrocarbons is excessive, but the emission of oxides of nitrogen is within acceptable limits. As the combustion temperature increases to more than about 1,450°F., nitrogen combines with oxygen to form oxides of nitrogen in large quantities and very rapidly. At the same time, the higher temperature results in a decrease in hydrocar-

bon formation and enables the carbon monoxide to be burned and form harmless carbon dioxide.

Although the formation of oxides of nitrogen occurs rapidly, some time is required for the production thereof. In conventional engines, ample time exists in the exhaust manifold and tail pipe for the formation of oxides of nitrogen. In methods and apparatus according to the invention, however, the exhaust gases are cooled or quenched to a temperature less than about 1,450°F. immediately upon their exhaust from the combustion chamber, thereby inhibiting and minimizing the formation of oxides of nitrogen. The present invention, therefore, permits high temperature combustion of fuel, thereby minimizing the formation of hydrocarbons and carbon monoxide, and effects substantially instantaneous quenching of the exhaust gases, thereby inhibiting the formation of oxides of nitrogen. As a consequence, the noxious emissions of an engine may be reduced to acceptable levels and, in fact, an engine constructed in accordance with the invention has reduced noxious emissions to levels at least as low as those specified for the year 1980.

The high temperature fuel combustion, followed by substantially instantaneous quenching of the exhaust gases, enables other advantageous results to be achieved. For example, the rapid cooling of the exhaust gases reduces their volume, thereby making it possible to reduce back pressure on an engine. In addition, the quenching of the exhaust gases effects silencing or muffling of the engine noise without the necessity of utilizing conventional mufflers. The heat extracted from the exhaust gases may be utilized to convert an aqueous liquid to steam which then may be ejected into and mixed with the exhaust gases for further treatment and cooling thereof. The exhaust gases then can be treated chemically in the system with catalysts so as to convert carbon monoxide to carbon dioxide. If desired, a percentage of the exhaust gases may be recycled through the engine, thereby further minimizing the emission of noxious substances.

An object of this invention is to provide improved methods and apparatus for controlling noxious exhaust gases of combustion by inhibiting the formation of noxious products during and after combustion.

Another object of the invention is to provide methods and apparatus of the character referred to which are adaptable not only to internal combustion engines, but which also are applicable to the control of noxious gases emitted by other sources of contamination.

A further object of the invention is to provide exhaust emission control means and methods which are relatively inexpensive and which do not require extensive modification of an engine.

Another object of the invention is to provide exhaust emission control apparatus which can be incorporated as an integral part of newly manufactured engines and which also may be added to engines currently in use.

A further object of the invention is to provide exhaust emission control apparatus for internal combustion engines and which is applicable equally to liquid cooled and air cooled engines.

Another object of the invention is to provide apparatus of the character referred to and in which the heat of the exhaust gases is utilized to generate steam for the purging of noxious components of the exhaust gases.

A further object of the invention is to provide apparatus and methods capable of purging noxious gases of

combustion, and which also reduces back pressure on an engine and muffles the noise thereof.

Other objects and advantages of the invention will be pointed out specifically or will become apparent from the following description when it is considered in conjunction with the appended claims and the accompanying drawings, in which:

FIG. 1 is a somewhat diagrammatic, front elevational view of an internal combustion engine equipped with apparatus constructed in accordance with the invention;

FIG. 2 is a rear elevational view of the apparatus illustrated in FIG. 1;

FIG. 3 is a side elevational view;

FIG. 4 is a longitudinal sectional view of the heat exchange apparatus associated with the left bank of cylinders;

FIG. 5 is a top plan view of the apparatus shown in FIG. 4;

FIGS. 6, 7 and 8 are sectional views taken on the lines 6—6, 7—7, and 8—8, respectively, of FIG. 5; and

FIG. 9 is a sectional view taken on the line 9—9 of FIG. 4.

