COMBUSTOR FOR POWER VAPOR GENERATORS

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ABSTRACT
The vapor generators are for powering external combustion engine systems. The combustors thereof provide heat in response to engine power demand to vaporize liquid in their boiler tubes. Their combustion emissions are with low noxious pollutant content over the power operating range of the engine system. Internal arrangements are incorporated in the combustors that maximize burning-up of fuel that is injected into the primary combustion zone. Portions of the combustors that may reach above 2,100°F are minimized to inhibit the formation of nitrous oxide. Regions that might fall below 1,500°F are controlled to avoid quenching that would result in the formation of carbon monoxide and unburned hydrocarbon particles. The flow of combusted gases is moderated by arranging for the flow of incoming air to be in the counter direction. Air and fuel particles are thoroughly intermixed towards complete combustion. A wide range of available fuels may be used, and operation over at least a 20:1 ratio of fuel input is effected. An important feature hereof is the use of a flat spiral wall of fluid filled tubing above the combustion zones. Fluid to be vaporized flows through the fluid tube wall, and shields the combustor housing from reaching excessive temperature.

6 Claims, 5 Drawing Figures
COMBUSTOR FOR POWER VAPOR GENERATORS

CROSS REFERENCE

This patent application is a continuation-in-part of my copending application for "Vapor Generators With Low Pollutant Emission," Ser. No. 261,691, filed June 12, 1972.

BACKGROUND OF THE INVENTION

The basic engine power cycles in current use were originated before the turn of the century. The Rankine cycle involves the vapor engine principle, wherein the engines are fueled externally (ECE). Most of today's cars, buses and trucks are fueled internally, as combustion engines (ICE). The Otto cycle uses carbureted gasoline air/fuel mixtures that are exploded against the engine's pistons. Gas turbines function generally on the Brayton cycle. Other variations are the Stirling and the Diesel engine cycles. Nevertheless, none of these engine cycles transform the heat energy that is generated into practical work with high efficiency. The Carnot cycle delineates the theoretical limits of such power conversion from heat energy.

The automakers have thoroughly mastered the mass production of ICE piston engine using liquid petroleum fuel. The automobile industry has thoroughly developed gasoline fueled ICE engines so that they cost less, weigh less, require less space, and use less fuel for given output ratings than other engine types currently available. Internal combustion engine, however, present a high noxious pollution factor. In operation, measured fuel and air mixtures are fed into each cylinder successively, exploded, then exhausted to the atmosphere, all at many times per minute. Their pistons convert the explosion energy into work. The air/fuel mixture often is improperly carbureted and upon entering the cylinders only some portions of the charge burn well, while other portions have too little or too much fuel for the contained air. Another important defect is the relatively cooler cylinder walls that cause incompletely burned fuel therein.

The portions of the air/fuel charges that burn poorly, or not at all, contain carbon monoxide and hydrocarbons. The higher temperatures in the explosions cause the oxygen and nitrogen of air in the charge to form unwanted oxides of nitrogen (NOx). To date, researchers have determined that these inherent faults of the ICE systems may be moderated but not sufficiently so to their noxious pollution. The relatively high adverse pollutants emissions from ICE engines are today a significant cause of smog and unhealthy city climates. The present invention is directed towards improved and practical vapor generators of superheated vapor at high temperatures and high pressure with relatively low resultant pollution for powering ECE systems. In ECE systems, heat energy is generated by burning fuel, as heated gas. This energy is presented to the power expander, e.g., a vapor turbine, through a different medium, namely superheated steam. The combustor-vapor generator is separate from the power expander of an ECE system, and is thermodynamically independent of it.

SUMMARY OF THE INVENTION

Superheated steam is generated by the combustor or burner hereof, as at the order of 1,000°F, and high pressure as at the order of 1,000 pounds per square inch. The flow of the superheated steam to the vapor power expander is controlled through a throttle valve. Superheated steam has been found to be preferable to vapor of available organic fluids, as fluorocarbons. Water is stable under superheat conditions.

