

Description

The invention relates generally to apparatus and methods for creating particle-containing foams, especially (but not exclusively) foamed fracturing fluids carrying high concentrations of proppant material.

During the completion of an oil or gas well, or the like, one technique which is sometimes used to stimulate production is the fracturing of the subsurface producing formation. This is accomplished by pumping a fluid at a very high pressure and rate into the formation to hydraulically create a fracture extending from the well bore out into the formation. In many instances, a proppant material such as sand is included in the fracturing fluid, and subsequently deposited in the fracture to prop the fracture so that it remains open after the fracturing pressure has been released from the formation.

In recent years, it has become popular to utilize a fracturing fluid which has been foamed. There are a number of advantages of foamed fracturing fluids which are at this point generally recognized. For example, one advantage of foamed fracturing fluids is that they have low fluid loss characteristics resulting in more efficient fracture treatments and reduced damage to water sensitive formations.

Another advantage is that foamed fracturing fluids have a relatively low hydrostatic head, thus minimizing fluid entry into the formation and its resulting damage. Also, foamed fracturing fluids have a high effective viscosity permitting the creation of wider vertical fractures and horizontal fractures having greater area. Another advantage is that foamed fracturing fluids typically have a high proppant carrying capacity allowing more proppant to be delivered to the site of the fracture and more proppant to remain suspended until the fracture heals.

Currently available foamed fracturing fluids do have at least one major disadvantage, and this pertains to the proppant concentrations available with currently practiced foam generator techniques. Typically, current techniques involve blending a mixture of proppant and liquid containing a suitable surfactant. The mixture is pumped to high pressure after which the gaseous phase, typically nitrogen or carbon dioxide, is added to produce the foamed proppant-laden fracturing fluid.

This technique involves an inherent proppant concentration limitation due to the concentration limitation of the proppant/liquid mixture. The theoretical maximum concentration of a sand/liquid mixture is approximately 34 pounds of sand per gallon (4.1 g/cm³) of liquid. This corresponds to a liquid volume just sufficient to fill the void spaces of bulk sand. In common practice, this maximum is further limited by the blending and pumping equipment capabilities and lies in a range of 15 to 25 lb/gal. (1.8 to 3.0 g/cm³).

Typically, foams are produced which have approximately three unit volumes of gaseous

phase per unit volume of liquid phase corresponding to a foam quality, that is a gaseous volume fraction, of 75%. Herein lies the problem; when the liquid phase is foamed, the gas expands the carrier fluid to approximately four times its original volume. A sand concentration of 25 pounds of sand per gallon (3.0 g/cm³) of liquid in a sand/liquid slurry is reduced to approximately 6 pounds of sand per gallon (0.7 g/cm³) of carrier fluid, i.e., foam by the process of foaming. Even the theoretical maximum sand concentration of 34 lb/gal (4.1 g/cm³) in the sand/liquid slurry would only produce an 8.5 lb/gal (1.0 g/cm³) concentration in a 75% quality foam.

The concentration of proppant in the fracturing fluid is of considerable importance since this determines the final propped thickness of the fracture. A fracturing fluid with a sand concentration of 34 pounds of sand per gallon (4.1 g/cm³) of carrier fluid could theoretically prop the fracture at its hydraulically created width.

Another problem encountered with many fracturing fluids including foam also involves proppant concentration and this pertains to the fracturing fluid's compatibility with the formation core and formation fluids, particularly in gas wells. For example, many formations contain clays which swell when contacted by water base fluids resulting in reduced formation permeability. Foamed fracturing fluids reduce this problem due to their low fluid loss and low hydrostatic head characteristics, both of which result in less fluid entering the formation. However, even with foamed fracturing fluids, the theoretical maximum sand concentration is 34 pounds of sand per gallon (4.1 g/cm³) of liquid phase of the foam and as previously mentioned, the current practical limit is about 25 pounds per gallon (3.0 g/cm³). A foamed fracturing fluid with a greater concentration of sand to-liquid would be highly desirable for water sensitive formations since a given amount of sand could be delivered to the formation with less liquid in the carrier fluid.

Prior to the present invention, the typical approach to these problems of the inherent limitation of sand concentration in foam, created by the limitation on the proportion of sand which can be carried by the liquid prior to foaming, has been to concentrate the sand in the sand/liquid slurry prior to forming.

One example of a foam sand concentrator of that type which also generally explains the inherent limitations in the prior art foaming processes, is shown in U.S. Patent No. 4,448,709 to Bullen. Bullen indicates that the physical limitation of the high pressure pumps utilized in his process limits the sand concentration in the initial liquid/sand slurry to about 10 pounds of sand per gallon (1.2 g/cm³) of liquid. When such a slurry is foamed to a 75% quality, the resulting foam carries 2 1/2 pounds of sand per gallon (0.3 g/cm³) of foam, if no concentration is used. The Bullen concentrator is stated to be capable of removing about 50% of the liquid from the slurry, thus doubling the proppant concentration in the sub-

sequent foam to a maximum of about 5 pounds per gallon (0.6 g/cm³) of 75% quality foam, that is 20 pounds per gallon (2.4 g/cm³) of liquid in the resulting foam.

Other examples of devices which concentrate sand in the sand-liquid slurry prior to foaming are shown in U.S. Patent No. 4,126,181 to Black and U.S. Patent No. 4,354,552 to Zingg.

Thus it is apparent that although the prior art has recognized the problem of the inherent limitations on sand concentration in foamed proppant carrying fracturing fluids, no satisfactory solution to the problem has been provided.

We have now devised apparatus and methods by which sand concentrations many times greater than even the theoretical maximum concentration of 34 pounds sand per gallon (4.1 g/cm³) of liquid phase can be achieved. Tests have produced stable foams having said concentrations up to 100 pounds of sand per gallon (12 g/cm³) of liquid phase in the foam.

This is accomplished by introducing the sand at high pressures with the gas stream into the mixing vessel, and introducing the high pressure liquid stream separately into the vessel, thus mixing the gas, liquid and sand at high pressure in the foam generator vessel.

This avoids the inherent sand carrying limitation present when the sand is introduced in a sand/liquid slurry.

The invention thus provides a method of generating a foam containing particulate material, comprising:

- (a) introducing a stream of gas and particulate material into a vessel;
- (b) introducing a stream of liquid into said vessel; and
- (c) mixing said streams and thereby forming a foam containing particulate material.

