

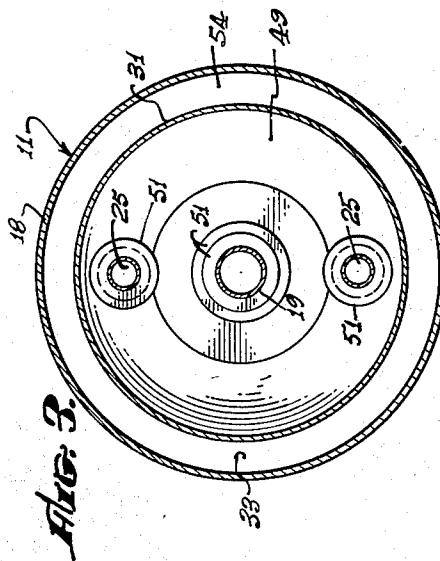
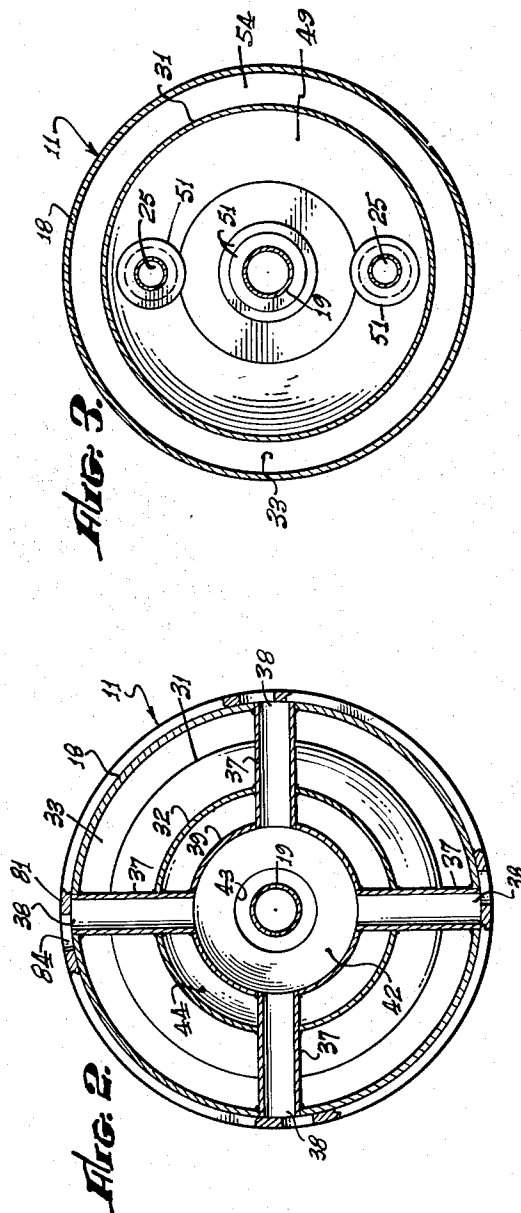
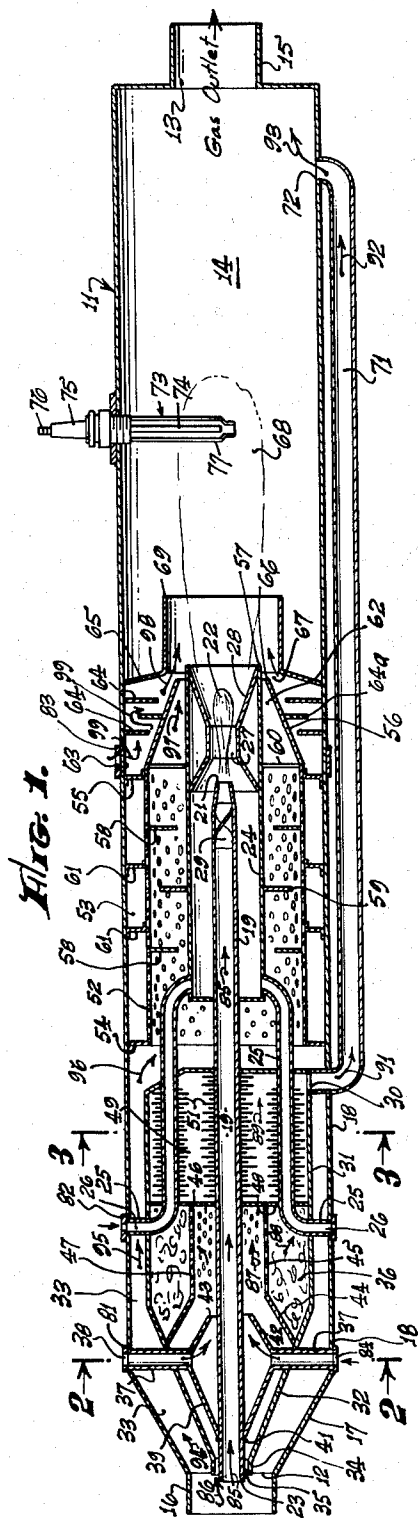
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METHOD AND APPARATUS FOR TREATING EXHAUST GASES WITH AN
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METHOD AND APPARATUS FOR TREATING EXHAUST GASES WITH AN EXHAUST GAS BURNER WITH CATALYTICALLY INDUCED FLAME