Apparatus constructed in accordance with the invention is disclosed as being applied to a liquid cooled, internal combustion engine 1 having a block 2 and two cylinder banks 3 and 4 in each of which are four cylinders. Each of the cylinders is surrounded by a jacket (not shown) having passages through which an aqueous liquid coolant, such as water and a freezing point depressant, may circulate as is conventional. The engine includes a crank shaft 5 at the forward end of which is mounted a fan (not shown) and which drives a coolant pump (not shown) by means of which coolant may be delivered from the engine block via a transfer line to the upper tank of a conventional radiator (not shown). Coolant in the radiator may descend to a lower tank or sump whence it returns to the engine block via a transfer line (not shown). As thus far described, the engine 1 is a conventional, liquid cooled, V-8 internal combustion, automotive engine. It will be understood, however, that the engine could be any conventional air-cooled engine.

The engine block 2 is provided with a pair of cylinder head assemblies 6 and 7 each of which has a series of four exhaust gas ports, as is conventional, by means of which the hot products of combustion are exhausted from a cylinder. Atop the heads are rocker arm covers 8 and 9 and air cleaners 8a and 9a, respectively. The respective exhaust ports normally communicate with exhaust manifolds which conduct the exhaust gases through one or more suitable mufflers for discharge to atmosphere. Apparatus constructed in accordance with the invention, however, utilizes two heat exchangers or receivers 10 in lieu of the exhaust manifolds with which engines of the kind disclosed conventionally are equipped. Each receiver is the same, so only one will be described in detail.

The receiver 10 comprises a cylinder or jacket 11 that is sealed at its opposite ends by housings 12 and 13 which are welded, bolted, or otherwise secured to the cylinder 11. Within the cylinder 11 is mounted a rotatable cluster 14 of conduits, each conduit comprising a tube 15 having its opposite ends fitted into and extending through openings formed in discs 16 which, in turn, are fixed within sleeves 17 that are journaled by bear-

ings 18 at opposite ends of the cylinder 11. The cylinder 11 includes a plurality of flanged inlet tubes 19, 20 and 21 that are adapted to be bolted to the cylinder head assemblies at the exhaust ports of the cylinders, the tube 20 constituting a double tube so as to receive the gases exhausted from the two inboard cylinders.

Certain ones of the tubes 15 are linked by vanes 22 located in the path of exhaust gases admitted to the cylinder 11 via the inlets 19, 20 and 21 so that the gas discharged to the cylinder will act on the vanes 22 and impart rotation to the tube cluster 14.

The head 12 has a chamber 23 therein which communicates via a passage 24 with a chamber 25 with which each of the tubes 15 also communicates. A seal 26 prevents leakage of fluid from the chamber 25 past the disc 16. Also communicating with the chamber 23 is one end of a liquid supply line 27, the opposite end of which communicates with a pump 28 via a check valve 29. The pump communicates with a tank or hot well 30 via lines 31 and 32 and a drain pump 33. The tank 30 is adapted to contain a source of water or other aqueous liquid. The pump 28 is driven by an electric motor 34. An exhaust stack 30a has one end secured to the tank 30 and its other end open to atmosphere.

The operation of the motor 34 is controlled by a relay 35 of known construction mounted on the head 12. The relay is operated by a switch of known construction carried by a float 36 mounted in the chamber 23 so as to rise and fall in accordance with the level of liquid in the chamber. The relay 35 is connected to the vehicle battery (not shown) and its operation is such that, when the float 36 is at a relatively low level, the relay 35 energizes the motor 28 so as to deliver fluid from the tank 30 to the chamber 23. As the level of liquid rises in the chamber 23, the float 36 also will rise. When the float 36 reaches a predetermined level, the relay 35 will be opened, thereby discontinuing operation of the motor 28.

