Oct. 5, 1965 C. W. MORRIS ETAL 3,209,532

AFTERBURNER AND MUFFLER DEVICE

Filed April 1, 1963 3 Sheets-Sheet 1

FIG. 1.

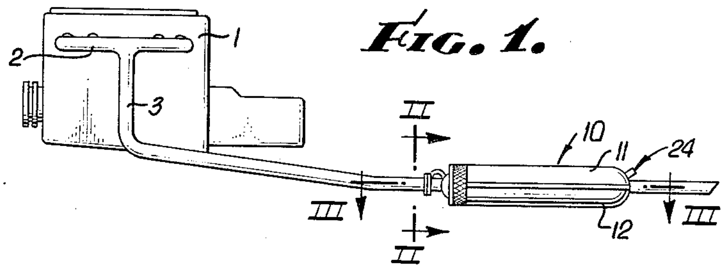


FIG. 2.

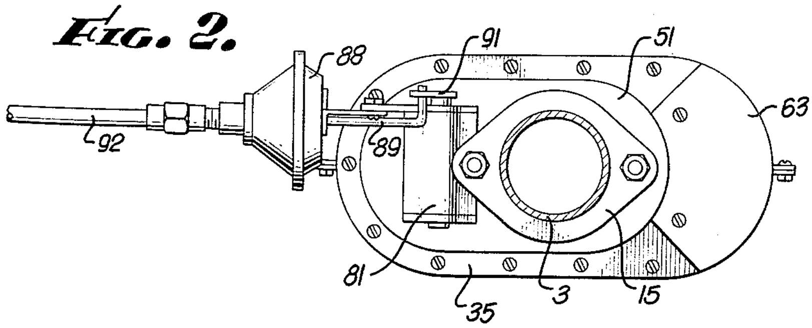


FIG. 4.

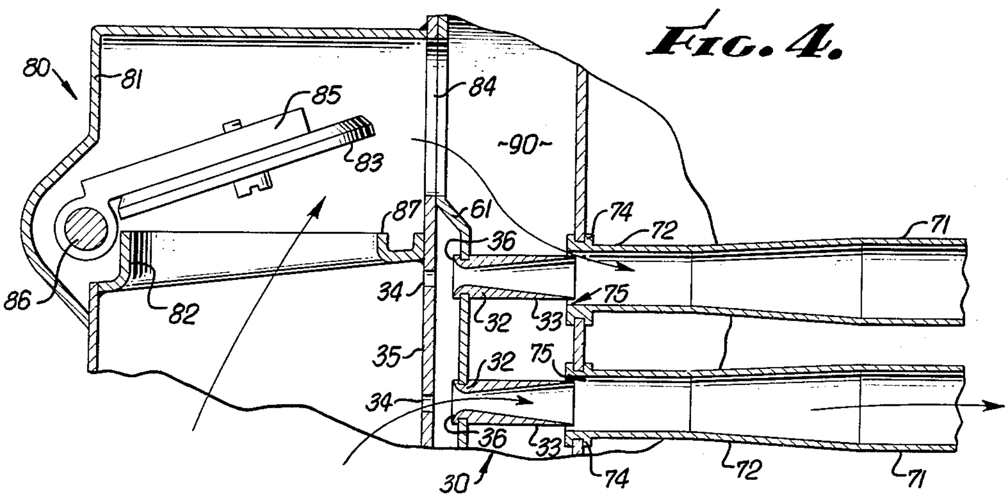
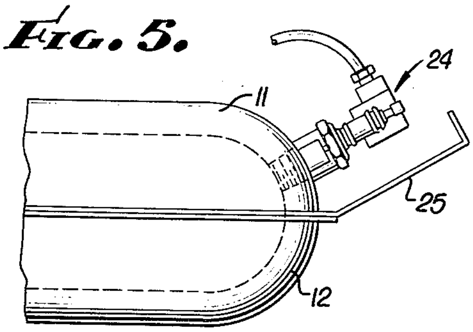


FIG. 5.



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AFTERBURNER AND MUFFLER DEVICE

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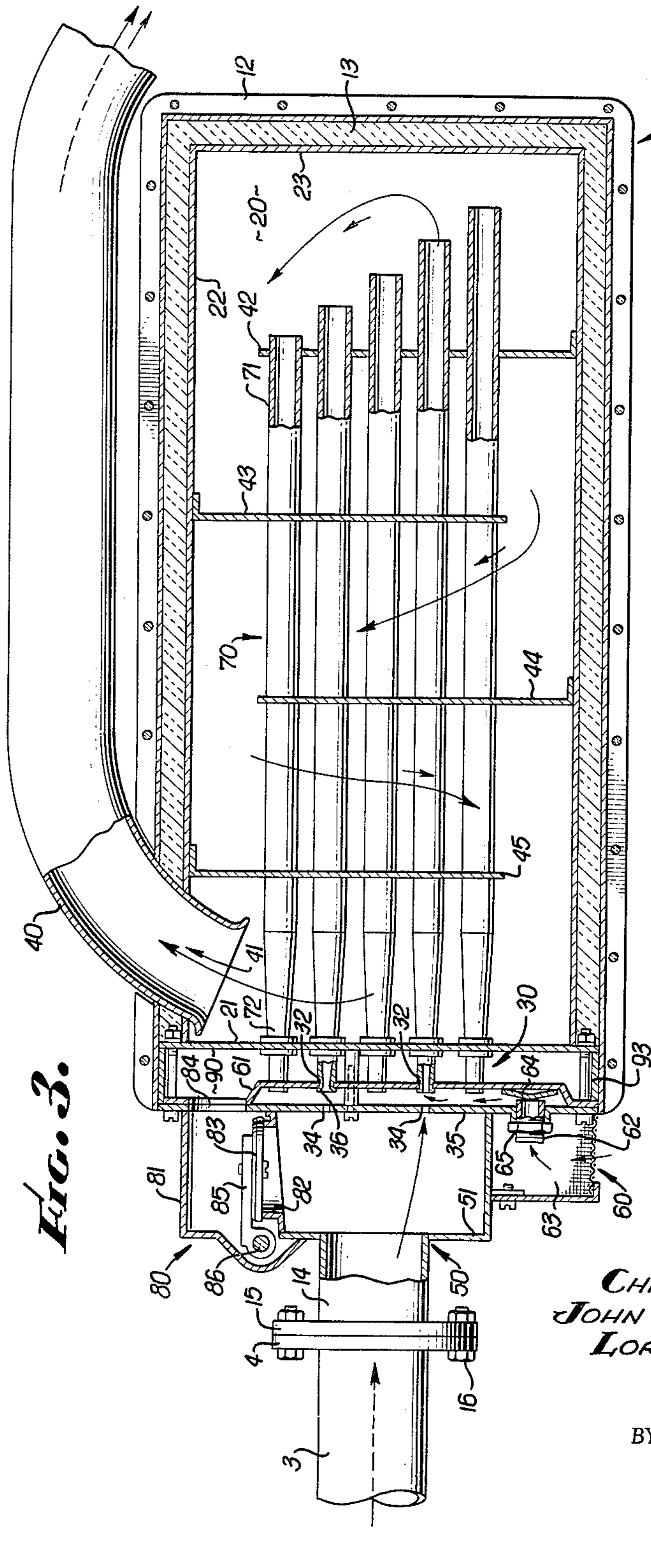

FIG. 3.

