Dec. 27, 1960 D. W. BURGOON ET AL 2,966,345

MIXING APPARATUS

Filed Jan. 21, 1958

2 Sheets-Sheet 1

FIG. 2

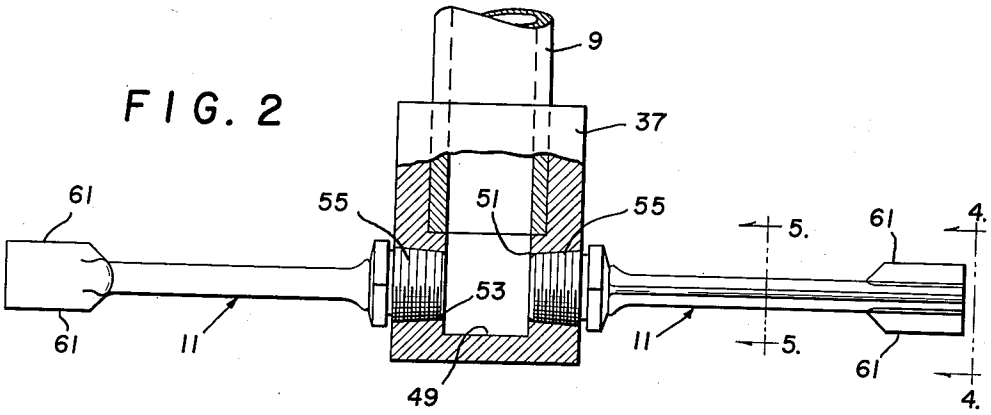

FIG. 3

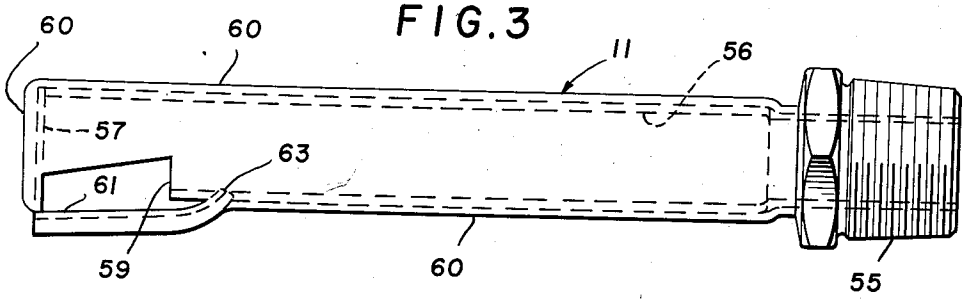

FIG. 4

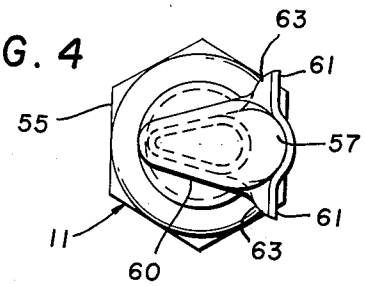

FIG. 5

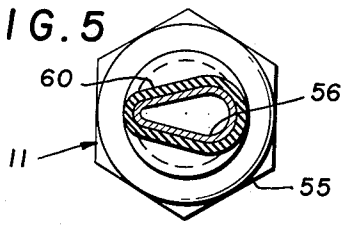

FIG. 6

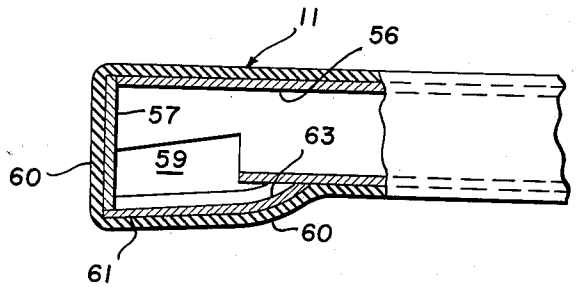

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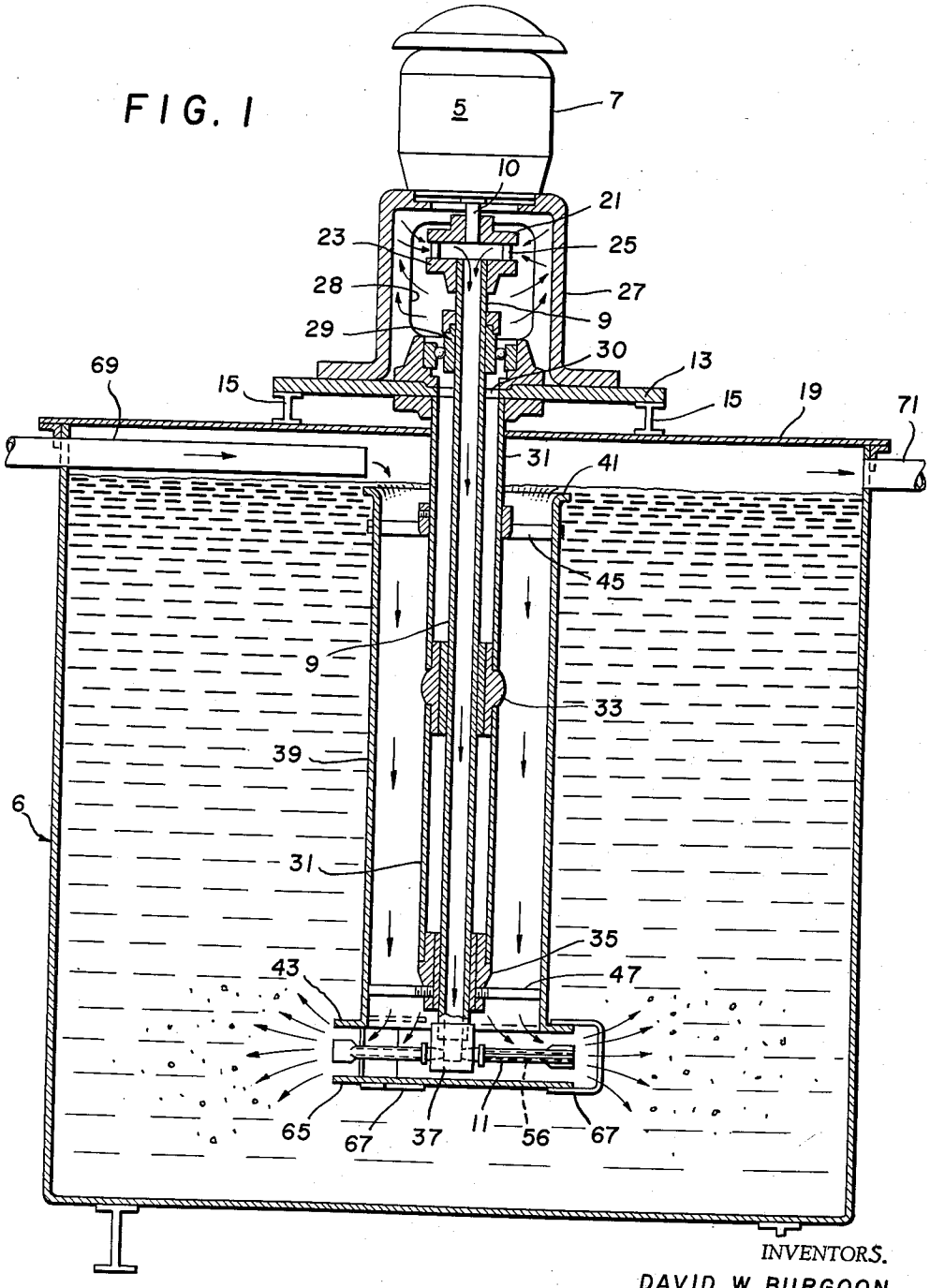
FIG. 1



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2,966,345

MIXING APPARATUS

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4 Claims. (Cl. 261—87)

The present invention relates generally to mixing apparatus, and is particularly directed to means for introducing and mixing substances, whether gaseous, liquid or solid, into a liquid.