The head 13 includes a chamber 37 which is isolated from the interior of the cylinder 11 by a seal 38 and which is in communication with the end of each of the tubes 15. In communication with the chamber 37 is a fitting 39 to which is joined one end of a conduit 40, the opposite end of which is joined to an ejector 41 such as that described in Bulletin No. 100 of Penberthy Manufacturing Company. The ejector 41 has an enlarged mixing chamber 42 into which gases from the cylinder 11 may be discharged via a discharge port 43. Also in communication with the chamber 42 is the discharge end of a venturi tube 44 that is fitted to the conduit 40. Also in communication with the chamber 42 and in a position to receive the discharge from the venturi tube 44 is a second venturi tube 45.

Joined to the ejector 41 is a sleeve 46 which overlies the venturi tube 45 and is joined to one end of a conduit 47. The sleeve 46 provides an annular chamber 48 surrounding the venturi tube 45, and in communication with the chamber 48 is one end of a tube 49, the opposite end of which is secured to and communicates with the rocker arm cover 8. Adjacent the end of the venturi tube 45 the chamber 48 is restricted by an annular, inwardly projecting rib 50, the rib 50 forming still another venturi tube.

The conduit 47 communicates with the upper end of a filter housing 51 of known construction within which is contained filter material selected from the class in-

cluding aluminum oxide, activated charcoal and calcium carbonate, or a combination of such materials. The filter housing 51 is supported by means of a bracket 52 that may be carried by the cylinder 11.

Fitted to the filter housing 51 is one end of a condenser tube 53 of substantial length and which has its other end communicating with the hot well or supply tank 30. Preferably, the tube 53 is provided with cooling fins 54.

The cylinder 11 is provided with an opening in which is fitted one end of a by-pass tube 55, the opposite end of which communicates with a valve housing 56. An exhaust tube 57 has one end fitted to the housing 56 and its opposite end open to atmosphere. Within the valve housing 56 is a valve V which is capable of selectively opening and closing the exhaust tube 57. The position of the valve is controlled by steam pressure within a housing 58 to which steam may be admitted via a line 59 and which is supplied with steam from either or both of the chambers 37 via lines 60 and a tee fitting 61. The presence of sufficient steam pressure in the housing 58 acts on and displaces a piston P which, in turn, displaces the valve and closes the exhaust tube 57.

Shifting of the piston to effect closing of the exhaust tube 57 also displaces an operating stem 62 that is carried by the piston and mounted in a sleeve 63 fitted to the housing 58. Connected to the sleeve 63 is a drain line 69 which communicates with the hot well 30. Displacement of the stem 62 effects closing of a switch 64 that is mounted on a bracket 65 carried by the housing 58. The switch 64 is connected to the vehicle battery and to a solenoid 66 having a latching plunger 67 that normally is projected by a spring 68 into one of a number of circumferentially spaced openings in the sleeve 17 so as to lock the tube cluster 14 against rotation. Energization of the solenoid 66, however, effects retraction of the plunger 67, thereby freeing the cluster 14 for rotation.

The vehicle engine 1 includes the conventional carburetor 70, an air cleaner 71 and an intake manifold 72 for delivering a mixture of fuel and air to the engine cylinders. Preferably, a tube 73 establishes communication between the air cleaner 71 and the exhaust stack 30a to divert a portion of the exhaust gas from the stack to the air cleaner for recycling through the engine.

In the operation of the apparatus described thus far, and assuming that the engine is cold, starting of the engine will cause exhaust gases to be discharged from the combustion chambers of the engine cylinders directly into the receivers 10. Initially, water contained in the tubes 15 of the respective receivers will be cold and there will be no steam anywhere in the system. Accordingly, the solenoids 66 will be deenergized and the latching plungers 67 will be in their cluster-locking position.

Exhaust gases admitted to the cylinders 10 will flow around the tubes 15 and heat the water therein very quickly so as to convert the water to steam. Until such time as sufficient steam is generated to close the valve in the exhaust pipe 57 and close the switch 64, the great majority of the exhaust gases will be discharged from the cylinders 10 via the exhaust conduits 55 and the exhaust pipe 57.