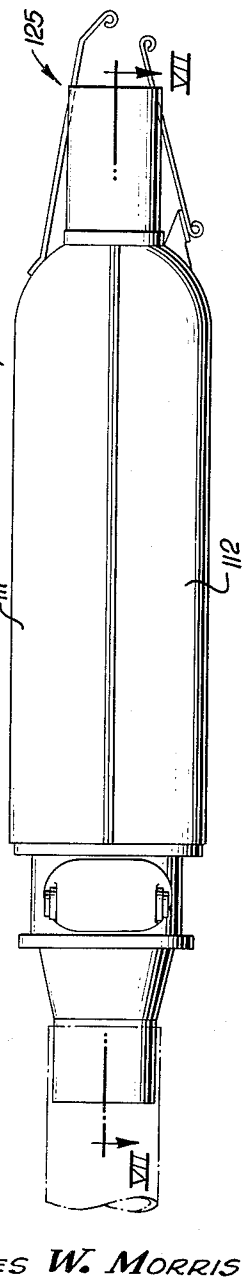

FIG. 6.

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AFTERBURNER AND MUFFLER DEVICE

Filed April 1, 1963 3 Sheets-Sheet 3

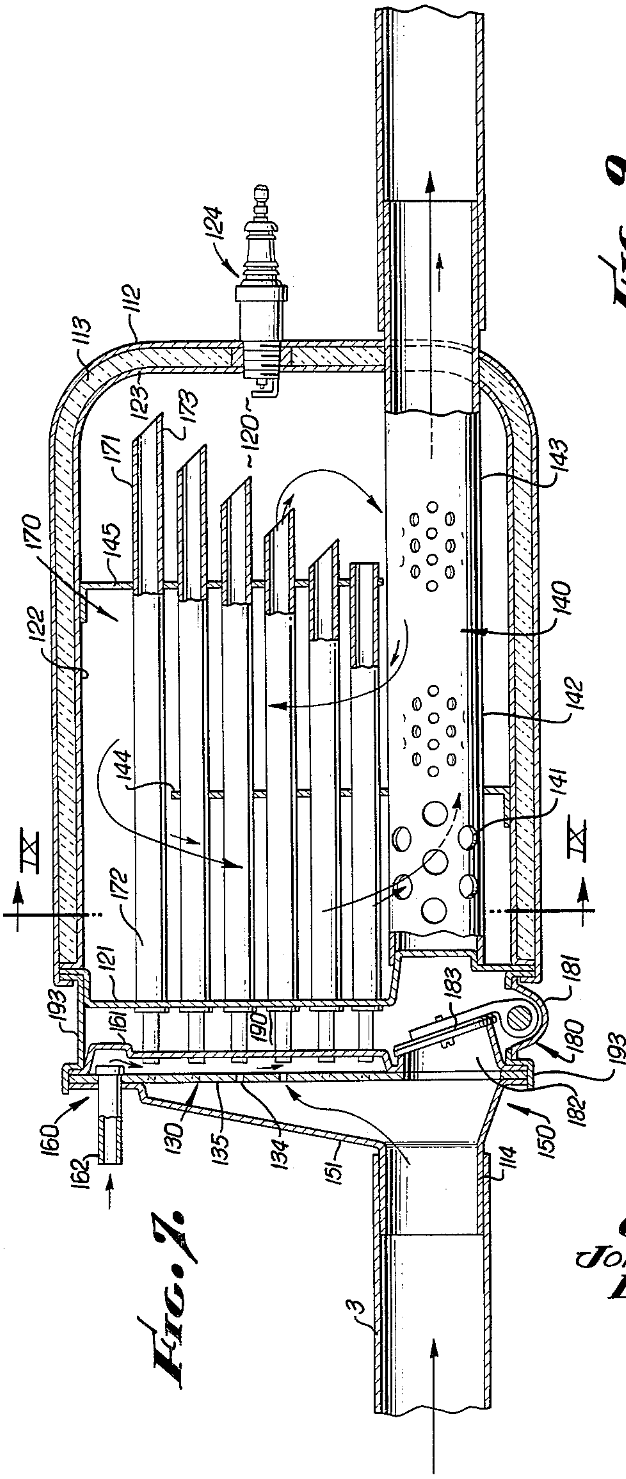

FIG. 7.

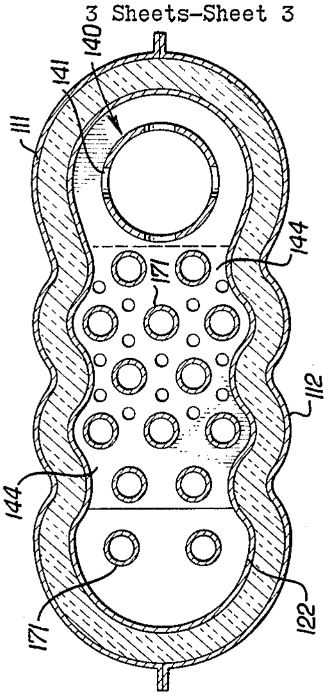

FIG. 9.

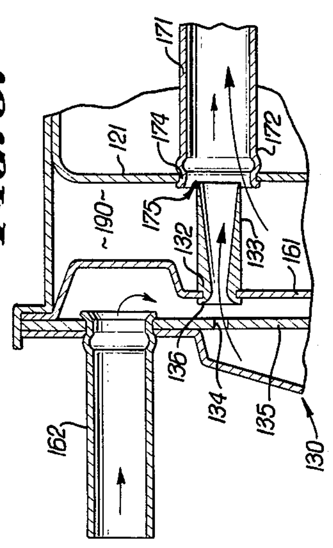

FIG. 8.

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3,209,532
AFTERBURNER AND MUFFLER DEVICE

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Filed Apr. 1, 1963, Ser. No. 269,486
6 Claims. (Cl. 60—30)

This is a continuation-in-part of our copending application Serial No. 195,789 filed May 18, 1962, for Adaptable Afterburner.

The present invention relates in general to an afterburner and muffler 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, light weight, inexpensive device which is free from numerous adjustable parts, is readily installed and easily adaptable for a wide variety of internal combustion engines, is capable of operating efficiently over a wide range of engine operating conditions, rapidly obtains the temperature required to eliminate those compounds generally considered to be the primary cause of air contamination such as smog and is effective in dispersing pressure pulses in the exhaust gas flow to attenuate the pressure pulses and muffle the sounds of combustion.

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 at 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. to 500° F. during deceleration and be about 400° F. during idling. 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.

