United States Patent [19]

Johnson, Jr.

[11] **3,807,632**

[45] **Apr. 30, 1974**

[54] **SYSTEM FOR ERODING SOLIDS WITH A CAVITATING FLUID JET**

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[22] Filed: **Sept. 26, 1972**

[21] Appl. No.: **292,460**

Related U.S. Application Data

[60] Division of Ser. No. 175,150, Aug. 26, 1971, Pat. No. 3,713,699, which is a continuation-in-part of Ser. No. 12,449, Feb. 18, 1970, abandoned, which is a division of Ser. No. 745,611, July 17, 1968, Pat. No. 3,528,704.

[52] **U.S. Cl.**..... **239/104,** 239/124, 239/288.5, 239/290, 239/424, 175/67

[51] **Int. Cl.**..... **E21b 7/18,** B05b 1/28, B05b 15/04

[58] **Field of Search**..... 299/14, 17, 4; 175/67, 175/69, 14, 65; 134/1; 239/595, 601, 594, 590, 288, 514, 124, 288.5, 418, 421, 288.3, 423, 424, 103, 120–122, 290

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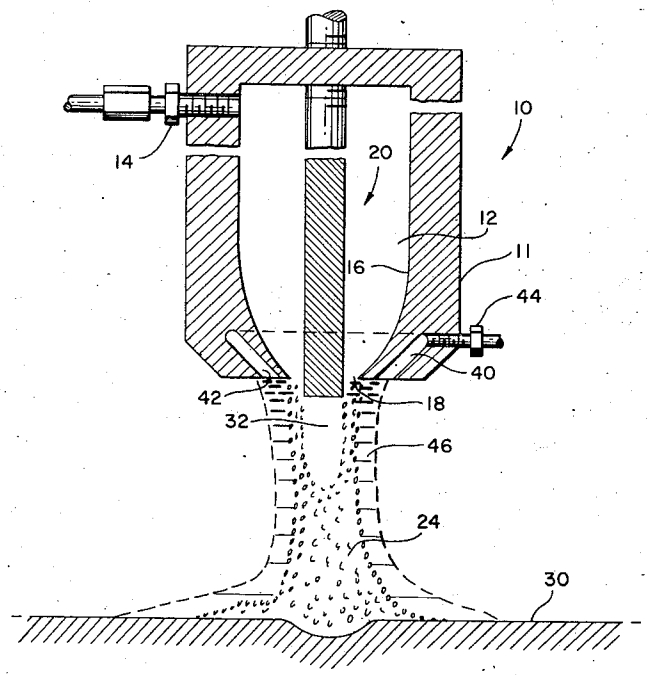
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[57] **ABSTRACT**

An improved system for advantageously utilizing the destructive forces of cavitation for the erosion of solids which comprises forming a fluid jet by directing a fluid through a restricted orifice at a speed sufficient to form vapor cavities in the fluid jet, surrounding the fluid jet with a liquid medium, and impinging the fluid jet against the solid at a distance from the orifice where the vapor cavities collapse.