French patent specification FR-A-2521869 describes a foam-forming head particularly for attachment to an agricultural spray boom, which comprises a body, a main flow passage (for a frother eg. gas) disposed through the body and having an inlet and an outlet, an annular plenum disposed in said body and surrounding said main flow passage; a second flow passage (for the foam base material) disposed in the body and having a first inlet end and a second end communicated with the annular plenum.

The present invention provides apparatus for use in the method of the invention, which apparatus comprises a body; a main flow passage disposed through said body and having an inlet and an outlet; and annular plenum disposed in said body and surrounding said main flow passage; a second flow passage disposed in said body and having a first inlet end and a second end communicated with said annular plenum; characterised by adjustable annular nozzle means, disposed in said body between said annular plenum and said main flow passage, for providing an annular flow path of adjustable width communicating said annular plenum with said main flow passage.

In order that the invention may be more fully understood, reference is made to the accompanying drawings, wherein:

Fig. 1 shows a sectioned elevation view of one embodiment of dry sand foam generator of the invention, in combination with a schematic illustration of associated equipment utilized with the foam generator.

Fig. 2 is a graphical illustration of the theoretical maximum sand concentrations of both the prior art wet sand foam generation techniques and the new dry sand foam generation techniques of the present invention, as a function of foam quality. On the left-hand vertical axis of Fig. 2, the foam sand concentrations are displayed as weight of sand per volume of foam, and on the right-hand vertical axis of Fig. 2, the liquid sand concentrations are displayed as weight of sand per volume of liquid phase contained in the foam.

Fig. 3 is a graphical illustration of the composition of foams created by the apparatus and methods of the present invention, as a function of foam quality and particulate concentration.

Referring now to the drawings, and particularly to Fig. 1, a system generally designated by the numeral 10 is illustrated for producing foamed fracturing fluids carrying high concentrations of proppant material in accordance with the principles of the present invention. The system 10 is based upon the use of a dry sand foam generating apparatus generally designated by the numeral 12. The foam generating apparatus 12 may also be generally referred to as a vessel 12.

Although the invention is being disclosed in the context of the production of a proppant carrying foam for hydraulic fracturing of a well, the invention is also useful in other areas such as foamed gravel packing wherein said or the like is packed in an annulus surrounding a well casing. Further, while specific reference to a particulate material comprising sand will be discussed, it is to be understood that any other particulate may be utilized such as, for example, sintered bauxite, glass beads, calcined bauxite, and resin particles, as well as any other conventionally known particulates for use in the treatment of subterranean formations.

The foam generating apparatus 12 has a body 14 with a straight vertical main flow passage 16 disposed therethrough. Main flow passage 16 has an inlet 18 at its upper end, and an outlet 20 at its lower end.

Foam generating apparatus 12 includes an upper first nozzle insert 22 threadably engaged at 24 with an upper threaded counterbore 26 of body 14. Nozzle insert 22 has an inner end 28 received in the body 14 and adjustably positioned relative to an annular conically tapered first seat 30 surrounding main flow passage 16.

Inner end 28 of nozzle insert 22 has a conically tapered annular surface 32 defined thereon. The conical taper of surface 32 is complementary with that of annular seat 30, that is, the taper on both the surface 32 and seat 30 are substantially

the same. In the example shown, surface 32 and seat 30 are each tapered 60° from the horizontal.

An annular conical first flow path 34 is defined between tapered surface 32 and seat 30 and has a width defined vertically in Fig. 1 which is adjustable by adjustment of the threaded engagement 24 between insert 22 and body 14.

Below the threaded engagement 24, insert 22 has a reduced diameter cylindrical outer portion 36 closely received within an upper cylindrical bore 38 of body 14 with a seal being provided therebetween by O-ring 40.

Below cylindrical portion 36 is a nozzle end portion 42 of insert 22 having a further reduced diameter.

An upper annular plenum 44 is defined between nozzle portion 42 of insert 22 and upper bore 38 of body 14, and surrounds the main flow passage 16.

A transverse liquid inlet passage 46, which may generally be referred to as a second flow passage 46, is disposed in the body 14. Inlet passage 46 has an outer inlet end 48, and an inner second end 50 which is communicated with the annular plenum 44.

As is further explained below, liquid inlet passage 46 is utilized to introduce a liquid stream, generally a water based liquid including surfactant, into the foam generating apparatus 12. The liquid stream also may contain other additives such as viscosifying agent, crosslinking agent, gel breakers, corrosion inhibitors, clay stabilizers, various salts such as potassium chloride and the like which are well-known conventional additives for fluids utilized in the treatment of subterranean formations.

The viscosifying agent can comprise, for example, hydratable polymers which contain in sufficient concentration and reactive position, one or more functional groups such as hydroxyl or hydroxylalkyl, cis-hydroxyl, carboxyl, sulfate, sulfonate, amino or amide. Particularly suitable such polymers are polysaccharides and derivatives thereof, which include but are not limited to, guar gum and derivatives thereof, locust bean gum, tara, konjak, tamarind, starch, karaya, tragacanth, carrageenan, xanthan and cellulose derivatives. Hydratable synthetic polymers include, but are not limited to, polyacrylate, polymethacrylate, polyacrylamide, maleic anhydride-methylvinyl ether copolymers, polyvinyl alcohol and the like.

Various crosslinking agents for the above viscosifying agents are well known and include, but are not limited to, compounds containing titanium (IV) such as various organotitanium chelates, compounds containing zirconium IV such as various organozirconium chelates, various borate-containing compounds, pyroantimonates and the like.

A lower second nozzle insert 52 is threadably engaged at 54 with an internally threaded lower counterbore 56 of body 14.

Second nozzle insert 52 is constructed similar to first nozzle insert 22, except that its upper inner end has a radially inner conical tapered surface 58

which is complementary with a downward facing conically tapered second annular seat 60 defined on body 14 and surrounding main flow passage 16. In the example shown, surface 58 and seat 60 are each tapered 15° from the horizontal.

Although the tapered annular openings associated with seats 30 and 60 are each tapered downwardly in Fig. 1, the apparatus 12 can be inverted with the seats 30 and 60 then being tapered upwardly so that the conical fluid jets ejected therefrom are directed against the downward flow of gas and sand through flow passage 16.

A lower second annular plenum 62 is defined between second nozzle insert 52 and a lower counterbore 64 of body 14.

A transverse supplemental gas inlet passage 66 is disposed in body 14 and communicates a supplemental gas inlet 68 thereof with the second plenum 62.

