(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 445 875 A1**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: **91200440.5**

(51) Int. Cl.[5]: **B01F 5/20**

(22) Date of filing: **01.03.91**

(30) Priority: **09.03.90 US 491561**

(43) Date of publication of application:
11.09.91 Bulletin 91/37

(84) Designated Contracting States:
DE DK FR GB IT NL

(71) Applicant: **PUMPTECH N.V.**
Atlantic House Noorderlaan 147 Bus 5C
B-2030 Antwerpen(BE)
(84) **DE DK GB IT NL**

Applicant: **COMPAGNIE DES SERVICES DOWELL SCHLUMBERGER**
50, Avenue Jean Jaurès B.P. 360
F-92541 Montrouge Cédex(FR)
(84) **FR**

(72) Inventor: **Althouse, James**
62, Church Street
Hudson Ohio 44236(US)
Inventor: **Hitt, Robert**
Crêt de Fraisses
F-42530 Saint Genest Lerpt(FR)

(74) Representative: **Richebourg, Michel François**
Etudes et Fabrication Dowell Schlumberger
Z.I. Molina La Chazotte B.P. 90
F-42003 Saint-Etienne Cédex 1(FR)

(54) Method and apparatus for mixing solids and fluids.

(57) A method and apparatus useful for dispersing solids in liquids. A mixer device implementing the method is capable of continuously mixing solid and liquid materials whose physical properties may be allowed to vary over a wide range of values without degradation of product quality. Basic components of the mixer consist of a rotatable turbine 22 enclosed in a casing 20. The turbine is configured so as to open an "eye" in the rotating liquid where solids may be introduced into the liquid stream. Make-up liquid is supplied at a controlled pressure to the turbine through an annular suction inlet. The mixer is configured so that the ratio of solid material to liquid material remains constant from their initial contact with one another to their discharge from the apparatus as a mixed product. A more thorough mixing of solids and liquids is achieved by directing the flows of materials by the method described, and the reliability and dynamic range of the mixer are significantly improved with respect to the performance of devices taught in the prior art.

EP 0 445 875 A1

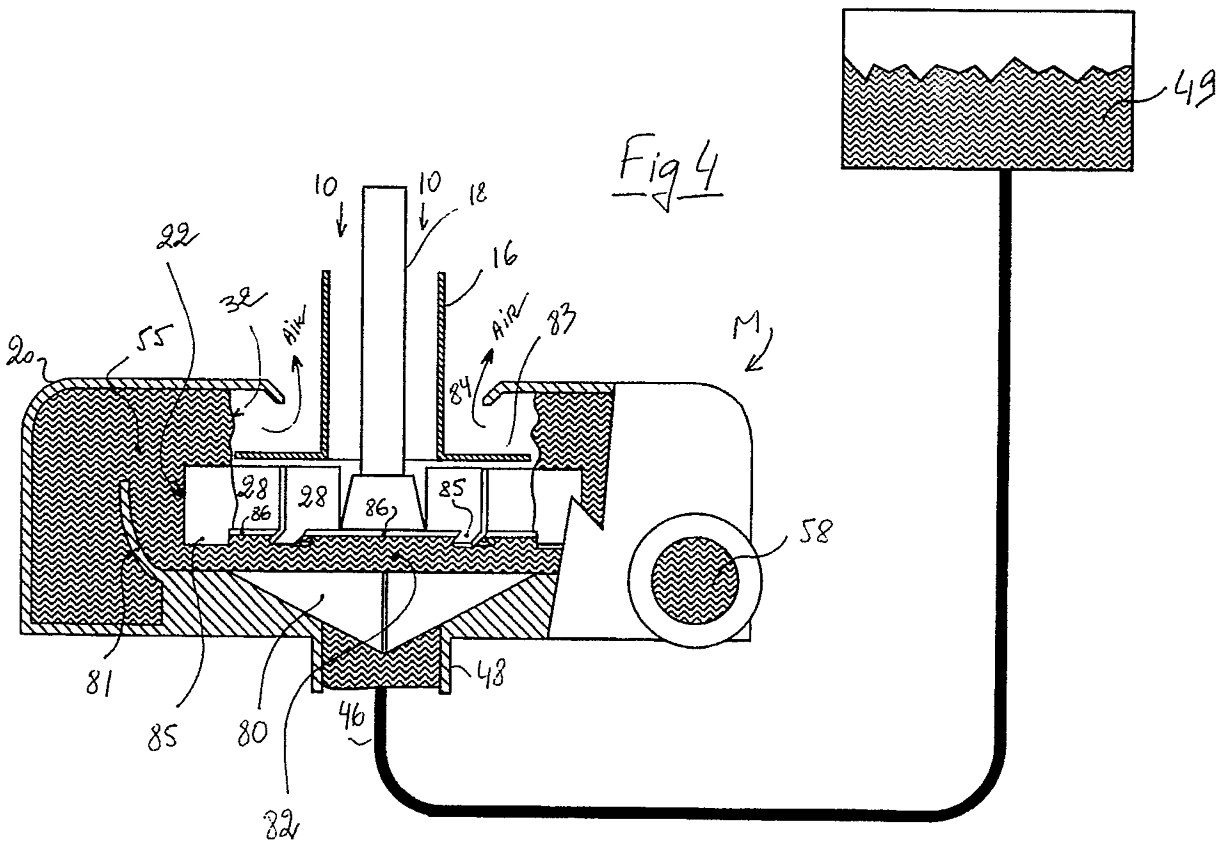

10
10
18
16
22
32
AIR
AIR
83
20
55
84
M
49
28
28
86
86
85
58
81
85
80
48
46
82

Fig 4

Background : Field of the Invention

This invention relates to a method and apparatus for continuously mixing solid particles with a liquid composition, and especially for continuously mixing cement particles with mix water or mix fluid in the oil-, gas-, or geothermal industries, for the cementing of drilled wells.

Background : Description of the Prior Art

Methods for the mixing of materials have long been divided into two general classes. In the first of these, batch mix methods, the required amounts of components of the mixture are placed in a vessel. The components are stirred or circulated in the vessel in order to produce a specified volume of mixture. According to the second general class of mixing methods, continuous mix methods, specified amounts of the required components of the mixture are metered into a mixing region.
Here they are blended together, and the resulting mixture withdrawn at a rate equal to the volumetric rate of the incoming components. The mixing region often consists of a simple stirred vessel but various forms of ejectors, jet mixers and the like, in which mixing is accomplished by eduction, are also well known.

The need for, and advantages of, continuous mix methods over batch mix methods in many applications are familiar to the art. Among the advantages are the ability to continuously change the specified proportions of the mixture in the course of mixing; the elimination of inventory or storage of mixed material prior to any further steps in a sequential process; and the ability to apply a large amount of power into a small mixing volume whereby the components are more efficiently mixed together.

An important disadvantage of continuous mix methods has also long been known to the art. Conventional methods of continuous mixing require that the inflow of each component, the outflow of the resulting mixture, and the proportions of the respective components must be controlled simultaneously. For example, if a change in the proportion of two components is specified, it is not sufficient to change the flow rate of just one of these into the mixer in order to effect the specification. The discharge rate of the mixture must be changed at the same time. If it were not, the mixing region would flood or starve and the continuous mixing process stop. When subsequent steps in a sequential process require that a mixture be supplied at a specified rate, as is often the case when continuous mixing methods are advantageous, the rates of each inflowing component must be altered simultaneously to obtain both the specified proportions and the specified discharge rate from the mixer. The requirement for simultaneous control of multiple variables leads to complex proportioning control systems in which the advantages of continuous methods are outweighed by the disadvantages of high cost and unreliability.

