Aug. 22, 1961 E. B. McMILLAN ET AL 2,996,877

METHOD FOR GENERATING JET POWER THROUGH SULFIDE REACTION

Original Filed July 28, 1947 3 Sheets-Sheet 1

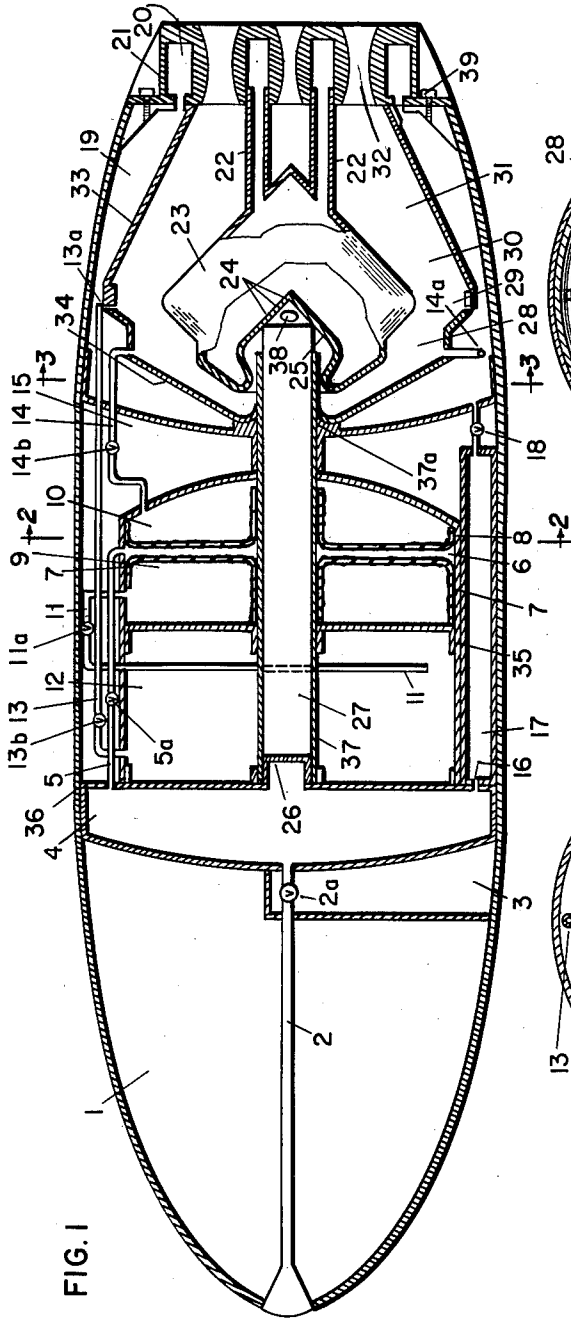

FIG. 1

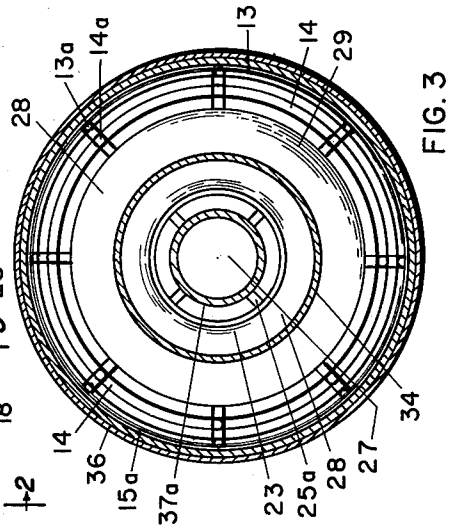

FIG. 3

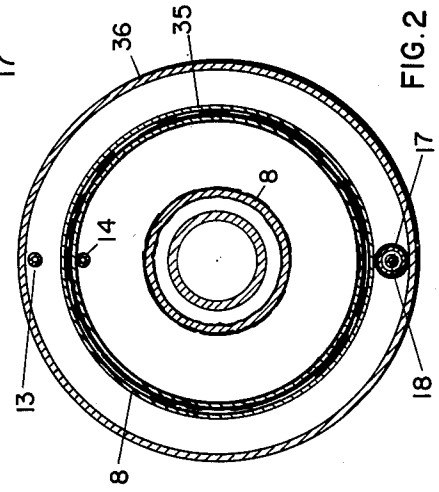

FIG. 2

INVENTORS
EDWARD B. McMILLAN
DUDLEY F. STRAUBEL

BY Robert J. Crooker
THEIR ATTORNEY

METHOD FOR GENERATING JET POWER THROUGH SULFIDE REACTION

Original Filed July 28, 1947 3 Sheets-Sheet 2

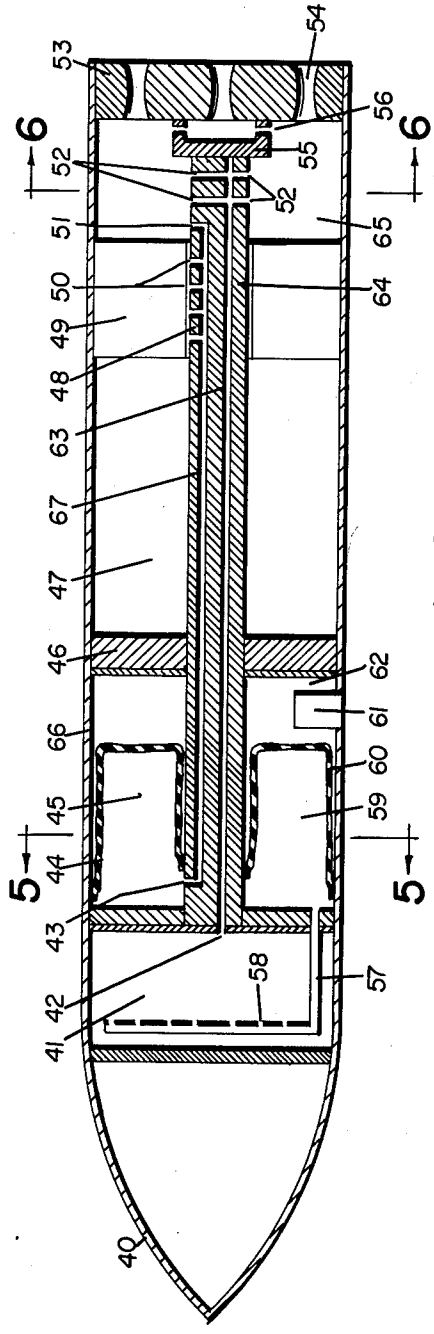

Fig. 4

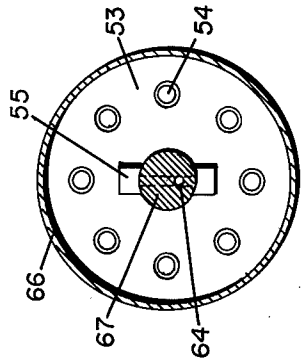

Fig. 6

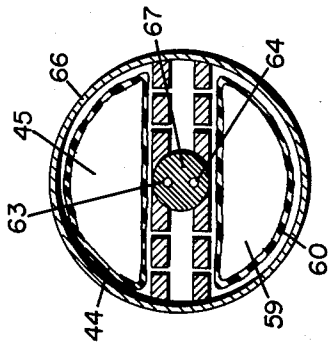

Fig. 5

INVENTORS:
EDWARD B. McMILLAN
DUDLEY F. STRAUBEL

BY Robert G. Cooke

THEIR ATTORNEY

Aug. 22, 1961 E. B. McMILLAN ET AL 2,996,877

METHOD FOR GENERATING JET POWER THROUGH SULFIDE REACTION

Original Filed July 28, 1947 3 Sheets-Sheet 3

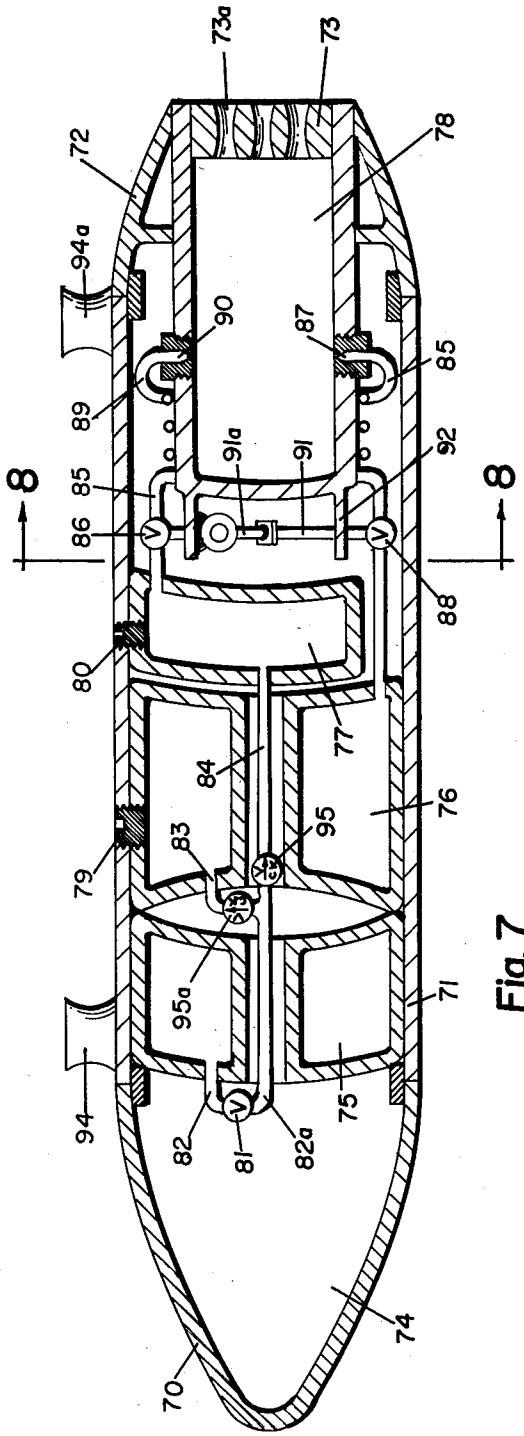

Fig. 7

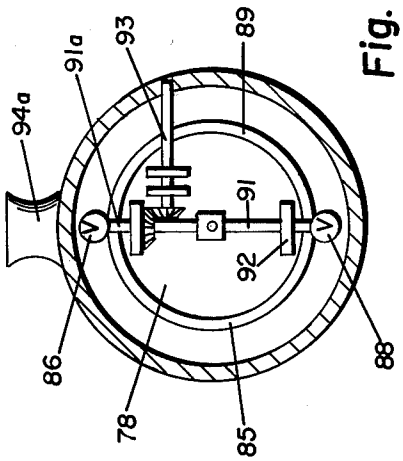

Fig. 8

INVENTORS:
EDWARD B. McMILLAN
DUDLEY F. STRAUBEL

BY Robert S. Cooke

THEIR ATTORNEY

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METHOD FOR GENERATING JET POWER THROUGH SULFIDE REACTION

Edward B. McMillan, Ipswich, Mass. (134 Perkins Road, Topsfield, Mass.), and Dudley F. Straubel, Central St., Rowley, Mass.

Substituted for abandoned application Ser. No. 764,237, July 28, 1947. This application May 27, 1957, Ser. No. 662,965

1 Claim. (Cl. 60—35.4)

This invention relates to an improved method for developing jet power and to an improved jet power plant.

This application is a substitute for our application Serial Number 764,237, filed July 28, 1947, entitled Jet Power Through Sulfide Reaction, now abandoned. Reference is also made to our U.S. Patent 2,744,380 of May 8, 1956, entitled "Method of Generating Jet Power Through Sulfide Reaction," which claims related subject matter.

The well known fuel combination of hydrazine hydrate with hydrogen peroxide yields a high specific impulse. This combination having a moderately high specific weight, the product of its specific impulse and specific weight, namely its propulsive capacity, is also high. In the rocket and jet propulsion art it is hard to increase the specific impulse, which is proportional to the the exhaust velocity; however, when one endeavors to use fuels of still higher specific weight as by using aniline with fuming nitric acid, the specific impulse is enough lower, so that little, if any, increase in the propulsive capacity is obtained.

Solid fuels are especially desired for certain types of rocket equipment, but in the present state of the art they still possess relatively low propulsive capacity.

Another deficiency in the art is that the supply of hydrocarbon fuels is very limited by economic and strategical circumstances.

It is an object of our invention to provide a new simple method and structure giving improved efficiency in developing jet power using readily available substances as fuels and giving greater output of useful work per unit of space required for the power plant.