As is further explained below, transverse gas inlet passage 66 and the adjustable lower nozzle insert 52 are utilized to provide supplemental gas, if necessary, to the proppant carrying foam. In some instances, however, such supplemental gas may not be necessary, and the transverse gas inlet passage 66 will not be used. In fact, the methods of the present invention can in many instances be satisfactorily performed with a foam generator in which the lower second nozzle insert 52 and the associated transverse gas inlet passage 66 are eliminated.

The main flow passage 16 can generally be described as including an upper portion 70 disposed through first nozzle insert 22, a middle portion 72 defined within the body 14 itself, and a lower portion 74 defined in second nozzle insert 52.

Also schematically illustrated in Fig. 1 are a plurality of associated apparatus which are utilized with the foam generating apparatus 12 to produce a proppant laden foamed fracturing fluid.

A high pressure sand tank 76 is located vertically directly above the foam generating apparatus 12. Sand tank 76 is substantially filled with a particulate material such as sand 78 through a sand fill inlet valve 80.

The sand tank 76 is then filled with high pressure nitrogen gas from a nitrogen gas supply 82 through primary nitrogen supply line 84. A pressure regulator 86 and other conventional equipment (not shown) for controlling the pressure of the gas supplied to sand tank 76 are included in supply line 84. While the gas supply 82 is disclosed as nitrogen, many other gases are suitable for use in generating a foam according to the methods and using the apparatus of the present invention. Such other gases include, without limitation, air, carbon dioxide, as well as any inert gas, such as any of the noble gases.

After the sand tank 76 is filled with sand 78, it is pressurized with nitrogen gas to a relatively high pressure, preferably above 500 psi (3.45 MPa) for reasons that are further explained below.

This dry sand 78 is introduced into the foam

generating apparatus 12 by opening a valve 88 in sand supply line 90 which extends from a bottom 92 of sand tank 76 to inlet 18 of main flow passage 16 of foam generating apparatus 12. The sand supply line 90 preferably is a straight vertical conduit, and the valve 88 is preferably a full opening type valve such as a full opening ball valve.

When the valve 88 is opened, a stream of gas and sand is introduced into the main flow passage 16 of apparatus 12. The dry sand 78 flows by the action of gravity and differential gas pressure downward through sand supply line 90 into the vertical bore 16 of foam generating apparatus 12.

A water based liquid 94 is contained in a liquid supply tank 96. A high pressure pump 98 takes the liquid 94 from supply tank 96 through a suction line 100 and discharges it under high pressure through a high pressure liquid discharge line 102 to the inlet 48 of transverse liquid inlet passage 46.

The liquid 94 in supply tank 96 will have a sufficient concentration of a suitable surfactant mixed therewith in tank 96, so that upon mixing the liquid 94 with gas and sand in flow passage 16, a stable foam will be formed. Suitable surfactants are well known in the art and include, by way of example and not limitation, betaines, sulfated or sulfonated alkoxylates, alkyl quaternary amines, alkoxylated linear alcohols, alkyl sulfonates, alkyl aryl sulfonates, C₁₀-C₂₀ alkyl-diphenyl ether sulfonates and the like.

The liquid and surfactant flow through the transverse liquid inlet passage 46 into the annular plenum 44. The liquid and surfactant then flow from the annular plenum 44 in the form of a self-impinging conical jet flowing substantially symmetrically through the first annular flow passage 34 and impinging upon the vertically downward flowing stream of gas and sand flowing through main flow passage 16.

This high pressure, high speed, self-impinging conical jet of water based liquid and surfactant mixes with the downward flowing stream of gas and dry sand in a highly turbulent manner so as to produce a foam comprised of a liquid matrix of bubbles filled with nitrogen gas. This foam carries the sand in suspension therein.

If supplemental gas, in addition to the gas introduced with the dry sand from sand tank 76, is required to achieve the desired foam quality, that gas is supplied from nitrogen gas supply 82 through a supplemental gas supply line 110 having a second pressure regulator 112 disposed therein. Supplemental gas supply line 110 connects to supplemental gas inlet 68 of transverse gas inlet passage 66 so that gas is introduced into the second annular plenum 62 and then through the conical flow passage defined between conically tapered surface 58 on the inner end of lower nozzle insert 52 and the tapered annular lower seat 60 of body 14.

In the testing of the foam generating apparatus 12 which has been done to date, however, it has

been determined that in many instances sufficient gas can be introduced with the dry sand 78 from the sand tank 76, and that the desired foam quality can be controlled by controlling the amount of liquid introduced through transverse liquid inlet passage 46.

The proppant laden foam generated in the foam generating apparatus 12 exits the outlet 20 and is conducted through a conduit 114 to a well 116. As will be understood by those skilled in the art, the foam fracturing fluid is directed downwardly through tubing (not shown) in the well 116 to a subsurface formation (not shown) which is to be fractured.

When conducting a hydraulic fracturing operation, the pressure of the fracturing fluids contained in conduit 114 when introduced into the well head 116 are substantially in excess of atmospheric pressure. Well head pressures in a range from 1000 psi to 10,000 psi (6.89 to 68.9 MPa) are common for hydraulic fracturing operations.

The delivery rate of dry sand 78 into the foam generator 12 is controlled by the differential gas pressure between the sand tank 76 and the bore 16 of the foam generator apparatus 12. For a given sand delivery rate, flow rate of the liquid jet entering transverse liquid inlet passage 46 determines the liquid sand concentration, that is the pounds of sand per gallon of liquid phase in the carrier fluid, of the generated foam. The volumetric flow rate of gas through said supply line 90 required to deliver the dry sand together with the volumetric flow rate of supplemental gas, if any, supplied through transverse gas inlet passage 66 determine the quality, that is the gaseous volume fraction of fluid phases, of the generated foam.

If it is desired to vary the flow rate of dry sand 78 into the foam generating apparatus 12, that will generally be accomplished by varying the nitrogen pressure supplied to the sand tank 76.

If it is desired to vary the flow of liquid to the transverse liquid inlet passage 46 of foam generator 12, that will be accomplished by varying the pumping rate of pump 98.

The setting of the threaded engagement of upper nozzle insert 22 with body 14 permits adjustment of the width of the first annular flow path 34. This adjustment is generally utilized for the purpose of achieving an appropriate mixing energy and thus a satisfactory foaming of the materials which are mixing with the main flow passage 16. This adjustment also conceivably could be used to affect the flow rate of liquid therethrough.

