

Oct. 5, 1965

C. W. MORRIS ETAL
ADAPTABLE AFTERBURNER

3,209,531

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2 Sheets-Sheet 1

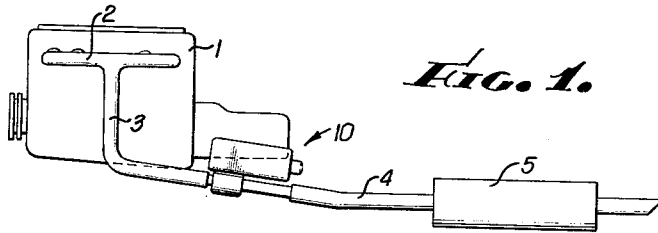


FIG. 1.

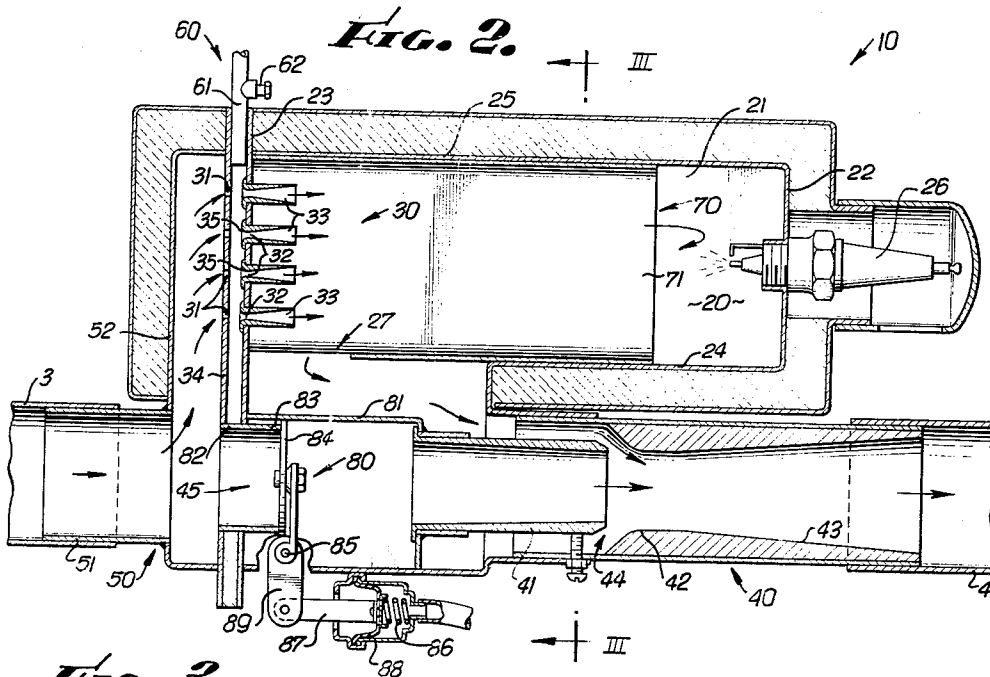


FIG. 2.

FIG. 3.

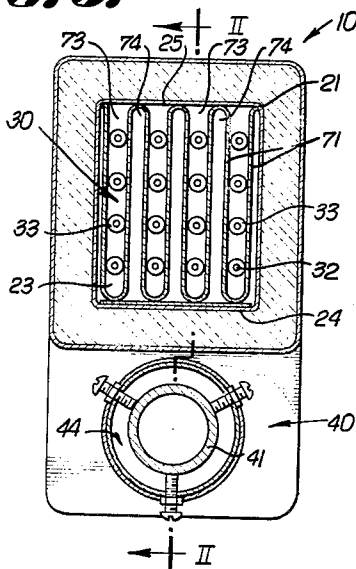
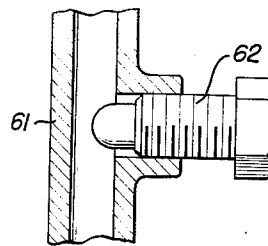


FIG. 4.



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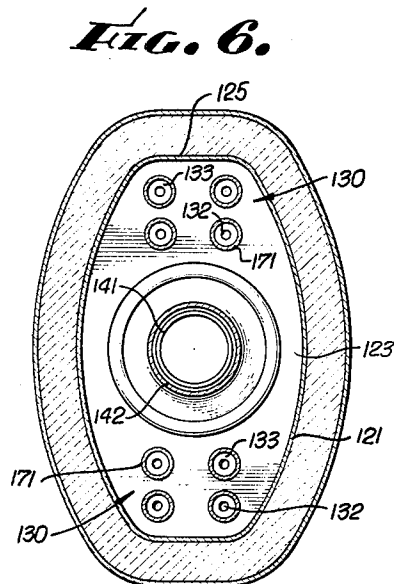
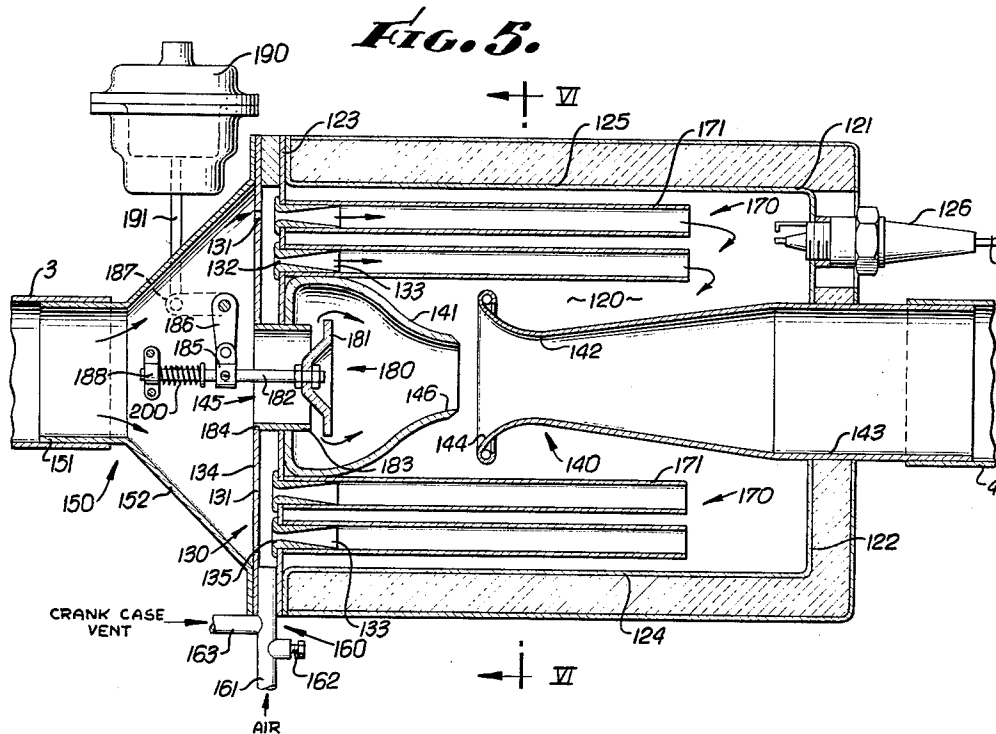
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2 Sheets-Sheet 2



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3,209,531

ADAPTABLE AFTERBURNER

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32 Claims. (Cl. 60—30)

In general, the present invention relates to a device for reducing the content of hydrocarbons, carbon monoxide, oxides of nitrogen and other noxious components in exhaust gases from internal combustion engines. More particularly, the present invention pertains to a compact, lightweight, inexpensive device which is free from numerous adjustable parts, is readily installed and easily adaptable for a wide variety of internal combustion engines, and is capable of operating efficiently over a wide range of engine operating conditions and rapidly obtains the temperature required to eliminate those compounds generally considered to be the primary cause of air contamination such as smog.

