

SPECIFICATION

Method and apparatus for concentrating sludge

This invention relates to a method and apparatus used in sludge treatment for concentrating sludge.

5 Sludge formed in the course of, say, sewage treatment is generally at least 98% water and is disposed of after going through sludge concentration, pretreatment with an injected chemical, followed by dewatering, drying and incineration. As the government antipollution regulations have become increasingly rigorous and our hygienic system and other environmental conditions have changed, a great amount of sludge of very high water content is produced and it must first be concentrated to reduce the load during subsequent treatments. 10

Conventionally, sludge is in most cases concentrated by a thickener in which solids having an average apparent specific gravity of about 1.03 settle out by gravity. But in this method, the solids take a lot of time to settle and the sludge is not concentrated to a satisfactory extent. Another conventional technique for sludge concentration is the dissolved-air floatation system wherein air dissolved under pressure is released to form bubbles which adsorb the solids in the sludge. This system separates solids from liquid more efficiently than concentration by a thickener because the solids on bubbles rise faster than the solids in the sludge settle out by gravity. According to this system, a tank containing water and air is pressurized at about 3 to 5 kg/cm² to dissolve air in water, and as the water having air dissolved therein is mixed with an incoming sludge in a mixing vessel, the pressure in the vessel is restored to atmospheric pressure to release excess dissolved air to thereby form air bubbles in the sludge in the vessel. But this system is not as practical as the system using a thickener for the following reasons: (1) much power is consumed to generate pressure for dissolving air in water, (2) applying and reducing pressure involves a complex mechanism that is not always consistent in operation, (3) little air dissolves in water so not many air bubbles are formed, (4) solids are bonded to the gas through weak physical adsorption, (5) since the strength of adsorption of solids is proportional to the surface area of air bubbles, very fine air bubbles are required and (6) uniform separation efficiency is not obtained because it is difficult to control the quantity of air bubbles to closely follow changes in the solids content of the sludge supplied. 15 20 25

In one widely employed method of separating solids from sludge by means of physical adsorption of bubbles on solids, the removal of solids is not carried out efficiently unless the average diameter of foam bubbles is relatively small with respect to the diameter of solids particles. This is because the bonding strength between the solids and bubbles is based on physical adsorption. Therefore, in the prior art, it has been thought that it is necessary to provide colloidal bubbles 30 — 50 μ m in diameter by the cycle of applying and reducing pressure as in the dissolved-air floatation system, or by employing high speed rotor blades rotating at 4000—5000 turns per minute. When foam bubbles larger than 30—50 μ m in diameter are employed, it is necessary to add to the sludge being treated a polymeric flocculant so as to promote adsorption of large bubbles on the solids. However, even if the polymeric flocculant is added it is essentially necessary to use bubbles less than 100 μ m in diameter as long as physical adsorption is utilized. 30 35

On the other hand, the gas-solid ratio has a close relation to the concentration of solids in sludge. In general, the larger the gas-solid ratio the higher the separating ratio or concentration of solids. However, as far as physical adsorption is concerned, the bonding strength between the solids and bubbles has a limit. When the ratio is over 0.02, excess foam which is not adsorbed on the solids moves upward in the sludge disturbing the solids in the floating layer. This results in reduction of the concentration of solids. Therefore, as long as the physical adsorption is utilized, the concentration of solids, after treatment, is 4—5% at best. 40 45

USP 3,642,617 discloses a method of concentrating sewage utilizing a foam of fine air bubbles formed by mixing water, a surfactant and air. According to this method, activated sludge containing 1% solids can be concentrated to sludge containing 4% solids. This is because the method utilizes physical adsorption between solids in sludge and bubbles, and because the foam bubbles are accompanied by much water which dilutes the sludge to be treated. In addition, because the surfactant employed in this method to make bubbles stable is preferably a non-ionic surfactant, the foam will never be electrically charged. 50

In addition, though the USP 3,642,617 does not state clearly, it is supposed that the average diameter of the foam bubbles is less than 100 μ m. 55

Therefore, the primary object of this invention is to provide a method free from the above described defects of the conventional dissolved-air floatation system.

Another object of this invention is to provide a method and apparatus for concentrating sludge with high efficiency.

60 Fig. 1 is a schematic flow sheet of the conventional dissolved-air floatation system; 60

Fig. 2 is a schematic flow sheet of the method of this invention;

Fig. 3 is a schematic perspective view, with part taken away, of the foaming apparatus according to this invention;

Fig. 4 is a schematic elevational sectional view of the apparatus of Fig. 3;

Fig. 5 is a schematic perspective view, with part taken away, of the foam mixing apparatus of this invention;

Fig. 6 is a schematic cross section showing the construction of the part of the apparatus near its outlet; and

Fig. 7 is a schematic perspective view, with part taken away, of the scraping machine according to this invention.

As a result of various studies of the foaming mechanism of the conventional dissolved air floatation system, it was found that the mechanism of applying and reducing pressure can be eliminated by using a suitable foaming agent to form bubbles or foam under atmospheric pressure. It was also found that the size and quantity of bubbles can be simply controlled by mechanical agitation and that the bubbles formed in this manner are reasonably effective for adsorbing and floating the solids in the sludge.

