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Hall et al.

[11] **3,708,121**

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[54] **APPARATUS FOR FORMING PULSE JETS OF LIQUID**

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[73] Assignee: **Exotech Incorporated**, Gaithersburg, Md.

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[21] Appl. No.: **135,120**

[52] **U.S. Cl.** **239/102**

[51] **Int. Cl.** **B05b 3/14**

[58] **Field of Search** 239/99, 101, 102, 329, 456, 239/533, 570, 571

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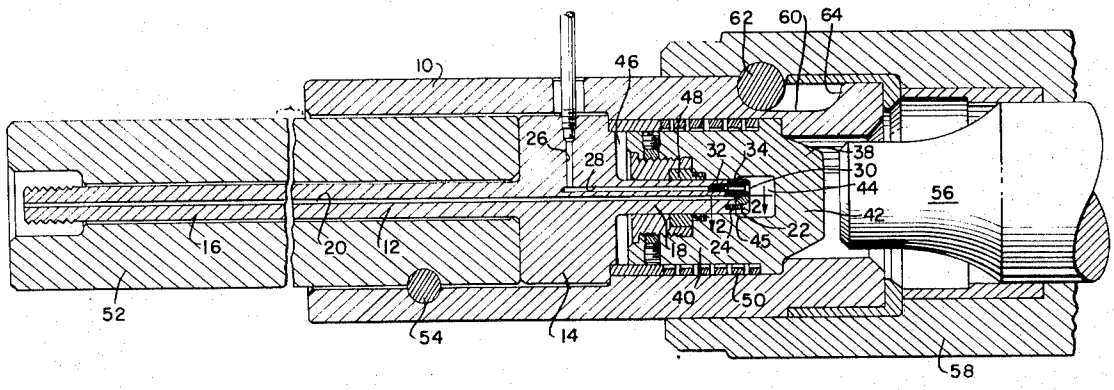
[57] **ABSTRACT**

Apparatus for forming pulsed jets of liquid. A pressure cylinder cooperates with a barrel inlet end to define a charge chamber. With the pressure cylinder in its normal position, the barrel inlet opening is blocked. Upon actuation of the device, the pressure cylinder is forced toward the barrel inlet end, applying pressure to charge material within the charge chamber, until the barrel outlet opening is unblocked and the pressurized charge material is expelled through the barrel as a pulsed jet.