The most common way of mixing materials into or with liquids, liquid solvents or liquid carriers is through mechanical agitation which keeps the added material in turbulent contact with the liquid to thereby disperse or dissolve such material throughout the liquid. However, such manner of mixing frequently requires a relatively long period of operation, principally because the material being added is exposed to only a relatively small amount of the liquid at any given time. Furthermore, the pressure of the liquid, which increases with the depth, may be a deterrent to the mixing process.

The primary object of the present invention is to provide an improved mixing apparatus, which is effective to more rapidly expose material to a liquid, or a liquid carrier or solvent, and to introduce and distribute such material throughout the liquid below the surface thereof. A further object is to provide a mixing apparatus which is operable to introduce material to be mixed with a liquid into such liquid below the level thereof, and is also operable to utilize the pressure existing in such liquid to aid in effecting dispersion or dissolving of the added material within the liquid.

Other objects and advantages of the invention will be made apparent by reference to the accompanying drawings and the following description of certain preferred embodiments thereof. In the drawings:

Figure 1 is an elevational view, partly in section, of apparatus embodying the present invention.

Figure 2 is an enlarged fragmentary view of the structure in Figure 1, partly in section.

Figure 3 is an enlarged top plan view of a portion of the structure in Figure 2, with the addition of a coating material.

Figure 4 is an enlarged end view of Figure 2, taken along the line 4—4, also including the coating material.

Figure 5 is an enlarged view taken along the line 5—5 in Figure 2, with the addition of a coating material.

Figure 6 is a fragmentary view, partly in section, of a modified form of the structure in Figure 3.

Apparatus constructed in accordance with the principles of this invention is capable of achieving extremely rapid and efficient mixing of free-flowing materials, whether gaseous, liquid or solid, with a liquid. However, the chosen embodiment is especially adaptable for and has been very advantageously used in connection with the introduction of air or other oxygen containing gas into fluid waste material, and the invention will, therefore, be particularly described with respect to such operation.

As seen in Figure 1 of the drawings, the illustrated embodiment comprises a waste aerator including a power driven rotor mechanism 5 operating in a tank 6 containing fluid waste material. The rotor mechanism includes generally a motor 7 having a vertically depending tubular

shaft 9 coupled to the motor drive shaft 10, and a pair of rotor arms 11 which are fixed to the lower end of the tubular shaft 9 and extend outwardly therefrom at generally right angles to the shaft 9. The entire rotor assembly is supported on a platform 13 which is carried by a pair of spaced-apart I-beams 15. The latter extend across the upper part of the aerator tank 6 and are suitably fixed in position on a pair of the tank frame members 19 which are disposed along opposite sides of the tank.

For securing the tubular shaft 9 in driven relation to the motor 7, there is provided a coupling comprising a pair of annular members 21 and 23. The upper coupling member 21 is suitably fixed to the motor drive shaft 10 for rotation therewith, and the lower member 23 is similarly secured to the upper end of the tubular shaft 9. A series of circumferentially arranged bolts 25 or the like serve to hold the annular coupling members in axially spaced relation to each other. A generally cylindrical housing 27, having one or more enlarged side openings 28 therein, is disposed in position on the platform to support the motor 7 in elevated relation to the platform and to provide an enclosure for the upper end of the shaft 9.

The tubular shaft 9 is additionally supported adjacent its upper end by a thrust bearing 29, which is mounted on the platform 13 above an opening 30 through which the shaft extends downwardly into the tank 6. An elongated cylindrical sleeve 31 is affixed to the bottom of the platform 13 in concentric relation to the rotor shaft 9 to provide a housing for the shaft. An intermediate guide bearing 33 and a lower end bearing 35 are suitably secured within the sleeve 31 in positions to rotatably receive an intermediate and the lower end portion, respectively, of the shaft 9. At the lower end of the rotor shaft there is provided a hub 37 to which is fixed the radially extending rotor arms 11. In the illustrated form of the apparatus, there are provided two rotor arms 11 which are coaxially disposed with respect to their length. However, it should be understood that a single, radially-extending arm might be used, as may three or more rotor arms designed and disposed in accordance with the teachings of this invention.

