A method of generating an abrasive liquid jet comprising a high pressure liquid jet and abrasive particles for performing working operations such as cutting and cleaning. The method involves the delivery of the abrasive particles to the high pressure liquid in a dense phase slurry. The dense phase slurry is in the form of a paste which can be delivered along a supply line. Typically, the dense phase slurry comprises a mixture of an abrasive material, water and a thickening agent. The liquid jet and the abrasive slurry are brought together in a nozzle assembly (10). The nozzle assembly (10) has a body (11) defining a chamber (17). The liquid is introduced under pressure into the chamber (17) as a liquid jet through a delivery nozzle (13). The dense phase abrasive slurry containing the abrasive particles is introduced into the chamber (17) through supply openings (23). An outlet (19) is provided from the chamber (17) through which of the liquid and abrasive slurry can issue as an abrasive liquid jet.
GENERATION OF ABRASIVE LIQUID JETS

FIELD OF THE INVENTION

0001 This invention relates to the generation of abrasive liquid jets. More particularly the invention relates to a method of and apparatus for generation of such abrasive liquid jets.

BACKGROUND ART

0002 High pressure liquid jets consisting of a liquid, such as water, mixed with an abrasive material, such as garnet, are used for performing working operations such as cutting and cleaning, on a wide variety of material. Typically, powdered abrasive material is mixed with a high pressure water jet in a nozzle assembly which then directs the water jet mixed with abrasive material to a working zone at which a cutting, cleaning or other working operation is to be performed. The nozzle assembly typically includes a mixing chamber into which the abrasive material is delivered and mixed with a high pressure water jet passing through the mixing chamber. The abrasive material is delivered through one or more supply openings into the mixing chamber. The water jet is produced by a delivery nozzle which opens onto the mixing chamber. The water jet with the abrasive material mixed therein exits the mixing chamber through a focusing conduit or “nuzzle” extending therefrom.

0003 One method of delivering the abrasive material to the mixing chamber involves the use of compressed air to convey the abrasive material through a supply line to the mixing chamber, the abrasive material being drawn into the mixing chamber by a Venturi effect due to the high pressure water jet passing through the mixing chamber.

0004 Where the nozzle assembly is a substantial distance from the abrasive material source, for example when the nozzle assembly is used in an underwater application, the supply line can potentially be very long. The air compressor supplying the compressed air must therefore have a high capacity due to high head losses through the supply line and also the need to prevent settling and therefore blocking of the supply line. The need for a high capacity compressor makes the use of compressed air impractical in such circumstances. It would also not be possible to use compressed air in underwater applications when the nozzle assembly is used at depths where the surrounding water pressure is very high, as there could be leakage of water into the nozzle assembly and supply line.

0005 Another method of delivering the abrasive material is to use water to convey the material through the supply line as a slurry. To prevent settlement, the abrasive material must be held in suspension within the water as the slurry travels through the supply line. This therefore requires a high volume of water to be delivered through the supply line if the material is to be maintained in suspension. The slurry velocity also needs to be relatively high for this reason. The high velocity slurry can, however, abrade the supply line. The supply pressure must therefore be kept relatively low for safety reasons. It is also important to avoid separation of the abrasive material from the water in the slurry, such as for example at bends in the supply line, as separation of the abrasive material can contribute significantly to an increase in abrasion of the supply line. This introduces heavy duty plumbing requirements for the supply line which in turn can lead to reliability problems. Additionally, because only a relatively small amount of abrasive material compared with the volume of water can be supplied at any one time to the mixing chamber, the working efficiency (and in particular the cutting efficiency) of the abrasive liquid jet is relatively low.

0006 To overcome some of the above-noted problems, U.S. Pat. No. 4,555,872 (Yie) proposes that the abrasive material be introduced to a nozzle assembly in the form of a foam containing this material to minimise the energy loss to the water jet within the mixing chamber. In practice however, this method of supplying the abrasive material is not suitable for underwater applications. A foam cannot be readily transported for long distances along a supply line. Also a relatively large volume of foam will need to be supplied to enable sufficient abrasive material to be introduced into the mixing chamber. This requires a special nozzle assembly having a large number of supply openings about the periphery of the mixing chamber. Furthermore, in underwater operations, the high ambient water pressure surrounding the nozzle assembly at deeper depths prevents the use of low pressure foam, with sea water being able to readily seep into the nozzle assembly and up the supply line.

