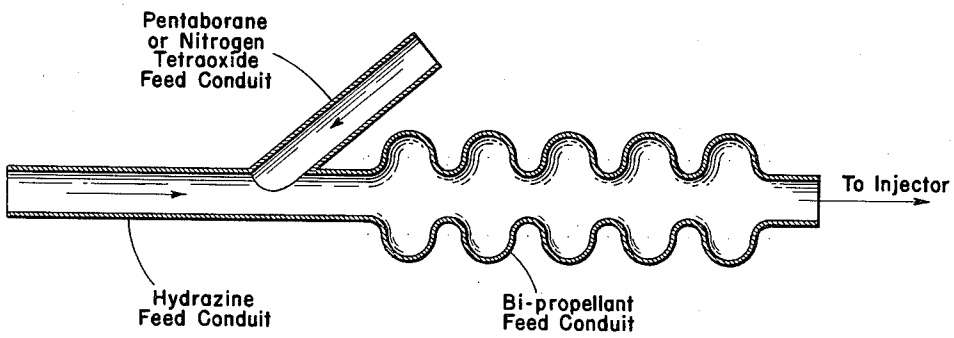
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COMPOSITIONS, PROCESSES, AND APPARATUS FOR THE IMPROVEMENT OF BI-PROPELLANT FUELS

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COMPOSITIONS, PROCESSES, AND APPARATUS FOR THE IMPROVEMENT OF BI-PROPELLANT FUELS

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The present invention relates to methods for improving the performance of liquid propellant compositions employed in jet and rocket engines. More particularly, the present invention relates to compositions, processes, and apparatus for improving the thrust and specific impulse of liquid propulsion compositions, and specifically those formed of pentaborane and hydrazine.

The most desirable and efficient firing of this latter fuel composition involves the complete conversion of pentaborane and hydrazine to boron hydride and hydrogen, since the formation of these products effects a greater decrease in the standard change of free energy than that otherwise accomplished by the various subsidiary side reactions which normally intervene; and, in addition, is thermodynamically more efficacious. The principal reaction may be represented as follows:

$$2B_5H_9+5N_2H_2\rightarrow 10BN+19H_2$$

Thus, in the conventional reaction of these bi-propellant components, pentaborane will, in addition to its reaction with hydrazine, react with the decomposition products of hydrazine, such as, for example, nitrogen and ammonia; reactions which require relatively high energies of activation, and which proceed at a much slower rate. Similarly, where the pentaborane is permitted to decompose prior to interaction with hydrazine, and products such as boron hydride fragments (e.g. B_xH_y) and elemental boron result, the reactions occurring between these components and hydrazine are extremely slow. Thus, the competing side reactions are seen to slow the thrust and impulse induced by the principal reaction. The avoidance of such undesirable side reactions can be substantially effected by the prompt and thorough intermixture of the two propellant components, thus reducing and substantially eliminating the formation of the aforesaid decomposition products of the original reactants in the combustion chamber of the rocket engine. It is noted that hydrazine is the more readily decomposed of the two propellants upon atomization in the combustion or thrust chamber. Decomposition in the aforesaid chamber, prior to the interaction of the components in the principal and direct reaction, is caused by the high temperatures present and required therein.

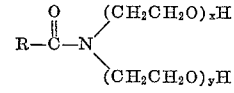
Accordingly, it is an objective of the present invention to provide for the reaction of rocket multi-propellants and particularly bipropellant compositions without the prior decomposition of the mono-propellant components; and to accomplish this by an extremely rapid and uniform admixture of the fuel components preferably in the feed line to the injector positioned in the thrust or combustion chamber.

Thus, in accordance with the present invention, effective admixture of the fuel components is accomplished by an interrelated combination of steps comprising, illustratively, introducing into at least one and preferably each of the bi-propellant fuel components, hydrazine and pentaborane, a suitable surface active agent which, while reducing the surface tension thereof, will not hydrolyze or otherwise inhibit the principal reaction of the bi-propellant system referred to hereinabove. To attain a satisfactory increase in the intensity of admixture of the bi-propellants, prior to and during injection into the combustion chamber, the non-hydrolytic, chemically inert surface active agents should be incorporated in each of the components in an amount within the range of 0.1 percent to 1.0 percent by weight of each of said propellants. The inclusion of quantities of surface active agent towards the upper end of this range is normally indicated with hydrazine, particularly, due to the comparatively greater surface tension inherent therein; i.e., 4.56×10^{-3} foot-pound per foot at 77° F., as compared to that of pentaborane; i.e., 1.465×10^{-3} foot-pound per foot at 68° F. Introduction of the respective surface active agents is conveniently accomplished in the storage containers used by the individual propellants.