After a relatively short time, the water in the tube cluster 14 will be converted to steam, whereupon steam will enter the chambers 37 in the housings 13 and be discharged via the tubes 60 and 59 to the housing 15

and effect closing of the valve V and closing of the switch 64. The exhaust tube 57 thus will be sealed and the solenoids 66 will be energized so as to retract the latching rods 67, thereby freeing the tube clusters 14 for rotation. As exhaust gases continue to be discharged from the engine cylinders into the receivers 10, the gases will impinge upon the vanes 22 and impart rotation to the tube clusters 14, thereby preventing any one of the tubes 15 from being exposed constantly to the hot gases of combustion.

Whenever hydrocarbon fuels are burned, at least trace amounts of unburned fuel and carbon monoxide will result. The quantity of these constituents principally is a function of the ratio of the amount of air to the amount of fuel, referred to as the air-fuel mixture ratio. The theoretically correct air-fuel mixture ratio is between 15 to 16 pounds of air per pound of fuel. When the mixture contains excess air, i.e., a lean mixture, there will be some oxygen in the exhaust and a minimum amount of carbon monoxide and unburned fuel. When there is an excess of fuel in the mixture, i.e., a rich mixture, there is insufficient oxygen to effect complete combustion of the fuel and the amounts of unburned hydrocarbons and carbon monoxide are increased. To reduce the amounts of hydrocarbons and carbon monoxide in the exhaust, it is important to operate the engine on a lean mixture. Unfortunately, however, a lean mixture of about 15 to 16 pounds of air per pound of fuel results in the generation of combustion temperatures in excess of about 1,450°F. Temperatures in excess of about 1,450°F. cause nitrogen, a constituent of air, to combine with oxygen, of which there is an excess amount in a lean mixture, thereby producing oxides of nitrogen which, if discharged to atmosphere through the exhaust system, can pollute the atmosphere with toxic oxides of nitrogen.

Apparatus constructed in accordance with the invention enables optimum air-fuel mixtures to be delivered to the combustion chambers of the engine, thereby minimizing the emissions of hydrocarbons and carbon monoxide, and also inhibits or minimizes the emissions of oxides of nitrogen. The minimization of the oxides of nitrogen emission is achieved by cooling the exhaust gases substantially instantaneously upon their discharge from the combustion chambers.

To be effective in the control of emissions of oxides of nitrogen, the exhaust gas cooling must take place as quickly as possible upon the discharge of the exhaust gases from the combustion chamber and the gases must be cooled to a temperature below that at which nitrogen combines with oxygen. Although the combination of nitrogen with oxygen to form oxides of nitrogen occurs rapidly, the process still requires some finite period of time and, the longer the time at which exhaust gases remain at a temperature above about 1,450°F., the longer is the time available for oxides of nitrogen to be formed. In a four cycle engine operating at 3,000 rpm, only a little more than 0.01 second is available to exhaust the gases of combustion from the cylinder, a relatively short time in which to enable nitrogen to be converted to nitrogen oxide.

Fuel burned at the optimum air-fuel ratio will have a combustion temperature considerably in excess of about 1,450°F. Consequently, gases exhausted from the engine cylinders will be in excess of 1,450°F. These exhaust gases are discharged through the engine exhaust ports directly into the cylinders 11 where they impinge

immediately on the tubes 15 which contain water. The water in the tubes 15 extracts heat from the exhaust gases, thereby cooling the latter to a temperature lower than about 1450°F. The water in the tubes is converted to steam. Steam from each tube cluster passes to the associated chambers 37 in the heads 13 and thence into the associated conduits 40 whence they are discharged to the ejectors 41. Passage of the steam through the venturi tube 44 creates a low pressure at the exhaust port 43 through which the cooled exhaust gases in the cylinders 11 are drawn into the mixing chamber 42 where the exhaust gases are mixed with the steam. In the mixing chamber, the exhaust gases are further cooled by the steam.

