[54] VERY HIGH VELOCITY FLUID JET
NOZZLES AND METHODS OF MAKING
SAME

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239/596, 600, 601

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ABSTRACT
A very high velocity fluid jet nozzle comprised of a
heavy walled vitreous body defining a jet orifice circular
in cross section and substantially greater in length
than the cross sectional diameter thereof, the orifice
being defined by a smooth surface blending into an
entry chamber defined by the vitreous body, the nozzle
being made by a process including the steps of pressurizing
the bore of a heavy walled vitreous capillary tube,
softening a portion of the tube so as to form a chamber
therein, and severing the tube at the chamber and at
points spaced from the chamber.

15 Claims, 8 Drawing Figures
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**VERY HIGH VELOCITY FLUID JET NOZZLES AND METHODS OF MAKING SAME**

This application is a Continuation of Application Ser. No. 875,726 filed Nov. 12, 1969, now abandoned.

This invention relates to fluid jet nozzles and methods of making the same and, more particularly, to improved high velocity fluid jet nozzles and improved methods of making the same.

Hitherto, various methods and apparatus have been proposed for cutting, piercing, separating or otherwise penetrating various materials such as precipitation-hardening stainless steels, titanium and titanium alloys, high strength alloy steels, wood, cardboard and various other materials by means of a supersonic jet of liquid initially pressurized to thousands of atmospheres of pressure and subsequently discharged through a nozzle at supersonic velocities. Representative methods and apparatus are disclosed, for example, in U.S. Pat. Nos. 2,985,050 and 3,212,378 and in the applicant's co-pending application, Ser. No. 733,495, filed May 31, 1968, now U.S. Pat. No. 3,524,367. In apparatus of the indicated character, difficulties have been encountered in obtaining satisfactory nozzles capable of forming coherent high velocity fluid jets. For example, hitherto, small nozzles adapted to be used at relatively low pressures have been machined from such materials as sapphire to obtain orifice jewels which have been utilized in spray guns, and small glass nozzles have been drawn for low pressure applications such as are encountered in electro-chemical machining. Nozzles for use with driving pressures in excess of ten thousand pounds per square inch have also been proposed, these last mentioned prior nozzles having been machined from metal alloys and sintered materials. However, the aforementioned nozzles have been unsatisfactory when efforts have been made to utilize such nozzles for forming coherent very high velocity fluid jets by initially pressurizing a working liquid to thousands of atmospheres of pressure and discharging the pressurized fluid through the nozzle. Experimentation has shown that nozzles for obtaining coherent high velocity jets should have a throat length that is much greater than the orifice diameter and that the nozzle orifice should have a large smoothly blended entry into the throat portion, a perfectly circular transverse cross section, a very smooth surface finish and a sharp edged exit. Optimization of the aforementioned characteristics becomes increasingly critical as driving pressures increase and/or orifice diameters decrease. Prior nozzles formed by the removal of material, as for example, those formed from sapphires, metal and sintered materials are extremely difficult and expensive to fabricate into the required configurations. On the other hand, while good configurations have been obtained with prior drawn nozzles, as for example, those formed from glass, such prior drawn nozzles tend to shatter under high driving pressures, have a very short useful life, and are difficult to mount in suitable holders.

An object of the present invention is to overcome the aforementioned as well as other disadvantages in prior nozzles of the indicated character and to provide improved fluid jet nozzles and methods of making the same which enable the development of very high velocity jets of fluid displaying great coherence upon exit from the nozzle orifice.

Another object of the invention is to provide improved high velocity fluid jet nozzles and improved holders therefor which are economical to manufacture and assemble, durable, efficient and reliable in operation.

Another object of the invention is to provide improved high velocity fluid jet nozzles and nozzle assemblies for use in producing high velocity fluid jets by the employment of driving pressures in excess of 70,000 pounds per square inch.

Another object of the invention is to provide improved high velocity fluid jet nozzles which may be easily and inexpensively fabricated and which may be utilized to generate fluid jets of excellent quality exhibiting good coherence at high velocities.

Another object of the invention is to provide an improved method of making nozzles having orifices as small as 0.002 inches in diameter and operable at driving pressures of 70,000 pounds per square inch or greater to provide high velocity fluid jets for use in cutting, piercing, separating or otherwise penetrating various materials.