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The present invention has to do with improved methods and apparatus for effecting substantially complete combustion of the combustible constituents of exhaust gases before discharging them into the atmosphere.

An object of the invention is to avoid the deleterious effect of unconsumed constituents in discharged gases such as the exhaust from internal combustion engines, utilizing gasoline or other petroleum products as fuel which consist largely of hydrocarbons.

A more specific object is to accomplish the consumption of such unburned residues effectively, economically and without excessive increase of weight which must be carried by mobile apparatus, especially small passenger automobiles.

As a solution to the problem of obnoxious atmospheric conditions resulting from the discharge into the atmosphere of incompletely burned gas engine exhaust, various proposals have been made. For example, in the case of large busses and heavy trucks in which the exhaust gas issues at relatively high temperature and the aggregate quantity of unburned constituents is so great that a hot flame may be produced sufficient for maintaining combustion, after burners have been proposed into which the exhaust gas is passed and ignited by means of pilot flames or otherwise. In order to insure complete combustion of the exhaust gas, it is desirable to mix sufficient air with the exhaust gas to form a lean mixture, for making certain that substantially every particle of combustible residue can be oxidized. On the other hand, in order to maintain a combustion zone at a sufficiently high temperature to assure sustained combustion, for example, when idling or running down hill and less heat is produced, it is desirable that a relatively rich mixture be admitted to the combustion area.

Another proposal which has been made is to pass the entire volume of exhaust gas over a relatively large quantity of catalytic material, which promotes oxidation even of lower temperature exhaust gas in the presence of air, and renewing the catalytic material often enough to make sure that it is in effective acting condition.

An object of the present invention, therefore, is to extend the range of usefulness of after burning for the consumption gas engine exhaust as well as reducing the cost and increasing the reliability thereof. More particularly it is an object to accomplish after burning effectively in passenger cars in which the temperature of exhausted gas and of after burning would normally be too low to maintain after burning combustion reliability. Moreover, it is an object to avoid the necessity for providing and frequently renewing large quantities of expensive substances such as catalytic agents.