Bi-propellants for use in rocket engines are derived from a relatively small group of oxidizers and a large group of fuels. Oxidizers which have been considered for rocket applications include O_2, O_3, H_2O_2, HNO_3, N_2O_4, $C(NO_4)_4$, F_2, ClF_3, OF_3, etc. Fuels can be organic or inorganic and include hydrazine, as noted above, and modified hydrazine derivatives and compounds containing at least one amino radical. Thus, by way of further illustration, the organic fuels can be hydrocarbons, alcohols, amines, ethers, nitroparaffins, aromatic compounds, etc. Important inorganic fuels include H_2, NH_3, N_2H_4, B_2H_5, B_5H_{10}, $LiNH_2$ and their derivatives.

It is noted that the preferred bi-propellant composition for use herein is formed from a mixture of hydrazine and pentaborane. Other bi-propellant systems, such as, for example, hydrazine and nitrogen tetroxide, may also be so employed.

Suitable surface active agents for hydrazine, ammonia, or any propellants containing an amino group or groups herein, are saturated and unsaturated hydrocarbyl amides of the formula:



where R is a hydrocarbyl radical, that is a monovalent hydrocarbon radical, containing from 8 to 20 carbon atoms, and wherein each of x and y is an integer from 1 to 49, and the value of $(x+y)$ is within the range of 5 to 50 inclusive. Illustrative of these surface active fatty acid amides are hydrogenated tallow amide wherein the value total of $(x+y)$ in the above formula is 5 (trade name: Ethomid O/15); hydrogenated tallow amide, wherein the value of $(x—y)$ is 50 (trade name: Ethomid HT/15); and oleyl amide, wherein the value of $(x+y)$ is 5 (trade name: Ethomid HT/60). An additional advantage inherent in the use of these agents is their ability to inhibit the soaking back of heat from the combustion chamber by virtue of the foam produced by their surface activity right at the exit of the injector in the reaction chamber of a rocket or jet aircraft, thus providing insulation against the receding of the heat from said combustion chamber by convection or radiation. Obviation of the difficulty posed by possible pre-ignition of the propellant fuel components is thus a significant advantage and improvement of this invention.

While the incorporation of surface active agents contributes to the desired intermixture of bi-propellants, such as hydrazine and pentaborane, this step is most efficacious when one of the components, pentaborane preferably, is introduced into admixture with the hydrazine component at an angle of at least 90° thereto; that is, at an angle vertical to the flow of hydrazine in the main feed line, or in such a manner that the feed of pentaborane at the point of entry into the main feed line is substantially countercurrent to the flow of hydrazine. This is accomplished by providing that the pentaborane feed line be disposed at an angle of from 90° to 175°, and preferably within the range of 100° to 145° to the

hydrazine feed line. The angular flow of pentaborane into the main flow of hydrazine is occasioned by the molar ratio of the propellants employed and their respective density in the feed line. Thus, the stoichiometric proportions of these ingredients is 5 moles of hydrazine to 2 moles of pentaborane for the principal reaction recited hereinabove. The more closely the admixture of pentaborane flow with hydrazine feed approaches a direct countercurrent flow, the more efficient, of course, the mixing effected at this point will be. As indicated, the exact angle between the two feed lines is determined by the volumetric ratio of the two feeds, the relative pressure of delivery of these components into a common feed, and the distance between the point of mixing and the hydrazine or pentaborane tank, since it is essential that neither component enter the storage container of the other. An illustrative example of the angular feed of pentaborane described hereinabove is shown in the accompanying figure.

From the point of entry of pentaborane into the hydrazine feed to the injector communicating with the rocket combustion chamber, the bi-propellant feed line describes a series of dilations and constrictions, and thus a sequential difference in diameter along its course. This variation in diameter may be irregular or constitute a regular recurring sequence. The purpose of this modification of the feed line is to assure a continued turbulence in the fluid stream and a sustenance of the intermixture abetted by the inclusion of surface active agents in the fuel components and initiated by the angular influx described hereinabove.