0007 It is against this background, and the problems and difficulties associated therewith, that the present invention has been developed.

DISCLOSURE OF THE INVENTION

0008 According to one aspect of the invention there is provided a method of generating an abrasive liquid jet comprising a high pressure liquid jet and abrasive particles, characterised in that the abrasive particles are delivered for interaction with the high pressure liquid in a dense phase slurry.

0009 The interaction between the high pressure liquid jet and the abrasive particles imparts acceleration to the abrasive particles. The interaction may involve some intermixing between the liquid jet and the dense phase slurry.

0010 Preferably, the dense phase slurry is in the form of a paste which can be delivered along a supply line.

0011 Preferably, the dense phase slurry comprises a mixture of an abrasive material, water and a thickening agent.

0012 Conveniently, the dense phase slurry is mixed with the high pressure liquid jet in an interaction chamber. Typically, the interaction chamber is defined within a nozzle assembly. The nozzle assembly may also incorporate a delivery nozzle for supplying the high pressure liquid jet to the interaction chamber.

0013 In one arrangement, the dense phase abrasive slurry can be drawn into the interaction chamber by the Venturi effect induced by the water jet. There is therefore minimal effect on the energy of the water as it is mixed with the slurry.

0014 In another arrangement, the dense phase slurry may be delivered into the interaction chamber under pressure. In such a case, the dense phase slurry is introduced into the interaction chamber at about the same pressure as the liquid jet.
The dense phase abrasive slurry may be pumped into the interaction chamber using positive displacement helical rotor, peristaltic, air diaphragm or any other slurry pump capable of accurate dosage and possessing the required pumping head and adequate abrasive resistance.

The dense phase abrasive slurry may include between about 10% to 95% abrasive material by mass depending on the application of the nozzle assembly. Therefore, a lower amount of abrasive material is required when the nozzle assembly is used in cleaning applications. However, in cutting applications, the abrasive material content would be much higher.

The liquid, particularly water, can be at pressures from about 50,000 kPa up to about 600,000 kPa depending on the application of the nozzle assembly. The higher pressures are used in cutting applications while the lower pressures are used in cleaning applications.

The abrasive slurry may include between about 0.04% to 5% of thickening agent by mass. The thickening agent acts to maintain the abrasive material in suspension within the slurry. Various thickening agents can be used in dependence on the macro-mechanical properties required for the abrasive slurry.

Such thickened slurries also differ in that they may or may not be thixotropic systems; that is, ones whose viscosity decreases and pour-ability increases significantly when the mixture is disturbed or agitated.

There is a wide range of thickening agents able to become highly hydrated materials in solutions and suspensions and they can come from several chemical classes both inorganic such as attapulgite clay, sepiolite clay, sodium bentonite and sodium silicate or water glass, as well as organic polymers such as carboxy methyl cellulose, hydroxy ethyl cellulose, sodium carboxy methyl cellulose, polyethylene oxide, polyacrylamides and especially the long carbohydrate chains such as gums, starches and cellulose chains, that can come from both land plants (eg locust bean gum, guar gum, psyllium gum, starches, cellulose) microbes (eg xanthan gum), and seaweeds (algicides, carrageen etc.) and may be chemically modified.

Various types of abrasive material may be used, for example, silicon carbide, aluminum oxide, garnet, silica sand, metallic slag, glass beads and iron.

The use of a dense phase slurry for supplying the abrasive material avoids the need for high capacity compressors or high volume of water for supplying the abrasive material to the nozzle assembly. The abrasive material can also be delivered at controlled rates in the form of the abrasive slurry to the chamber of the nozzle assembly. This allows for more accurate and precise control of the operation of the nozzle assembly when it is located a long distance from the abrasive material source. The abrasive slurry can also be used even when there is a high ambient water pressure surrounding the nozzle assembly. This makes the present invention particularly applicable for underwater applications.

According to another aspect of the invention, there is provided a method of operating a high pressure liquid nozzle assembly having an interaction chamber, the method including supplying a dense phase abrasive slurry to the interaction chamber, the abrasive slurry comprising a mixture of an abrasive material, water and a thickening agent.

According to still another aspect of the invention there is provided a nozzle assembly comprising a body defining an interaction chamber, liquid introduction means for introducing a liquid under pressure into the chamber as a liquid jet, slurry introduction means for introducing a dense phase abrasive slurry into the chamber, and an outlet from the chamber through which the liquid and abrasive slurry can issue as an abrasive liquid jet.