The present invention presents certain improvements on previously proposed means of after burning, chief among which the following features may be noted: fundamentally, catalysis of a small fraction of the exhaust gas is employed to generate heat and the remainder of the gas is subjected to the effect of such heat for promoting complete combustion. In one embodiment a fractional por-

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tion of the exhaust gas is withdrawn from the main body and passed through a high velocity tube to a pilot burner without substantially any cooling to aid in maintaining such withdrawn portion of the gas at a high enough temperature for sustained operation of the pilot flame. Moreover, no more than a stoichiometric quantity of primary air is mixed with the gas supplied to the pilot burner to keep the pilot flame hot. Less, preferably, than a stoichiometric mixture of the air is provided to give a rich mixture. In addition, another fractional quantity of exhaust gas is withdrawn from the main body and passed over a catalyst with additional air whereby oxidation thereof is promoted catalytically to insure that such second portion of air and exhaust gas will chemically unite rapidly for the generation of a high degree of heat.

The catalysis takes place in a heat transfer chamber containing heat exchangers through which the high velocity tube for the pilot flame gas and the primary air for the pilot flame also pass so that they are well preheated, thereby making sure that the pilot flame will be sustained, even in the case of a low power passenger car in which the heat of combustion might otherwise be too low to maintain a pilot flame. The remainder of the engine exhaust, that is, the main body of the exhaust gas, together with secondary air, is passed in proximity to the sustained pilot flame whereby combustion thereof is insured. Preferably the quantity of secondary air is as great or greater than a stoichiometric mixture so as to form a lean mixture of combustible material with air and make substantially certain that all of the combustible residues in the exhaust gas are consumed before being discharged to the atmosphere.

Since only a small portion of the exhaust gas is subjected to catalysis, the amount and cost of catalyst required are minor and the size and weight of the catalytic chamber are relatively small, rendering the arrangement practical for small inexpensive passenger automobiles.

These and other features of the invention and the invention itself will be better understood from the following detailed description of a preferred and illustrative embodiment of the invention shown in the accompanying drawing where:

Fig. 1 is a longitudinal sectional view of an illustrative embodiment of the invention;

Fig. 2 is a view of a cross section at twice the scale of Fig. 1, represented as cut by a plane 2—2 indicated in Fig. 1, as seen when looking in the direction of the arrows shown in Fig. 1, and

Fig. 3 is a view of a cross section at twice the scale of the apparatus of Fig. 1 represented as cut by a plane 3—3, indicated in Fig. 1.

The embodiment illustrated in the drawing has been so designed that it may replace the muffler of an automobile and perform the function of a muffler as well as an after burner. However, the invention is not limited to the combination of a muffler with an after burner, and the arrangement effectively consumes combustible constituents of exhaust gas independently of any action as a muffler.

The apparatus illustrated comprises a casing 11 composed of suitable sheet material such as metal which will withstand the temperature of exhaust gases and after burning thereof, with an inlet opening 12 at one end and a gas outlet opening 13 at the other end. The casing 11 is elongated, tubular in form, preferably but not necessarily cylindrical. The space 14 within the casing 11 toward the outlet end thereof serves as the after burner combustion chamber. Preferably, to retain combustion within the casing 11, the outlet opening 13 is of reduced size which facilitates also the provision of a nipple 15 for connection to a tail pipe or the like.

The inlet opening 12 also is smaller in diameter than

the casing 11 and as shown a nipple 16 is provided for connection to a conventional pipe from the exhaust manifold of the internal combustion engine. Preferably also the casing 11 is formed with a diverging portion 17 extending from the inlet opening 12 to the full diameter of the outer wall 18 of the casing 11 in order to aid passage of the main body of the exhaust gas from the inlet opening 12 toward the outer wall 18.

For the formation of a pilot burner and the supply of exhaust gas thereto, a high velocity tube 19 is mounted within the casing 11. The high velocity tube 19 is open at both ends and extends from the inlet opening 12 of the casing 11 toward the after burner combustion chamber 14. Preferably the high velocity tube 19 is mounted coaxially with the casing 11. The right hand end or outlet end 21 of the high velocity tube 19 serves as a nozzle for a pilot flame 22. Preferably the tube 19 is tapered to form a nozzle 21 of slightly reduced diameter whereby the gas entering the entry end 23 of the high velocity tube 19 passes through rapidly without expansion or consequent cooling and is slightly compressed at the nozzle 21 to maintain or increase the temperature thereof.

