June 5, 1951 J. A. GRAND ET AL 2,555,333

SOLID FUEL

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FIG. 1

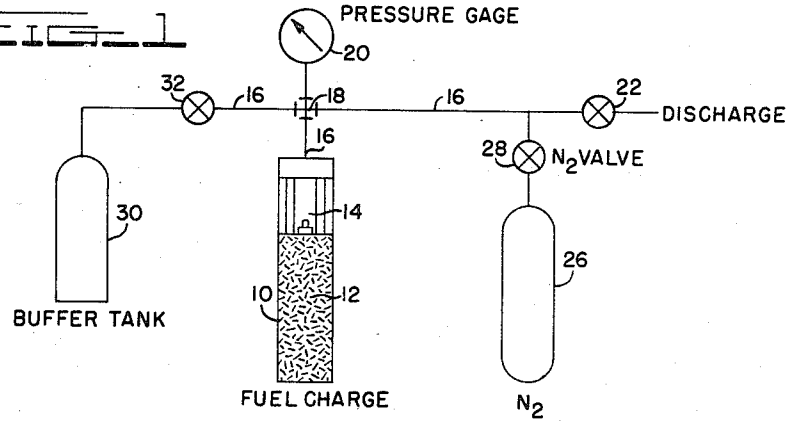


FIG. 2

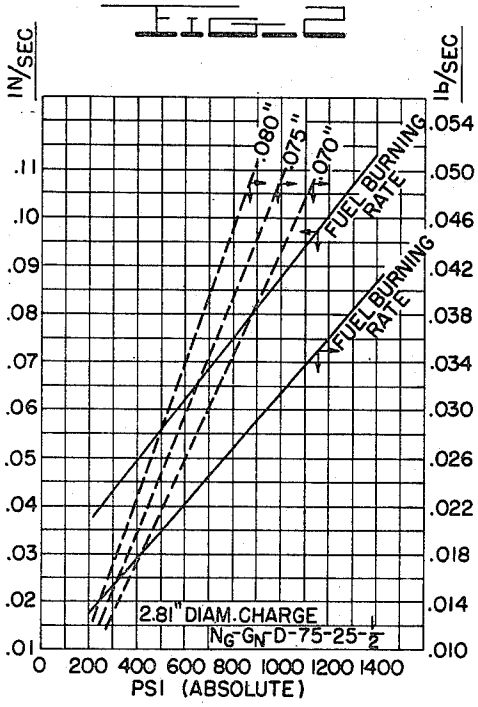


FIG. 3

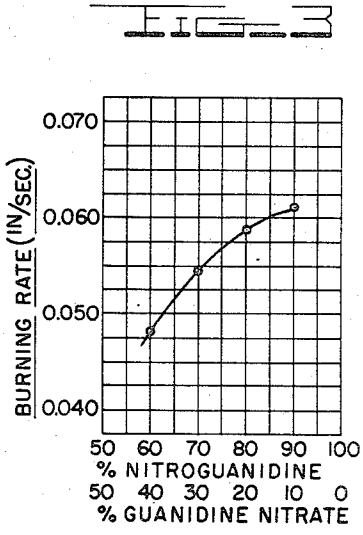


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FIG. 4

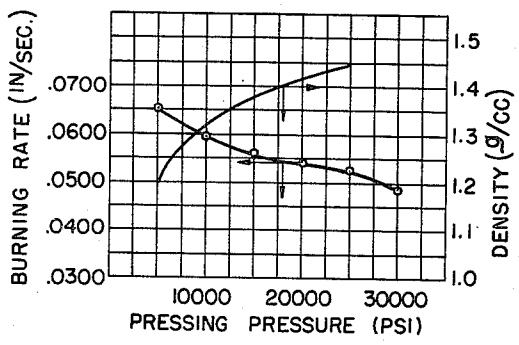



FIG. 5

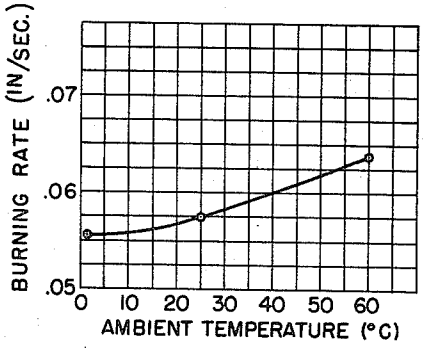
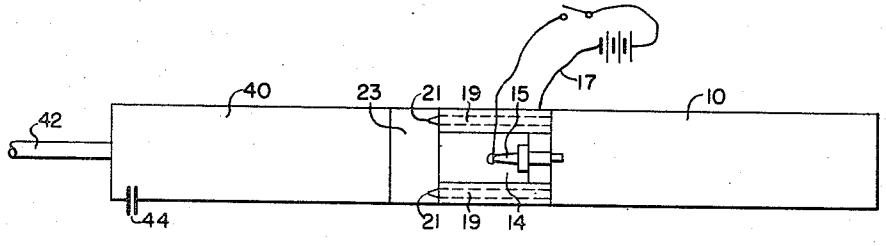