Although not shown in Fig. 1, suitable flowmeters may be placed in lines 84, 102 and 110 to measure the flow of fluids therethrough. Flow of sand out of tank 76 can be measured by measuring a change in weight of the tank 76 and its contents.

It is noted that the high pressure nitrogen supply illustrated in Fig. 1, namely the cylinder 82 of compressed nitrogen gas and the pressure regulator 86, are representative of the equip-

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ment utilized for the laboratory tests described below. In actual field usage, however, nitrogen will typically be supplied by a positive displacement cryogenic pump which pumps nitrogen in a supercooled liquid state into the supply lines 84 and/or 110. In such a system, the mass flow rate of nitrogen will be known and controlled by the volumetric rate of the cryogenic pump.

Referring now to Fig. 2, a graphical representation is presented of the theoretical maximum sand concentration of a foam as a function of foam quality, both for wet sand foam generation such as has been practiced in the prior art where the sand is introduced in a sand/liquid slurry, and for dry sand foam generation as disclosed in the present application wherein the sand is introduced with a stream of gas. There are two sets of data displayed in Fig. 2. Foam sand concentration, e.g., the pounds of sand per gallon of foam, is displayed vertically on the left side of the graph. The values displayed on the right-hand vertical axis of Fig. 2 are for liquid sand concentrations, e.g., the pounds of sand per gallon of liquid phase of the foam.

Looking first at the foam sand concentrations displayed on the left-hand vertical axis of Fig. 2, the theoretical maximum foam sand concentration for a wet sand foam generation process like that utilized in the prior art is shown by the dashed line 118 and is seen to be a decreasing linear function of foam quality. The plotted maximum concentrations for the wet sand foam generation process as represented by line 118 are obtained by adding sufficient gas volume to the liquid occupying the void volume of bulk sand to obtain a given foam quality.

The theoretical maximum foam sand concentration for the dry sand foam generation process of the present invention is represented by the solid line 120 and is seen to be an increasing linear function of foam quality. The plotted maximum concentrations for the dry sand foam generation process as represented by straight line 120 are obtained by adding sufficient liquid to the gas volume occupying the void volume of bulk sand to obtain a given foam quality.

It is noted that the lines 118 and 120 intersect at a point 122 corresponding to a 50% foam quality. At a 50% foam quality, both the wet sand foam generation process represented by line 118 and the dry sand foam generation process represented by line 120 provide an identical foam since they both contain equal volumes of gas and liquid and an identical amount of sand.

It is further noted that for foam qualities less than 50%, the theoretical maximum foam sand concentrations for the dry sand process of the present invention are lower than those for the wet sand foam generation process of the prior art, and thus it may be undesirable to use the dry sand foam generation process when a relatively low quality foam below 50% is desired. It must be remembered, however, that the values shown in Fig. 2 are theoretical maximums, which differ substantially from the practical maximums which

can be obtained in some cases, and thus in some situations there may still be an advantage to using the dry sand foam generation process of the present invention for relatively low quality foams below 50% quality.

It is generally desired that the foam produced by the present invention have a "Mitchell quality", that is, a volume ratio of the gaseous phase to the total gaseous and liquid phases and disregarding the volume of the particulate solids, in the range from about 0.53 to 0.99. This can also be expressed as a quality in the range from about 53% to about 99%. A general discussion of the Mitchell quality concept can be found in U.S. Patents Nos. 4,480,696 to Almond et al., 4,448,709 to Bullen, and 3,937,283 to Blauer et al.

For the purposes of the present invention, it is preferred that an upper limit of foam quality be about 96%, because the properties of the foam become somewhat unpredictable at higher quality levels where the foam may convert to a mist. Thus, the generally preferred range of quality for foams generated by the dry sand foam generation process of the present invention is in a range from about 53% to about 96%.

Referring now to the liquid sand concentrations displayed on the right-hand vertical axis of Fig. 2, the theoretical maximum liquid sand concentrations for the prior art wet sand foam generation process and for the dry sand foam generation process of the present invention are shown by dashed line 124 and solid line 126, respectively.

For the prior art wet sand foam generation processes, line 124 shows a constant 34 lb/gal (4.1 g/cm³) theoretical maximum liquid sand concentration. As previously explained, this is determined by the volume of liquid required to fill the void spaces in tightly packed sand.

However, for the dry sand foam generation process of the present invention as represented by solid line 126, the maximum liquid sand concentration is unbounded as the foam quality approaches 100%.

As is apparent from the graphical comparisons shown in Fig. 2, the potential for achieving high sand concentrations in a proppant carrying foam utilizing the dry sand foam generation techniques of the present invention is many times greater than that using prior art wet sand foam generation techniques.

With the methods of the present invention, proppant carrying foamed fracturing fluids can be produced which contain a ratio of sand to the liquid phase of the foam, that is, a liquid sand concentration such as that represented on the right-hand vertical axis of Fig. 2, substantially in excess of both the theoretical maximum ratio of particulate material to liquid which could have been contained in the liquid, i.e., 34 lbs/gal (4.1 g/cm³), and the somewhat lower practical maximum ratio, i.e., 15 to 25 lbs/gal (1.8 to 3.0 g/cm³), which could have been contained in the liquid as a result of limitations on pumping equipment and the like. In this regard, referring now to Fig. 3, the preferred compositions of foams produced by the

present invention include those compositions denoted by the trapezoidal region defined by the points, A, B, C and D.

A number of laboratory tests, which are described below, have been performed with the dry sand foam generation process of the present invention, and it has been determined that with the apparatus illustrated in Fig. 1, it is desirable that the process be performed with a nitrogen gas pressure within the sand tank 76 at least equal to about 500 psi (3.45 MPa). At such supply pressures, the pressure drop between tank 76 and bore 16 of foam generating apparatus 12 is only about 5 psi (34.5 kPa), so that the pressure at which the foam is generated in bore 16 is also equal to at least about 500 psi (3.45 MPa).

Tests have been conducted utilizing a gas pressure in sand tank 76 ranging from about 50 psi (345 kPa) up to about 1,000 psi (6.89 MPa). At nitrogen pressures in sand tank 76 lower than about 500 psi (3.45 MPa), it has been observed that there is an excess of gas present in the foam generating apparatus 12, and a continuous uniform foam is not produced; instead, the fluid exiting outlet 20 has intermittent slugs of gas contained in the foam.

With nitrogen gas pressure in sand tank 76 in excess of about 500 psi (3.45 MPa), a continuous substantially uniform foamed fluid is produced.