The invention of our prior copending application Serial No. 195,789 filed May 18, 1962, directed toward solving the aforementioned problems, comprised in general the provision of an enclosed burner chamber having an ignition means mounted therein and an outlet remote from the ignition means. A bank of small venturi pumps was associated with the burner chamber to admix additional gases comprising air to a portion of the exhaust gases directed into the burner chamber. The bank of venturi pumps comprised generally a fixed orifice means for providing a plurality of spaced axially parallel pump inlet sections opening to the 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 diffuser section associated with each throat section opening into the burner chamber. Means were provided for supplying gas comprising air between the fixed orifice means and the indicated wall means. The added gas comprising air was thus entrained into the individual venturi pumps through the ports in the throat sections thereof. Valve means were also provided responsive to operating conditions of the internal combustion engine for bypassing a portion of the exhaust gases past the bank of venturi pumps. By selectively directing the flow of exhaust gases past the bank of venturi pumps when the rate of flow of exhaust gases is increased, the amount of air added to the total volume of exhaust gases can be held substantially unchanged when the flow rate of exhaust gases is increased to more than twice its minimum rate.

We have found that when starting an internal combustion engine in a cold condition, the exhaust gases must warm the exhaust manifold of the engine, the exhaust pipe and the internal parts of the adaptable afterburner before it is possible to obtain more than spasmodic combustion in the combustion chamber, particularly during deceleration of the engine. Also, the prior bypassing of the exhaust gases past the bank of primary venturi pumps and then almost immediately emitting it to the atmosphere has caused objectionable sounds of internal combustion to be emitted from the adaptable afterburner.

It is therefore an object of our present invention to disclose and provide both apparatus and methods for modifying the exhaust gas from an internal combustion engine to complete the combustion therein which is capable of fast warm-up, attains stabilized burning within the burner chamber more quickly than heretofore possible such that combustion within the burner chamber is sustained during deceleration of the internal combustion engine in a shorter period after starting the engine and in which the sounds of internal combustion are effectively muffled or silenced within the device prior to the emission of exhaust gases to atmosphere.

It is another object of the present invention to disclose and provide a compact inexpensive combination afterburner and muffler device which may be readily attached not only to new internal combustion engines and vehicles employing the same, but which can also be adapted readily and be attached to existing vehicles by merely replacing existing mufflers therein.

Another object of the present invention is to disclose and provide a combination afterburner and muffler device which does not employ catalysts and in which the operative temperatures for sustained combustion within the device are more rapidly reached so that the major portion of hydrocarbons and carbon monoxide contained in the exhaust gases upon starting of the internal combustion engine may be promptly consumed and burned and continuously thereafter even during short periods of operation.

A further object of the present invention is to disclose and provide an afterburner and muffler device capable of burning exhaust gases with air added in approximate accordance with the variation in the combustible content of said gases under different operating conditions of the engine and which is further capable of muffling all exhaust gases emitted from the internal combustion engine, the operation thereof being accomplished automatically and without the use of complicated or expensive machinery or instrumentation.

A still further object of the present invention is to disclose and provide apparatus and methods for directing pressure pulses of exhaust gases emitted by an internal combustion engine in predetermined flow paths for introducing an additive gas comprising air to a portion of said pulses and mixing it therewith while dividing all of said pulses into a plurality of elements, and thereafter attenuating said elements and thereby muffling the sounds of internal combustion emitted with said exhaust gases from the internal combustion engine.

Generally stated, the afterburner and muffler device for use in modifying exhaust gases from an internal combustion engine, in accordance with the present invention, comprises a housing to be associated with an exhaust pipe of an internal combustion engine replacing the conventional muffler. An enclosed burner and muffler chamber is provided within the housing with an ignition means mounted therein and an outlet therefrom disposed remotely from the ignition means. A bank of venturi pumps is disposed within the housing in the path of flow of exhaust gases entering said housing from the internal combustion engine. Each of the venturi pumps includes an inlet, throat and diffuser sections. The inlet section of each pump opens to the exhaust gases entering the housing, the throat section is provided with at least one port for receiving an additive gas comprising air and the diffuser section of each pump is open to the enclosed burner and muffler chamber. Means are provided for supplying gas comprising air to each of the ports, the air being entrained into the individual venturi pumps by the pressure difference therebetween created by the flow of the exhaust gases through the venturi pumps. Means responsive to the operating conditions of the internal combustion engine are provided for bypassing a portion of the exhaust gases entering the housing past the bank of venturi pumps to avoid the addition of gases comprising air within the bank to such bypassed gases. However, rather than emitting such bypassed exhaust gases to the atmosphere as in our copending application, they are directed into the burner and muffler chamber immediately after bypassing the bank of venturi pumps. All exhaust gases are passed through the burner and muffler chamber but the volume 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. Also, it is a particular feature of the present invention that silencing or muffling of all the exhaust gases passing into the burner and muffler chamber is accomplished by dividing each pressure pulse of exhaust gas entering the housing into individual elements and directing them through heat exchanger conduits of unequal length to attenuate or space the individual elements and thereby muffle the sounds of internal combustion.

The method of treating exhaust gases emitted from an internal combustion engine to complete the combustion thereof, according to the present invention, in general comprises the steps of: first establishing a primary flow path for pulses of exhaust gases emitted from an internal combustion engine. Each pulse of exhaust gases flowing in the primary path is then divided into a plurality of individual elements. An additive gas comprising air is introduced to each of the elements and mixed therewith to provide a plurality of individual mixtures comprising an element of a pressure pulse of exhaust gas and an additive gas comprising air. Each mixture is then directed into a common chamber wherein combustion thereof may be effected by spark ignition. A secondary flow path for at least a portion of the pulses of exhaust gases emitted from said internal combustion engine is selectively established in response to the operating conditions of the internal combustion engine. Upon operating conditions of the internal combustion engine causing increase in the flow rate of exhaust gases emitted therefrom, the secondary flow path is selectively placed in operation. The pressure pulses of exhaust gas following the secondary path are also divided into a plurality of individual elements and directed through conduits of unequal length into the burner chamber. The gases thus directed into the burner chamber from the primary and the secondary flow paths may then be ignited within the chamber by spark ignition and thereafter be emitted therefrom to atmosphere.

The foregoing and various other objects, uses and advantages of the present invention, as well as a better understanding thereof, will become apparent to those skilled in the art from a consideration of the following detailed description of exemplary embodiments of the afterburner and muffler device in accordance with the present invention. Reference will be made to the appended sheets of drawings in which:

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

FIG. 2 is an end view of the exemplary embodiment of afterburner and muffler device of FIG. 1 taken therein along the plane II—II;

FIG. 3 is a longitudinal section view taken through the exemplary embodiment of afterburner and muffler device of FIG. 1 along the plane III—III therein;

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

FIG. 5 is a detail view of a portion of the exemplary embodiment of afterburner and muffler device of FIGS. 1–4;

FIG. 6 is a side view of an alternative exemplary embodiment of an afterburner and muffler device in accordance with the present invention;

FIG. 7 is a longitudinal sectional view of the alternative exemplary embodiment of afterburner and muffler device of FIG. 6 taken therein along the plane VII—VII;

FIG. 8 is a detail view of a portion of the alternative exemplary embodiment of afterburner and muffler device of FIGS. 6 and 7; and

FIG. 9 is a transverse section of the alternative exemplary embodiment of afterburner and muffler device of FIG. 7 taken therein along the plane IX—IX.

