Jan. 14, 1964 W. K. FORTMAN ETAL 3,117,551

LIQUID FUEL PROPELLANT

Filed Aug. 12, 1960 2 Sheets-Sheet 1

FIG. 1.

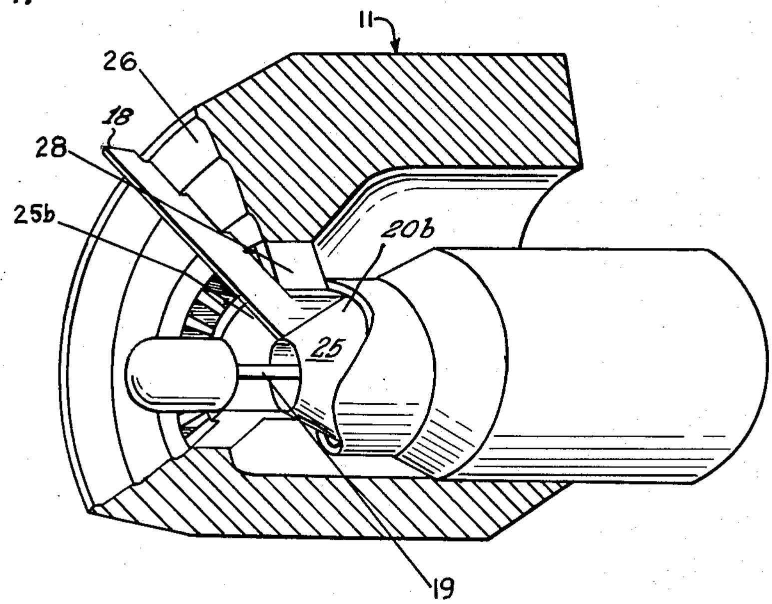
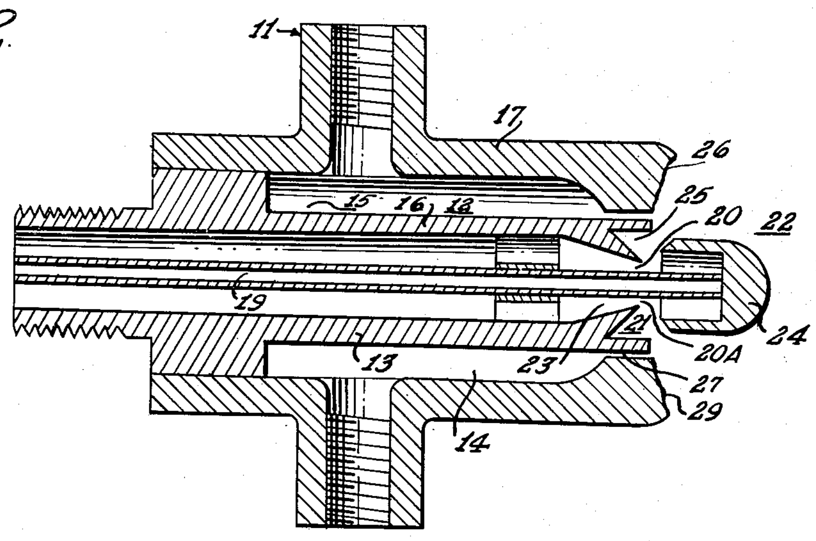


FIG. 2.



INVENTORS
WILLIAM K. FORTMAN
NATHANIEL HUGHES
BY Andrew L. Bain
George B. Oujevolk
ATTORNEYS

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Filed Aug. 12, 1960 2 Sheets-Sheet 2