Also attached to the rotor shaft housing 31 is a re-circulating or draft tube 39, which is preferably formed with a funnel-like upper lip portion 41 and a circumferentially-flanged lower end portion 43. Suitable brace means 45 and 47 provide attachment with the upper and lower portions, respectively, of the sleeve 31, at positions such that the upper end of the tube 39 is slightly below the level of the liquid in the tank 6. The lower flanged portion 43 of the re-circulating tube 39 is preferably disposed in closely overlying relation to the rotor arms 11. In this manner, the liquid adjacent the upper level in the tank 6 is directed over the lip 41 and downwardly through a path which includes the rotor arms 11.

The rotor hub 37 includes a central passageway 49 (Figure 2) affording fluid communication with the interior of the tubular rotor shaft 9. A pair of diametrically opposed, lateral passageways 51 and 53 in the hub are also in fluid communication with the passage 49, and these lateral passages include threaded outer end portions for detachably receiving the externally threaded inner ends 55 of the rotor arms 11.

As seen particularly in Figure 5, the rotor arms 11 are generally streamlined in cross-section along their length, so as to reduce resistance as much as possible to the movement of the arm through the liquid. Each of the rotor arms includes an axial passageway 56 (Figure 3) which extends from the hub end of the arm to a wall 57 at the outer end of the arm. Thus, fluid communication is established between the hollow shaft 9

and the entire length of each rotor arm. In order to continue this path of fluid communication to the liquid in the tank, there is provided a pair of openings **59** (Figures 3 and 6) at the outer end of each of the rotor arms **11**. These openings are preferably disposed along the top and bottom surfaces of each arm, adjacent the leading edge thereof, and communicate with the passageway **56** extending through the rotor arm.

At the leading edge of each of the rotor arms and in advance of the openings **59**, there is further provided a pair of generally flat vanes **61** which extend substantially at right angles to the direction of movement of the arms. Each of the vanes **61** extends along the rotor arm to a position slightly beyond the inner end of the slotted opening **59** and terminates in a tapering rib section **63**. The rib **63** preferably extends inwardly of the leading edge of the rotor. Thus, it is seen that the hydra-foil contour of each rotor arm is interrupted at the tip of the arm and in advance of the slots **59** by the vanes **61**. The purpose of this particular construction will be explained in detail in a following portion of the description.

Although the rotors **11** shown in Figures 1 and 2 are preferably made of a durable metal material, such as an aluminum-bronze alloy or the like, it may be advantageous in some instances to apply a coating to the rotors, such as is indicated by the numeral **60** in Figures 3 to 5. The particular coating material thus used may vary with the existing conditions, but it is suggested that rubber, neoprene, chromium, Stellite, various ceramic and metal-ceramic materials, and the like may be among the suitable types of coating materials for the rotor. Although it is preferred that the coating extend over all of the rotor arm except for the vanes **61**, as seen in Figures 3 to 5, it may be desirable in some instances to also coat the vanes, as shown in the modification illustrated in Figure 6.

To complete the description of the structure comprising the illustrated rotor assembly, it will be noted that there is also provided a circular bottom plate **65**, which is fixed to the flanged lower end **43** of the recirculating tube **39** by a plurality of circumferentially-spaced brackets **67**. The plate **65** serves primarily to assist the tube **39** in directing the flow of fluid past the rotor arms **11** as it flows from the top of the tank **6** downwardly through the recirculating tube **39**. There is also provided an inflow pipe **69** at the upper section of the tank, which is positioned to direct the inflow of fluid waste material into the recirculating tube **39**, and an outflow pipe **71** is disposed at the opposite side of the tank in a position affording run-off of the aerated liquid from the tank **6**.

Having in mind the above described structure, it is desirable that an explanation of the presently accepted principles underlying the observed operation of the invention be given in order that the operation of the disclosed mechanism be more clearly understood. Based on such observations, it appears that the apparatus of the invention accomplishes its intended function as a result of the establishment of regions of cavitation within the liquid, and the introduction to such regions of the material which is to be mixed with the liquid.