5 Claims, 3 Drawing Figures



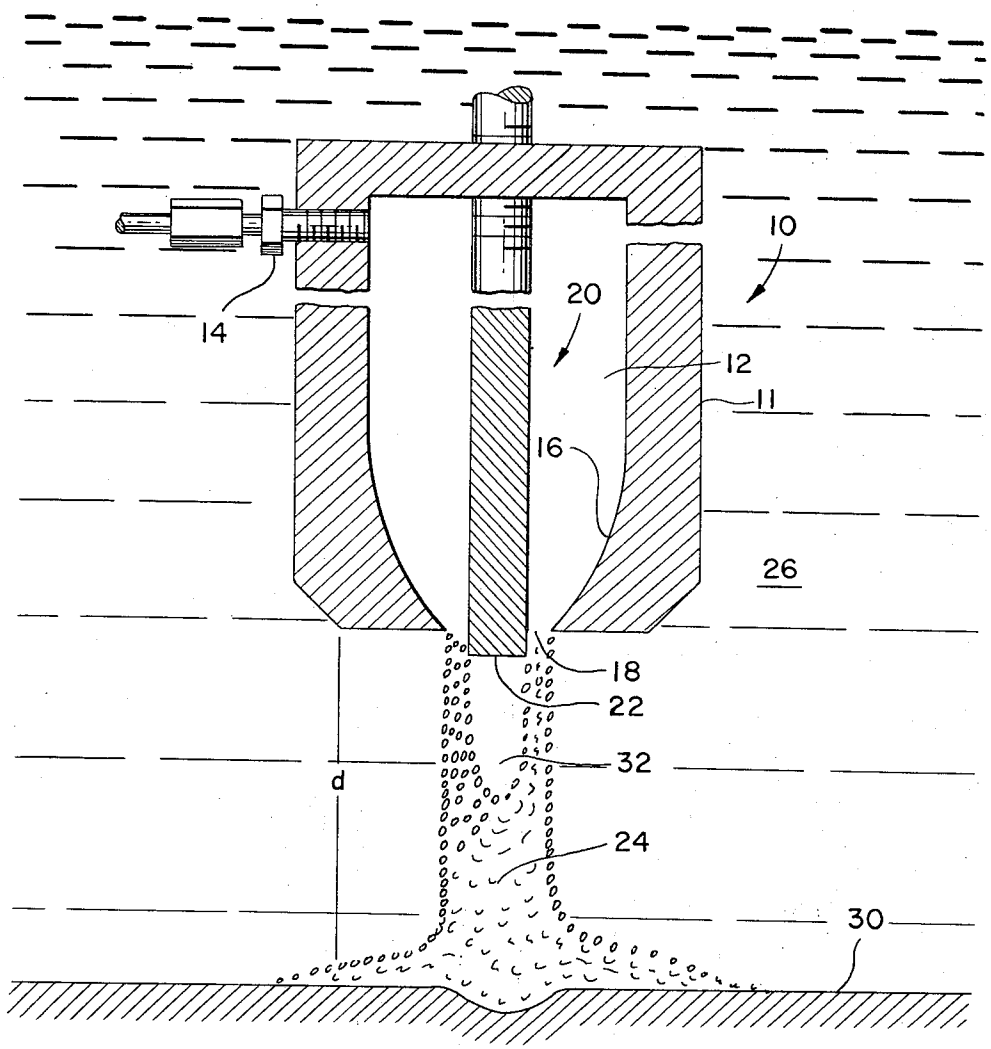


FIG. 1

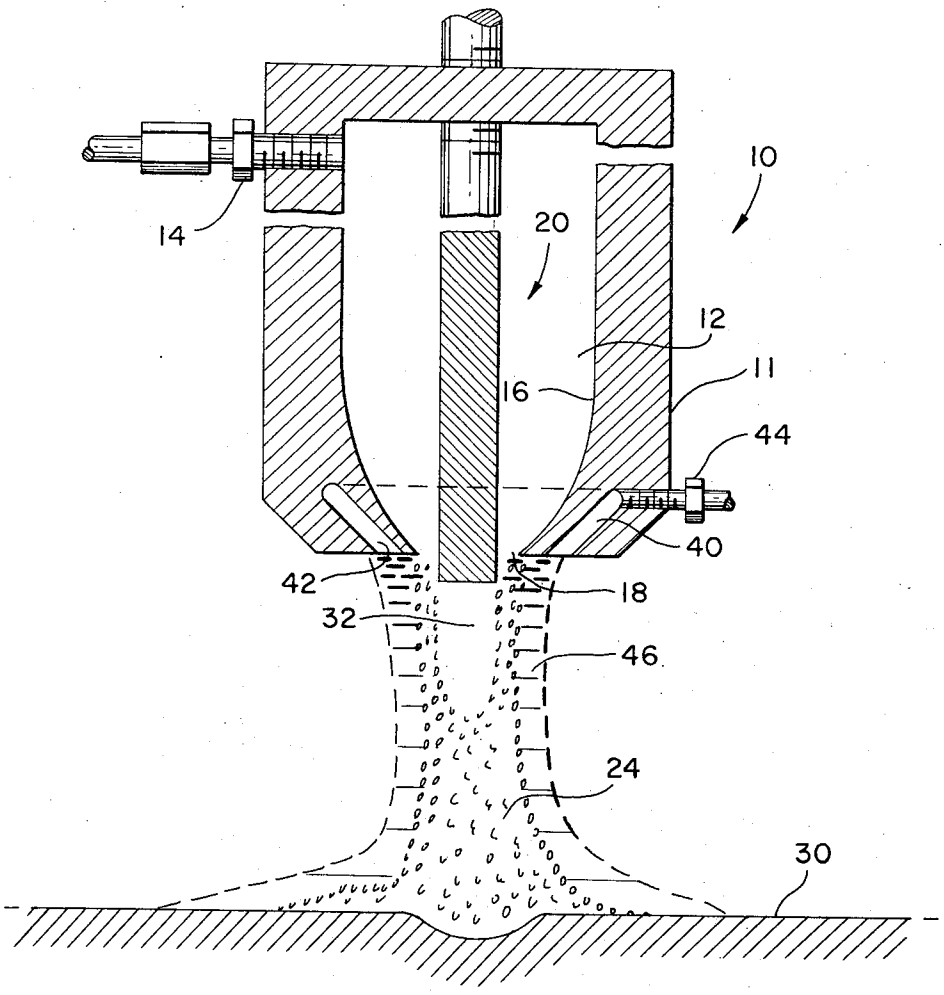


FIG. 2

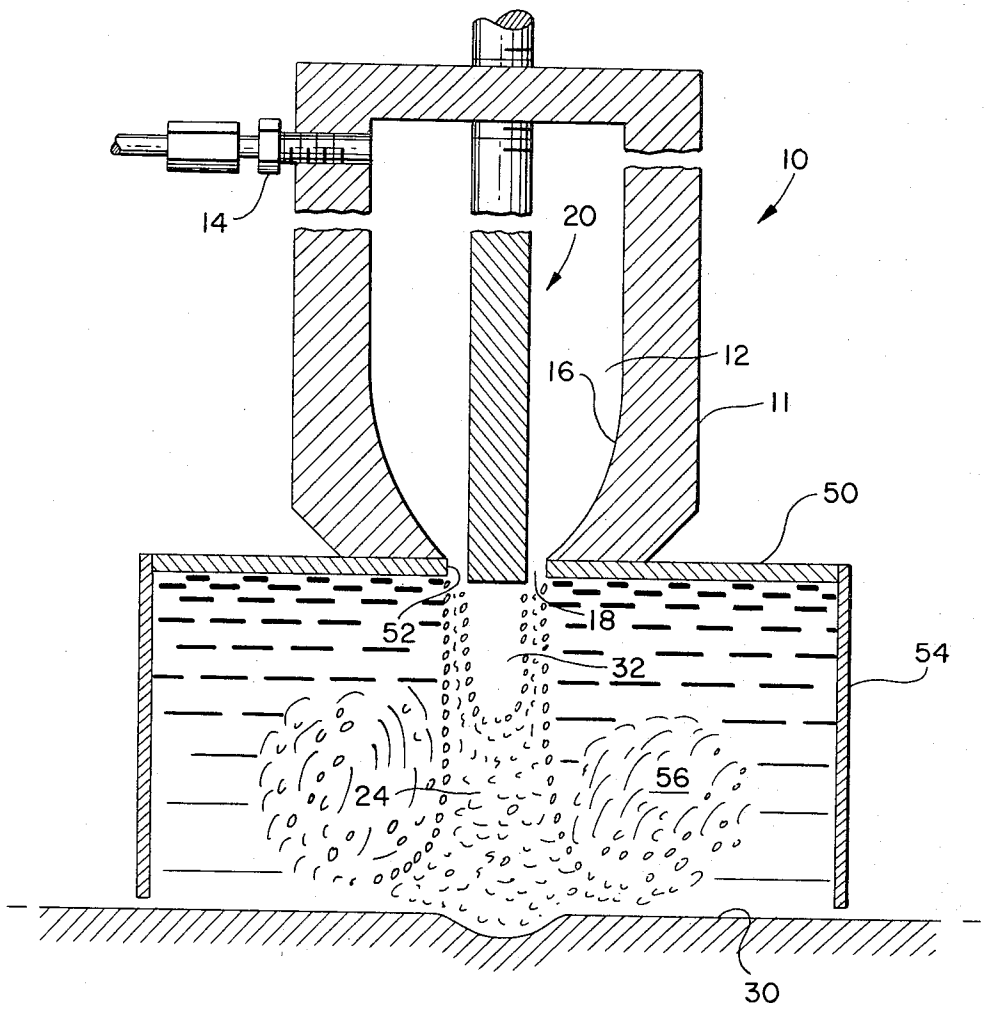


FIG. 3

SYSTEM FOR ERODING SOLIDS WITH A CAVITATING FLUID JET

This application is a division of application Ser. No. 175,150, filed Aug. 26, 1971, and now U.S. Pat. No. 3,713,699, which is a continuation-in-part of application Ser. No. 12,449, filed Feb. 18, 1970, and now abandoned, which is a division of application Ser. No. 745,611, filed July 17, 1968, and now U.S. Pat. No. 3,528,704.

This invention relates to an improved system for eroding solids with a cavitating fluid jet. More particularly, this invention relates to an improved system for surrounding the cavitating fluid jet with a liquid medium to increase the cavitation intensity and the destructive force of the fluid jet.

In my U.S. Pat. No. 3,528,704, issued Sept. 15, 1970, there is shown a process and apparatus for drilling by a cavitating fluid jet, in which a stream of water having vapor cavities formed therein is projected against a solid