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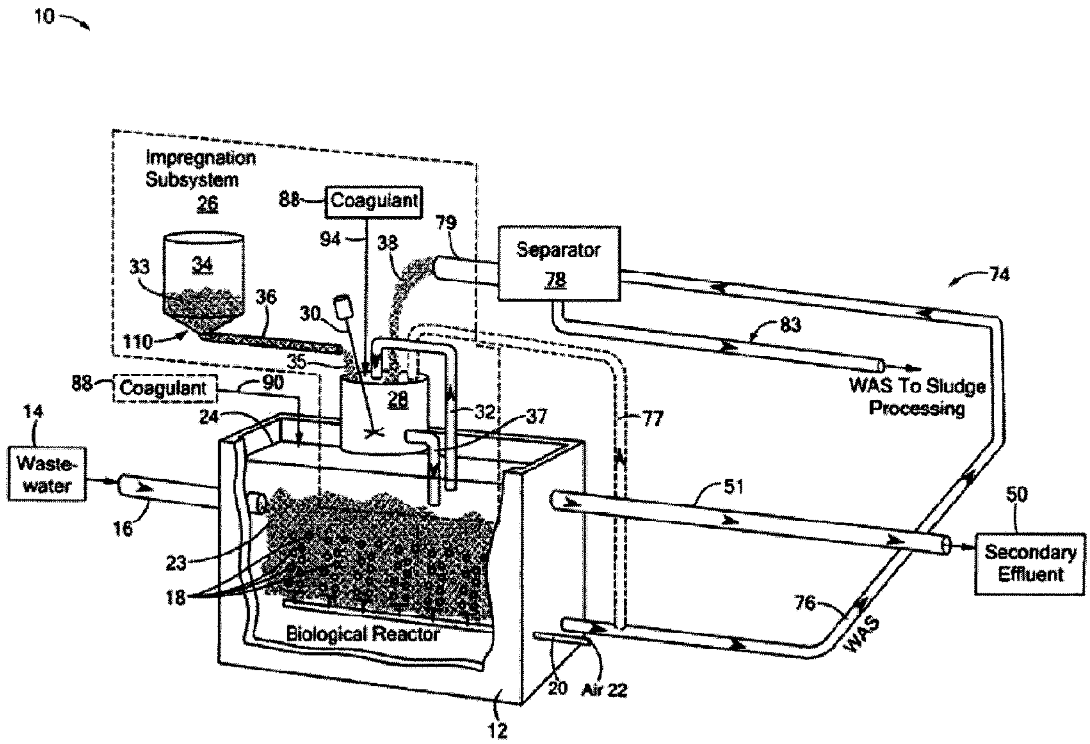
(54) **Titre : SYSTEME ET PROCEDE POUR AMELIORER UN PROCEDE DE TRAITEMENT D'EAUX USEES**
(54) **Title: SYSTEM AND METHOD FOR ENHANCING A WASTEWATER TREATMENT PROCESS**




(57) **Abrégé/Abstract:**
A system for enhancing an activated sludge process including at least one biological reactor. A weighting agent impregnation subsystem is coupled to the biological reactor for mixing biological flocs and weighting agent to impregnate the weighting agent into the biological flocs to form weighted biological flocs. A weighting agent recovery subsystem is configured to recover the weighting agent from the weighted biological flocs and reintroducing the recovered weighting agent to the weighting agent impregnation subsystem.

# ABSTRACT

A system for enhancing an activated sludge process including at least one biological reactor. A weighting agent impregnation subsystem is coupled to the biological reactor for mixing biological flocs and weighting agent to impregnate the weighting agent into the biological flocs to form weighted biological flocs. A weighting agent recovery subsystem is configured to recover the weighting agent from the weighted biological flocs and reintroducing the recovered weighting agent to the weighting agent impregnation subsystem.

# SYSTEM AND METHOD FOR ENHANCING A WASTEWATER TREATMENT PROCESS

## FIELD OF THE INVENTION

This invention relates to a system and method for enhancing a wastewater treatment process.

## BACKGROUND OF THE INVENTION

Municipal and industrial wastewater treatment facilities often include primary, secondary and tertiary processes to treat wastewater to remove contaminants, such as suspended solids, biodegradable organics, phosphorus, nitrogen, microbiological contaminants, and the like, to provide a clean effluent. The clean effluent is typically subject to strict local, state and federal regulations.

The primary treatment processes often includes screens, grit chambers and/or primary clarifiers to remove large solids and other suspended matter to provide a primary effluent. Activated sludge is one type of secondary process which utilizes a biological reactor(s) which contains a large population of microorganisms that ingest contaminants in the primary effluent to form biological "flocs." Oxygen is typically fed into the biological reactor(s) to promote growth of these biological flocs. The combination of primary effluent, or in some cases raw sewage, and biological flocs, is commonly known as mixed liquor. The population or concentration of microorganisms in the mixed liquor is often referred to as mixed liquor suspended solids (MLSS).

After sufficient treatment in the biological reactor, the biological flocs in the mixed liquor are then typically sent to a secondary clarifier where the biological flocs are separated by gravity from the mixed liquor to provide a secondary effluent and a settled sludge. The secondary effluent, or "clean" effluent, may be discharged back to the environment or processed by additional tertiary treatment processes. The majority of the settled sludge in the secondary clarifier is typically recycled back to the biological reactor by a return activated sludge subsystem. The remaining, excess sludge is wasted from the system to control the concentration of mixed liquor suspended solids.

However, separation of the biological flocs from the mixed liquor in the secondary clarifier is difficult because the biological flocs are only marginally heavier than water, and therefore settle slowly. As a result, the secondary clarifier of a typical activated sludge process is often the bottleneck in most wastewater treatment processes that utilize activated sludge as a secondary process. The crucial solids separation step of the biological flocs from the mixed liquor in the secondary clarifier is therefore typically the rate limiting process which is governed by a variety of factors, most notably the specific gravity, or density, of the biological flocs.

Moreover, solids separation in the secondary clarifier in a typical activated sludge processes may be unreliable due to the many types of settling problems that are caused by *inter alia*: overgrowth of filamentous organisms, viscous bulking caused by the overgrowth of either zoogleal organisms or exocellular polysaccharide material, pin floc, straggler floc, excessive solids loading on the secondary clarifiers, excessive secondary clarifier surface overflow rate, and the like.

Sequencing batch reactor (SBR) systems may also be used to treat wastewater. A typical conventional SBR system includes one or more sequencing batch reactors which contains a large population of microorganisms that ingest contaminants in the influent wastewater to form biological flocs and treat the wastewater. However, during the settling phase of a typical conventional SBR system, the biological flocs settle slowly because they are only marginally heavier than water. The solids separation in the settling phase is also unreliable due to the many types of settling problems discussed above. This can result in reduced treatment capacity and/or compromised effective quality.

Another method of treating wastewater, such as wastewater from breweries, pharmaceutical plants, food processing plants, pulp and paper facilities, ethanol production facilities, and the like, is to use an anaerobic treatment reactor. The anaerobic treatment reactor creates an anaerobic environment which contains a population of microorganisms that ingest contaminants in the influent wastewater to form biological flocs and treat the wastewater. The wastewater is typically fed near the bottom of the anaerobic treatment reactor and into a sludge blanket where the microorganisms consume the waste therein. In operation, wastewater fed into the bottom of the anaerobic treatment reactor flows upward through the anaerobic sludge blanket to treat the wastewater.

However, if the flow rate of influent wastewater is too fast, the anaerobic sludge blanket can expand and become diffuse. The result may be an excess loss of microorganisms in the treated effluent which may compromise the quality of the treated effluent.

