The Rating of Rocket Fuels

Rocket Fuels Using Atomic Energy As A Primary Heat Source

By THOMAS S. GARDNER, Johnson City, Tennessee

The first paper (1) in this series developed methods for the evaluation of rocket fuels using chemical sources of oxidizers for the thermal reaction. In the last few years several factors have appeared which make it desirable to extend this work into the use of atomic energy as a primary heat source rather than using chemical reactions of substances to furnish the necessary heat for expansion of gases to use as thrusts on the basis of Newton's Third Law of Motion.

The use in Germany of a true rocket ship, the Me-163 as a fighter plane, conclusively shows the practicality of the rocket as a power source extraneous to and independent of the atmosphere to supply one of the components of the fuel system as exemplified by the jet plane and the conventional type of screw drives of the airplane. The V-2 and the Me-163 used chemical fuels. The V-2 (2) used calcium or sodium permanganate with hydrogen peroxide to yield super-heated steam to drive a turbine connected to the rocket motors. This is similar to the MnO_2-H_2O_2 system examined earlier in the series (1). The V-2 then utilized hydrazine and hydrogen peroxide in methanol solution to heat the fuel chambers by a strong exothermic reaction, while the main drive consisted of alcohol or gasoline and liquid oxygen as the oxidant. Some of the thermodynamic properties of the first and last systems of the V-2 were examined (1) and shown to be inferior to the CS_2-N_2O system investigated in this country. The fuel system of the Me-163 was probably similar to the V-2 but it has not been published in detail at the present time. It is now no longer possible to ignore the rocket drive principle as a major form of propulsion.

Popular qualitative and historical descriptions of rockets have been described recently (3). However, it is possible that chemical rockets may become obsolete even before they are perfected for primary rocket drives. This is due to the development of atomic energy. At the present time atomic energy is utilizable either as a relatively low temperature reaction in the pile, or as a violent explosive form as in the atomic bomb (4). In neither case is atomic energy applicable to a rocket drive. However, the utilization of atomic energy is in the most elementary phase, and many scientists having any knowledge of it or of atomic and nuclear reactions believe that it can be developed for many sources of primary heat engines, and by extrapolation, as a primary heat source useful for rocket drives.

Therefore, in order to examine some of the theoretical uses of atomic energy as a rocket drive, we have to make only one assumption. We have to assume that atomic energy using small amounts of an atomic fuel can furnish a constant, controllable, high temperature (1000-5000° A) heat source. We can then apply certain analytical processes to the concept and develop some conclusions as to the secondary fuel conditions if we make this assumption which is probably realizable within ten years.

It would be impractical to eject sufficient atomic fuel alone to yield the thrust required by the application of Newton's Third Law. The quantity would be prohibitive from the cost standpoint, and in no case would it be possible to utilize over a fraction of the available energy. This is due to the fact that all rocket motors are limited by temperature considerations. There are no known metals or alloys of metals that will stand a working temperature of 5000° A, or even for that matter 3000° A for any length of time. The complete composition of the alloys used for jet planes has not been published. Columbium (5) has been reported to be used in jet turbines, and also molybdenum (6) for temperatures of about 1500° F. (816° C). Turbo-jet motors have been stated to operate at only about 1000° C. (7) It may be safely assumed that no present type of engine operates with a wall temperature much above 1500°

C (1773° A). Therefore we can reasonably assume that about 2000° A (1727° C) is the maximum temperature attainable in a rocket motor within the near future. Rocket chambers with removable interior linings of metallic molybdenum or tungsten processed by the powder metallurgy technique could probably withstand these conditions for a while. Thus we probably cannot use atomic energy directly but only as a primary, constant heat source to eliminate chemical reactant fuels. However, chemical reactant fuels may still be useful for some years due to the development of compounds such as ClF_3 (b. p. 12° C.) that react violently with water to yield incandescent gases (8).