surface in such a manner that the vapor cavities collapse at the point of impact with the solid material. Because the vapor cavities collapse with violence, substantial damage or advantageous erosion can be done to the solid by the jet. The energy required to produce cavitation in the water is relatively modest and can be obtained within a wide range of parameters of pressure, velocity, and the like. Further, the cavitation can be concentrated into a very small area thus providing a very efficient and effective device for an environment such as underground drilling.

When the cavitating fluid jet is used in air, however, as described in my above-mentioned patent, the surrounding atmosphere tends to leak into the jet and replace the water vapor in the cavities which cushions the collapse of the cavities at the point of impact, thereby reducing the shock and destructive force of the jet. Further, the greater the distance between the orifice of the fluid jet and the point of collapse of the cavities the greater effect the surrounding atmosphere has on the intensity of the cavity collapse. This is referred to as venting of the cavitating fluid jet which eventually will change the jet into a plurality of liquid drops in a gaseous medium, rather than a plurality of vapor cavities in a liquid medium. This, of course, would destroy the destructive force of the jet by cavitation although there would be liquid impact damage due to the presence of the liquid drops. Liquid impact erosion, however, as opposed to cavitation erosion is unsuitable from both a time and power viewpoint.

In accordance with the present invention, it has been found that this process of eroding with a cavitating fluid jet can be enhanced and its destructive power increased without an increase in time and power requirements by surrounding the cavitating fluid jet with a liquid medium. Preferably, the surrounding liquid medium is of the same fluid but of lower or negligible velocity when compared to the velocity of the jet. One way for carrying out the improved process of this invention is to submerge the cavitating apparatus underwater to thereby surround the fluid jet with a liquid medium.