The above as well as other objects and advantages of the present invention will become apparent from the following description, the appended claims and the accompanying drawing.

FIG. 1 is an enlarged cross sectional view of a high velocity fluid jet nozzle embodying the present invention, showing the same installed in a nozzle assembly embodying the present invention;

FIG. 2 is a longitudinal view, with portions broken away, illustrating one step in the method of making the nozzle illustrated in FIG. 1;

FIG. 3 is a longitudinal view illustrating another step in the method of making the nozzle illustrated in FIG. 1;

FIG. 4 is a sectional view of the nozzle illustrated in FIG. 1 showing the same removed from the nozzle assembly;

FIG. 5 is a sectional view of another embodiment of the invention;

FIG. 6 is a sectional view of apparatus which may be employed in practicing the present invention;

FIG. 7 is a sectional view of the apparatus illustrated in FIG. 6, showing the same during another step in a method employing the present invention; and

FIG. 8 is a sectional view of still another embodiment of the invention.

Referring to the drawings, one embodiment of the invention is illustrated in FIG. 1 thereof and is comprised of a nozzle assembly, generally designated 10, which is particularly adapted for use in producing very high velocity fluid jets and may be used, for example, in apparatus of the types disclosed in the aforementioned United States Letters Patent and in practicing the methods disclosed in the aforementioned co-pending application of the applicant, although it will be understood that the present invention is applicable to other uses.

As shown in FIG. 1, the nozzle assembly 10 is comprised of a high pressure tubular member 12 which may be formed of steel or other suitable material having sufficient strength to withstand the high fluid pressures exerted thereon. The tubular member 12 defines an inlet passageway 14 which may be connected to a suitable source of pressure (not shown). The periphery of the end portion of the tubular member 12 is provided with
a frusto-conical surface 16 adapted to mate with a complementary tapered surface 18 provided in a bore 20 defined by a nozzle holder 22. The tapered surfaces 16 and 18 provide a fluid tight connection between the tubular member 12 and the holder 22 and at the same time permit assembly and disassembly of the tubular member 12 and the holder 22. It will be understood that other means may be utilized to connect the tubular member 12 to the holder 22, as for example, the connecting means disclosed in the applicant's co-pending application entitled "Means for Sealing Fittings and Nozzle Assemblies at Extremely High Fluid Pressures".

The nozzle holder 22 is also preferably made of steel or other suitable material having sufficient strength to withstand the pressures exerted thereon and defines a reduced diameter outlet passageway 24 the inner end of which communicates with the bore 20 and the outer end of which communicates with a flared outlet 26.

A tubular retaining member 28 is provided which is positioned within the bore 20, the retaining member preferably being formed of vinyl or other semi-rigid material. As shown in FIG. 1, the nozzle assembly 10 also includes a precision nozzle 30 which may be formed from heavy wall glass capillary tubing of close dimensional tolerances such as round bore thermometry tubing and marine barometer tubing. It will be understood that the nozzle 30 may be formed of other vitreous materials such as quartz or alumina. The body of the nozzle 30 is preferably circular in transverse cross section and defines an entrance chamber 32 communicating with an elongate throat 34, the length of the throat 34 being substantially greater than the diameter of the throat and having a smoothly blended entry with the chamber 32. The chamber 32 and throat 34 are preferably circular in transverse cross section and have a very smooth surface finish. The diameter of the throat 34 may be as small as 0.002 inches but is shown enlarged in the drawings for purposes of clarity. The exit end 36 of the throat 34 terminates in a sharp edged exit 38 as shown in FIGS. 1 and 4, while the chamber 32 is coaxially aligned with the bore 14 of the tubular member 12 and communicates with the bore 20 of the holder 22. The nozzle 30 is positioned within the bore 40 of the tubular retaining member 28 in closely fitting relationship therewith, but as shown in FIG. 1, the nozzle 30 and retaining member 28 are not either directly or indirectly threaded or otherwise rigidly affixed to the nozzle holder 22.

