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PROCESS AND APPARATUS FOR GAS GENERATION FROM SEMI-SOLIDS

Filed Nov. 7, 1961

2 Sheets-Sheet 1

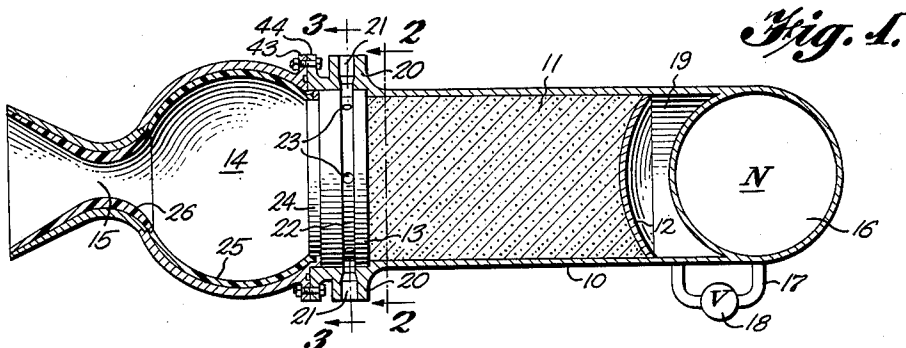


Fig. 2.

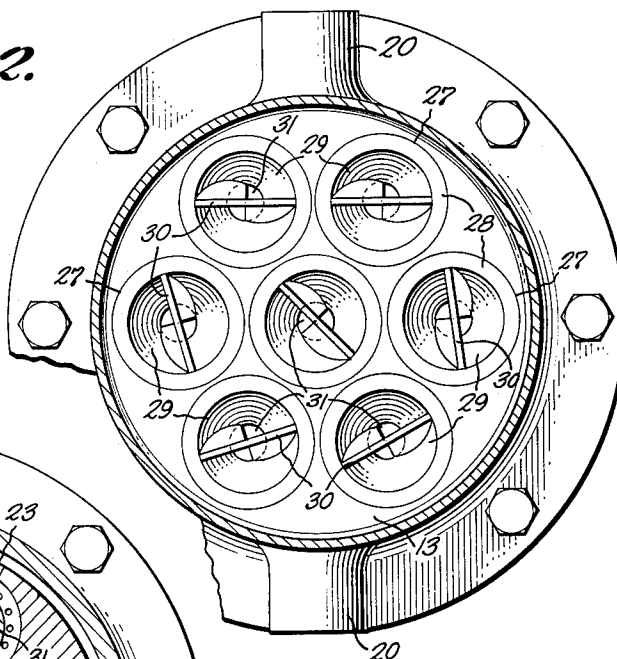
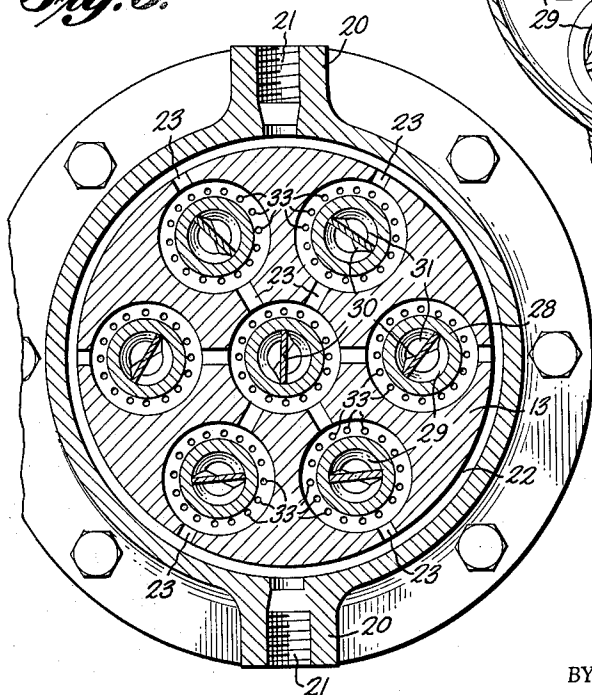


Fig. 3.



