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REACTION PROPELLED DEVICE FOR
OPERATION THROUGH WATER
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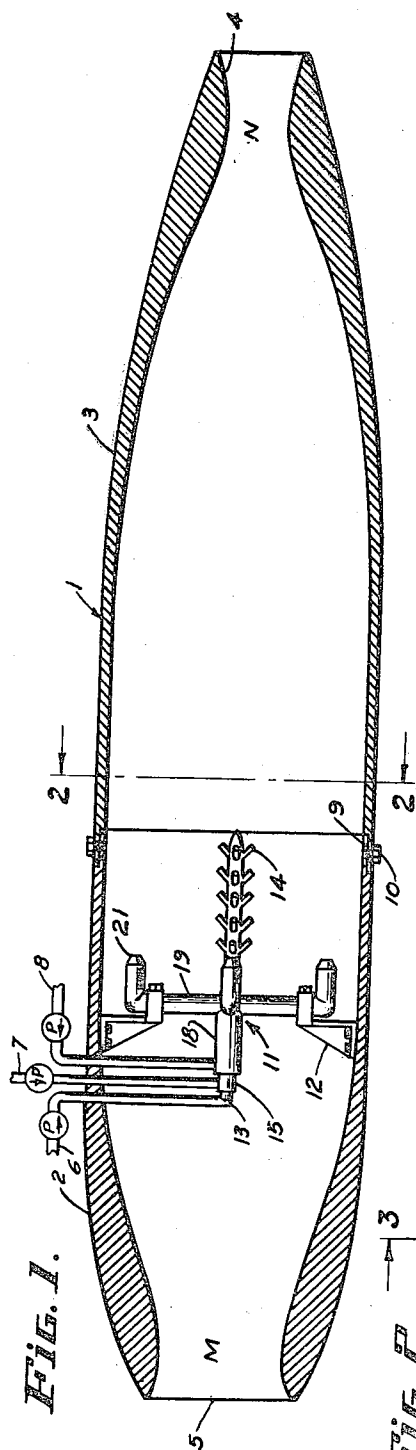


Fig. 1.