This phenomenon of cavitation occurs as a result of relative movement between a solid and a liquid, usually at relatively high velocities, wherein the solid and liquid separate to produce one or more cavities or voids along the surface of the solid. These cavities are produced by and are occupied by vapor from the surrounding liquid. Consequently, the cavities take the form of bubbles and these bubbles continue to exist until the pressure and temperature condition existing therein reach a condition of instability. Thereupon, the vapor condenses and the bubbles collapse.

In the present invention, the above described condition of cavitation is intentionally established in the fluid waste material held in the tank **6**, and air is introduced into, or made available to, the cavitation zones prior to collapse thereof. More particularly, the described construction of the rotor arms **11** is such that rotation of these arms at sufficiently high speeds causes the flat face of the vanes **61** to produce cavitation in an area adjacent each of the slotted openings **59**. Since each of these openings **59** is in communication with the atmosphere above the liquid in the tank **6**, through the rotor passage **56**, the hollow shaft **9** and the opening **28** in the housing **27** above the tank, air is readily available to the cavitator regions. Consequently, air passes downwardly through the shaft **9** and out the rotor arm openings **59** behind the vanes **61** to enter the voids produced by the cavitation. As the air-laden voids collapse, the air contained therein is utilized by the fluid waste.

It should be recognized that the cavitational effect described above results from the particular rotor arm construction and the rapid motion of the arm through the media, and the mixing of the fluid or other material being introduced through the rotor arms **11** with the liquid in the tank is achieved in a very short time. In the described system, there is a rapid dissolution into the fluid waste of the oxygen in the air. This dissolution of oxygen into the waste is extremely important in sewage treatment, particularly where aerobic organisms are utilized to render oxygen absorbing compounds in the waste substantially innocuous to plant and marine life.

In the illustrated apparatus, which is particularly designed for treating waste material, the draft or recirculation tube **39** is effective to produce continual vertical movement of the fluid waste through a path which includes the rotor arms **11**. The circular plate **65** disposed below the rotor arms further defines the path past the zone of cavitation and produces a restriction in the fluid flow past the rotors, which is believed desirable for achieving the best results. However, it should be noted that these latter features of construction only incerase the efficiency of the apparatus and may be dispensed with, without departing from the broader principle disclosed herein of introducing material int ozones of cavitation.

Furthermore, it has been determined that the disclosed apparatus may in some instances produce a rotation of the fluid in the tank which results in the formation of a vortex at the upper end of the draft tube **39**. With such condition existing in the tank, there may be a sufficiently great loss of air in the tank to seriously affect the treatment of the fluid waste material and, consequently, it may be desirable to provide suitable baffles within the tank to prevent or minimize such rotation of the fluid.

It will also be noted tht the rotor arms **11** are especially designed to localize the regions of cavitation and to prevent excessive wear on the rotor arms. The arms **11** are streamlined along their length to prevent or at least minimize the occurrence of cavitation at any position therealong other than at the tip of each arm, where the vanes **61** are positioned, shaped and proportional to produce sufficient pressures at predetermined speeds of operation to cause cavitation. Further, as indicated above, the rotor arms **11** are preferably made of a hard metal such as an aluminum-bronze alloy, stainless steel, and the like, which are resistant to wear. Then too, the use of a suitable coating on the arms may be advantageous under some circumstances. It is believed, however, that various applications of the rotor assembly in mixing various materials will require separate determinations as to what type of material is best for the rotor arms and whether the arms should be coated.

Although the openings **59** and the vanes **61** are disposed on both the upper and lower surfaces of the rotor arms **11**, it should be clear that a single opening and vane will also be effective in producing a mixing of the

air with the liquid in the tank, provided, in each case, that the openings are disposed behind the vanes **61** and within the perimeter of the vanes. That is to say, the vanes shoud extend outwardly from the openings **59** to create the desired effect. However, the use of a pair of openings in connection with a pair of vanes for producing cavitation further increases the amount of air that can be mixed with the liquid in any given period of time. The disposition of a vane and opening along the lower surface of the arm provides an additional advantage in the treatment of fluid waste, in that it affords a scouring action along the bottom of the tank and thus keeps the tank free of deposits which otherwise must be periodically removed from the tank. Apparently the lower vane **61** produces a sufficient increase in pressure downwardly in the tank, as the voids produced during cavitation collapse, to provide substantially continuous movement of the fluid waste along the bottom of the tank. A similar scouring effect is also noted along the sides of the tank.