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2 Sheets-Sheet 2

Fig. 4.

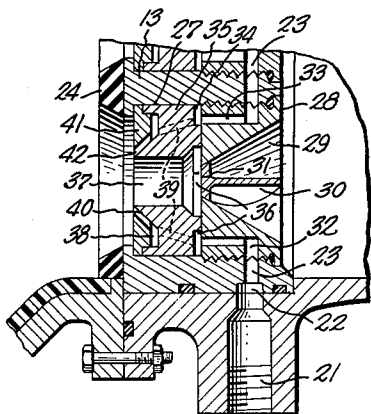


Fig. 6.

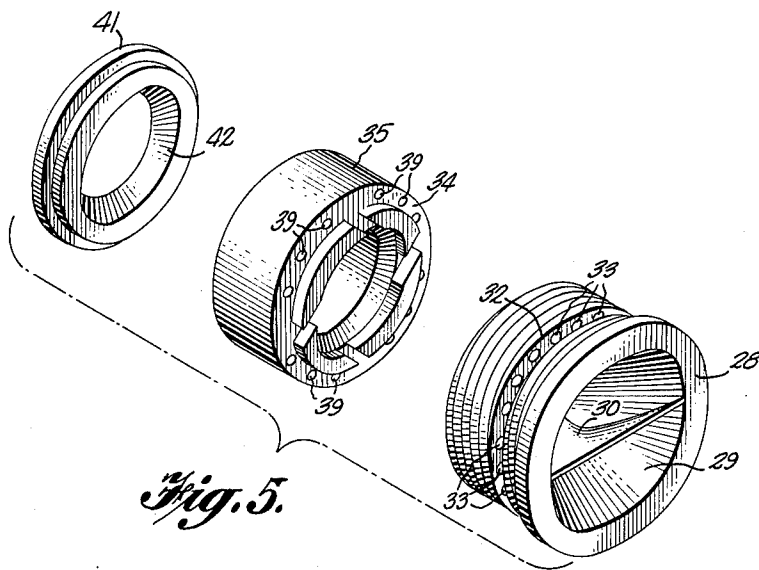
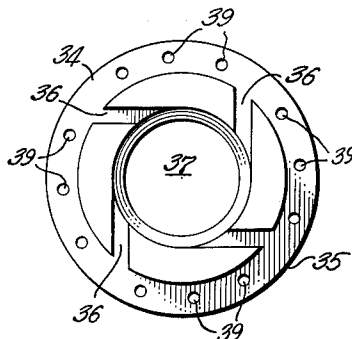


Fig. 5.

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PROCESS AND APPARATUS FOR GAS GENERATION FROM SEMI-SOLIDS

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14 Claims. (Cl. 60—39.06)

This invention relates to gas generator apparatus for extruding and burning a paste-like, extrudible fuel. It is particularly designed for the spray burning of a viscous monopropellant, a composition that is substantially self-sufficient with regard to its oxidant requirements, or the spray burning of a viscous fuel used in a bipropellant system where the fuel is maintained separately from the oxidizer source until admixture at the point of combustion.

Gas generators burning a semi-solid plastic or paste-like monopropellant hitherto have extruded it from a storage chamber into a combustion chamber in the form of any desired coherent shape, such as a column, strip or the like and have ignited the leading face of the continuously advancing shaped mass. Upon reaching equilibrium burning, the material forms a characteristic downstream converging shape, such as a cone in the case of an extruded column of circular cross-section. This shape thus presents a burning surface of predeterminable area which can be varied and controlled by varying the rate of extrusion and/or varying the size and shape of the cross-sectional area of the feeding or extrusion orifice or tube. The extent of overall burning surface area relative to the length of the columns can also be regulated by providing a plurality of feeding orifices or tubes which can be varied in number. Thus, mass burning rate of the monopropellant and the amount and pressure of combustion gases generated can be regulated by controlled feeding.