From the mixing chamber 42 the mixture of steam and exhaust gases is discharged via the venturi tube 44 into the conduit 47 leading to the filter chamber 51. Passage of the mixture past the restricting rib 50 creates a low pressure in the chamber 48, thereby enabling blowby gases from the rocker arm covers 8 and 9 to be entrained with the steam-gas mixture and cooled.

As the steam-gas mixture reaches the filter chamber 51, the mixture is hot and moist, thereby enabling the carbon monoxide to combine with the water of the steam to form carbonic acid. The carbonic acid reacts with calcium carbonate in the filter chamber to form negative calcium ions and positive bicarbonate ions which, being unstable in hot water, break up and release carbon dioxide and water. The water regenerates the calcium carbonate and the carbon dioxide emerges as a gas.

Simultaneously with the formation of carbonic acid, nitrous oxide will combine with the moisture of the steam to form nitrous acid which is neutralized by the calcium carbonate. The aluminum oxide functions as a back up neutralization agent for nitrogen oxides and the activated charcoal functions as an absorber of carbon monoxide, carbon dioxide, the hydrocarbons, the nitrogen oxides and lead additives to the fuel.

From the filter chamber 51, the steam-gas mixture enters the condensing conduit 53 where it is cooled and condensed, thereby separating the liquid from the gas. The liquid and gas are delivered to the hot well 30. From the hot well, the exhaust gases enter the exhaust stack 30a. A portion of the exhaust gases will be diverted via the tube 73 to the intake manifold of the engine, passing through the air cleaner 71. The remainder of the exhaust gases will be exhausted to atmosphere from the exhaust stack.

Apparatus constructed in accordance with the invention has been tested and temperatures at various points along the system taken. For example, the temperature of exhaust gases at the exhaust ports of the engine has been measured at 1,650°F., the temperature of exhaust gases in the cylinders 11 has been measured at 614°F., and the temperature of gases leaving the exhaust stack 30a has been measured at 180°F.

Tests of the exhaust emitted from the exhaust stack have shown hydrocarbons to be present to the extent of 25 parts per million, carbon monoxide to be present to the extent of 0.21 percent and nitrogen oxides to be present to the extent of 80 parts per million. These results are at least as good as the results targeted for the year 1980 by the Department of Commerce.

The quenching or cooling of the exhaust gases in the heat exchangers 10 results in additional advantages. The quenching of the gases necessarily reduces their

volume and their velocity. The reduction in volume, coupled with the positive withdrawing or acceleration of the gases from the cylinders 11 due to the low pressure generated by the venturi in each of the ejectors 41, reduces the back pressure exerted on the engine and, consequently, increases the engine efficiency. Although normal exhaust manifold back pressure is considered to range from 24 to 28 psia, the back pressure measured with apparatus constructed in accordance with the invention ranges between 19 and 20 psia under steady operating conditions.

An additional advantageous characteristic of apparatus constructed in accordance with the invention resides in the silencing or muffling of engine noise without the necessity of a conventional muffler. Exhaust gases contain a large level of noise energy as they pass directly from the engine. Noise attenuation, to a large extent, is a function of the passage of time required for the noise energy to pass through a system. Any means for extending the time required for the noise to pass through the system, therefore, will reduce the level of noise emitted. Quenching of the exhaust gas temperature in apparatus constructed according to the invention from 1,650°F. to 180°F. slows the computed gas velocity from 2,130 feet per second to 675 feet per second for a reduction ratio of 3.15 to 1. Moreover, sound carried within a moving gas travels at a velocity that is directly proportional to the square root of the absolute temperature of that gas. Thus, a reduction in both velocity and temperature of the gas will result in deceleration of the sound wave.