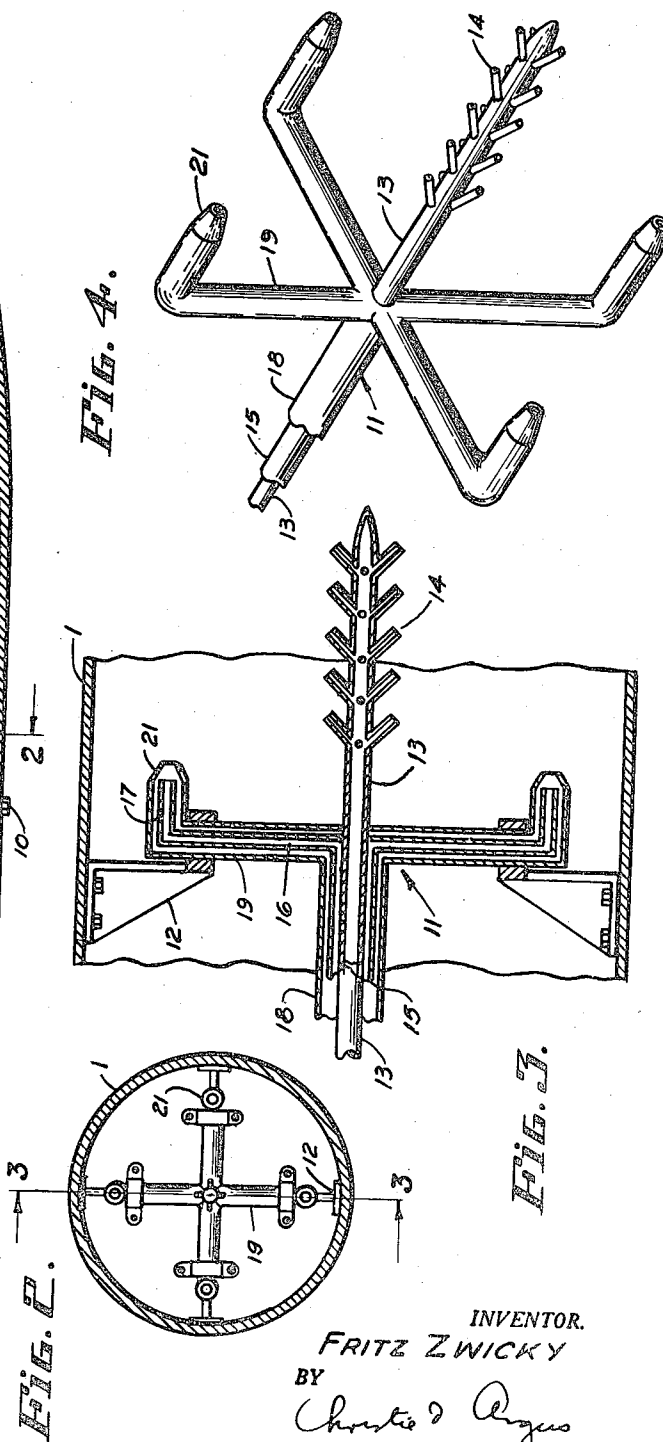


Fig. 2.

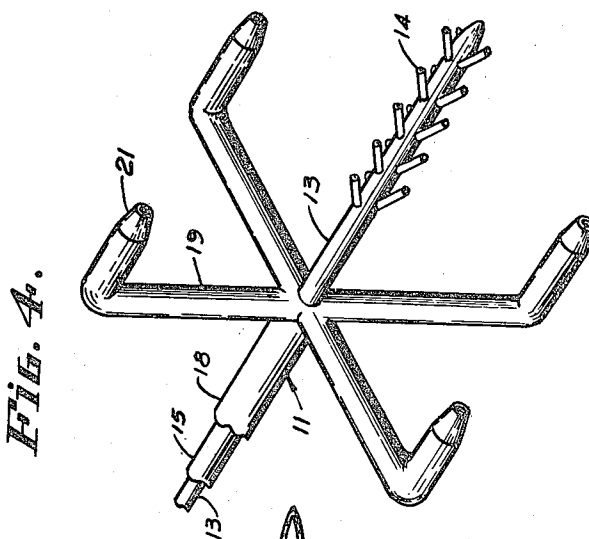


Fig. 3.

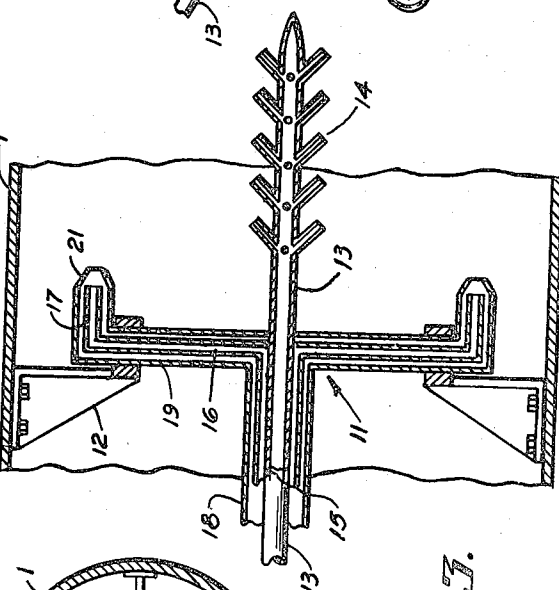


Fig. 4.

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REACTION PROPELLED DEVICE FOR
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This invention relates to propulsion units of the type adapted for propulsion of craft or devices through water, and more particularly to jet propulsion means and methods.

The principal object of this invention is to provide an efficient way of driving reaction propelled devices or craft.

In my copending application, Serial No. 550,693, filed August 23, 1944, I have disclosed and claimed a jet propelled device, adapted to be driven through a fluid medium such as water, in the form of an elongated duct or channel having an entrance at the front through which the fluid from the medium may enter, and an exhaust nozzle at the rear through which it may exit. The chemical reaction between suitable propellants or chemicals injected into the fluid of the medium within the duct produces gases which operate to force the fluid in the duct as well as the products of reaction through the exhaust nozzle at a high velocity. The mechanical reaction of the exhausted mass produces the propulsion. In the operation of the apparatus described in my said prior application in a water medium, the gases formed by the reaction in the duct exist in the duct as a dispersion of gas bubbles in the water.