We have attained certain objectives recognized in the jet and rocket propulsion art, not combined elsewhere to the same extent as our process:

(1) Our fuels possess high thermal energy.

(2) Their high specific heat permits the introduction and storage of significant amounts of heat into them prior to operation of the chemical jet engine.

(3) The control of fuel weight and volume, which has been one of the greatest problems of rockets design, has been improved. Fuel combinations of unusually high specific weight have been devised, without accompanying loss of propulsive capacity, but rather with an increase in the latter.

(4) The advantage of our process in the propulsion of continuous ram jet equipment is particularly outstanding, as we have fuels of nearly double the usual specific weight.

(5) We have attained ease of starting and high reaction speed, as the activation energies of our reactions are low.

(6) An explosive rate of reaction in a chain branching manner is obtained through the use of sulfur.

(7) Our solid fuel combinations possess higher propulsive capacity than other solid fuels known to us.

(8) We have devised for the most part simple fuels of common occurrence in nature. For example, the supply of sodium and magnesium is nearly inexhaustible.

(9) Our process and its arrangement provide advantages which are not dependent upon a fixed form of apparatus.

(10) We have devised fuels which exceed ethyl alcohol, aniline, and hydrazine hydrate in their propulsive capacity.

The method of attack used by us to solve the many problems presented by the said main objectives was:

(1) To inject a fuel consisting of a sulfide of a metal, or of boron, or of hydrogen, or of a mixture of these, into a final combustion chamber or zone with sufficient expansive force to drive it on through, by exothermally generating it, accompanied by the release of gas, from two other fuels in a prior combustion zone.

(2) To inject a fuel consisting of a sulfide of a metal, or of boron, or of hydrogen, or a mixture of these, into a final combustion chamber or zone and to drive it on through by expansive force imparted to it in the final zone by a gas-generating agent, such as hydrazine, or ammonia, or an acid, or an oxidant such as oxygen or fluorine.

(3) To employ in either combustion zone fluxes and reaction control agents to adjust the reactions to the best conditions for accomplishing useful work.

(4) Substantially in the absence of oxygen, to form the above sulfides from two classes of substances, as follows:

(*a*) Reducing agent reactant having a low energy of activation requirement to supply low molecular weight elements reactable with sulfur to form sulfides. These reactants include compounds of lithium, sodium, potassium, beryllium, magnesium, and boron, such as the amides, amines, azides, alkyls, aryls, borines, boranes, carbides, hydrides, imides, and nitrides. Substances readily releasing hydrogen when brought in contact with the metals lithium sodium, potassium, beryllium, magnesium and boron, may be combined with such metals to form metal hydrides useful as reducing agent reactants in the present method. Useful hydrogen releasing agents include hydrazine compounds, hydrazoic compounds, ammonia, or other nitrogen hydrides. Addition compounds of the preceding substances may also be used.

(*b*) Sulfur, hydrogen sulfide, hydrogen polysulfides, sulfur nitride, or organic sulfides, or other sulfur carriers releasing sulfur to the above hydrogen, lithium, sodium, potassium, beryllium, magnesium, and boron containing substances.

(5) To discharge the above substances from the final combustion chamber in a highly propulsive state, in the form of a gas-like jet material formed by an explosive reaction.

In general the following results are attained by our invention:

We have devised a unique process for producing hydrogen gas as a propellant, without oxidation, as the result of an explosive reaction. This has been one of the major goals of rocket propulsion science.

We have provided a power plant that can be used to propel rockets, planes, boats, torpedoes, other projectiles or physical objects. It can operate in air at atmospheric pressure, or in water, or even in rarefied air. It is adapted to operate under conditions peculiar to the widest ranges of commercial and military use, including also jet-assisted take-off.

Our invention provides means for reacting substances without diverting much of the produced power to auxiliary service such as the operation of compressors, which heretofore have often been required to keep reactions at sufficient pressure. Reaction violence is controlled by chemical means, and chemical means is employed to predetermine the rate at which reactions shall occur in the power plant.

The foregoing and certain other objects of our invention, which will later appear in the specification, are attained in a way that will be understood upon considering the following typical example, and typical modifications,

of a suitable chemical jet power plant or engine and its principle of operation.

For purposes of disclosure we illustrate diagrammatically the principal features of our invention. The drawings are not to scale, certain parts being exaggerated for clarity in disclosing the best mode in which we have contemplated applying the principle of the invention, and to distinguish it from other inventions.

In the drawings:

FIG. 1 is a diagrammatical longitudinal view of our invention, partly in section, and broken away in parts;

FIG. 2 is a transverse sectional view on the line 2—2 of FIG. 1;

FIG. 3 is a transverse sectional view on the line 3—3 of FIG. 1;

FIG. 4 is a diagrammatic longitudinal view in section, showing a different mechanism and arrangement of apparatus for performing our process;

FIG. 5 is a transverse sectional view on the line 5—5 of FIG. 4;

FIG. 6 is a transverse sectional view on the line 6—6 of FIG. 4;

FIG. 7 is a diagrammatic longitudinal view in section, showing a third mechanism, being an assisted take-off-motor for performing our process;

FIG. 8 is a transverse sectional view on the line 8—8 of FIG. 7.

Four preferred embodiments of our invention now will be described. The first comprises FIGS. 1, 2, and 3; the second FIGS. 4, 5, and 6; the third FIGS. 7 and 8; the fourth employs the well-known athodyd continuous ram jet equipment for our process.

FIRST EMBODIMENT—THE EQUIPMENT

An arrangement of apparatus for storage and use with stable reactants is comprehensively illustrated in FIGS. 1, 2, and 3.

In general, such apparatus may comprise a bullet-shaped nose and an outer jacketed casing.

In the nose is space for cargo, such as explosives or equipment and for valve controlled, automatically regulated means to take water or even air from the surrounding medium and deliver it to a zone of reactions. In the stern, jacket spaces within the outer shell serve as a preheating conduit for a fluid reactant. Forward of the main reaction chamber, jacket spaces serve as unheated housings for fluid reactant pipelines or conduits. The outer casing encloses the tank storage for solid and fluid reagents, also generating space for gas to feed the reactants into the main reaction chamber against reaction pressure and also generating space for the oxidizing agent. The outer casing also encloses the main reaction chamber and the double-cone through the inverted end of which pre-heated reactant is fed. A plate through which the power jets are propelled by the reactions provides a common closure for the outer jacketed casing and the main reaction chamber. This plate is attached with safety studs or the like which fail when safe reaction chamber pressure is exceeded.