7 Claims, 12 Drawing Figures



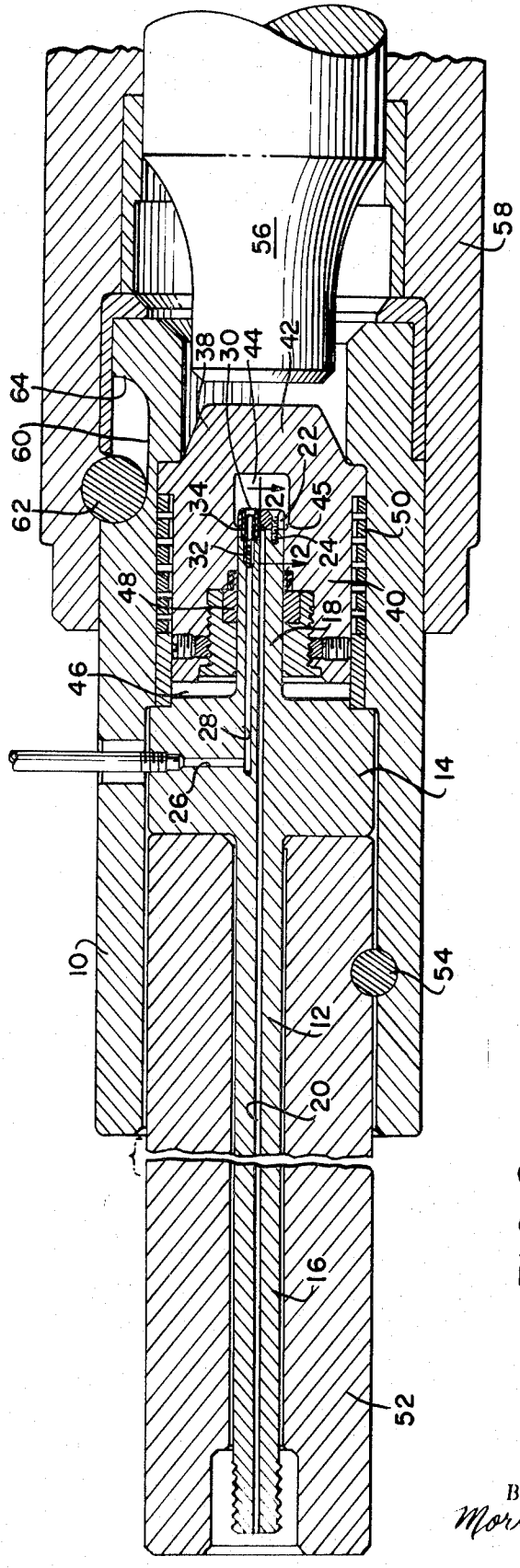


FIG. 1.

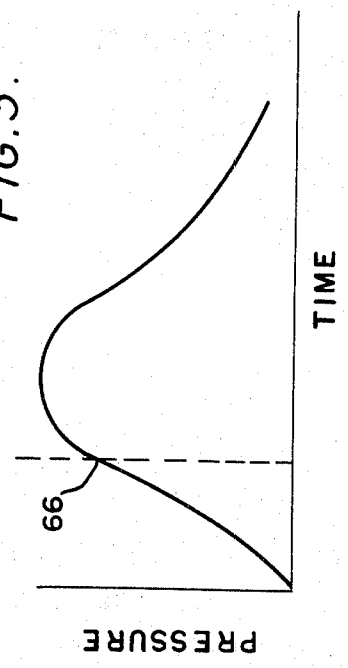


FIG. 3.

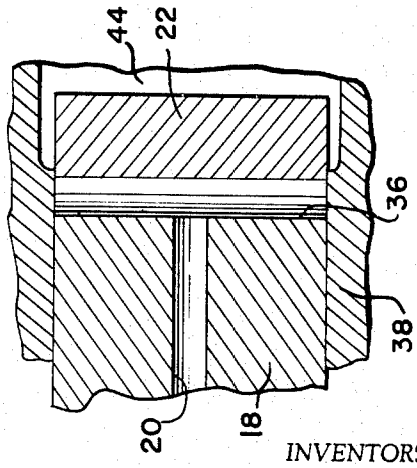


FIG. 2.

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FIG. 4a.

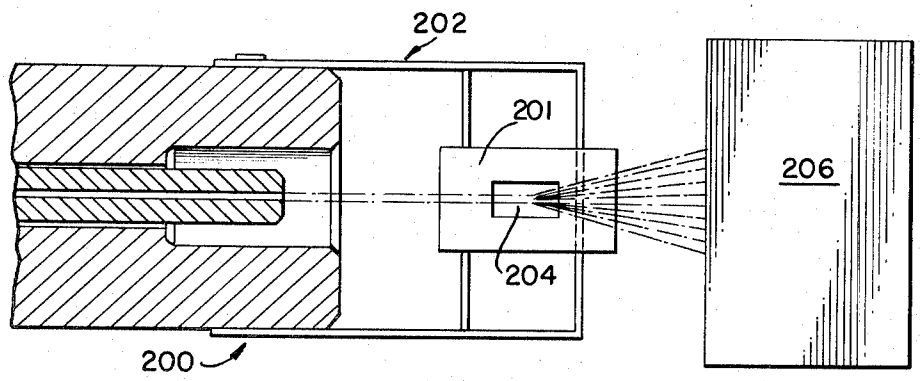

FIG. 4b.

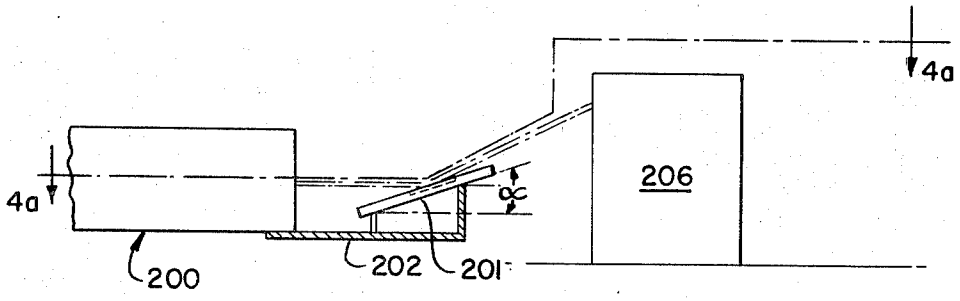

FIG. 5a.