The tests to date have all been run with water based fluids, varying from plain water up to a viscosified fluid containing 40 pounds of derivatized guar per 1,000 gallons (4.82 g/cm³) of water, all with satisfactory results.

All tests to date have been run utilizing a surfactant sold under the trade name "Howco Suds", a water-soluble biodegradable surfactant blend, which can be obtained from Halliburton Services, Duncan, Oklahoma.

Example 1

An early test was conducted utilizing a pressurized air source at 82 rather than pressurized nitrogen. The sand tank 76 was pressurized to approximately 75 psi (520 kPa) with compressed air. The differential pressure between sand tank 76 and main flow passage 16 of the foam generator was about 50 psi (345 kPa). The test was run until a five-gallon bucket (1.9×10⁻²m³) was filled with foam exiting outlet 20. The weight of sand delivered from sand tank 76, and water delivered from supply tank 96 were determined, and converted to a volume basis. In that manner it was determined that the five gallons (1.9×10⁻²m³) of foam collected included 1.32 gallons (5.0×10⁻³m³) of sand and 0.37 gallons (1.4×10⁻³m³) of water. The remaining volume of the five gallons (1.9×10⁻²m³) of foam, 3.31 gallons (1.3×10⁻²m³) was comprised of air. From this data, a foam quality of 89.9% was calculated. The liquid sand concentration was calculated to be 74.9 pounds of sand per gallon (9.0 g/cm³) of water in the foam, which corresponds to 7.53 pounds of sand per gallon (0.9 g/cm³) of foam. In this test, the liquid was actually

introduced through passage 66 rather than passage 46, so that the liquid entered flow passage 16 as a concentric conical jet tapered downwardly at an angle of 15° to the horizontal. The foam generating apparatus 12 utilized in this test had a bore 16 with a diameter of 3/8 inch (9.5 mm).

Example 2

A later test was run, again using a foam generator with a 3/8-inch (9.5mm) bore. In this example, the liquid stream was injected into passage 46 so that it entered the main flow passage 16 at a downward angle of 60° to the horizontal. Air pressure supplied to the top of tank 76 was at 69 psi (475 kPa). Air pressure measured in line 90 immediately above the apparatus 12 was 50 psi (345 kPa). A liquid flow rate through line 102 of 0.34 gallon (1.3×10⁻³m³) per minute at a pressure of 175 psi (1206 kPa) was measured. A total weight of sand injected was measured to be 41.64 pounds (18.9 kg). Again, the test was run until a five-gallon (1.9×10⁻²m³) can of foam was produced. The sand volume in the foam was calculated to be 1.89 gallons (7.2×10⁻³m³). The liquid volume in the foam was calculated to be 0.42 gallon (1.6×10⁻³m³). This left an air volume in the foam of 2.69 gallons (1.0×10⁻²m³). From this a quality of 86.5% was determined. A liquid sand concentration of 99.9 pounds of sand per gallon (12.0 g/cm³) of liquid phase of the foam was calculated. This foam was observed to be a good stable foam.

In both of Examples 1 and 2 described above, it was observed that there was substantial excess air present in the process, as slugs of air were intermittently produced from outlet 20 between slugs of foam.

Substantial further testing was conducted and modifications were made to attempt to eliminate this excess air. Testing was done utilizing centrifugal separators to separate the foam from the excess air.

Finally, later testing showed that the problem of excess air was eliminated when the pressure of gas supplied to sand tank 76 exceeded about 500 psi (3.45 MPa). This is shown in the following Example 3.

Example 3

This test was run using a foam generator with a 5/8 inch (15.9mm) bore. The liquid stream was injected into passage 46 so that it entered the mainflow passage 16 at a downward angle of 60° to the horizontal. The test apparatus was modified to allow the generated foam to be collected in a receiver vessel (not shown) at approximately the same pressure as that at which it was generated. The volume of generated foam was determined by measuring the volume of water displaced from the receiver vessel. An average nitrogen pressure in sand tank 76 was 756 psig (5.2 MPa gauge). Average pressure in the bore 16 of foam generating apparatus 12 was 750 psig (5.2 MPa gauge). Average pressure in the foam receiver vessel was 730 psig (5.0 MPa gauge). The test was run for 5.0

minutes. Total sand weight delivered was 292 lb. (133 kg) for a sand rate of 58.4 lb/min (26.5 kg/min). Total liquid supplied was 3.0 gal ($1.1 \times 10^{-2} \text{ m}^3$) for a liquid rate of 0.60 gallons per minute ($2.3 \times 10^{-2} \text{ m}^3$ per minute). The gas flow rate of the apparatus 12 was calculated to be 55.7 standard cubic feet (1.56 m^3) per minute. Total foam generated was 57.37 gal (0.22 m^3). From this data, a foam quality at the foam generator 12 of 93% was calculated. A liquid sand concentration of 97.3 pounds of sand per gallon (11.7 g/cm^3) of liquid phase of the foam was calculated. This corresponds to a foam sand concentration of 6.8 pounds of sand per gallon (0.8 g/cm^3) of foam. The volumetric rate of foam production at the generator was 11.26 gallons ($4.3 \times 10^{-2} \text{ m}^3$) per minute.

Finally, it has been determined subsequent to the testing described above, that at high gas supply pressures, e.g., 900 psi (6.2 MPa), it is not necessary to direct the liquid phase into the foam generator as a self-impinging conical jet; instead a simple "tee" can be used to mix the liquid with the gas and dry sand.

Claims

1. A method of generating a foam containing particulate material, comprising:

(a) introducing a stream of gas and particulate material into a vessel;

(b) introducing a stream of liquid into said vessel; and (c) mixing said streams and thereby forming a foam containing particulate material.

2. A method according to claim 1, wherein said particulate material is sand; and the particulate material and liquid are introduced at rates such that the foam contains a ratio of particulate material to liquid phase of the foam in excess of approximately 34 pounds of particulate per gallon (4.1 g/cm^3) of liquid.

3. A method according to claim 1 or 2, wherein in step (a) the gas/particulate stream is introduced into a cylindrical bore (16) of said vessel; in step (b) the liquid stream is introduced into an annular plenum (44) surrounding said bore and communicated with said bore by an annular opening surrounding said bore; and in step (c), the liquid stream flows radially inward through said annular opening to impinge upon the gas/particulate stream.