Studies have established that the contamination of the atmosphere in and around metropolitan centers is primarily due to the presence of hydrocarbon gases. It has also been established that the major contributing cause to such atmospheric pollution is the tremendous volume of hydrocarbon gases, carbon monoxide and nitrogen oxide discharged into the atmosphere from the exhaust and crankcases of automobiles and other vehicles driven by internal combustion engines. During idling and deceleration the exhaust gases carry very large quantities of hydrocarbons and carbon monoxide; during acceleration and at ordinary cruising speeds the hydrocarbon content of the exhaust gases is not excessive but there is a substantial concentration of nitrogen oxide gases in such exhaust gases. In metropolitan areas the progress of an automotive vehicle is a succession of idling interspersed with bursts of acceleration and periods of rapid deceleration; as a result, extremely large quantities of hydrocarbon gases, carbon monoxide and nitrogen oxides are discharged into the atmosphere. Research has shown that during deceleration as high as 15% of the fuel is actually pumped out of the exhaust system in an unburned condition.

However, the flexibility of an internal combustion engine introduces a great number of very difficult problems in the treatment of its exhaust gases. The operating conditions of an internal combustion engine may be classified as idling, deceleration, acceleration and cruising speeds. The hydrocarbon content of the exhaust gases varies greatly under these different operating conditions as does carbon monoxide and the nitrogen oxides. For example, during idling and deceleration the hydrocarbon content of the exhaust gases is high whereas during acceleration and cruising it is relatively low. An average internal combustion engine of the character used in an automobile may carry 800 p.p.m. of hydrocarbons in its exhaust during idling. This may drop to 200 p.p.m. during acceleration and cruising, but during deceleration the hydrocarbon content of the gases being exhausted may readily reach 5500 p.p.m.

Similarly, the carbon monoxide content of exhaust gases may vary from 6% during idling, to 2½% during acceleration, to 0.5% during cruising and rise to 4% during deceleration. In addition, temperatures above 1200° F. are required to cause combustion of carbon monoxide and temperatures above 1500° to 2000° F. are necessary in order to obtain complete combustion of carbon monoxide. The exhaust temperature (at the outlet of an exhaust manifold of an internal combustion engine) may vary from 400° F.—600° F. during deceleration to

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about 800° F. during idling. Similarly, during cruising speeds the temperatures reach 800°–900° F. and during acceleration reach 1100° F.—1200° F. It can easily be seen that during normal operation, the engine temperature is not sufficiently high to actually burn or cause combustion of carbon monoxide.

Another variable which must be taken into consideration comprises the volumetric flow of exhaust gases; the volumetric flow is ordinarily low during idling and deceleration, e.g., 5–10 cubic feet per minute, but it is high during acceleration and cruising, e.g., greater than 100 cubic feet per minute. Moreover, the pressure of the exhaust gases also varies within wide limits. The pressure of the exhaust gases is ordinarily low during idling and deceleration but is high during acceleration and cruising.

In addition to the effect on exhaust gases, the widely varying operating conditions have a major effect on the vent gases from the crankcase. At all times during the operation of an internal combustion engine, a significant amount of evaporation takes place from the hot oil in the crankcase and these vapors are usually discharged to the atmosphere through the oil-filling aperture. However, during cruising and particularly during acceleration, the quantity of vent gases from the crankcase is greatly increased because combustion gases from the cylinders blow by the pistons into the crankcase. In fact, the quantity of crankcase vent gases in total is so great that it has been estimated that it contributes 10% to 40% of noxious gases discharged by vehicles, such as hydrocarbons and carbon monoxide.

Finally, it should be noted that there is a substantial proportion of nitrogen oxide in the exhaust gases, particularly during acceleration and cruising. It has been found that if the proportion of exhaust gases containing such nitrogen oxide is cooled to preferably atmospheric temperature or at least below 150° F. and then recycled into the intake manifold of the engine, a substantial reduction of the total content of these components conventionally discharged to the muffler or the atmosphere is effected.

These varying characteristics of an internal combustion engine and its exhaust gases have heretofore presented practically insurmountable problems with the notable exception of the devices disclosed in the copending applications of Charles W. Morris, Serial No. 10,405, dated February 23, 1960, and Serial No. 90,783, dated February 21, 1961, now Patent Nos. 3,037,344 and 3,083,525 respectively. As is generally known in the afterburner art, the County of Los Angeles, State of California, is presently intensively testing all available afterburners to ascertain which, if any, can meet standards which have been set up by the State of California for reducing the noxious portions of exhaust gases, such as hydrocarbons. Based on preliminary test results, of all available afterburners tested to date, only the devices disclosed in the aforementioned copending applications have been found to meet the required State standards. Except for the aforementioned devices, not only have the prior art devices failed to achieve a practical level of efficiency, but also they have generally involved such complicated systems, usually including catalysts and such material modifications of the normal carburetors, cooling systems, etc., as to render them completely unacceptable. A device capable of being used on millions of automobiles and trucks must be simple and effective without the necessity of employing an engineer to operate the device. The average owner of an automobile is not in a position to spend a large sum of money on a device of a complicated nature requiring hours of labor in order to adapt and install the device in his vehicle.

For example, it should be noted that the way the hydrocarbon gases and carbon monoxide are usually rendered

innocuous is to complete their oxidation to water and carbon dioxide. However, such combustion process requires large quantities of oxygen or air in excess of the stoichiometric amounts in order to insure that it will be carried to completion. As already noted, such combustion process also requires high temperatures so it is necessary that these large amounts of air be supplied to a device which maintains these high temperatures so that the combustion process may proceed. In practice, this means that any such combustion device or afterburner should receive up to 50% added air by volume during low exhaust gas flow conditions such as idling and deceleration. Prior art devices either just ignore this problem which resulted in relatively incomplete combustion or required complicated additional pumping devices to charge the necessary air into the afterburner.

In common with the devices disclosed in the aforementioned copending applications, the device of the present invention may be installed not only on new vehicles but also on cars and trucks now in service. It is to be remembered that for every new automotive vehicle there are approximately seven vehicles of older vintage now in service, and it is essential that these older vehicles be equipped with the devices which correct, ameliorate and render innocuous the exhaust gases being discharged thereby. The present invention is therefore directed to a compact device which is readily attached to automobiles and trucks now in service and which does not require modification of such existing vehicles. In fact, the present invention, if desired, may be readily attached to the mufflers presently used in vehicles without adding substantially to their size. The present invention is directed to a device which is capable of effectively destroying or minimizing the hydrocarbons and carbon monoxide content of exhaust gases from internal combustion engines without problems such as requiring periodic charging with fresh catalyst or regeneration of catalyst. The device of the present invention can be manufactured economically in large quantities, sold at a reasonable price, and installed by any mechanic without difficulty. It does not require the attachment to or interference with carburetors or cooling systems. It does not impose any substantial drain upon the electrical system of a vehicle. Thus, the same device can be adjusted and effectively used on a wide variety of internal combustion engines such as 4-cylinder, 6-cylinder or 8-cylinder engines.

It should be noted that the devices of the aforementioned copending applications as well as the device of the present application achieve the advantageous results just described. However, the device of the present invention incorporates substantial changes over the devices described in the aforementioned copending applications, and these changes yield additional substantial advantageous results. For example, the device of the present invention utilizes a unique combination of gas flow patterns and heat exchange surfaces to obtain operating temperatures very quickly and achieve improved performance over a wide range of operating conditions. In addition, the device of the present invention is substantially easier to manufacture and is readily adaptable to any size of internal combustion engine. Further, the device of the present invention maintains proper pressure conditions throughout its parts so as to obtain the desired gas flow throughout the device.

In general, one of the objects of the present invention is to disclose and provide a small, compact, inexpensive afterburner which may be readily attached not only to new internal combustion engines and vehicles employing the same, but which can also be adapted and attached to existing vehicles.

Another object of the present invention is to disclose and provide a simple afterburner which does not employ catalysts and in which operative temperatures are rapidly reached so that the major proportion of hydrocarbons and carbon monoxide contained in the exhaust gases may

be consumed and burned even during short periods of operation.

A still further object of the present invention is to disclose and provide an afterburner capable of burning exhaust gases with air added in approximate accordance with the variation in the hydrocarbon content of said gases under different operating conditions of the engine, such variations being accomplished automatically and without the use of complicated or expensive machinery or instrumentation.

A still further object of the present invention is an afterburner capable of minimizing the nitrogen oxide content of exhaust gases.

A further object of the present invention is an adaptable, easily manufactured afterburner having gas flow patterns and heat exchange surfaces therethrough adapted to achieve the ultimate efficiency for the afterburner over a wide range of operating conditions.

Still a further object of the present invention is an afterburner designed to maintain the proper pressure therethrough over a wide range of operating conditions.