In accordance with my present invention I obtain improved efficiency of a jet propelled duct in a water medium, by the injection of chemical propellant into the water in the duct. I obtain the improved efficiency by the provision of means for reducing the surface tension of the water film surrounding the individual bubbles created from the chemical reaction, so as to release in the duct energy given up by the expanding bubbles which would otherwise pass out through the exhaust nozzle and become lost. I accomplish this desired result by injecting within the duct a suitable surface tension depressor which has the effect of reducing the surface tension of the film enveloping the gas bubbles.

A feature of my invention is the provision of an injecting system within the duct, arranged to inject the chemical at a desired location in the duct, and a means for injecting a surface tension depressor located in such a manner as to create the surface tension reducing effect at satisfactorily spaced intervals downstream from the region where the reaction has occurred.

The foregoing and other features of my invention will be better understood by the accompanying drawings of which:

Fig. 1 is a longitudinal cross section view showing a device in accordance with this invention;

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Fig. 2 is a transverse cross section view taken on the line 2—2 looking towards the front end of Fig. 1;

Fig. 3 is a cross section view taken on the line 3—3 of Fig. 2 showing the injector system and fastenings;

Fig. 4 is a perspective view of the injector system.

Referring to Fig. 1 I have illustrated a propulsion unit constructed according to my invention, especially adapted for the propulsion of a projectile or craft through water. It comprises an outer shell 1, which may be torpedo-shaped. It has a nose piece 2 and a tailpiece 3 terminating in exhaust nozzle 4 at the rear. The shell is adapted to take in water through the inlet opening or mouth M and expel it through the exhaust nozzle N. The entry portion of the nose piece is preferably trumpet-shaped inside and gradually increases to a maximum diameter in a streamlined curve. It should be understood that this particular shell, while convenient and desirable for good operation, need not be used in every respect, but may be departed from to such extent as particular conditions dictate.

The outer surface of nose piece 2 may be streamlined from the leading edge of inlet opening 5 to the point where injector tubes 6, 7 and 8 enter the shell. Streamlining both inside and outside is desirable to prevent turbulence. For similar reasons the outside of tailpiece 3 is streamlined and the discharge side of nozzle 4 is flared out toward the rear from the throat of jet end. When the propulsion device is installed in a craft, outside streamlining is not necessary, since an outer encasing assembly (not shown) around the shell is the part that should have the outside streamlining. The inside should be, of course, preferably streamlined in any event. For purposes of assembly I prefer to use a slip joint 9 which is secured rigidly by a number of cap screws 10. These sections may alternatively be threaded or screwed together, if desired, instead of being held by cap screws.

There is centrally located within shell 1 a fuel and surface tension depressant injector member 11. This injector member 11 is held in position with respect to shell 1 by streamlined slanting vanes 12 to which the injection system is secured by any suitable means preferably metal clamps. This injection system comprises a longitudinal central surface tension depressant delivery conduit from which exit a series of nozzles 14, installed at an angle rearwardly and pointing in such a manner that the surface tension de-

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pressor is squirted into the assembly in the direction of the exhaust nozzle end.

Surrounding the surface tension depressant conduit 13 is a fuel injection tube 15 through which a propellant slurry may be forced by a suitable pressure means (not shown). This conduit 15 connects with the cross conduits 16 which are terminated by short right angle injectors 17.

Surrounding conduits 13 and 15 is a third conduit 18 to which water under pressure is forced from a suitable source of water supply (not shown). Conduit 18 connects to an outer cross conduit 19 which surrounds cross conduit 16. The ends of cross conduit 19 turn perpendicular and surround injector 17 of the propellant feed conduit. Water under pressure is forced through conduit 18 and discharges through tapered nozzle 21, thereby carrying out with itself the propellant material slurry passing through injector 17. Conduits 13, 15 and 18 are connected respectively to the surface tension depressor, propellant, and water supply sources under pressure by connecting conduits 6, 7 and 8 respectively.

The chemicals used as the propellant or reactant should be substances which react violently with water, are thermally stable, capable of withstanding shock and preferably not spontaneously inflammable. These compounds should preferably be able to withstand grinding and should preferably be noncorrosive. These substances should produce large volumes of gases per unit mass of chemical and should have a high heat of reaction in order to evaporate as much water as possible. It is also desirable that they react instantaneously with water so that all gas will be formed in the region of highest pressure.