If a very small quantity of atomic fuel can be used without having to obtain the minimum mass for an explosive reaction, it can be fed into the rocket chambers simultaneously with **any** substance that has certain engineering and thermodynamic properties to yield a suitable thrust for rockets. In such a case we can eliminate the greatest single hazard of rocketry, the unstable oxidants that often require refrigeration, pressure tanks, or have to be used within a certain period of time of filling the tanks such as in the case of Loxygen without refrigeration. For example, any fuel that can be fed easily into the rocket chambers would be utilizable, provided it would yield gases at a relatively low temperature (cir. 500° C.), or that decomposes to yield gases at low temperatures by heat alone. The fuel, to be practical, should either be a gas or a liquid, such as water. Also the rocket fuel should absorb heat easily, i. e., have strong absorption bands in the infra red and up to about 30,000° A. The incandescent gases should not dissociate at too low a temperature nor absorb large quantities of heat on dissociation such as the formation of atomic hydrogen from hydrogen gas.

The kinetic energy of a gas is a function of temperature only, but the momentum of the gas molecule is a function of mass and velocity, and at constant temperature the momenta of different gases are proportional to the square root of their molecular weights. Therefore a comparison of the momentum function ($\sqrt{M}$) on a unit weight basis is indicative of relative momenta capable of being imparted by the gases at the same temperature. However, the thermal efficiency of a rocket fuel at a maximum constant temperature of operation of 2000° A would be a function of available thrust, i.e., volume of gases and heat absorbed per mole of fuel, and in the final analysis, per gram of fuel carried (i. e., unit weight basis). The thrust delivered per unit weight is very important as the rocket must carry its fuel and every extra pound requires a greater fuel load. Thus in the use of an atomic heat source the efficiency of the fuel systems used might be written as a first approximation on a thermodynamic basis from engineering consideration as:

$$E_{ae} = V_1/Q_1$$

in which E_{ae} is the efficiency using atomic energy; V_1 volume of gases per unit weight (gram) at the maximum temperature utilizable (2000° A); and Q_1 the Kcal. of heat absorbed per unit weight from the standard temperature selected (27° C) to the maximum temperature.

The following thermodynamic data was used for these calculations:

Most of the heat equations were the ones previously used (1) and had been calculated from band spectra accurate to within 3% up to 2000° A (9).

$$O_2;\ C_p = 6.26 + 2.746 \times 10^{-3}T - 3.43 \times 10^{-7}\ T^2$$

$$H_2O;\ C_p = 6.89 + 3.283 \times 10^{-3}T - 3.43 \times 10^{-7}\ T^2$$

$$SO_2;\ C_p = 8.12 + 6.825 \times 10^{-3}T - 2.103 \times 10^{-6}\ T^2$$

$$CO_2;\ C_p = 6.85 + 8.533 \times 10^{-3}T - 2.475 \times 10^{-6}\ T^2$$

$$H_g;\ C_p = 1.666$$

The heat capacity of mercury vapor has been checked as a monoatomic gas for 548-629° A (10). The specific heat of liquid mercury per gram was taken as $3.336 \times 10^{-2} - 6.9 \times 10^{-6}$ T after Winkelman (11).

The following heats of vaporization per gram at 27° C (300° A) were used (12):

H_2O, 581.1 g-cal/g; SO_2, 81.8; CO_2, 18.9; and for Hg at 357° C, 70.8.

It has been previously shown that the decomposition of 100% hydrogen peroxide would raise the decomposition gases, water vapor and oxygen, to about 1270° A by the heat of decomposition. It is possible at the present time to produce, stabilize and safely store, concentrated hydrogen peroxide. The Elektrochemische Werke Muenchen A. G. developed a vacuum concentration method of producing hydrogen peroxide of 80% or higher strength (13.). This material was used as a fuel in submarines, rockets, rocket aircraft, torpedoes, etc. In this country the Buffalo Electro-Chemical Co., Inc., of Buffalo, N. Y. (14) independently developed a process for producing hydrogen peroxide of 90+% concentration. The heat of decomposition of 30% H_2O_2 is $-\Delta H = 12.13$ kcal; and 100% material, $-\Delta H = 12.88$ kcal. (1). As data on 90+% solutions have not been published the data on 100% material was used in these calculations with proper allowances for the water content on a 90% basis.