4. A method according to claim 3, further comprising a step of adjusting a width of said annular opening.

5. A method according to claim 1 or 2, wherein in step (a), the gas/particulate stream is introduced into a substantially linear flow passage (16) of said vessel; and in steps (b) and (c), a self-impinging conical jet of said liquid stream discharges substantially symmetrically into said flow passage and impinges upon said gas/particulate stream.

6. A method according to claim 5, wherein in step (a), the flow passage is oriented substantially vertically and said gas/particulate stream is intro-

duced substantially vertically downward into said flow passage.

7. A method according to any of claims 1 to 6, further comprising a step of introducing another stream of gas into said vessel, and mixing this stream with the other two streams.

8. A method according to any of claims 1 to 7, wherein steps (a), (b) and (c) are all performed at relatively high pressures substantially in excess of atmospheric pressure, eg. at least equal to about 500 psi (3.45 MPa).

9. A method according to claim 1, 2 or 3, wherein in step (a), the gas is nitrogen and the particulate material is sand; and in step (b), the liquid is an aqueous based liquid including a surfactant.

10. A foam generating apparatus (12), comprising: a body (14); a main flow passage (16) disposed through said body and having an inlet (18) and an outlet (20); an annular plenum (44) disposed in said body and surrounding said main flow passage; a second flow passage (46) disposed in said body and having a first inlet end (48) and a second end (50) communicated with said annular plenum; characterised by adjustable annular nozzle means (22), disposed in said body between said annular plenum and said main flow passage, for providing an annular flow path (34) of adjustable width communicating said annular plenum with said main flow passage.

11. Apparatus according to claim 10, wherein said adjustable nozzle means includes a nozzle insert threadably engaged with a threaded bore (26) of said body, said nozzle insert having an inner end (28) received in said body and adjustably positioned relative to an annular seat (30) surrounding said main flow passage by adjusting a threaded engagement of said nozzle insert with said threaded bore of said body.

12. Apparatus according to claim 11, wherein a first portion of said main flow passage is centrally axially disposed through said nozzle insert.

13. Apparatus according to claim 10, 11 or 12, wherein said annular flow path is a conical flow path.

14. Apparatus according to claim 10, 11, 12 or 13, further comprising: a second annular plenum (62) disposed in said body and surrounding said main flow passage; and third flow passage (66) disposed in said body and having a first inlet end (68) and a second end communicated with said second annular plenum; a second adjustable annular nozzle means (52), disposed in said body between said second annular plenum and said main flow passage, for providing a second annular flow path of adjustable width communicating said second annular plenum with said main flow passage; said first and second adjustable nozzle means including first and second nozzle inserts threadably engaged with first and second aligned threaded bores of said body, each of said first and second nozzle inserts having an inner end received in its respective threaded bore of said body and adjustably positioned relative to first and second annular seats, respectively surround-

minutes. Total sand weight delivered was 292 lb. (133 kg) for a sand rate of 58.4 lb/min (26.5 kg/min). Total liquid supplied was 3.0 gal ($1.1 \times 10^{-2} \text{ m}^3$) for a liquid rate of 0.60 gallons per minute ($2.3 \times 10^{-2} \text{ m}^3$ per minute). The gas flow rate of the apparatus 12 was calculated to be 55.7 standard cubic feet (1.56 m^3) per minute. Total foam generated was 57.37 gal (0.22 m^3). From this data, a foam quality at the foam generator 12 of 93% was calculated. A liquid sand concentration of 97.3 pounds of sand per gallon (11.7 g/cm^3) of liquid phase of the foam was calculated. This corresponds to a foam sand concentration of 6.8 pounds of sand per gallon (0.8 g/cm^3) of foam. The volumetric rate of foam production at the generator was 11.26 gallons ($4.3 \times 10^{-2} \text{ m}^3$) per minute.

Finally, it has been determined subsequent to the testing described above, that at high gas supply pressures, e.g., 900 psi (6.2 MPa), it is not necessary to direct the liquid phase into the foam generator as a self-impinging conical jet; instead a simple "tee" can be used to mix the liquid with the gas and dry sand.

Claims

1. A method of generating a foam containing particulate material, comprising:

(a) introducing a stream of gas and particulate material into a vessel;

(b) introducing a stream of liquid into said vessel; and (c) mixing said streams and thereby forming a foam containing particulate material.

2. A method according to claim 1, wherein said particulate material is sand; and the particulate material and liquid are introduced at rates such that the foam contains a ratio of particulate material to liquid phase of the foam in excess of approximately 34 pounds of particulate per gallon (4.1 g/cm^3) of liquid.

3. A method according to claim 1 or 2, wherein in step (a) the gas/particulate stream is introduced into a cylindrical bore (16) of said vessel; in step (b) the liquid stream is introduced into an annular plenum (44) surrounding said bore and communicated with said bore by an annular opening surrounding said bore; and in step (c), the liquid stream flows radially inward through said annular opening to impinge upon the gas/particulate stream.

4. A method according to claim 3, further comprising a step of adjusting a width of said annular opening.

5. A method according to claim 1 or 2, wherein in step (a), the gas/particulate stream is introduced into a substantially linear flow passage (16) of said vessel; and in steps (b) and (c), a self-impinging conical jet of said liquid stream discharges substantially symmetrically into said flow passage and impinges upon said gas/particulate stream.

6. A method according to claim 5, wherein in step (a), the flow passage is oriented substantially vertically and said gas/particulate stream is intro-

duced substantially vertically downward into said flow passage.

7. A method according to any of claims 1 to 6, further comprising a step of introducing another stream of gas into said vessel, and mixing this stream with the other two streams.

8. A method according to any of claims 1 to 7, wherein steps (a), (b) and (c) are all performed at relatively high pressures substantially in excess of atmospheric pressure, eg. at least equal to about 500 psi (3.45 MPa).

9. A method according to claim 1, 2 or 3, wherein in step (a), the gas is nitrogen and the particulate material is sand; and in step (b), the liquid is an aqueous based liquid including a surfactant.

10. A foam generating apparatus (12), comprising: a body (14); a main flow passage (16) disposed through said body and having an inlet (18) and an outlet (20); an annular plenum (44) disposed in said body and surrounding said main flow passage; a second flow passage (46) disposed in said body and having a first inlet end (48) and a second end (50) communicated with said annular plenum; characterised by adjustable annular nozzle means (22), disposed in said body between said annular plenum and said main flow passage, for providing an annular flow path (34) of adjustable width communicating said annular plenum with said main flow passage.