The range in constrictive and dilated diameters of the common bi-propellant feed line is determined by two principal factors. The minimum diameter is that below which retardation in fluid flow sufficient to effect a backing up or choking of the bi-propellant feed to the injector occurs. The maximum diameter is that beyond which neutralization of the pressure inducing passage of the bi-propellant feed through the common feed line to the injector is caused to occur. An illustrative example of a suitable bi-propellant feed line of variable diameter is seen in the accompanying figure. In summary, the figure thus shows feed lines for the individual fuel components joining to form a common bi-propellant fuel line which extends to the engine injector.

The range for the ratio of variation in cross-sectional area, although it can be any value within the above limitation, is preferably in the range between 1.5/1.0 and 10/1.0. The larger the ratio, the better is mixing. On the other hand, the larger ratio causes high frictional loss and pressure drop in the line. The maximum allowable pressure drop in the feed line is equal to the pressure difference between the storage tank and reaction chamber minus the pressure drop across the injector. The optimum ratio of variation in cross-sectional area should be one corresponding to this maximum allowable pressure drop in the feed conduit leading from the point of joinder of the individual feed lines to the injector in the thrust chamber of a rocket or an aircraft jet.

There is also included desirably in the common bi-propellant feed line a packed bed of small, inert solid particles formed normally of the same inert composition which provides the inner wall or lining of said propellant feed lines.

As a result of the combination of steps described hereinabove, there is introduced through the injector into the rocket combustion chamber a thorough admixture of the bi-propellant fuel composition of such atomized homogeniety as to react directly in the desired manner with the substantial avoidance of side reactions and decomposition products such as alluded to hereinabove.

The following examples are further illustrative of the invention:

Example 1

To 1000 gallons of hydrazine in a high pressure storage container is added 0.3 percent by weight of the surface active agent hydrogenated tallow amide (trade name: Ethomid 0/15) of average molecular weight 498. Similarly, into 500 gallons of pentaborane in a standard storage container, 0.1 percent by weight of the same surface active agent is introduced. The two storage containers are then attached to suitable feed lines which join at an angle of 90°, the feed of each of the components through the individual feed lines to the point of joinder being regulated so that stoichiometric proportions of 5 moles of hydrazine to 2 moles of pentaborane are intermixed at the point of joinder and fed through a common bi-propellant feed line of variable diameter, as seen in the accompanying figure, to the thrust chamber of a rocket engine.

Example 2

The procedure of Example 1 is repeated, substituting 0.5 percent by weight of the hydrogenated tallow amide (trade name: Ethomid O/15) of average molecular weight 498, in the hydrazine fuel component. The angle at which the feed lines of hydrazine and pentaborane join is 100°.

Example 3

The procedure of Example 1 is repeated, substituting 0.5 percent by weight of hydrogenated tallow amide (trade name: Ethomid HT/15) of an average molecular weight of 2478, in the hydrazine component, and 0.1 percent by weight of said amide in the hydrazine fuel component. The angle at which the feed lines of the two fuel components is 145°.

Example 4

The procedure of Example 2 is repeated, substituting oleyl amide (trade name: Ethomid HT/60) of an average molecular weight of 500 as the surface active agent therein. The angle at which the pentaborane feed line joins the hydrazine feed line is 175°.

Example 5

The procedure of Example 2 was repeated substituting nitrogen tetraoxide for pentaborane therein, using a mole ratio of 3:2. The angle at which the nitrogen tetraoxide feed line joins the hydrazine feed line is 135°.

Example 6

To 2000 gallons of unsymmetrical dimethyl hydrazine in its high pressure storage tank is added 0.4 percent by weight of the surface active agent, hydrogenated tallow amide (trade name: Ethomid O/15), of average molecular weight 498. This storage tank and a high pressure storage tank of pentaborane are attached to suitable feed lines which join at an angle of 110°; the flow of each of the components through the individual feed lines to the point of joinder being regulated so that stoichiometric proportions of 5 moles of hydrazine to 2 moles of pentaborane are intermixed at the point of joinder and fed through a common bi-propellant feed line of variable diameter to the thrust chamber of a rocket.

Example 7

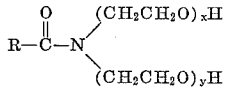
The procedure of Example 5 is repeated, substituting unsymmetrical dimethyl hydrazine for hydrazine.