One disadvantage encountered in this known extrusion method is that the extrusion rate is limited within a fairly narrow range because of the physical properties of the composition. As the extrusion rate increases, the height of the extruding column or strip will also increase and if this height surpasses a practical limit, there is a possibility that the column or strip might slump, sag, or fragment under the stress of its own weight. Fragmentation is undesirable in a gas generator designed to burn the monopropellant fuel in the form of extruding cohesive columns since it causes an unscheduled and uncontrollable increase in burning surface area which destroys the preprogrammed ballistic performance and can explode the generator.

There have been attempts to increase the extrusion rate by spraying the propellant into the combustion chamber which, since it would eliminate the column or strip, would not limit the extrusion rate by a factor such as column length or cohesiveness of the composition. However, the fabrication of workable apparatus to convert a highly-viscous semi-solid mass into a spray of particulate material has not been successful due to the employment of apparatus known in the liquid spraying art. This apparatus is not adapted to handle such a highly-viscous semi-solid mass resulting in clogging of the apparatus or inadequate comminution.

Gas generators for burning an extruded column or strip may also possess a fast-stop capability by the use of a sliding plate or guillotine blade which moves into the path of the extruding propellant. This start-stop operation is limited in the number of times it can be performed because the plate or blade is exposed to the hot combustion gases as it moves into the stop position.

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Repeated stops will eventually cause the plate or blade to be consumed by the hot combustion gases or, if the plate or blade is upstream of the extrusion member, may additionally cause this extrusion device to be consumed. In either event, there is the danger of the burning progressing upstream into the storage chamber creating undesirable burning or even explosion.

It is an object of the present invention to provide a gas generator of the extruded-fuel type having an increased extrusion rate because of its spraying capability.

A further object is to provide an unlimited start-stop capability in the subject gas generator.

A still further object is to provide immediate start-stop response with no transient build-up or tail-off.

Another object is to provide variable control of extrusion rate as required by the particular demands of the utilizing system.

Still another object is to provide cooling means to protect the extrusion member and to prevent temperature rise upstream of the combustion chamber which, in turn, prevents autoignition of the propellant in the storage chamber.

An additional object of the present invention is to prevent burn-back of the flame into the propellant storage chamber.

Other objects and advantages of the invention will be made obvious by the following description in conjunction with the drawings wherein:

FIGURE 1 is a partial cross-sectional view of a partly diagrammatic embodiment of the invention.

FIGURE 2 is a downstream view of the inlet side of the extrusion member taken on line 2—2 of FIGURE 1.

FIGURE 3 is a cross-sectional view on line 3—3 of FIGURE 1.

FIGURE 4 is a longitudinal cross-sectional view of a nozzle assembly.

FIGURE 5 is an exploded view of a nozzle assembly.

FIGURE 6 is a downstream view of the vortex section of the nozzle assembly.

Broadly speaking, the invention comprises apparatus for extruding a plastic or paste-like monopropellant composition from a storage chamber, through an extrusion plate, and injecting it in the form of a finely-divided particulate spray, into a combustion chamber. In practice, the extrusion plate is provided with an orifice or orifices having a swirl vane at the upstream end which imparts rotation to the propellant. Downstream of the swirl vane, the rotating propellant encounters a primary gas stream which is ducted tangentially into a vortex chamber to assist in the monopropellant flow therethrough. As the rotating mass of propellant leaves the vortex chamber and enters the combustion chamber, it encounters a secondary gas stream applied transverse to the flow of propellant. This secondary gas counteracts the tendency of the propellant to be hurled or to spin outwardly, chops or atomizes the propellant and directs the finely-divided propellant into the combustion chamber as a spray.

FIGURE 1 shows a longitudinal sectional view of a gas generator such as a rocket motor of the type which, by way of example, is adapted to use the apparatus of the present invention. This rocket motor consists of a fuel tank or storage chamber 10 which may be of generally cylindrical shape and which is adapted to contain a plastic or paste-like monopropellant 11. Slidably mounted in the forward end of the storage chamber 10 is an extrusion piston 12 which extrudes the propellant 11 through an extrusion member 13 into a combustion chamber 14. The extrusion member 13 is shown in detail in the remaining figures. An exhaust nozzle 15 is in open communication with the combustion chamber 14 to receive and discharge the gases generated therein. The piston 12 is actuated to extrude the propellant 11 by