The ease with which the afterburner and muffler device of the present invention may be installed in a conventional internal combustion engine-exhaust system is exemplified by FIG. 1. As shown there, the internal combustion engine **1** is provided with the usual exhaust manifold **2** having an exhaust outlet **3**. As shown in our copending application Serial No. 195,789 filed May 18, 1962, such exhaust outlet **3** is ordinarily connected by means of an exhaust pipe with conventional form of muffler. However, the device of the present invention, indicated generally by the numeral **10**, may be associated with the exhaust outlet **3** replacing and obviating the conventional form of muffler. The installation of the present device may be accomplished by any mechanic by the use of suitable adapters, variations in diameter of exhaust pipe, etc. being readily compensated for.

As shown in FIGS. 1 through 3, the preferred exemplary form of afterburner and muffler device, indicated generally at **10**, may be provided with a metal, insulated housing formed by upper and lower housing shells **11** and **12** respectively, shown bolted together in FIGS. 1 and 2 and with the upper shell removed in FIG. 3. Insulation material **13** may be provided within the housing to reduce the passage of heat and noise through the walls of the housing. The housing may be associated easily with exhaust pipe **3**, leading from the internal combustion engine **1**, by means of the housing inlet **14**. Outlet **3** and housing inlet **14** may be fastened together by any suitable means, as for example, by the provision of the flanges **4** and **15** connected by bolts **16**.

An enclosed burner and muffler chamber is provided within the housing including an ignition means and an outlet therefrom. In the exemplary embodiment of FIGS. 1 through 5, the enclosed burner and muffler chamber **20** is preferably formed by an enclosure having at least one side wall **22** and opposing first and second end walls, **21** and **23** respectively. Ignition means, indicated generally at **24** in FIGS. 1 and 5, are mounted in the afterburner and muffler chamber on an end wall, preferably the second or far end wall **23** relative to the bank of venturi pumps, indicated generally at **30**. Such ignition means **24** may comprise of a conventional spark plug. A metal shield **25** may be provided to prevent damage occurring to the ignition means **24** from flying debris or other foreign matter when the device is employed under a moving vehicle. An outlet, indicated generally at **41** is provided from the afterburner and muffler chamber **20** through the side wall **22** for emitting exhaust gases from the chamber into the exhaust pipe **40** and from there to the atmosphere. Outlet **41** is preferably positioned adja-

cent the first end wall **21**, near the bank of venturi pumps, indicated generally at **30**, remote from the ignition means **24** so that the exhaust gases must pass forwardly through the chamber. Baffles **42**, **43**, **44** and **45** may be provided to cause flow of exhaust gases from the end of afterburner chamber **20** near the ignition means **24** and second end wall **23** to flow in a serpentine manner to the outlet **41** near the first end wall **21** and remote from wall **23** and ignition means **24**.

A bank of venturi pumps is provided within the housing to receive exhaust gas from an internal combustion engine, admix an additional gas such as air and diffuse the mixture into the afterburner and muffler chamber **20**. Each of said pumps is provided with an inlet section opening to exhaust gases entering the housing, a diffuser section opening to the enclosed burner and muffler chamber through a heat exchanger tube and a throat section having at least one port therein. As shown in the exemplary embodiment of FIGS. 3 and 4, the throat sections **32** and diffffuser sections **33** are in a generally axially parallel array with each diffuser section positioned to discharge into the afterburner and muffler chamber **20** through the heat exchanger conduits indicated generally at **70**. Inlet sections **34** opening to the exhaust gases entering the housing are provided in the exemplary embodiment by a fixed orifice plate **35** spaced forwardly in said housing from the end wall **21** of the afterburner and muffler chamber. Inlet sections **34**, provided by the orifices in plate **35**, are each aligned with a throat section **32** for directing elements of a pressure pulse of exhaust gas through the throat and diffuser sections into the afterburner and muffler chamber **20**. The effective throat zone of each venturi pump is provided between the venturi pump inlet **34** and the throat section **32** where the flow of exhaust gas through the pump passes through the space between plate **35** and wall **61**. The cross section of the stream or jet of exhaust gas passing through such space expands slightly from the inlet sections or orifices **34** to the throat section **32**, its smallest cross section existing, therefore, adjacent the wall or plate **35**. The orifices or inlets **34** are preferably provided with a ratio of perimeter to cross-sectional area of about 20 inches per square inch to provide a similar ratio for the smallest cross section of the exhaust gas flowing through the throat section of the pump. As described, such smallest cross section occurs in the effective throat zone adjacent the plate **35**.

Exhaust gas supply means, indicated generally at **50**, in the exemplary embodiment may include the tubular inlet **14** adapted to be connected to the internal combustion engine exhaust outlet or pipe **3** and a housing **51** provided to direct exhaust gases to the fixed orifice means, plate **35** in the exemplary embodiment, and the inlet sections **34** of the bank of venturi pumps.

Means for supplying gas comprising air to the ports in the throat sections of the venturi pumps are provided in the exemplary embodiment as indicated generally at **60**. Such means may include a housing formed by the fixed orifice plate or wall **35** and the spaced wall **61**. An additive gas, such as air and/or crankcase vent gases, may be introduced into the space between orifice plate **35** and wall **61** by an inlet conduit **62**, such additive gas being drawn through a filter **63** against a deflection plate **64**. Means are provided in association with the inlet sections, throat sections **32** and wall **61** for providing at least one port for each throat section opening between said fixed orifice plate **35** and wall **61** outwardly of the afterburner and muffler chamber **20**. Such port may be considered to be formed around the gas stream or jet of exhaust gas passing from the inlets **34** to the throat sections **32** by the spacing of plate means **35** from the wall **61** and the lip means **36** on the throat section **32**. The port thus formed may be considered to provide a band-like opening around each exhaust gas stream or jet exposing the perimeter of such gas jet to the additive gas comprising air introduced between the plate **35** and wall **61**. The additive gas is supplied in a single body thereof directly to and completely around the perimeter of each of the ports in the throat sections **32** without preheating and in variable amounts further controllable by the setting of closure means **65** on the inlet conduit **62**.