Noting that solids in the sludge are charged electrically either negatively or positively, we have found that a more stable bond between bubbles and solids is obtained by establishing electrochemical adsorption of the solids onto the bubbles, and that although it is considered to be intrinsically essential to use water as a carrier for air bubbles in the conventional dissolved-air floatation system, electrically charged bubbles are adequately stable for practical purposes and they can be formed without using water as a carrier.

Therefore, this invention provides a method of concentrating sludge that comprises feeding a gas into a liquid phase containing a foaming agent to form bubbles and an electrifying agent to provide electrically charged bubbles, mixing the bubbles with an incoming sludge to adsorb the bubbles onto the solids in the sludge, and introducing the resulting bubble-sludge mixture into a floating zone where the sludge solids with the adsorbed bubbles float to separate from the liquid phase. In this method, the bubbles are electrically charged to become stable, and the bubbles remain adsorbed on the solids in the sludge more stably than when they are not charged.

The principle of floatation as effected in the method of this invention is the same as in the conventional dissolved-air floatation system wherein bubbles are adsorbed on a floc or solids (having an apparent specific gravity of about 1.02 to 1.30) to reduce the apparent specific gravity to less than 1.0 (the specific gravity of water) so that they float on the surface of water. According to the conventional technique, however, the bubbles are bonded to solids through physical adsorption. The effectiveness of physical adsorption depends on the surface area of the bubbles so that the size of the bubbles must be adequately small as compared with the particle size of the floc and it has proven difficult to control the formation of such fine bubbles by the cycle of applying and reducing pressure. In addition, since air bubbles are formed by releasing pressurized water when it is mixed with an incoming sludge, dilution of the sludge is unavoidable and as a result, the use of a large sludge concentrator becomes necessary.

According to this invention, a foaming zone or an apparatus for forming bubbles using a suitable foaming agent is provided separately from a sludge-bubble mixer, and the incoming sludge is mixed only with such bubbles. By treating the surface of the bubbles with an electrifying agent to charge them electrically either positively or negatively, the floc of solids are electrochemically adsorbed on the bubbles (through agglomeration of the bubbles and solids) to provide an even more stable bond between the solids and bubbles.

The invention also provides an apparatus for concentrating sludge by means of the aforesaid concentrating method which apparatus comprises a mixing zone, a flotation zone and a foaming zone, further having means for separating part of the clarified water from the flotation zone and adding a foaming agent and an electrifying agent to the water, means for feeding the foaming zone with part of the clarified water containing the foaming agent and the electrifying agent, means for supplying a gas to said foaming zone to form electrically charged bubbles in the clarified water containing the foaming agent and the electrifying agent, means for sending a sludge and the resulting bubbles to said mixing zone, and means for supplying the mixture of sludge and bubbles from said mixing zone to said flotation zone.

The solids are charged negatively when the incoming sludge is composed of organic matter, charged positively when the sludge is composed of inorganic matter. That is, the electrical charge of the bubbles is opposite that of the solids in the sludge to be treated.

According to this invention, froth is formed simply by bubbling a gas (e.g. air or oxygen) into a liquid phase that contains a foaming agent and an electrifying agent and the resulting bubbles can be readily reduced in size by mechanical agitation. Typical examples of the foaming agent are cationic surfactants such as alkylamine and quaternary ammonium salt. Any compound can be used without particular limitation if it is able to form bubbles without requiring a carrier unlike the conventional dissolved-air floatation system that cannot form air bubbles in the absence of carrier water. Such foaming agent is added to a liquid phase which is generally water which may be supplied from part of the clarified water in the flotation zone.

According to this invention, the size of bubbles to be formed is controlled by mechanically agitating the liquid phase to which the above identified foaming agent has been added, and such mechanical agitation may be performed by a homogenizer or a turbo-agitator. Larger rpms produce smaller bubbles, but from an economical viewpoint, bubbles which are from 300 to 500 μm in size are

preferred. In the conventional dissolved-air floatation system, air bubbles having a size of less than about 100 are generally formed.

In a preferred embodiment, the foaming apparatus of the invention comprises: an agitation vessel; agitating means provided in the agitation vessel for forming bubbles by dispersing and diffusing incoming air into a liquid chemical also introduced in the vessel; a foam chamber provided in the upper portion of the vessel for accommodating bubbles rising on the surface of the liquid chemicals as a result of agitation of said air and chemical; a liquid separating zone where bubbles from said foam chamber are held temporarily until said chemical is separated from said bubbles; bubble recovery means for recovering bubbles from said liquid separating zone, and recycling means for returning to said agitation vessel said chemical that has been separated by said liquid separating means. The agitating means is preferably rotated at 1000 rpm.

The bubbles thus formed are stable by themselves and can be mixed with an incoming sludge in an amount just enough to adsorb solids in the sludge. Positively or negatively charged bubbles can be produced by using an electrifying agent, e.g. a cationic or anionic surface active agent as well as the foaming agent, and such bubbles are more stable and form an even stronger bond with the solids in the sludge.