Zingg and Stoskopf in U.S. Pat. No. 3,256,181 (1966) disclosed a method by which many of the advantages of continuous mixing methods are retained, and by which the disadvantage described above can be overcome. The method depends on a pressure balance principle. Liquid is supplied under pressure to a mixing region and swirled so that an "eye" is opened to the atmosphere at the center of the mixing region. Rotation of an annular body of fluid establishes a pressure at the periphery of the body of fluid which balances the pressure of the supply fluid. Liquid cannot flow into the eye and flood out from the mixing region. Nor can atmospheric air cross the rotating annular body of liquid to reach the mixing region. When a specified amount of material (generally taken to be more dense than the liquid) is metered into the eye, it is propelled by rotation out into the pressurized liquid, mixed with the liquid, and the resulting mixture discharged under pressure from the mixing region.

In typical embodiments of the method described by Zingg and Stoskopf, the liquid supplied to the mixing chamber is pressurized by a centrifugal pump impeller. These embodiments constitute one class of "constant volume" continuous mixers. When a change in the proportion of components is required, it is sufficient to change the flowrate of the component being introduced into the eye of the mixing region. A change in flowrate of material into the eye results in a net change of pressure in the mixing region. This change in pressure will induce the opposite (volumetric) change in flow of liquid supplied by the centrifugal pump impeller in order to maintain pressure-balance in the mixing region. Consequently, control of the proportion of components of the mixture is simplified.

Zingg and Stoskopf (1966) did not recognize that ease of control could be the principal advantage of one of the embodiments of their method. Its potential value has only come to be recognized in the subsequent practice and further development of their method.

Subsequent practice and further development of the method of mixing a particulate material and a pumpable liquid disclosed by Zingg and Stoskopf have also revealed that it cannot be usefully implemented under many conditions of practical interest today. As the volumetric ratio of solid particles to liquid is increased, implementation of Zingg and Stoskopf's method produces a progressively less acceptable mixture or slurry. The product becomes an air-entrained suspension of agglomerated particles. This agglomerated mixture is not useable in the form produced by the method. In addition, air-entrainment causes a substantial loss in pressure in the mixing region, so that the efficiency of the implementation of the method is poor.

The potentially poor performance of Zingg and Stoskopf's method was not recognized at the time it was disclosed. Their method was originally intended to be implemented for the production of a slurry of sand or sand-like particles and gel composition which is used in treatments intended to increase the productive efficiency of earth wells. At the time the method was disclosed, a typical volumetric ratio of particles to liquid was 1:10. Ratios as high as 1:4 were reported, but these represented exceptionally high solids loading and were intended to test the limits of then-current practice. A greater understanding of the processes involved in the treatment of earth wells, and improvements in gel composition and associated equipment, have led to the use of slurries with a volumetric ratio exceeding 1:1 in modern treatments. At these high volumetric ratios, implementation of Zingg and Stoskopf's method often produces an air-entrained slurry unsuitable for use.

Portland cement slurry is a second example of a liquid-particle system in which implementation of the method fails to produce an acceptable product. Pumpable slurries of portland cement are introduced into earth wells in order to secure pipe or casing to the rock face of the well bore. These slurries often have volumetric ratios of particles to liquid exceeding 1:1. Implementation of Zingg and Stoskopf's method produces a highly agglomerated, air entrained slurry of very poor quality. Other examples of systems which require high volumetric rations of particles to liquid will be obvious to those familiar with the art.

Zingg and Stoskopf's method is flawed because it incorporates no means to regulate the proportion of the inflowing materials at their point of contact. While the over-all ratio of particles to liquid can be controlled, their ratio when they are initially mixed cannot. Zingg and Stoskopf's method calls for the introduction of particles into the liquid at an uncontrolled volumetric ratio that is always much higher than that specified for the product mixture. The result is an air-entrained paste or mass of agglomerates which is not readily dispersed into a uniform slurry of acceptable quality. The reason why this result is a necessary consequence of implementation of their method, and the reason why it is a insurmountable flaw of that method can be best explained by consideration of the various forms of apparatus which have been applied to implement their method.

The blender apparatus disclosed by Zingg and Stoskopf in U.S. Pat. No. 3,326,536 (1967) has been replaced in current use by the apparatus first described by Althouse in U.S. Pat. No. 4,453,829 (1984). Both of these are continuous process mixers in which liquid and solid materials are fed at a relatively high rate through a relatively small mixing volume. The mixing volume is held almost constant by hydrodynamic gradients induced by the devices. That is, according to the method described by Zingg and Stoskopf (1966), one rotating element acts as a centrifugal-pump impeller and induces a flow of liquid and slurry through a casing. A second rotating element, usually termed a "slinger," is used to open an atmospheric eye at the top of the mixer where solids may be introduced directly. These two rotating elements establish a hydraulic balance between them such that any change in the flow of solids through the slinger is dynamically compensated by a change in the flow of liquid induced by the impeller. Consequently, the mixing volume, although small with respect to the flowrate of materials through the mixer, remains almost constant. Extraneous means of volume- or liquid-flow-control are not used.

Significant disadvantages of machines like those described by Althouse (1984), and by Zingg and Stoskopf (1967) have been discussed in the literature. Improved versions of configurations based on the slinger-impeller balance principle are described by MacIntire in U.S. Pat. Nos. 4,614,435 (1986) and 4,671,665 (1987). MacIntire discloses therein a means of allowing air to vent itself from the casing of machines of this type. His improvement was justified by the observation that machines of this type have a limited solids flow capacity. When the solids flow rate reaches a certain value, which appears to be a function of the size of the slinger, its impeller looses prime and ceases to operate as an effective centrifugal pump. The casing floods with solids, and the mixing process must be stopped. In a typical application of a continuous oilfield mixer, an unanticipated shut-down can result in costly remediation work and often presents a serious safety hazard.

MacIntire (1986, 1987) attributes the capacity limitation to air entrained in the inflowing solid stream which is carried out into the casing by centrifugal forces. This entrained air can find its way to the impeller suction, resulting in a loss-of-prime condition. The impeller can no longer supply pressured fluid to the mixing region, and the process must be stopped. He discloses a means of allowing this air to vent back to the atmosphere before it reaches the impeller suction region.

As embodied, the MacIntire device incorporates no means to assure a flow of air to the vent other than the radial pressure gradient established in its casing. When the entrained air is sufficiently finely dispersed, and the mixture in the casing sufficiently viscous, air can be carried to the impeller suction in spite of a provision for allowing it to vent. These conditions are common in practice and are aggravated by an increase in the solids-liquid ratio of the mixture

Various means of encouraging the air to travel to the vent instead of the impeller suction might be imagined by those familiar with the art. A simple solution would be to place The centrifugal pump impeller in a separate casing as described in Zingg and Stoskopf's (1967) preferred embodiment of their apparatus. However, none of these means overcome the further difficulty that entrained air may equally well be discharged from the mixer. Mixers of this type are typically used to feed pressurized slurry to plunger pumps. An air-entrained slurry is relatively elastic, and its compressibilty results in a gross degradation of the performance of plunger pumps. Additionally, the flow of solids into the mixer is typically controlled by feedback from an instrument or "densitometer" used to measure the density of the slurry at the outlet of the mixer The density of an air-entrained slurry cannot be related to a set-point or desired density in any convenient manner. A control system of this type will always be more-or-less inaccurate.

The problem of air-entrainment at high solids flow rate is the result of a flaw in the conception of the machines based the method disclosed by Zingg and Stoskopf (1966). MacIntire's explanation of the origin of the difficulty is incomplete, and his improvement only addresses a symptom of the real problem. All machines utilizing the slinger-impeller balance principle, as originally disclosed by Zingg and Stoskopf (1966), bring solid particles into contact with a liquid composition in a sequence which is known to be one of the least efficient possible.