A plurality of heat exchanger conduits for directing exhaust gas flow into the afterburner and muffler chamber toward the ignition means in heat exchange relation to the interior of such chamber is provided. In the exemplary embodiment, such heat exchanger conduits are indicated generally at **70**. Each conduit **71** is of a generally tubular configuration with an inlet portion **72** mounted in the first end wall **21** of the afterburner and muffler chamber and an outlet portion **73** opening toward said end wall **23** and ignition means **24**. Each of the heat exchanger conduits is provided with a larger cross section at its outlet portion within the chamber **20** than at its inlet section adjacent the wall **21**, the inlet section be of generally frusto-conic configuration, so that the flow of exhaust gases through the conduits is promoted by a reduction in pressure experienced by gas flowing through the conduits. As shown in FIG. 4, each of said heat exchanger tubes **71** is disposed within the chamber **20** with its inlet portion mounted in the end wall **21** and surrounding an outlet portion of a diffuser section **33**. The mounting means **74** for each inlet section **72** of the heat exchanger conduits **71** for mounting the inlet section **72** in the end wall **21** defines an annular port, indicated at **75**, opening to the afterburner and muffler chamber **20** through the interior of the heat exchanger tube **71**.

Means responsive to the operating conditions of the internal combustion engine **1** for bypassing a portion of the exhaust gases past the bank of venturi pumps, indicated generally at **30**, to the inlet portions of heat exchanger tubes or conduits, indicated generally at **70**, are provided so that all exhaust gases pass through the heat exchanger tubes or conduits and the amount of air admixed into the total volume of exhaust gases by said blank of venturi pumps, indicated generally at **30**, is not substantially increased when the flow rate of exhaust gases into said housing is increased more than twice the minimum flow rate of exhaust gases. As shown in the exemplary embodiment of FIGS. 3 and 4, such means indicated generally at **80**, may comprise a valve housing **81**, a valve housing inlet conduit **82**, a valve **83** and an outlet **84** opening said valve housing to a space **90** formed between the wall **61**, of the exemplary means for supplying gas comprising air to the ports in the throat sections of the venturi pumps, and the first end wall **21** of the afterburner and muffler chamber **20**. The valve **83** may be pivotally mounted by an arm **85** on a pivot axis **86** so that it may seat upon or abut a seat or limit stop **87** formed by the inlet **82**. An actuator **88** acts through a link **89** and arm **91** connected to the pivotal axis **85** of valve **83** to move the valve between open and closed positions. Actuator **88** includes a spring-biased diaphragm with the link **89** connected to a central area thereof. One side of the diaphragm is open to atmospheric pressure while the opposite side of the diaphragm is interconnected to the intake manifold of the engine by an enclosed tube **92**. The pressure within the intake manifold is always somewhat lower than atmospheric pressure, varying from a fraction of a pound per square inch less than atmospheric pressure when the throttle is wide open, to as much as twelve pounds per square inch less than atmospheric when the throttle is fully closed during deceleration conditions or when the engine is being used for braking action, as when a vehicle goes down hill with the throttle closed and clutch engaged. The spring bias in the actuator opposes the diaphragm movement caused by the intake manifold suction pressure and biases the valve **83** into an open position. In normal operation, after the engine has been started and the car is idling, the suction in the intake manifold is about nine to ten pounds per square inch. The actuator is designed to allow movement of the diaphragm against the resistance of the aforementioned spring means to close the modulating valve **83** and thus directing all of the exhaust gases through the inlet sections or orifices **34** in the bank of venturi pumps indicated generally at **30**. The closed position of valve **83** shown in FIG. 3 is typical of the positioning of valve **83** during deceleration or idling conditions of the internal combustion engine and is the condition for minimum exhaust gas flow. Also the maximum proportion of added air is then required. When the engine throttle is opened to increase engine power to cause movement of the car, the suction in the intake manifold changes to between seven to five pounds per square inch suction which is not sufficient to keep the actuator spring fully compressed, particularly with the additional effect of increased exhaust gas pressure on the modulating valve **83**, as exhaust gases enter the exhaust gas supply means indicated generally at **50**. The valve means is preferably adjusted to cuse initial opening of the valve as the intake manifold suction changes from about eight pounds per square inch to a value of about five pounds per square inch when the valve is fully open. The valve means is thus responsive to increased absolute engine intake manifold pressure and to the increase in flow of exhaust gas from the engine **1**. Upon acceleration of the engine **1**, the valve means bypasses a portion of the exhaust gases past the bank of venturi pumps, indicated generally at **30**, into the space, indicated generally at **90**, formed between walls **61** and **21** and from there, through the heat exchanger conduits, indicated generally at **70**, into the afterburner and muffler chamber **20**. By controlling the proportion of exhaust gases directed around the bank of venturi pumps to the chamber **90** in response to the operating conditions of the internal combustion engine, as indicated above, the volume of air admixed with exhaust gases under idling conditions may be maintained about 40% of the volume of exhaust gases supplied to the bank of 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.

Walls **61** and **21** of the exemplary embodiment of FIGS. 1 through 5 along with an outer enclosure wall **93** define chamber **90** about the diffuser sections **33** of the venturi pumps. Means are associated with such walls, particularly the conduit mounting means **74**, defining annular ports indicated generally at **75** opening to each heat exchanger tube **71** from the chamber or space **90**. Therefore, exhaust gas bypassed by the valve means, indicated generally at **80**, about the bank of venturi pumps, indicated generally at **30**, is directed through valve housing outlet **84** into the chamber **90** about the diffuser sections **33** and through the individual annular ports, indicated generally at **75**, and into the heat exchanger conduits or tubes, indicated generally at **70**, to the afterburner and muffler chamber **20**. Such bypassed exhaust gases are mixed within the heat exchanger tubes or conduits along with the mixtures of exhaust gas and additive gas emitted by the bank of venturi pumps into the heat exchanger tubes or conduits. All exhaust gases and added gases are thus directed into the afterburner and muffler chamber **20** through the heat exchanger tubes or conduits. It is a particular feature of the present invention that the heat exchanger tubes or conduits, indicated generally at **70**, are provided in unequal lengths so that a pulse of exhaust gas emitted from the internal combustion engine directed into and divided among the heat exchanger tubes or conduits is emitted into the afterburner and muffler chamber **20** as separate elements in spaced intervals. Each pressure pulse of exhaust gas may thereby be attenuated and the noise of internal combustion effectively silenced within the device.

Combustion of the exhaust gases within the afterburner and muffler chamber **20** may be effected by spark ignition by the ignition means **24**. The ignited gases pass back through the chamber **20** about the heat exchanger tubes or conduits in serpentine fashion, and in heat exchange relation thereto, to the outlet **41** of exhaust pipe **40** to emit such attenuated and muffled exhaust gases to the atmosphere.

An alternative exemplary embodiment of the afterburner and muffler device of the present invention is shown in FIGS. 6 through 9. Referring first to FIG. 6, it can be seen that the alternative exemplary embodiment of the afterburner and muffler device, indicated generally at **100**, may be provided with a metal, insulated housing formed by upper and lower housing shells **111** and **112** respectively. The housing shells may be both fitted together, welded or fastened together by any suitable means. As shown in FIG. 7, insulation material **113** may be provided within the housing to reduce the passage of heat and noise through the walls thereof. The housing may be associated easily with an exhaust pipe **3** by means of a housing inlet **114** shown fitted within the pipe 3. Inlet **114** may be securely fastened within the exhaust pipe **3** by welding or any other suitable fastening means.