pressurized gas, such as nitrogen, admitted from a tank 16, forming the front wall of storage chamber 10, through a conduit 17, having a valve 18 therein, to the storage chamber portion 19 between the piston 12 and tank 16. The control of valve 18 may be either manual or automatic and may be varied to control the gas pressure applied to piston 12 and thus control the extrusion rate of propellant 11. A conventional igniter such as hot wires or hypergolic igniter, not shown, may be provided in the combustion chamber 14 to ignite the propellant. One or more bosses 20 are provided on the rocket motor having a center tap 21, opening, on the inside of the motor, into a slot 22 formed on the periphery of the extrusion member 13. Passageways 23 extend radially from the slot 22 toward the center of the extrusion member 13. Insulation 24, 25 and 26 afford protection at the interior of the combustion chamber 14 from the hot combustion gases. Flange members 43, 44 are used in uniting the rocket motor components.

FIGURE 2 is a view of the inlet side of the extrusion member 13 located in the rocket motor. The member 13 is shown as having seven circular orifices 27 for positioning nozzle assemblies which have at their upstream a retainer section 28. These retainer sections 28 have a passageway in the shape of a truncated cone 29 through which the propellant 11 is extruded. Located in and attached to the cones 29 are swirl vanes 30 that cause rotation of the propellant as it is extruded through the cones 29 and out the downstream circular apertures 31. Here, by way of example, the swirl vanes are shown as providing a 90° revolution through their length.

FIGURE 3 is a cross-sectional view of the rocket motor along the line 3—3 of FIGURE 1 showing the passageways 23 opening into and communicating the annular recesses 32 in the retainer sections 28. On the downstream face of the recesses 32 are arranged a plurality of smaller passageways 33 which extend downstream.

FIGURE 4 is a cross-section through one orifice 27 in the extrusion member 13 showing the arrangement of the nozzle assembly. The passageways 33 in each of the above-described retainer sections 28 communicate with an annular recess 34 on the upstream end of a vortex section 35. The upstream face of the vortex section 35 abuts the downstream face of the retainer section 28 which, due to their lapped surfaces, forms a gas-tight seal. Slots 36 extend tangentially from the recess 34 into a vortex chamber 37 which is in axial alignment with the downstream circular aperture 31 of retainer section 28.

Recess 34 communicates with a further annular recess 38 through a plurality of passageways 39 in the vortex section 35. Recess 38 is formed with a downstream converging inside face 40. Ring 41 abuts the downstream face of vortex section 35 and restricts the area of communication between the recess 38 and the combustion chamber 14 to form a downstream converging opening 42 coaxial about the vortex chamber 37 at its downstream end, which opening 42 can be varied by the use of rings 41 of varying thickness.

FIGURE 5 is an exploded view of the nozzle assembly. The swirl vane or deflector plate 30 is shown, by example, as being constructed to impart a clockwise rotation to the propellant being extruded. In the vortex section 35, the slots 36, shown tangential to the vortex chamber 37, are also arranged to exert a clockwise influence. The complete extrusion member 13 is formed by first inserting in each orifice 27 a ring 41 until it abuts a shoulder located at the extreme downstream end of the orifice. A vortex section 35 next follows until it abuts ring 41. The nozzle assembly is then completed and retained by inserting a retainer section 28 which is threaded to connect with a threaded portion of orifice 13. When completely inserted, retainer section 28 abuts vortex section 35.

FIGURE 6 is a downstream view of vortex section 35 showing the construction of the slots 36 tangential to the vortex chamber 37.

In operation, the plastic propellant 11 is forced under pressure from piston 12 or other pressure means into cones 29 in retainer section 28. The propellant 11 is forced to rotate in the cones 29 by the presence of swirl vanes 30. The cone shape produces a lower pressure drop than would a cylinder having a constant inner diameter equal to the downstream circular aperture 31 of the cones 29 and thus, a lower piston pressure is required to achieve a desired angular rotation. The higher the extrusion rate of the propellant 11 produced by increased piston pressure, the greater will be the angular velocity of the propellant as it leaves the apertures 31 at the downstream end of the cones 29 and proceeds into the vortex chambers 37.