## SUMMARY OF THE INVENTION

This invention features a system for enhancing an activated sludge process including at least one biological reactor. A weighting agent impregnation subsystem is coupled to the biological reactor for mixing biological flocs and weighting agent to impregnate the weighting agent into the biological flocs to form weighted biological flocs. A weighting agent recovery subsystem is configured to recover the weighting agent from the weighted biological flocs and reintroduce the recovered weighting agent to the weighting agent impregnation subsystem.

In one embodiment, the weighting agent recovery subsystem may include a separator subsystem for separating the weighting agent from the weighted biological flocs. The separator subsystem may include a shear mill. The separator subsystem may include a centrifugal separator. The separator subsystem may include an ultrasonic separator. The separator subsystem may include a shear mill and a wet drum magnetic separator. The separator subsystem may include a shear mill and a centrifugal separator. The separator subsystem may include an ultrasonic separator and a wet drum magnetic separator. The separator subsystem may include an ultrasonic separator and a centrifugal separator. The shear mill may include rotor and a stator, wherein the rotor and/or the stator include slots sized as to optimize separation of weighting agent from the weighted biological flocs. The weighting agent impregnation subsystem may include a weighting agent storage tank and at least one line. The weighting agent impregnation subsystem may include a weighting agent feeder subsystem configured to control the delivery rate of the weighting agent from the weighting agent storage tank to the weighting agent impregnation tank. The weighting agent feeder subsystem may include a pneumatic feeder subsystem. The pneumatic feeder subsystem may include porous media disposed on selected areas of the inside of the weighting agent storage tank and the inside of the at least one line. The pneumatic feeder subsystem may be configured to deliver a controlled supply of compressed air to the porous media to regulate fluidization and delivery of the weighting agent to the weighting agent impregnation tank. The weighting agent impregnation subsystem may include an impregnation tank and at least one mixer. The weighting agent impregnation subsystem may include a venturi mixer/eductor. The majority of the weighting agent may have a particle size less than about 100 μm. The majority of the weighting agent may have a particle size less than about 40 μm. The majority of the weighting agent may have a particle size less than about 20 μm. The weighting agent may include magnetite. The biological reactor may include at least one aeration tank and/or one or more sequencing batch reactors for receiving a flow of wastewater and for introducing dissolved oxygen to a population of microorganisms to promote growth of biological flocs in a mixed liquor defined by a concentration of mixed liquor suspended solids. The at least one biological reactor may be configured as at least one anaerobic treatment reactor. The system may include a flocculant injection subsystem configured to introduce a flocculant to the mixed liquor to enhance settling and thickening of weighted biological flocs and to provide agglomeration of non-impregnated biological flocs and/or partially impregnated biological flocs with weighted biological flocs. The system may include at least one clarifier configured to collecting the weighted biological flocs from the mixed liquor and configured to provide a secondary effluent and a settled sludge. The system may include a return activated sludge subsystem configured to recycle the majority of settled sludge to the biological reactor and/or to the weighting impregnation subsystem. The system may further include a wasting subsystem configured to waste remaining settled sludge of the weighting agent recovery subsystem to control the population of the microorganisms in the mixed liquor. The capacity of the system may be increased by increasing the concentration of mixed liquor suspended solids in the biological reactor by reducing the amount of the settled sludge wasted by the wasting subsystem. The amount of settled sludge wasted by the wasting subsystem may be reduced to increase the concentration of mixed liquor suspended solids for enhancing nitrification of ammonia in the mixed liquor. The nitrification may be enhanced by increasing the amount of dissolved oxygen introduced into the biological reactor. The biological reactor may include at least one anoxic zone configured to remove nitrogen from the mixed liquor. The biological reactor may include at least one anaerobic zone configured to remove phosphorus from the settled sludge. The system may further include a coagulant addition subsystem for adding coagulant to remove phosphorus by precipitation and/or coagulation. The coagulant addition subsystem may add to coagulant to the weighting agent impregnation subsystem and/or the at least one biological reactor and/or the flocculant injection subsystem to remove phosphorus by precipitation and/or coagulation. The weighting agent to a mixed liquor may be greater than about 1:5 to 1. The system secondary effluent may have a total suspended solids concentration less than about 30 mg/L. The weighting agent impregnation subsystem may be located downstream from the biological reactor and before the secondary clarifier.

This invention also features a system for enhancing an activated sludge process including at least one biological reactor. A weighting agent impregnation subsystem coupled to the biological reactor for mixing biological flocs and weighting agent having particle size less than about 100 μm to impregnate the weighting agent into the biological flocs to form weighted biological flocs. A weighting agent recovery subsystem is configured to recover the weighting agent from the weighted biological flocs and reintroducing the recovered weighting agent to the weighting agent impregnation subsystem.

In one embodiment, the majority of the weighting agent may have a particle size less than about 40 μm. The majority of the weighting agent may have a particle size less than about 20 μm.

This invention also features a method for enhancing a wastewater treatment process, the method including: a) receiving influent wastewater in at least one biological reactor, b) forming biological flocs in the biological reactor, c) impregnating weighting agent into the biological flocs to form weighted biological flocs, and d) recovering weighting agent from the weighted biological floes to reintroduce the weighting agent to step c).

In one embodiment, the method may include the step of separating the weighting agent from the weighted biological flocs. The method may include the step of collecting the weighting agent and recycling the weighting agent to step c). The method may include the step of providing weighting agent in which the majority of the weighting agent has a particle size less than about 100 μm. The method may include the step of providing weighting agent in which the majority of the weighting agent has a particle size less than about 40 μm. The method may include the step of providing weighting agent in which the majority of the weighting agent has a particle size less than about 20 μm. The method may include the step of introducing dissolved oxygen to a population of microorganisms to promote growth of biological flocs in a mixed liquor defined by a concentration of mixed liquor suspended solids. The method may further include the step of introducing a flocculant to the mixed liquor to enhance settling and thickening of the weighted biological flocs and to establish agglomeration of non-impregnated biological flocs and/or partially impregnated biological flocs with the weighted biological flocs.

Various embodiments relate to a system for enhancing an activated sludge process comprising at least one biological reactor, a weighting agent impregnation subsystem coupled to the biological reactor to receive mixed liquor comprising a combination of wastewater and biological flocs, the weighting agent impregnation subsystem including a weighting agent storage tank and at least one line, the weighting agent storage tank containing virgin weighting agent and a weighting agent impregnation tank connected to the weighting agent storage tank by said line, and at least one mixer, the biological flocs and weighting agent being mixed by the mixer in the weighting agent impregnation tank, the majority of the weighting agent having a particle size less than 100 μm, to impregnate the weighting agent into the biological flocs to form weighted biological flocs; the system further comprising a weighting agent recovery subsystem configured to recover the weighting agent from the weighted biological flocs and reintroduce the recovered weighting agent to the weighting agent impregnation tank of the weighting agent impregnation subsystem; wherein the weighting agent recovery subsystem includes a separator subsystem for separating the weighting agent from the weighted biological flocs, wherein the weighting agent impregnation subsystem includes a weighting agent feeder subsystem configured to control the delivery rate of weighting agent from the weighting agent storage tank to the weighting agent impregnation tank, and further wherein the weighting agent feeder subsystem includes a pneumatic feeder subsystem, wherein the pneumatic feeder subsystem includes porous media disposed on selected areas of the inside of the weighting agent storage tank and the inside of the at least one line, configured to deliver a controlled supply of compressed air to the porous media to regulate fluidization and delivery of the weighting agent to the weighting agent impregnation tank.