An enclosed burner and muffler chamber is provided within the housing in the alternative exemplary embodiment as indicated at **120**. Enclosed burner and muffler chamber **120** is preferably formed by an enclosure having at least one side wall **122** and opposing first and second end walls **121** and **123** respectively. Ignition means, indicated generally at **124**, may be mounted in the afterburner and muffler chamber on end wall **123** preferably remote from the bank of venturi pumps, indicated generally at **130**, and the outlet from chamber **120** to be subsequently described. As shown in FIG. 6, metal shield means, indicated at **125**, may be provided to protect the ignition means from flying debris or other foreign matter which the device might encounter when employed under a moving vehicle.

In the present alternative exemplary embodiment of FIGS. 6 through 9, the outlet means of the afterburner and muffler chamber **120** is provided by a ported exhaust pipe or outlet, indicated generally at **140**. Such exhaust outlet or pipe from the afterburner and muffler chamber is provided with large ports **141** near the first end wall **121** of the chamber remote from the ignition means **124** so that the exhaust gases in leaving the chamber, indicated generally at **120**, must pass forwardly through the chamber back past the plurality of heat exchanger tubes or conduits indicated generally at **170**. Additional, smaller ports **142** and **143** are provided in the exhaust pipe or outlet of the alternative exemplary embodiment to allow the partial discharge of exhaust gases flowing forwardly within the afterburner and muffler chamber toward the large outlet ports **141**. As in the prior embodiment, baffles **144** and **145** may be provided within the afterburner and muffler chamber about the heat exchange tubes or conduits to cause exhaust gases passing forwardly within the afterburner and muffler chamber toward the outlets **141** to flow in a serpentine manner, ensuring flow of such exhaust gases about each heat exchanger tube or conduit.

A bank of venturi pumps is provided within the housing **110** to receive exhaust gas from an internal combustion engine, admix an additional gas such as air and diffuse the mixture into the afterburner and muffler chamber **120** as in the prior embodiment. Such means are indicated generally at **130** and include a fixed orifice plate **135** providing inlet sections **134**, throat sections **132** and diffuser sections **133** mounted in a generally axially parallel array on wall **161**. Each diffuser section **133** is positioned to discharge into the afterburner and muffler chamber through the heat exchanger conduits **171**. Round edge orifices are preferred.

Exhaust gas supply means in the alternative exemplary embodiment indicated generally at **150** and include the tubular inlet **114** adapted to be connected to the internal combustion engine exhaust outlet or pipe **3** and a housing **151** provided to direct inflowing exhaust gases to the plate **135** and its inlet section **134**.

Means for supplying gas comprising air to and completely around the perimeter of the ports in the throat sections of the venturi pumps are provided, as indicated generally at **160**. Such means in the alternative exemplary embodiment include a housing formed by the fixed orifice plate or wall **135** and a spaced wall **161**. As in the prior embodiment, an additive gas, such as air and/or crankcase vent gases, may be introduced into the space between the orifice plate **135** and wall **161** by an inlet conduit **162**. The gas comprising air drawn into the inlet **162** into the space between the orifice plate **135** and wall means **161** provides a single body of gas comprising air surrounding the perimeters of the ports **136** of the venturi pump throat sections. Exhaust gases directed through the plurality of inlet sections provided by the orifice plate **135** flow in jets of exhaust gases through this body of added gases comprising air. As previously described with the prior embodiment, the additive gas comprising air is entrained into the jets of exhaust gas flowing through the individual venturi pumps formed by the inlet sections **134**, throat sections **132** and diffuser sections **133**.

A plurality of heat exchanger tubes or conduits for directing exhaust gas flow into the afterburner and muffler chamber toward the ignition means in heat exchange relation to the interior of such chamber is provided in the alternative exemplary embodiment, as indicated generally at **170**. Each conduit **171** is of generally tubular configuration of constant cross section for its entire length with an inlet portion **172** mounted in the first end wall **121** of the afterburner and muffler chamber and an outlet portion **173** opening toward the end wall **123** and ignition means **125**. As shown in FIG. 8, the mounting means **174** for each inlet section **172** is comprised by deforming the inlet section to grasp the end wall **121** when inserted therein. Such mounting means **174** for each inlet section defines an annular port, indicated at **175**, opening to the afterburner and muffler chamber **120** through the interior of the heat exchanger tubes **171**.

Means responsive to the operating conditions of the internal combustion engine **1** for by-passing a portion of the exhaust gases past the bank of venturi pumps to the inlet portions of the heat exchangers tubes or conduits are provided so that all exhaust gases pass through the heat exchanger tubes or conduits into the afterburner and muffler chamber in the alternative exemplary embodiment. Such means as shown generally at **180**, comprise a valve housing **181**, a valve housing inlet **182**, and a valve **183**. Valve housing **181** in the present alternative exemplary embodiment is formed in part by the wall means **161** and end wall **121** of the afterburner and muffler chamber. The valve **183** may be pivotally mounted and operated in response to changes and operating conditions of an internal combustion engine as described in detail with relation to the prior preferred exemplary embodiment.

Walls **161** and **121** of the alternative exemplary embodiment along with additional outer enclosure walls **193** define a chamber **190** about the diffuser sections **133** of the venturi pumps. The conduit means **174** provide annular ports, indicated generally at **175**, opening the chamber **190** to the heat exchanger tubes **171**. Therefore, exhaust gases by-pass about the bank of venturi pumps by the valve means indicated generally at **130**, are directed through the valve housing into the chamber **190** through the heat exchanger conduits or tubes, indicated generally at **170**, and to the afterburner and the muffler chamber **120**. As in the prior embodiment then, all exhaust gases and added gases are directed into the afterburner and muffler chamber **120** through the heat exchanger tubes or conduits.

It is a particular feature of the present alternative exemplary embodiment that the heat exchanger conduits

171 are of unequal length to discharge exhaust gases into the chamber 120 toward the ignition means 124 in attenuated, spaced relation. The exhaust gases are then redirected about the exterior of the heat exchanger conduits past the plurality of outlet ports 143, 142 and 141 to be emitted to atmosphere through the exhaust or outlet pipe, indicated generally at 140. Additional silencing or muffling of the alternative exemplary embodiment is obtained by allowing partial dispersion of exhaust gases through the smaller outlet ports 142 and 143 prior to the main flow of exhaust gases through the larger outlet ports 141.

The method of treating exhaust gases emitted from an internal combustion engine to complete the combustion thereof has been partially disclosed herein by the prior detailed descriptions of exemplary embodiments of apparatus, according to the present invention, which employ the method. The first step in the present method is to establish a primary flow path for pulses of exhaust gases emitted from an internal combustion engine. The exhaust gas flowing in the primary path is then divided into a plurality of individual and distinct generally circular, parallel gas jets, each pressure pulse thereof being divided into individual elements.