In one arrangement, the abrasive slurry is introduced into the chamber to surround or otherwise be sidewardly of the liquid jet. In another arrangement, the liquid jet is introduced into the chamber to surround or otherwise be sidewardly of the abrasive slurry.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The invention will be better understood by reference to the following description of two specific embodiments thereof, as shown in the accompanying drawings in which:

**FIG. 1** is a schematic sectional view of a nozzle assembly employed in the first embodiment; and

**FIG. 2** is a schematic sectional view of a nozzle assembly employed in the second embodiment.

**BEST MODE(S) FOR CARRYING OUT THE INVENTION**

The first embodiment relates to generation of an abrasive water jet utilising a nozzle assembly 10 as shown in **FIG. 1** of the drawings. The nozzle assembly 10 is accommodated in a cutting head (not shown) connected to two supply lines one for water and the other for a dense phase abrasive slurry.

The nozzle assembly 10 includes a body 11 defining a water delivery nozzle 13 having an inlet 14 and a nozzle orifice 15. Water under high pressure can be supplied to the inlet 14 of the water delivery nozzle 13 by way to the water supply line (not shown). The resultant high pressure water jet generated by the water delivery nozzle 13 issues from the nozzle orifice 15 into an interaction chamber 17 defined within the body 11. A focusing conduit 19 extends from the body 11 and has a focusing passage 21. The nozzle orifice 15 of the water delivery nozzle 13 is aligned with the focusing passage 21, as can be seen in the drawing.

The high pressure water jet delivered by the delivery nozzle 13 passes through the chamber 17 and through the focusing passage 21 of the focusing conduit 19. The water is delivered at pressures from 50,000 kPa up to 600,000 kPa, depending on the application of the nozzle assembly 10. The higher pressures are used in cutting applications while the lower pressures are used in cleaning applications.

Supply openings 23 are provided on either side of the chamber 17. A dense phase abrasive slurry supplied by the slurry supply line can be delivered through the supply openings 23 to the chamber 17 to thereby interact with the high pressure water jet to produce an abrasive liquid jet which issues from the outlet end of the focusing conduit 19. The interaction between the water jet and the slurry in the chamber 17 involves the water jet accelerating the abrasive
slurry and some intermixing therebetween. The slurry in effect coats the high pressure water jet and is conveyed therewith.

[0033] The abrasive slurry is drawn into the chamber 17 by the Venturi effect of the high pressure water jet passing through the chamber 17 from nozzle orifice 15. With this arrangement, the abrasive is introduced into the chamber 17 about the water jet issuing from nozzle orifice 15.

[0034] This method of supplying abrasive material is particularly applicable where the nozzle assembly 10 is located a substantial distance from the abrasive material source. Furthermore, it enables the nozzle assembly 10 to be used in underwater applications when the ambient water pressure is high. The use of an abrasive slurry also allows for accurate control of the rate of supply of the delivery material to the chamber 17.

[0035] The dense phase abrasive slurry comprises a mixture of abrasive material, water and a thickening agent.

[0036] The dense phase abrasive slurry may include between 10% to 95% abrasive material by mass depending on the application of the nozzle assembly. Therefore, a lower amount of abrasive material is required when the nozzle assembly 10 is used in cleaning applications. However, in cutting applications, the abrasive material content would be much higher.

[0037] In this embodiment, the abrasive material is garnet.

[0038] The abrasive slurry may include between 0.04% to 5% of thickening agent by mass. The thickening agent acts to maintain the abrasive material in suspension within the slurry. Various thickening agents can be used according to the macro-mechanical properties required for the abrasive slurry.

[0039] By way of example, a dense phase abrasive slurry suitable for a cleaning operation would have the following composition:

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Mass Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>82.0</td>
</tr>
<tr>
<td>Garnet (abrasive)</td>
<td>17.9</td>
</tr>
<tr>
<td>Bentonite (thickening)</td>
<td>0.1</td>
</tr>
</tbody>
</table>

[0040] Similarly, a dense phase slurry suitable for use in cutting operations would have the following composition:

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Mass Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>28.0</td>
</tr>
<tr>
<td>Garnet (abrasive)</td>
<td>71.6</td>
</tr>
<tr>
<td>Bentonite (thickening)</td>
<td>0.4</td>
</tr>
</tbody>
</table>

[0042] It has, however, somewhat unexpectedly been found that the cutting and cleaning performance of a liquid jet comprising a water jet and a dense phase slurry can be significantly increased if the dense phase slurry is introduced to the water jet in a high pressure condition. Specifically, the dense phase slurry is preferably at the same high pressure as the water jet. The second embodiment relates to generation of such an abrasive water jet utilising a nozzle assembly 40 as shown in FIG. 2 of the drawings.