These and various other objects, uses and advantages of the present invention will become apparent to those skilled in the art from the following description of certain exemplary forms that this invention may assume in actual practice.

Generally stated, the invention contemplates the admixing of air to exhaust gases from an internal combustion engine in a bank of small primary venturi pumps. Fixed orifice means admit exhaust gases from supply means, communicating with an internal combustion engine, to each of the primary venturi pumps. Additional means are provided for supplying gases, as air or crankcase gas, to the throat section of each primary pump where the exhaust gas and added gases are thoroughly mixed.

Combustion of the mixed exhaust gases and added gases (as air) is accomplished in an enclosed burner chamber having ignition means mounted therein and an outlet therefrom remote from the ignition means. The diffuser sections of each of the primary venturi pumps discharge into the burner chamber. Preferably, means are provided for conducting the flow of incoming and outgoing gases in predetermined gas flow patterns whereby the incoming gases are in heat exchange relation with the outgoing ignited gases. Such means may direct gases from the small venturi pump diffuser sections between heat exchanger wall means to an end of the ignition chamber near the ignition means. Flow of ignited or combusted gases to the outlet of the chamber remote from the ignition means may be directed by such means between the heat exchanger wall means in counter current, heat exchange relation to the gases in and flowing from the diffuser sections.

A large secondary venturi pump having inlet, throat and diffuser sections is also provided where the inlet section is in valve modulated communication with the supply means connected to the internal combustion engine and the throat section is provided with a port in communication with the outlet of the burner chamber. Gas flow through the large venturi pump may be comprised of by-passed gases entering the inlet section from the exhaust gas supply means and combusted gases from the primary venturi pumps and the burner chamber entering the throat section. Back pressure on the bank of primary venturies may be regulated by the large venturi pump, its throat section being in series therewith, by regulating the gas flow through the large venturi. Such regulation may be effected by valve means, responsive to the operating conditions of the internal combustion engine, for modulating the flow of exhaust gases from the supply means, by-passing the bank of primary venturi pumps and entering the large venturi pump inlet section. The secondary, large venturi pump may be adjusted to insure proper functioning of the bank of small, air admixing, venturies and to add a desired proportion of air to ex-

haust gas or, when re-introduction of exhaust gases to reduce the nitrogen oxide content of the exhaust gases is desired, to reduce the pumping effect of the large venturi and cause a portion of the exhaust gases to flow back to the carburetor intake. Also, the provision of the secondary large venturi pump, allowing by-passing of exhaust gases past the primary venturies, allows the amount of air admixed with the exhaust gases in the bank of primary venturies to remain substantially unchanged when the volume of exhaust gases is increased more than twice the minimum volume of exhaust gases.

In order to facilitate understanding of the device of the present invention, reference will now be made to the appended drawings of some specific embodiments of the present invention:

FIG. 1 is a diagrammatic side view of an internal combustion engine and its exhaust system equipped with one form of the present invention;

FIG. 2 is a longitudinal section taken through one form of the device of the present invention illustrated in FIG. 1;

FIG. 3 is a transverse section taken along the plane III—III in FIG. 2;

FIG. 4 is a detail view of a portion of the device of FIGS. 1 through 3;

FIG. 5 is a longitudinal section taken through another form of the device of the present invention illustrated in FIG. 1; and

FIG. 6 is a transverse section taken along the plane VI—VI in FIG. 5.

The ease with which the device of the present invention may be installed in a conventional internal combustion engine-exhaust system is exemplified by FIG. 1. As there shown, the internal combustion engine 1 is provided with the usual exhaust manifold 2 having an exhaust outlet 3. Ordinarily, such exhaust outlet is connected as by means of a pipe 4 with a muffler 5. The device of the present invention, generally indicated by the numeral 10, is inserted in pipe 4 between the exhaust muffler 5 and the exhaust outlet 3. A portion of the normal exhaust pipe 4 may be cut away and means provided for attaching the device 10 so as to be in the path of the normal exhaust gases from the manifold. Such installation may be accomplished by any mechanic and by the use of suitable adaptors, variations in diameter of exhaust pipe, etc., being readily compensated for. It should be noted that the entire device 10 occupies not more than one-half foot of cubic space and generally only about one-third of a cubic foot of space, and such small volume can readily be installed in a number of positions along the exhaust pipe 4 between the exhaust manifold 2 and the muffler 5.

Although a device embodying the mode of operation of the present invention may assume many forms and modifications, the exemplary form shown in FIGS. 2, 3 and 4 is illustrative of the teachings of this invention. The device is indicated generally at 10, and includes an enclosed burner chamber 20; a bank of small primary venturi pumps, indicated generally at 30; a large secondary venturi pump, indicated generally at 40; exhaust gas supply means, indicated generally at 50; additional gas supply means, indicated generally at 60; means for directing flow of gases within chamber 20 in predetermined gas flow patterns, indicated generally at 70; and valve means, indicated generally at 80, for modulating by-pass flow of exhaust gas from the exhaust gas supply means to the secondary venturi pump.

Burner chamber 20 is preferably an enclosed burner or combustion chamber formed by an enclosure 21 having opposing end walls 22 and 23, respectively, and opposing side walls 24 and 25, respectively. Ignition means 26, which may consist of a conventional sparkplug, is mounted in the burner chamber 20 on an end wall, preferably the far end wall 22 relative to the bank of primary venturi pumps indicated generally at 30. An outlet, indicated at 27, is located in one side wall 24 preferably adjacent the end wall 23, near the bank of primary venturi

pumps, in side wall 24 and remote from the ignition means 26.

A bank of small primary venturi pumps, indicated generally at 30, is provided to receive exhaust gas from an internal combustion engine, admix an additional gas such as air, and diffuse the mixture into the burner chamber 20. As shown in FIGS. 2 and 3, the bank of small primary venturi or injector pumps includes a plurality of individual venturi or injector pumps having throat sections 32 and diffuser sections 33 mounted on end wall 23 with diffuser sections 33 positioned with their axes generally parallel and positioned to discharge into burner chamber 20. Fixed orifice means for admitting exhaust gases from the exhaust gas supply means to each primary venturi pump are provided in the exemplary embodiment by the generally vertical ported wall 34, spaced from the end wall 23 of the burner chamber 20 wherein the throat sections 32 and diffuser sections 33 of the primary venturi pumps are mounted. Orifices 31, or their ports, on the wall 34 may be considered to comprise inlet sections for each of the respective primary venturi pumps with which they are aligned.

Exhaust gas supply means, indicated generally at 50, may include a tubular inlet 51 adapted to be connected to the internal combustion engine exhaust outlet or pipe 3 and a housing 52 adapted to direct exhaust gases to the fixed orifice means, as wall 34, and the inlet sections, or orifices 31, of the primary venturi pumps.

Additional means for supplying an additive gas, such as air, to the primary venturi pumps to be mixed with the exhaust gases is indicated generally at 60. Such means, as in the exemplary embodiment, may include a housing formed by the fixed orifice plate or wall 34 and burner chamber end wall 23. An additive gas (such as air) inlet conduit 61 may extend between walls 34 and 23 and be provided with closure means 62, as shown in detail in FIG. 4, for regulating the supply of additive gas into the space between walls 34 and 23. Since the inlet section of each primary pump is formed in the fixed orifice plate or wall 34 which is spaced from the wall 24 in which the throat sections 32 of each pump are mounted, the additive gas entering such space is readily entrained into the flow of exhaust gas from the orifice to the throat sections. Each throat section is provided with a port 35 extending completely around its perimeter opening the throat section to this additive gas. Preferably, the throat sections 32 using units of inches have a ratio of perimeter to cross-sectional area of at least about 20 to 1. The additive gas is supplied directly to and completely around the perimeter of the ports 35 in the throat sections 32 without preheating and in variable amounts controlled by the setting of closure means 62.