The bubbles may be mixed with an incoming sludge simply by forcing them into the passage carrying the sludge. In a particular embodiment of mixing, bubbles may be carried by a screw conveyor or pneumatic conveyor into a mixing vessel, or they may be directly supplied into an incoming sludge by using an ejector that forces the bubbles into the passage of the sludge.

The use of a separate agitation vessel for mixing simply prolongs the time required for bubble-containing sludge to reach the floatation vessel, and the sludge may separate into froth and water before reaching the floatation vessel. Preformed bubbles may be directly supplied to a floatation vessel where they are mixed with incoming sludge to float solids in the sludge, but this arrangement requires pressure to supply the bubbles which then necessitates the use of a carrier liquid that results in unnecessary dilution of the sludge.

Thus, in a preferred embodiment, the mixing apparatus of this invention comprises: a cylindrical mixing vessel having at least one impeller mounted on a shaft; a foam inlet through which preformed bubbles are introduced into said mixing vessel; a fluid inlet provided upstream of said foam inlet for supplying said mixing vessel with a fluid to be treated; an outlet through which a mixture comprising said bubbles mixed with a forced flow formed by the action of said impeller and flowing downstream of the mixing vessel is discharged; and an impeller provided near said outlet for achieving accelerated mixing of said mixture.

The resulting sludge-bubble mixture is then passed to the floatation zone, where the solids in the sludge float on the surface of water. The solids floating on the surface of the water must be removed from the upper part of the separation vessel by a scraping machine. Conventionally, floating solids are moved to a trough by a skimmer that rotates on the surface of water around the central axis of the floatation (or separation) vessel at a constant rate. However, such method often collects not only the floating solids but also a large amount of water beneath them, thus failing to achieve the intended object of performing adequate concentration of the solids. In addition, the rotating skimmer kneads the once scraped solids to make further removal of moisture from the solids difficult.

Thus, in a preferred embodiment of the invention, the scraping machine comprises a shaft-driven scraper having a substantially horizontally arranged scraping plate, transport means comprising a plurality of plate members that move on said scraping blade in a radial direction for transporting, in a radial direction of said scraper, a scraped mass that has been cut with said scraping blade by means of the rotation of said scraper and which is carried on said scraping blade, and transmission means for transmitting the rotational motion of the driving shaft of said scraper to the translational movement of said plate members.

This invention is hereunder described in detail by reference to the accompanying drawings. Fig. 1 is a schematic flow sheet of the known dissolved-air floatation system. Sludge from a line 1 is supplied to a mixing vessel 2 where it is mixed with a flocculant from a line 3 to form a floc of suspended solids in the sludge. The sludge is then carried along a line 4 to a floatation tank 5. Part of the clarified water is separated from the floatation tank 5 through a line 6 and pressurized with a pump 7. Air supplied from a compressor 8 is mixed with the separated clarified water in a mixer 9 and dissolved under pressure in a pressurized tank 10. The water thus having air dissolved therein under pressure is carried along a line 11 and released into the flow of sludge in the line 4 through a reducing valve 12, whereupon the dissolved-air is released to form air bubbles which are adsorbed on the solids in the sludge. The resulting sludge-bubble mixture is sent through the line 4 to the floatation tank 5 where the solids encased in bubbles which have a smaller apparent specific gravity than water, rise up to the surface and are recovered by way of a line 13 for subsequent treatments.

Fig. 2 is a schematic flow sheet of the process for concentrating sludge according to this invention. Sludge coming from a line 21 is sent to a mixing zone (mixing vessel) 22 where it is mixed with electrically charged bubbles supplied from a line 23. The mixing zone is provided with a suitable agitator (not shown). The bubbles mixed with the sludge are not only adsorbed on the solids (having an apparent specific gravity of about 1.02 to 1.3) in the sludge but also are trapped within the finely

divided solids by the action of the agitator. The resulting sludge-bubble mixture now has an apparent specific gravity of about 0.4 to 0.6. The mixture is then carried along a line 24 to a floatation zone 25, wherein separation of the solids from the sludge is finished in about 30 minutes and the solids recovered by way of a line 26 for subsequent treatments. Almost all the solids present in the incoming

5 sludge have been recovered, and the solids content has increased to about 9% or more. 5

The clarified water is recovered from the floatation zone 25 through a line 27 and part of it is supplied to a conditioning zone 28 where it is mixed with a foaming agent and an electrifying agent from a line 29. The foaming agent is added in an amount of about 0.15 g per liter of the separated water, and the electrifying agent is used in an amount of about 0.3 to 0.7 g per liter of the water. The 10 clarified water containing the foaming agent and electrifying agent is supplied through a pump 30 to a foaming zone 31 where it is mixed with a gas (air or oxygen) from a line 32 to form electrically charged bubbles. According to this invention, adequately small bubbles are obtained simply by bubbling a gas 10 through the clarified water, but an agitating means in the foaming zone may be used to agitate the water and control the size of bubbles to be formed. The resulting bubbles are supplied through the line 15 23 to the mixing zone as described before. Unlike the conventional dissolved-air floatation system, this invention uses no carrier water to form bubbles, and so, only the bubbles can be extruded to the mixing zone 22 or mixing vessel by simple means such as a screw conveyor or pneumatic conveyor. In an alternative mode of embodiment, no mixing vessel is used and the bubbles may be directly supplied to the sludge by the action of an ejector. 15