By surrounding the fluid jet with a liquid medium such as by forming the fluid jet underwater, venting of the fluid jet to the atmosphere is virtually eliminated, thereby effectively increasing the destructive force of the cavitating fluid jet over a similar jet operated in the atmosphere. Also, because venting is eliminated, the distance between the solid to be eroded and the fluid jet can be increased without danger of the jet breaking up prematurely into liquid drops.

Further, by surrounding the fluid jet with an essentially stationary body of water as contemplated by the present invention, the force of the jet shears the relatively stationary water and creates a high turbulent zone around the periphery of the fluid jet. This creates a multitude of vortices around the periphery of the jet with corresponding low pressures in the center of the vortices. When the pressure in these turbulent vortices decreases below the vapor pressure of the jet, additional vapor cavities will be formed within the vortices, thus increasing the number of vapor cavities in the jet and hence the destructive force of the fluid jet.

It can be seen, therefore, that the present invention as broadly described above provides an improved process for eroding with a cavitating fluid jet and, as more fully described below, new and novel apparatus is also provided for carrying out this improved process.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory but are not restrictive of the invention.

The accompanying drawings which are incorporated in and constitute a part of this application illustrate several embodiments of the invention and together with the description serve to explain the principles of the invention.

Of the drawings:

FIG. 1 is a cross-sectional view showing apparatus for creating a cavitating fluid jet that is submerged in a body of water and illustrating a preferred method for carrying out the present invention;

FIG. 2 is an embodiment of a cavitating fluid jet of the present invention that does not require submersion of the apparatus in a body of water; and

FIG.3 is an alternative embodiment similar to the device shown in FIG. 2.

Reference will now be made in detail to the preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings.

Cavitation as used in the specification and claims refers to the formation and growth of vapor-filled cavities in a flowing fluid where the local pressure of the fluid is reduced below the vapor pressure of the fluid, thus inducing formation of vapor-filled cavities. When such cavities collapse, enormous pressures are created in the vicinity of the collapse and the erosion of solids exposed to such collapsing cavities is called cavitation erosion.

The concept in the process and apparatus of the present invention, therefore, essentially consists of inducing formation of these vapor-filled cavities in a high-velocity fluid jet and, by proper adjustment of the distance between the orifice of the jet and the surface to be damaged, permitting the jet to impact the surface at the point of collapse of the cavities.

For many years, cavitation has been a problem, particularly in the choice and design of propellers, hydraulic equipment, and other mechanical arts where there is relatively high-speed movement between an article and a fluid. Work in the past has been chiefly directed to eliminating the damage caused by cavitation, whereas in the present invention the objective is to utilize the damaging effect of cavitation.

The theory and effect of a cavitating fluid jet and various nozzle arrangements for forming a cavitating fluid jet are more fully described in my prior U.S. Pat. No. 3,528,704 and the teachings of that patent are herein incorporated by reference.

To illustrate the improvements and advantages realized by the present invention and as shown in the drawings, there is provided cavitating apparatus, generally **10**, having housing **11** and an internal chamber **12**. Chamber **12** receives fluid, preferably water, under pressure by connection to a suitable source of fluid through a fitting **14** near one end of the housing. The interior surface **16** of chamber **12** tapers to an outlet opening or restricted orifice **18** at the opposite end of the housing. As shown in FIG. **1**, a stem member **20** is positioned within chamber **12** and terminates at a lower surface **22** adjacent orifice **18**. Preferably, and as shown diagrammatically in FIG. **1**, stem **20** is threadably received within housing **10** so that it can be longitudinally adjusted with respect to orifice **18**.

In accordance with the improved system of the present invention, the fluid jet **24** formed by the cavitating apparatus and emerging from orifice **18** is surrounded with a liquid medium. In accordance with a preferred embodiment and as schematically illustrated in FIG. **1**, this can be carried out by submerging apparatus **10** in a body of water **26** so that the fluid jet **24** emerging from orifice **18** is surrounded by water that is essentially stationary with respect to the high-velocity jet.