11. Apparatus according to claim 10, wherein said adjustable nozzle means includes a nozzle insert threadably engaged with a threaded bore (26) of said body, said nozzle insert having an inner end (28) received in said body and adjustably positioned relative to an annular seat (30) surrounding said main flow passage by adjusting a threaded engagement of said nozzle insert with said threaded bore of said body.

12. Apparatus according to claim 11, wherein a first portion of said main flow passage is centrally axially disposed through said nozzle insert.

13. Apparatus according to claim 10, 11 or 12, wherein said annular flow path is a conical flow path.

14. Apparatus according to claim 10, 11, 12 or 13, further comprising: a second annular plenum (62) disposed in said body and surrounding said main flow passage; and third flow passage (66) disposed in said body and having a first inlet end (68) and a second end communicated with said second annular plenum; a second adjustable annular nozzle means (52), disposed in said body between said second annular plenum and said main flow passage, for providing a second annular flow path of adjustable width communicating said second annular plenum with said main flow passage; said first and second adjustable nozzle means including first and second nozzle inserts threadably engaged with first and second aligned threaded bores of said body, each of said first and second nozzle inserts having an inner end received in its respective threaded bore of said body and adjustably positioned relative to first and second annular seats, respectively surround-



ing said main flow passage; and first and second aligned portions of said main flow passage are centrally axially disposed through said first and second nozzle inserts, respectively.

Patentansprüche

1. Verfahren zur Herstellung eines körniges Material enthaltenden Schaumes, gekennzeichnet durch

(a) Einführen eines Stromes aus Gas und körnigem Material in ein Gefäß;

(b) Einführen eines Stromes einer Flüssigkeit in das Gefäß; und

(c) Vermischen der beiden Ströme zur Bildung des das körnige Material enthaltenden Schaumes.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß das körnige Material Sand ist und daß das körnige Material und die Flüssigkeit mit einer solchen Geschwindigkeit eingeführt werden, daß das Verhältnis von körnigem Material zur Flüssigkeitsphase des Schaumes ungefähr $4,1 \text{ g/cm}^3$ (34 Pfund pro Gallone) übersteigt.

3. Verfahren nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß im Schritt (a) der Strom aus Gas und körnigem Material in eine zylindrische Bohrung (16) des Gefäßes eingeführt wird, im Schritt (b) der Flüssigkeitsstrom in einen die Bohrung umgebenden Ringraum (44) eingeführt wird, der durch eine die Bohrung umgebende ringförmige Öffnung mit der Bohrung in Verbindung steht, und im Schritt (c) der Flüssigkeitsstrom durch die ringförmige Öffnung radial einwärts fließt und aus den Strom aus Gas und körnigem Material auftritt.

4. Verfahren nach Anspruch 3, dadurch gekennzeichnet, daß die Weite der ringförmigen Öffnung eingestellt wird.

5. Verfahren nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß im Schritt (a) der Strom aus Gas und körnigem Material in einen im wesentlichen geradlinigen Durchflußkanal des Gefäßes eingeführt wird, und daß in den Schritten (b) und (c) ein selbst-treffender konischer Strahl des Flüssigkeitsstroms im wesentlichen symmetrisch in den Durchflußkanal austritt und auf den Strom aus Gas und körnigem Material auftritt.

6. Verfahren nach Anspruch 5, dadurch gekennzeichnet, daß im Schritt (a) der Durchflußkanal im wesentlichen vertikal gerichtet ist und der Strom aus Gas und körnigem Material im wesentlichen vertikal nach unten gerichtet in den Durchflußkanal eingeführt wird.

7. Verfahren nach einem der Ansprüche 1 bis 6, gekennzeichnet durch den weiteren Schritt der Einführung eines weiteren Gasstroms in das Gefäß und Mischung dieses Stromes mit den anderen beiden Strömen.

8. Verfahren nach einem der Ansprüche 1 bis 7, dadurch gekennzeichnet, daß die Schritte (a), (b) und (c) bei verhältnismäßig hohen, im wesentlichen über Atmosphärendruck liegenden Drücken von wenigstens etwa 3,45 MPa (500 Psi) ausgeführt werden.

9. Verfahren nach Anspruch 1, 2 oder 3,

dadurch gekennzeichnet, daß im Schritt (a) das Gas Stickstoff ist und das körnige Material Sand ist und daß im Schritt (b) die Flüssigkeit eine ein Benetzungsmittel enthaltende Flüssigkeit auf wässriger Basis ist.

10. Vorrichtung (12) zur Erzeugung von Schaum, enthaltend einen Körper (14), einen durch den Körper verlaufenden Hauptdurchflußkanal (16) mit einem Einlaß (18) und einem Auslaß (20), einen den Hauptdurchflußkanal umgebenden, in dem Körper angeordneten Ringraum (44), einen zweiten, in dem Körper angeordneten Durchflußkanal (46) mit einem ersten Einlassende (48) und einem zweiten Ende (50), das mit dem Ringraum in Verbindung steht, gekennzeichnet durch einstellbare, ringförmige Düsenmittel (22), die in die Körper zwischen dem Ringraum und dem Hauptdurchflußkanal angeordnet sind und einen ringförmigen Strömungsweg (34) einstellbarer Weite bilden, der den Ringraum mit dem Hauptdurchflußkanal verbindet.

11. Vorrichtung nach Anspruch 10, dadurch gekennzeichnet, daß die einstellbaren Düsenmittel einen Düseneinsatz enthalten, der mit einer Gewindebohrung (26) des Körpers in Gewindeeingriff ist, ein in dem Körper aufgenommenes inneres Ende (28) hat und zu einem ringförmigen, den Hauptdurchflußkanal umgebenden Sitz (30) dadurch einstellbar angeordnet ist, daß der Gewindeeingriff des Düseneinsatzes mit der Gewindebohrung des Körpers verstellt wird.

12. Vorrichtung nach Anspruch 11, dadurch gekennzeichnet, daß ein erster Teil des Hauptdurchflußkanals axial mittig in dem Düseneinsatz angeordnet ist.

13. Vorrichtung nach Anspruch 10, 11 oder 12, dadurch gekennzeichnet, daß der ringförmige Strömungsweg ein konischer Strömungsweg ist.