Various embodiments relate to a method for enhancing a wastewater treatment process in a system comprising: a) receiving influent wastewater in at least one biological reactor; b) forming biological flocs in the biological reactor; c) providing a weighting agent impregnation subsystem including a weighting agent feeder subsystem; d) controlling the delivery rate of weighting agent to the weighting agent impregnation tank; e) impregnating weighting agent, the majority of the weighting agent having a particle size less than 100 μm, into the biological flocs to form weighted biological flocs; f) separating the weighting agent from the weighted biological flocs; and g) recovering of weighting agent from the weighted biological flocs to reintroduce the weighting agent to step e).

The subject invention, however, in other embodiments, need not achieve all these objectives and the claims hereof should not be limited to structures or methods capable of achieving these objectives.

## BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Other objects, features and advantages will occur to those skilled in the art from the following description of a preferred embodiment and the accompanying drawings, in which:

Fig. 1 is a three-dimensional view of one embodiment of the system for enhancing a wastewater treatment process of this invention;

Fig. 2 is a schematic side view showing in further detail one embodiment of the weighting agent feeder subsystem shown in Fig. 1;

Fig. 3 is a microscopic photograph showing one example of weighting agent impregnated into a biological flocs to form a weighted biological flocs in accordance with this invention;

Fig. 4 is a schematic side-view showing another embodiment of the weighting agent impregnation subsystem shown in Fig. 1;

Fig. 5A is a schematic side-view of one embodiment of the separator shown in Fig. 1;

Fig. 5B is a schematic top view showing one example of slots in the rotor and stator of the shear mill shown in Fig. 5A;

Fig. 5C is a three-dimensional view of one embodiment of the shear mill in Fig. 5A;

Fig. 6 is a three-dimensional front-view of another embodiment of the separator shown in Fig. 1;

Fig. 7 is a three-dimensional front-view of yet another embodiment of the separator shown in Fig. 1;

Fig. 8 is a three-dimensional front-view of one example of a wet drum magnetic separator which may be utilized by the weighting agent recovery subsystem shown in Fig. 1;

Fig. 9 is a three-dimensional view of another embodiment of the system for enhancing a wastewater treatment process of this invention;

Fig. 10 is a schematic block diagram of one embodiment of the biological reactor shown in Fig. 9 including an anoxic zone configured to remove nitrogen and an anaerobic zone configured to remove phosphorus;

Fig. 11 is a schematic side-view of another embodiment of the system for enhancing a wastewater treatment process of this invention;

Fig. 12 is a schematic side-view of yet another embodiment of the system for enhancing a wastewater treatment process of this invention; and

Fig. 13 is a schematic block diagram showing one embodiment of the primary steps of the method for enhancing a wastewater treatment process of this invention;

## DETAILED DESCRIPTION OF THE INVENTION

Aside from the preferred embodiment or embodiments disclosed below, this invention is capable of other embodiments and of being practiced or being carried out in various ways. Thus, it is to be understood that the invention is not limited in its application to the details of construction and the arrangements of components set forth in the following description or illustrated in the drawings. If only one embodiment is described herein, the claims hereof are not to be limited to that embodiment. Moreover, the claims hereof are not to be read restrictively unless there is clear and convincing evidence manifesting a certain exclusion, restriction, or disclaimer.

There is shown in Fig. 1 one embodiment of system 10 for enhancing a wastewater treatment process of this invention. System 10 may be used to enhance wastewater treatment processes, including, *inter alia*, activated sludge wastewater treatment processes, SBR processes, anaerobic treatment reactor processes, or any other similar type wastewater treatment processes. When used to enhance an activated sludge wastewater treatment process or an SBR process, system 10 includes at least one biological reactor 12, e.g., an aeration tank, which receives a flow of wastewater 14 by line 16. Biological reactor 12 preferably introduces dissolved oxygen 18 by line 20 exposed to ambient air 22 to a population of microorganisms to promote growth of biological flocs 23 in mixed liquor 24. Mixed liquor 24 is typically a combination of wastewater 14 and biological flocs 23 and may be defined by a concentration of mixed liquor suspended solids (MLSS). In other examples, system 10 may also be used to enhance an anaerobic treatment process. In this case, biological reactor 12 is configured as an anaerobic treatment reactor. To do this, no oxygen is introduced to reactor 12 and an anaerobic environment is created therein.

System 10 also includes weighting agent impregnation subsystem 26 which, in one embodiment, preferably includes weighting agent storage tank 34 coupled to line 36, weighting agent impregnation tank 28, and mixer 30. Weighting agent impregnation tank 28 receives mixed liquor 24 from biological reactor 12 by line 32 or settled sludge from the bottom of biological reactor 12 via line 77. Impregnation tank 28 preferably receives virgin weighting agent 33, e.g., from weighting agent storage tank 34 by line 36, as shown at 35, and/or recycled weighting agent 38 from weight agent recovery subsystem 74.

In one design, weighting agent impregnation subsystem 26 preferably includes weighting agent feeder subsystem 110 configured to control the delivery rate of virgin weighting agent 33 to weighting agent impregnation tank 28. Weighting agent feeder subsystem 110, Fig. 2, typically includes pneumatic feeder subsystem 112 which includes porous media 114, e.g., a plurality of stainless steel screens disposed on selected areas of the inside of weighting agent storage tank 34, e.g., areas 116 and 118 at the bottom of weighting agent storage tank 34. Porous media 114 is also preferably disposed on the inside of line 36. In one design, pneumatic feeder subsystem 110 is configured to regulate supply of compressed air 120 by lines 121 to the porous media 114 in tank 34 and in line 36 to regulate the delivery rate of weighting agent 33 delivered to weighting agent impregnation tank 28. In one example, porous media 114 may be a porous stainless steel material with an ultra-smooth finished contact surface made for precise control of permeability and strength. Porous media 114 produces an evenly distributed layer of air 120 that fluidizes weighting agent 33 in areas 116 and 118 of storage tank 34 and in line 36 above porous media 114. The boundary layer above porous media 114 reduces buildup, friction, and wear. It also makes weighting agent 33 easier to convey by eliminating compaction and drag of weighting agent 33 in areas 116 and 118 of storage tank 34 and in line 36. One example of pneumatic feeder subsystem is available from Young Industries (Muncie, PA).

In operation, the delivery rate of weighting agent 33 to weighting agent impregnation tank 28, Fig. 1, is controlled by regulating the amount of air 120, Fig. 2, delivered by lines 121 to porous media 114. Higher rates of weighting agent 33 delivered to weighting agent impregnation tank 28 may be used for initially impregnating the entire population of biological flocs 23 in biological reactor 12 and a secondary clarifier (discussed below) with weighting agent. Thereafter, a maintenance dose of weighting agent 33 may be supplied to weighting agent impregnation tank 28 to maintain a desired concentration of weighting agent.

Mixer 30 mixes the mixed liquor or the settled sludge in tank 28 with virgin weighting agent 33 and/or the recycled weighting agent 38 to impregnate the weighting agent into the biological flocs in mixed liquor or the settled sludge to form weighted biological flocs. Mixer 30 preferably utilizes a mixing energy sufficient to impregnate the weighting agent into biological flocs suspended in a mixed liquor or the settled sludge to form weighted biological flocs. The weighted biological flocs in tank 28 are then sent back to biological reactor 12 by line 37. The treated secondary effluent 50 exits reactor 12 by line 51.

Fig. 3 shows a microscopic view of one example of biological flocs 23 impregnated with virgin weighting agent 33 and recycled weighting agent 38 to form weighted biological floc 25.