FIG. 6

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# UNITED STATES PATENT OFFICE

2,555,333

## SOLID FUEL

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Application May 27, 1948, Serial No. 29,608

1 Claim. (Cl. 52—7)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

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This invention relates to solid, synthetic fuels and in particular to a solid, synthetic fuel which, upon combustion, liberates a comparatively large volume of gas at a relatively high temperature and pressure sufficient for the operation of equipment such as small turbines, fire-fighting equipment and the like.

The general object of the invention is to provide a fuel which, upon combustion, will liberate approximately one liter of gas per gm. of fuel burned under standard conditions of temperature and pressure.

It is also an object of the invention to provide a fuel which will liberate the equivalent of that volume of gas at a pressure within the range of from about one hundred to about 2000 pounds per square inch.

It is a further object of the invention to provide a fuel which will not only liberate a gas in the above volume and within the above pressure range but also at a temperature of about two thousand degrees Fahrenheit.

The attainment of these objectives is set forth in the following description and in the drawings hereto appended both of which are merely illustrative of preferred embodiments and features of the invention and should not be taken in a limitative sense. In these drawings:

Figure 1 is a diagrammatic arrangement of apparatus used in testing the fuel under various conditions of temperature and pressure.

Figure 2 is a graph showing a comparison of the fuel burning rate versus pressure and calculated nozzle mass discharge rate versus pressure. Fuel burning rates are measured values while the nozzle mass discharge rates represent calculated values for a gas temperature of 600° C.

Figure 3 shows burning rate versus composition at a constant gas pressure of five hundred pounds per square inch.

Figure 4 shows the effect of loading pressure on the burning rate at five hundred pounds per square inch gas pressure. Also the increase in loading density with increase in loading pressure is shown.

Figure 5 shows the effect of the ambient temperature on the burning rate, at five hundred pounds per square inch gas pressure.

Figure 6 is an elevational view of the applicants' fuel charge cartridge and igniter connected to a small turbine.

The applicants, in their research on solid fuels for powering small gas turbines, jet propulsion units and gas pressurizing apparatus such as fire-fighting equipment and the like, found that mix-

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tures of nitroguanidine, guanidine nitrate and a combustion catalyst, when burned, liberated a relatively large volume of gas under a pressure sufficient for the sustained operation of small gas turbines and the like equipment. The temperature of the gas evolved was well within the operation range of the turbine and there were relatively no solid particles carried over in the liberated gas.

Mixtures of nitroguanidine and guanidine nitrate, in loose condition are highly explosive when subjected to a detonation wave. The applicants found that by compressing the mixture under a pressure of from 5,000 to 30,000 pounds per square inch the mixture was no longer subject to detonation and could be handled with comparative safety.

It was required that the fuel be contained in a cylindrical steel cartridge approximately 3" O. D., $2\frac{1}{16}$" I. D. x 18" long. This requirement was met by compressing the solid fuel in the cartridge within the range of pressure above indicated. The cartridge was held by a steel die during the compressing operation, thereby preventing rupture of the steel cartridge at these heavy pressures. The cartridge tube was lined with an asbestos sheet liner to prevent all over burning of the fuel and to thereby retrict the burning to the exposed end surface. In the combustion of the fuel where slow burning is required it is of paramount importance that the fuel burn only on the desired surface or surfaces.

Mixtures of nitroguanidine and guanidine nitrate alone will not support a desirable combustion. In order to obtain a sustained combustion it is necessary to have present in the mixture a relatively small percentage of a combustion catalyst. The applicants have found that any one of the following catalysts will sustain combustion of the fuel mixture until it is completely burned: ammonium dichromate, activated chromic oxide, copper chromite, chomic nitrate, zirconia, cerium oxide, thorium oxide and thorium nitrate. Of these catalysts, the applicants prefer to use ammonium dichromate because of its availability and ease of handling.

In Table I is given the effect of the catalyst on the burning rate in inches per second at a gas pressure of 500 pounds per square inch of nitroguanidine (hereinafter designated $N_g$) and guanidine nitrate (hereinafter designated $G_n$) and a catalyst, ammonium dichromate (designated D), in proportions of 75 $N_g$, 25 $G_n$, and ¼ to 8 parts D.