The physical properties of mixtures of solid particles in liquids are strongly influenced by the ratio of the two in the mixture. A rule of thumb teaches that the particulate matter should always be introduced into the desired mass of fluid so that the solids concentration is brought up to the desired level by progressive addition of solids, and never the other way around. The reasoning behind this rule is that the apparent viscosity of a slurry of particles in a liquid rises slowly with the addition of particles until a critical value is reached; at which point the mixture turns from a fluid to a paste or mass of partly wetted agglomerates. It requires several orders of magnitude less energy to disperse flowable particles into a slurry than it does to disperse a paste into a liquid. The degree of respective energy demand (at the same solids-liquid ratio) is a strong function of particle size. Coarse sand at relatively low concentration does not form stable agglomerates. Very fine particles, like portland cement particles, readily form an intractable paste. Thus, when one mixes contrary to the rule, the quality of the mixed product will be a strong function of the physical properties, and ratio, of the components of the mixture.

In mixers based on the method disclosed by Zingg and Stoskopf (1966), solids are always introduced into a partially or fully developed slurry to create an abnormally high-density, air-entrained paste. In the course of normal operation, the mixer is in a steady-state condition. Its discharge rate is fixed by suitable external control, usually by fixing the rate of plunger pumps supplied by the mixer. The density and consistency of the discharged slurry is controlled by the rate of solids in-flow and is likewise fixed by feedback control from a densitometer. The bulk of the slurry in the casing is necessarily at the same density and consistency as the discharged slurry. Solids are continuously introduced into this slurry at the slinger where a local volume of heavier-than-desired slurry or paste is formed. Liquid is continuously introduced at the impeller where a local volume of lighter-than-desired slurry is formed. These two slurries are respectively impelled into the recirculating slurry in the casing, re-mixed to the desired density, and further recirculated. The heavier-than-desired slurry created at the slinger has properties that degrade performance of the entire system.

The agglomerated paste must be dispersed into previously mixed slurry and make-up liquid in order to form a blend of the correct density and consistency before its discharge from the casing. The energy required to disperse it is several orders of magnitude greater than that required to disperse solid particles into fresh liquid at the desired ratio. Since the energy input into the mixer is relatively constant, product quality degrades rapidly as the solids-liquid ratio is increased.

At high solids flow rates, dispersion occurs throughout the mixer (and not just in the slinger region) so that air entrained in agglomerates can reach the suction of the impeller. A still higher solids flow rates, the mixer lacks sufficient power to fully disperse these agglomerates, and they are pumped out the discharge, resulting in an inconsistent, air-entrained slurry of very poor quality.

A second important disadvantage of mixers based upon the slinger-impeller balance principle is that they flood with air at high flow capacities. The size of the atmospheric eye in the slinger is determined by a balance of slinger hold-back pressure and impeller discharge pressure, as explained by Althouse (1984) in the patent cited above. When the capacity of the mixer is increased, the impeller discharge pressure falls for two reasons. Firstly, a flow of fluid through a centrifugal impeller results in a net subtracive fluid velocity with respect to that tangential fluid velocity which establishes discharge pressure in the casing. Secondly, as the capacity is increased, the fluid friction losses in the supply piping to the mixer grow. These losses result in a decrease in absolute pressure in the casing. It is the absolute casing pressure which is balanced by the slinger and "held back" to form an eye into which solids are added. When the mixer capacity is increased, the atmospheric eye in the slinger becomes larger.

In an ideal machine the radius of the eye cannot exceed the radius of the slinger so long as the pressure in the mixing region is greater than atmospheric pressure. In the real machines constructed according to Zingg and Stoskopf (1966) the liquid supply pressure is greater than atmospheric. So in principle air should never reach the mixing region. In practice air can do so. The reason is as follows.

The causes of eye enlargement described above usually occur together and interact additively. At high capacities the eye becomes so large that the annular body of rotating liquid and inflowing particles becomes very thin. In addition, the bulk of the stream of inflowing solids follows paths along the leading edge of the slinger blades. The "wall" which prevents air from entering the mixing region becomes unstable and the eye highly irregular. Atmospheric air over-reaches the perimeter of the slinger and floods the casing. As a result the mixer catastrophically looses prime and fails in service.

In a typical application of the mixer, make-up fluid is supplied from a storage tank. When the level in this tank falls during the course of a continuous mixing process, the hydrostatic head available at the liquid inlet to the impeller decreases.
Thus the atmospheric eye is further enlarged by the effective loss of absolute casing pressure in the mixer. Zingg and Stoskopf (1966, 1967) disclosed a constant level supply tank to supress this undesirable behavior, but their solution requires an additional piece of equipment and was never widely used. In practice, the degradation of prodcut quality and risk of loosing prime are augmented by the sensitivity of mixers, based on the slinger-impeller balance principle, to the absolute pressure available at their inlet.

The device described by MacIntire (1986, 1987), with provision for allowing air to vent itself, actually increases the risk of air flooding the casing. There is an interface of slurry and atmospheric air at or near the perphery of the vent during the course of operation of the mixer. That is to say, the vent serves to open an atmospheric eye much like that opened by the slinger. The size of this vent-eye is regulated by the same rules which pertain to the slinger. Thus, when casing pressure falls, the atmospheric interface at the vent grows outward radially. At high mixer capacity, this interface will grow close to the diameter of the impeller, and air will spill over the impeller rim from the vent. the mixer is likely to immediately and catastrophicly loose prime, flood with solids, and fail in service.

Objects and Advantages

The method and apparatus disclosed herein do not suffer from any of the disadvantages inherent in the principles and practice of those taught by the prior art, but incorporate the objects of a simple, continuous, constant-volume mixing system. The method is based upon the invention of a means by which solid particles may be introduced into a stream of fresh inflowing liquid before that liquid is recirculated into slurry of the desired density in a casing. Hydraulic balance is maintained based on a principle different from that applied in the prior art. The method and apparatus also have other advantages over those used in current practice.

Accordingly, a primary object of the invention is to provide an improved mixing method and apparatus for continuously and rapidly intermixing a liquid and particulated solids, especially at high solids concentration and especially where the solids consist of fine particles.

A further object of the invention is to provide an improved mixer which can be operated over a wide dynamic flow-range of solids and liquids while minimizing the risk of unanticipated shut-downs and undesirable variations in mixture quality.

A further object is to provide an improved mixer which is low in self contained inventory, and wherein rapid changes may be effected in the volume of the materials being mixed while maintaining predetermined proportions of the components.

A further object is to provide an improved mixer which develops a positive flow pressure of the mixed slurry useful for moving the slurry to other equipment without requiring a pump or the like.

A further object is to provide an improved continuous mixer wherein the mechanism may continue to be operated, even though the delivery line from the mixer has been closed of otherwise shut off.

A further object is to provide an improved mixer which will continuously produce a liquid-solids mixture having a predetermined density.

A further object is to provide an improved mixer, especially for mixing cement particles and water in the oilfield industry, with no or little air in the cement slurry allowing accurate density measurement.

Still further objects and advantages will be-come apparent from a consideration of the ensuing description and drawings.

Drawing Figures

FIGURE 1 is front elevation view, mostly in section of the mixer apparatus of this invention.

FIGURE 2 is a progressive section view, looking down on the blender from above.

FIGURE 3 is a front elevation view, mostly in section of the turbine used in an alternate embodiment of this invention.

FIGURE 4 and FIGURE 5 represent a front elevation view, mostly in section, of two mixers according to the invention, preferred for oilfield applications.

According to the broad concept of this invention, an annular body of liquid is swirled in a casing by a turbine or an impeller element. The rotation of the liquid serves to establish increasing radial velocity and pressure gradients in the liquid. At some finite inner radius the absolute pressure is taken to be a minimum. At some finite outer radius, the absolute pressure is that developed by the rotation of the annular body of liquid between these radiii plus that at the inner radius. Supply liquid is introduced into the swirling body of liquid across an annular section whose inner radius is greater than that of the inner radius of the rotating body of liquid and whose outer radius is less than that of the outer radius of the rotating body of liquid. The pressure of the supply liquid is regulated such that it closely matches that of the rotating annular body of fluid across the section at which the supply liquid is introduced.