In operation of the apparatus shown in FIG. **1**, water under pressure is fed to chamber **12** through fitting **14** and exhausted through orifice **18**. Because of the area contraction effect of surface **16**, the velocity of the water increases as it leaves the housing. As the velocity of the stream increases, generally above about 350 feet per second, the pressure in the lowest pressure region of the stream near stem **20** decreases and because of this reduced pressure, vapor cavities are formed within the water stream.

These vapor cavities will collapse at a certain distance from orifice **18** where the stream velocity is reduced to a point where the stream pressure will no longer permit the presence of these cavities; in other words, at the point where the local pressure of the stream or jet is above the vapor pressure of water. Thus, in use, nozzle **10** is placed a distance d from a solid **30** to be eroded so that the area of maximum cavity collapse will be located on the surface of the solid.

As described in my aforementioned patent, the location of stem **20** within the orifice **18** causes an increase in the velocity of the stream by reducing its area of exhaust. Additionally and as the water stream passes the surface **22** of stem **20**, an evacuated core area **32** is formed that helps to reduce the pressure and increase the formation of vapor cavities in the fluid jet.

Further, pulsing of thhe fluid stream also adds to the effectiveness of the apparatus and this can be done by valving the supply of water to chamber **12** as described in my aforementioned patent.

In accordance with the present invention, by surrounding the stream with a liquid medium **26**, loss of vapor cavities and/or reduction in intensity of cavity collapse due to venting of the jet is substantially avoided. Further, the force of the high-velocity stream shearing the surrounding liquid creates vortices in the stream and increases the number of vapor cavities in the jet. Both of these phenomenon increase the maximum number of cavities collapsing at the surface and thus increase the destructive force of the fluid jet.

Further, it has been found that the distance d or "stand off" distance between the jet nozzle and the surface to be eroded can be substantially increased without diminishing the effectiveness of the fluid jet. Thus, while in some areas of application it may be possible to place the nozzle as close to the surface to be eroded as desired, it will be appreciated by those skilled in the art that there will be other applications where a larger stand-off distance may be necessary.

The present invention, therefore, not only maximizes formation of vapor cavities in the jet to increase its destructive force but also increases its versatility and efficiency in operation.

The present invention also encompasses new and novel apparatus for accomplishing an eroding function.

There is shown in FIG. **2**, for example, cavitating apparatus for forming a fluid jet that need not be submerged underwater during operation but that can be used in the atmosphere while still operating according to the process of the present invention. In the device shown in FIG. **2**, the lower end of housing **11** is provided with an internal, annular chamber **40** having an annular discharge opening **42** surrounding orifice **18** of cavitating apparatus **10**. A fitting **44** is provided for supplying fluid to chamber **40**. The discharge opening **42** of chamber **40** is arranged so that the stream of fluid **46** passing out through annular discharge opening **42** passes alongside and surrounds the fluid jet **24** emerging from orifice **18**.

In accordance with the invention and in operation of the device shown in FIG. **2**, a fluid, such as water, is supplied to chamber **40** at a much lower driving pressure than the fluid supplied to chamber **12**, so that the velocity of annular stream **46** is much lower than the velocity of fluid jet **26** and is in essence relatively stationary compared to the speed of the fluid jet.

It can be seen that by surrounding the fluid jet with an annular stream of water as shown in FIG. **2**, venting of the fluid jet is reduced and vortices around the periphery of fluid jet **24** will be created, thereby maximizing the formation of vapor cavities in the jet and increasing the destructive capability of the cavitating apparatus without requiring underwater operation.