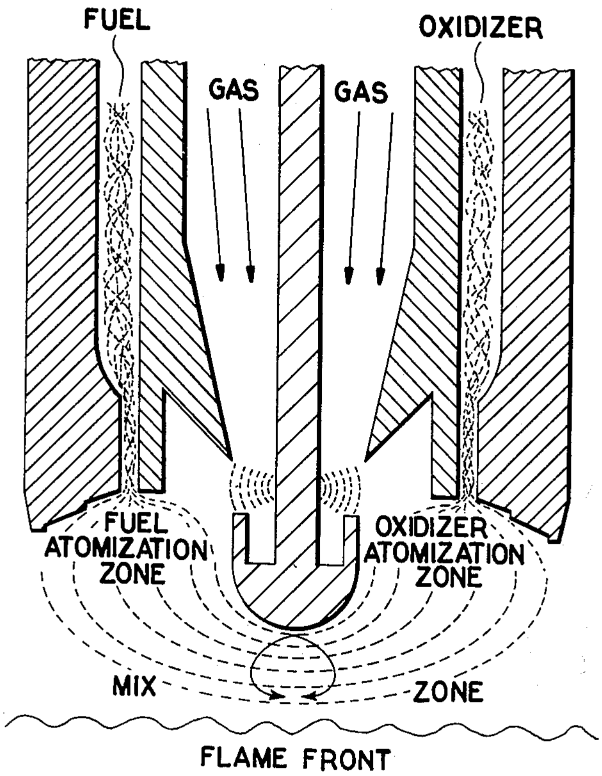

FIG. 3

WILLIAM K. FORTMAN
NATHANIEL HUGHES
INVENTORS.

BY S. A. Giarratana
George B. Oujevolk
ATTORNEYS

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3,117,551
LIQUID FUEL PROPELLANT

William K. Fortman, Metuchen, N.J., and Nathaniel Hughes, New York, N.Y., assignors to General Precision Inc., Little Falls, N.J., a corporation of Delaware

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The present invention relates to the generation and utilization of audible and ultrasonic waves, and more particularly to an acoustic generator for the generation of audible and ultrasonic waves and shock waves as well as using these phenomena in a controlled manner in conjunction with one or more fluid mediums in a treating or reaction zone, e.g., a combustion zone.

It is well known that ultrasonic waves in the audible or ultrasonic range have many applications, mainly in gaseous state or in media containing suspensions of fluid or solid aerosols. Other applications exist in flame vibration in combustion studies where the aim is increased thermal efficiency. Work has also been done in the field of signalling, metallurgy, foam breaking and various chemical effects.

Some of the first ultrasonic generators based on the air jet principle were suggested by J. Hartmann (20 Phys. Rev. 719–727, 1922). These generators consist of a jet opposed coaxially by a resonator. When an air jet exceeding the speed of sound is forced through the nozzle and a cavity resonator is placed within one of the so-called intervals of instability, a harmonic vibration corresponding approximately with the natural vibrations of the resonator are produced.

In about 1947, Hartmann developed a stem generator which basically consists of a nozzle and a resonator which are coupled coaxially by a central stem. Studies of this type of generator showed that an air jet velocity below the speed of sound could produce sound waves. In this way it differs considerably from the earlier generators which find their explanation in the structure of a supersonic jet.

The Yellot and Savory U.S. Patent No. 2,519,619 made some novel improvements on the Hartmann generator by adding a stem protruding from the resonator towards the nozzle. This patent also teaches the use of regenerator pads and regenerator cylinders which, according to the patent, provides improved sound generation and the sensitivity of the generator to adjustment is lessened. In this type of generator, the nozzle and the resonator are clamped or screwed into a frame permitting adjustment of the gap between nozzle and resonators.

In another version of the Hartmann whistle generators, Dr. R. M. G. Boucher has constructed an independent secondary resonance chamber into which the nozzle and resonator are fitted coaxially opposed. The entire base is then surmounted by an exponential horn for directional sound emission. The ratio of resonator to nozzle is from 1.33 to 2.5 and higher efficiencies than any previously reported are claimed for this device.

In most applications where sound is air coupled to the material to be treated, it is desirable to bring the material close to the sound energy source as it is desirable to treat a maximum amount of material in the shortest amount of time. Generally all processes are dynamic and involve movement of one sort or another. Even in batch processes, the material undergoing a chemical or other reaction is stirred or aerated. Whether the material is gas, liquid or free flowing powder or a mixture of some or all of these, almost without exception it is desirable to keep exposing new interfaces. This is specially true in the treatment of solids and liquids and gases with sharp temperature gradients such as flames because a considerable impedance mismatch is encountered by the sound wave at each interface and boundary.