Pressurized inert gas, such as nitrogen in the case of a monopropellant which generally contains sufficient oxidizer, is admitted into center taps 21 and passes to slot 22 in extrusion member 13. From here the gas proceeds into the passageways 23 directly and also by way of the annular recesses 32 in the retainer sections 28. Gas is thus in contact with all of the nozzle assemblies and flows down the passageways 33 into the annular recesses 34 of the vortex sections 35, at which point it forms two paths.

Some of the inert gas, hereafter called primary gas, is directed into slots 36 and enters the vortex chambers 37. Since the slots 36 are arranged tangentially to the vortex chambers, the primary gas spins or swirls upon admission to the vortex chambers 37 and contacts the swirling propellant 11 leaving the cones 29. The primary gas serves a wiping function as it prevents the propellant from adhering to or clogging the sides of the vortex chambers 37 as the swirling mass of propellant and air proceeds downstream. Additionally, the primary air imparts further rotational movement to the propellant 11. The diameter of the vortex chambers 37 is constructed larger than the diameter of the downstream circular apertures 31 of the cones 29 to provide adequate space for the primary gas and additionally to provide space for the propellant 11 to begin breaking up due to its rotational movement and the presence of the primary gas. The mass of swirling, partially-separated propellant then leaves the vortex chamber and enters the combustion chamber 14, its natural tendency being to sling or spin outward due to the high rotational energy.

While primary gas is being directed into slots 36, the remaining gas, hereafter called secondary gas, is directed down passageways 39 into annular recesses 38 and out of opening 42 so that a wall of downward converging secondary gas meets the propellant 11 emerging from each vortex chamber 37. This secondary gas restrains the tendency of the propellant 11 to spin outward, chops up or atomizes the propellant, and controls the angle of the spray cone of propellant particles in the combustion chamber 14.

The spray cone formed by the atomized propellant can be varied by the momentum of the secondary gas, which momentum is, in turn, varied by regulating the pressure of the gas admitted to center tap 21 through any conventional pressure regulator connected to a pressurized gas source. The angular velocity of the propellant 11 leaving the vortex chamber 37 also helps determine the configuration of the atomized propellant in the combustion chamber. This angular velocity can be varied by varying the extrusion rate of the propellant 11 since the greater the extrusion rate, the greater will be the rotational effect exerted on the propellant by the swirl vanes 30. The primary gas velocity will also vary as the gas pressure is varied, but its rotational effect upon the propellant is substantially less than that of the swirl vanes 30. Thus, by controlling extrusion rate and gas pressure, the angle of the spray of atomized propellants can also be controlled. It has been found that the optimum burning pattern is where the spray is confined to a downstream converging cone that appears to cross over to form a downstream diverging cone whose included angle is 20 to 40 degrees. In practice, it is feasible to maintain the gas

pressure approximately two times the maximum combustion chamber pressure to assure a high velocity delivery into the vortex chamber 37 and out of the opening 42.

It would be possible to provide for greater rotational effect upon the propellant 11 by the primary gas, but such rotation is possible only with considerably increased primary gas flow. This increased gas flow would necessitate larger or heavier tanks for compressed gas storage that are undesirable in the application of the subject gas generator as a rocket motor.

By providing this spray of atomized propellant in a manner which can be scheduled and controlled, a greater total burning surface is realized than in the case of an extruded column or strip. This atomizing eliminates the problem of slumping, sagging, unscheduled fragmentation, or protrusion of the propellant out of the exhaust port at increased extrusion rates. It has been found that the increase in extrusion rates of the subject gas generator over the prior art, given the same size orifices 27 in an extrusion member 13, may reach fortyfold or more, depending on the limiting shear rate of the propellant.

The secondary gas serves the additional function of blocking any burn-back of the flame in the combustion chamber 14 into the vortex chamber 37 and possibly into the storage chamber 10 where explosion could occur. The primary gas would also serve as a block against burn-back should the flame unaccountably progress past the secondary gas. Both gases also function as a coolant for the propellant 11 and extrusion member 13 to reduce the danger of autoignition of the upstream portion of the extruding propellant because of heat transfer and additionally protect the nozzle structure. The insulation 24 at the downstream end of the extrusion member 13 helps to minimize heat transfer from the combustion chamber 14 and reduces the amount of gas needed for cooling when the gas generator is stopped.