The inner radius of the rotating body of fluid defines an "eye". The casing is open to the atmosphere over the circular section of the eye, and thus the pressure at the inner radius of the rotating annular body of liquid is fixed at atmospheric. Supply liquid is introduced at a radius greater than that of the eye and at a pressure slightly more than atmospheric. Thus the pressure gradient in the rotating body of fluid is not disturbed, and the system remains in balance. Supply liquid cannot flood the eye and flow out of the casing to atmosphere, nor can atmospheric air reach the source of supply liquid, nor can it be introduced into the mixture.

Solid particles and the like may be introduced into the eye where they contact the inflowing supply liquid arriving across the annular section. Vigorous mixing takes place in the rotating body of liquid where solids and inflowing supply liquid are brought into intimate contact.

The inflowing solid particles and liquid are continuously contacted together at the proper proportions or specified ratio of components for the mixture. Solids are not recirculated into already-mixed slurry so that the formation of agglomerates is precluded.

Liquid or slurry is drawn off from the casing at a pressure established by the rotation of the annular body of mixture in the turbine. Thus only one means of rotating the body of liquid is required to impell solids into the supply liquid, to mix the components together, and to pressurize the resulting slurry for discharge from the casing.

Referring particularly to FIGURE 1, except as noted, the mixer apparatus of this invention is generally indicated by the letter M.

Above the mixer is a hopper or silo 10. The hopper serves as a container for solid particles, and is equipped with a solids-flow regulating means (valve 1) 12 which controls the flow of solids into a solids inlet cone 16 of the mixer.

A drive shaft 18 is positioned inside the solids inlet cone 16, such that the bottom of the drive shaft extends through a solids inlet 17 of the mixer and into a casing 20. The drive shaft 18 is coupled to a rotary drive means (not shown) which may or may not be supported by an element of the mixer as installation requirements dictate. The mixing-pressurizing element of the mixer is a turbine **22** which is secured to the bottom of the drive shaft **18** by a bolt fastener **24**.

The turbine **22** is disposed within the casing **20** coaxially with the longitudinal axis of the casing. The turbine has an insert **26** to which a plurality of blades **28** is attached. These blades extend in an inward radial direction along the top of the insert **26** to a radius approximately equal to or a little less than that of the radius **30** (FIG. 2) of the atmospheric eye of the mixer under "nominal conditions" that are defined below. The atmospheric eye is a generally cylindrical volume defined by the interface **32** of atmospheric air with fluid composition in the mixer. The interface is drawn in FIGURE 2 as a curly line to to indicate that it is never perfectly smooth or cylindrical in practice. In the preferred embodiment, the blades are not extended fully into the eye to avoid interference with the flow of solids into the turbine.

The blades **28** are also extended in a inward radial direction along the bottom of the insert **26** to an inner radius which should be determined as follows.

Choose a "nominal eye diameter" with sufficient cross-sectional area to admit the maximum flow of solids specified in normal operation.

Choose a turbine diameter and operating speed sufficient to develop a specified discharge pressure, taking the pressure at the eye radius to be atmospheric. The turbine outer radius should normally be approximately twice that of the nominal eye radius.

The pressure at the periphery of the turbine insert **36** can never be allowed to be less than atmospheric or air will have entry to the suction region of the turbine. This adverse condition is precluded by seting the radius of the inner edge of the blades in the suction **34** less than that of the radius of the perphery of the insert **36**. To determine the exact ratio, one must specify a minimum net positive suction head available (NPSHA). The pressure developed in the annualar body of fluid between the radius at **34** and the radius at **36** at the specified rotational speed of the turbine should be greater than the diference between atmospheric pressure and the minimum expected NPSHA.

One must then specify a maximum NPSHA. When the apparatus is operated under this condition the absolute pressure at the periphery of the insert **36** is the maximum NPSHA plus the difference between atmospheric pressure and the minumum NPSHA. This pressure will be balanced by the pressure developed in the annular body of fluid between the actual eye radius and the periphery of the insert **36** plus atmospheric pressure. Use the nominal eye radius in this relationship to find the radius of the insert. Then find the inner radius of the suction blade edges. If these are pitched as shown in FIGURE 1, use a hydraulic average. One should also note that if the insert radius is greater than about 75% of the turbine it may be necessary to adjust some of the specifications.

Those familiar with the art will also recognize that appropriate safety factors should be incorporated in all calculations. They will also note that the calculation of exact dimensions may be further refined depending on the particular type or style of turbine chosen for a specific application.

To provide for smoothness of flow, a continuation of the casing **20** and the insert **26** are configured to form an annular turbine inlet **40** between them. The cross-sectional area of this inlet should be chosen such that the fluid is not accelerated in the suction in accordance with good hydraulic practice. The turbine inlet **40** is connected directly and smoothly to the liquid suction inlet **42** also formed between the insert **26** and the inner casing wall. Stator blades **44**, which suppress liquid prerotation and make mixer performance more predictable, should be installed in the liquid suction by attachment to the casing inner wall. The annular suction inlet is continued smoothly into circular section at the liquid inlet to the mixer **46**. A manifold or fluid supply pipe **48** is provided to supply liquid from a liquid reservoir **49**.

The turbine blades **28** extend in an outward radial direction to the periphery of the turbine and are curved in conformity with good turbomachine design principles. In the preferred embodiment shown, an upper shroud **50** is installed on the turbine between the solids inner edge of the blades **38** and the periphery of the turbine. The shroud **50** serves to define a plurality of flow passages **52** between the blades and prevents inflowing solids from eroding the upper edges of the blades and the inner wall of the casing **20** opposite. The height of these passages should be constant so that the outflowing mixture in the turbine is decelerated in the radial direction. Deceleration serves to minimize eductor effects which might induce air entrainment. A plurality of pump-back vanes **54**, in accordance with standard practice, is used to prevent backflow of materials in the gap between the shroud and the inner wall of the casing, which gap also serves as a means to exhaust air.

The turbine **22** discharges across its periphery into a receiver volume **55** defined by a continuation of the casing **20.** In the preferred embodiment, the receiver volume of the casing **55** is "semi-voluted." The cross-sectional area of this volume viewed normal to the tangential flow of mixture in the casing is increased starting from an edge **56** (FIG. 2) directly ahead of the discharge outlet **58.** The law of increase is taken from good hydraulic practice and should be arithmetic with distance around the circumference of the mixer to the discharge outlet. However, the total cross-sectional area is always made sufficiently large that the receiver volume of the casing **55** allows for recirculation of the mixture. This feature serves to damp out any irregularities in the flow of solids into the mixer, providing for more precise control of mixture quality. In general, the cross-sectional area should at no point be less than the outlet **58** cross-sectional area, which is determined by standard hydraulic practice.

In the embodiment shown, the casing is voluted along the longitudinal axis of the mixer. This configuation is preferred over the standard method of radial voluting for two reasons. Firstly the the velocity, and consequently the pressure, opposite the turbine discharge is held relatively constant. Thus, the eye remains symmetric with the solids inlet, avoiding the risk a spray of fluid across a segment of that inlet. Secondly it provides a device of overall smaller diameter, which is more convenient and economical.

In order to provide for additional damping and better control where necessary, a certain portion of the discharged mixture may be recycled or recirculated from the discharge of the mixer **58** back to the liquid supply pipe of the mixer **48** by means of a recirculating pipe **60**. The degree of recirculation is proportional to the size selected for this pipe and may be determined by rules and principles well known to those familiar with the art. A valve (valve 2) **62** is provided so that the mixer can be operated in either the recirculating or direct mode according to the circumstances described herein.

The precise configuration of the turbine **22** depends on the performance desired of a preferred embodiment. FIGURES 1 and 2 illustrate a turbine of the radial type which is particularly suited for the specification of low specific speed. It would be selected when a relatively high discharge pressure with respect to capacity is required. At higher specific speeds where capacity is more important than discharge pressure, a Francis configuration would be specified. A vortex-type turbine is shown in FIGURE 3, on which the names and identifying numbers of the parts are retained. This configuration would be specified, for example, where extremely abrasive solids are processed, and close clearances in the solids or slurry flow-paths were especially undesirable.