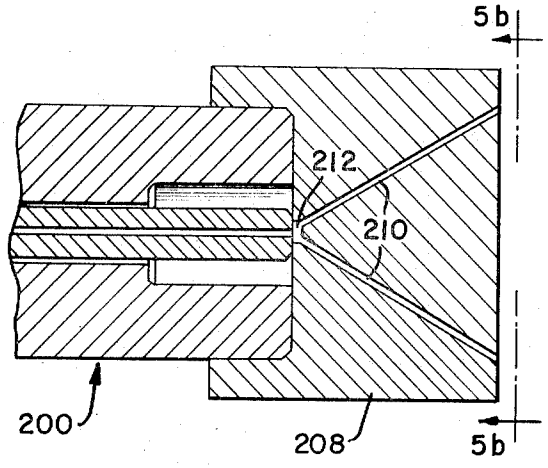

FIG. 5b.

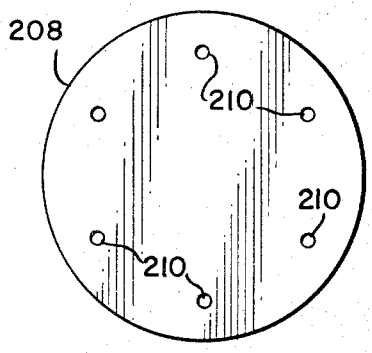

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FIG. 6b.

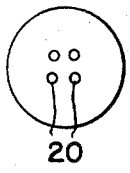


FIG. 6a.

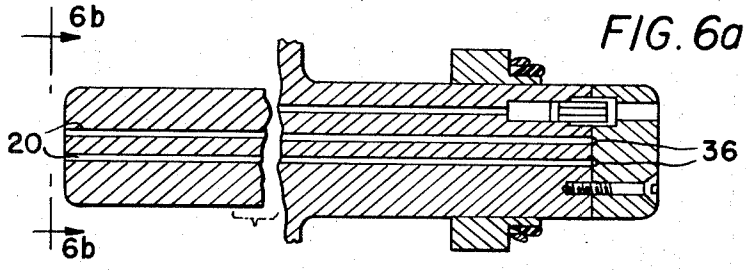


FIG. 7.