Suitable reactants are the alkali metal borohydrides, alkaline earth metal borohydrides, other metal borohydrides, metal hydrides, metal silicides, and borohydrides and metal alloys which combine violently with water giving off gas and heat. I prefer to use such substances as LiBH_4 , $\text{Al}(\text{BH}_4)_3$, LiH , B_2H_6 , or other higher boron hydrides as propellants to generate the required power for propulsion through water, although the operation is not limited to these substances. Other substances which may be used, for example, in place of the above are molten Mg, amalgamated Al, NaH, Na-K alloy, CaH_2 , $\text{Be}(\text{BH}_4)_2$, $\text{Mg}(\text{BH}_4)_2$, NaBH_4 , activated boron and activated silicon. The silicon and boron are activated by alloying them with substances that make them water reactive. These are injected into the water producing gases, heat and steam from the chemical reaction which in turn produce the exhaust jet which through its mechanical reaction generates useful thrust.

Where the propellant is solid a paste may be prepared by incorporating reactant material which has been ground to a size of approximately 100 angstroms in radius and incorporating this powder in substances such as crystal oil, carbon tetrachloride, gasoline or saturated hydrocarbons. The material may be ground to this fineness in a colloid mill or other suitable apparatus. Any carrying medium used must be absolutely free of water. Grinding shall preferably be performed in one of the above mediums in order to prevent hydrolysis or oxidation of the substance.

The propellant may be injected as a slurry and fed through the propellant injector 17 by some suitable pressure means (not shown). The preferred type of propellant substance is one capable of reacting instantaneously with water forming the lowest possible number of hydroxide moles

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and capable of producing the largest volume of water insoluble non-condensable gases at the temperature and pressure existing in the system, per unit weight of reactant. It is preferable that the specific heat of solid reactant be as low as possible. The weight of propellant used is preferably between 1:100 and 1:12,000 of the weight of water admitted.

The following is the manner in which the propulsion unit operates: The propulsion unit must be brought up to speed by some auxiliary means such as a screw propeller or other assisting device (not shown). The faster the speed the greater will become the stagnation pressure which is generated within the propulsion unit. The stagnation pressure is defined as:

$$P_s = P_o + \frac{\rho}{2} u_o^2$$

wherein

η_d = diffuser efficiency from the entrance to the widest diameter of the duct; that is, the ratio of the increase in pressure, at a given velocity, in the region of the widest diameter above the pressure of the surrounding medium to the increase in pressure, at the same velocity in the region of widest diameter above the pressure of the surrounding medium, which would have been attainable if the fluid flow in the conduit had occurred without losses such as friction and turbulence.

P_o = the pressure of the fluid in the outside medium.

ρ = density of the fluid medium.

u_o = velocity of the fluid in the outside medium relative to the propulsion device travelling through it.

Until the pressure in the apparatus just ahead of the fuel injector is sufficiently high to oppose the pressure generated by the reaction between the propellant and water in the injector and apparatus the mixture of water, steam and gas will not discharge completely through the nozzle. When the desired speed is reached some suitable injecting means (not shown) is started into operation and the propellant is fed into the duct 15 as a continuous stream through injector 17. The injected propellant reacts when coming in contact with the water in injector pipe 18 and in duct 19 and generates heat and large volumes of gas and steam under pressure. To reduce losses due to irreversible processes it is desired to have the gas dispersed as an emulsion of fine bubbles throughout the water in the region of highest stagnation pressure. If, however, the process were permitted to proceed without interference the gases would remain finely dispersed in the water and would not have the opportunity of completely expanding. To overcome this difficulty the surface tension depressant injectors 14 squirt a small amount of wetting agent into the water stream at a point downstream from that at which the propellant is injected, thereby lowering the surface tension of the water and permitting the uniform expansion of the minute gas bubbles as the pressure decreases from the high internal pressure of the small bubbles to approximately that of the surrounding medium. Small gas bubbles are necessary to produce the original internal pressure as is seen by the equation:

(1)

(1)

$$P_o = P_s + \frac{2\sigma}{r}$$

in which

P_{0i} = the initial internal pressure of the bubbles above the stagnation pressure.