20 The solids that have been separated from the sludge by the method of this invention have an apparent specific gravity of 0.4 to 0.6, generally below 0.5, and the value is appreciably smaller than 0.8 to 0.9 that is achieved by the conventional dissolved-air floatation system. The concentrated sludge thus obtained is spongy and elastic and can be pressed between rollers without adding a chemical as is required in the conventional sludge concentration system. The resulting ease of handling and treatment 25 plus elimination of the use of a chemical are great advantages of the invention. 25

The desired separation of water can also be easily accomplished by centrifuging because the solids are firmly bonded to bubbles and the solids-bubble mixture generally has an apparent specific gravity of 0.5 or lower. Another advantage of this invention is that appreciable simplification of the overall sludge treatment is realized because the sludge concentrate obtained by supplying oxygen into 30 the clarified water to form bubbles can be subjected to the subsequent aerobic digestion of solids as such. 30

Fig. 3 is a schematic perspective view, with part taken away, of a preferred embodiment of the foaming apparatus according to this invention, and

Fig. 4 is a schematic elevational sectional view of the foaming apparatus of Fig. 3. In the figures, 35 like numerals identify like members. The foaming apparatus shown comprises coaxial outer and inner cylinders 41 and 42 having a common base. The following description primarily concerns Fig. 3 but Fig. 4 shows in more detail how bubbles are formed in the apparatus of this invention, and so, it should be understood that the explanation of Fig. 3 equally applies to Fig. 4. 35

Air and a liquid chemical containing a foaming agent and an electrifying agent supplied through a 40 conduit 43 are introduced from below, as shown by the arrow in Fig. 3, into an agitation tank 45 through a diffuser 44, and in the tank 45, the air is dispersed and diffused in said chemical by means of an impeller 46. The numeral 47 represents the chemical accommodated in the agitation tank. The gas-liquid mixture containing bubbles thus formed by the agitation of air and chemical rises on the surface 48 of the liquid chemical and ascends along the agitation tank to overflow into an internal annular tray 45 49 before passing into a foam chamber 50. The foam chamber 50 comprises a first annular space defined by the internal annular tray 49, an external annular tray 51 and the outer cylinder 41. The bubbles forced along the internal annular tray 49 toward the external annular tray 51 pass through a plurality of annular holes 52 made in the external annular tray and enter a liquid separating zone 53. The liquid separating zone 53 comprises a second annular space above the surface 48 that is defined by the 50 outer cylinder 41 and the inner cylinder 42. As the bubbles descend down the zone 53, excess chemical is removed by gravity, and recovered from the surface 48. A communicating hole 54 is provided in the agitation vessel constituted of the inner cylinder 42, below the level of the surface of the liquid phase preferably in the bottom of the agitation vessel, and the surface of the liquid in the agitation vessel is flush with the surface of the liquid in the second annular space. The bubbles that have been freed of 55 excess chemical in the liquid separating zone 53 passes through a foam recovery means 55 constituted of a conduit open to the second annular space and is recovered from the apparatus of this invention as shown by the arrow in Fig. 3. A baffle 56 is provided in the agitation vessel so that the liquid chemical will not move the following rotational motion of the impeller. In Fig. 3, M indicates a motor. 55

Electrically charged bubbles coming out of the foaming apparatus are mixed with excess sludge by 60 a suitable means and attach to and float solids in the sludge to increase the concentration of the solids. In the illustrated embodiment, the apparatus is constituted of coaxial inner and outer cylinders and such arrangement is advantageous for providing a compact apparatus. 60

There is no particular limitation as to the point where air and liquid chemical are introduced into the agitation vessel, but if agitation is performed with an impeller provided at the center of the agitation 65 vessel, air and chemicals are preferably introduced into the vessel from the center of the bottom. To 65

provide even smaller bubbles, two impellers may be employed. The foam chamber is preferably provided right above the agitation vessel so as to make use of the rising of the bubble-containing gas liquid mixture during agitation, but in another embodiment, bubbles may be drawn off from the side of an agitation vessel having an enclosed top. The function of the foam chamber is not only to relieve bubbles from the agitation vessel but also to separate liquid from the bubbles by holding them for a suitable period of time. The bubbles coming from the foam chamber enter the liquid separating zone through a plurality of annular holes. The holes may be replaced by annular slits or a network structure.

Alternatively, the foam chamber may be combined integrally with the liquid separating zone, in other words, bubbles may be directly recovered from the foam chamber after achieving complete separation of liquid in the chamber. For example, a liquid chemical holding vessel equipped with an impeller may be divided into two zones that communicate with each other through a central or peripheral (annular) opening. In such arrangement, an agitation vessel is defined by the lower zone including the surface of the liquid chemical; and the air and chemical supplied are mixed under agitation with the impeller to form bubbles. The bubbles rise on the surface of the liquid chemical to enter the upper zone. The upper zone serves both as a foam chamber and as a liquid separating zone, and as they are held there for a given period, excess chemicals are separated by gravity. Consequently, bubbles can be directly recovered from the upper zone. In the alternative arrangement, an internal tray is inclined downwardly either from the center outward or from the periphery inward, and this permits the separated excess chemical to be returned to the agitation vessel. The purpose of adding the liquid chemicals is to facilitate bubble formation and to electrically charge the bubbles formed either positively or negatively. A polymeric flocculant or a surfactant is generally used as an electrifying agent. The electrifying agent is not restricted to a specific one as long as it can provide electrically charged bubbles.