Means for directing flow of gas within chamber 20 in predetermining heat exchange relation are provided and are indicated generally at 70 in the exemplary embodiment of FIGS. 2 and 3. Such means may include conduit means or heat exchanger wall means. In the exemplary embodiment, convoluted metal sheet 71 provides a series of generally vertical space heat exchanger walls with the diffuser sections 33 of the primary venturi pumps disposed in alternative convolutions. Gas flow from the bank of primary venturi pumps is thus in a pattern of spaced, vertically extending columns of flow moving toward the far end or wall 22 and the ignition means 26. The flow of ignited or combusted gases from the combustion or burner chamber out of the outlet 27, preferably remotely spaced from ignition means 26 and near the bank of primary venturi pumps, is directed in between the other convolutions in a gas flow pattern counter current to the incoming gases and in heat exchange relation thereto. Referring to FIG. 3, the incoming gases flow in alternative convolutions as 73 while the outgoing gases flow in the other convolutions as 74.

Large secondary venturi pump, indicated generally at

40, has an inlet section 41, a diffuser section 43 and a throat section 42. Inlet section 41 is in communication with the exhaust gas supply means, indicated generally at 50, as shown in FIG. 2. Throat section 42 is provided with an adjustable port, indicated at 44, in communication with the outlet 27 from the burner chamber 20. The back pressure in chamber 20 acting on the bank of primary venturi is directly effected by the back pressure of the large venturi pump and the size of adjustable part 44.

Valve means for modulating the flow of exhaust, gases from the supply means, indicated generally at 59, to the inlet 41 through opening 45 of the secondary venturi pump are provided. Such means, as indicated generally at 80, may include a valve housing 81 receiving the inlet section 41 and an inlet conduit 82, disposed between housing 81 and supply means 50. Conduit 82 provides a flange portion 83 having an end acting as a limit stop for valve 84. The modulating valve may include a valve plate 84 mounted on a pivot axis 85 wherein valve 84 is adapted to seat upon or abut limit stop 83. Valve means 80 is adapted to maintain valve 84 closed upon flange or stop limit 83 during idling and deceleration to direct all exhaust gases from the internal combustion engine 1 to the inlet sections 31 or fixed orifice means of the small venturi pumps, indicated generally at 30. Valve 84 is preferably biased into an open position by a spring 86 and moved to the closed position by a pneumatic motor means 88 connected through link 87 and arm 89, the arm 89 being rotatable upon pivot pin 85. The valve means is responsive to increased absolute engine intake manifold pressure and to the increase in flow of exhaust gas from the engine 1, as upon acceleration thereof, and bypasses a portion of the exhaust gases past the small venturi pumps and burner chamber 20 through the large venturi pump, since its opening bias may become effective during periods of high exhaust gas flows. By thus controlling the proportion of exhaust gases admitted directly to the large secondary venturi pump in response to operating conditions of the internal combustion engine, the volume of air admixed with exhaust gases under idling conditions may be maintained less than about 40% of the volume of exhaust gases supplied to the bank of primary venturi pumps and the volume of air admixed under all other conditions of load, power and speed not over twice the volume of air added under idling conditions. The addition of air to the exhaust gases in the bank of primary venturi pumps is thus provided in a fairly uniform quantity due to the presence of the large secondary venturi. The provision of a single usual type of venturi would add increasing amounts of additive gas, as air, to the exhaust gases with an increase in the rate of flow of such exhaust gases therethrough. For example, if the conventional single venturi pump would add two cubic feet of air per minute when the exhaust gas flow therethrough was five cubic feet per minute (an amount equal to 40%), it would add about sixteen cubic feet of air per minute when the exhaust gas flow increased to forty cubic feet of air per minute. The combination of a bank of primary venturi pumps and a large secondary venturi pump as herein described operates in a different manner and obtains a different result; it can be set to add a predetermined volume of air under low exhaust flow conditions (as when an engine is idling) and not more than $1\frac{1}{2}$ or twice that amount under all other conditions of load, power and exhaust flow. Preferably, under idling conditions, the volume of added air by this device is less than 40% of the volume of exhaust gases (for example, when the exhaust gas flow is 5 c.f.m. there is added not over 2 c.f.m. and generally between 1.5 and 1.9 c.f.m. of air). Under all other conditions of operation and exhaust gas flow, even when the exhaust gases are supplied to the device at the rate of 40 c.f.m., the device will preferably add not over 4 c.f.m. of air.

An alternative exemplary embodiment of the after-

burner device, according to the invention, is shown in FIGS. 5 and 6. The large secondary venturi pump, indicated generally at 140, is centrally located within burner chamber 120 and the means for directing the flow of gases within burner chamber 120, as indicated generally at 170, is provided generally around the large venturi pump.

As in the embodiment of FIGS. 2, 3 and 4, there is provided an enclosed burner chamber 120 comprising an enclosure 121 having end walls 122 and 123, respectively, and side walls 124 and 125, respectively. Ignition means 126 are mounted therein on wall 122 and there is an outlet therefrom provided remote from the ignition means. Such outlet is provided by the port 144 in the throat 142 of the alternative form of secondary venturi pump, as shown in FIG. 2.

A bank of small primary venturi pumps, indicated generally at 130, are provided as in the embodiment of FIGS. 2, 3 and 4 having inlet sections 131 formed in the fixed orifice plate or wall 134; throat sections 132 mounted in wall 123 and having ports 135 opening to the additional supply means for supplying an additive gas comprising air, indicated generally at 160; and axially parallel diffuser sections 134 extending into and discharging into the burner chamber 120. An alternative form of exhaust gas supply means 150 is shown in FIG. 5 including an inlet 151 and a generally symmetrical housing 152 directing exhaust gas from exhaust pipe 3 to the fixed orifice means or primary venturi pump inlet section 134.

Means for conducting gases from the burner chamber in counter current, heat exchange relation to gases in the diffuser sections are provided in an alternative embodiment 170 comprising a plurality of tubes or conduits 171. Each tube or conduit 171 directs exhaust gases from a diffuser section toward the far end 122 of burner chamber 120 and ignition means 126. The pattern of gas flow into the chamber is thus comprised of a plurality of individual spaced, generally parallel, tubular gas flows. Ignited or combusted gas is removed from chamber 120 by the ported throat section 142 of the large venturi pump, indicated generally at 140, by the port 144 positioned remote from the ignition means and nearer to the bank of primary venturi pumps than the open ends of the conduits or heat exchanger tubes 171. Flow of combusted gases from chamber 120 is thus in counter current, heat exchange relation to the inflowing exhaust gases.

Large secondary venturi pump, indicated generally at 140, according to the alternative exemplary embodiment of FIGS. 5 and 6 includes an inlet section 141 spaced from the combination throat section 142 and diffuser section 143. Inlet section 141 has a relatively large cross-sectional area initially and necks down to a smaller nipple or discharge orifice portion 146. The initially enlarged cross-section is provided to facilitate flow of gas thereto from the alternative embodiment of valve means 180. Inlet section 141 is disposed with its discharge opening section 146 spaced from and in alignment with the port 144 or bell end inlet opening of the throat section 142. Throat section 142 is thus open at port 144 to the inlet section 141 and the burner chamber 120. The back pressure on the bank of primary venturi pumps 130 is therefore controlled by the back pressure and flow condition of the large venturi pump as in the embodiment of FIGS. 2, 3 and 4.

Valve means for modulating the flow of exhaust gases from the supply means, indicated generally at 150, to the inlet 141 of the secondary venturi, in the exemplary embodiment of FIGS. 5 and 6 are indicated generally at 180. Such modulating valve means is responsive to the operating conditions of engine 1 and includes a valve cap 181 mounted upon a slidable shaft 182. Valve cap 181 closes upon a stop limit or flange portion 183 of valve inlet 184 controlling the flow of exhaust gas into the inlet section 141 through opening 145. Shaft 182 is slidably mounted in a sleeve member 188 mounted to hous-

ing 152, and is axially actuated by attached fitting 185 depending from crank arm 186. Crank arm 186 is pivotally mounted on housing 152 and is adapted by an arm 187, shown in phantom line, to be controlled by a rod 191 depending from a pneumatic motor 190. The modulating valve, indicated generally at 180, may thus be operated by pneumatic motor 190 which is made responsive to intake manifold suction. By means of pneumatic motor 190, a decrease of pressure in the intake manifold closes the modulating valve means 180 against the countering load of a spring means 200 which opens the valve at higher intake manifold pressures. An increase in vacuum above about 16 inches of mercury preferably closes the modulating valve. A countering load is provided by spring means 200 which preferably opens the valve at vacuum pressures between zero and 15 inches of mercury.