In this embodiment of the invention the end 42 of the nozzle 30 and the end 44 of the retaining member 28 are firmly seated on one side of a ring shaped gasket 46 capable of deforming to effect a fluid tight seal under pressure without extruding. The left side of the gasket 46, as viewed in FIG. 1, bears against the shoulder 48 on the holder 22 defining the end of the bore 20. The gasket 46 may be formed of cellulose acetate composite or other suitable material having the desired characteristics. With such a construction, under fluid pressure, the nozzle 30 seats itself and seals in the zone of the gasket 46 due to area differential principles.

In operation, fluid such as water initially pressurized to thousands of atmospheres of pressure, for example, 70,000 pounds per square inch, flows through the inlet passageway 14 of the tubular member 12 and into the bore 20 defined by the holder 22. The highly pressurized fluid enters the chamber 32 of the nozzle 30 and issues from the throat 34 in the form of a coherent high velocity fluid jet traveling at supersonic velocity. The nozzle 30 is throughout this operation held seated on the gasket 46 by the highly pressurized fluid supplied against the rearward or right hand (as viewed in FIG. 1) end of the nozzle 30; and, as during the operation the nozzle 30 is virtually surrounded by the fluid pressure, the internal forces and stresses remain low thereby preventing shattering of the glass nozzle when it is subjected to the extremely high fluid pressures.

The present invention also contemplates an improved method of making the nozzle 30 illustrated in FIGS. 1 and 4. In accordance with the present invention a length of heavy wall glass capillary tubing 50 of close dimensional tolerances, such as round bore thermometry tubing or marine barometer tubing, is closed at one end with a suitable plug 52, as illustrated in FIG. 2, and slight air pressure is applied through the bore 54 of a tube 56 to the other end of the bore 58 of the capillary tubing 50. Careful heating of a short portion of the tubing 50 softens the vitreous material permitting a spindle shaped bubble to form which may be drawn out as shown in FIG. 3 to form the chamber 60 while maintaining approximately the original outside diameter of the tubing. Separation of the tubing at the bubble chamber 60 and at undisturbed adjacent points of the tubing yields the nozzles 30 and 130 as shown in FIGS. 4 and 5. The shape of the nozzle 30 illustrated in FIG. 4 results when the tubing is cut completely through while the shape of the nozzle 130 shown in FIG. 5 displaying a short projection 62 results when the exit end of the nozzle is cut to form a circumferential groove after which the small core of vitreous material is fractured. The embodiment of the invention illustrated in FIG. 5 has the advantage of producing an ample flat surface or shoulder 64 for subsequent sealing while producing a clean sharp edged exit 138 from the throat 134 of the nozzle 130.

Another method of making high velocity fluid jet nozzles is illustrated in FIGS. 6 and 7 wherein the heavy wall capillary tubing 50 is inserted into a forming die 70 defining a flared bore 72 of the desired configuration. The bore 58 of the capillary tubing 50 is then plugged and pressurized in the manner previously described and the portion of the capillary tube within the forming die 70 is heated. The pressurized and heated capillary tubing is then expanded to fill the bore of the die 70 as illustrated in FIG. 7 to form the nozzle 230. Such method provides control of the bore contour and allows the diameter of the throat 234 to be enlarged a predetermined amount by providing clearance 74 between the outside diameter of the tubing and the forming die 70 prior to expansion.

The method described in connection with FIGS. 6 and 7 may also be used to produce expansion nozzles 330 of the type illustrated in FIG. 8. Such nozzles have an entry chamber 332 smoothly blending with a minimum diameter throat portion 334, the throat portion 334 in turn smoothly blending with a diverging expansion portion 336 and may be produced by heating a pressurized thick walled capillary tubing in a forming die having the desired configuration.

While nozzles of the types illustrated in FIGS. 1, 4, 5, 7 and 8 may be formed from commercially available glass capillary tubing, it will be understood that such nozzles may be formed of other materials such as quartz or alumina.
Fluid jets developed by nozzles embodying the present invention and made in accordance with the above described methods display great coherence upon exit from the nozzle orifice capable of effectively piercing, cutting, separating or otherwise penetrating materials of the type hereinbefore described. It has also been found that nozzles embodying the present invention and made in accordance with the above described methods are capable of withstanding driving pressures in excess of seventy thousand pounds per square inch without shattering when assembled in nozzle assemblies as hereinbefore described.