When it is desired to stop the gas generator, propellant extrusion is terminated but gas flow is continued. The primary gas wipes the propellant in the vortex chamber 37 out into the combustion chamber 14 where it is atomized and consumed. The stopping is abrupt, with no tail-off or reduced gas generation such as found when burning the extruded propellant as a column or strip where the characteristic cone or wedge has to burn away with a progressive reduction in burning area. Upon stopping, the primary and secondary gases again block any tendency of the flame to burn back into the combustion chamber. After stopping, the gas pressure can be reduced since the gases will mainly serve as a coolant to prevent any heat in the combustion chamber 14, which will remain for a definite period of time above the autoignition point of the propellant, from being transferred to the storage chamber 10.

Restart of the gas generator is as quick as shut-down with no transient build-up to an equilibrium burning surface such as found when igniting a column or strip of extruded propellant. The desired extrusion rate and inert gas pressure is selected and the propellant is sprayed once again into the combustion chamber. The start-stop capability is virtually unlimited as the primary and secondary gases prevent the flame and the hot combustion gases from reaching the extrusion member 13 or the nozzle assembly therein, therefore eliminating the possibility of consumption of the apparatus by the flame or hot combustion gases. When restarting, ignition can be provided by the igniter, not shown, or if the prior burning was of sufficient duration and the stop period was for a short period of time, then the various insulations in the combustion chamber will be above the autoignition point of the propellant so that any particle in the spray touching the insulation will ignite and cause immediate ignition of the entire propellant.

If a high stoichiometry is desired, but the monopropellant is incapable of being loaded with sufficient solid oxidizer without destroying the requisite cohesiveness and

fluidity of the composition, the aforescribed inert gas can be replaced by an oxidizing gas such as oxygen or air which would provide additional oxidizer to permit the attainment of the high stoichiometric level.

The invention is not limited to using a monopropellant but can be used in a bipropellant system requiring only the substitution of an oxidizer such as oxygen or air, for the inert gas. Sufficient oxygen or air would be supplied as the primary and secondary gases to support the necessary combustion.

While the above-described exemplary embodiment employed swirl vanes 30 to impart rotation, it is also contemplated to use rifling in the cones 29. Rifling is a system of spiral grooves such as encountered in a rifle barrel. A thick, highly-viscous mass coming in contact with this rifling would again rotate, not just on the portion in contact with the rifling, but throughout the entire mass in the cone since the propellant is sufficiently cohesive to overcome any tendency to shear or separate on the edges of the grooves.

Both the monopropellant and the fuel used in a bipropellant system are preferably extrudible thixotropic paste-like masses which require a finite stress to produce flow, are capable of continuous flow at ambient temperatures under a maximum shear stress at a wall of 10 p.s.i., and have a minimum tensile strength of about .01 p.s.i. Many different compositions tailored to different performance requirements can be made having these desired physical characteristics.

The monopropellant compositions generally and preferably comprise a stable dispersion of a finely-divided, insoluble solid oxidizer in an oxidizable liquid fuel.

The liquid fuel can be any oxidizable liquid, preferably an organic liquid containing carbon and hydrogen. Suitable liquid fuels include hydrocarbons, such as triethyl benzene, dodecane, liquid polyisobutylene, hydrocarbon oils and the like; compounds containing oxygen linked to a carbon atom as, for example, esters, like dimethyl maleate, diethyl phthalate, dibutyl oxalate and the like; alcohols such as benzyl alcohol, triethylene glycol and the like; ethers such as methyl α -naphthyl ether and the like; and many others.