Fig. 5 is a schematic perspective view, with part taken away, of a preferred embodiment of the foam mixing apparatus according to this invention. Fig. 6 is a schematic cross section showing details of the mechanism for achieving accelerated mixing of the mixture of a forced flow of fluid and preformed bubbles.

Fig. 5 shows a foam mixing apparatus 61 of this invention which is constituted of a cylindrical mixing vessel 63 having at least one impeller (mixing impeller) 62 mounted on a shaft. Bubbles preformed with a suitable foaming apparatus are introduced into the mixing vessel through a foam inlet 64 as shown by the arrow, and a solids-containing fluid — for example, excess sludge — to be treated, is supplied to the mixing vessel through a fluid inlet 65 as shown by the arrow. The impeller 62 is driven by a motor M to forcibly form a vortex in the fluid. The electrically charged bubbles supplied through the foam inlet 64 are pulled into the vortex and mixed with the fluid as they flow downstream following the movement of the vortex. As shown, another impeller 67 is provided near an outlet 66 to accelerate the velocity of the fluid having bubbles dispersed therein. The impeller cooperates with a surrounding guide 68 to pressurize the fluid (or accelerate its velocity) so as to force it to the bottom of a floatation vessel (not shown). As shown specifically in Fig. 6, the impeller 67 cooperates with the guide 68 to function as a pump. Therefore, with respect to the mixing vessel, the impeller 67 is a pushing means that pushes the incoming fluid flowing downstream of the mixing vessel, to thereby permit the fluid to flow downwardly at adequately high speed. The impellers 62 and 67 may be coaxial and driven together with a motor M. This arrangement provides a compact mixing apparatus. It is to be noted here that the velocity of the fluid being forced to flow downstream of the mixing vessel must be higher than that of the bubbles floating to the surface of the stationary fluid.

The impeller 67 may be of propeller or screw conveyor type so long as it provides a forced stream of the incoming fluid that flows downstream of the mixing vessel. The invention has been described as if the mixing vessel was a vertical cylinder, but the same effect will be obtained if it is laid on its side.

As described herein, according to a preferred embodiment of this invention, preformed bubbles can be directly mixed with a fluid to be treated, say, excess sludge, without using a carrier fluid, and consequently, by mixing the bubbles with the fluid just before they enter a floatation vessel, the separation of the bubbles from the fluid takes place only in the floatation vessel. As a further advantage, since the mixing apparatus of this invention is very small and also functions as a pump, the size of the overall treatment system can be reduced by fitting the apparatus in a pipe for feeding the fluid.

Fig. 7 is a schematic perspective view, with part taken away, of a floatation vessel in a sludge concentrator equipped with a scraping machine according to a preferred embodiment of this invention. With the conventional scraping machine, the scraped solids "roll" in front of skimmer as it moves, and in consequence, the solids pick up water from the surface of the water and are kneaded together with the water to form a creamy mass. It is very difficult to remove water from such creamy mass in a subsequent step. It sometimes happens that floating solids are pushed under by the scraping blade which hence fails to scrape them. In addition, a hopper which generally has a sectoral cross section that opens at an angle of about 60 degrees reduces the effective space for flotation or prevents the flotation of solids. In an extreme case, the solids separate from the gas bubbles and settle out again.

By reference to Fig. 7, a floatation vessel 71 has at the bottom an inlet 72 through which sludge to be treated, say, excess sludge, is introduced into the vessel together with bubbles that attach to a float the solids in the sludge. The numeral 73 indicates the layer of floating solids in concentrated sludge.

According to this invention, a scraping machine 74 comprises a scraper 77 and a transport means 78,

and the scraper 77 comprises a horizontal scraping blade 76 mounted on a shaft 75 in such a manner that its height is adjustable. In the illustrated embodiment, the transport means 78 is constituted of a plurality of scraping plates 81 which are secured to a chain 79 at a given distance and move on a shoulder 80 of the scraping blade 76 from the center outward in a radial direction of the flotation vessel 71. A fixed gear 82 secured to the shaft 75 is linked by a chain to a rotating gear 83 attached to the scraper 77 to constitute a transmission means. As the gear 83 rotates, the chain to which the scraping plates are fastened is caused to rotate. Consequently, following the rotation of the shaft 75 that rotates via the speed reducing mechanism 84, the scraper 77 and scraping blade 76 cuts the floating solids along a horizontal plane as it moves around the shaft 75 on the surface of the liquid in the flotation vessel. The scraping plates 81 that constitute the transport means 78 move along the scraping blade 76 from the center outward in a radial direction in response to the rotation of the chain 79 following the rotation of the fixed gear 82 and rotary gear 83. This way, the plates carry the sliced floating solids on the blade 76 to a pit surrounding the flotation vessel 71 and dumps them into the pit. The plates achieve such carrying and dumping operation without kneading the solids at all. The scraping machine of this invention has a movable overflow weir 86 which is capable of changing the thickness of floating solids by controlling the height of water to be introduced into the flotation vessel. And, by changing the thickness of floating solids, the final content of solids can be adjusted.