Cargo space in the nose is designated by numeral **1**. Numeral **2** designates an inlet, controlled by valve **2***a*, for taking in water or air from the surrounding medium by ram or scoop action due to the forward speed of the power plant.

Numeral **3** designates space for actuating mechanisms of known type, operatively associated with a valve **2***a* in inlet **2**.

Various operating elements may be arranged in the jacketed casing, as indicated in FIGS. 1, 2, and 3.

Immediately aft of the nose is a chamber **4** to receive water or air, as from inlet **2**, which may be open momentarily before the main reaction commences; for example, if the equipment was being used as a torpedo, water would be scooped in as the first step after launching. The water then generates pressure by reaction in chamber **4** with calcium hydride. Chamber **4** communicates its pressure through conduit **5** and metering valve **5***a* into spool-shaped space **6**, enclosed in shell **35**, containing (and divided transversely into two halves by), flexible bags **7** and **8**, the edges of which are attached and sealed to the walls of shell **35** and defining spaces **9** and **10**. The pressure thus exerted against the bags empties their contents through connecting conduits **11** and **14**, respectively.

The pressure in space **6** also empties bag **8** of its contents, a reaction control agent, through conduit **14**, metering valve **14***b* and injection orifices **14***a* located in shell **34** into reaction zone **28** of the main reaction chamber which comprises zones **28**, **29**, **30**, **31**, within shells **33** and **34**, for the control of reaction temperature, to promote association of reaction products, and to otherwise readily exert control over the specific impulse generated.

In approaching the main reaction chamber, conduits **13** and **14** pass through space **15** which separates and insulates the compartments forward of it from the heat of the main reaction chamber. They then pass through space **19**, containing the reactant which absorbs and recovers heat conducted through the reaction chamber walls. In the last stages of the complete reaction of the power plant, this space may also contain the feed pressure gas generated in chamber **4**.

The pressure in chamber **4** also exerts itself through orifice **16**, moisture trap **17**, and conduit **18** against the liquid sodium metal reactant in chamber **19**. This metal is thereby driven into and through space **20** contained in nozzle plate **21**. From there conduits **22** direct the flow into container **23**, occupying the central portion of the main reaction chamber. This pressure further forces the liquid metal out through orifices **24** in the forward inverted face **25** of the container **23**, bursting the seal initially placed over them.

The forward end of container **23** is attached to wall **34** by supports **25***a*, shown in FIG. 3.

The pressure in chamber **4** is further exerted for the purpose of feeding reactants into the main reaction chamber as follows: It is directed against the face of piston **26**, which slides in central cylinder **37** to feed sulfur charge against face **25** of container **23**. At that face the sulfur reacts with the reactant emerging from orifices **24** after breaking nitric acid capsule **38**. The portion of the central cylinder, **37***a*, extending into the main reaction chamber is replaceable when eroded by re-use.

Other equipment may be used for the same purpose, for example, the sulfur charge may be fed into the power plant from remote tanks with screw feeds, in the molten state. It may be included in a blast of hydrogen or hydrogen sulfide. It may also include sodium, potassium, or lithium, the sulfur and the metals being intimately mixed. It may also include other reactants which will not react with it or each other at normal storage temperatures. Catalysts and fluxes for later reactions may also be included.

Here it should be noted that if it is elected not to use a briquetted charge, a liquid one may be employed in its place and stored in cylinder **37** and an injection nozzle or nozzles placed at the aft end for its injection into zone **28** of the main reaction chamber. Jacket space **19** may be used as the storage space and conduit for a sulfur releasing charge, also, with the metal, hydride, borine, or hydrazoic compound, or hydrazine compound injected at the after end of cylinder **37**.

Many variations of our process are adaptable to this and other equipment and are not primarily dependent upon any narrowly defined form of equipment.

Having explained in general the arrangement of the nose, the jacket of the outer casing, and the general features of feeding reactants to the main reaction chamber, reference is now made to the more specific features of the power plant proper.

The power plant is started in the instant case by injection of water through control valve **2***a* in chamber **4**. The source of the water may be the sea, if the equip-

ment is a torpedo, or in other cases a water tank or the like. Pressure for feeding reactants is generated by the reaction of the water and calcium hydride or other gas generating reactants. Generation of a non-oxidizing gas is preferred in the instant design and is illustrated in the table of additional typical reactions. The reactants injected into the main reaction chamber are initially sealed from it by valves and breakage seals. The latter are broken and removed by feed pressure.

The main reaction chamber

The essential ingredients for generating power according to our invention are processed in the chamber comprising reaction zones **28**, **29**, **30**, and **31**. FIGS. 1, 2, and 3, which depict a typical arrangement of apparatus for carrying out the process. However, the steps can be successfully performed by other means and arrangements of devices than those shown, which are merely illustrative, although preferred by us.

The main reaction chamber consists of the space between central double-cone shaped container **23** and walls **33** and **34**. This space is so arranged as to provide for gradually increasing volume and for injection, with suitable cross-current, of additional reagents at appropriate points.

The flow proceeds violently outward in reaction zone **29** to the maximum diameter of the main reaction chamber. There the reaction control agent enters the stream, being injected by orifices **13***a*. This new cross-current re-associates previously dissociated material, thus increasing the amount of heat energy available for useful work.

This discharge bursts into reaction zones **30** and **31** where further mixing of the flow and final reaction of its constituents occur. The violent rush of a mass of vaporous, and molten material continues out through the jet nozzles **32**. On exhausting beyond these they perform useful work, propelling the power plant forward by jet reaction or driving physical obstacles to the rearward. The nozzles may be conventional in form, say, convergent-divergent rearwardly. The nozzle plate **21** is jacketed at **20** and arranged so as to collect heat dissipated by the discharge stream passing through the nozzles. The plate is attached by safety shear studs **39**, which fail if the safe operating pressure for the main reaction chamber is exceeded.

The foregoing typical embodiment of our invention may be operated in rarefied atmosphere, or in normal atmosphere, or submerged in water. The following materials specification provides for re-use of the power plant structure, so that the same container, control, conduits, reaction chambers, etc., may be capable of being recharged with chemical load and used a number of times.