The amount of heat required to raise the rocket gases to 2000° A were calculated using the heat equations by the well known thermochemical relation:

$$-\Delta H = \int_{300}^{2000} C_p \, dT$$

On applying these principles we obtain the following table for a few of the most important fuels to be used as probable secondary systems using atomic heat as the primary heat source.

Compound	M. W.	M	M/g.	Q_1	V_1	E_{ae}
H_2O	18.0	4.24	0.24	1.46	9.16	6.27
CO_2	44.0	6.63	0.15	0.47	3.75	8.00
SO_2	64.0	8.00	0.12	0.40	2.57	6.43
Hg	200.6	14.16	0.07	0.13	0.82	6.31
H_2O_2 (100%	34.0	5.83	0.17	0.41	11.73	28.81
H_2O_2 (90%)[a]	(31.2)	(5.59)	0.18	0.48	13.67	28.49

a. 2.65 moles hydrogen peroxide, 0.56 moles water. Thermochemical data for the calculations used that for 100% hydrogen peroxide. In both cases for hydrogen peroxide the Q_1 values are low because only atomic heat is required to raise the temperature from 1270° A to 2000° A, as the heat of decomposition is sufficient to yield the temperature cited for 100% hydrogen peroxide and the same value was used for the 90% material. Spontaneous decomposition takes place at 151° C (15), and this is ideal for a rocket chamber kept to a high temperature by atomic heat.

An examination of the systems in the table shows that hydrogen peroxide is far superior to any other fuel investigated due to its stored chemical energy and decomposition into water and oxygen, thus increasing the volume of the gases and thrust thereby. In this case atomic energy would be a booster for the gases to yield the desired thrust.

The heavy pressure cylinders required by carbon dioxide and sulfur dioxide minimize their value in spite of their E_{ae} values which appear very favorable. For example, the weight of the pressure cylinder is usually greater than the weight of the liquified gases, which would more than halve their efficiency, and put both materials well below water and hydrogen peroxide.

An examination of the relative momenta on a unit weight basis of the gases shows that water is superior to all other fuels investigated, and hydrogen peroxide comes in second but still far above the other compounds.

The poor showing of mercury in regard to the momentum factor is in contrast to the hopes placed in it by some investigators who have not followed through the thermal efficiencies and other factors that are necessary for a fuel which has to be transported by the expenditure of other fuel.

For a closed svstem flight of long duration it would be necessary to remove from the atmosphere carbon dioxide and water eliminated by the crew of a ship. If atomic energy is used as described they can be used as fuel for the ship. All organic waste products convertable to liquids or gases could also be used for fuel. It is evident that, if atomic energy be used to maintain a rocket chamber at a high temperature, entirely new systems of fuels become of interest. Thus hydrogen peroxide would probably be best for the main drive whenever available, but water could be used if the cost of atomic fuel should be sufficiently low to allow the generation of the extra heat required between water and hydrogen peroxide with its stored chemical energy. If space for storage were at a premium, hydrogen peroxide would be superior to water. Both water and hydrogen peroxide require only light weight containers.

The use of atomic energy will not make superstratospheric flight easy, but it will simplify problems. The unfortunate fact is that we would like to have a new principle of free space flight in addition to the use of Newton's Third Law which necessitates the loss of a part of the mass of the rocket ship in order to have motion at all. It is also unfortunate that at the present time we do not have a new principle of free space flight in sight in our present system of physics. Further study in the gravitational field equations may result in such a new principle and be as fruitful as the use of the Maxwell-Hertz field equations have been for electro-magnetic and electrostatic fields. Until that date we must utilize the rocket thrust principle as our sole method of free space flight.

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