*Table I*

| Fuel | Burning Rate in./sec. @ 500 p. s. i. | |
|---|---|---|
| $N_gG_n$: 75-25 | No sustained Combustion. | |
| $N_gG_nD$: | | |
| 75-25-¼ | .049 | .055 |
| 75-25-½ | .056 | .058 |
| 75-25-¾ | .060 | .060 |
| 75-25-1 | .051 | .052 |
| 75-25-5 | .078 | |
| 75-25-8 | .085 | |

The above data in the lower percentage region shows that the percentage of the catalyst affects the burning rate only slightly but that its presence is necessary to sustain combustion. Properly prepared chromic oxide functioned just as satisfactorily as ammonium dichromate, but the latter is preferred as it is more convenient to use. A commercial grade of chromic oxide was unsatisfactory.

The analysis and physical characteristics of the gas discharged from burning $N_gG_nD$ 75–25–½ @ 500 p. s. i. is given in the following table.

*Table II*

| Component | Volume Per Cent | Characteristics |
|---|---|---|
| Nitric Oxide | 0.2 | |
| Carbon Dioxide | 1.2 | Mol. Wt.=20.9 |
| Carbon Monoxide | 14.3 | |
| Oxygen | 0.2 | Gas Yield=0.98 liter/gm. |
| Hydrogen | 13.0 | |
| Nitrogen | 37.1 | Heat Evolved=0.67 Kgcal./gm. |
| Water | 26.4 | |
| Ammonia | 7.6 | $\frac{C_p}{C_v}$=1.35 |
| | 100.0 | |

The above is an approximate analysis of the combustion gas at room temperature and pressure and does not include a small amount of carbon and chromic oxide. Since nitroguanidine and guanidine nitrate have negative stoichiometric balances, the effluent gas is reducing, and therefore does not oxidize metallic surfaces with which it comes into contact. From $N_gG_nD$ 75–25–½ approximately one liter of gas at STP/gm. is released with pressure burning at 500 p. s. i. On the basis of heats of formation of reactants and products 0.67 kilogram calories per gram of fuel is evolved. Without reference to change of equilibria except for dissociation of $NH_3$, the ratio $C_p$ to $C_v$ is 1.35 for the temperature range inherent to this problem.

Referring to the drawings, Figure 1 discloses a schematic arrangement of apparatus for generation of gas by the combustion of the solid fuels of the applicants. This apparatus is particularly effective in the determination of the rate of burning and the volume of gas evolved under predetermined conditions of gas pressure. The arrangement may comprise a fuel cartridge 10 containing a compressed fuel charge 12. The cartridge is provided with fuel igniter 14 and is connected to conduit system 16 through cross 18 to gauge 20 and through throttle valve 22 to the atmosphere. High pressure nitrogen tank 26 is connected to conduit system 16 through valve 28. Also buffer tank 30 is connected to conduit system 16 through valve 32. The function of the nitrogen tank is to supply nitrogen to the conduit system in replacement of the air therein and to maintain a predetermined pressure on the gas ab initio. The function of buffer tank 30 is to provide a cushion against sudden increases or decreases in pressure and to cause an even and steady rate of flow of the combustion gases.



In the operation of this testing apparatus pressure in the system is brought up to the desired magnitude by opening valve 28 with throttle valve 22 closed. This pressure is indicated by gauge 20. Then simultaneously with the closing of the igniter switch (not shown in Fig. 1) throttle valve 22 is opened and the combustion gases produced by the burning of fuel charge in cartridge 10 are discharged therethrough. Pressure may be maintained constant during the burning period by manual control of throttle valve 22. Toward the end of the combustion of the fuel charge, valve 32 may be closed in order that a better indication of completion of burning may be given. Because of the relatively slow rate of burning the timing of the burning may be readily determined with a stopwatch and visual observation of the pressure gauge.

The effect of gas pressure on the burning rate was obtained in the above manner as well as with nozzles of various diameters on a mixture of $N_gG_nD$ 75–25–½ and is shown in Figure 2 of the drawings. In this figure not only is the linear burning rate of the fuel shown as a function of the gas pressure but also the nozzle mass discharge rate is plotted for various diameter jets. The burning rate is indicated in inches per second and the nozzle mass discharge rate in pounds per second. The pressure range covered from about two hundred pounds per square inch to about fourteen hundred pounds per square inch absolute. The diameter of the pressed fuel charge was approximately 2.81 inches. The curves clearly show the increase in the nozzle mass discharge rate with the increase in the nozzle diameter. The intersections of the nozzle mass discharge rate vs. pressure curve and the burning rate vs. pressure curve represent the equilibrium burning pressure for that particular nozzle.