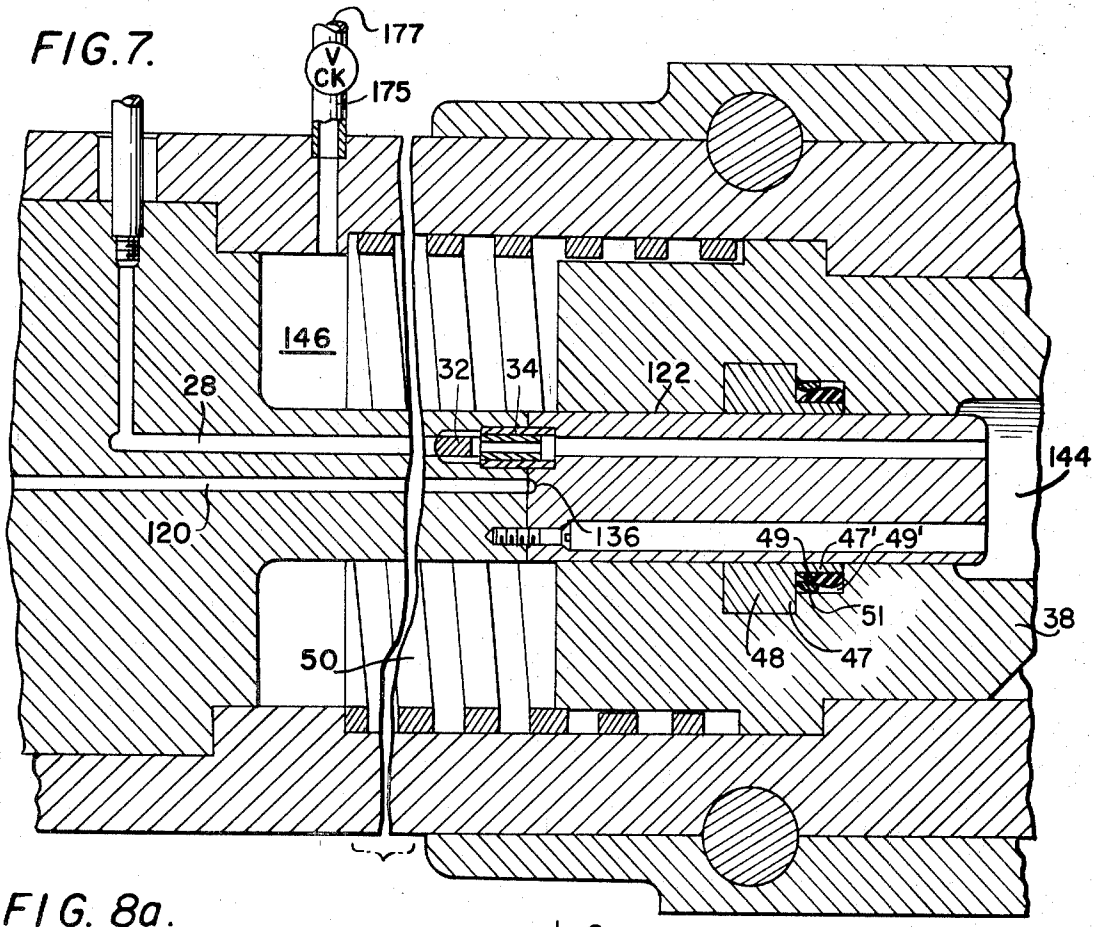
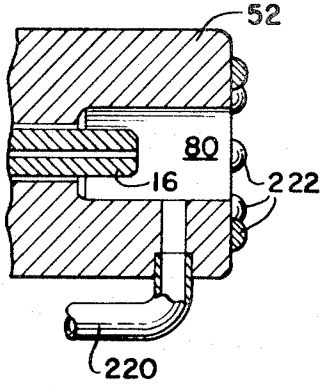


FIG. 8a.



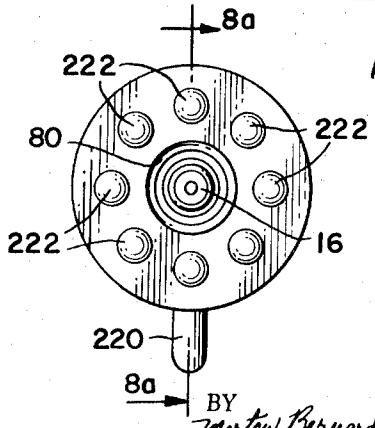


FIG. 8b.

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APPARATUS FOR FORMING JETS OF LIQUID

The present invention pertains to apparatus for forming pulsed jets of liquid. More particularly, the present invention pertains to apparatus for forming high pressure, high velocity pulsed jets of liquid suitable for such operations as fracturing rock.

Pulsed jets of liquid are useful for such operations as cutting metal and fracturing rock. Pulsed jets can be generated by several means. Cumulation and shaped charge techniques have been used, but the expense and hazard associated with explosive materials have limited their use. Piston expulsion of liquid is utilized in apparatus in which a piston is actuated to contact a liquid charge, expelling the charge from the apparatus at a high velocity and pressure. Such apparatus known heretofore have required considerable energy to create the necessary high velocity and pressure in the liquid jet.

The present invention is directed to an apparatus for generating pulsed jets of liquid in which a piston is actuated to move a pressure cylinder from its rest position in which the liquid outlet is blocked to a second position in which the liquid outlet is opened, permitting the liquid to discharge. During the time the cylinder is moving, pressure is built up on the liquid charge material, and when this pressure reaches the desired level, the outlet is opened to discharge the pulsed liquid jet at the desired velocity and pressure. As a consequence, the desired velocity and pressure are obtained with minimum expenditure of energy. Pressures of 300,000 to 500,000 p.s.i. are obtained with the present invention.

These and other aspects and advantages of the present invention are more apparent in the following detailed description and claims, particularly when considered in conjunction with the accompanying drawings in which like parts bear like reference numerals. In the drawings:

FIG. **1** is a fragmentary sectional view of apparatus in accordance with the present invention;

FIG. **2** is a fragmentary view taken along line **2-2** of FIG. **1**;

FIG. **3** is a pressure-time diagram of the charge material within the apparatus as the apparatus is actuated.

