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CHEMISTRY IN SPACE BOOSTERS

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People often ask, "Exactly what does a chemist do in the rocket industry?". They generally know that "the fuels and oxidizers are discovered and made by chemists", but "what else do they do... or do they sit back and loaf while others, the designers and engineers, build the rockets and motors?". Well, let me acquaint you with some of the areas in which a chemist has to contribute.

First, to briefly review the principles by which a rocket works, then lets take some specific examples of portions of the system and see what the chemist has to do with it.

A rocket, as you know, is basically a recoil machine... you push material out the back end, and force tends to push the vehicle in the opposite direction. This material can be various substances, rifle bullets, rocks, compressed gasses, etc., of course, the efficiency of these systems ^{is} poor, so it behooves the engineer to use a system which can get the most mileage for a given quantity of propellant.

One factor which determines this "mileage" is the propellant's specific impulse... or the amount of force (in pounds) which can be obtained by burning one pound of propellant. The higher the specific impulse, the more push you get and consequently, the less propellant which must be carried for a specific mission.

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There are other properties which are desirable, however. I will list these and then come back and briefly discuss them.

Now Chart 3

Chemical

1. High Heat of Combustion
2. Low Heat of Formation of Reactants
3. Low Molecular Weight of Products
4. High Thermal Stability
5. High Combustion Efficiency
6. Good Combustion Stability
7. Good Ignition Characteristics
8. Material Compatability
9. Reproducibility

Now, lets cover them in more detail:

1. Heat of Combustion - This is the amount of energy released upon burning. The more energy available, the more push you get on your rocket.
2. Heat of Formation of the reactants or propellants - All compounds are produced, at least indirectly, by reacting their elements together. In doing this, a certain amount of the total energy can be removed and consequently is not available when you later burn the propellants in the rocket engine. Thus, the amount of the total energy removed in forming the propellant compounds, the heat of formation, should be as small as possible. This is why hydrogen, H_2 , which being a simple compound, has a low heat of formation, is higher energy fuel than hydrazine, N_2H_4 .

3. Low Molecular Weight of Products or exhaust gases - The ultimate velocity which a rocket can reach is a function of how fast the particles are traveling when you throw them out the rear end. So, you want them to be traveling as fast as possible. It is obvious that you can throw a baseball faster than a lead shot-put, because the baseball is lighter. By the same token, light weight exhaust products will travel faster than heavier ones if they have the same energy. Again, hydrogen which burns with oxygen to form water, having a molecular weight of 18, is a better propellant combination than kerosene-type fuels with oxygen. These fuels contain carbon which burns to carbon dioxide and this has a molecular weight of forty-four.

Describe
regenerative
cooling necessary

Example: Radiator

4. High Thermal Stability - In liquid rocket engines, with which I'm most familiar, the fuel is often used to cool the thrust and combustion chambers in order to keep the metal from melting. If the fuel tends to decompose or come apart due to heat, then it wouldn't be long before the coolant tubes would become stopped-up and the engine would melt... this is not very good for the performance of successful missions. So, it is desirable that the fuel have a high decomposition temperature.

5. High Combustion Efficiency - Any material which is not burned means a weight penalty or loss of available energy. For this reason alone, I think I can safely say that you will not see wood used as a rocket fuel...too much ash, even though it's fuel qualities are quite desirable for other purposes.

6. Good Combustion Stability - The burning characteristics should be predictable and quite smooth in nature. High combustion efficiency and high energy content are not enough to determine a good fuel...Nitroglycerine has these two qualities, but I would hesitate to ride a rocket using it as a propellant.

7. Good Ignition Characteristics - A normally smooth-burning propellant combination which is hard to ignite might lead to a dangerous build-up of mixture combination if it doesn't ignite at the correct time. The engine generally uses fuel-rich mixtures ^{to lower} for cooling of the combustion temperatures and to control the burning rate, however as the mixture ratio approaches stoichiometric conditions, or quantities for complete combustion, the danger of explosion or detonation becomes greater. Thus, engine ignition is usually designed to occur when little oxidizer is present and then it is increased to the proper design level.

8. Material Compatibility - The propellant, tanks, plumbing, engine seals, gaskets, pumps, and their necessary lubricants must not be chemically reactive toward each other or else corrosion, or other damage will cause them to fail with the resultant mission abort.

9. Reproducibility (Final Composition) - The propellants have to be uniform in properties and purity or all of the above characteristics will be different. If the purity of the gasoline sold at service stations varied markedly due to varying molecular weights of its constituents, then the density change alone could

vary the distance which a tank of gas would take your car from less than 1 mile to possibly 400 miles. The viscosity (resistance to flow) could change from that of asphalt to natural gas. Yes! Uniform quality is a necessary thing.

The values of the things mentioned are determined primarily by chemists or persons using chemical methods. Often there are no known materials which have all of the desired properties, so the chemist is called upon to modify existing materials or even make completely new compounds in order for the designers and engineers to build high performance rockets or vehicles.