The extension of blades into the annular suction region in order to regulate the pressure of the supply liquid is incorporated into the preferred embodiment because of its simplicity. Those familiar with the art will also recognize that various commonly known means for controlling the pressure of the inflowing supply fluid could also be used. For example, a regulated low pressure booster pump could be placed in the line between the liquid reservoir **49** and the fluid supply pipe **48**. This means and others of the like sort may also be selected in accordance with the method of this invention.

The invention may be illustrated by describing a typical operation in which portand cement powder is mixed with water to obtain a cementatious slurry suitable for pumping into a well in order to provide a hydraulic seal between the casing and rock formations opposite that casing.

At the start of the operation, a drive means rotates the drive shaft 18 and turbine 22. Once the turbine is in motion, water is supplied to the inlet of the mixer 48. The water flows into the turbine through the liquid inlet passage defined by the liquid inlet 46 of the mixer, the liquid suction inlet 42, and the annular turbine inlet 40. The water is rotated by the turbine and develops pressure and velocity at is flows out into the casing receiver volume 55. Air in the mixer is discharged through the gap between the turbine upper shroud 50 and the inner wall of the casing 20 directly opposite. Thus the mixer can be primed even when it is convenient to keep its outlet 58 blocked. Once the mixer has been primed in this fashion and is pumping, it will remain in a primed state even if the absolute pressure along the liquid inlet path is allowed to fall below atmospheric.

After the mixer is primed, cement powder is metered into the turbine along the solids inlet path defined by the means of flow regulation 12, the solids inlet cone 16, the solids inlet 17, and the air-liquid interface 32. The water and cement particles are brought into contact at this point. They then pass through the passages in the turbine 52 where they are mixed and pressurized as a slurry. Under these conditions, the mixer is operated in the recirculating mode with valve 62 open. When the density of the slurry reaches the desired value as determined by a measurement means, the outlet is opened and the slurry flows under pressure to a high-pressure pump which delivers it into a well.

As pumping begins, cement powder continues to flow along the solids inlet path. Water is drawn into the mixer through the liquid inlet path based on a volumetric balance which says that the rate of inflowing water equals the rate of outflowing slurry less the rate of inflowing cement powder. Thus the density of the slurry may be controlled by regulating the flow of cement powder into the mixer or by regulating the flow of slurry out of the mixer in combination or singly. Multiple control actions are not required. Once the mixer has reached a steady state condition, the recirculation value may be closed. This action is desirable when the mixer is required to operate around the maximum of its design capacity, and flow losses must be reduced. At lower capacity the valve should be left open in order to maintain more precise control of the density of the slurry.

A modified version of the mixer according to the invention, and especially adapted for preparing continuously cement slurries for the oil-, gas-, or geothermal industries, namely for the cementing of drilled wells, is represented on Figures 4 and 5.

In Fig 1 to 5, same numerical references have the same meaning.

Referring to Figure 4, the casing 20 of the mixer M contains a turbine 22 with blades 28. The cement particles flow from the non-represented hopper 10 into the solid particles inlet 16, 17. Water, or water-based fluid with usual oilfield cementing additives, enters through the inlet 46, 48 from an atmospheric fluid reservoir, either by gravity or through a feeding pump.

A stator 80 prevents the incoming fluid to spin, allowing a constant pressure to establish in the volume 82 immediately below the turbine 22.

The receiver volume 55 is most preferably limited outwardly by a somewhat cylindrical wall 81, and most preferably the slurry outlet 58 is placed behind the said wall as represented on Figures 4 and 5.

An horizontal disk 83 is provided above the turbine 22 so as to partially overlap with blades 28 as shown on Figure 4. While not essential for the operation of the mixer, this disk is most preferred since it prevents the outcoming of solids dust through the air escape vent 84.

The blades 28 may optionnally extend downwardly to form a scoop 85, the purpose of which is to keep the machine primed even at low presssure and expecially when the whole mixer M is built in an inclined configuration, by helping the incoming fluid to be forced upwards.

The machines shown on Figure 4 and on Figure 5 present the advantage of a very stable eye, what is an essential condition to reach the purposes of the inventions as recited above. In that respect, the horizontal disk 86 at the bottom of the turbine defines the position of the eye or interface 32 for a given water or fluid pressure at the inlet 46.

Such machines are especially useful for continuously mixing cement particles with mix water or mix fluid in the oilfield industry and related industry with a very accurate control and monitoring of the dentity of the produced slurry.

Figure 5 represents a further version of the machine represented on Figure 4, where the water or fluid inlet 46, 48 is located at the top of the casing 20. Water or fluid is flowing, either from an atmospheric tank 49 by gravity or through a feeding pump.

Most preferably, the water is introduced in the top cylindrical chamber 90 of the mixer, as defined by the upper part of the casing 20 and an intermediate horizontal wall 91. Both the upper part of the casing 20 and the horizontal wall 91 feature a central hole as represented on Figure 5, aimed at providing space for the air vent 84 and the solid particles inlet 16.

To be noted that the horizontal disk 91 ends inwardly with a certain overlap of the turbine blades 28 while the upper part of the casing 20 extends inwardly beyond the limit of the disk 91 so that the eye (air/slurry interface) can establish and get stabilized in a position which is intermediate between the two inwards limits of, respectively, the upper part of the casing 20 and the disk 91.

In a preferred embodiment a fixed system of blades, generally represented as 92, is positioned in the above mentioned central hole, so that the incoming water in chamber 90 is prevented from spinning.

The principal objects of the invention are effected because the proportions of the components of the mixture are never allowed to exceed the design or desired proportions in any part of the apparatus under a wide variety of typical operating conditions.

The mixing of portland cement slurry was used to illustrate the operation of the invention because this slurry is notoriously difficult to mix to specification. In machines configured according to the prior art, cement powder would be introduced into slurry which has already been mixed to the desired density. But oil-field cement slurries are mixed to a desired density such that there is a minimum amount of "free water" available. That is to say, the proportion of powder to liquid is specified such that there is a minimum of excess water beyond what is required to wet the powder. Any additional volume of cement powder above the "free water point" results in a viscous paste or agglomerates of partly wetted and generally air-entrained solids. These are difficult to reduce to a uniform, pumpable, air-free slurry by any economical means. The mixer disclosed herein is not subject to this fault. Cement powder is introduced directly into water and before the mixture is substantially pressurized by the turbine. Thus, high-quality cement slurry can be supplied by the mixer with no further processing steps required.

Some unexpected advantages accrue to a mixer based on the method suction pressure balance in a single turbine as opposed to discharge pressure balance between a slinger and impeller as disclosed in the prior art. The turbine can be designed according to well-known design principles for turbo-machinery. The blades may be swept back to define a best efficiency point or best-efficiency-point range for the machine. Erosion by abrasive solids is greatly reduced.

Additionally, because all of the fluid flows through the turbine in the form of a pumpable slurry, its hydraulic efficiency can be made as high as is consistent with modern turbo-machine design practice. The impeller element described in the prior art can be designed according standard design principles, and its efficiency may be high. But the slinger described in the prior art serves as a "hold-back" means. It absorbs motor horse-power to little apparent advantage. With respect to the slurry in the casing, it operates in a "shut in" condition where its hydraulic efficiency is very low. The small boost in discharge pressure noted by Zingg and Stoskopf (1966) is due to the fact that the slinger peripheral velocity is necessarily larger than that of the impeller and this "excess velocity" can be recovered as pressure by a suitable diffuser means. However, the effect is always small, and its contribution to the overall efficiency of devices described in the prior art is virtually negligible. A slinger demands horsepower which serves neither to pump nor to mix, but is directly lost to heat. The mixer disclosed here does not set an inefficient slinger against a potentially efficient impeller. The normal drop-off of discharge pressure with increased capacity becomes a positive advantage instead of an insurmountable conceptual flaw. Under comparable operating conditions, the mixer requires about half the input horsepower of machines designed according to prior art.