A flat double spiral tubing array forms a heat shield above the combustor hereof. Water flowing through this array absorbs heat, and prevents the housing from becoming too heated. The combustor-vapor generator is constructed of simple components; and is rugged, reliable and efficient. Its arrangements assure relatively clean emission operation from idling condition through top power demand. The combustor has low noxious pollutant emission over the wide power demand of a vehicle in operation. Water is fed into the vapor generator by a suitable high pressure pump in general proportion to output power demand. The result is a steam flow rate rapidly responsive to power demands of the ECE system as a whole. The respective steam, and the fuel and air mass flows are continuous and continual through their controls while the engine system is ON, and provides a power drive basis for the vehicle that is as smooth and effective as commercial ICE cars, buses and trucks.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view through an exemplary combustor-type generator.

FIG. 2 is a schematic showing of some tubes of the boiler section.

FIG. 3 is a diagram of the double spiral tubing array of the water wall shield.

FIG. 4 is an enlarged cross-sectional view taken along the line 4—4 at the center of the array of FIG. 3.

FIG. 5 is a system diagram of the water/vapor tubing of the boiler and water shield sections of the exemplary combustor.

THE COMBUSTOR-VAPOR GENERATOR

The exemplary vapor generator 30 and integrally assembled combustor 55 are shown in cross-sectional view in FIG. 1. Its internal construction and combustion process are arranged to maximize fuel combustion and to minimize hot spots above about 2,100°F to keep formation of NOx below the requisite minimum to meet the EPA Emission Standards. These factors are also arranged to minimize undue quenching at relative cold spots, e.g., below about 1,500°F, to keep the formation of CO and hydrocarbons within these Standards. Further, these factors remain operative over the power demands and operating range made upon the vapor generator 30 by the engine system it is part of. Operation of the combustor (55) is maintained with air and fuel injection at a given relative mass ratio, as 30, with an operative turndown range of at least 20 to 1. Reference is made to my aforesaid copending patent application for details of an ECE system using a combustor-vapor generator of the type hereof.

The combustor system 55 may be designed to use fuels that are currently generally available, including automotive gasoline, kerosene, Diesel No. 1 and Jet A fuel, as well as for unleaded gasoline, and JP-4 aircraft class fuel. The overall efficiency of vapor generation hereof is in the order of 95 percent at the lower power level of 50 HP, as at idling condition with accessory drive in a 240 HP vehicle; to the order of 90 percent at its top power level. The temperature of its gaseous...
exhaust is acceptably warm to the touch, as are the outer exposed surfaces. The vapor generator and combustor hereof (30,55) are suitable for mass production, of relatively inexpensive material, at reasonable unit cost.

Combustor 55 is of the axial flow turbulent vortex type. Combustion therein is accomplished within a 15 inch diameter chamber 132 for firewall 135; 15 inches high in the 240 HP 50-passenger bus; 7/3 inches high for a passenger car of 120 HP hereof. The combustion gases are inert before they propel over top level 156 of firewall 135, and on to the convection bank of fluid/vapor tubing 160. The volume of the bus combustor (55) is 1.5 cubic feet. Its heat release at a 28 gallon per hour fuel rate provides approximately 2.15 × 10⁶ BTU per cubic foot per hour.

The fuel is herein atomized by a spinning cup 60 at the bottom center of the combustor. An atomizer nozzle or equivalent may instead be used. Fuel is introduced to the center of cup 60 through U-tube 61. Tube 61 is sized to supply the fuel at pressures below 10 psi. Spin cup 60 is rotated at 12,000 rpm for atomization velocity sufficient to atomize all of the fuel fed even at its high flow rate. Spin cup 60 and its motor 62 are cooled by air injected into its well 135. Such air is diverted from scroll 72 through duct 137, flowing passed spin cup 60 inwardly into the combustion zones.

Air enters the primary combustion zone 133 and secondary zone 132 above it through a grid of apertures 140 contained in cylindrical firewall 135. The exemplary grid 140 comprises an array of the order of 2800 holes in the larger bus unit, consisting of 30 rows of 94 holes each on a 0.5 inch grid. The six bottom rows of apertures (140) substantially form the air inlet for primary combustion zone 133, and are 13/16 inch in diameter. The remaining apertures are the bulk of the air inlet supporting combustion in the secondary zone 132, and are 1/8 inch in diameter. Other grid arrays and apertures diameters are feasible therefor, as to number, position and construction.

An important component of combustor 55 is the annular air deflector-baffle system. Baffles 145 comprise a series of spaced conical downwardly directing air deflection plates 146. Deflection baffles 145 contribute to the preheating, the remixing of inlet air with atomized fuel, and control the velocity distribution of gases within combustor 31, to promote rapid and full combustion of the atomized fuel and even of fuel droplets that may have formed therein, as will now be set forth.