When internal combustion engine 1 operates under idling or deceleration conditions, modulating valve means 80 (FIGS. 2 and 3) or modulating valve means 180 (FIGS. 5 and 6) close openings 45 or 145 to the large secondary venturi pump indicated generally at 40 or 140. Consequently, all the exhaust gases from the internal combustion engine pass through inlets 31 or 131 to the small venturi pumps 30 or 130. The exhaust gases then pass through throats 32 or 132 of venturi pumps 30 or 130 and thereby suck air and/or crankcase vent gases through ports 35 or 135 from additive gas supply means 60 or 160. The mixture of exhaust gases with these added gases is then discharged by the diffuser sections into burner chamber 20 or 120 where it is ignited by ignition means 26 or 126. The burning mixture of gases is conducted out of burner chamber 20 or 120 in counter current heat exchange relation to the exhaust gases entering the burner chamber. The mixture of gases then leaves the burner chamber by passing through port 44 or 144 in throat 42 or 142 of the large venturi 40 or 140 to the muffler.

When the internal combustion engine 1 is operated under accelerating or cruising conditions, the modulating valve 80 (FIGS. 2 and 3) or modulating valve 180 (FIGS. 5 and 6) opens substantially proportionately to the volume of exhaust gases produced by the internal combustion engine. A portion of the exhaust gases then passes through opening 45 or 145 directly into inlet 41 or 141 and throat section 42 or 142 of the large venturi pump and then to the engine muffler.

Exhaust gases from an internal combustion engine which is cruising or accelerating, are at relatively high temperatures (800° F.-1200° F.) and contain relatively low proportions of hydrocarbon (about 200 p.p.m.) and carbon monoxide. A very small proportion of air, if any, is thus needed to be added to exhaust gases and such exhaust gases are supplied to the device at relatively high volume and pressure. It should be noted particularly that during acceleration and cruising considerable amounts of air are present in the exhaust gases entering the device of the present invention. Such air enters through the carburetor and remains unused in the engine. During idling and deceleration, exhaust gases are at lower temperatures (400° F.-800° F.) and are supplied in lower volume and at lower pressures. However, the exhaust gases during deceleration and idling carry a high proportion of hydrocarbon (5000-5400 p.p.m.) and a large proportion of air needs to be mixed therewith to insure combustion. By means of the modulating valve of the present invention, a proper amount of air is admitted at all times to maintain combustion in the burner chamber under all engine load and operating conditions. As set forth above, the modulating valve bypasses a portion of the exhaust gases by the small venturi pumps during acceleration and cruising operating conditions, i.e., during low concentration of hydrocarbons. Consequently, the proportion of air sucked into the exhaust gases varies in general inversely with respect to the flow of the exhaust gases through this device when the flow of exhaust gases is more

than about twice the minimum flow of exhaust gases, i.e., twice the flow under idling conditions. It should be noted that for cruising speeds in a range slightly above idling, e.g., up to about 15 miles per hour in a conventional automobile engine (Chevrolet 6-cylinder having 236 in.³ displacement) that the proportion of air to exhaust gases does increase. The means of this invention thus permit the addition of air in approximate accordance with the variation in hydrocarbon content of the supplied gas under the different operating conditions of the internal combustion engine. In effect, the amount of air added to the exhaust gases increases as the volume of exhaust gas flow increases to about twice its minimum volume and then remains substantially constant or decreases depending on the particular design of the large venturi. The amount of air added by the device of the present invention may be decreased at high speeds because of the unused air present in the exhaust added through the carburetor. It should be noted that the amount of hydrocarbons discharged by the internal combustion engine remains roughly constant over all operating conditions since the decrease in concentration is approximately balanced out by the increase of the total volume of the exhaust gases.

The operation of the modulator valve in the present invention may be controlled in many different ways. As set forth above, the opening of the modulating valve may be controlled by the pressure in either the intake or the outlet manifold of the internal combustion engine. Similarly, the modulator valve may be controlled by a device responsive to the temperature variations in the exhaust gases, or by a device sensitive to the variations in volumetric flow of the exhaust gases. In any event, the actual control means for the modulating valve may take any convenient form. It is noted that the form may be a pneumatic motor operated by the intake manifold pressure. More simply, the control means may be a weighted arm controlling a butterfly valve responsive to the outlet manifold pressure. Another alternative is a spring which tends to close the valve plus a solenoid which is energized by a switch which is closed when the throttle is fully closed. Thus, the modulating valve would be held closed against the pressure pulses in the exhaust leaving the various engine valves. The use of a pneumatic motor, or a positive action switch such as that just mentioned, is preferred since these tend to give the greatest assurance that the modulating valve will be held firmly closed at low speeds and achieve the best air pumping without partial exhaust leakage due to pressure pulses. These particular forms are less susceptible to the effect of road bounces causing the inertia of the weighted arm to actuate the valve in an undesired manner.

As noted, the fumes from gases usually discharged by the crankcase through the oil-filling aperture may be conducted to the device of the present invention. During acceleration, combustion gases blow by the pistons into the crankcase and the blow-by gases from the oil-filling vent may amount to 1.6 c.f.m. with the hydrocarbon content as high as 6000 p.p.m. The device contemplates conducting such blow-by gases from the crankcase to the atmospheric air intake of my device to consume such hydrocarbon and thereby further prevent pollution of the atmosphere. Conduit 163 exemplifies a gas conducting element whose other end is in communication with a vent from the crankcase. It should be noted that during periods of acceleration and cruising, the hydrocarbon content of the exhaust gases is at a minimum, while the hydrocarbon content of the crankcase vent gases is at a maximum. On the other hand, during deceleration and idling, the situation is exactly reversed. Consequently, by mixing the crankcase vent gases with the exhaust gases, the hydrocarbon content of the mixture becomes much more stable over all operating conditions of the combustion engine and "flame out," i.e., loss of burning conditions in the device is substantially inhibited. Without the addition of crankcase vent gases, the exhaust gases

during cruising or acceleration can become too lean to support burning in the afterburner.

Further, it should be noted that the modulating valve means may also be used to reduce the proportion of oxides of nitrogen in the exhaust gases. This effect can be obtained by having the modulator valve, when it opens to bypass some exhaust gases directly to the muffler, to simultaneously open a separate port and conduit of predetermined area leading to a cooling coil or other cooler. Thus, a proportion (about 10%–20%) of the exhaust gases can be diverted to the cooler, cooled below 150° F. or preferably to atmospheric temperature and then passed into the intake manifold of the engine. In this manner, the valve recirculates exhaust gases to the intake manifold only when such gases have a high proportion of nitric and nitrous oxides and such recirculation reduces the total content of these components, eventually discharged to the muffler or atmosphere.

One feature of the present invention is the extremely high ratio of perimeter to cross-sectional area of the throat of the small venturi pumps. One advantage of such feature is that a much larger area is thereby made available for gas ports in the wall of the venturi throat. Another advantage is that the gas admitted through the gas ports into the stream of exhaust gases passing through the venturi throat need diffuse only the minimum distance to become completely mixed with the exhaust gases. It must be remembered that the flow in a venturi is substantially laminar so that mixing will be only by diffusion. These advantages can be illustrated with reference to the present embodiment of applicant's invention. In a typical automobile engine, (a six cylinder Chevrolet engine having a volumetric displacement of 236 cubic inches and idling at 500 r.p.m.) approximately 5–10 cubic feet per minute of exhaust gases is discharged under idling condition. For such volume of flow, in order to obtain the necessary pressure drop to achieve the desired amount of air intake, design considerations show that the venturi should have a cross-sectional throat area of about 0.20 square inch. If the usual circular venturi is used, to obtain an area of 0.20 square inch, its throat would have a radius of about 0.25 inch and a ratio of perimeter to area would be about 8. However, if applicant's plurality of small venturis is used with a perimeter to cross-sectional area ratio of only 32, then approximately 16 small venturis having a radius of 0.0625 inch would be employed. Thus, in applicant's design, the added gas must diffuse less than one-fourth of the distance of the design employing one large venturi. In addition, applicant's plurality of small venturis affords about 64 times more area for air ports in the throat of the venturis. It should be noted that applicant's device achieves the aforementioned advantages preferably by using a perimeter to cross-sectional ratio in units of inches of above 40, however, the ratio may be above about 20.