A further advantage of the method is that a turbine configuration may be selected from a larger group of standard types than is possible in the design of machines based upon the teaching of prior art. A turbine configuration may be chosen from a spectrum whose limits range from "radial flow" to "mixed flow" configurations. A "vortex" or "recessed impeller" configuration may also be selected in accordance with this invention.

A further advantage is that the apparatus disclosed herein is smaller and cheaper than machines designed according to the prior art.

A further advantage is that the apparatus described here can be used in a variety of oilfield services. The mixing of cement powder is used to illustrate its operation in detail because cement slurries are difficult to mix. Mixers designed according to the teaching of the prior art were intended exclusively as sand blenders. They cannot mix cement slurry of acceptable quality under many circumstances. Cement particles readily form pastes and agglomerates which, because of the small size of the particles, are difficult to disperse into a consistent slurry. Nor can mixers designed according to prior art mix acceptable gel or polymer solution. Water soluble polymers are also difficult to disperse in aqueous media. Many of these are effectively undispersible in a medium which already contains dissolved polymer. Consequently, a mixer which does not bring polymer powder in immediate, direct contact with a fresh aqueous medium will produce low quality product. The mixer disclosed here calls for the contact of solid particles with fresh make-up fluid at the proper solids-liquid ratio and maintains that ratio throughout their passage through the device. Consequently, it will mix high quality cement, gel, or sand slurry indifferently.

A further advantage is that the mixer disclosed here can process a large flow of solid particles whose density is less than that of the liquid also composing the mixture. Machines designed according to the prior art are able to process small ratios of low-density solids due to recirculation of mixture in the chambers defined by the slinger blades, but they stop-up at typically higher rates. Since this mixer contacts inflowing particles with the full volumetric flow of fresh make-up liquid at the air-liquid interface, mixing of high solids-liquid ratios of low-density particles is not precluded.

Claims

1. A method of mixing a pumpable liquid and a particulate material, comprising:
   (a) swirling a body of liquid around an axis such that a vortex or eye is established whose interface between the liquid and the atmosphere is substantially coaxial with the axis of rotation of said body of liquid, and such that an increasing radial pressure gradient is established from said interface to the radius of the periphery of said body of liquid;
   (b) adjusting the pressure of a make-up liquid such that it is greater than the minimum pressure and less than the maximum pressure in said swirling body of liquid;
   (c) introducing a supply of said make-up liquid into said swirling body of liquid across an annular section whose inner radius is greater than the radius of said eye, and whose outer radius is less than the radius of said swirling body of liquid;
   (d) introducing particulate matter into said eye, and slinging the particles through said interface and into said make-up fluid where the two are mixed together;
   (e) withdrawing the mixture of the two at a radius greater than that of said swirling body of liquid;

2. A method in accordance with claim **1** wherein the pressure of said make-up liquid is regulated by rotation of said turbine.

3. A method in accordance with claim **2** wherein fresh make-up liquid is supplied at an absolute pressure between the vapor pressure of said make-up liquid and an absolute pressure of 1.5 atmospheres.

4. A method in accordance with claim **1** wherein said particulate matter is cement and said liquid is an aqueous composition.

5. A method in accordance with claim **1** wherein said particulate matter is an earth formation propping agent and said liquid is a gel composition.

6. A method in accordance with claim **1** wherein said particulate matter is a hydratable polymer and said liquid is an aqueuous composition.

7. A method of mixing a pumpable liquid and a particulate material, comprising:
   (a) swirling a body of liquid around an axis by applying power to a turbine such that a vortex is established whose interface between the liquid and the atmosphere is substantially coaxial with the axis of rotation of said turbine, and such that an increasing radial pressure gradient is established from said interface to the radius of the periphery of said turbine;
   (b) swirling a body of make-up liquid at the opposite face of said turbine such that a decreasing radial pressure gradient is es-

tablished from a radius larger than that of said vortex to a radius greater than one tenth of the radius of said vortex;
(c) introducing swirling make-up liquid into the swirling body of liquid across an annular inlet section whose inner radius is greater than the radius of said vortex, and whose outer radius is less than the radius of said turbine;
(d) introducing particulate matter into said vortex, and slinging the particles through said interface and into the make-up fluid where the two are mixed together;
(e) withdrawing the mixture of the two from a casing containing said turbine;
(f) introducing fresh make-up liquid to said body of make-up liquid from a liquid suction inlet to said turbine.

8. An apparatus for mixing liquid and particulate solids comprising:
(a) a casing or enclosed housing having a generally cicular peripheral wall, a top, a bottom, a mixture outlet means, said mixture outlet means coupled to said peripheral wall, a particulate solid inlet passage, said inlet passage being centrally disposed in said top, an annular liquid inlet means, said liquid inlet means being centrally disposed in said bottom;
(b) a rotatable turbine, said turbine being disposed within said housing and spaced from said peripheral wall, the axis of rotation of the turbine coaxial with the longitudinal axis of said housing, said turbine having an open central part facing said particulate solids inlet bore, and an annular open part facing said liquid inlet means;
(c) means for rotation of said turbine.

9. Apparatus in accordance with claim **8**, wherein said turbine is furnished with blades extended into said annular liquid inlet means.

10. Apparatus in accordance with claim **9**, wherein said liquid inlet means is furnished with stator blades.

11. Apparatus in accordance with claim **8**, wherein the configuation of said turbine is selected from the group consisting of radial flow turbines, Francis turbines, and mixed flow turbines,

12. Apparatus in accordance with claim **11**, wherein the said turbine incorporates an upper shroud with pump-back vanes.

13. Apparatus in accordance with claim **8**, wherein the configuration of said turbine is of the vortex or recessed-impeller type.