A sound wave is a series of moving sonic pressure crests and troughs and sound energy is propagated by the molecular motion of gas molecules as the energy of the sound becomes superimposed on the existing random kinetic energy of gas molecules. As sound energy is added to the velocity of a gas molecule, the resultant energy forms a group of higher energy molecules or a zone of high pressure flanked on opposite sides by zones of lower pressure. As the molecules move out of the higher pressure zone into a zone of lower pressure, they strike and otherwise give momentum to the molecules of the lower pressure zone. In such manner, the molecular motion becomes the carrier wave upon which the sound is superimposed and transported, molecule to molecule, until the sound becomes audible. As the pressure waves build and weaken, so does the temperature. Thus, if heat is removed from the higher pressure molecules there will be a decided equalization of temperature effect which, in turn, equalizes pressure differences and thereby effectively absorbs the sound energy.

Relating the foregoing to the disclosed apparatus, the molecules of gas exhausted from the engine cylinders will form sound waves having molecular groups of greater and lower pressures. The molecules of the greater pressure groups will give up their heat in the heat exchangers 10 more quickly than will the molecules of the lower pressure group, thereby tending to equalize the temperatures and pressures of the groups of molecules and effecting absorption of the sound energy.

Apparatus constructed in accordance with the invention is adapted for use not only on newly manufactured engines, but is equally well adapted for use on existing engines. The only modification of an existing engine that is required to permit the apparatus to be incorpo-

rated therewith is to replace the conventional exhaust manifold system with the heat exchangers 10 and their associated parts.

The apparatus also is capable of use in connection with oil, coal or gas fire boilers. The important characteristics of the invention are that the exhaust products of combustion be cooled substantially instantaneously upon their discharge from the combustion chamber and that the temperature of the exhaust products be such as to convert liquid to steam, followed by mixing of the exhaust gases and steam.

It is not necessary that the system be a closed one in which the liquid that is utilized as the supply for the steam be recirculated through the apparatus. Instead, a source of fresh feed liquid may be maintained and the condensate from the steam collected without recirculation.

The disclosure is representative of presently preferred methods and apparatus, but is intended to be illustrative rather than definitive of the invention. The invention is defined in the claims.

I claim:

1. A method of reducing undesirable emissions caused by the combustion of hydrocarbon fuel, said method comprising introducing a mixture of fuel and air to a combustion chamber in a lean ratio such as to provide an excess of air sufficient to minimize the formation of carbon monoxide and to assure combustion of said fuel at a temperature in excess of about 1,450°F.; combusting said fuel in said chamber; exhausting the gases of combustion from said chamber; and quenching said gases to a temperature below about 1,450°F. substantially instantaneously upon their exhaust from said combustion chamber to inhibit the formation of oxides of nitrogen.

2. The method set forth in claim 1 wherein the quenching of said gases is accomplished by converting a liquid to steam by means of the heat of said gases.

3. The method set forth in claim 2 including mixing said gases and said steam following the quenching of said gases.

4. The method set forth in claim 3 including condensing said steam to liquid and separating the condensed liquid from said gases.

5. The method set forth in claim 4 including recycling a portion of separated gases to said combustion chamber.

6. A method of reducing undesirable emissions caused by the combustion of hydrocarbon fuel, said method comprising introducing a mixture of fuel and air to a combustion chamber in a lean ratio such as to provide an excess of air sufficient to minimize the formation of carbon monoxide and to assure combustion of said fuel at a temperature in excess of about 1,450°F.; combusting said fuel in said combustion chamber; exhausting the gases of combustion from said chamber into a receiver; introducing to said receiver a liquid convertible to steam by the heat of said gases and in such quantity as to quench gases in said receiver to a temperature below about 1,450°F.; and discharging said gases and said steam from said receiver along separate paths.

7. The method set forth in claim 6 including establishing a low pressure zone externally of said housing by means of said steam to accelerate the discharge of said gases from said housing.