In addition to aforementioned feature which the device of the present invention has in common with the devices in the aforementioned co-pending application, the device of the present invention has many unique, additional advantageous features. One of such features is the utilization of a large venturi pump to control the pressure in the burner chamber. When the internal combustion engine is operated under idling or de-acceleration conditions, the total volume of gas flow through the exhaust system is not sufficient to raise the back pressure of the exhaust system substantially above atmospheric pressure. However, when the internal combustion engine is operating under cruising, and particularly accelerating conditions, the large volume of exhaust gas flow causes a substantial increase in the back pressure of the exhaust system and particularly may cause a higher pressure in the burner chamber than in the inlet sections of the small venturi pumps. Obviously, under such conditions no air will be pumped into the system but rather exhaust gas will be discharged. However, in the device of the present inven-

tion, the increased volume of the exhaust gases produced during acceleration is utilized to operate a large venturi pump whose throat is connected to the burner chamber. Consequently, the burner chamber pressure will, under all normal operating conditions, be maintained lower than the inlet pressure of the small venturis. By adjustment of the size of the port in the throat of the large venturi serving as an outlet for the burner chamber, the device of the present invention can maintain the amount of added air substantially constant, decrease it as desired when the exhaust gas flow exceeds a given amount i.e. about twice the flow under idling conditions or even cause back flow of exhaust gases through the conduit 61 or 161, and, if so adapted, to the intake manifold of the engine.

Another feature of the present invention is the wide adaptability of the device of the present invention by utilizing a plurality of small venturis to pump the air into the device. In this way, the proper size of venturi throat for a particular engine may easily be obtained by merely varying the number of small venturi air pumps and the rest of the device may be a single standard size. Further, the use of a plurality of small venturis makes the device, as a whole, easy to manufacture and permits a shorter diffuser section than could be easily obtained with the annular form utilized in the devices of the co-pending applications. Most important of all, the utilization of a plurality of small venturis permits a very great increase in the heat exchange surface available in the device. Consequently, with the small size and mass involved, it is easy to insulate the device and the low heat loss, combined with the large heat exchange surface, permits a rapid heat-up of the device.

Still another feature of the present invention is the proper control of the heat exchange between the gas streams. Unlike most systems previously used, the device of the present invention does not preheat the air prior to its entry into the venturi pumps. In general, it has previously been assumed that the preheating of air, since it would be beneficial to support the combustion in the burner chamber, is always desirable. However, since the venturi air pump operates on a volumetric flow basis, the preheating of the air will reduce the mass of air actually entering into the combustion process. Consequently, the preheating of the air requires that the venturi pump be sufficiently large so that it will pump a sufficient amount of air when the device is operated in a heated condition. Further, to obtain a sufficient mass of air during the operation of the device in its heated condition necessarily an excess amount of air is added when the device is cold and during its warm-up period. Thus, it is possible that on cars with well-tuned engines, having exhaust gases that are low in combustible content, that the chilling of the gases due to the higher air flow during start-up will be such as to prevent adequate heating of the combustion chamber and the combustion process will not be able to reach the point where the carbon monoxide will oxidize to carbon dioxide. While the device of the present invention does not preheat the air entering the combustion chamber, it has been found very desirable that counter-flow heat exchange take place between the burner chamber and the entering mixture of air and exhaust gases. In this way, the device of the present invention is able to preheat the mixture before it enters the combustion chamber. In addition, the large heat exchange surface achieved by using a large number of small venturi pumps produces a regenerative effect by storing heat during periods of high concentrations of combustibles, and thus aids in maintaining a high operating temperature during periods of low concentrations of combustibles. Consequently, a high overall oxidation of combustibles is achieved. Finally, it should be noted that during acceleration and cruising, the excess exhaust gases are bypassed by the combustion chamber. Since, during acceleration and cruising the operating temperature of the exhaust gases is very high, this arrangement minimizes

the heat exchange between these high temperature exhaust gases and burner chamber and thus inhibits the obtaining of excessively high temperatures in the burner chamber.

The foregoing description and examples are only illustrative of the present invention and are not limitations on its scope, since many other specific embodiments will be obvious to one skilled in the art in view of my disclosures. All alterations, modifications and variations of the present invention which are obvious to one skilled in the art or come within the scope of the following claims are considered as part of the present invention.

We claim:

1. A compact, self-controlling device for completing the combustion of exhaust gases from an internal combustion engine by admixing the proper amount of air at high temperature and spark ignition comprising:

- an enclosed burner chamber having ignition means mounted therein and an outlet therefrom remote from said ignition means;
- a bank of small primary venturi pumps having throat and diffuser sections, the diffuser sections being axially parallel and discharging into the burner chamber;
- exhaust gas supply means for supplying exhaust gases from an internal combustion engine;
- fixed orifice means for admitting exhaust gases from said supply means to each of said primary venturi pumps;
- additional means for supplying gases comprising air to the throat sections of said primary venturi pumps;
- means for conducting gases from the burner chamber in counter current, heat exchange relation to gases in the diffuser sections, to the outlet from said burner chamber;
- a large secondary venturi pump having inlet, throat and diffuser sections, said inlet being in communication with said means for supplying gases, the throat section being provided with a port in communication with the outlet from said burner chamber whereby said secondary venturi pump controls the back pressure on the bank of primary venturis; and
- a valve modulating the flow of exhaust gases from the supply means to the inlet of said secondary venturi, said valve being responsive to operating conditions of said internal combustion engine to control the proportion of exhaust gases admitted directly to said secondary venturi pump so that the volume of air admixed with exhaust gases under idling conditions is less than 40% of the volume of exhaust gases supplied and the volume of air admixed under all other conditions of load, power and speed is not over twice the volume of air added under idling conditions.

2. An apparatus for burning combustibles in exhaust gases emitted from an internal combustion engine comprising:

- a bank of primary venturi pumps having inlet sections adapted to receive exhaust gases from an internal combustion engine, throat sections adapted to receive an additive gas and diffuser sections adapted to mix said exhaust gas and additive gas;
- a combustion chamber containing ignition means and an outlet, said diffuser sections being adapted to discharge into said combustion chamber; and
- a secondary venturi pump having an inlet adapted to receive said exhaust gas from an internal combustion engine bypassing said bank, a throat section communicating with said inlet and with said outlet of said burner chamber, and an outlet adapted to be connected to means exhausting to atmosphere.

3. An apparatus as in claim 2 wherein valve means are provided in association with said second venturi pump inlet to regulate flow of exhaust gases through said inlet bypassing said bank of primary venturi pumps, said valve means being operable in response to the flow pres-

sure of exhaust gas exerted thereon during operation of said internal combustion engine.

4. An apparatus as in claim 2 wherein valve means are provided in association with said second pump inlet to regulate flow of exhaust gas through said inlet bypassing said bank of primary venturi pumps, said valve means including a valve plate and means for operating said valve plate in response to changes in operating characteristics of an internal combustion engine.

5. An apparatus as in claim 2 wherein means are provided within said burner chamber for directing gas discharged from said diffuser sections to adjacent said ignition means and to direct outgoing gases in said chamber to said chamber outlet in counter current heat exchange relation to said gas discharged from said diffuser sections.

6. A compact, self-controlling device for completing the combustion of exhaust gases from an internal combustion engine by admixing the proper amount of air at high temperature and spark ignition comprising:

- an enclosed burner chamber having ignition means mounted therein and an outlet therefrom remote from said ignition means;
- a plurality of small venturi pumps each having inlet, throat and diffuser sections, the diffuser sections of said venturi pumps being mounted in said burner chamber and having means associated therewith in said burner chamber for conductive gases discharged by said diffuser sections into said burner chamber adjacent said ignition means and conducting gases out of said burner chamber through said outlet in counter current heat exchange relation to the gases entering said burner chamber, the throat sections of said venturi pumps each having a port extending completely around their perimeter and having a ratio of perimeter to cross-sectional area of at least about 20 inches per square inch, and the inlet sections of said venturi pumps opening to said exhaust gases;

means for supplying gas comprising air directly to and completely around the perimeter of the ports in the throat sections of said venturi pumps without preheating such gas, said means having closure means therein for regulating the air supply to said ports; and

- a large venturi pump having inlet, throat and diffuser sections, the throat section of said venturi pump having at least one port in its perimeter forming the outlet of said burner chamber, and the inlet section of said venturi pump opening to said exhaust gases and having a modulating valve means therein responsive to the operating conditions of said internal combustion engine for bypassing a portion of said exhaust gases past said small venturi pumps and combustion chamber through said large venturi pump so that the volume of air admixed with the exhaust gases under all conditions of load, power and speed other than idling is not more than twice the amount of air added to the exhaust gases under idling conditions.