Because weighted biological flocs generated by weighting agent impregnation subsystem 26 have a greater specific gravity than non-impregnated biological flocs, they settle faster than non-impregnated biological flocs. Thus, the time needed to separate weighted biological flocs from the mixed liquor of system 10 is reduced when compared to a conventional activated sludge wastewater treatment system or SBR system. The weighted sludge blanket of an anaerobic treatment system is also more compact and dense and therefore can handle higher flow rates and is not as diffuse. The result is system 10 can substantially increase the capacity of such wastewater systems while providing a high quality treated effluent.

In another embodiment, weighting agent impregnation subsystem 26', Fig. 4, where like parts have been given like numbers, may be configured as venturi mixer/eductor 27 having nozzle 31 and funnel 45 which receives virgin weighting agent 33, e.g., from tank 34 by line 36, and/or recycled weighting agent 38 from separator 78. Weighting agent impregnation subsystem 26' may also include pneumatic feeder subsystem 110, similar as discussed above with reference to Fig. 2 for controlling the delivery rate of weighting agent 33 to funnel 45, Fig. 4. Venturi mixer/eductor 27 preferably receives mixed liquor by line 32 or settled sludge by line 77, as shown in Fig. 1.

In operation, the velocity of mixed liquor in line 32 or the settled sludge in line 77 is increased through nozzle 31. Virgin weighting agent 33 and/or recycled weighting agent 38 in funnel 45 enters nozzle 31 by line 39 and travels downstream to line 37. The widening of line 37 at 41 induces intimate mixing and entrainment, as shown at 43. This impregnates the virgin and/or recycled weighting agent into the biological flocs to form weighted biological flocs. The weighted biological flocs are then returned to biological reactor 12 by line 37, as shown in Fig. 1.

In one example, the weighting agent may be magnetite, or any similar type weighting agent or magnetically separable inorganic material known to those skilled in the art which increases the density of the biological flocs when impregnated therein. In one example, the majority of the weighting agent has a particle size less than about 100 μm. In other examples, the majority of the weighting agent particles have a size less than about 40 um or less than about 20 um.

System 10, Fig. 1, also includes weighting agent recovery subsystem 74 which receives settled sludge from biological reactor 12 by line 76. Weighting agent recovery subsystem 74 preferably includes separator subsystem 78 which recovers the weighting agent from the weighted biological flocs in the settled sludge in line 76 and reintroduces (recycles) weighting agent 38 to weighting agent impregnation subsystem 26, 26', Figs. 1 and 4.

In one design, separator subsystem 78 may be configured as shear mill 112, Fig. 5A, which shears the sludge in line 76 to separate the weighting agent from the weighted biological flocs. Shear mill 112 ideally includes rotor 80 and stator 82. In operation, the settled sludge in line 76 enters shear mill 112 and flows in the direction of arrows 180 and enters rotor 80 and then stator 82. Shear mill 112 is designed such that there is a close tolerance between rotor 80, Fig. 5B and stator 82 . Rotor 80 is preferably driven at high speeds, e.g., greater than about 1,000 r.p.m. to form a mixture of weighting agent and obliterated flocs in area 182, Fig. 5A, of shear mill 112. The mixture of weighting agent and obliterated flocs exits shear mill 112 by line 79, as shown by arrows 184. Fig. 5C shows in further detail the structure of one embodiment of shear mill 112. Preferably, rotor 80, Figs. 5A-5C, and/or stator 82 includes slots which function as a centrifugal pump to draw the settled sludge from above and below rotor 80 and stator 82, as shown by paths 182, 183, Fig. 5A, and then hurl the materials off the slot tips at a very high speed to break the weighted biological flocs into the mixture of weighting agent and obliterated flocs. For example, rotor 80, Fig. 5B, may include slots 186 and stator 82 may include slots 188. Slots 186 in rotor 80 and/or slots 188 in stator 82 are preferably optimized to increase shear energy to efficiently separate the weighting agent from the weighted biological flocs. The shear developed by rotor 80 and stator 82 depends on the width of slots 186 and 188, the tolerance between rotor 80 and stator 82, and the rotor tip speed. In one example, rotor 80 is driven at about 9,000 ft/min. The result is shear mill 112 provides a shearing effect which effectively and efficiently separates the weighting agent from the weighted biological flocs to facilitate recovery of the weighting agent.

In another design, separator subsystem 78'', Fig. 6, where like parts have been given like numbers, may be configured as ultrasonic separator 116. Ultrasonic separator 116 typically includes one or more ultrasonic transducers, e.g., ultrasonic transducer 262, 264, 266, 268, and/or 270, available from Hielscher Ultrasonics GmbH, Stuttgart, Germany, which generates fluctuations of pressure and cavitation in the settled sludge in line 76. This results in microturbulences that produce a shearing effect to create a mixture of weighting agent and obliterated flocs to effectively separate the weighting agent from the weighted biological flocs in the settled sludge. The resulting mixture of weighting agent and obliterated flocs exits ultrasonic separator 116 by line 79.

In yet another design, separator subsystem 78, Fig. 7, where like parts have been given like numbers, may be configured as centrifugal separator 118. Centrifugal separator 114 typically includes cylindrical section 302 located at the top of hydrocyclone 300 and conical base 304 located below section 302. The settled sludge in line 76 is fed tangentially into cylindrical section 302 via port 303. Smaller exit port 306 (underflow or reject port) is located at the bottom of conical section 304 and larger exit port 308 (overflow or accept port) is located at the top of cylindrical section 302.

In operation, the centrifugal force created by the tangential feed of the sludge by port 303 causes the denser weighting agent to be separated from the weighted biological flocs in the settled sludge. The separated weighting agent is expelled against wall 308 of conical section 304 and exits at port 306. This effectively separates the weighting agent from the weighted biological flocs. The recovered weighting agent 38 exits via port 306 and may be deposited to weighting agent impregnation system 26, 26', Figs. 1 and 4. The less dense biological flocs remain in the sludge and exit via port 308 through tube 310 extending slightly into the body of the center of centrifugal separator 118.

Although as discussed above, separator subsystem 78 may be configured as a shear mill, an ultrasonic separator, or a centrifugal separator, this is not a necessary limitation of this invention. In other designs, separator subsystem 78 may be configured as a tubular bowl, a chamber bowl, an imperforate basket, a disk stack separator, and the like, as known by those skilled in the art.

In the example above where a separator 78, Figs. 5A-5C, is configured as shear mill 112 to create the mixture of weighting agent and obliterated biological flocs, wet drum magnetic separator 81, Fig. 8, or centrifugal separator 118, Fig. 7, may be used to recover the weighting agent therefrom. Further details of the design and operation of wet drum magnetic separator 81 are disclosed in co-pending application U.S. Publication No. 2008/0164184, entitled "Fluidic Sealing System For a Wet Drum Magnetic Separator", and U.S. Publication No. 2008/016483, entitled "Collection System for a Rotating Wet Drum Magnetic Separator".

In the example where separator subsystem 78, Fig. 6, is configured as an ultrasonic separator 116 to create the mixture of weighting agent and obliterated biological flocs, wet drum magnetic separator 81, Fig. 8, or centrifugal separator 118, Fig. 7, may be used to recover the weighting agent therefrom.

The result of recovering and recycling the weighting agent as discussed above with reference to Figs. 5A-7 significantly reduces the operating costs of wastewater treatment system 10.

System 10, Fig. 1 may also include wasting subsystem 83 which wastes the remaining settled sludge of separator subsystem 78 to control the population of the microorganisms in mixed liquor 24 in biological reactor 12.