As described herein, according to this invention, floating solids are cut along a horizontal plane by a scraping blade without being kneaded together and without picking up water. In short, the floating solids are removed after making "parallel movement" with respect to the surface of the liquid in the flotation vessel without being kneaded together and without picking up water from the surface of the liquid. In consequence, the dewatering of the concentrated sludge in a subsequent step becomes very easy.

In the illustrated embodiment, a plurality of scraping plates are used for transporting and removing sliced solids on the scraping blade. If necessary, the scraping plates may be designed to move inwardly in a radial direction.

EXAMPLES

EXAMPLE 1

Excess sludge formed by the activated sludge process was concentrated by the method of this invention using an apparatus of the same type as shown in Fig. 2. The solids in the sludge had an apparent specific gravity of 1.03 and a pH of 6.8. To the clarified water separated from the flotation tank, 0.15 g of lauryltrimethylammonium chloride (foaming agent) per liter of the clarified water and 0.25 to 0.5 g of a vinylpyridine copolymer salt (polymeric electrifying agent) per liter of the clarified water were added, and the mixture was supplied to the foaming zone where it was mechanically agitated with a homogenizer. The bubbles formed were forced into the mixing vessel where they were mixed with sludge supplied at a rate of 2 liters per minute. After about ten minutes of mixing under agitation, the bubble-sludge mixture was sent to the flotation tank where the solids were separated from the sludge over a period of about 30 minutes. The results obtained are set forth in the following table.

TABLE 1

sludge concentration (ppm)	amount of foam based on sludge (%)	gas-solid ratio air (g) $(\frac{\quad}{\text{solids (g)}})$	concentration of chemicals in sludge		floating solids		Solid content in clarified water (ppm)
			surfactant (ppm)	polymeric reagent (ppm)	concentration (%)	apparent specific gravity	
4857	10	0.027	3.2	7	8.4	0.53	42
10950	20	0.047	6.3	14	9.1	0.58	23
10950	40	0.095	12.6	28	9.3	0.36	21
19430	20	0.013	6.3	21	9.9	0.64	22
10430	20	0.027	12.6	42	10.8	0.39	20

* foam consisted of 79% air and 21% water.

EXAMPLE 2

A series of tests were carried out utilizing the apparatus shown in Figs. 2 — 7. The foaming agent is lauryltrimethylammonium chloride and the electrifying agent is a polymeric reagent of vinylpyridine copolymer salt. They were added in an amount of 0.2 — 0.35 g per liter of clarified water supplied from the flotation zone. The resulting mixture was passed into the foaming vessel where it was mechanically agitated by means of turbine blades to form electrically charged bubbles, which were forced into the mixing zone and combined therein with the sludge being supplied at a rate of 11 — 20 l/min. Sludge containing 0.8% solids was concentrated to sludge containing 5 — 9% solids. The results are summarized in Table 2. The water level shown in the Table means the liquid level in the flotation vessel, which can be adjusted by means of a movable weir to vary the residence time of froth in the vessel. The residence time was determined on the basis of the volume of froth above the water level.

For comparison, the same test was carried out in the absence of a polymeric flocculant. However, in these test, the flotation of solids was not satisfactory. The separated water contained a relatively large amount of solids. Thus, the resulting experimental data showed that a satisfactory separation of solids was not achieved.

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TABLE 2

Run No.	sludge supply (l/hr)	initial solids concentration (%)	chemical added (ppm)	water level (mm)	foam residing time (mm)	solid load per unit area (kg/m ² .Hr)	gas-solid ratio air (kg) solids (kg)	final conc. of solids (%)	apparent specific gravity	S.S. in separated water (ppm)
1	1288	0.43	33.2	932	10.4	16.3	0.10	5.16	0.53	9
2	1200	0.43	35.7	915	17.6	15.2	0.10	6.33	0.57	5
3	1257	0.43	29.2	900	20.4	15.9	0.09	7.25	0.55	6
4	1212	0.42	36.5	900	20.6	15.3	0.10	7.35	0.53	—
5	1209	0.42	39.8	880	22.0	15.2	0.10	8.20	0.49	10
6	1174	0.42	36.5	855	25.0	14.9	0.10	9.25	0.51	10
7	665	0.83	47.1	900	19.6	16.5	0.06	6.15	0.63	5
8	672	0.83	45.4	890	26.5	16.7	0.06	7.63	0.65	—
9	624	0.83	46.8	875	34.5	15.5	0.06	8.13	0.59	9
10	681	0.83	46.3	860	40.0	16.9	0.06	9.18	0.67	10
11	675	0.83	45.9	855	42.0	16.8	0.06	9.22	0.61	7

Note: 1) Average foam diameter: 300 ~ 500 μ m.

2) The amount of chemical added is based on the amount of sludge supplied.

Therefore, the method of this invention serves the purpose only by mechanically mixing sludge with bubbles in the amount necessary to adsorb solids in the sludge. Electrically charged bubbles are so stable that they do not coalesce even when they are mixed with the sludge under agitation. Rather, they have a tendency to penetrate into a cleaved floc of solids to reduce their apparent specific gravity to about 0.4 — 0.5.