[0043] The nozzle assembly 40 comprises a body 41 having a first portion 43, a second portion 45, and a third portion 47.

[0044] The second portion 45 defines an interaction chamber 49 into which a dense phase slurry is delivered under pressure through a delivery passage 51 defined in the first portion 43. The delivery passage 51 has an inlet 52 and an outlet end 53 which opens onto the chamber 49.

[0045] The body 41 includes an annular passage 55 for delivery of water under high pressure into the chamber 49. The passage 55 is defined between the first portion 43 and the second portion 45, and an annular inlet 57 and an annular outlet 59 opening onto the chamber 49.

[0046] The third portion 47 defines an outlet nozzle 61 having a convergent section 63 and a straight section 65. The convergent section 63 has the inlet end thereof opening onto the chamber 49 and the outlet end thereof opening onto one end of the straight section 65. The straight section 65 terminates at the other end thereof at a discharge port 67 through which the abrasive high pressure liquid discharges.

[0047] The outlet end 53 of the delivery passage 51 is aligned with the outlet nozzle 61 as can be seen in the drawings.

[0048] A dense phase abrasive slurry of the type described in relation to the first embodiment is delivered under pressure along a supply line to the delivery passage 51 for entry into the chamber 49 through the delivery passage outlet 53. High pressure water is also delivered into the chamber 49 through the annular passage 55. With this arrangement, the high pressure water enters the chamber around the dense phase slurry. In other words, the dense phase slurry is introduced centrally with respect to the high pressure water flow such that the high pressure water surrounds the slurry at entry. The high pressure water coats the dense phase slurry in the chamber 49 and the resultant jet discharges under high pressure through the discharge port 67 of outlet nozzle 61. Interaction between the high pressure water and the abrasive slurry in the chamber 49 involves the high pressure water accelerating the abrasive slurry which it coats. There is some intermixing between the high pressure water and the slurry, although it is preferable that the mixing be minimal.

[0049] Typically, the high pressure water and the high pressure dense phase abrasive slurry are introduced in the chamber 49 at the same pressure. The pressure can be in the range of about 500 to 2500 bar. The lower pressures are typically used for cleaning operations while the higher pressures are used for cutting operations. Because the abrasive slurry is introduced at the same pressure as the high pressure water jet there is minimal energy loss in accelerating the slurry. In a typical situation, the high pressure water flows at a rate of about 100 litres per minute and the dense phase abrasive slurry flows at a rate of about 3.5 litres per minute.
[0050] The high pressure water and the high pressure abrasive slurry are carried in supply lines of approximately the same internal diameter. Consequently, the abrasive slurry, while being pumped at high pressure, is at a relatively low velocity. The low velocity of the abrasive slurry is particularly advantageous from a safety aspect. For example, if a breach occurred in the supply line for the high pressure abrasive slurry, the low velocity would ensure that abrasive slurry would not spout from the breach in a manner which would present a danger.

[0051] The feature whereby the high pressure water jet coats the slurry also serves to confine the abrasive material as it is directed towards the working zone. This is particularly advantageous in underwater environments where the abrasive material might otherwise be dispersed in the water environment rather than being directed to the working zone.

[0052] It has been found that the second embodiment can provide a significant performance enhancement in comparison to the first embodiment. For example, it has been found that a liquid abrasive jet generated according to the second embodiment can be propelled twice the distance that could be achieved with a liquid abrasive jet generated according to the first embodiment.

[0053] From the foregoing, it is evident that the present invention provides a simple yet highly effective way of generating an abrasive liquid jet which is particularly, although not necessarily solely, applicable in situations where a working operation (such as cutting or cleaning) is performed remote from the source of abrasive material used in the generation of the abrasive liquid jet. The use of the dense phase abrasive slurry enables the abrasive material to be conveyed from the source to the working zone in a safe, convenient and efficient manner.

[0054] Modifications and variations as would be deemed to be obvious to the person skilled in the art are included within the ambit of the present invention.