The solid oxidizer can be any suitable, active oxidizing agent which yields an oxidizing element such as oxygen, chlorine or fluorine readily for combustion of the fuel and which is insoluble in the liquid fuel vehicle. Such oxidizers include inorganic oxidizing salts such as ammonium, sodium and potassium perchlorate or nitrate and metal peroxides such as barium peroxide. The amount of solid oxidizer incorporated varies, of course, with the particular kind and concentration of fuel components in the formulation, the particular oxidizer, and the specific requirements for a given use, in terms, for example, of required heat release and rate of gas generation, and can readily be computed by those skilled in the art.

Finely-divided solid metal powders such as aluminum, magnesium, zirconium and beryllium may be incorporated in the monopropellant composition as an additional fuel component along with the liquid fuel. Such metal powders possess the advantages both of increasing the fuel density and improving the specific impulse of the monopropellant because of their high heats of combustion. High loadings of such finely-divided metal powders reduce the amount of solid oxidizer which can be introduced without adversely affecting the physical properties of the monopropellant slurry. In such case, the use of an oxidizing primary and secondary gas as aforescribed can effectively supplement the oxidizer in the monopropellant.

The composition for the fuel used in a bipropellant system generally and preferably comprises a stable dispersion of a finely-divided solid fuel such as carbon, silicon, boron, metals such as aluminum, magnesium, zirconium and beryllium, and metal hydrides such as

zirconium hydride, in an oxidizable liquid fuel, similar to those described above for use in monopropellant compositions.

The physical properties of the viscous fuel compositions in terms of dispersion stability, cohesiveness, tensile strength and thixotropy, can be improved by the addition of a gelling agent such as a synthetic polymer, e.g., polyvinyl chloride, polyvinyl acetate, cellulose acetate and ethyl cellulose, or metal salts of higher fatty acids, e.g., sodium or magnesium stearates or palmitates. The desired physical properties can also be obtained without a gelling agent by using a liquid vehicle of substantial intrinsic viscosity, such as liquid organic polymers, e.g., liquid polyisobutylene, liquid siloxanes, liquid polyesters and the like.

It is possible to use the gas generator in applications other than a rocket motor. It can be used for driving a turbine, reciprocating engine, or the like or in any application requiring high temperature or high pressure gas as the source of energy. A particular application is in thrust vectoring where the gas generator is used to steer a larger rocket or space craft. The nozzle 15, which can be supersonic, as shown, or sonic, mates with the exit flare of the exhaust nozzle on the larger rocket so that the exhaust gases discharged through the nozzle 15 intercept the gas flow in the larger rocket nozzle, creating a shock wave. The pressure rise downstream of this shock wave results in a side force sufficient to turn the larger rocket.

While this application has been drawn to a particular exemplary embodiment, it is obvious that various changes may occur to those skilled in the art which will fall within the spirit and scope of the invention as described in the following claims.

We claim:

1. A gas generator comprising a fuel chamber for containing an extrudible paste-like fuel which is fluid under stress at ambient temperatures, a combustion chamber, an extrusion member positioned between said fuel chamber and said combustion chamber, said extrusion member having at least one passage extending therethrough, said passage being a downstream converging passageway where the inlet is larger than the outlet and having therein means for imparting rotation to said fuel as it passes therethrough, said passage further formed downstream of said outlet, as a vortex chamber having substantially tangential ports at its upstream end for introducing a primary gas, and means for introducing a secondary gas transverse to the downstream end of said vortex chamber whereby said fuel is directed into said combustion chamber as a particulate spray.

2. A gas generator comprising a fuel chamber for containing an extrudible paste-like fuel which is fluid under stress at ambient temperatures, a combustion chamber, an extrusion member positioned between said fuel chamber and said combustion chamber, said extrusion member having at least one passage extending therethrough, said passage formed at the upstream end as a downstream converging truncated cone and having a swirl vane positioned therein for imparting rotation to said fuel as it passes through said truncated cone, said passage further formed, downstream of said truncated cone, as a vortex chamber having substantially tangential ports at its upstream end for introducing a primary gas, and means for introducing a secondary gas transverse to the downstream end of said vortex chamber whereby said fuel is directed into said combustion chamber as a particulate spray.