14. Vorrichtung nach Anspruch 10, 11, 12 oder 13, gekennzeichnet durch einen zweiten Ringraum (62), der in dem Körper angeordnet ist und den Hauptdurchflußkanal umgibt; einen dritten Durchflußkanal (66), der in dem Körper angeordnet ist und ein erstes Einlassende (68) und ein zweites Ende hat, das mit dem zweiten Ringraum in Verbindung steht; zweite einstellbare ringförmige Düsenmittel (52), die in dem Körper zwischen dem zweiten Ringraum und dem Hauptdurchflußkanal angeordnet sind und einen zweiten ringförmigen Strömungsweg einstellbarer Weite bilden, der den zweiten Ringraum mit dem Hauptdurchflußkanal verbindet, erste und zweite Düsenansätze der ersten bzw. zweiten einstellbaren Düsenmittel, die im Gewindeeingriff mit ersten und zweiten, zueinander ausgerichteten Gewindebohrungen des Körpers stehen und jeweils ein inneres Ende haben, das in der zugehörigen Gewindebohrung des Körpers aufgenommen ist und einstellbar zu dem ersten bzw. zweiten ringförmigen, jeweils den Hauptdurchflußkanal umgebenden Sitz angeordnet ist, und erste und zweite ausgerichtete Teile des Hauptdurchflußkanals, die axial mittig in dem ersten bzw. zweiten Düsenansatz angeordnet sind.



Revendications

1. Procédé de génération d'une mousse contenant des particules de matériau, comprenant:

(a) l'introduction d'un courant de gaz et de matériau en particules dans un récipient;

(b) l'introduction d'un courant de liquide dans ledit récipient; et

(c) le mélange desdits courants, suivi de la formation d'une mousse contenant du matériau en particules.

2. Procédé selon la revendication 1, dans lequel ledit matériau en particules est du sable; et le matériau en particules et le liquide sont introduits à des débits tels que la mousse renferme une proportion de matériau en particules par rapport à la phase liquide de la mousse supérieur à environ 4,1 g/cm³ (34 livres par gallon) de particules de liquide.

3. Procédé selon la revendication 1 ou 2, dans lequel, au stade (a) le courant gaz/particules est introduit dans un orifice cylindrique dudit récipient (16); au stade (b) le courant liquide est introduit dans une chambre annulaire (44) entourant ledit orifice et communiquant avec ledit orifice par une ouverture annulaire entourant ledit orifice; et, au stade (c), le courant liquide coule radialement à l'intérieur de ladite ouverture annulaire pour être propulsé contre le courant gaz/particules.

4. Procédé selon la revendication 3, comprenant en outre un stade de réglage de la largeur de ladite ouverture annulaire.

5. Procédé selon la revendication 1 ou 2, dans lequel, au stade (a) le courant gaz/particules est introduit dans un passage de courant pratiquement linéaire (16) dudit récipient; et, aux stades (b) et (c), un jet conique autopropulsé dudit courant liquide se décharge pratiquement symétriquement dans ledit passage de courant et est propulsé contre le courant gaz/particules.

6. Procédé selon la revendication 5, dans lequel le passage de courant est orienté pratiquement verticalement et ledit courant gaz/particules est introduit pratiquement verticalement vers le bas dans ledit passage de courant.

7. Procédé selon l'une quelconque des revendications 1 à 6, comprenant en outre un stade d'introduction d'un autre courant de gaz dans ledit récipient et de mélange de ce courant avec les deux autres courants.

8. Procédé selon l'une quelconque des revendications 1 à 7, dans lequel les stades (a), (b) et (c) sont tous réalisés, à des pressions relativement élevées, supérieures à la pression atmosphérique, par exemple au moins égales à environ 3,45 MPa (500 psi).

9. Procédé selon l'une des revendications 1, 2 ou 3, dans lequel, au stade (a), le gaz est de l'azote et le matériau en particules est du sable; et, au stade (b), le liquide est une liquide à base d'eau contenant un tensioactif.

10. Appareil générateur de mousse (12), qui comprend: un corps (14); un passage de courant

principal (16) disposé à travers ledit corps et pourvu d'une admission et d'une évacuation; une chambre annulaire disposée dans ledit corps et entourant ledit passage de courant principal; un second passage de courant disposé dans ledit corps et pourvu d'une admission (18) et d'une évacuation (20); une chambre annulaire (44) disposée dans ledit corps et entourant ledit passage de courant principal; un second passage de courant (46) disposé dans ledit corps et pourvu d'une première extrémité d'admission (48) et d'une seconde extrémité (50) communiquant avec ladite chambre annulaire; caractérisé par un moyen d'injection annulaire réglable (22), disposé dans ledit corps entre ladite chambre annulaire et ledit passage de courant principal, pour fournir un chemin d'écoulement annulaire (34) de largeur réglable faisant communiquer ladite chambre annulaire avec ledit passage de courant principal.

11. Appareil selon la revendication 10, dans lequel ledit moyen d'injection annulaire réglable comprend une buse rapportée, vissée, dans un alésage fileté (26) dudit corps, ladite buse possédant une extrémité interne (28) engagée dans ledit corps et ajustée en position, par rapport à un coussinet annulaire (30) entourant ledit passage de courant principal, par ajustage d'un engrènement fileté de ladite buse avec ledit alésage fileté dudit corps.

12. Appareil selon la revendication 11, dans lequel une première partie dudit passage de courant principal est disposée suivant l'axe central de ladite buse rapportée.

13. Appareil selon l'une des revendications 10, 11 ou 12, dans lequel ledit écoulement annulaire est un écoulement conique.

14. Appareil selon l'une des revendications 10, 11, 12 ou 13, comprenant en outre: une seconde chambre annulaire (62) disposée dans ledit corps et entourant ledit passage de courant principal; un troisième passage de courant (66) disposé dans ledit corps et pourvu d'une première extrémité d'admission (68) et d'une seconde extrémité communiquant avec ladite seconde chambre annulaire; une seconde buse annulaire ajustable (52), disposée dans ledit corps entre ladite seconde chambre annulaire et ledit passage de courant principal, pour fournir un second écoulement annulaire de largeur réglable faisant communiquer la seconde chambre annulaire avec ledit passage de courant principal; lesdites première et seconde buses ajustables comportant des première et seconde buses rapportées, vissées dans les premier et second alésages filetés alignés dudit corps, chacune desdites première et seconde buses rapportées ayant une extrémité interne logée dans son alésage fileté respectif dudit corps et ajustée en position par rapport aux premier et second coussinets annulaires, entourant respectivement ledit passage de courant principal; et les première et seconde parties alignées dudit passage de courant principal sont disposées suivant l'axe central desdites première et seconde buses rapportées respectivement.