Fuel combustion initiates in the lower region 133 as the primary zone. Combustion therein occurs under relatively fuel rich conditions, thereby retarding the formation of oxides of nitrogen. The active addition of ample secondary air into the next upper and adjacent zone 132 completes combustion of the hydrocarbons species and carbon monoxide, while avoiding sufficient residence time at reaction temperatures that might form objectionable quantities of nitrogen oxides. Air baffle/deflector assembly 145 is arranged to direct the input air from scroll 72 through the upper grid of holes (140) inwardly into the secondary zone 132, but importantly also downwardly towards and into the lower primary combustion zone 133, see arrows a. Towards this end the downwardly oriented conical lips 146 of deflectors 145 are at 45°. The atomized fuel spreads away from cup 60, in annular array in primary zone 133, and the air supplied through the lower few baffles (145) is towards and into the atomized fuel as the primary combustion zone 133.

It is noted that the aforesaid air flow is 360° around. This occurs up and down within the firewall 135, all downwardly but in the opposite direction to that of prior combustion gas flow. This latter flow is from lower zone 133 up through zone 132, and out above the combustor 55, namely to the combustion gaseous zone 134 centrally of tube bundle 160. In prior art combustors, the input air generally was introduced and directed along in and with the general path of the primary combustion gases, herein from zones 133 to 132 to 134. The process of the exemplary combustor propels distinct tubular streams of air from grid 140 downwardly in the direction of the sprayed fuel and also opposite to the flow direction of the primary combusted fuel from zone 133 up through zone 132 and to top zone 134. The pre-swirled air in scroll 72 contributes to the tortuosity in this process. The downwardly baffled tubular streams of air enhances the molecular turbulence of the atomized fuel enhancing the combustion process in the primary zone 133, and from then on.

Further, the baffles 145 direct the incoming swirling air stream into the generally central secondary combustion zone 132 to further turbulate and mix-up uncombusted fuel droplets, as well as combustible pollutants and particles that move up thereto from primary zone 133. This action enhances the surrounding of and intermixing with oxygen these particles to be combusted towards their complete burning with low noxious emission.

By maintaining the overall air/fuel mass ratio at twice stoichiometric as aforesaid, and turbulating the air streams with the basic atomized fuel, small packets of air and fuel are formed. This results in full burn of the fuel, substantially, with resultant pollutants in the overall gaseous emission from the combustor-vapor generator to the atmosphere through its exhaust ducts within the EPA Emission Standards referred to. Creation of such turbulence in the secondary combustion zone 132 enhances such result. Further, the counter direction of incoming air downwardly through baffle array 145 moderates the rate of flow of combusted fuel up from zone 133 to zones 132 and out through zone 134. This permits sufficient residence time for efficient combustion of the atomized fuel particles, particularly when surrounded by the ample air in the small packets.

The central reigniter tower 150 still further contributes towards full combustion. It comprises, in the exemplary form, an assembly of five annular horizontal discs 151 supported in vertical posts 152. The posts 152 are mounted in the combustor 55 by tie-rods 153 welded to edges of baffles 146. Alternatively, posts 152 may extend to the combustor base and be secured by extensions indicated at 154. The tower 150 is shown positioned above top level 156. It however may be located somewhat lower, even extending into primary zone 133. Optimum location in a particular design can be readily determined for lowest noxious pollutant results. The tower 150 is optional. It is designed for structural integrity in the high temperature high turbulence region of power combustor 55.

The practical effect and result of the vigorous intermixing, turbulizing and chopping-up of the atomized fuel and air streams, with the stated air/fuel ratio, in the combustion process hereof is to burn the fuel quite completely. This result is particularly effective due to
the multitude of small fuel/air packets formed. The fuel and air rate fed in, and the travel path provided assures the combustion at the order of 2,100° and below, with negligible hot spots thereat, to hold $NO_x$ production below the target minimum over the power operating range, e.g. 10 parts-per-million (ppm) in the exhaust.