P_s = the stagnation pressure.

σ = the surface tension of the liquid, and

r = radius of the bubble.

Small bubbles, however, have the disadvantage that if a surface tension remains high the gas within the bubble will not expand to its fullest extent and the bubble will remain confined throughout the operation and exhausts through the nozzle as small gas bubbles. If this occurs much of the energy of expansion is wasted through the nozzle. The internal pressure of the bubble as it exhausts into the outside medium is given by the equation:

$$(2) \quad P_{0i} = p_0 + 2\sigma/r'$$

where

P_{0i} = the final internal pressure in the bubble as it is discharged into the outer medium.

p_0 = pressure in the outer medium.

σ = the surface tension of the water.

r' = final radius of the bubble.

Small bubbles are necessary to insure a high expansion ratio and these produce high thermodynamic efficiency if the surface tension of the bubble film is caused to drop shortly after the bubble has formed. The expanded bubbles, having a low surface tension film, have the additional advantage of being less apt to coalesce at the end of their expansion, in this manner avoiding the possibility of cavitation, which is detrimental to the smooth functioning of the duct. To permit full expansion it is obvious that σ must be decreased as much as possible during the process of expansion in the duct. This is accomplished almost reversibly and involves a minute loss of the energy of expansion if the surface tension lowering agent is introduced gradually, starting at some point downstream from the region in which the propellant is injected and the reaction with the water takes place. Such surface tension lowering agents include soaps, sulfated fatty alcohols, sulfated fatty acid esters, sodium oleate, dialkyl esters of sodium sulfosuccinic acid (aerosols), saponin, and other similar substances which are capable of decreasing the surface tension of the liquid from 72 dynes/cm. for pure water to as low as 20 dynes/cm. upon the addition of a small percent of a surface tension lowering agent. A suitable ratio of the surface tension lowering agent to the weight of propellant used is about 1:1000 parts by weight. To insure the maximum pressure in the gas bubble at the time of its formation during the chemical reaction which occurs in the stagnation region of the duct, it is evident from Equation 1 that the surface tension must be initially as high as possible and the diameter of the gas bubble created must be as low as possible. Gas bubbles having a radius between 100 and 10,000 angstroms are satisfactory. These may be obtained by grinding the solid material in a colloid mill as described above, thereby insuring small particles. Again it is seen from Equation 2 that to reduce the final internal pressure in the bubble to a minimum, the surface tension must be made as low as possible, while the radius of the expanded bubble r' must be permitted to increase to its largest possible size for the given pressure within the system in order to insure a full expansion of the gas.

The bubbles formed act as storage reservoirs

which absorb a portion of the energy through compression. This energy is later utilized when it is released during the exhaust stages thus tending to equalize the exhaust velocity of the stream leaving the duct. For desirable operation this exhaust velocity should be maintained as uniform as possible throughout the cycle.

My invention has the advantages, either in the valveless type of duct arrangement illustrated in Fig. 1 wherein no water inlet valve is provided between the mouth 5 and the injector, or in the type of duct having such a water inlet valve, as illustrated in my said copending application, Serial No. 550,693, filed August 23, 1944. The arrangement is especially advantageous with the valveless type of duct as illustrated in the present application wherein the expansive force of the chemical reaction operates against the stagnation pressure due to the water at the entrance, rather than against a closed water inlet valve. The reason for this is that a given amount of propulsion force is obtainable by the use of my present invention at a lower pressure within the duct than when my invention is not used. In consequence, by the use of my invention I can propel the valveless duct device at a lower speed through the water than otherwise, as the very high speed necessary to create a large stagnation pressure is not necessary.

By means such as described in this invention it is apparent that I have provided a simple apparatus for efficiently utilizing a substantial portion of the available energy generated by the reaction between the propellant and the water.

I claim:

1. A reaction propelled device for propulsion through water comprising an elongated passageway having an inlet opening and an exhaust nozzle through which water flows, a propellant injector comprising a propellant conduit opening into said passageway, means for placing propellant in said conduit under pressure to force it into said passageway, a water conduit surrounding said propellant conduit, means for forcing water under pressure through said conduit and into said passageway, a surface tension depressant conduit situated downstream from the region into which said propellant is discharged, injecting means for injecting from the surface tension depressant conduit into the passageway and means for feeding surface tension depressor under pressure into said surface tension depressant conduit.