14. Apparatus in accordance with claim **8**, wherein the said housing is voluted in an axial direction.

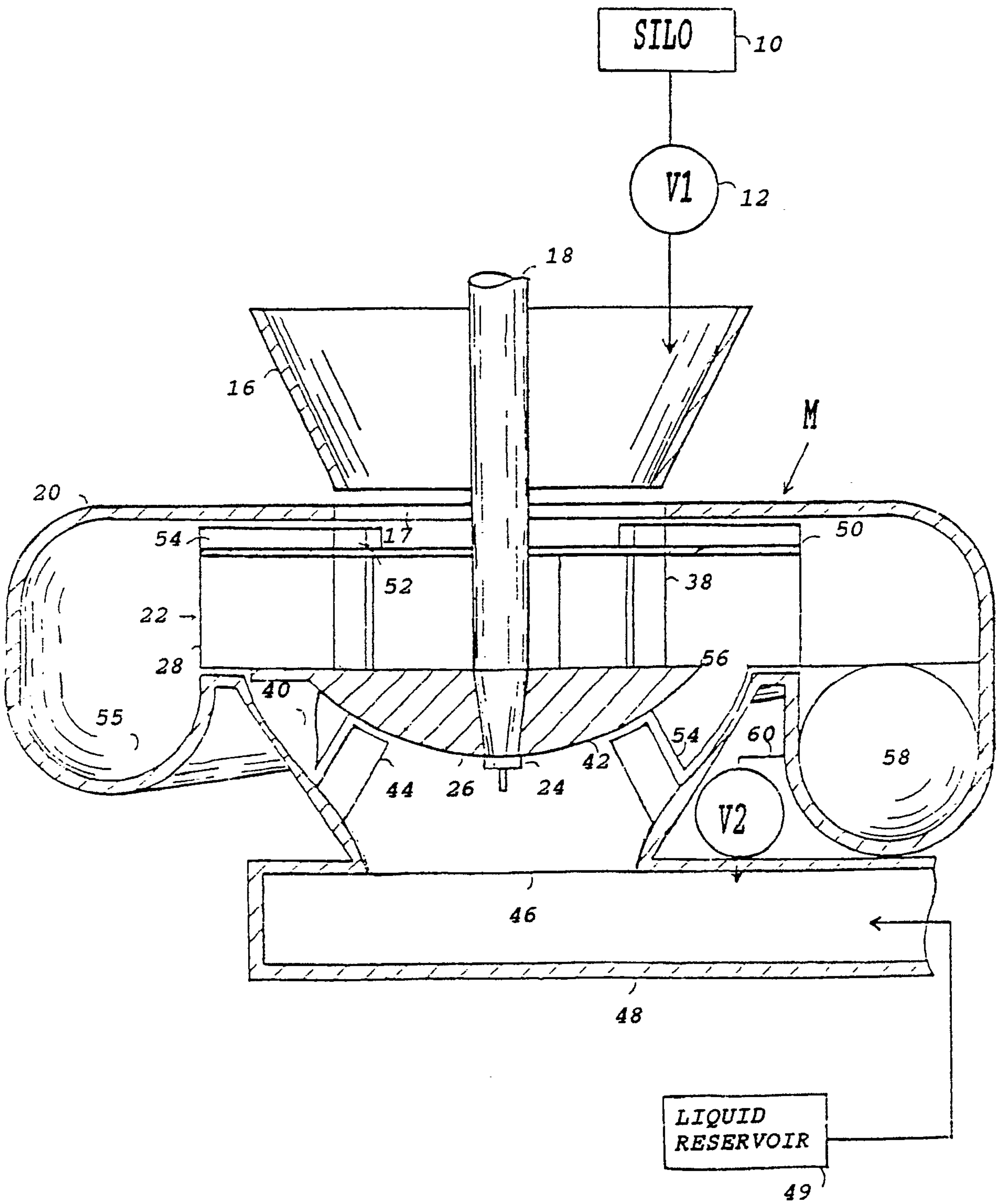

SILO
10
V1
12
18
16
M
20
54
17
50
52
38
22
28
56
40
55
54
60
58
42
44
26
24
V2
46
48
LIQUID
RESERVOIR
49

FIG 1

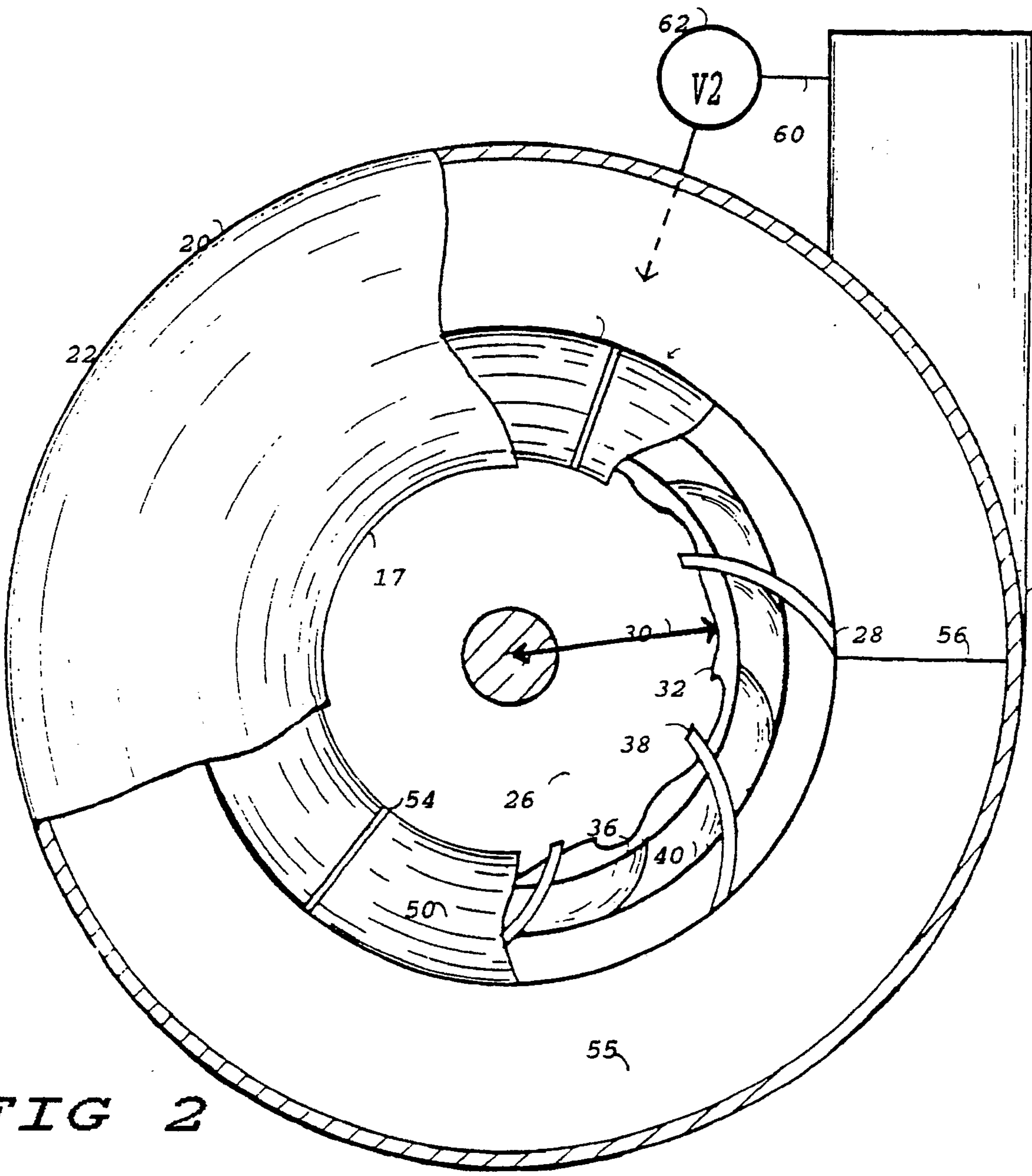

62
V2
60
20
22
17
30
28
56
58
32
38
26
54
36
40
50
55

FIG 2

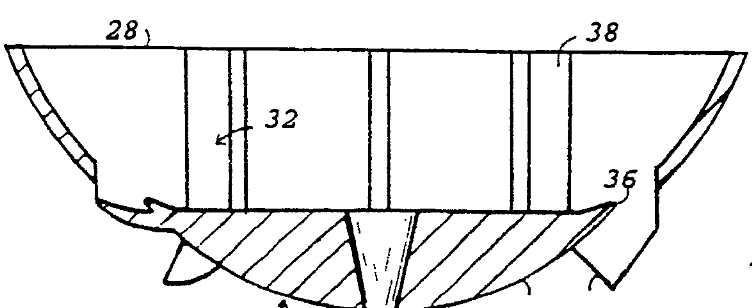

28
38
32
36
22
26
34

FIG 3

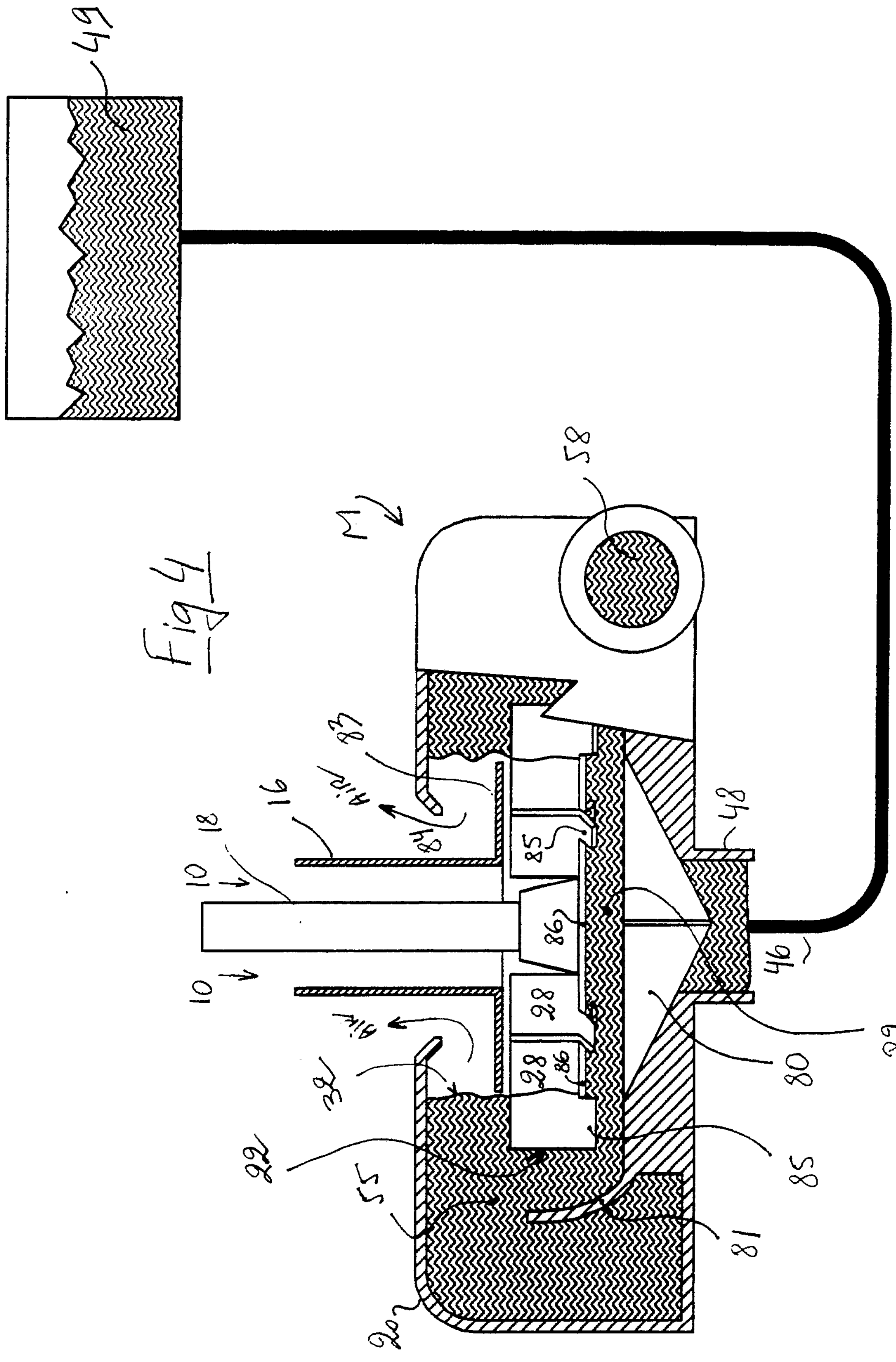
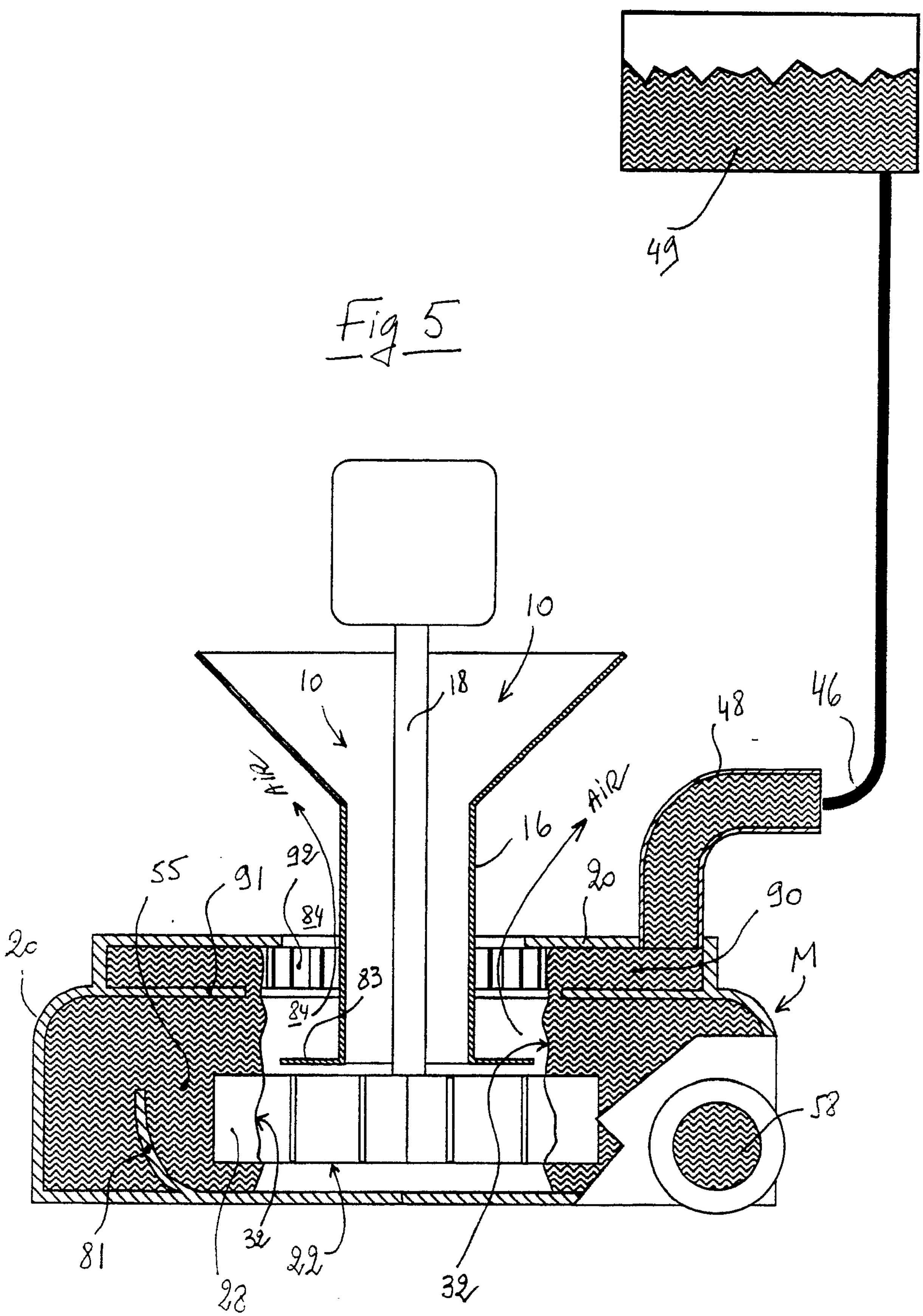

49
58
M
83
Air
84
16
18
10
10
85
86
28
28
86
48
46
80
82
32
22
55
85
81
20

Fig 4

Fig 5


49
10
10
18
48
46
AiR
AiR
16
55
91
92
84
20
90
2c
84
83
M
58
81
32
22
28
32

European
Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 91 20 0440

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
D,A	US-A-3 326 536 (ZINGG) * Claim 1; fig. *	1,7,8	B 01 F 5/20
A	EP-A-0 239 148 (SCHLUMBERGER)		
A	EP-A-0 241 056 (SCHLUMBERGER)		
A	WO-A-8 103 143 (ARRIBAU)		
A	EP-A-0 310 984 (ABNOBA)		
A	DE-B-1 085 851 (BAYER)		

TECHNICAL FIELDS SEARCHED (Int. Cl.5)
B 01 F

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	30 May 91	PEETERS S.

CATEGORY OF CITED DOCUMENTS

X: particularly relevant if taken alone
Y: particularly relevant if combined with another document of the same catagory
A: technological background
O: non-written disclosure
P: intermediate document
T: theory or principle underlying the invention

E: earlier patent document, but published on, or after the filing date
D: document cited in the application
L: document cited for other reasons

&: member of the same patent family, corresponding document