Show Chart 4

The physical properties which the designers want in propellants are:

1. High Density - The more the propellant weighs per given volume, then the smaller and lighter the structure or tank has to be in order to carry the required weight of propellants.
2. Low Viscosity - Liquid propellants have to be pumped from their tanks through plumbing lines, cooling tubes and finally into the engine. The more viscous the fluid, the more energy is necessary to pump it. Larger present day engines burn in the order of a ton or more of propellants a second, so a free-flowing liquid is much easier to handle than a more syrupy fuel.
3. Low Temperature - Coefficients of density and viscosity - This property determines the amount of change in density or viscosity which occurs as the temperature is raised or lowered. The current wide-range motor oils (10W-30) are examples a material having a low viscosity temperature-coefficient, as opposed to the

older type of motor oils which wouldn't let your car start because it became as thick as glue on cold winter mornings... usually when you were late to school.

4. Low Vapor Pressure (High Boiling Point) - Liquids having high vapor pressure are hard to store and pump because ^{they are} it is easily gassified and form "vapor locks".

This property is important for safety reasons also. By nature, the fuels are fairly easily ignited and if it has a low boiling point then the storage and handling problems are compounded. Liquid hydrogen, which boils at -453°F , is a good example of this. Test and handling facilities for liquid hydrogen may easily cost in the millions of dollars... If we had a liquid hydrogen which boiled 600°F higher (with all its other properties remaining the same) then space flight would be a lot easier and cheaper for everyone.

5. Low Freezing Point - This requirement is quite obvious if one remembers that liquid oxygen which boils at -323°F is stored adjacent to the fuel... and solid fuel is hard to pump.

6. High Specific Heat of propellants - This property is a requirement of the motor coolant system. If it takes a lot of heat to raise the propellant temperature just a little bit, then the coolant flow rates in the thrust and combustion chambers can be less and higher performance, lower stability fuels can be used.

7. Low Specific Heat of the products - By the same token, if only a little heat is required to raise the exhaust gas temperature by a large amount, then the exhaust gas particles, having a high temperature, will have a very high exhaust velocity.

8. High Thermal Conductivity of propellants - This property is a measure of the rate of heat transfer through the propellants. Again, the engine coolant system requires maximum design cooling, thus it is favorable that the heat adsorbed from the walls of the coolant chamber be transferred as rapidly as possible to the remainder of the coolant propellant. Otherwise, heat will build-up at the coolant walls and the fuel will decompose due to the temperature or the engine walls will melt.

The values of all of these properties have to be known before the designer can start to make the actual drawings and designs.

Weight is the magic word in designing rocket vehicles, because every unnecessary pound in the vehicle is that much penalty in the payload weight. Consequently, the individual components are designed to the limit of their capabilities. Only when the propellant and material properties are known exactly can the pumps, tank and plumbing wall thickness, or even the size of the propellant tanks themselves be decided.

This leads us to the other components of the system and the materials from which they are made. The properties already mentioned of the propellants will determine to a large extent what materials will be used. For example; the gaskets, o-rings, and

seals in the flanges must not be dissolved, attacked or reactive
~~in contact~~ with the fuel or oxidizer in which it may come in contact...
kerosene type fuels cause natural rubber to soften and swell and dissolve most petroleum greases used in bearings and valves. So, chemists have come up with chloroprene and polyvinyl chloride rubbers which don't soften or swell in the fuel, and silicone greases which aren't dissolved or washed-out.

Liquid oxygen is a peculiar beast; in that, when most organic materials are in contact with it, a shock or sudden impact will cause a detonation or violent explosion. One of the earlier vehicles was lost because of a ten cent gasket. It was in a valve, then when the valve was opened the shock wave caused the gasket to explode. The liquid oxygen line ruptured and the fireworks began. Since learning the cause of this failure, all materials which are used in the oxidizer system are now tested for liquid oxygen impact sensitivity. This is done by immersing the sample in liquid oxygen and dropping a weight from a given height. This test simulates the shock which a material may receive when a valve is suddenly opened or closed somewhere in the system.

The lubricants used in the liquid oxygen valves have to perform their job at -300°F ... it must lubricate the part as well as withstand the cold which is sufficient to make a banana hard enough to drive a nail into wood, cause rubber to shatter like glass when struck on a solid object or freeze methane (natural gas).

This temperature problem eliminates most elastomers, or plastic materials, (which we commonly use in normal aircraft and automobile construction), from use in the liquid propellant rocket systems. The gaskets and washers which are now used in your car, in the gas cap, carburetor, engine, and fuel pump, become too brittle and break.

New materials had to be developed for these uses.

Si-N Polymers

Now we have plastics which are elastic at 1000°F (the melting point of zinc, the metal which is used for galvanizing metal parts). At the other extreme, there are others which are flexible at liquid helium temperature where every other material is frozen solid.

Aclar, Mylar

The development of materials for rocket vehicle applications is furnishing tangible benefits to you in everyday living. The greasless frying pans now being sold are a direct outgrowth of the studies on coatings of materials to protect against high temperature and chemical corrosion.