FIGS. **4**(a) and **4**(b) illustrate the use of a deflection plate with apparatus in accordance with the present invention;

FIGS. **5**(a) and **5**(b) illustrate an alternative means for deflecting the jet produced by apparatus of this invention;

FIGS. **6**(a) and **6**(b) illustrate apparatus of this invention designed to produce multiple jets;

FIG. **7** illustrates apparatus of this invention including means for flushing the jet nozzle to prevent plugging; and

FIGS. **8**(a) and **8**(b) illustrates apparatus of this invention designed for underwater use.

As depicted in FIG. **1**, a preferred embodiment of apparatus in accordance with the present invention includes an elongated cylindrical housing **10** having an elongated barrel **12** positioned within it. Barrel **12** includes a middle portion **14** of an enlarged diameter which fits snugly within housing **10**, an elongated forward portion **16** of a relatively small diameter, and a rear portion **18** also of a small diameter substantially the same diameter as that of forward portion **16**. Axial bore **20** passes through barrel **12** and serves as an acceleration path for pulsed jets of liquid. Preferably, bore **20** tapers from a larger diameter in rear portion **18** to a smaller diameter in forward portion **16** so that as liquid charge travels through bore **20** the charge velocity and pressure increase. End cap **22** is fastened to the rearward end of barrel **12**, for example, by means of bolt **24**.

A radial bore **26** passes through housing **10** and into central portion **14** of barrel **12**. Within central portion **14** radial bore **26** intersects longitudinal bore **28** which passes through rear portion **18** of barrel **12** and communicates with bore **30** through end cap **22**. For a small distance within barrel **12** and cap **22** and adjacent the interface of those two components bore **28** and **30** have a slightly increased diameter within which is positioned check valve **32**. Bushing **34** retains check valve **32** in this area. Bore **20** does not pass longitudinally through cap **22**, but instead, as seen in FIG. **2**, at the intersection of barrel **12** and cap **22**, bore **20** intersects with radial bore **36** that passes completely through cap **22**.

Pressure cylinder **38** includes a forward portion **40**, encircling rearward portion **18** of barrel **12**, and a rearward portion **42** enclosing cap **22** but leaving a small chamber **44** to the rear of cap **22**. Chamber **44** has a diameter slightly greater than the diameter of cap **22** and barrel rearward portion **18**. This increased diameter extends forward about cap **22** to a point about at the longitudinal midpoint of cap **22** at which location chamber **44** ends and pressure cylinder **38** contacts cap **22** at circumference **45**, usually through an intermediate layer of fluid. Pressure cylinder **38** does not contact central portion **14** of barrel **12** but instead a small chamber **46** is present between pressure cylinder **38** and central portion **14**. Preferably, chamber **46** has a longitudinal dimension slightly smaller than the longitudinal dimension of chamber **44** to avoid direct contact at cap **22**. Thus, pressure cylinder **38** is able to move from its rearward position, as depicted in FIG. **1**, to a forward position in which forward portion **40** of pressure cylinder **38** contacts central portion **14** of barrel **12** before rearward portion **42** can contact cap **22**. Pressure cylinder **38** is biased to its rearward position as depicted in FIG. **1** by means such as spring **50** which is engaged between housing **10** and pressure cylinder **38**. Seal **48** is positioned between rearward portion **18** of barrel **12** and forward portion **40** of pressure cylinder **38** to provide a substantially fluid-tight seal. Seal **48** comprises a rigid, non-resilient member **47**, such as metal, which sealingly engages portion **18**, a resilient member **49** and a chamfer ring **51**. Member **47** has a lip **47'** and resilient member **49** rests on this lip so that it does not engage portion **18**. In use, pressure is exerted upon member **49** by fluid in the interface between portion **18** and portion **40** which passes through gap **49'** and, as a consequence, resilient member **49** exerts a force on member **47**, particularly lip **47'**, to seal member **47** against portion **18**. Camfer ring **51** prevents extrusions of member **49** into the interface between member **47** and portion **40**.

Forward portion **16** of barrel **12** is encircled by cylinder **52** which has an outer diameter substantially the same as central portion **14**. Retainer **54** retains barrel **12** and cylinder **52** within housing **10**. Barrel **12** is

additionally keyed within housing **10** and cylinder **52** to prevent rotation.