Fluorine, when used as the oxidant, must be dry while in the storage spaces, conduits, and injection orifices in order to minimize its attack on them. Fluorine lines in the vicinity of the heat of the main reaction chamber may be of a heat resistant iron alloy, lined with platinum. In lower temperature zones they may be made of fluorine resistant plastics or rubbers, externally armoured to have sufficient bursting strength. For expendable installations colloidal graphite linings on iron can be used.

The walls **33** and **34** and the outer wall of container **23**, lining the main reaction chamber may consist of graphite backed and strengthened with heat and acid resistant iron alloy. The graphite can be made removable, for replacement after sufficient erosion. The graphite surfaces can be sealed and coated with catalysts such as manganous oxides and a temporary coating of water glass or of silicic acid gel. Expendable power plants can have a reaction chamber lining of iron alloy coated with colloidal graphite. The construction of the nozzle plate **21**, nozzles **32**, and conduits **22** can be similar to that of the walls. Portion **37***a* of the central tube **37** may be of iron reinforced graphite. Where a briquet or other solid charge is used, a compressible lining must be placed between the charge and the graphite.

Oxygen bearing materials should be avoided for the linings of the spaces and conduits coming in contact with the reducing agents such as the metals, amides, hydrides, hydrogen, and sulfur carriers.

Reaction control agents

For the purpose of our process we use a class of substances which we classify as reaction control agents. We define them as materials which do one or more of the following things:

(1) Catalyze the reactions.

(2) Promote association of the products and prevent loss of heat from dissociation.

(3) Accelerate or decelerate propulsion with easily metered and injected agents.

(4) Increase propulsive power without doing so primarily by increasing heat generation of the reaction control agent itself, although this may occur incidentally.

(5) Act as a gas generating agent through its own case of decomposition under the conditions of the process.

Typical preferred reaction control agents include the following:

(1) For increase of propulsive power by catalysis: water, caustic, acid, waterglass, manganous oxides, peroxides, hydrogen peroxide, ammonia sources, hydrazine compounds;

(2) For increase of propulsive power by promotion of association acceleration, or gas generation: ammonia, hydrazine and hydrazoic compounds, nitrides, hydrogen peroxide, amines.

(3) Deceleration: injection of an excess of gas generating agents until the reaction becomes too diluted; reduction in injection of catalytic and accelerating agents.

In our examples and in our table of additional typical reactions, we illustrate the use of these reaction control agents.

Fluxing agents

Fluxing agents are employed to assist in the fusing and entrainment in the efflux of solid secondary reaction products. This prevents clogging of parts of the reaction chamber and assists in the progressive reduction in the combined weight of the engine and its fuel load.

The choice of fuels can be made with this end in view, since the sulfides and oxides of certain of our reducing agent reactants are of themselves fluxes, particularly those of boron and lithium. These fuels can be mixed with others for fluxing purposes. As is known in the pyrometric and metallurgical art, various chlorides and fluorides can be used in small proportion to depress the melting point. One of the special merits provided by the use of sulfur in a reaction for propulsive purposes is the low melting point and fluxing action of some metallic sulfides, particularly those of our fuels. An advantage provided for our process by the equipment for our second, third, and fourth embodiments is the absence of baffles, provided by the straight-line flow of the jet efflux. This may further be enhanced by the use of a single nozzle.

Gas generating agents

Gas-generating agents for the purposes of this invention are substances which are injected into a final combustion chamber or zone to impart expansive force to reactive sulfides of our specified reducing agents, such as hydrogen, boron, and certain metals.

The addition of gas generating agents is adjusted, as illustrated in the embodiments that follow, for the most effective balance of physical and chemical reaction conditions to obtain the best propulsive capacity. In this way they resemble our reaction control substances, with which they are often identical in chemical description. The distinction is largely that the gas-generating agents are employed where vaporous products are absent or nearly

absent, while the reaction control substances are used to augment larger quantities of vapor and are used in some instances as catalysts.

Standards of comparison and performance for the reactions

In order to compare our reactions with known propulsion reactions we have arbitrarily taken certain standards of performance and balanced our reactions to meet at least one common standard physical condition. The common physical basis to which we have reduced the comparison of reactions is nearly the same number of calories per mole of gas in each of any two reactions being compared with each other. The greater efficiency of one propulsive concept over the other then becomes particularly apparent.

We have assumed, as is common, that the most practical guide to the suitability of propellants is that product of the average specific weight of the fuels by the specific impulse imparted by the discharge gases. We use the definition of the specific impulse as being the thrust delivered per unit weight rate of propellant consumption. It is well known that the specific impulse depends primarily upon the square root of the ratio of the temperature of the gases in the reaction chamber to their molecular weight.

We have frequently contrived in our examples to obtain improved propellant suitability by employing fuels which have a high average specific weight without at the same time yielding a gas-like jet discharge in which the gases have a high average molecular weight. By using fuel combinations having a high average specific weight, we avoid the use of supply tanks having large volumes and weight. The specific weight advantage of our process is most apparent in athodyd continuous ram jet embodiments.

In the present state of the art, the increase of specific impulse is considered difficult. We have succeeded in this, as our high heat content permits us to introduce hydrogen and nitrogen into our gas-like jet discharge.

First example under first embodiment, FIGS. 1, 2, 3

The first example illustrating our process is the following: Magnesium in the form of turnings and powder is briquetted together with magnesium hydride, sulfur, and a gas releasing sulfur carrier. Sodium, a gas generating agent, hydrogen peroxide, and a reaction control substance, hydrazine, are also reacted in the process. The magnesium and sulfur form their sulfide on entering the reaction chamber **33** from cylinder **37** at point **38**. The sulfur carrier, in this case pure sulfur nitride, yields sulfur to the magnesium and releases nitrogen which helps to sweep the sulfides out into reaction zone **28**, where they react exothermally with hydrogen peroxide injected through orifices **14***a* from space **15**. Molten sodium enters the reaction chamber from spaces **19** and **23** through orifices **24** and there reacts with sulfur from the briquetted charge, sodium sulfide then bursting into zone **28** also. The stream of gas-like reaction products, gases and liquids, continues outward into zone **29**, where it enters a cross-current of hydrazine injected through orifices **13***a* from combined space **9** and **12**. This adjusts the temperature, pressure, and average heat content per mole to the desired level. The equation which describes the reaction follows, indicating the mole proportions of fuels and agents, now however, showing the intermediate sulfide forming steps, or dissociation of products:

$$8Na+2S_2+0.5N_4S_4+3Mg+MgH_2 +20H_2O_2+11.3N_2H_4\rightarrow 4Na_2O+4MgO +6SO_2+20H_2O+12.3N_2+23.6H_2$$

Together with dissociation of the reaction products there are nearly 65 gaseous moles produced. The above proportions of ingredients were selected so as to yield physical reaction conditions comparable to those of other reactions with which we will make comparisons. The propulsive capacity of this reaction namely the product of the specific weight and the specific impulse represents a marked improvement over the reaction of ethyl alcohol with liquid oxygen, when the latter fuels are proportioned so as to yield an equivalent number of calories per mole. This improvement results from the higher average specific weight of our fuels, the lower average molecular weight of our exhaust gases, and their higher average exhaust efficiency.