2

This is normally achieved by stirring, tumbling, aerating or by some other external energy source which moves the material towards and past the sound source. However, even under ideal conditions the moving mass is usually influenced by the excess driving gas being discharged at random from the sound generator.

In the prior art devices hereinbefore described, little attempt has been made to co-relate the fluid supply means and the sound generator, e.g., whistle. Much energy is lost by allowing the fluid to dissipate at random after its release from the resonator cavity. It has now been discovered that one or a plurality of fluid mediums can be supplied directly towards, to, and past the sound source. Heretofore, inducing sonic vibrations in flames has always presented problems due to the flame layer temperature gradients which present sound impedance barriers to an external sound source. Contrary to the prior art devices, the present invention contemplates generating the sound in an active reaction zone, e.g., within the flame envelope. Where flames are in laminar layers above a disintegrating solid charge, there is contemplated the sending of a shock wave between the burning zone and the flame to cause a quicker gas release, turbulance and physical disturbance to increase the reaction rate, e.g., the burning rate. At the same time, additional fluids, liquid and gas are introduced into the sound source zone. The molecular interaction of the reacting particles in the reaction zone is then increased by passing the particles from the sound source zone past an acoustic treating zone, the geometric configuration of the combined sound source zone and acoustic treating zone being such as to not only impel the fluid particles into the reaction zone, but the sound vibrations impart very high velocities to the molecules of the reacting components in the reaction zone to increase the activity therein.

The invention in its broader aspects contemplates feeding into a sound source zone one or more fluids required for a desired reaction, e.g., combustion; generating in said sound source zone a sound of high intensity, so directed and controlled as to carry said fluids into an acoustic treating zone of a geometric configuration designed to loosen the bonds between individual fluid particles and direct said particles into a reaction zone, e.g., combustion chamber; at the same time, said acoustic treating zone beams the sound waves from the sound source zone into the reaction zone causing a sound therein of an intensity sufficient to cause intense molecular activity therein.

Thus, it is an object of the present invention to provide means for treating one or a plurality of fluids by sound means.

Another object of the present invention is to provide means to accomplish an efficient bi-propellant injection into an engine combustion chamber.

The invention also contemplates providing propellant injection means which are particularly useful for rocket engines.

With the foregoing and other objects in view, the invention resides in the novel arrangement and combination of parts and in the details of construction hereinafter described and claimed, it being understood that changes in the precise embodiment of the invention herein disclosed may be made within the scope of what is claimed without departing from the spirit of the invention.

Other objects and advantages will become apparent from the following description taken in conjunction with the accompanying drawing in which:

FIGURE 1 is a perspective view of a sound source zone and a portion of an acoustic treating zone contemplated herein showing a portion of a nozzle and a section cut through the surrounding casing to illustrate the disposition of the nozzle in the casing;

FIGURE 2 shows a longitudinal sectional view of one embodiment of FIG. 1; and,

FIGURE 3 depicts diagramatically what takes place in another type of acoustic treating zone, the device illustrated being a modification of the generic device herein contemplated.

Generally speaking, the present invention contemplates the combination of a fluid feed nozzle having a plurality of narrow neck feeding orifices discharging into a sound source zone, i.e., where said nozzle spouts, in which there is a stem passing through the jet nozzle, said stem being preferably hollow and adapted to bring additional fluid to the sound source zone or pass through said zone into a reaction zone, e.g., combustion chamber. Associated with the sound source zone is an acoustic treating zone including a sound wave radiator having a shock ridge surrounding the sound source, a resonator facing the radiator, and advantageously, a secondary resonance chamber interposed between the feeding orifices and the stem axially opposed to the resonator. The geometric configuration of the sound source zone and the acoutic treating zone is such as to conduct the fluid from the sound source zone into the acoustic treating zone while treating the fluid particles at a sound intensity sufficient to convert or maintain the fluid in the gas or aerosol phase. In the acoustic treating zone the action of the sound shock waves therein created acting on the fluid impart great velocity to the individual molecules of the fluid which is then passed into the reaction zone.