In another embodiment, system 10', Fig. 9, where like parts have been given like numbers includes biological reactor 12, weighting impregnation subsystem 26 and/or weighting impregnation subsystem 26', Fig. 4, and weighting agent recovery subsystem 74 with separator subsystem 78, which function similar as discussed above with reference to Figs. 1-8. In this example, system 10' also includes flocculant injection subsystem 42, typically located downstream from biological reactor 12, although flocculant injection subsystem 42 may be at any desired location in system 10. In this example, flocculant injection subsystem introduces flocculant 44 into mixed liquor 24 by line 135. Flocculant 44 enhances settling and thickening of the weighted biological flocs suspended in mixed liquor 24 in secondary clarifier 46 and establishes agglomeration of non-impregnated biological flocs and/or partially impregnated biological flocs with the weighted biological flocs in secondary clarifier 46. In one example, flocculant 44 may be cationic or anionic polymer, such as Drewfloc® 2270 (Ashland Chemical, New Jersey), or any similar type polymer known to those skilled in the art.

The agglomeration of non-impregnated biological flocs and/or partially impregnated flocs with the weighted biological flocs makes larger weighted biological flocs to provide for rapid settling of the weighted biological flocs in settling zone 64 of clarifier 46. Flocculant 44 also enhances settling and thickening of the weighted biological flocs in thickening zone 66 of clarifier 46 by reducing the size of, and increasing the density of, the weighted biological flocs. This creates "drainage" channels between the weighted biological flocs which allow water at bottom 69 of clarifier 46 to flow towards top 71 of clarifier 46 and weighted biological flocs to flow towards bottom 69 in thickening zone 66 of secondary clarifier 46 to enhance the thickening process.

System 10' also preferably includes secondary clarifier 46 which may be used to separate and collect the weighted biological flocs from the mixed liquor. In one example, a rake or siphon (draft tube) subsystem 67 is used to remove settled sludge 54 at bottom 69 of clarifier 46. Because the weighted biological flocs have a greater specific gravity than non-impregnated biological flocs, they settle faster in secondary clarifier 46 than non-impregnated biological flocs utilized in a typical system for an activated sludge process. Thus, secondary clarifier 46 effectively and efficiently separates the weighted biological flocs from the mixed liquor to provide secondary effluent 50'. As a result, the time needed to separate weighted biological flocs from mixed liquor 24 of the system 10' is reduced when compared to a typical activated sludge or similar type wastewater treatment process. This increases the capacity of system 10' to process wastewater 14. Therefore, system 10' is more effective, efficient, reliable, cost effective, and robust than a typical system for an activated sludge process. Moreover, the size of clarifier 46 and/or biological reactor 12 can be reduced, allowing system 10' to treat the same quantity of wastewater in a smaller footprint. This reduces the installation costs and land requirements of system 10'. Additionally, the problems associated with the separation process of the biological flocs from the mixed liquor in the secondary clarifier, as discussed in the Background Section, are alleviated.

System 10', Fig. 9, may also include return activated sludge subsystem 70 which recycles the majority of settled sludge 54 in secondary clarifier 42 to biological reactor 12 by line 72 using pump 47 and/or sends the settled sludge 54 to weighting impregnation subsystem 26, 26' via line 119.

The capacity of system 10', Figs. 1-9, to process wastewater 14 may be increased by increasing the concentration of the MLSS in biological reactor 12 by reducing the amount of settled sludge wasted by wasting subsystem 83. The amount of settled sludge wasted by wasting subsystem 83 may also be reduced to increase the concentration of MLSS in aeration tank 12 to enhance nitrification of ammonia in mixed liquor 24. The nitrification process may also be further enhanced by increasing the amount of dissolved oxygen 18 introduced to biological reactor 12 by line 20.

Coagulant 88, Figs. 1 and 9, may be added to biological reactor 12, as shown at 90 or to weighting agent impregnation tank 28, as shown at 94, for removing phosphorus and other contaminants from mixed liquor 24 by precipitation and/or coagulation, as known by those skilled in the art. In other examples, coagulant 88 may be added to flocculant injection port 42, Fig. 9, as shown at 92, to remove phosphorus by precipitation and/or coagulation. In yet another example, coagulant 88 may be added to weighting agent impregnation tank 28, Figs. 1 and 9, as shown at 94, or to venture mixer/eductor 27, Fig. 4, as shown at 108, for removing phosphorus by precipitation and/or coagulation.

The ratio of the weighting agent, e.g., magnetite or similar type materials known to those skilled in the art, to mixed liquor and/or settled sludge may be greater than about 1.5 to 1.0. In one example, secondary effluent 50 has a suspended solid concentration of less than about 30 mg/L, which may meet local, state, and federal guidelines for secondary effluent 50.

System 10", Fig. 10, where like parts have been given like numbers, may include biological reactor 12', e.g., an aeration tank, having anoxic zone 87 with mixer 91 configured to remove nitrogen from mixed liquor 24. In this example, recycle line 100 connected to line 135 recycles mixed liquor 24 to anoxic zone 87, as shown by arrows 101. Biological reactor 12' may also include anaerobic zone 93 with mixer 95 configured to remove phosphorus from the mixed liquor 24 In this example, line 72 of return activated sludge subsystem 70 recycles the settled sludge to anaerobic zone 84. Many other possible biological nutrient removal configurations may be utilized, as known to those skilled in the art.

Although as shown above with reference to Figs. 1 and 9, system 10, includes weighting agent impregnation subsystem 26, 26' which receives mixed liquor from biological reactor 12 and then dispenses the weighted biological flocs back into the biological reactor, this is not a necessary limitation of this invention. In other designs, weighting agent impregnation subsystem 26, 26', may receive mixed liquor from biological reactor 12 and dispense the weighted biological flocs between biological reactor and the secondary clarifier. For example, system 10''', Fig. 11, where like parts have been given like numbers, may include weighting impregnation subsystem 26, 26', similar as discussed above with reference to Figs. 1 and 4, which dispenses the weighted biological flocs to line 135 between biological reactor 12 and clarifier 46.

In other designs, weighting agent impregnation subsystem 26, 26' may be located between the biological reactor and the secondary clarifier. For example, system $10^{IV}$, Fig. 12, where like parts have been given like numbers, includes weighting agent impregnation subsystem 26, 26' located between biological reactor 12 and clarifier 46. In this example, wastewater 14 may be from a brewery processing system or similar type processing system which has a high concentration of biodegradable organic matter in the incoming wastewater 14. In this design, system $10^{IV}$ may not need return activated sludge subsystem 70, a shown in Fig. 9, because enough organisms are grown from the removal of influent organic matter to maintain a suitable population of microorganisms in the mixed liquor 24.

The method for enhancing a wastewater treatment process, in one embodiment of this invention, includes receiving a flow of wastewater in at last one biological reactor, step 200, Fig. 13. Biological flocs are then formed in the biological reactor, step 202. Weighting agent is then impregnated into the biological flocs to form weighted biological flocs, step 204. The weighting agent is then recovered and reintroduced to step 204, step 206. The details of the operation of steps 200-206 are discussed in detail above with reference to Figs. 1-9.

Although specific features of the invention are shown in some drawings and not in others, this is for convenience only as each feature may be combined with any or all of the other features in accordance with the invention. The words “including”, “comprising”, “having”, and “with” as used herein are to be interpreted broadly and comprehensively and are not limited to any physical interconnection. Moreover, any embodiments disclosed in the subject application are not to be taken as the only possible embodiments. Other embodiments will occur to those skilled in the art and are within the following claims.

In addition, any amendment presented during the prosecution of the patent application for this patent is not a disclaimer of any claim element presented in the application as filed: those skilled in the art cannot reasonably be expected to draft a claim that would literally encompass all possible equivalents, many equivalents will be unforeseeable at the time of the amendment and are beyond a fair interpretation of what is to be surrendered (if anything), the rationale underlying the amendment may bear no more than a tangential relation to many equivalents, and/or there are many other reasons the applicant can not be expected to describe certain insubstantial substitutes for any claim element amended.