FIG. **3** diagrammatically shows an alternative embodiment that also permits use of the cavitating apparatus in the atmosphere while utilizing the advantages of the present invention. In the device shown in FIG. **3**, means are provided for trapping and returning spent water from the cavitating fluid jet to the area around fluid jet **24** to provide the relative stationary fluid medium surrounding the jet emerging from orifice **18**. As embodied and as shown in FIG. **3**, this means includes an annular disc **50** having an opening **52** aligned with orifice **18** of the jet and radiating outwardly perpendicular to the axis of the fluid jet. Further, a tubular barrier of flexible material **54**, such as canvas or the like, is attached to the periphery of disc **50** and extends down, close to the surface **30** to be eroded. Barrier **54** traps spent fluid from jet **24** and maintains it in space **56** between disc **50** and surface **30** so that the jet can be surrounded with a relatively stationary liquid medium.

A pressure greater than atmosphere will result under disc **50** and by proper selection of the area of this disc, an upward force supporting the apparatus can be generated. Further, the flexible character of barrier **54** permits operation of the embodiment shown in FIG. **3** over a rough or non-flat surface.

Thus, it can be seen that each of the nozzles described in FIGS. **1–3** are adapted to exhaust and direct a stream of water in which vapor cavities have been formed against a surface to be eroded while surrounding the jet with a liquid medium in accordance with the present invention. This is accomplished either by operating the cavitating apparatus underwater, as shown in FIG. **1**, or by utilizing apparatus of the type exemplified in FIGS. **2** and **3**.

As more fully described in my earlier patent, it is to be appreciated that a plurality of jets may be utilized to perform an erosion operation and that suitable apparatus can be provided for traversing the jets across the surface to be eroded in a planned geometric pattern without departing from the scope of the present invention.

The invention in its broader aspects is not limited to the specific details shown and described, and departures may be made from such details without departing from the scope of the present invention and without sacrificing its chief advantages.

What is claimed is:

1. A nozzle for causing cavitational erosion of a solid surface comprising a housing for receiving a pressurized fluid therethrough, said housing having an interior surface tapering to a narrower cylindrical outlet orifice; means for feeding fluid under relatively high pressure to said housing so that it exhausts through the orifice as a high-speed fluid jet; an annular discharge opening closely surrounding the outer perimeter of the fluid jet orifice and located so that it discharges a second stream of fluid along side of and closely surrounding the outside of said fluid jet; and means for supplying fluid under relatively low pressure to said annular discharge opening so that it exhausts as a relatively slow annular stream compared to the high-speed fluid jet, to thereby provide a relatively stationary fluid medium surrounding the fluid jet whereby vapor cavities are formed in the region of high turbulence around the periphery of the fluid jet as the fluid jet shears the relatively stationary fluid medium.

2. The nozzle of claim **1** including a rod located within the fluid jet orifice to form an annular discharge orifice for the fluid jet and produce additional vapor cavities within the interior of the fluid jet.

3. A nozzle for causing cavitational erosion of a solid surface comprising a housing for receiving a pressurized fluid therethrough, said housing having an interior surface tapering to a narrower cylindrical outlet orifice; means for feeding fluid under relatively high pressure to said housing so that it exhausts through the orifice as a high-speed fluid jet; and confining means surrounding the fluid jet orifice and extending downwardly therefrom and open to the surface to be eroded, said confining means comprising a disc extending outwardly from the fluid jet orifice, and side walls extending downwardly from the periphery of the disc forming a chamber having an opening facing toward the surface to be eroded, said disc and side walls in combination with said surface trapping spent water from the fluid jet to thereby provide a relatively stationary fluid medium surrounding the outside of the fluid jet whereby vapor cavities are formed in the region of high turbulence around the periphery of the fluid jet as the fluid jet shears the relatively stationary fluid medium.

4. The nozzle of claim **3**, including a rod located within the fluid jet orifice to form an annular discharge orifice for the fluid jet and produce additional vapor cavities within the interior of the fluid jet.

5. The nozzle of claim **3**, wherein the side walls are of flexible material.

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