What is claimed is:

1. A liquid bi-propellant composition for rockets that comprises the components hydrazine, pentaborane, and a surface active agent for each of said hydrazine and said pentaborane, each of said surface active agents being present in an amount by weight of each of said components within the range of 0.1 percent to 1.0 percent.

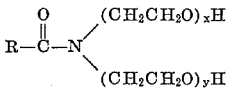
2. A liquid bi-propellant composition for rockets that comprises the components hydrazine and pentaborane, the mole ratio thereof being 5:2 respectively; and a surface active agent for each of the said hydrazine and pentaborane.

3. A process for intimately admixing the bi-propellant fuel components hydrazine and pentaborane in a mole ratio of 5:2 respectively, that comprises introducing at least into the hydrazine component, prior to admixture thereof, a surface active agent of the formula:



wherein R is a hydrocarbyl radical containing within the range of 8 to 20 carbon atoms, and wherein each of x and y is an integer within the range of 1 to 49, and the value of $(x+y)$ is within the range of 5 to 50 inclusive, in an amount by volume of 0.1 percent to 1.0 percent of each of said propellant components; introducing one of said components into the other of said components in a flow which enters the latter component at an angle within the range of 90° to 175°; and passing the resulting bi-propellant flow through a feed line composed of a plurality of constrictions and dilations of variable diameter to the reaction chamber of a rocket engine.

4. A process for intimately admixing the bi-propellant fuel components hydrazine and pentaborane in a mole ratio of 5:2 respectively, that comprises introducing into said hydrazine component prior to admixture thereof, a surface active agent of the formula:



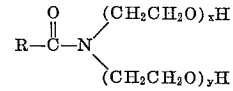
wherein R is a hydrocarbyl radical containing within the range of 8 to 20 carbon atoms, and herein each of x and y is an integer within the range of 1 to 49, and the value of $(x+y)$ is within the range of 5 to 50 inclusive, in an amount by volume of 0.1 percent to 1.0 percent of each of said propellant components; introducing one of said components into the other of said components in a flow which enters the stream of flow of the latter component at an angle within the range of 90° to 175° thereto; and passing the resulting bi-propellant flow through a common feed line packed with a large number of small and inert solid particles.

5. A process for intimately admixing a bi-propellant fuel composition, that comprises introducing into the individual components thereof, hydrazine and pentaborane, prior to admixture, in an amount by volume of 0.1 percent to 1.0 percent of each of said propellant components, a suitable non-hydrolytic surface active agent which is uninhibitory to reaction between said fuel components; introducing the resulting pentaborane composition into the resulting hydrazine composition in a mole ratio of 2:5 respectively, and at an angle within the range of 100° to 145° counter to the flow of said hydrazine;

and passing the resulting bi-propellant flow through a feed line composed of a plurality of constrictions and dilations to the reaction chamber of a rocket engine.

6. A process for intimately admixing a bi-propellant fuel composition, that comprises introducing into the individual components thereof, hydrazine and pentaborane, prior to admixture, in an amount by volume of 0.1 percent to 1.0 percent of each of said propellant components, a suitable non-hydrolytic surface active agent which is uninhibitory to reaction between said fuel components; introducing the resulting pentaborane composition into the resulting hydrazine composition in a mole ratio of 2:5 respectively, and at an angle within the range of 100° to 145° counter to the flow of said hydrazine; and passing the resulting bi-propellant flow through a feed line composed of a plurality of constrictions and dilations to the reaction chamber of a rocket engine, packed with a large number of small and inert solid particles.

7. A process for intimately admixing a bi-propellant fuel composition, that comprises introducing into the individual components thereof, hydrazine and nitrogen tetraoxide, prior to admixture thereof, in an amount by volume of 0.1 percent to 1.0 percent of each of said propellant components, a surface active agent of the formula:



wherein R is a hydrocarbyl radical containing within the range of 8 to 20 carbon atoms, and wherein each of x and y is an integer within the range of 1 to 49, and the value of $(x+y)$ is within the range of 5 to 50 inclusive; introducing the resulting nitrogen tetraoxide composition into the resulting hydrazine compostion at an angle within the range of 100° to 145° counter to the flow of said hydrazine; and passing the resulting bi-propellant flow through a feed line composed of a plurality of constrictions and dilations to the reaction chamber of a rocket engine.

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