Surrounding the portion of the tube 19 toward the nozzle 21 is a shell 24 closed at one end to form a pilot flame air mixing chamber. Primary air supply ducts, for example, a pair of ducts 25 are provided extending from primary air supply openings 26 in the outer wall 18 of the casing 11 to the pilot flame air mixer shell 24. As shown, the ducts 25 are joined to the shell 24 at the closed end thereof or near the end thereof toward the inlet end 12 of the casing 11. For directing the mixture of air issuing from the shell 24 and gas issuing from the nozzle 21 a Venturi throat 27 is mounted in the outlet end of the pilot burner shell 24 so that the main portion of the pilot flame 22 is formed in the diverging portion 28 of the Venturi 27. For promoting turbulence and good mixing of air and gas in the pilot burner, helical vanes 29 are mounted within the high velocity tube 19 near the nozzle 21.

The construction and arrangement of the high velocity tube 19 and the pilot burner within the Venturi 27 maintain the pilot burner gas substantially at the temperature of the exhaust gas entering the inlet 12 and thus aid in sustaining the pilot flame 22. However, in order to make sure of maintaining the pilot flame air and gas at ignition temperature for insuring sustained existence of the pilot flame 22 regardless of operating conditions of the engine or use of the after burner on a low power vehicle in which the exhaust gases may issue from the engine at a relatively low temperature, preheating means are provided both for the exhaust gas passing through the high velocity tube 19 and the air supply therefor.

A preheat chamber comprising a housing 31 is mounted within the casing 11 surrounding the high velocity tube 19 approximately at the central portion thereof and also surrounding the corresponding portion of the primary air ducts 25. The preheat chamber housing 31 is closed at the end thereof toward the outlet end of the casing 11, except for an outlet opening 30 for preheat combustion products. The housing 31 for the preheat chamber is spaced from the outer wall 18 of the casing 11 and is formed with a conical portion 32 partially corresponding to the conical portion 17 of the casing 11 to form a passageway 33 for the main body of gas entering the inlet opening 12 of the casing 11.

Furthermore, the conical portion 32 of the housing for the preheat chamber is formed with an annular lip 34 surrounding and spaced from the high velocity tube 19 preferably receding somewhat from the entry end 23 of the high velocity tube 19. In this manner an annular orifice 35 is formed for withdrawing a second fractional portion of gas from the main body of exhaust gas entering the inlet opening 12 of the casing 11. A mass of catalytic material 36 is mounted within the housing 31 of the preheat chamber and catalyst air supply ducts 37

are provided for causing the portion of gas entering the orifice 35 to unite rapidly with air by catalytic action so as to generate heat. This heat is employed for raising the temperature of the gas passing through the high velocity tube 19 and the primary air flowing in the ducts 25, which supply the pilot flame 22. As shown, the catalyst air supply ducts 37 extend inward, radially through the passageway 33, from catalyst air supply openings 38 in the outer wall 18 of the casing 11, in the stream of hot exhaust gas for preheating catalyst air.

In order to serve also as structural supporting members the catalyst air supply ducts 37 may be four in number and joined in any suitable manner as by means of welding or brazing to the casing wall 18 and to the conical portion 32 of the preheater housing 31. In addition a biconical hollow member 39 is joined to the radial ducts 37 and also to the high velocity tube 19 toward the entry end thereof, for example, by means of a welded or brazed joint or the like 41. A portion 42 however, of the biconical hollow member 39 has an inner edge 43 spaced from the outer surface of the high velocity tube 19 in order to provide a directed passageway for catalyst air from the ducts 37 into the housing 31.