What is claimed is:

**WHAT IS CLAIMED IS:**

1. A system for enhancing an activated sludge process comprising at least one biological reactor, a weighting agent impregnation subsystem coupled to the biological reactor to receive mixed liquor comprising a combination of wastewater and biological flocs, the weighting agent impregnation subsystem including a weighting agent storage tank and at least one line, the weighting agent storage tank containing virgin weighting agent and a weighting agent impregnation tank connected to the weighting agent storage tank by said line, and at least one mixer, the biological flocs and weighting agent being mixed by the mixer in the weighting agent impregnation tank, the majority of the weighting agent having a particle size less than 100 μm, to impregnate the weighting agent into the biological flocs to form weighted biological flocs; the system further comprising a weighting agent recovery subsystem configured to recover the weighting agent from the weighted biological flocs and reintroduce the recovered weighting agent to the weighting agent impregnation tank of the weighting agent impregnation subsystem; wherein the weighting agent recovery subsystem includes a separator subsystem for separating the weighting agent from the weighted biological flocs, wherein the weighting agent impregnation subsystem includes a weighting agent feeder subsystem configured to control the delivery rate of weighting agent from the weighting agent storage tank to the weighting agent impregnation tank, and further wherein the weighting agent feeder subsystem includes a pneumatic feeder subsystem, wherein the pneumatic feeder subsystem includes porous media disposed on selected areas of the inside of the weighting agent storage tank and the inside of the at least one line, configured to deliver a controlled supply of compressed air to the porous media to regulate fluidization and delivery of the weighting agent to the weighting agent impregnation tank.

2. The system of claim 1, in which the separator subsystem includes a shear mill.

3. The system of claim 2, in which the shear mill includes rotor and a stator, where the rotor and/or the stator include slots sized as to optimize separation of weighting agent from the weighted biological flocs.

4. The system of any one of claims 1-3, in which the biological reactor includes at least one aeration tank and/or one or more sequencing batch reactors for receiving a flow of wastewater and for introducing dissolved oxygen to a population of microorganisms to promote growth of biological flocs in the mixed liquor defined by a concentration of mixed liquor suspended solids.

5. The system of claim 4, further including a flocculant injection subsystem configured to introduce a flocculant to the mixed liquor to enhance settling and thickening of weighted biological flocs and to provide agglomeration of non-impregnated biological flocs and/or partially impregnated biological flocs with weighted biological flocs.

6. The system of claim 5, further including at least one clarifier configured to collect the weighted biological flocs from the mixed liquor and configured to provide a secondary effluent and a settled sludge.

7. The system of claim 6, further including a return activated sludge subsystem configured to recycle the majority of settled sludge to the biological reactor and/or to the weighting impregnation subsystem.

8. The system of any one of claims 1-7, further including a wasting subsystem configured to waste remaining settled sludge of the weighting agent recovery subsystem to control the population of the microorganisms in the mixed liquor.

9. The system of claim 1, in which the biological reactor includes at least one anoxic zone configured to remove nitrogen from the mixed liquor.

10. The system of claim 1, in which the biological reactor includes at least one anaerobic zone configured to remove phosphorus from the settled sludge.

11. The system of claim 1, further including a coagulant addition subsystem for adding coagulant to remove phosphorus by precipitation and/or coagulation.

12. The system of claim 11, in which the coagulant addition subsystem adds coagulant to one or more of the weighting agent impregnation subsystem, the at least one biological reactor,

and the flocculant injection subsystem, to remove phosphorus by precipitation and/or coagulation.

13. The system of claim 6, in which the weighting agent impregnation subsystem is located downstream from the biological reactor and before a secondary clarifier.

14. The system of any one of claims 1-3, in which the at least one biological reactor is configured as at least one anaerobic treatment reactor.

15. A method for enhancing a wastewater treatment process in a system according to any one of claims 1-14, the method comprising:

    a) receiving influent wastewater in at least one biological reactor;

    b) forming biological flocs in the biological reactor;

    c) providing the weighting agent impregnation subsystem including the weighting agent feeder subsystem;

    d) controlling the delivery rate of weighting agent to the weighting agent impregnation tank;

    e) impregnating weighting agent, the majority of the weighting agent having a particle size less than 100 μm, into the biological flocs to form weighted biological flocs;

    f) separating the weighting agent from the weighted biological flocs; and

    g) recovering of weighting agent from the weighted biological flocs to reintroduce the weighting agent to step e).

16. The method of claim 15, further including the step of introducing dissolved oxygen to a population of microorganisms to promote growth of biological flocs in the mixed liquor defined by a concentration of mixed liquor suspended solids.

17. The method of claim 15, further including the step of introducing a flocculant to the mixed liquor to enhance settling and thickening of the weighted biological flocs and to establish

agglomeration of non-impregnated biological flocs and/or partially impregnated biological flocs with the weighted biological flocs.