Fuel particles and droplets, and incompletely burned particulates and pollutants, that emerge from the primary combustion zone 133 encounter reigniter tower 150 in the secondary combustion zone 132. Besides the turbulence and further breakup in that caused by tower 150 as aforesaid, the glowing state of its components 151, 152, ignites particles, particulates and pollutants that impinge. This tower “reignition” action assures cleanliness of the exhaust gases with a minimum of noxious pollutants. The deflector baffles 145 also are at sufficiently high temperatures to similarly serve as reigniters. The baffles 145 and the components 151, 152 of tower 150 are arranged to operate in the cherry-red to light orange temperature range, namely the order of 1,300° to 1,850° F, the tower ranging higher. The conical baffles 145 made of Inconel No. 601 material are structurally intact in combustor 55. The tower 150 not being directly cooled, is constructed of columbium, molybdenum or other suitable high temperature metal or alloy.

Minimization of quenching in the combustion process is accomplished in the combustor-vapor generator (30, 55). The downwardly air projecting baffles 145 are somewhat cooled by the air incoming, which keeps them from rising much above light orange at 1,850° F. The baffles 145 thoroughly preheat the incoming air and thereby inhibit the air from quenching, or only partially burning in the fuel combustion process hereof. An important feature of the set of baffles 145 is that they are arranged so that their inner downwardly directed portions 146 are sufficiently long to inhibit heat in radiation form from the combustion zones 132, 133 from reaching out to the firewall 135. For this purpose, also the length of their annular horizontal shelf portions 147 is suitably proportioned with the angle and length of the downwardly directing portions 146. Such radiation protection of firewall 135, together with its intimate contact with the much cooler incoming swirling air in the scroll 72 that surrounds it, prevents it from exceeding a cherry red temperature.

The radially inner bank of superheat steam tubes 161 are preferably provided with fins 162 along their surface. These fins 162 are hit by the initial hottest phase of the convection heat flow 175. They may even run cherry red. Nevertheless, their presence prevents these tubes from lowering to quenching temperature, and also serves a refluxing function. The convection bank 160 is a counter flow heat exchanger. The feedwater is injected at 29 into the outermost coil in the radial group, and the superheated steam is extracted from the end 31 of the innermost coil. Thus the hottest combustion gases heat the hottest fluid (vapor) and the coldest combustion gases heat the coldest fluid (water). As the combustion gases flow through convection bank 160 as indicated by arrows 175, and give up their heat, the tubes thereof in turn transfer the heat into the vapor or fluid therein, as the case may be. As the water flows from the outside coils towards the center, picking up increasing gaseous heat and velocity, the internal diameter of the tubing (161) becomes progressively larger to minimize flow pressure drop.

The two outermost rows of tubing carrying initial water, are arranged to have water flow in parallel, also to reduce flow pressure drop. The boiler 160 is all monotube in the evaporation and inner superheat region to avoid pressure imbalance. Heat transfer into tube bundle 160 is by the use of finned tubing which also provides an internal burst strength many times that of bare tubing per se. The use of pre-determined fin height also accurately allocates the gas flow cross sectional areas such that the heat transfer coefficient can be varied to obtain the most efficient enthalpy rise in particular portions of vapor generator 30. Further, the outside fin heights per se on the respective tube sections of tube bundle 160 are increasingly higher in the path of the combustion gases along arrows 175. This arrangement recovers lower levels of heat energy of the gases along routes 175 until entering as exhaust 176 into plenum 177, through openings 179. The boiler housing 178, 180 may advantageously be made of 1010 steel. The tubing (160) is constructed of relatively inexpensive No. 18-8 corrosion resistant steels. The exhaust ducts (not shown) are made large to avoid excessive combustion pressure drop. The exhaust velocity is thus so low that a silencing device is not required.

THE WATER WALL HEAT SHIELD

An important feature of the present invention is the heat shield positioned above the hot gaseous exit zone 134 of the combustor (55). The heat shield is composed of a flat tubing array juxtaposed with a metal plate 169. Plate 169 is supported over and upon tube bundle 160, see FIG. 1. Heat insulation material 173, as “Kaowool,” is packed over the top layer of the tube bundle, as well as over and about tubing 165 up to housing cover 180. Cover 180 is in annular slot 181 of the housing. The plate 169 is of high nickel alloy material as “Inconel” No. 601, to withstand the high heat flux and temperatures at zone 134. Liquid (water) flows continually through tube array 165 and thus carries off heat energy. The “water wall” 165 thereby is a cooling factor for the composite heat shield 165, 169. The net temperature of its face plate 169 is designed to not fall below 1,500° F to avoid quenching action on the combustion process.