A conical baffle 44 is also mounted within the conical portion 32 of the housing 31 of the preheater chamber which cooperates with the conical portion 42 of the hollow biconical member 39 to form a converging annular passageway for the catalyst gas. This shaping of the passageway together with the sharpness of the edge 43 around which the catalyst air enters promotes turbulence thereof and good mixing before passage over the mass of catalytic material 36. Means are provided to insure thorough and complete exposure of the air and gas mixture to the catalytic material 36. As shown the catalytic material 36 is confined within the space bounded by the conical baffle 44, the adjacent portion of the housing 31, a perforated shell 45 concentric with the high velocity tube 19 and the housing 31, and a perforated transverse end plate 46, which serves also as structural support for the high velocity tube 19. The shell 45 is provided with openings 47 spaced around its periphery and along the length thereof. However, the plate 46 is closed between the high velocity tube 19 and the shell 45 in order to force the air and gas mixture to enter the space containing the catalytic material 36 and issue from openings 48 into a space 49 within the housing 31, serving as the heat exchanger space.

In order to promote transfer of heat from the products of combustion within the space 49, which have been caused to become heated rapidly by the catalytic action, fins 51 are joined to the portions of the high velocity tube 19 and the primary air supply ducts 25 within the heat exchanger space 49. It will be understood that in order to achieve effective interchange of heat, the fins 51 and the tubes 19 and 25 are composed of a substance having good heat conductivity such as copper, for example, and care is taken that the fins 51 are brought into intimate thermal contact with the tubes 19 and 25 by continuous brazing, welding, or the like.

If it is desired to provide a muffler in the after burner casing 11, a suitable baffle structure is mounted within the outer wall 18 of the casing 11 between the wall 18 and the pilot burner shell 24. This may take a form as shown, of a hollow concentric perforated cylinder 52 supported coaxially within the casing 11. The space 53 between the perforated cylinder 52 and the casing wall 18 is closed at both ends, for example, by means of a flange 54 formed on the hollow cylinder 52 and an annular disc 55 located toward the other end. Preferably the exhaust end of the hollow cylinder 52 is tapered to form a frustoconical nose 56 to cause the exhaust gases from the passageway 33 to travel with increased velocity, closely along the outer surface and toward the front edge 57 of the shell 24. A plurality of annular baffles are provided such as baffles 58 secured to the hollow cylindrical member 52 and extend-

ing closely but not fully toward the shell 24 and a baffle 59 secured to the shell 24 and extending closely but not fully toward the hollow cylindrical member 52. Solid baffles 61 are also provided in the space 53 to force the exhaust gases from the passageway 33 to travel around the baffles 58 and 59 and through the perforations in the hollow cylindrical member 52. Radial rods or stays 60, only two of which are visible, serve to support the outward end of the pilot burner shell 24 in the hollow cylinder 52.

Secondary air for combustion of the gas from the passageway 33 issuing from the converging throat 62 formed between the forward end of the shell 24 and the frustoconical nose 56 is admitted around the frustoconical nose 56. To this end secondary air inlet openings 63 are provided which are spaced around the periphery of the outer wall 18 of the casing 11, only one of which is visible in the sectional view illustrated. For inducing turbulence of the secondary air a plurality of annular baffles is provided including baffles 64 secured to the outer wall 18 of the casing 11, and baffles one or more, 64a, secured to the frustoconical member 56, restricting but not fully closing the passageway between the outer wall 18 of the casing 11 and the frustoconical nose 56. Moreover, a dished annular baffle 65 is preferably also secured to the outer wall 18 of the casing 11, extending inward to a point somewhat in advance of the forward edge 66 of the frustoconical nose 56 and nearly as far forward as the edge 57 of the shell 24 to form a restricted annular orifice or exit passageway 67. In addition, to confine and direct a flame 68 formed by the combustion of the mixture of air and gas issuing from the annular orifice 67, a tubular nozzle 69 is secured to the inner edge of the dished baffle 65 or formed integral therewith.

Preferably the products of combustion or catalytic oxidation formed in the heat exchanger chamber 49 issuing from the outlet 30 are carried to the outlet end of the casing 11 by providing a tube 71 connected at one end to the outlet 30 and at the other end to a lateral opening 72 in the casing 11.