It should be recognized that there are several variable factors which enter into the establishment of cavitation, and such factors must be considered in adapting the principles of this invention to particular usages. These factors include the relative velocity between the rotor and the liquid at the vanes **61**, the density of the liquid material in the tank, and the depth of the liquid material at the position of the submerged rotor arms **11**. The relative velocity will, of course, be determined by the length of the rotor arms and the position of the vanes **61** therealong for any given speed of the rotor shaft **9**.

The vertical ends of the vanes **61** and the position of the vanes at the ends of the rotor arms **11** are important features of the rotor arms in achieving maximum effect.

Cavitation was successfully achieved in the area of the vanes **61** of the described apparatus by operating the motor **7** at 580 revolutions per minute and using rotor arms having a length of 8 inches and a maximum cross-sectional dimension of ⅞ inch. Each arm was essentially a symmetrical, hydra-foil section with a radius of curvature of 9/32 inch at the leading edge and 9/32 inch at the trailing edge. The rotors were operated at a depth of 5 feet below the level of the liquid contained in a tank which was 10 feet square. The openings **59** at the end of the rotor arms were 1 inch long and 5/16 inch wide, and the vanes **61** produced a vertically extending surface approximately 1⅛ inches high and extending along the arm a distance of about 1 9/16 inches. Other operations involving similar rotor arms up to about 11 inches in length and in depths of submergence of the rotor arms from one to ten feet were also very successful. Consequently, it is seen that there is a substantial latitude for conditions which are favorable to the operation of the described apparatus.

Furthermore, although the illustrated apparatus includes a pair of diametrically disposed rotor arms **11**, various other arrangements might well be used. However, the factors favorable to cavitation must be kept in mind in designing mixing apparatus which follows the teachings of this invention. For example, if a number of rotor arms in fairly close relation to each other are used at the end of the shaft, each arm will disturb the liquid so as to materially affect the relative velocities present at the succeeding arms. Consequently, less efficient results are likely to occur than with the use of but one or two rotor arms. The same situation is likely to occur when a plurality of rotor arms are disposed along the shaft in vertically spaced relation to one another. In the latter case, there is also a difference in liquid pressure at each rotor arm, which may preclude cavitation at certain of the levels for any given speed.

Although described with respect to the introduction of air into fluid waste, it should be recognized that the principles of the present invention are also applicable

to mixing other materials. For example, other gases, solid particles and liquids can be introduced through the tubular shaft **9** and effectively mixed with any liquid material into which the shaft **9** has been submerged. The same principles affording entry of air and other gaseous substances into the liquid will apply to the mixing of solid particles or liquids. It is evident, of course, that such solid particles should be of a relatively small size so that they can be delivered in a free flowing condition through the shaft **9** and rotor arms **11**.

While the subject invention has been described with respect to particular apparatus, it will be apparent from the foregoing that various modifications may be made without departing from the principles of invention disclosed herein.

This application is a continuation in part of our earlier filed application Serial Number 537,092, filed on September 28, 1955, and entitled "Mixing Apparatus" and now abandoned.

We claim:

1. Apparatus for introducing air into fluid material held in a vessel comprising a motor, means for supporting a motor above the level of the fluid material, an elongated hollow shaft connected with said motor for rotation thereby and extending downwardly into the fluid material, means on said shaft at a position above the level of the fluid material which affords communication between the hollow center of the shaft and the atmosphere, a plurality of arms fixed to the lower end of said shaft in laterally extending relation thereto and at a position intermediate the upper and lower levels of the fluid material, each of said arms being streamline in cross-section and having at its outer end a projecting element on the leading edge of the arm, said projecting element on each arm comprising a vane disposed generally perpendicular to the plane of movement of said arms and in substantially radial relation to said shaft, whereby rotation of said arms through the fluid material at relatively high speed produces cavitation in the zone immediately rearward of each of said vanes, means defining a passageway through each of said arms providing fluid communication between the hollow portion of said shaft and openings disposed in the upper and lower surfaces, respectively, of said arm at positions immediately rearward of each of said vanes, and a housing carried by said motor supporting means in surrounding relation to said shaft to provide a restricted passageway between the upper level of the fluid and the level adjacent said arms, said housing affording substantially unrestricted movement of the air flowing through said arms through paths extending beyond the outer end portions of said arms, whereby rotation of said arms is effective to provide air at the zones of cavitation along the upper and lower surfaces of each of said arms immediately rearward of said vanes, and whereby the resulting bubbles produced in said cavitation zones are directed away from said arms in a downward and upward direction, respectively, with the downwardly moving bubbles and the agitation of the fluid material thus produced in a downward direction providing a scouring action on the bottom and lower sides of said vessel.