Shield face plate 169 is a thermal isolator, maintained in the range of 1,500° to 2,000° F. It is preferably spot welded to tubing array 165, as at each 1.5 inches along its spiral tubes 166, 166′, to establish intimate thermal contact. The tubing of array 165 is not provided with fins. Its material is stainless steel as No. 1010, since its operating temperature herein reaches only up to the order of 1,100° F. The shield plate 169 and water wall 165, together with insulation packing 173 combine herein to keep cover 180 at the order of 200° F, safe to touch. Such result inhibits heat loss to the outside of the housing, improving efficiency. Isolator plate 169 prevents the lower temperature of water wall 165 from contacting the combustion gases and thus protects against any quenching by it. Further, isolator plate 169 serves to reignite unburned gas and fuel particles that impinge on it.

The feed water then enters the “water wall” 165. The water wall array consists of a double wound pancake spiral 166, 166′ so that entrance and exit from the spiral is in the same plane or layer of tubing 165, see FIG.
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3. The water spirals inward to the center and then reverses and spirals outward to the periphery. The tube wall is not intended for high grade energy transfer, but rather as an inexpensive method to absorb only a minimum value of the high heat flux density that is impinging directly on shield plate 169. The water wall 165 is used as the last stage of feed-water heating before the evaporation zone of the boiler 160, as described in connection with FIG. 5. The double flat spiraling of the tube pairs 166, 166' is illustrated in FIG. 3. In its central portion an "S" fitting 170 couples the spirals 166, 166' as a continuous tubing array (165), see FIG. 4. Water input into tube 166' at 167 thereupon continues inwardly to central coupling 170, and back outwardly in tube 166 to connection 167. This constitutes a flat water wall 165.

A diagram of the exemplary tube bundle 160 is shown in FIG. 5. Its tubes are wound into a cylindrical "bundle" with its central cylindrical region incorporating the combustor 55. In the 240 HP vehicle as said 50-passenger bus, the outer two wraps of tubing 164 are with relatively higher fins, and are used as the input fluid preheat section. Input line 29 connects to the high-pressure feedwater pump of the ECE system. The tube bank (160) thereof is 11 tubes high, in parallel connections, to minimize pressure drop. The next three tube wraps 163 constitute the liquid to vaporization section. Its first wrap has an exit line 168 for the water wall tube 166', across connections indicated at 167, 167'. Return spiral tube 166 connects with return tube 168 hereof. The feedwater in the water wall 165 is heated-up, thereby using its location and function to advantage herein. The fins on the intermediate tubes 163 extend less than for tubes 164. The superheat steam tubes 161 are larger in diameter, and are closer to the combustion process. Their steam output line 31 leads to the power expander and its throttle. The normalizer tubes 185, 186 lead into the superheat tubes 161 herein, but may instead be located in the vaporizer section 163 as indicated at 187, 188. Their purpose is defined in the aforesaid application.

What is claimed is:

1. A vapor generator comprising a housing, a fluid/vapor tube bundle therein, a combustor for providing heated gas through burning of injected fuel and air, said heated gas being arranged to flow across said tube bundle and convert fluid pumped therethrough into high-temperature high-pressure vapor, and a heat shield positioned between the combustor gas exit region and said housing to absorb heat energy and thereby moderate the temperature of the housing thereat, said heat shield including a tubing array connected with the fluid feed circuit of said tube bundle whereby said absorbed heat energy heats-up the liquid en route to the vaporization phase, said tubing array being in a flat planar arrangement.

2. A vapor generator as claimed in claim 1, in which said flat tubing array is constructed in a spiral formation.

3. A vapor generator as claimed in claim 1, further including a thermal isolator sheet underlying said flat tubing array to prevent lower temperatures of the array from quenching said heated gas, and in which said sheet and the tubing array are joined into close thermal contact.

4. A vapor generator as claimed in claim 2, further including a thermal isolator sheet of metal material underlying said flat tubing array to prevent lower temperatures of the array from quenching said heated gas, and in which said metal sheet and the tubing array are welded into close thermal contact, said metal sheet being positioned within the combustor whereby its temperature rises to ignite unburned gas and fuel particles that impinge upon the sheet.

5. A vapor generator as claimed in claim 2, further including thermal insulation between said tubing array and the adjacent housing.

6. A vapor generator as claimed in claim 4, further including thermal insulation between said tubing array and the adjacent housing.

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