Under normal operating conditions an independent igniter is not required for the after burner illustrated. Nevertheless, as a safeguard in event that a very small quantity of combustible gas should enter the catalytic inlet orifice 35 during certain operating conditions such as prolonged down-hill driving when unheated raw gasoline tends to be discharged into the exhaust manifold, a conventional igniter 73 may be provided. This may take a form as illustrated, of a high voltage electrode 74 secured to and insulated from the casing 11 by means of a porcelain bushing 75 or the like having a high voltage terminal 76 for connection to the ignition system of the automobile and cooperating with a low voltage electrode 77 grounded to the casing 11.

An advantageous form of construction of a preferred embodiment of the invention has been illustrated in which a small fraction of the exhaust gas is withdrawn through the annular orifice 35 for catalytic oxidation in the housing 31 of the preheat chamber, and the remainder of the gas is divided between the high velocity tube 19 and the annular passageway 33 for combustion or chemical union with atmospheric oxygen promoted entirely by temperature and the tendency for combustible substances and oxygen to unite at sufficient temperature. Such combustion may take place in the formation of flames 22 and 68 but is not necessarily limited to the actual formation of flame.

In the construction illustrated, the major portion of the combustible gas or engine exhaust products remaining after withdrawal of the fraction thereof through the orifice 35 for catalytic oxidation travels through the passageway 33 and the minor portion travels through the high velocity tube 19. However, the invention is not limited thereto, and does not exclude having the entire remainder of the exhaust gas not withdrawn through the annular

orifice 35 travel through the central coaxial tube 19, in which case the pipe from the exhaust manifold of the engine may be connected directly to the lip 34. It will be understood that in this case, the portions of the apparatus serving as a muffler being omitted, the members 16 and 17 may be omitted and the portion of the outer wall 18 of the casing 11 illustrated in the drawing to the left of the tubular nozzle 69 may also be omitted with the diameters of the tube 19 and the shell 24 appropriately increased so that the nozzle 69 may have substantially the diameter of the casing 11 at its outlet end. Alternatively, the shell 24 may be extended so that the space therewithin takes the place of the major combustion chamber 14 illustrated within the casing 11.

In this case the diameters of the primary air inlet openings 26, the catalysis air inlet opening 38, in relation to each other and in relation to the cross sectional areas of the annular catalysis gas inlet opening 35 and the internal diameter of the tube 19 are so selected as to insure a quantity of air no less than a stoichiometric mixture at the nozzle 21 so that the mixture will be lean rather than rich if departing from a stoichiometric mixture, in order to make sure of complete combustion of the exhaust gas.

In the construction illustrated, the admission of suitable amounts of primary and secondary air and catalytic air to provide a stoichiometric mixture passing over the catalytic material 36, a rich mixture at the nozzle 21 and a lean mixture at the major combustion nozzle 69 may be facilitated by the means of damper rings for adjustment of air proportions. For example, there is a damper ring 81 for control of the air admitted through the ducts 37 for the catalytic oxidation; there is a damper ring 82 for control of the primary air admitted through the ducts 25; and there is a damper ring 83 for control of the quantity of secondary air admitted for the major combustion. As illustrated in Fig. 2 more clearly, the damper ring 81 consists of a band rotatably mounted on the shell 11 with guides (not shown) to maintain the ring 81 in alignment with the air inlet openings 38 formed in the shell 11. Corresponding damper openings 84 are formed in the damper ring 81 so that by adjustment of the angular position of the ring 81, the degree of registry of the openings 38 and 84 may be varied for adjustment of the effective area of the air inlet openings. A similar construction and arrangement of the damper rings 82 and 83 may be employed, as will be understood by those skilled in the art.

Any suitable material, preferably in finely divided form, may be employed as the catalytic substance 36. For example, platinum gauze may be successfully employed.