The exhaust gas jets are then directed through a single body of additive gas comprising air to entrain amounts of such additive gas with each gas jet. In the exemplary embodiments described herein, such gas jets are formed by passing the exhaust gases through the multi-orificed plates 35 and 135. The jets so formed are then directed through the body of additive gas disposed within the chamber 90 and 190 formed between the respective orifice plates 35, 135 and the wall means 61 and 161. Mixing of the entrained additive gases with the jets of exhaust gases is then accomplished by directing such jets into the throat and diffuser sections of the bank of venturi pumps. Each mixture is thereafter separately passed into the afterburner and muffler chamber through the heat exchanger conduits or tubes. The mixtures may then be subjected to combustion within such chamber common to all the mixtures.

Further, in accordance with the present method, a secondary flow path for at least a portion of the pulses of exhaust gases emitted from the internal combustion engine is selectively established in response to the operating conditions of the internal combustion engine. Upon an increase in absolute pressure in the intake manifold and the increase in flow of exhaust gas from the internal combustion engine, a secondary flow path for a portion of the pulses of exhaust gases is established to direct such portions into the aforementioned common chamber without the steps of introducing an additive gas comprising air and the mixing of the exhaust gas elements and additive gases occurring in the primary flow path. Upon establishing the secondary flow path in response to the operating conditions of the internal combustion engine by opening the valve means in the exemplary embodiment, the portions of pulses of exhaust gases following the secondary flow path are directed into the common chamber with the exhaust gases and additive gases flowing in the primary flow path. All gases in the chamber are then subjected to combustion by igniting them and are thereafter emitted to atmosphere. According to the present method, therefore, while all exhaust gases from the internal combustion engine are passed into the common chamber where the step of combustion occurs, only the exhaust gases following the primary flow path are subjected to the steps of adding and mixing an additive gas comprising air.

It is a further feature of the present method that all exhaust gases following both the primary flow path and secondary flow path may be divided into a multitude of individual pressure pulse elements. The exhaust gases following the primary flow path may be divided in passing through the bank of venturi pumps and then directed in such divided state through the heat exchanger conduits or tubes, indicated generally at 70, in the exemplary embodiment of FIGS. 1 through 5. The flow of exhaust gases through the secondary path may also be divided into a multitude of individual pressure pulse elements. In the exemplary embodiment of FIGS. 1 through 5, for example, it can be seen that the flows of exhaust gases past the valve 83, through chamber 90 and into the plurality of heat exchanger conduits or tubes, indicated generally at 70, and also that through the annular ports 75 are effectively divided into a multitude of individual pressure pulse elements. The flow of divided pressure pulse elements in both the primary flow path and secondary flow path are commingled within the heat exchanger conduits or tubes prior to their introduction into the common chamber, as chamber 20 within the exemplary embodiment of FIGS. 1 through 5. The heat of all the exhaust gases is thus presented to the afterburner and muffler chamber during initial warm-up of the engine with the throttle open above that required merely for engine idling.

A study of exhaust velocity through exhaust pipes with relation to the number of cylinders firing has shown average exhaust gas pulse spacing of from 27 inches to 38 inches. The over-all average spacing has been found to be about 30 inches between primary pulses regardless of engine displacement. There is a variation in this spacing between specific pulses on a single engine because of the engine firing order and exhaust system dimensions, i.e. six cylinder or eight cylinder and V-type or siamesed exhaust pipes. To prevent the overlapping of the effect of succeeding pressure pulses when attenuating them according to the present method, it has been found expedient to spread each pulse out over a length of 16 to 24 inches. For example, in the method employed by the alternative exemplary embodiment herein, when the valve means is open under powered operation of the internal combustion engine, the exhaust gas has to travel unequal distances from the valve opening to enter the respective rows of heat exchanger tubes, whether pasing through the bank of venturi pumps or by-passing such bank and entering through the chamber 190. Thus, individual or distinct elements of each pressure pulse enter the nearest tube first so that by the time the pulse has reached the second row of tubes, from the bottom in FIG. 7, the element or partial pulse in the first row of tubes has travelled a distance down the first tube equal to approximately the distance between the first (bottom) row of tubes and the second row. This movement and division of each pressure pulse of exhaust gas continues proportionately with relation to the remaining rows of tubes as well. When the partial pressure pulse or element emitted from each of the heat exchanger conduits or tubes of the first (bottom in FIG. 7) row of tubes, the partial pulse or element in each of the second row of tubes is approximately two inches behind each of the elements in the first tubes. The provision of unequal length flow paths by the heat exchanger tubes for each row of elements causes a further attenuation or spacing of the elements in the first and second rows. Thus when each element or portion of an exhaust gas pulse is exiting from a heat exchanger tube in the second row, each element or portion of exhaust gas pulse emitted from the first row of heat exchanger tubes is already returning forwardly within the chamber toward the exhaust ports 141 providing as much as three inches gap between the elements in the first and second rows of partial pulses or elements. A similar circumstance occurs between the successive rows of heat exchanger tubes or conduits so that an original single pressure pulse of exhaust gas may be divided not only into a plurality of individual elements, but be spread over a distance, in the exemplary embodiment of FIG. 7, for example, of somewhat better than 10 inches. This spread can be controlled by adjusting the relative lengths of the heat exchanger conduits to increase or decrease such spread.

In the exemplary embodiment of FIG. 7, additional spread of the presure pulse elements may be effected by providing release holes in the end of the second baffle **144** near the exhaust tube, indicated generally at **140**, providing a short path for exhaust gas directed toward ports **141** as well as the long path around baffle **144**. Such provision may further spread the original pulse an additional six inches or more making the total pressure pulse spread in the exemplary embodiment of FIG. 7 at least 16 inches. As indicated previously, it is desirable that such spread of each exhaust gas pulse be over a length of about 16 to 24 inches. When the present device is used with internal combustion engines of small cubic displacement such as 80 cubic inches displacement or less, there may be only a limited number of venturi pumps employed in the bank and a corresponding number of heat exchanger tubes available for spreading the exhaust gas pulse. In such case, additional partial pressure release openings may be provided in selected tubes or conduits of the heat exchanger conduit means indicated generally at **170** so as to allow release of portions of the pulse prior to emission from the ends of such heat exchanger tubes and cause the spreading of the original pulse over as much as a distance of twenty inches. However, the method and apparatus as disclosed in the prior exemplary embodiments is preferred.