7. A device for completing the combustion of exhaust gases from an internal combustion engine by admixing the proper amount of air at high temperature and spark ignition comprising:

- an enclosed burner chamber having ignition means mounted therein and an outlet therefrom;
- a plurality of small venturi pumps each having inlet, throat and diffuser sections, the diffuser sections of said venturi pumps opening into said burner chamber, the throat sections of said venturi pumps having at least one port therein, and having a ratio of perimeter to cross-sectional area of at least about 20 inches per square inch, and the inlet sections of said venturi pumps opening to said exhaust gases;
- means for supplying gas comprising air to the ports in the throat sections of said venturi pumps; and

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a large venturi pump having inlet, throat and diffuser sections, the throat section of said large venturi pump having at least one port in its perimeter opening to the outlet of said burner chamber, and the inlet section of said venturi pump opening to said exhaust gases and having a modulating valve means therein responsive to the operating condition of said internal combustion engine for bypassing a portion of said exhaust gases directly into the inlet of said large venturi pump so that the amount of air admixed with the exhaust gases under all conditions of load, power and speed is not over twice the volume of air added under idling conditions.

8. A device as stated in claim 7 wherein the diffuser section of said plurality of small venturi pumps have means associated therewith in said burner chamber for conducting gases discharged by said diffuser sections into said burner chamber adjacent said ignition means and conducting gases out of said burner chamber through said outlet in counter current heat exchange relation to the gases entering said burner chamber.

9. A device as stated in claim 7 wherein the means for supplying gas comprising air to the ports in the throat sections of said small venturi pumps has closure means therein for regulating the gas supply to said ports.

10. A device as stated in claim 7 wherein said plurality of small venturi pumps has throat sections each having a port extending completely around their perimeter.

11. A device for completing the combustion of exhaust gases from an internal combustion engine by admixing the proper amount of air at high temperature and spark ignition comprising:

an enclosed burner chamber having ignition means mounted therein and an outlet therefrom;

a bank of small venturi pumps, each of said pumps having an inlet section opening to the exhaust gases, a diffuser section opening to the burner chamber and a throat section having a generally circular cross-section with a ratio of perimeter to cross-sectional area of at least about 20 inches per square inch at its smallest cross-section and means on said throat section providing at least one port therein;

means for supplying gas comprising air to the ports in the throat sections of said venturi pumps; and

means responsive to the operating conditions of said internal combustion engine for bypassing a portion of said exhaust gases so that the amount of air admixed with the total volume of exhaust gases is not substantially increased when the volume of exhaust gases is increased more than twice the minimum volume of exhaust gases.

12. A device for completing the combustion of exhaust gases from an internal combustion engine by admixing the proper amount of air at high temperature and spark ignition comprising:

an enclosed burner chamber having ignition means mounted therein and an outlet therefrom;

at least one small venturi pump having inlet, throat and diffuser sections, the diffuser section of said venturi pump opening into said burner chamber, the throat section of said venturi pump having at least one port therein, and the inlet section of said venturi pump opening to said exhaust gases;

means for supplying gas comprising air to the port in the throat section of said small venturi pump;

a large venturi pump having inlet, throat and diffuser sections, the throat section of said large venturi pump having at least one port in its perimeter opening to the outlet of said burner chamber, and the inlet section of said large venturi pump opening to said exhaust gases and having valve means therein responsive to the operating conditions of said internal combustion engine for bypassing a portion of said exhaust gases by said small venturi pump and combustion chamber through said large venturi pump so

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that the amount of air admixed with the exhaust gases is not substantially increased when the total volume of exhaust gases is increased more than twice the minimum volume of exhaust gases.

13. An apparatus for burning combustibles in exhaust gases emitted from an internal combustion engine comprising:

a combustion chamber having ignition means and an outlet;

first injector means having inlet portions to communicate with a supply of exhaust gases from an internal combustion engine, throat portions to receive unheated air and outlet portions to inject mixed exhaust gases and air into said combustion chamber; and

second injector means for injecting gases from said combustion chamber into exhaust gases by-passing said chamber, said second injector means having an inlet to communicate with a supply of exhaust gases from said internal combustion engine, a throat section, an outlet section to be connected with an egress to atmosphere by-passing said combustion chamber and means for communicating said throat section of said second injector with said combustion chamber outlet to introduce combusted exhaust gases from said combustion chamber into said second injector means at its throat section.

14. An apparatus as in claim 13 including valve means in the inlet of said second injector means to regulate the flow of exhaust gases from said supply through said inlet, said valve means including an air valve and means for operating said valve in response to changes in the operating characteristics of an internal combustion engine.

15. An apparatus as in claim 13 wherein the outlet portions of said first injector means are provided with heat exchanger and gas flow directing means in said combustion chamber to direct gas flow from said outlet portions toward and adjacent to said ignition means and to direct outflow of gas to said outlet in counter current heat exchange relation to said outlet portions.

16. A device as in claim 11 wherein:

orifice plate means are provided in said device opening on one side thereof to said exhaust gases from said internal combustion engine, said inlet sections being provided by said plate means;

wall means are provided between said orifice plate means and said burner chamber for mounting said throat and diffuser sections aligned to said inlet sections with the diffuser sections opening into said burner chamber, said wall means being spaced from said orifice plate means; and

means are provided in association with each throat section adjacent said wall means to provide a port therein opening between said orifice plate means and said wall means toward an aligned inlet section, the throat section of each aligned inlet section and diffuser section being open between said orifice plate and port to receive said gas comprising air.

17. A device for completing the combustion of exhaust gases from an internal combustion engine by admixing air and spark ignition of the resultant mixture, comprising:

an enclosed burner chamber including a first end wall, an opposite second end wall, at least one side wall, ignition means mounted at said second end wall and an outlet therefrom adjacent said first end wall;

a bank of venturi pumps comprising a fixed orifice means for providing a plurality of spaced axially parallel pump inlet sections opening to said exhaust gases, a pump throat section axially aligned with each inlet section and mounted in a wall means spaced from said fixed orifice means, means on each throat section providing at least one port therein opening outwardly of said burner chamber between said fixed orifice means and said wall means, and a

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diffuser section associated with each throat section opening into said burner chamber;
 means for supplying gas comprising air between said fixed orifice means and said wall means to each said port; and
 valve means responsive to operating conditions of the internal combustion engine for by-passing a portion of said exhaust gases past said bank of venturi pumps.

18. A device as in claim 17 wherein said valve means includes a valve plate and means for operating said plate in response to change in the absolute pressure in the intake manifold of said internal combustion engine so that the volume of air admixed with the exhaust gases under all conditions of load, power and speed other than idling is not more than twice the amount of air added to the exhaust gases under idling conditions.

19. A compact, self-controlling device for completing the combustion of exhaust gases from an internal combustion engine by admixing air at high temperature and spark ignition of the resultant mixture, comprising:
 an enclosed burner chamber having ignition means mounted therein and an outlet therefrom remote from said ignition means;
 a bank of venturi pumps having throat and diffuser sections, the diffuser sections being axially parallel and discharging into the burner chamber, each throat section having a generally circular cross-section and a ratio of perimeter to cross-sectional area of at least about 20 inches per square inch at its smallest cross-section;
 exhaust gas supply means for supplying exhaust gases from an internal combustion engine;
 fixed orifice means for admitting exhaust gases from said supply means to each of said venturi pumps;
 additional means for supplying gases comprising air to each throat section of said pumps;
 means for conducting gases from the burner chamber in countercurrent heat exchange relation with gases in the diffuser sections to the outlet from said burner chamber;
 an exhaust pipe communicating with said outlet from said burner chamber; and
 valve means for modulating the flow of exhaust gases from the supply means to the exhaust pipe by-passing said bank of venturi pumps, said valve means being responsive to operating conditions of said internal combustion engine to control the proportion of exhaust gases by-passing said bank so that the volume of air admixed with the exhaust gases under idling conditions is about 40% of the volume of exhaust gases supplied and the volume of air admixed under all other conditions of load, power and speed is not over twice the volume of air added under idling conditions.