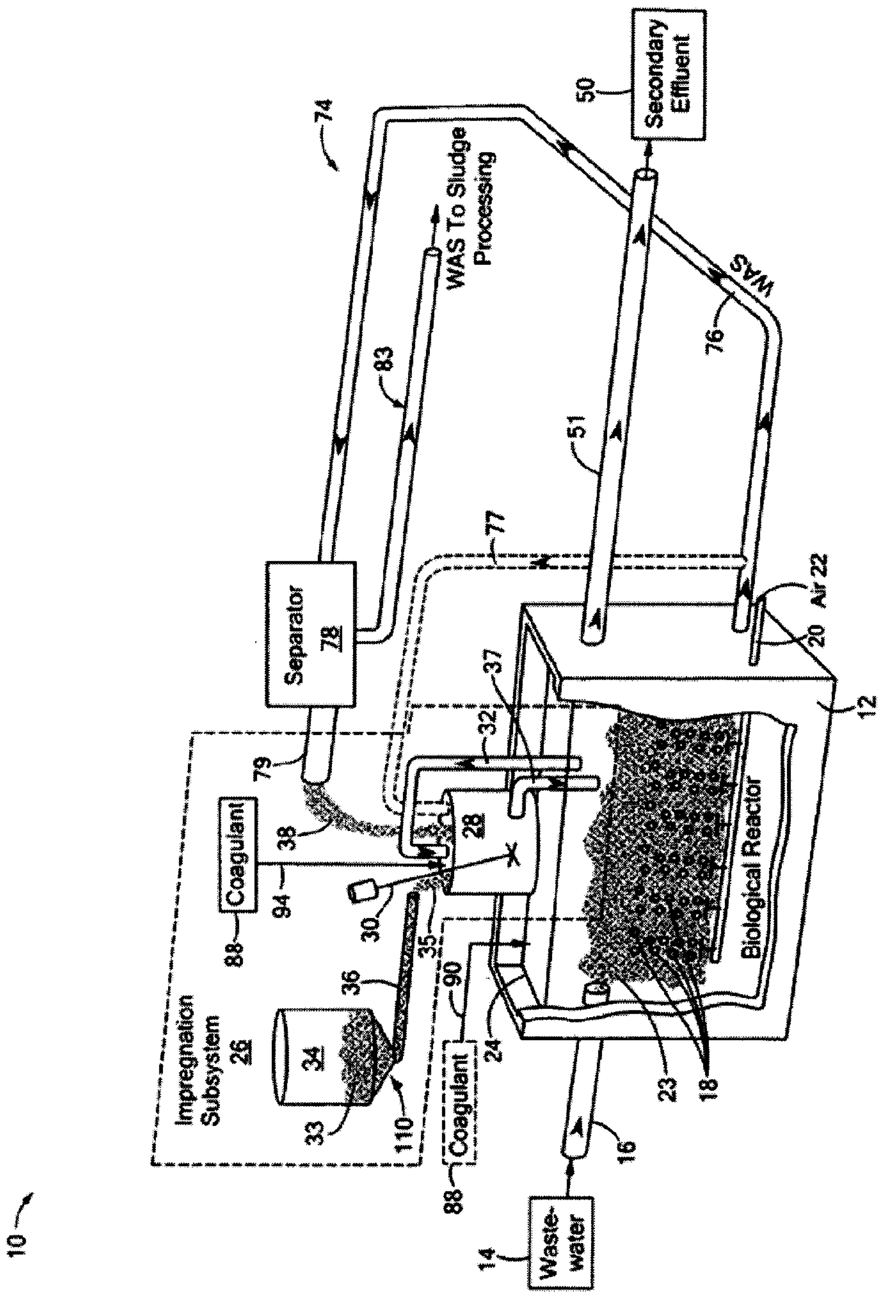

Secondary Effluent
WAS To Sludge Processing
WAS
Separator 78
Impregnation Subsystem 26
Coagulant
Coagulant
Biological Reactor
Waste-water
Air 22