Second example under first embodiment

In this example a combination of a metal and a hydrogen releasing group, an amide, is reacted with sulfur, a gas-generating agent, and a reaction control substance. An imide may be similarly used. Lithium amide containing an excess of lithium metal is used. It is placed in cylinder **37** in the form of a briquette, held together by lithium, sodium, and magnesium turnings as binders and encased peripherally with rubber and nitrocellulose in a magnesium tube. Pressure from space **4** feeds the tube against orifices **24** of space **23**. From the latter issues gaseous sulfur. The metallic sufides are formed in zone **38**, from whence they burst outward into zone **28**. There they react exothermally and violently with hydrogen peroxide injected through orifices **14***a* from space **15**. The gas-like jet stream explodes outward through zone **29**, where it is modified by hydrazine injected through orifices **13***a* from space **12** and space **9** combined. The nearly finished gas-like jet stream swerves into combustion zones **30** and **31**, mixing and completing reaction, finally passing out of the combustion chamber through converging-diverging orifices **32** and exerting a propulsive impulse of a sustained character.

The lithium amide may also be injected as a molten liquid from cylinder **37**, the rear end of it being closed with injection orifices and the forward end open to gas pressure. Sodamide may be similarly used. The equation for the reaction is as follows, but neglects intermediate reactions and does not show the exact character of the dissociation of the end products, which however, has been ascertained:

$$2LiNH_2+0.5S_2+5H_2O_2+0.8N_2H_4\rightarrow SO_2+Li_2O+7H_2O+1.6H_2+1.8N_2$$

Together with dissociation of the reaction products there are nearly 12.5 gaseous moles produced. The equation approximates the best proportions, some empirical adjustment for actual engine conditions being required. The propulsive capacity of the reaction represents an improvement over that obtained in the reaction of hydrazine hydrate with hydrogen peroxide when those fuels are proportioned so as to yield an equivalent average number of calories per mole of gases. This advantage can be attributed to the higher specific weight of the fuels.

Third example under first embodiment

A metallic hydride, for example lithium or sodium hydride, can be reacted with a sulfur bearer, such as hydrogen sulfide, to obtain motive power. In the example that follows, liquid or solid lithium hydride is reacted with steam containing hydrogen sulfide. In the second stage of the reaction, the products of the initial reaction are oxidized with hydrogen peroxide, and in the third and final stage a reaction control substance, hydrazine, is added. The hydride is injected at zone **38** from storage space **27**, either as a briquette or as a pre-fused liquid. The hydrogen sulfide is injected in the gaseous state through orifices **24** from storage spaces **23** and **19**. The process may be varied so that hydrogen polysulfides may be used, the lithamide being injected from spaces **23** and **19** and the polysulfide from cylinder **37**, through orifices in the rear. The hydrogen peroxide is injected at orifices

14*a* into zone 28. The equation for the reaction is as follows, including hydrazine injected from orifices 13*a*:

$$2LiH+H_2S+5H_2O_2+1.87N_2H_4\rightarrow Li_2O+7H_2O+SO_2+1.87N_2+3.74H_2$$

Accounting for dissociation of the reaction products there are generated nearly 15 gaseous moles. The equation shows the recommended proportions of reactants for typical conditions. The propulsive capacity of the reaction represents an improvement over that obtained in the reaction of ethyl alcohol with oxygen, when the latter are proportioned so as to yield an equivalent number of calories per mole. This advantage results from both a higher specific weight of fuels and a higher jet discharge velocity.

Fourth example under the first embodiment

Jet propulsion in which the efflux is gaseous but minus steam or other gaseous oxides is believed to be very particularly novel in principle. In a reaction of this character, now illustrated, nitrogen and hydrogen at a high velocity are generated by the reaction of sulfur with a compound of lithium or sodium of the amide type. Their imides may also be used, or hydrides of these metals. We have selected lithium amide in a liquid state near the boiling point and containing an excess of lithium, and we react it with gaseous sulfur. Both fuels are heated short of the boiling point before injection into the power plant storage spaces. The amide is injected into the main reaction chamber at point 38 from storage space 37, while the gaseous sulfur is forced into the same zone through orifices 24 from spaces 19 and 23. Feed pressure is applied from space 4. The mole proportions of reactants employed are given by the equation that follows:

$$4LiNH_2+S_2+0.9N_2H_4\rightarrow 2Li_2S+2.9N_2+5.8H_2$$

Accounting for dissociation of the reaction products, there are nearly 9 gaseous moles produced. Their propulsive capacity exceeds that obtained from the reaction of aniline with fuming nitric acid when these have been proportioned for an equivalent heat content per mole. The improvement is chiefly in the specific impulse, and the sulfide reaction can be further improved by dilution with gas-generating agents.

SECOND EMBODIMENT—APPARATUS, FIGS. 4, 5, 6

A different apparatus for the utilization of the power plant process is enclosed in a cylindrical shell 66. A streamlined shape closes the forward end 40. The after end is terminated in a nozzle plate 53. In the forward end is located a reaction control substance storage space 59, which is constructed somewhat similarly to space 9 of FIG. 1 if it is desired to employ it and auxiliary space 41 for generation of oxygen from hydrogen peroxide, or hydrogen peroxide from sodium peroxide and acid. If not, conduit 57 is to be connected directly to conduit 42, as is the case in the immediate examples. Pressure generated or stored in space 62 collapses bag 60 gradually, forcing reaction control substance stored in space 59 through conduits 57, 42, and 64, and orifices 52 into the final zone of the main reaction chamber 65.