20. A device for completing the combustion of exhaust gases from an internal combustion engine by admixing the proper amount of air at high temperature and spark ignition of the resultant mixture comprising:
 an enclosed burner chamber having ignition means mounted therein and an outlet therefrom remote from said ignition means;
 a bank of small venturi pumps each having inlet, throat and diffuser sections, the diffuser sections of said venturi pumps being mounted in said burner chamber and having means associated therewith in said burner chamber for conducting gases discharged by said diffuser sections into said burner chamber adjacent said ignition means and conducting gases out of said burner chamber through said outlet in countercurrent heat exchange relation to the gases entering said burner chamber through each said diffuser section, the throat sections of said venturi pumps each having a port extending completely around their perimeter, and the inlet sections of said venturi pumps opening to said exhaust gases;

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means for supplying gas comprising air directly to and completely around the perimeter of the ports in the throat sections of said venturi pumps without preheating such gas, said means having closure means therein for regulating the air supply to said ports;
 an exhaust pipe having an inlet, an outlet and at least one port in its perimeter providing the outlet of said burner chamber; and
 a modulating valve means responsive to the operating conditions of said internal combustion engine for by-passing a portion of said exhaust gases past said small venturi pumps to said exhaust pipe so that the volume admixed with the exhaust gases of load, power and speed other than idling is not more than twice the amount of air added to the exhaust gases under idling conditions.

21. The method of treating exhaust gases emitted by an internal combustion engine to complete the combustion thereof comprising the steps of:
 establishing a primary flow path for the pulses of exhaust gases emitted from an internal combustion engine;
 dividing each exhaust gas pressure pulse flowing in said primary path into several distinct generally circular flow elements;
 directing said flow elements through a single body of gas comprising air;
 mixing said exhaust gas elements and said additive gas by entraining said additive gas into said exhaust gas elements in amounts proportionate to the rate of flow of said elements and their perimeter exposure to said additive gas and thereafter dispersing the mixtures thereof into a common chamber;
 igniting said mixtures by spark ignition in said chamber;
 emitting said ignited gases to atmosphere;
 selectively establishing a secondary flow path for at least a portion of the pulses of exhaust gases emitted from said internal combustion engine; and
 emitting a portion of the pulses of exhaust gases from said internal combustion engine to atmosphere through said secondary flow path so that the amount of additive gas admixed into the total volume of exhaust gases is not substantially increased when the flow rate of exhaust gases emitted from said engine is increased to more than twice a minimum flow rate of exhaust gases.

22. The method of claim 21 with the further steps of regulating the entrainment of additive gas into each exhaust gas element by creating a back pressure within said chamber dependent upon the gas flow conditions within said secondary flow path; and selectively controlling the conditions of gas flow within said secondary flow path in response to the operating conditions of said internal combustion engine.

23. A method of treating gases to complete their oxidation comprising the steps of:
 establishing a primary flow path for gases to be oxidized;
 dividing the gases in said primary flow path into several distinct generally circular parallel jets;
 directing said jets through a single body of additive gas comprising air;
 mixing each of said exhaust gas jets with an amount of additive gas entrained with each jet in passing through said single body of additive gas and thereafter dispersing the distinct mixtures thereof into a common chamber;
 subjecting said mixtures in said chamber to oxidation and emitting them to atmosphere;
 selectively establishing a secondary flow path for at least a portion of the gases to be oxidized; and
 emitting a portion of the gases to be oxidized to atmosphere through said secondary flow path by passing said primary flow path in response to flow conditions

of gases to said primary flow path so that the amount of additive gas entrained into the total volume of gas flow is not substantially increased when the flow rate of the gases to said primary flow path is increased to more than twice a minimum flow rate thereto.

24. An afterburner and muffler device for modifying exhaust gases from an internal combustion engine by admixing air and spark ignition of the resultant mixture comprising:

an enclosed burner and muffler chamber having ignition means mounted therein and an outlet therefrom remote from said ignition means;

a bank of venturi pumps, each of said pumps having inlet, throat and diffuser sections, the inlet sections of said venturi pumps opening to said exhaust gases, the throat sections of said venturi pumps having at least one port therein and the diffuser sections of said pumps opening to said enclosed burner and muffler chamber;

means for supplying gas comprising air to each said port; and

means responsive to the operating conditions of said internal combustion engine for bypassing a portion of said exhaust gases past said bank of venturi pumps so that the volume of air admixed with exhaust gases under all conditions of load, power and speed is not over twice the volume of air added under idling conditions.

25. A device for completing the combustion of exhaust gases from an internal combustion engine as in claim 24 wherein:

orifice plate means are provided in said device opening on one side thereof to said exhaust gases from said internal combustion engine, said inlet sections being provided by said plate means;

wall means are provided between said orifice plate means and said burner chamber for mounting said throat and diffuser sections aligned to said inlet sections with the diffuser sections opening into said burner chamber, said wall means being spaced from said orifice plate means; and

means are provided in association with each throat section adjacent said wall means to provide a port therein opening between said orifice plate means and said wall means toward an aligned inlet section, the throat section of each aligned inlet section and diffuser section being open between said orifice plate and port to receive said gas comprising air.

26. A device for completing the combustion of exhaust gases from an internal combustion engine as in claim 25 wherein the throat section of each aligned inlet section and diffuser section has a generally circular cross-section with a ratio of perimeter to cross-sectional area of at least about twenty inches per square inch at the smallest cross-section thereof.

27. A device for completing the combustion of exhaust gases from an internal combustion engine as in claim 24 wherein said valve means includes a valve plate and means for operating said plate in response to change in absolute pressure in the intake manifold of said internal combustion engine.

28. A device for completing the combustion of exhaust gases from an internal combustion engine as in claim 24 having heat exchange means in said burner chamber associated with the diffuser sections of said venturi pumps for conducting gases discharged by said diffuser sections into said burner chamber adjacent said ignition means and for conducting gases out of said burner chamber through said outlet in countercurrent heat exchange relation to the

gases entering said burner chamber through each said diffuser section.

29. A device for completing the combustion of exhaust gases from an internal combustion engine as in claim 24 including the provision of a secondary venturi pump having inlets, throat and diffuser sections, the throat section of said large venturi pump having at least one port in its perimeter opening to the outlet of said burner chamber, the inlet section of said large venturi pump opening to said exhaust gases and the diffuser section of said large venturi pump opening to an egress to atmosphere; and said valve means responsive to operating conditions of the internal combustion engine for bypassing a portion of said exhaust gases past said bank of venturi pumps includes means for directing the by-passed exhaust gases to the inlet of said large secondary venturi pump.

30. A device for completing the combustion of exhaust gases from an internal combustion engine as in claim 28 wherein the flow of exhaust gases through said secondary venturi pump affects the back pressure on the bank of venturi pumps and the volume of air admixed with exhaust gases under idling conditions is less than forty percent of the volume of exhaust gases supplied and the volume of air admixed under all other conditions of load, power and speed is not over twice the volume of air added under idling conditions.

31. An afterburner and muffler device for modifying exhaust gases from an internal combustion engine by admixing air and spark ignition of the resultant mixture, comprising:

an enclosed burner and muffler chamber having ignition means mounted therein and an outlet therefrom remote from said ignition means;

a plurality of exhaust gas and air mixing means each comprising inlet means communicating with a supply of exhaust gas for establishing a jet of exhaust gas, throat means aligned to and spaced from said inlet means for receiving said jet and diffuser means aligned to said throat means for diffusing said jet into said chamber;

means for introducing an additive gas comprising air into said exhaust gas jet between said inlet means and said throat means; and

means responsive to the operating conditions of said internal combustion engine for bypassing a portion of said exhaust gases past said mixing means so that the volume of air admixed with exhaust gases under all conditions of load, power and speed is not over twice the volume of air added under idling conditions.

32. A device for completing the combustion of exhaust gases from an internal combustion engine as in claim 30 wherein:

orifice plate means are provided in said device opening on one side thereof to said exhaust gases from said internal combustion engine and each said inlet means is provided by an orifice in said orifice plate means.

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