Figure 3 is a graph of the burning rate in inches per second as a function of the composition over a range in composition of from 60 parts nitroguanidine and 40 parts guanidine nitrate to 90 parts nitroguanidine and 10 parts guanidine nitrate. All mixtures were burned under a pressure of 500 pounds per square inch gas pressure. It is interesting to note that increasing the proportion of nitroguanidine from 60 to 90 parts with a corresponding complementary decrease in the guanidine nitrate increased the burning rate only from about 0.0483 to about 0.0614 inch per second. All of these mixtures contained one half part of ammonium dichromate as a combustion catalyzer.

Figure 4 shows the effect of loading pressure in pounds per square inch on the linear burning rate in inches per second and the increase in density in gms. per cubic centimeter on a mixture of $N_g$–$G_n$–D—75–25–2 at a gas pressure of five hundred pounds per square inch. The range of loading pressures covered was from about 5000 pounds to about 30,000 pounds per square inch. With the indicated increase in pressure the linear burning rate dropped from about 0.065 inch per second at 5,000 pounds per square inch to about 0.0485 inch per second. Density of the fuel mixture was increased from about 1.2 at 5,000 to about 1.45 at 25,000 pounds per square inch.

Figure 5 shows the effect of the ambient temperature on the rate of burning of the fuel. This graph shows that over an ambient temperature

range of from about zero to about 60° C., the burning rate increased from about 0.0505 to about 0.0675 inch per second on a mixture of $N_g$–$G_n$–D—75–25–½ burned at a gas pressure of 500 pounds per square inch. The fuel has a desirable temperature coefficient of burning in that this value is low or exhibits little change in burning rate with initial temperature.

Figure 6 is an elevational view of a fuel charge cylinder and igniter connected to a small turbine. Here **10** represents the fuel charge cylinder which is threadedly engaged to igniter **14**. Plug **15** which is of the hot wire type extends into the fuel charge and ignites the latter when electrical circuit **17** is closed. The gas generated by the combustion of the fuel passes through conduits **19** and nozzles **21** which are circumferentially arranged in chamber **23**. The gas passes from the nozzles into turbine **40** which is of the two stage type, and out through vent **44**. The rotors of the turbine are mounted on shaft **42** and impart a rapid rotation thereto as the gas impinges upon the inclined vanes of said rotors.

Ignition is not limited to the electrical circuit disclosed. The fuel charge may be ignited by mechanical means with a percussion cap.

Test runs of the apparatus disclosed by Figure 6 were made with the following results, using a fuel charge 2.81 inches in diameter.

*Table III*

| Gas Pressure in p. s. i. | R. P. M. | Horse Power Developed |
|---|---|---|
| 300 | 21,000 | 0.8 |
| 350 | 24,000 | 1.4 |
| 450 | 27,000 | 1.6 |
| 800 | 38,000 | 2.7 |

These results speak for themselves. They show that the applicants' fuel generates a gas pressure sufficiently high to impart a high rate of rotation to a small turbine motor, at a horsepower of definite magnitude.

The applicants' invention is not limited to the powering of small turbines as above described. It may be used for powering any small displacement engine and in particular it may be used for powering fire fighting equipment. On shipboard much of the firefighting equipment is operated by power received from the ship's



power plant. In the event of this power plant being disabled and rendered inoperative the firefighting equipment dependent thereon is useless. In view of the fact that the applicants' fuel liberates a relatively large volume of gas at high pressure it can be used for displacing the fire extinguishing liquid from the tanks in which it is stored.

It is therefore seen that the applicants' invention is a solid fuel composition consisting of definite proportions of nitroguanidine, guanidine nitrate and a combustion catalyst. The components bear a definite relationship to each other within the range of proportions given. Obviously slight variation from the given proportions could be made by one skilled in the art without departing from the spirit and scope of the invention. Such variation is included within the scope of the invention to the extent as defined by the herewith appended claims.

The invention herein described may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

What is claimed is:

A compressed solid fuel charge characterized upon combustion by the liberation of a relatively large volume of reducing gas at a relatively high pressure and moderate temperature consisting essentially of about 75 parts by weight of nitroguanidine, about 25 parts by weight of guanidine nitrate and from about ¼ to about 5 parts by weight of copper chromite as a combustion catalyst said charge having been compressed under a pressure of from about 5,000 to about 30,000 p. s. i.

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