Piston **56** is positioned behind pressure cylinder **38** and is surrounded by jacket **58** within which it fits snugly but slidingly. Housing **10** has on its outer surface adjacent jacket **58** an elongated recess **60**, and retainer **62** within recess **60** maintains housing **10** and jacket **58** together while permitting longitudinal movement therebetween from the position of FIG. **1** to a position in which retainer **62** is at the rearward end **64** of recess **60**.

When it is desired to generate pulsed liquid jets, liquid charge material is introduced through inlets or bores **26** and **28**. The pressure of this charge causes it to pass check valve **32** and to flow through bore **30** into charge chamber **44**. Piston **56** is then actuated to impact against pressure cylinder **38**. The pressure cylinder moves forward, applying pressure to the charge material within chamber **44**. FIG. **3** depicts this pressure on the charge within chamber **44** as a function of time. Pressure cylinder **38** is dimensioned so that as it moves forward, thereby increasing the pressure on the charge in zone **44**, circumference **45** passes bore **36** as the pressure is at its optimum value, depicted at point **66** in FIG. **3**. Once circumference **45** has cleared bore **36**, the charge material enters barrel bore **20**, so that the pressure on the charge material reaches a peak and then drops off as illustrated in FIG. **3**. The charge material is then expelled from barrel **12** as a pulsed liquid jet. Pressure cylinder **38** continues to move forward against the bias of spring **50** until the pressure cylinder contacts central portion **14** of barrel **12**. This impact is transmitted through central portion **14** and cylinder **52**, and so the forward end of cylinder **52** also impacts against the material at which the pulsed liquid jet is directed. This additional impact causes a further fracturing of the material. The forward motion of barrel **12** and cylinder **52** carries with these components housing **10** which moves with respect to jacket **58** until rearward end **64** of groove **60** is against retainer **62**.

A small amount of charge material is forced backward through check valve **32** just prior to check valve **32** closing. This charge flow can be adjusted so that the volume of charge material within zone **44** is uniform for each firing of the apparatus. Piston **56** can be actuated by any suitable means such as an explosive charge, release of a pressurized fluid, release of a cocked spring, etc. If desired, piston **56** and pressure cylinder **38** can be formed as one piece.

FIGS. **4**(a) and (b) and **5**(a) and (b) illustrate two embodiments of this invention having attachments for angling the fluid jet produced by the apparatus of this invention. In each embodiment, the device for producing the fluid jet, generally designated by reference numeral **200**, may be a device such as illustrated in FIG. **1**. As shown in FIGS. **4**(a) and (b), a deflection plate **201** is attached to the end of device **200** by a support mechanism **202**. This deflection plate is arranged at an angle α to the fluid jet and contains slot **204**. When using a deflection plate **201**, the fluid jet will be deflected in the form of a spray. The width of the spray is determined by the width of slot **204** and may be controlled to provide a jet suitable for cutting a slot. Angle α may be as great as 15° to 20°. FIGS. **5**a and **5**b illustrates an alternative embodiment in which cap **208** is attached to the end of device **200**. In this embodiment cap **208** has a number of bores **210** arranged therein in conical fashion about a central opening **212** which is arranged co-axially with the expulsion bore **20** in device **200**. In this embodiment as the jet of water passes through cap **208** it is deflected in bore **212** to pass through bores **210**. The number of bores **210** can vary from one to any number, e.g., six as shown.

FIGS. **6**(a) and (b) illustrate an embodiment of the device identical with FIG. **1** accept for the inclusion of a plurality of expulsion bores **20**. As shown in FIG. **6**(a) there are two bores **36** passing through end cap **22** and each bore **36** has two expulsion bores **20** perpendicular to and interconnected therewith.