While preferred embodiments of the invention and methods of making the same have been illustrated and described, it will be understood that various changes and modifications may be made without departing from the spirit of the invention.

What is claimed is:

1. A nozzle assembly, the combination including a holding element defining a bore and a reduced diameter outlet passageway communicating with said bore, a nozzle disposed in said bore, said nozzle including a heavy walled body formed of vitreous material and defining an elongate capillary orifice circular in cross section and substantially greater in length than the cross sectional diameter thereof, said orifice being defined by a smooth surface and at an end blending into an enlarged entry chamber communicating with said bore at one end of said nozzle body, said orifice being throughout its length of lesser cross sectional diameter than said chamber and the end of said orifice remote from said chamber terminating at the other end of said body in a sharp edged exit and communicating with said outlet passageway, a tubular retaining member disposed in said bore end encompassing said nozzle body, and an annular sealing member surrounding said outlet passageway and bearing against said other end of said nozzle body, said nozzle body being free of rigid connection to said holding element to be maintained in seating relationship with said annular sealing member by fluid pressure applied at said one end of said nozzle body.

2. The combination as set forth in claim 1, wherein said sealing member bears against said holder.

3. The combination as set forth in claim 1, wherein said retaining member is formed of a semi-rigid material.

4. The combination as set forth in claim 1, wherein said retaining member is formed of vinyl material.

5. The combination as set forth in claim 1, wherein said nozzle body has an annular shoulder adjacent said sharp edged exit.

6. The combination as set forth in claim 1, wherein said body is formed of glass.

7. The combination as set forth in claim 1, wherein said sealing member bears against said holder, said nozzle body has an annular shoulder against said sharp edged exit, and said retaining member is formed of semi-rigid material.

8. The combination as set forth in claim 7, wherein said retaining member is formed of vinyl material.

9. The combination as set forth in claim 7, wherein said body is formed of glass.

10. The combination as set forth in claim 1, wherein said nozzle body is not rigidly affixed to said holder.

11. In a nozzle assembly, the combination including a holding element defining a bore and a reduced diameter outlet passageway communicating with said bore, a nozzle disposed in said bore, said nozzle including a heavy walled body formed of vitreous material and defining an elongate capillary orifice circular in cross section and substantially greater in length than the cross sectional diameter thereof, said orifice being defined by a smooth surface and blending into an enlarged entry chamber communicating with said bore at one end of said nozzle body, the end of said orifice remote from said chamber terminating at the other end of said body in a sharp edged exit and communicating with said outlet passageway, a tubular retaining member disposed in said bore and encompassing said nozzle body and an annular sealing member surrounding said outlet passageway and bearing against said other end of said nozzle body, said nozzle body being free of rigid connection to said holding element to be maintained in seating relationship with said annular sealing member by fluid pressure applied at said one end of said nozzle body.

12. In a nozzle assembly, the combination including a holding element defining a bore and an outlet passageway communicating with said bore, a nozzle disposed in said bore and comprising a nozzle body provided with nozzle passage means, said nozzle passage means being adapted to receive fluid at one end of said nozzle body and communicating with said outlet passageway at another end of said nozzle body, a tubular retaining member disposed in said bore and encompassing said nozzle body, and an annular sealing member surrounding said outlet passageway and bearing against said another end of said nozzle body, said nozzle body being free of rigid connection to said holding element to be maintained in seating relationship with said annular sealing member by fluid pressure applied at said one end of said nozzle body.

13. The combination as set forth in claim 12, wherein said nozzle is in closely fitting relationship with said tubular retaining member, and said tubular retaining member is free of rigid connection to said holding element.

14. The combination as set forth in claim 12, wherein said ends of said nozzle body are opposite ends thereof, said outlet passageway is of smaller transverse dimensions than said bore, and said nozzle passage means terminates at said other end of said body in a sharp edged exit.

15. The combination as set forth in claim 14, wherein said nozzle is in closely fitting relationship with said tubular retaining member, and said tubular retaining member is free of rigid connection to said holding element.