3. A gas generator comprising a fuel chamber for containing extrudible paste-like fuel which is fluid under stress at ambient temperatures, an extrusion member located at the downstream end of said fuel chamber through which said fuel is extruded, a combustion chamber positioned at the downstream end of said extrusion member in which the fuel is burned, and an exhaust port through which combustion gases created by the burning

of said fuel are discharged, said extrusion member having at least one passage extending from said fuel chamber to said combustion chamber and having therein mechanical means for imparting rotation to said fuel as it is extruded through said passage, said passage being formed as a downstream converging truncated cone portion opening into a vortex chamber portion which has substantially tangential ports at its upstream end for introducing a gas against said fuel, said fuel forming a particulate spray as it emerges from said vortex chamber and enters said combustion chamber.

4. A gas generator for the combustion of an extrudible paste-like fuel which is fluid under stress at ambient temperatures comprising an extrusion member having a plurality of passageways formed as downstream converging truncated cones and a vortex chamber, said truncated cones opening into said vortex chamber, each of said passageways having mechanical means positioned to impart rotation to said fuel to divide it into a particulate spray, means adjacent to the downstream end of the vortex chamber for introducing a gas transversely against the rotating fuel as it emerges from the vortex chamber, and a combustion chamber positioned downstream of said extrusion member wherein said particulate spray or fuel is burned.

5. A gas generator as claimed in claim 4 wherein said spray-forming means further comprises ports positioned substantially tangential to the vortex chamber at its upstream end for introducing a gas against the fuel.

6. A gas generator as claimed in claim 4 wherein said mechanical means are formed as a stationary swirl vane, said swirl vane being positioned in the truncated cone.

7. A gas generating method comprising the steps of extruding a continuous, semi-solid, paste-like monopropellant, said monopropellant being characterized by the ability to flow continuously at ambient temperatures under a maximum shear stress at a wall of 10 p.s.i. and having a minimum tensile strength of about .01 p.s.i., imparting an axial rotation to the extruded portion relative to the direction of extrusion, directing a gas flow against said extruded portion to form a particulate spray, said gas flow comprising a primary gas flow and a secondary gas flow, said primary flow being directed substantially tangentially against the outer surface of said extruded portion with said secondary flow being subsequently directed transversely against said portion, and burning said spray to generate combustion gases.

8. A gas generating method comprising the steps of extruding a continuous, semi-solid, paste-like fuel, said fuel being characterized by the ability to flow continuously at ambient temperatures under a maximum shear stress at a wall of 10 p.s.i. and having a minimum tensile strength of about .01 p.s.i., imparting an axial rotation to the extruded portion relative to the direction of extrusion, directing a gas flow against said extruded portion to form a particulate spray, said gas flow comprising a primary gas flow and a secondary gas flow, said primary flow being directed substantially tangentially against the outer surface of said extruded portion with said secondary flow being subsequently directed transversely against said portion, and burning said spray to generate combustion gases.

9. A gas generating method comprising the steps of extruding a continuous, semi-solid, paste-like fuel, said fuel being characterized by the ability to flow continuously at ambient temperatures under a maximum shear stress at a wall of 10 p.s.i. and having a minimum tensile strength of about .01 p.s.i., imparting an axial rotation to the extruded portion relative to the direction of extrusion, directing a gas flow against said extruded portion to form a particulate spray, said gas flow comprising an oxidizing gas to support combustion of said fuel, further comprising a primary gas flow and a secondary gas flow, said primary flow being directed substantially tangentially against the outer surface of said extruded por-

tion with said secondary flow being subsequently directed transversely against said portion, and burning said spray to generate combustion gases.

10. The method according to claim 9 wherein said fuel comprises a stable dispersion of finely-divided solid fuel in an oxidizable liquid fuel. 5

11. The method according to claim 10 wherein said liquid fuel is an organic liquid.

12. The method according to claim 11 wherein said solid fuel is selected from the group consisting of aluminum, magnesium, zirconium, beryllium, and hydrides of these metals. 10

13. The method according to claim 11 wherein said semi-solid, paste-like fuel additionally comprises a minor amount of a gelling agent for said organic liquid. 15

14. The method according to claim 13 wherein said gelling agent is selected from the group consisting of synthetic polymers and metal salts of higher fatty acids.

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