According to this invention, a flock of solids firmly bonded to bubbles are produced. Since only bubbles (not water) are added to the incoming sludge, virtually all solids in the sludge can be separated by suitably changing the supply of bubbles. Formation, transport and mixing of bubbles can be performed under atmospheric pressure, and this permits the use of a simplified equipment, reduces power and fuel consumption, provides constant operation and greatly reduces the initial investment. The final concentration of solids in the sludge is increased by about 50% over that achieved in the conventional dissolved-air flotation system.

As described herein, the method of this invention rapidly and easily concentrates excess sludge from a water treatment plant to reduce its volume so that the load during treatment may be reduced. The primary sources of the sludge to be treated by the method of this invention include, but are not limited to, waste water from a sewage treating plant, waste water from mines, waste water resulting from tunneling work, and industrial waste water.

CLAIMS

1. A method of concentrating sludge which comprises bubbling a gas into a liquid phase containing a foaming agent and an electrifying agent to form electrically charged bubbles, mixing the bubbles formed with an incoming sludge to adsorb the bubbles onto the solids in the sludge and introducing the resulting mixture of bubbles and sludge to a flotation zone where the solids attached to the bubbles float to separate from the liquid phase.

2. A method according to Claim 1 wherein the gas is air or oxygen, and the electrifying agent is a polymeric flocculant or surfactant or a cationic or anionic surface active agent.

3. An apparatus for concentrating sludge which comprises a mixing zone, a flotation zone and a foaming zone, further having means for separating part of the clarified water from the flotation zone and adding a foaming agent and an electrifying agent to the water, means for feeding the foaming zone with part of the clarified water containing the foaming agent and the electrifying agent, means for supplying a gas to said foaming zone to form electrically charged bubbles in the clarified water containing the foaming agent and the electrifying agent, means for sending a sludge and the resulting bubbles to said mixing zone, and means for supplying the mixture of sludge and bubbles from said mixing zone to said flotation zone.

4. An apparatus according to claim 3 wherein said foaming zone consists of a foaming apparatus comprising: an agitation vessel; agitating means provided in the agitation vessel for forming the electrically charged bubbles by dispersing and diffusing incoming air into a liquid phase containing the foaming agent and the electrifying agent also introduced in the vessel; a foam chamber provided in the upper portion of the vessel for accommodating bubbles rising to the surface of the liquid phase as a result of agitation of said air and liquid phase; a liquid separating zone where bubbles from said foam chamber are held temporarily until said liquid is separated from said bubbles; bubble recovery means for recovering bubbles from said liquid separating zone; and recycling means for returning to said agitation vessel said liquid that has been separated by said liquid separating means.

5. An apparatus according to Claim 4, wherein said foaming apparatus comprises inner and outer cylinders, an internal annular tray and an external annular tray being provided in the upper portion of the inner cylinder, said agitation vessel being constituted of said inner cylinder that holds said liquid phase, said agitating means comprising an impeller provided within said agitation vessel, said foam chamber comprising a first annular space defined by said internal tray, external annular tray and the outer cylinder, said liquid separating zone comprising a second annular space defined by said external annular tray, said outer cylinder and said inner cylinder, said foam recovery means comprising a conduit open to said second annular space, and said recycling means comprising a hole under the surface of the liquid phase that communicates the inside of said agitation vessel with the annular section defined by said inner and outer cylinders.

6. An apparatus according to either of claims 4 or 5, wherein said foaming apparatus has a liquid chemical accommodating vessel equipped with an impeller, said liquid phase accommodating vessel being divided by an internal tray into two communicating zones above the surface of the liquid phase, the lower zone serving as an agitation vessel and the upper zone as a separating zone that also serves as a foam chamber, said internal tray being inclined downwardly to provide recycling means for returning to the agitation vessel the liquid that has been separated in said separating zone, and conduit open to said foam chamber serving as foam recovery means.

7. An apparatus according to any one of claims 3 to 6, wherein said mixing zone consists of a foam mixing apparatus which comprises: a cylindrical mixing vessel having at least one impeller mounted on a shaft; a foam inlet through which preformed bubbles are introduced into said mixing vessel; a sludge inlet provided upstream of said foam inlet for supplying said mixing vessel with sludge to be treated; an outlet through which a mixture comprising said bubbles mixed with a forced flow by



Therefore, the method of this invention serves the purpose only by mechanically mixing sludge with bubbles in the amount necessary to adsorb solids in the sludge. Electrically charged bubbles are so stable that they do not coalesce even when they are mixed with the sludge under agitation. Rather, they have a tendency to penetrate into a cleaved floc of solids to reduce their apparent specific gravity to about 0.4 — 0.5.

According to this invention, a flock of solids firmly bonded to bubbles are produced. Since only bubbles (not water) are added to the incoming sludge, virtually all solids in the sludge can be separated by suitably changing the supply of bubbles. Formation, transport and mixing of bubbles can be performed under atmospheric pressure, and this permits the use of a simplified equipment, reduces power and fuel consumption, provides constant operation and greatly reduces the initial investment. The final concentration of solids in the sludge is increased by about 50% over that achieved in the conventional dissolved-air flotation system.