The pressure behind the feeding action is stored in space 62 or generated there by the reaction of the calcium hydride contained in capsule 61 with water already in space 62. This reaction and the power plant are started by the explosion of capsule 61 by a small powder charge. This same pressure is also transmitted to the gas-generating agent contents of space 45, within bag 44, thus injecting them into zone 49 of the main reaction chamber through orifices 43 and 50 and interconnecting conduit 63. Conduits and orifices are initially sealed by seals which can be broken by the initial pressure.

The sulfide forming reactants are lodged in the forward and middle zones, 47 and 49 respectively, of the main reaction chamber, commencing at forward wall 46 and extending to final gas-generation orifice 51.

The main reaction commences with the spraying of gas-generating agent against charge portion 49. The charge in most cases consists of a briquette in which a sulfur releasing agent and a metal or boron, or compounds of these, are mixed. These commence to interreact, and a reaction sequence follows similar to that described for our process in the first embodiment.

The jet efflux exhausts through nozzles 54. The central nozzle is only partially covered by bracket 55 which supports central member 67. This bracket is pierced with holes such as 56. FIGURES 5 and 6 show sectional views at lines 5—5 and 6—6, respectively. The former is a cross-section through the reaction control substance and gas-generating agent bags and the latter a section through the combustion chamber zone 63.

In connection with the use of solid charges in our embodiments, it should be understood that they are to be separated from rigid containers, in which they may be placed, by easily compressible liners, as of rubber, when expansion of the charge is to occur during the process reaction.

First example under second embodiment

The reaction between lithium amide and sulfur is already given as the second example under the first embodiment. Since the present embodiment provides for a solid charge occupying the reaction chamber, the physical state and arrangement of the fuels is different, although the chemical character and the over-all advantages of the reaction are the same. The briquette is a mixture of lithium amide and sulfur, together with particles of sodium encased in nitrocellulose solvent-applied film distributed throughout the briquette. This solid charge is located and reacted as described in the foregoing explanation of the apparatus.

The design of the second embodiment can be further simplified so that the entire supply of fuel is in the reaction chamber. The gas-generating agent and the reaction control substance can be entirely omitted. Instead, sulfur nitride or other solid gas-generating agents can be included in the briquette charge.

Second example under second embodiment

The solid charge is a briquet of lithium hydride, sulfur, and a little sulfur nitride. In addition, lathe turnings of magnesium are intermixed to help to hold it together and the entire charge is placed in a case of rubber and then inserted into the reaction chamber. Percussion should be avoided in handling the sulfur nitride, which should be pure. Gas-generating and reaction control agents are injected as previously instructed in the apparatus description and other similar examples. The mole proportions for the reactants are given in the following equation:

$$2LiH+0.5S_2+4H_2O_2+1.25N_2H_4\rightarrow Li_2O+SO_2+5H_2O+1.25N_2+2.5H_2$$

Together with dissociation of the reaction products there are nearly 11 gaseous moles produced. The propulsive capacity for the reaction represent a substantial improvement over that for ethyl alcohol with liquid oxygen for equivalent heat content per gaseous mole or where neither an excess of alcohol nor of oxygen is used. The advantage of our process derives primarily from the higher specific weight of its fuels.

THIRD EMBODIMENT—APPARATUS, FIGS. 7 and 8

The jet motor apparatus employed for the third embodiment is shown in FIGS. 7 and 8. It consists of a cylindrical shell 71, terminated at the forward end by a nose 70 for streamlining and at the after end by a tail cap 72, fastened to reaction chamber 78. The

latter is closed by nozzle plate 73. Attachment brackets 94 and 94a attach the motor to an airplane, when used for jet assisted take-off.

Within the parts of the outer shell are a storage space 74, a compressed nitrogen tank 75, a gas-generating agent tank 76, fuel tank 77, and as many other similar fuel tanks with pressure connections, conduits, and injection orifices as there are fuels and other substances for any particular reaction embodiment. There are also the reaction chamber 78, valve 81 controlling application of feed pressure through conduits 82 and 82a, check valves 95 and 95a, and conduits 83 and 84 connecting the pressure to tanks 76 and 77 respectively. The tanks are filled from external sources, usually with molten or liquid fuels, through screw plugs 79 and 80.

The pressure applied by the nitrogen, ammonia, or hydrogen, whichever the feed gas may be, breaks seals permitting the reactants to enter the reaction chamber 78 at injection orifices 87 and 90. The flow is metered by valves 86 and 88 and similar valves when additional tanks are used. These valves are in turn operated through rods such as 91 and 91a, supported from the outside of the reaction chamber wall by bearings 92. They are in turn operated by adjustment shaft 93, accessible from the outer surface of the motor.

Injection conduit 85 or conduit 89, or similar additional conduits are wound around the exterior of the main reaction chamber 78 when pre-heating by chamber heat is desired for any particular reactant or reactants. Reaction takes place in chamber 78 as the streams of reactants meet at various points in the chamber, as dictated by the reaction, the course of single or multistage reactions commencing at the forward end of the chamber. The jet-like propulsive efflux produced explodes out of the chamber through converging-diverging nozzles 73a in nozzle plate 73.

First example under third embodiment

In this embodiment liquid pentaborane containing a fraction of a mole of caustic is reacted with a hydrogen polysulfide and then with hydrogen peroxide, following which hydrazine is injected to control the physical constants of the jet efflux. The pentaborane and the polysulfide form new sulfides at the forward end of the reaction chamber. In the next zone to the rear hydrogen peroxide is injected for an oxidation reaction and in the rearward zone the reaction control substance hydrazine. The equation giving the mole proportions of reactants is as follows:

$$2B_5H_9+0.13NaOH+0.37H_2O+7.5H_2S_2+61.3H_2O_2+28N_2H_4\rightarrow 0.06Na_2O+15SO_2+5B_2O_3+28N_2+78.4H_2O+56H_2$$

Including dissociation, nearly 194 moles of gas are formed. The propulsive capacity obtained represents an improvement over that from the reaction of aniline with acid, for equivalent heat content per gaseous mole. Although in this case the specific weight of our fuels is less, the product of the specific weight and the specific impulse is greater, because a higher jet efflux velocity is obtained.

Further examples under the third embodiment are not here elaborated upon, since the examples of the preceding embodiments may be readily adapted to the equipment of the third. In addition, there is shown in the table of additional typical reactions, following the fourth embodiment, other reactions which can use the equipment of any embodiment.