It will be understood that the parts of the after burner illustrated may be composed to a large extent of sheet metal and if desired, drawn tubing, and that conventional methods of assembly and securing the parts may be employed, such as welding, brazing, or other methods of forming tight joints where required, or secure joints where only a support is required, which will not be affected by the temperatures of exhaust gases and of the combustion which takes place in various spaces within the after burner.

The relative proportion of the exhaust gases drawn through the various passageways may be varied according to the type of service to which the after burner is applied, and the invention is not limited to specific proportions. As an illustrative example, it may be stated however, that in the case of a 1956 Chevrolet passenger car engine the exhaust gases, at normal cruising speed of 40 miles per hour, for instance, seldom exceed 450 to 500 degrees F. In this case the arrangement is preferably such as to raise the temperature of the pilot portion of the gases to 750 or 800 degrees F. This causes ready establishment and maintenance of the pilot flame 22. Sufficient exhaust gas is passed through the catalytic material 36 to produce a higher temperature in the heat

exchanger 49, for example, a temperature of 1000 degrees or over. In this way a relatively small amount of catalyst is sufficient to maintain a high temperature in the pilot flame. This may be substantially accomplished by passing approximately 10% of the gas through the orifice 35 to the catalytic burner, approximately 10% of the gas through the high velocity tube 19, to the pilot nozzle 21 and the remainder or approximately 80% of the gas through the passageway 33 to the main combustion nozzle 69.

In such operation, a fractional portion of the exhaust gas, for example 10%, passes in a direction indicated by the arrows 85 through the high velocity tube 19 and the conical nozzle 29, through the nozzle 21, to form a pilot flame 22, primary air entering through the ducts 25 into the chamber formed in the shell 24 to join the gas issuing from the nozzle 21.

Another fractional portion of the exhaust gas enters through the annular orifice 35 in the direction of the arrow 86 for catalytic oxidation. This fraction may be no greater than that entering the high velocity tube 19, for example, approximately 10% of the entire body of exhaust gas if the outer passageway 33 is employed and if the nozzle 21 is employed as a pilot nozzle. However, if the passageway 33 is not employed and the main body of the gas enters the central tube 19, the proportion entering the annular orifice 35 is made only a small proportion, e.g., 10% of that entering the tube 19.

In the construction illustrated, after the gas for catalytic oxidation has entered in the direction of the arrow 86 it follows the direction of the arrow 87, passing through the perforations 47 in the hollow cylinder 45 through the catalytic substance 36 in the direction of the arrow 88 on through the openings 48 and through the heat exchanger chamber 49 in the direction of the arrows 89 past the heat exchanger fins 51 and out through the tube 71 in the direction of the arrows 91, 92 and 93.

In the construction illustrated where the central tube 19 is employed merely for supplying pilot gas, the main body of the exhaust, for example 80% thereof travels through the annular passageway 33, entering in the direction of the arrow 94, continuing along the direction of the arrow 95 around the primary air ducts 25, preheating primary air, along arrow 96 around the baffles 58, 61 and 59 in the direction of the arrow 97. Thereupon secondary air is drawn in with the mixture following the direction of the arrow 98. Gas travelling along the arrow 95 is heated by passing around the heat exchanger housing 31. The secondary air having entered through the opening 63, travels around the baffles 64 and 65 as represented by arrows 99.

In this manner catalysis of the gas entering the orifice 35 generates sufficient heat to raise the temperature of the gas travelling in the central tubes 19 and the primary air entering through the ducts 25 to insure sustained combustion of the gas issuing from the nozzle 21. This may constitute the entire remainder of the gas to be consumed. It may also, as in the construction illustrated, serve to form a pilot combustion area insuring ignition and combustion of a major body of air and gas travelling in the direction indicated by the arrow 98.