As described herein, the method of this invention rapidly and easily concentrates excess sludge from a water treatment plant to reduce its volume so that the load during treatment may be reduced. The primary sources of the sludge to be treated by the method of this invention include, but are not limited to, waste water from a sewage treating plant, waste water from mines, waste water resulting from tunneling work, and industrial waste water.

CLAIMS

1. A method of concentrating sludge which comprises bubbling a gas into a liquid phase containing a foaming agent and an electrifying agent to form electrically charged bubbles, mixing the bubbles formed with an incoming sludge to adsorb the bubbles onto the solids in the sludge and introducing the resulting mixture of bubbles and sludge to a flotation zone where the solids attached to the bubbles float to separate from the liquid phase.

2. A method according to Claim 1 wherein the gas is air or oxygen, and the electrifying agent is a polymeric flocculant or surfactant or a cationic or anionic surface active agent.

3. An apparatus for concentrating sludge which comprises a mixing zone, a flotation zone and a foaming zone, further having means for separating part of the clarified water from the flotation zone and adding a foaming agent and an electrifying agent to the water, means for feeding the foaming zone with part of the clarified water containing the foaming agent and the electrifying agent, means for supplying a gas to said foaming zone to form electrically charged bubbles in the clarified water containing the foaming agent and the electrifying agent, means for sending a sludge and the resulting bubbles to said mixing zone, and means for supplying the mixture of sludge and bubbles from said mixing zone to said flotation zone.

4. An apparatus according to claim 3 wherein said foaming zone consists of a foaming apparatus comprising: an agitation vessel; agitating means provided in the agitation vessel for forming the electrically charged bubbles by dispersing and diffusing incoming air into a liquid phase containing the foaming agent and the electrifying agent also introduced in the vessel; a foam chamber provided in the upper portion of the vessel for accommodating bubbles rising to the surface of the liquid phase as a result of agitation of said air and liquid phase; a liquid separating zone where bubbles from said foam chamber are held temporarily until said liquid is separated from said bubbles; bubble recovery means for recovering bubbles from said liquid separating zone; and recycling means for returning to said agitation vessel said liquid that has been separated by said liquid separating means.

5. An apparatus according to Claim 4, wherein said foaming apparatus comprises inner and outer cylinders, an internal annular tray and an external annular tray being provided in the upper portion of the inner cylinder, said agitation vessel being constituted of said inner cylinder that holds said liquid phase, said agitating means comprising an impeller provided within said agitation vessel, said foam chamber comprising a first annular space defined by said internal tray, external annular tray and the outer cylinder, said liquid separating zone comprising a second annular space defined by said external annular tray, said outer cylinder and said inner cylinder, said foam recovery means comprising a conduit open to said second annular space, and said recycling means comprising a hole under the surface of the liquid phase that communicates the inside of said agitation vessel with the annular section defined by said inner and outer cylinders.

6. An apparatus according to either of claims 4 or 5, wherein said foaming apparatus has a liquid chemical accommodating vessel equipped with an impeller, said liquid phase accommodating vessel being divided by an internal tray into two communicating zones above the surface of the liquid phase, the lower zone serving as an agitation vessel and the upper zone as a separating zone that also serves as a foam chamber, said internal tray being inclined downwardly to provide recycling means for returning to the agitation vessel the liquid that has been separated in said separating zone, and conduit open to said foam chamber serving as foam recovery means.

7. An apparatus according to any one of claims 3 to 6, wherein said mixing zone consists of a foam mixing apparatus which comprises: a cylindrical mixing vessel having at least one impeller mounted on a shaft; a foam inlet through which preformed bubbles are introduced into said mixing vessel; a sludge inlet provided upstream of said foam inlet for supplying said mixing vessel with sludge to be treated; an outlet through which a mixture comprising said bubbles mixed with a forced flow by



the action of said impeller and flowing downstream of the mixing vessel is discharged; and an impeller provided near said outlet for achieving accelerated mixing of said mixture.

- 5 8. An apparatus according to any one of claims 3 to 7, wherein said flotation zone is provided with a scraping machine comprising a shaft-driven scraper having a substantially horizontally arranged
5 scraping plate, transport means comprising a plurality of plate members that move along said scraping blade in a radial direction for transporting, in a radial direction of said scraper, a scraped mass that has
10 been cut with said scraping blade by means of the rotation of said scraper and which is carried on said scraping blade, and transmission means for transmitting the rotational motion of the driving shaft of
10 said scraper to the translational movement of said plate members
- 10 9. An apparatus according to Claim 8 wherein said transmission means comprises a fixed gear 10
coaxially mounted on said driving shaft, a rotating gear which is linked to said fixed gear and attached to
said scraper, and fastening means for said plate members which is linked to said rotating gear to
provide said plate members with a radial translational movement.
- 15 10. An apparatus according to Claim 9, wherein said fastening means is a chain.
- 15 11. A method of concentrating sludge according to Claim 1 substantially as hereinbefore specifically 15
described.
12. An apparatus for concentrating sludge substantially as hereinbefore specifically described with
particular reference to the drawings.