FOURTH EMBODIMENT—APPARATUS AND PROCESS

The inherent advantages of our process are particularly apparent when applied to the continuous ram jet type of propulsive equipment. While the equipment differs greatly from other jet propulsion equipment and the apparatus which we have described herein, the process remains substantially the same. Its characteristic feature is the use of air as the gas-generating oxidant. A particularly interesting feature is that in multistage versions of our process the ram jet is supplied with an explosive reaction in advance of the reaction of air with our fuel 3, described in column 6 of this specification. This provides a propulsive impulse less dependent upon the speed of the ram jet than the regular air reaction common to ram jets. It also serves to heat and expand the incoming air. As ram jet athodyd equipment is well known it will not be described further. Also, as we have taught the application of our process frequently in this specification, it will not be sketched for that purpose. Our high density fuels are shown to especial advantage in this equipment, since low specific gravity gas-generating agents and reaction control substances are not needed in any quantity, while many known fuels are inherently themselves of low specific weight.

Our liqiud or molten fuels may be injected into and reacted in ram jet combustion chambers in advance of the air injection point. As is generally known, the air injection is usually a diverging nozzle of large size, producing turbulent flow and shock wave pressures. The discharge of our sulfide forming state is arranged so as to be into the pressure zone. A solid fuel briquette may be also used, located as a ring or doughnut shaped charge surrounding the periphery of the diverging nozzle, heating it and exploding sulfides into the air pressure zone. In the following example the briquette consists of magnesium turnings, magnesium hydride, and pure sulfur nitride, which may however be replaced in various proportions with sulfur to reduce reaction speed. Beryllium carbide may be used to replace some of the magnesium, a greater heat being generated thereby. The descriptive equation is as follows:

$$N_4S_4+3Mg+MgH_2+13.2O_2+49N_2\rightarrow 4SO_2+4MgO+H_2O+6.7O_2+51N_2$$

The product of the specific weight and the specific impulse for the above reaction represents an improvement over ethyl alcohol and over hydrazine, either combusted in ram jet equipment, fuel proportions having been adjusted for the same heat content per gas mole on an average, for such reaction. In this example our advantage lies in the higher specific weight of our fuel.

In the foregoing disclosure we have explained how the uses of the sulfides as applied by us to the problems of jet engine operation give sulfide forming reactions and gas generating reactions that are violent enough to yield results of the kind currently required in improvements of jet power.

Exothermic sulfur

It will now be apparent how our concept takes full advantage of the exothermic character of sulfur. When we react it with metal or boron compounds to form the sulfide, it reacts exothermally like oxygen, as though we had oxygen in a solid and high density form at normal temperatures. But we get still another reaction, in which the sulfur itself is oxidized. The sulfur in the first case has served as an oxidant but in the second case as a reducing agent.

Simplicity of method

Our invention satisfies a longfelt want. Research has been directed for many years toward developing enough energy from rocket engines for practical use. We have accomplished that result with simple, readily available, common materials; many of them inorganic and more easily obtained than substances such as aniline or alcohol.

Application or use

Our contribution, therefore, is not merely the knowledge of how to accomplish the reactions. It is also in the application of that knowledge to more efficient and advantageous propelling of rockets and the like, as has

been alluded to in the statement of objects, and described in the foregoing specification.

TABLE OF ADDITIONAL REACTIONS

(1) Formation of sulfide, and gas generation:

$$2H_2S_2+N_2H_4\rightarrow 4H_2S+N_2$$

(2) Hydrazine as a reaction-control substance:

(*a*) $2(B_5H_9\cdot 4NH_3)+7.5H_2S_2+40N_2H_4\rightarrow 5B_2S_3+8NH_3+105.5H_2+40N_2$

(*b*) $C_4H_4S+2LiH+0.5N_2H_4\rightarrow Li_2S+C_4H_4+2H_2+0.5N_2$

(3) Hydrazine as gas generant; no oxidant used:

(*a*) $H_2S_2+4LiH+2N_2H_4\rightarrow 2Li_2S+2N_2+7H_2$

(*b*) $S_2+4LiH+3N_2H_4\rightarrow 2Li_2S+3N_2+8H_2$

(*c*) $H_2S_2+4LiH+0.5N_2H_4\rightarrow 2Li_2S+0.5N_2+4H_2$

(*d*) $H_2S+N_2H_4+2NaH\rightarrow Na_2S+N_2+4H_2$

Special attention is directed to Reactions **2**(*a*), **3**(*a*), **3**(*b*), **3**(*c*) and **3**(*d*) of the foregoing Table of Additional Reactions. It is to be noted that, in each of those reactions, the total number of moles of hydrogen and nitrogen in the output is at least 2.25 times the number of moles of sulfide in said output. Thus, the number of moles of low-molecular-weight gases is greatly in excess of the number of moles of sulfide, characterized by comparatively high molecular weights. A jet efflux having a high proportion of low-molecular-weight gases insures the fulfillment of the objects of this invention.

We claim:

A process for generating jet propulsion which comprises the steps of continuously supplying to and intimately mixing in a confined reaction zone substantially stoichiometric quantities of fuels consisting essentially of at least one fuel from each of the two groups of fuels herein defined, the first of said fuels being selected from the group consisting of the hydrides, amides and imides of lithium, sodium, potassium, beryllium, magnesium, and boron, and a compound of the formula ($B_5H_9\cdot 4NH_3$), and the second of said fuels being selected from the group consisting of sulfur, hydrogen sulfide, hydrogen polysulfide, nitrogen sulfide and thiophene, exothermally reacting said fuels to form the corresponding sulfides of lithium, sodium, potassium, beryllium, magnesium and boron, injecting into the exothermal reaction mixture a gas-producing agent selected from the group consisting of ammonia and hydrazine, the injection of said agent being at a rate and in a manner to effect an immediate and intimate mixture with said sulfides formed by said exothermal reaction, and further to effect rapid decomposition of said agent to generate gases, the gases from said decomposition and said exothermal reaction being rapidly developed and having low average molecular weight, retarding the escape of said gases from said reaction zone in order to develop high pressure therein, and projecting said gases as a jet from said reaction zone, the rate of injection of said gas-producing agent being sufficient to supply after decomposition at least 2.25 moles of nitrogen and hydrogen mixture for each mole of said sulfide formed by said exothermal reaction.

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