FIG. **7** illustrates another embodiment of the apparatus of this invention and differs from FIG. **1** in providing a means for flushing expulsion bore **20** to prevent plugging. In this embodiment end cap **22** of FIG. **1** is substantially elongated as shown by end cap **122** in FIG. **7**. Additionally, chambers **144** and **146**, which correspond to chambers **44** and **46** in FIG. **1**, are substantially enlarged. The device of FIG. **7** operates the same as the device of FIG. **1**, described above, except that in its end position pressure cylinder **38** and seal **48** have moved to a third position to the right of bore **136** so that chamber **146** is connected through bore **136** with bore **120**. Chamber **146** has connected therewith fluid pressure line **175** which contains check valve **177**. Check valve **177** operates upon a reduced pressure in chamber **146** to permit the introduction into this chamber of fluid under pressure, e.g., air or water. Fluid passes through bore **136** to flush bore **120**. As pressure cylinder **38** returns to its normal position, the pressure in chamber **146** will build up to close check valve **177**. The pressure in chamber **146** is balanced to allow return of pressure cylinder **38** to a position for operation of the jet valve **32**.

FIGS. **8**(a) and (b) illustrate a further embodiment of this device designed for operation under water. In this device cylinder **52** which surrounds portion **16** of barrel **12** is elongated to form chamber **80** forward of portion **16**. An air pressure line **220** is connected with chamber **80**. In operation under water, chamber **80** is always maintained at a sufficient pressure to prevent water, or other fluid media, from entering chamber **80**. Cylinder **52** may rest against the surface to be worked and impact this surface at the same time as the pulsed liquid jet. FIG. **8** also illustrates the attachment of breaking tools **222** which may be of any conventional shape. Breaking tools **222** causes further fracturing of the material being enclosed upon by the additional impact of cylinder **52**. The end of portion **16** may be positioned such that the fluid jet must penetrate one to three inches of water but greater distances substantially reduce the velocity of jet.

Although the present invention has been described with reference to preferred embodiments, numerous modifications and rearrangements could be made and still the result would be within the scope of the invention.

What is claimed is:

1. Apparatus for forming pulsed jets of liquid comprising:

an elongated cylindrical expulsion barrel having an inlet end, an outlet end and at least one longitu-

dinal bore therethrough from the inlet end to the outlet end;

an end cap having a forward face connected to said expulsion barrel inlet end, having a rear face, and having at least one radial bore therethrough communicating with said expulsion barrel longitudinal bore;

bias means;

a pressure cylinder encircling said expulsion barrel inlet end and said end cap and under urging of said bias means normally assuming a first position in which said pressure cylinder cooperates with said end cap to define a charge chamber extending behind said end cap rear face and around said end cap to a point intermediate said radial bore and said end cap rear face and capable of movement to a second position in which said charge chamber extends around said end cap to a point forward of said radial bore;

said expulsion barrel and said end cap having an inlet opening therethrough communicating with said charge chamber;

a check valve within the inlet opening for permitting charge flow through the inlet opening into the charge chamber while substantially preventing charge flow from the charge chamber through the inlet opening; and

actuating means for actuating said pressure cylinder to move said pressure cylinder against the urging of said bias means toward said end cap, thereby applying pressure on charge material within the charge chamber until the pressure cylinder reaches the second position and charge is expelled out the expulsion barrel as a pulsed liquid jet.

2. Apparatus as claimed in claim **1** further comprising a further cylinder encirclingly engaged about said expulsion barrel, a jacket slidingly engaging said actuating means and said pressure cylinder, and retaining means for retaining said jacket relative to said expulsion barrel and said further cylinder while permitting limited longitudinal movement therebetween, whereby upon actuation of said pressure cylinder, said expulsion barrel and said further cylinder move longitudinally with respect to said jacket.

3. Apparatus as claimed in claim **1** further comprising flushing means for flushing said expulsion barrel after expelling of the pulsed liquid jet.

4. Apparatus as claimed in claim **3** wherein the flushing means comprises said pressure cylinder and expulsion barrel which cooperate to form a second chamber, said pressure cylinder having a third position assumed upon the application of pressure on the charge material following the first and second position and expulsion of the liquid jet in which third position the second chamber communicates through said radial bore with the expulsion barrel and means for supplying pressure fluid to said second chamber when the pressure cylinder is in said third position.

5. Apparatus as claimed in claim **1** further comprising a deflection plate attached to the outlet end of said expulsion barrel at an angle to the longitudinal bore.

6. Apparatus as claimed in claim **1** further comprising a cap attached to the outlet end of the expulsion barrel, said cap containing at least one bore therein interconnecting with the longitudinal bore at an angle to the axis of said longitudinal bore.

7. Apparatus as claimed in claim **1** wherein said barrel contains a plurality of longitudinal bores communicating with the radial bore.

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