In carrying out the foregoing concept into practice the apparatus of FIGS. 1 and 2 herein contemplated has a feeding zone 12 contained in a jet nozzle 13. The feeding zone which is for feeding one or more fluids to the sound source zone is subdivided into a plurality of longitudinal outer ducts or feeding compartments 14 and 15 which are disposed between body jacket 16 and casing 17 of the nozzle. Although in the drawing only two such duct compartments 14 and 15 are depicted, many more such ducts can be provided by radial dividing walls. Furthermore, the cross sectional area of these ducts need not necessarily be the same. Indeed, they can be so sized as to furnish different fluids into the sound source zone in various proportions. Passing through the longitudinal center of the nozzle is a stem 19 which is preferably hollow and through which a second phase fluid can be introduced at any desired central position in a sound source zone 20, an acoustic treating zone 21 or a reaction zone 22. The second phase fluid may be of a characteristic completely different than the fluids passing through the outer feeding compartments 14 and 15 or causing the sound. In fact, the fluid passing through the hollow stem may even be an inert or noble gas. If the reaction zone already contains or has fed to it from outside sources a highway reactive material, e.g., a solid propellant, the presence of an inert gas at the sound source and in the adjacent acoustic treating zone may tend to retard any reaction in these two zones by the fluids fed thereto until these are carried into the reaction zone where the reaction is desired. It is also possible to circulate a cooling fluid through the stem. The sound forming gas is supplied by means of a compartment 23 surrounding the stem, to the sound source zone 20. This gas may also be of the kind required for a desired reaction, e.g., a fuel or oxidizer. Axially opposed to the spouting whistle mouth 20*a* which provides the sound is a resonator 24 which is a hollow cup having a U-shaped cross section. Surrounding the spouting mouth 20*a* is a cylindrical wall 25*b* which together with outer wall 20*b* of spouting mouth 20*a* defines a second resonance chamber 25, and machined in the face of casing 17 is a concave radiator 26, outer feeding ducts 14 and 15 discharging their fluid under pressure in the sound zone through narrow necks 27 located between the second resonance chamber 25 and radiator 26. The size of the gap at the narrow neck 27 will be to a large extent determined a rocket engine thrust.

To impart swirl to the discharge fluid, vanes 28 are disposed at or past the narrow neck 27, depending from the radiator. These vanes help separate fluid particles and impart greater activity.

These vanes 28 are shown in FIGURE 1 but purposely omitted from FIGURE 2 and FIGURE 3 to show other constructional features of the device.

One feature of the invention which appears to further break up the fluid and increase the molecular activity are a plurality of shock ridges 29 on the face of the concave radiator. As illustrated in the drawing, the face of the radiator is not a smooth curve but has a plurality of well defined circular indentations, i.e., shock ridges around the entire face of the radiator. These shock ridges 29 appear to play an important part in the activity taking place in the acoustic treating zone. The device shown in FIGURE 2 is readily coupled to a source of air used for producing the sound by means of threads 30 on the input side of casing 17. Fluid is introduced to the feeding compartments 14 and 15 through the threaded input sections 31 and 31*a*. Lines for carrying these fluids are coupled to these threaded sections.

As illustrated in FIGURE 3, the device contemplated herein is particularly useful for supplying of a fuel oxidizer mixture to a combustion zone. In FIGURE 3 the fuel and oxidizer are both introduced from the outer ducts or feeding compartments. The particular method of introducing the oxidizer and fuel depends to a large extent on the characteristics of these combustion intermediates.