8. The method set forth in claim 7 including mixing said quenched gases and said steam.

9. The method set forth in claim 8 including filtering the mixture of steam and gases.

10. The method set forth in claim 9 wherein the filtering of the mixture is accomplished with material selected from the class comprising aluminum oxide, activated charcoal, and calcium carbonate.

11. The method set forth in claim 8 including converting carbon monoxide in said gases to carbon dioxide.

12. The method set forth in claim 8 including converting oxides of nitrogen in said gases to nitrous acid.

13. The method set forth in claim 8 including condensing said steam to separate said steam and said gases.

14. The method set forth in claim 13 including recycling a portion of said separated gases to said combustion chamber.

15. Apparatus for treating noxious gases of combustion exhausted from a combustion chamber at a temperature sufficiently high to convert an aqueous liquid to steam, said apparatus comprising housing means; inlet means communicating with said housing means for admitting gases to said housing means; outlet means communicating with said housing means for discharging gases from said housing means; liquid conduit means; means supporting said liquid conduit means within said housing means in the path of gases admitted to said housing means; means for introducing an aqueous liquid to said liquid conduit means whereby the heat of the gases may convert said liquid to steam; steam conduit means in communication with said liquid conduit means for receiving steam herefrom; ejector means in communication with said outlet means and with said steam conduit means and operable in response to the flow of steam through said steam conduit means to establish a reduced pressure zone at said outlet means to accelerate the discharge of gases from said housing means; means forming a mixing chamber downstream from said ejector means; means establishing communication between said mixing chamber means and said ejector means whereby said gases and said steam may be delivered to and mixed in said mixing chamber means; means for condensing said steam and separating said gases therefrom; and means for recycling at least part of the separated gases to the combustion chamber.

16. The apparatus set forth in claim 15 including filter means interposed between said mixing chamber means and said condensing means.

17. The apparatus set forth in claim 16 wherein said filter means comprises materials selected from the class comprising aluminum oxide, activated charcoal, and calcium carbonate.

18. The apparatus set forth in claim 15 wherein said liquid conduit means comprises at least one tube.

19. The apparatus set forth in claim 15 wherein said liquid conduit means comprises a cluster of tubes.

20. The apparatus set forth in claim 19 including means mounting said cluster of tubes for rotation.

21. Apparatus for treating exhaust gases of fuel combusted in a combustion chamber, said apparatus comprising means for delivering a mixture of fuel and air to said chamber in a lean ratio such as to provide an excess of air sufficient to minimize the formation of car-

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bon monoxide and to assure combustion of said fuel at a temperature in excess of about 1,450°F.; a housing having an inlet in communication with said chamber for receiving exhaust gases therefrom and an outlet through which said gases may be discharged; liquid conduit means supported in said housing in the path of gases admitted thereto; means for supplying said liquid conduit means with a liquid convertible to steam by the heat of said gases and in such quantity as to cool said gases to a temperature below about 1,450°F. substantially instantaneously upon the admission of said gases to said housing; steam conduit means in communication with said liquid conduit means for receiving steam therefrom; ejector means in communication with said outlet and with said steam conduit means and operable in response to the flow of steam through said steam conduit means to establish a reduced pressure zone at said outlet to accelerate the discharge of gases from said housing; mixing chamber means downstream from said housing outlet for mixing said gases and said

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steam; means downstream from said mixing chamber means for condensing said steam and separating said gases therefrom; means for venting gases separated from said steam; and means for recycling at least part of the separated gases to said combustion chamber.

22. The apparatus set forth in claim 21 including filter means interposed between said mixing chamber means and said condensing means.

23. The apparatus set forth in claim 22 wherein said filter means comprises materials selected from the class comprising aluminum oxide, activated charcoal, and calcium carbonate.

24. The apparatus set forth in claim 21 wherein said liquid conduit means comprises at least one tube.

25. The apparatus set forth in claim 21 wherein said liquid conduit means comprises a cluster of tubes.

26. The apparatus set forth in claim 25 including means mounting said cluster of tubes for rotation.

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