Teflon coatings
on metal

The "Cermet" ovenware, which can be taken from a hot oven and immersed in cold water without breaking, are a direct consequence of the studies on nose cone materials. It may not be long before your present day two-ton automobile can be made to perform the same, but will weight only 1500 pounds ... yet be stronger and more powerful ... your tires may be permanently mounted and will last the life of the car.

Ceramic studies

The information which had to be learned in order to design and construct rocket and space vehicles will become more and more useful as industry takes advantage of it.

Titanium con-
struction, space
metals

Thirty years ago, about the only plastic materials used were patent leather products (for shoes and automobile car tops), natural rubber (for tires, raincoats, and hoses), and bakelite (car battery cases). Now you wear synthetic clothes (Nylon, rayon, Dacron), walk and drive on synthetic rubber, eat food which comes wrapped in plastic, drink from plastic glasses, ride in cars and boats with fiberglass-epoxy resin bodies, sleep on foam plastic beds, and sit on furniture which is coated with plastic finishes.

This is quite an impressive change in so short a time, but twenty years from now, you'll be telling your children how hard you had it ... your cars only got 20 to 30 miles per gallon, your house had to be repainted every 5 years, food would spoil in three to four days if it wasn't put in the refrigerator, clothes had to be cleaned after wearing them less than a week ... why - you even had to buy a new car fender if you hit another car. There will be a lot of changes due to the things which we're learning today. Life may not be quite the way the new television cartoon program "The Jetsons" pictures it, but it's closer than you think.

At Marshall Space Flight Center, one of the vehicles which we're building is the SATURN, S-I. This uses a kerosene-oxygen propellant combination. It is a little inconvenient to bring it with me - it's 21 feet in diameter, 78 feet long, and weighs 480 tons. However, to give you an idea Show EDROC engine of the workings of a rocket system, I brought along its little baby brother.

- Show fuel tank and plumbing This engine uses propane and compressed air as the propellants and has a thrust of about 3/10 pound. Vapor from the liquid propane is introduced into the engine through this series of plumbing. We control the amount of fuel by controlling its pressure and the size of the hole through which it goes to the engine. This gage measures the fuel pressure.
- Show fuel pressure gage
- Show oxidizer tank, gage plumbing The oxidizer portion of the system has similar components. The amount of thrust which a rocket engine can produce is a function of not only the propellant, but also the chamber pressure. This is measured by this gage.
- Show chamber pressure gage
- Show spark plug When the fuel and oxidizer are introduced into the combustion chamber, they are ignited by a spark plug, and the burned, exhaust gases exit through the throat. The resulting thrust, or recoil, causes the engine to be pushed back against this thrust measuring device, and the amount of thrust can be seen on the scale.
- Show exhaust port
- Show thrust scale It can be seen that the amount of thrust is proportional to the chamber pressure.
- Show engine This particular engine is not cooled so we won't be able to run it for more than a few seconds at a time --- or we'll end up with a "glob" of molten aluminum. Likewise, the fuel and oxidizer flow rates are low for the same reason. Consequently, the exhaust jet will only be about an inch long at the engine throat, and since the light is fairly bright in this room, I'll hold a dark background behind it so that you can see the jet. If you watch closely, you will see two or more
- Invite the students to come up for a closer look, if there aren't too many

shock diamonds in the jet. These are diamond-shaped spots of light which are indications of stable combustion and "high" chamber pressure (i.e., chamber pressure is greater than the pressure into which the gases are exhausting).

Look in engine throat when switch is turned on

First: Check to see that we have current to the spark plug.

Set P_o to 10-15 psig greater than P_f

Second: The fuel and oxidizer tank valves are turned on and the pressures set to the desired values.

Finally: We're ready to go

1. Turn on fire button.
2. Place dark background behind jet exhaust.
3. Read C_p , P_o , P_f and thrust to class.
4. Turn off engine after 10-15 seconds and invite questions while awaiting it to cool.
5. Repeat demonstration as applicable.

PHYSICAL

1. HIGH DENSITY
2. LOW VISCOSITY
3. LOW TEMPERATURE COEFFICIENTS OF DENSITY AND VISCOSITY
4. LOW VAPOR PRESSURE, HIGH BOILING POINT
5. LOW FREEZING POINT
6. HIGH SPECIFIC HEAT OF PROPELLANTS
7. LOW SPECIFIC HEAT OF PRODUCTS
8. HIGH THERMAL CONDUCTIVITY OF PROPELLANTS

DESIRED PROPERTIES OF PROPELLANTS

CHEMICAL

1. HIGH HEAT OF COMBUSTION.
2. LOW HEAT OF FORMATION OF REACTANTS
3. LOW MOLECULAR WEIGHT PRODUCTS
4. HIGH THERMAL STABILITY
5. HIGH COMBUSTION EFFICIENCY
6. GOOD COMBUSTION STABILITY.
7. GOOD IGNITION CHARACTERISTICS
8. MATERIAL COMPATIBILITY.
9. REPRODUCIBILITY (FINAL COMPOSITION)