In the design of a whistle assembly useful as the propellant injection means for rocket engines, use is made of standard tables and formulas such as are found in Mechanical Engineers Handbook 5th ed. pp. 337–338. These tables and formulas are only a guide however and resort must be had to trial and error. The device contemplated herein when properly sized can be used for a thrust of between 100 lbs. to 150 lbs. for hydrazine fuel and a chlorine trifluoride oxidizer. In this case there is an oxidizer to fuel ratio of three to one. The whistle shown in FIGURE 3 of the drawing can deliver 158 db sound at a distance of ten inches from the sound source at 42 pounds pressure at a frequency of 12,000 cycles per second.

The effect of using a whistle assembly of the type described herein as an injection head instead of the conventional injection heads as depicted by Barcel Barrere et al. in "Rocket Propulsion," Elsevier Publishing Co. 1960 (D. Van Nostrand Co. distributors) pages 383 to 390, is the fact that the sound source keeps the flame front back as shown in FIGURE 3. In the conventional showerhead type of injector, the size of the aerosol is limited by the size of the showerhead apertures. In the injector described herein, the aerosol size is limited solely by the dynamic factors in the acoustic treating zone. A whistle having a length of 4.120 inches and a diameter of 1.125 inches has a pressure drop of 10.75 p.s.i.g., and a flow rate of about 0.5 lb./sec. for a throat of .020 inch to deliver a thrust of about 125 lbs. using chlorine trifluoride and hydrazine as the propellant combination. The thrust may be increased by adjusting the throat dimensions.

It is to be observed therefore that the present invention provides for an apparatus 11 for subjecting a fluid medium to the treatment of sound waves. This apparatus comprises in combination; a feeding zone 12 including a nozzle 13, a jacket 16 defining said nozzle body, a casing 17 surrounding said jacket, the space between the said jacket and casing defining an outer duct 14, and a stem 19 passing through the center of said nozzle; a sound source zone 20 where the nozzle spouts and where the sound producing gas in said nozzle is forced through from a compartment 23 around said stem to give out a sound of high intensity; and, an acoustic treating zone **21** including a first resonator **24** coaxially opposed to said sound source zone **20**, a concave radiator **26** having shock ridges **29** thereon surrounding said sound source and said outer duct **14**, and a second resonance chamber **25** interposed between said radiator and said outer duct. There may be a plurality of outer ducts **15** divided by walls **18** and the cross sectional area of said ducts need not be uniform. Stem **19** is preferably hollow.

Furthermore, it is to be observed that as used herein, the terms "sound" and "whistle" include ultrasonic sounds or devices which produce no audible sound.

The present joint invention as set forth in this patent application is a continuation-in-part of the sole Fortmann U.S. patent application Serial No. 14,304, filed on March 11, 1960.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention as those skilled in the art will readily understand. Such modifications and variations are considered to be within the perview and scope of the invention and appended claims.

We claim:

1. In an apparatus for subjecting a fluid medium to treatment by sound waves, in combination;
   - a cylindrical jacket defining a nozzle;
   - a spouting mouth at one end of said nozzle so formed that a gas fluid can be forced through said nozzle and out of said mouth into a zone in the vicinity of said mouth;
   - a cylindrical casing surrounding said jacket, the space between said casing and jacket defining at least one outer duct with an opening at said one end so that a second fluid can be delivered into said zone through said opening;
   - a stem mounted in said nozzle so as to pass axially through said nozzle and mouth; and,
   - a cylindrical hollow resonator having one closed end and one open end, said stem passing axially through said resonator open end to said closed end, said resonator being mounted on said stem at said closed end, said open end being axially opposed to said mouth, so that when a gas is forced out of said mouth into said zone a sound of high intensity is there created.

2. A device as claimed in claim 1, including a concave radiator in said casing surrounding said mouth having a plurality of circular shock ridges thereon.

3. A device as claimed in claim 2, including a plurality of vanes in said outer duct disposed at said opening over said mouth between said jacket and casing.

4. A device as claimed in claim 3, including a secondary resonance chamber in said jacket surrounding said spouting mouth formed by a cylindrical wall surrounding said spouting mouth and an outer wall of said mouth.

5. A device as claimed in claim 4, said stem being hollow so as to deliver a third fluid past said spouting mouth.

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