2. A reaction propelled device for propulsion through water comprising an elongated passageway having an inlet opening and an exhaust nozzle through which water flows, a propellant injector opening into said passageway, comprising a plurality of water and propellant injectors and a centrally located surface tension depressant injector having a plurality of outlets and running lengthwise of the passageway.

3. A reaction propelled device for propulsion through water comprising an elongated passageway having an inlet opening and an exhaust nozzle through which water flows, a propellant injector opening into said passageway having four propellant and water injectors spacially distributed throughout the cross section and a centrally located surface tension depressant injector having a plurality of orifices running lengthwise through the passageway.

4. The method of propelling through water a device having a duct open at both ends to permit the passage of water through it from the sur-

rounding medium, which comprises admitting water from the surrounding medium into the duct at one end and introducing within the duct a water reactive propellant to react with the water at a region within said duct, injecting into the water at the downstream side of the reaction region a surface tension depressor and discharging water and gases at higher velocity through said exhaust opening.

5. The method of propelling through water a device having a duct open at both ends to permit the passage of water through it from the surrounding medium, which comprises admitting water from the surrounding medium into the duct at one end and introducing within the duct an amount of propellant to react with the water at a region within the duct and which does not exceed $1/100$ of the weight of the admitted water, injecting into the water at the downstream side of the reaction region a surface tension depressor and discharging the water and gases and steam through said exhaust opening.

6. The method of propelling through water a device having a duct open at both ends to permit the passage of water through it from the surrounding medium, which comprises admitting water from the surrounding medium into the duct at one end and introducing within the duct a mass of water reactive propellant to react with the water at a region within the duct and which is between $1/100$ and $1/12,000$ of the weight of the admitted water, injecting into the water at the downstream side of the reaction region a surface tension depressant and discharging the water, gases and steam through said exhaust opening.

7. A method of propelling through water a device having a duct open at both ends to permit the passage of water through it from the surrounding medium, comprising admitting water from the surrounding medium into one end of the duct, introducing a metal borohydride into the duct to react with the water at a region within the duct, and injecting into the water and downstream from said reaction region a surface tension depressant in the proportion of 1:100 to 1:1000 by weight of the propellant used.

8. A method of propelling through water a device having a duct open at both ends to permit the passage of water through it from the surrounding medium, comprising admitting water from the surrounding medium into one end of the duct, introducing a metal borohydride into the duct to react with the water at a region within the duct, and injecting into the water and downstream from said reaction region a surface tension depressant in the proportion of 1:1000 by weight of the propellant used.

9. A method of propelling through water a de-

vice having a duct open at both ends to permit the passage of water through it from the surrounding medium, comprising admitting water from the surrounding medium into one end of the duct, introducing a metal borohydride into the duct to react with the water at a region within the duct, and injecting into the water and downstream from said reaction region sodium oleate in the proportion of 1:100 to 1:1000 by weight of the propellant used.

10. A method of propelling through water a device having a duct open at both ends to permit the passage of water through it from the surrounding medium, comprising admitting water from the surrounding medium into one end of the duct, introducing a boron hydride into the duct to react with the water at a region within the duct, and injecting into the water and downstream from said reaction region a soap in the proportion of 1:100 to 1:1000 by weight of the propellant used.

11. A method of propelling through water a device having a duct open at both ends to permit the passage of water through it from the surrounding medium, comprising admitting water from the surrounding medium into one end of the duct, introducing an alkali metal borohydride into the duct to react with the water at a region within the duct, and injecting into the water and downstream from said reaction region a sulfated fatty acid ester in the proportion of 1:100 to 1:1000 by weight of the propellant used.

12. The method of propelling through water a device having a duct open at both ends to permit the passage of water through it from the surrounding medium, which comprises admitting water from the surrounding medium into the duct at one end, introducing lithium borohydride to react with the water at a region within the duct, and injecting into the water and downstream from said reaction region sodium oleate in the proportion of 1:100 to 1:1000 of the weight of propellant used.

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