It has been found that under all normal operating conditions, the temperatures within the afterburner and muffler chamber of the present device are maintained in a range between a minimum of about 800 to 1,000° F. and a maximum of 1800 to 1900° F. Internal combustion engines with fouled sparkplugs or that are poorly maintained can emit abnormally high portions of combustibles into the exhaust and abnormally high combustion chamber temperatures may result. It has also been found that on long mountainous downgrades where the engine is used as a braking-aid, the combustion chamber temperatures resulting from such steady state deceleration can continue to climb to particularly abnormally high temperatures. Also, in view of the heat exchanger means provided within the afterburner and muffler chamber, rising temperatures in such chamber cause increasing temperatures of the incoming gases and therefore a compounding in the rise in combustion temperatures within the chamber may occur. As safety protection for the present device, a thermal sensor of generally known construction has been employed within the chamber and associated with the means responsive to the operating conditions of the internal combustion engine for by-passing a portion of the exhaust gases past the bank of venturi pumps. The thermal sensor may be adjusted to be operated by abnormally high combustion temperatures, but below a destruction temperature, to cause operation of the exhaust modulating valve by-passing a portion of the exhaust gases past the gas comprising air pumping section or venturi pumps. This will cause a reduction in the proportion of gas comprising air being pumped into the exhaust gases entering the afterburner and muffler chamber and therefore reduce the amount of combustion taking place therein. A lowering of combustion temperatures during these abnormal conditions may therefore be effected to prevent the destruction of the device by the otherwise resultant abnormally high combustion temperatures. In the exemplary embodiments disclosed herein, such conventional thermal sensor employed wtih the aforementioned means for bypassing exhaust gases has been adjusted to maintain a top combustion temperature of 2100 to 2200° F.

From the foregoing descripton of exemplary embodiments of the methods and apparatus of the present invention, it can be seen that the afterburner and muffler chamber of the present device may be readily associated with the exhaust outlet or pipe of any internal combustion engine. The device modifies the exhaust gas from such engine to complete the combustion therein, attains stabilized burning within the burner chamber more quickly than was heretofore possible, sustains combustion within the inner chamber during deceleration of the internal combustion engine within shorter periods after starting of the engine and effectively treats and muffles the sounds of internal combustion emitted from the internal combustion engine prior to the emission of such exhaust gases to atmosphere. The device may be readily attached not only to new internal combustion engines and vehicles employing them, but is adapted to be readily attached to existing vehicles by merely replacing existing mufflers with a device of the present invention. The present device further provides a long trouble-free life of operation, is easy to manufacture, does not employ catalysts which must be periodically replaced, and will continue to operate effectively continuous in all situations of use even where the internal combustion engine may be poorly maintained, abused or gradually ages. The present device and the method it employs allows the burning of exhaust gases with air added in approximate accordance with the variation in the hydrocarbon content of the gases under different operating conditions of the engine, while automatically and without the use of complicated or expensive machinery or additional mufflers, effectively muffling or silencing all exhaust gas emitted from the internal commustion engine. Such muffling or silencing is accomplished by the present method and the apparatus employing such method, as disclosed herein, by directing pressure pulses of exhaust gases in predetermined flow paths for introducing an additive gas comprising air to a portion of the pulses and mixing such portions and additive gas while effectively dividing all exhaust gas pulses into a plurality of individual or distinct elements and thereafter effectively attenuating or spacing such elements as they are emitted into the afterburner and muffler chamber by the herein disclosed heat exchanger means.

Having thus disclosed exemplary embodiments of apparatus and methods of the afterburner and muffler device of the present invention, we wish it understood that various modifications, alterations and adaptations of the afterburner and muffler device as disclosed herein may come within the scope of the invention which is defined by the following claims.

We claim:

1. An afterburner and muffler device for use in modifying exhaust gases from an internal combustion engine, comprising:

a housing to be associated with an exhaust pipe of an internal combustion engine;

an enclosed burner and muffler chamber in said housing including an ignition means and an outlet therefrom;

a plurality of heat exchanger conduits within said enclosed burner and muffler chamber having inlet portions mounted in and opening through an end wall of said chamber, the outlet portions of said conduits opening within said chamber toward said ignition means;

a bank of venturi pumps within said housing, each of said pumps having an inlet section opening to exhaust gases entering said housing, a diffuser section opening to the enclosed burner and muffler chamber through said heat exchanger tubes and a throat section having at least one port therein;

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

means for communicating the inlet portions of said heat exchanger tubes past said bank of venturi pumps to the exhaust gases entering said housing; 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 to the inlet portions of said heat exchanger tubes through said communicating means so that all exhaust gases from said internal combustion engine pass through said tubes and combustion chamber but the amount of air admixed into the total volume of exhaust gases by said bank of venturi pumps is not substantially increased when the flow rate of exhaust gases into said housing is increased more than twice the minimum flow rate of exhaust gases.

2. An afterburner and muffler device as in claim 1 wherein the heat exchanger tubes are of unequal length to disperse exhaust gas pressure pulses entering said burner chamber.

3. An afterburner and muffler device as in claim 1 wherein the inlet portion of each heat exchanger tube has a smaller diameter than the remainder of the tube so that a reduction in pressure is effected within the tubes as the exhaust gases pass therethrough.

4. A combination afterburner and muffler device for use with the exhaust pipe of an internal combustion engine for modifying exhaust gases therefrom, comprising:

an enclosed burner and muffler chamber having an inlet, an outlet and an ignition means mounted therein;

a plurality of heat exchanger conduits for directing exhaust gas flow into said chamber toward said ignition means in heat exchange relation to the interior of said chamber;

first means for supplying exhaust gases to said heat exchanger conduits including means for admixing gas comprising air into said exhaust gases in proportion to the flow rate of said exhaust gases through said first means;

second means for supplying exhaust gases without admixing gas comprising air to said heat exchanger conduits bypassing said first means; and

means responsive to the operating conditions of said internal combustion engine for selectively directing exhaust gases to said first and second means for supplying exhaust gases to said heat exchanger conduits so that all exhaust gases pass through said heat exchanger conduits but the amount of gas comprising air admixed to the exhaust gases passing through said conduits is not substantially increased when the flow rate of exhaust gases into said device is increased more than twice the minimum flow rate when said engine is idling.

5. The combination afterburner and muffler device of claim 4 wherein said first means for supplying exhaust gases to said heat exchange conduits comprises a bank of venturi pumps, each of said pumps including an inlet section opening to said exhaust gases, a diffuser section opening to said heat exchange conduits and a throat section having at least one port therein opening to said means for admixing gas comprising air into said exhaust gases; and

wherein said second means for supplying exhaust gases to said heat exchange conduits bypassing said first means includes wall means defining a chamber about the diffuser sections of said venturi pumps and means associated with said wall means defining a port to each said heat exchanger tube.

6. The method of treating exhaust gases emitted from an internal combustion engine to complete the combustion thereof comprising the steps of:

establishing a primary flow path for 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 parallel jets;

directing said jets through a single body of additive gas comprising air to entrain an amount of said additive gas with each of said jets;

passing each said distinct jet and an amount of entrained additive gas through a diffuser to mix said jet and entrained gas separately from each other distinct jet;

directing each separate mixture of exhaust gas jet and entrained additive gas into a common chamber;

selectively establishing a secondary flow path for at least a portion of the pulses of exhaust gases emitted from said internal combustion engine in response to the operating conditions of said internal combustion engine;

dividing said portion of pulses of exhaust gases into a plurality of individual elements;

directing elements of pulses of exhaust gases following said secondary flow path into the separate mixtures of exhaust gas and additive gas prior to their entry into said common chamber;

subjecting all said exhaust gases and said additive gases to combustion in said chamber; and

emitting said gases to atmosphere.

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