2. A rotor mechanism for use in introducing gas into a liquid comprising a hollow rotatable shaft, a pair of rotor arms fixed at one end to said shaft and extending generally perpendicularly therefrom for rotation therewith through a plane generally perpendicular to the longitudinal axis of said shaft, said rotor arms each having an elongated main portion of streamline cross-section, the leading edge of each arm having a relatively broad curvature and with the upper and lower surfaces of said arm converging from said leading edge to a relatively narrow trailing edge along the arm, said arm having an internal passage extending the length of said arm and being in communication with the interior of said hollow shaft, and means mounted on the free end of said arm and extending in generally perpendicular relation to the

plane of movement of said arm defining a pair of generally flat vane surfaces adjacent said leading edge, with said vane surfaces projecting, respectively, above and below said upper and lower surfaces of said arm, the internal passage in said arm being closed off at the free end of the arm, and a discharge opening located in said arm directly behind each of said vane surfaces and in communication with the internal passage in said arm.

3. Means for treating liquid media having gaseous requirements for treating purposes comprising, a rotor mechanism adapted for submersion in said liquid media, said mechanism including a rotatab'e shaft and an arm extending laterally outwardly and generally perpendicularly therefrom, means attaching said arm to said shaft whereby said arm is actuated by rotation of said shaft to move in a generally circular path, said shaft and said arm having passageways therein in communication with each other whereby gas is fed through said shaft into said arm, the passageway in said arm being closed off at the free end thereof, said arm being streamline in cross-section substantially along its entire length and having a generally flat vane formed thereon at its outer end in generally perpendicular relation to the plane of movement of said arm and in projecting relation to the surface of said arm, whereby rotation of said arm at relatively high speed produces cavitation in the zone immediately rearward of said vane, said arm having a discharge opening formed therein immediately rearward of said vane, said discharge opening being disposed entirely within the path of said vane and being in communication with the passageway in said arm, whereby gas introduced into the passageway in said shaft is discharged behind said vane during rotation of said arm.

4. Means for introducing air into fluid material held in a vessel comprising a rotor mechanism adapted for submersion into the fluid material, said mechanism including a rotatable shaft and an arm extending outwardly and generally perpendicularly therefrom, means attaching said arm to said shaft whereby said arm is actuated by rotation of said shaft to move in a generally circular path, said shaft and said arm having passageways therein in communication with each other and placing the interior of said arm in communication with the atmosphere, whereby air from the atmosphere above the fluid material is fed through said shaft into said arm, said arm being generally streamlined in cross-section substantially along its entire length and having a generally flat vane formed adjacent the relatively broader leading edge of said arm at its outer end, said vane extending generally perpendicular to the path of rotation of said arm and above the surface of said arm, the passageway in said arm being closed off at the free end of said arm and said arm having a discharge opening formed therein behind said vane, said discharge opening being disposed within the path of movement of said vane and being in communication with the passageway in said arm, whereby air introduced from the atmosphere into the passageway in said shaft is discharged directly behind said vane during rotation of said arm, and a housing supported by said rotor mechanism in surrounding relation to said shaft in position to provide a passageway for the fluid material between the upper level thereof and a level adjacent and above the path of rotation of said arm, said housing being disposed to provide substantially unrestricted movement of the air flowing through the openings behind said vane through paths extending beyond the outer end portions of said arm.

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