[0055] Throughout the specification, unless the context requires otherwise, the word “comprise” or variations such as “comprises” or “comprising”, will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

The claims defining the invention are as follows:

1. A method of generating an abrasive liquid jet comprising a high pressure liquid jet and abrasive particles, characterised in that the abrasive particles are delivered for interaction with the high pressure liquid in a dense phase slurry.

2. A method according to claim 1 wherein the dense phase slurry is in the form of a paste which can be delivered along a supply line.

3. A method according to claim 1 or 2 wherein the dense phase slurry comprises a mixture of an abrasive material, water and a thickening agent.

4. A method according to claim 1, 2 or 3 wherein the dense phase slurry interacts with the high pressure liquid jet in an interaction chamber.

5. A method according to claim 4 wherein the interaction chamber is defined within a nozzle assembly.

6. A method according to claim 4 or 5 wherein the dense phase abrasive slurry is drawn into the interaction chamber by the Venturi effect induced by the water jet.

7. A method according to claim 6 wherein the abrasive slurry is delivered to the interaction chamber at ambient pressure.

8. A method according to claim 6 or 7 wherein the liquid is delivered to the interaction chamber at a pressure from about 50,000 kPa up to 600,000 kPa.

9. A method according to claim 4 or 5 wherein the dense phase slurry is delivered into the interaction chamber under pressure.

10. A method according to claim 9 wherein the dense phase slurry is introduced into the interaction chamber at about the same pressure as the liquid jet.

11. A method according to claim 10 wherein the delivery pressure of the slurry and liquid jet is in the range of about 500 to 2500 bar.

12. A method according to any one of the preceding claims wherein the dense phase abrasive slurry includes between about 10% to 95% abrasive material by mass.

13. A method according to any one of the preceding claims wherein the liquid is water.

14. A method according to any one of the preceding claims wherein the abrasive slurry includes between about 0.04% to 5% of thickening agent by mass.

15. A method according to any one of the preceding claims wherein the thickening agent comprises a material capable of becoming highly hydrated in solution.

16. A method according to claim 15 wherein the thickening agent is selected from a group comprising attapulgite clay, sepiolite clay, sodium bentonite, sodium silicate, water glass, carboxyl methyl cellulose, hydroxy ethyl cellulose, sodium carboxyl methyl cellulose, polyethylene oxide, polyacrylamides, and the long carbohydrate chains such as gums, starches and cellulose slurry.

17. A method according to any one of the preceding claims wherein the abrasive material is selected from a group comprising silicon carbide, aluminium oxide, garnet, silica sand, metallic slag, glass beads and iron.

18. A method according to any one of claims 4 to 17 wherein the dense phase abrasive slurry is introduced into the interaction chamber to surround or otherwise be sidewardly of the liquid jet.

19. A method according to any one of claims 4 to 17 wherein the liquid jet is introduced into the interaction chamber to surround or otherwise be sidewardly of the abrasive slurry.

20. A method of operating a high pressure liquid nozzle assembly having an interaction chamber, the method including supplying a dense phase abrasive slurry to the chamber, the abrasive slurry comprising a mixture of an abrasive material, water and a thickening agent.

21. A nozzle assembly for generating a high pressure abrasive liquid jet by a method according to any one of claims 1 to 19.

22. A nozzle assembly comprising a body defining an interaction chamber, liquid introduction means for introducing a liquid under pressure into the chamber as a liquid jet, slurry introduction means for introducing a dense phase abrasive slurry into the chamber, and an outlet from the chamber through which a mixture of the liquid and abrasive slurry can issue as an abrasive liquid jet.

23. A nozzle assembly according to claim 22 wherein the dense phase abrasive slurry is introduced into the chamber to surround or otherwise be sidewardly of the liquid jet.

24. A nozzle assembly according to claim 23 wherein the liquid introduction means is axially aligned with the outlet of the chamber.

25. A nozzle assembly according to claim 22 wherein the liquid jet slurry is introduced into the chamber to surround or otherwise be sidewardly of the dense phase abrasive slurry.
26. A nozzle assembly according to claim 25 wherein the abrasive slurry introduction means is axially aligned with the outlet of the chamber.

27. A method of generating an abrasive liquid jet substantially as herein described.

28. A nozzle assembly substantially as herein described with reference to the accompanying drawings.

* * * * *