While the invention has been described as embodied in concrete form and as operating in a specific manner in accordance with the provisions of the patent statutes, it should be understood that the invention is not limited thereto since various modifications thereof will suggest themselves to those skilled in the art without departing from the spirit of the invention.

I claim:

1. The method of effecting oxidation of the oxidizable constituents of a gaseous exhaust mixture, comprising in combination the steps of passing a first minor portion only of the gaseous mixture together with air into contact with a catalyst and thereby inducing exothermic oxidation of the oxidizable constituents of that first portion,

heating a second minor portion only of the gaseous mixture with heat derived from said catalyst induced exothermic oxidation, initiating and maintaining combustion of the oxidizable constituents of said heated second minor portion of the gaseous mixture together with air to produce a pilot flame, and introducing the remainder of said gaseous mixture together with air into proximity of the pilot flame to initiate and maintain oxidation of the oxidizable constituents of said remaining portion by the heat of the pilot flame, and thus finally producing an exhaust mixture substantially devoid of constituents which are combustible in air.

2. The method combination of claim 1 and in which the air used to produce the pilot flame is also heated with heat derived from the catalyst induced oxidation.

3. The method combination of claim 2 and in which the air used for the pilot flame is less than the stoichiometric quantity relative to the combustible constituents in the heated second portion of the gaseous mixture.

4. The method combination of claim 1 and in which the air used for the pilot flame is less than the stoichiometric quantity relative to the combustible constituents in the heated second portion of the gaseous mixture.

5. The method of effecting oxidation of the oxidizable constituents of a gaseous exhaust mixture, comprising in combination the steps of passing a first minor portion only of the gaseous mixture together with air into contact with a catalyst and thereby inducing exothermic oxidation of the oxidizable constituents of that first portion, forming a combustible mixture of constituents including air and a second minor portion only of the gaseous mixture, heating at least one of said constituents with heat derived from said catalyst induced oxidation and thereby heating said combustible mixture, initiating and maintaining combustion of said heated combustible mixture to produce a pilot flame, and introducing the remainder of said gaseous mixture together with air into proximity of the pilot flame to initiate and maintain oxidation of the oxidizable constituents of said remaining portion by the heat of the pilot flame, and thus finally producing an exhaust mixture substantially devoid of constituents which are combustible in air.

6. The method combination of claim 5 and in which the air used for forming the combustible mixture with the said second gaseous portion is less than the stoichiometric quantity relative to the combustible constituents of said second gaseous portion.

7. Apparatus for causing oxidation of the oxidizable constituents of the exhaust gas mixture from a previous combustion, said apparatus comprising an elongate external outer shell having at one end an intake for such gas mixture, a tubular walled passage having an open end in said intake and extending longitudinally within the shell to a discharge end within the shell, said tubular passage adapted to take and pass a first minor portion of said gas mixture, wall structure forming a catalyst chamber within said external shell, a catalyst in said chamber, wall structure within said external shell forming a second gas passage with an open end in said intake adapted to take and pass a second minor portion of said gas mixture and also forming an air passage adapted to take air externally of said shell, said second gas passage and said air passage leading to said catalyst chamber, wall structure forming a heat transfer chamber within said shell in communication with said catalyst chamber and adapted to take hot products of oxidation therefrom, said heat transfer chamber surrounding said tubular walled passage for transfer of heat to the first minor portion of gas in said passage, wall structure forming a second air passage adapted to take air externally of said shell and having a discharge end in the shell in the vicinity of the discharge end of the tubular gas passage, for inducing and maintaining a pilot flame within the casing in the vicinity of the discharge end of said tubular gas passage, and wall

structure forming a third gas passage within said shell, having an open end in said intake and adapted to take the remaining portion of the gas mixture and also forming a third air passage within said shell adapted to take air externally thereof, said third gas and air passages having discharge ends in the vicinity of the pilot flame.

8. The apparatus combination defined in claim 7, and in which said walled second air passage extends through said heat transfer chamber for heat transfer to the air passing through said passage.

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