FIG. 1

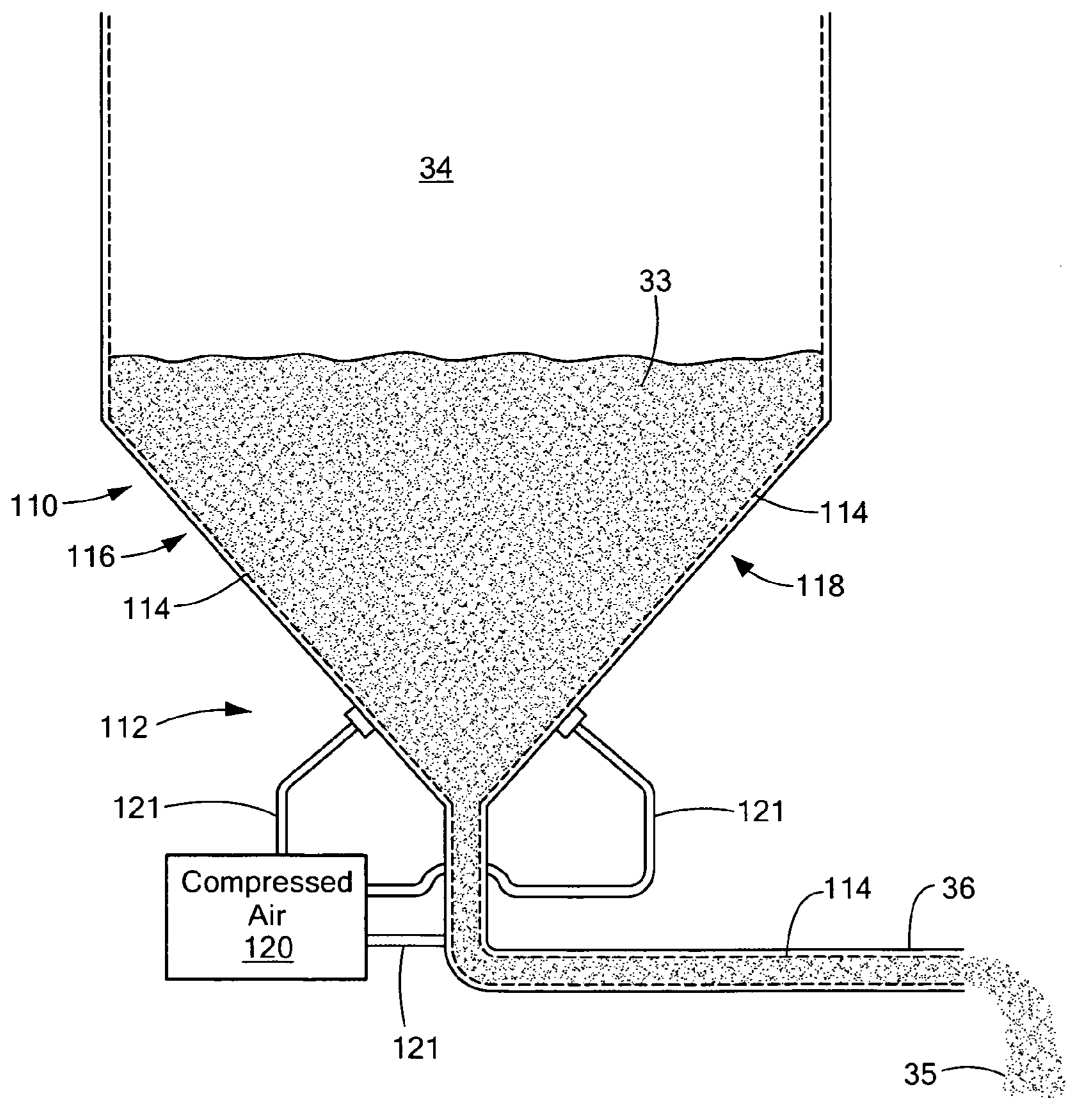

34
33
110
116
114
114
118
112
121
121
Compressed
Air
120
114
36
121
35

FIG. 2

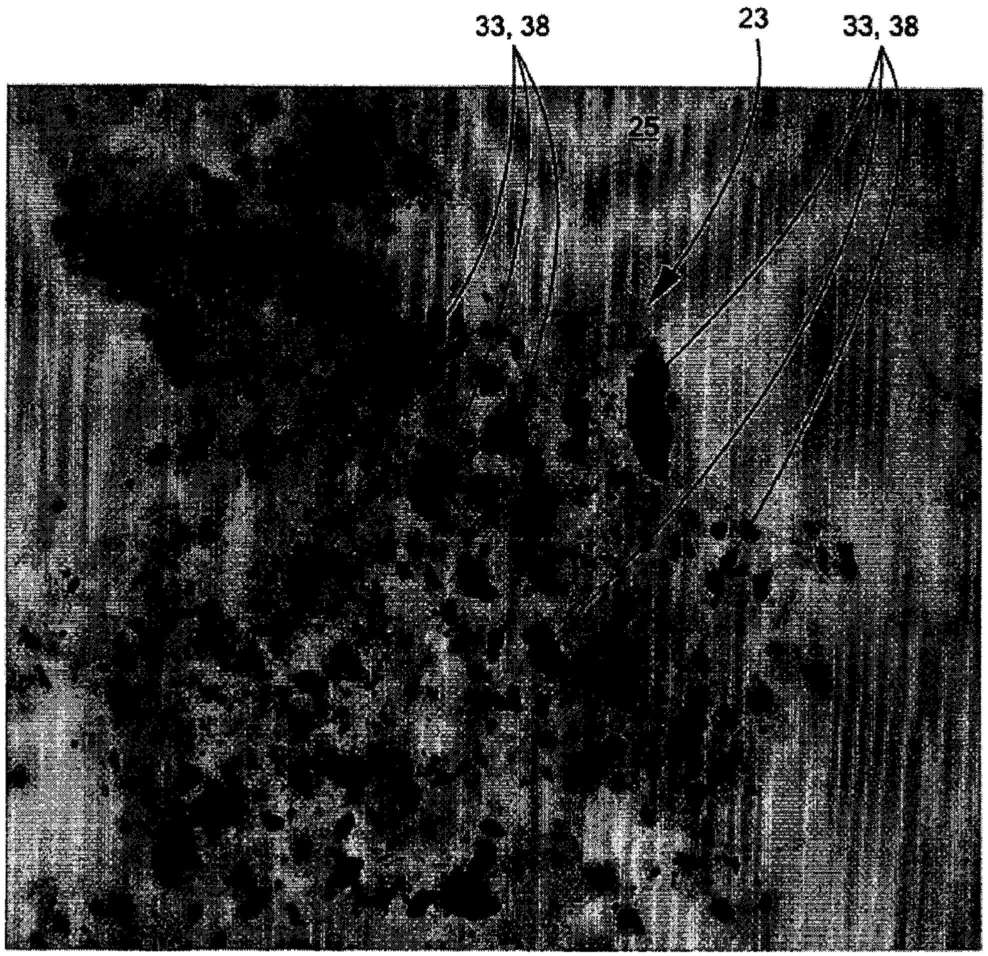



*FIG. 3*

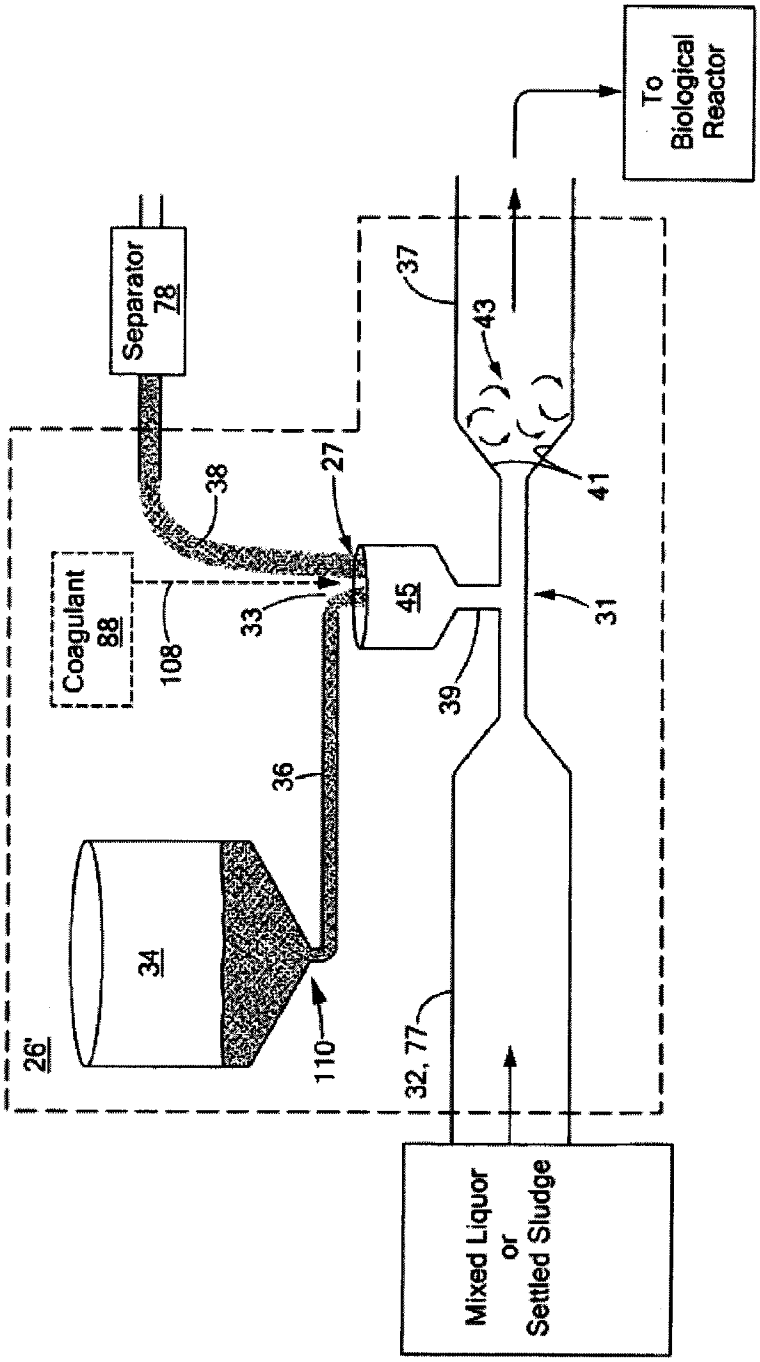

To
Biological
Reactor
Separator
78
Coagulant
88
108
38
27
33
45
31
39
41
43
37
36
34
110
26'
32, 77
Mixed Liquor
or
Settled Sludge

*FIG. 4*

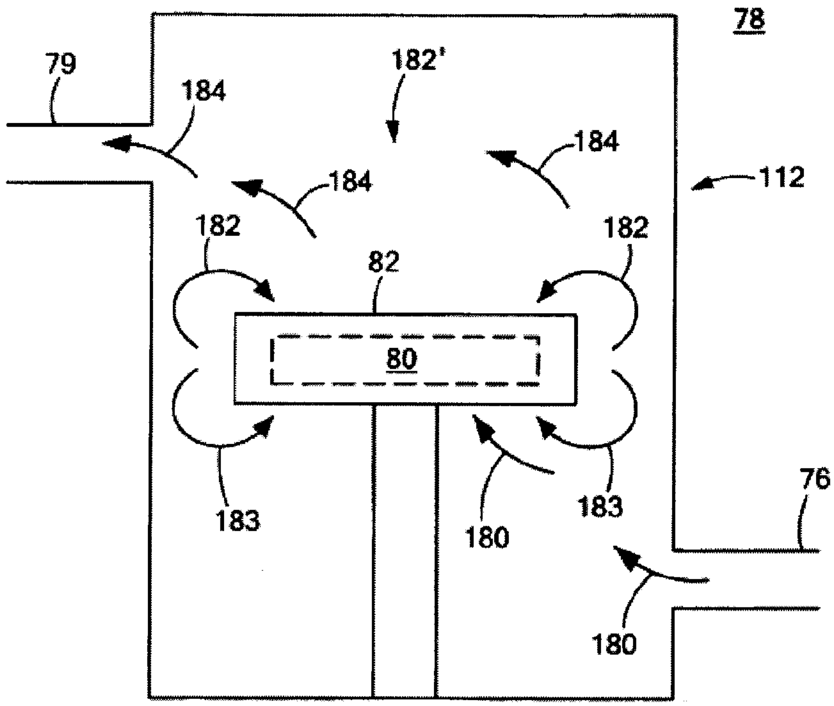

78
79
182'
184
184
184
112
182
182
82
80
183
183
180
180
76

*FIG. 5A*

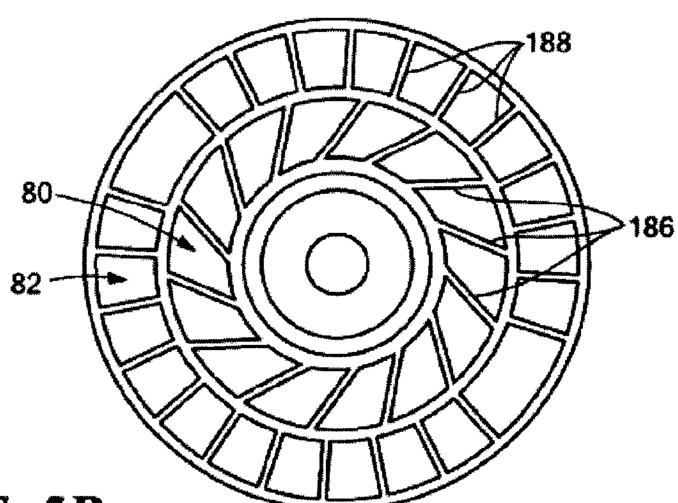

188
80
186
82

*FIG. 5B*

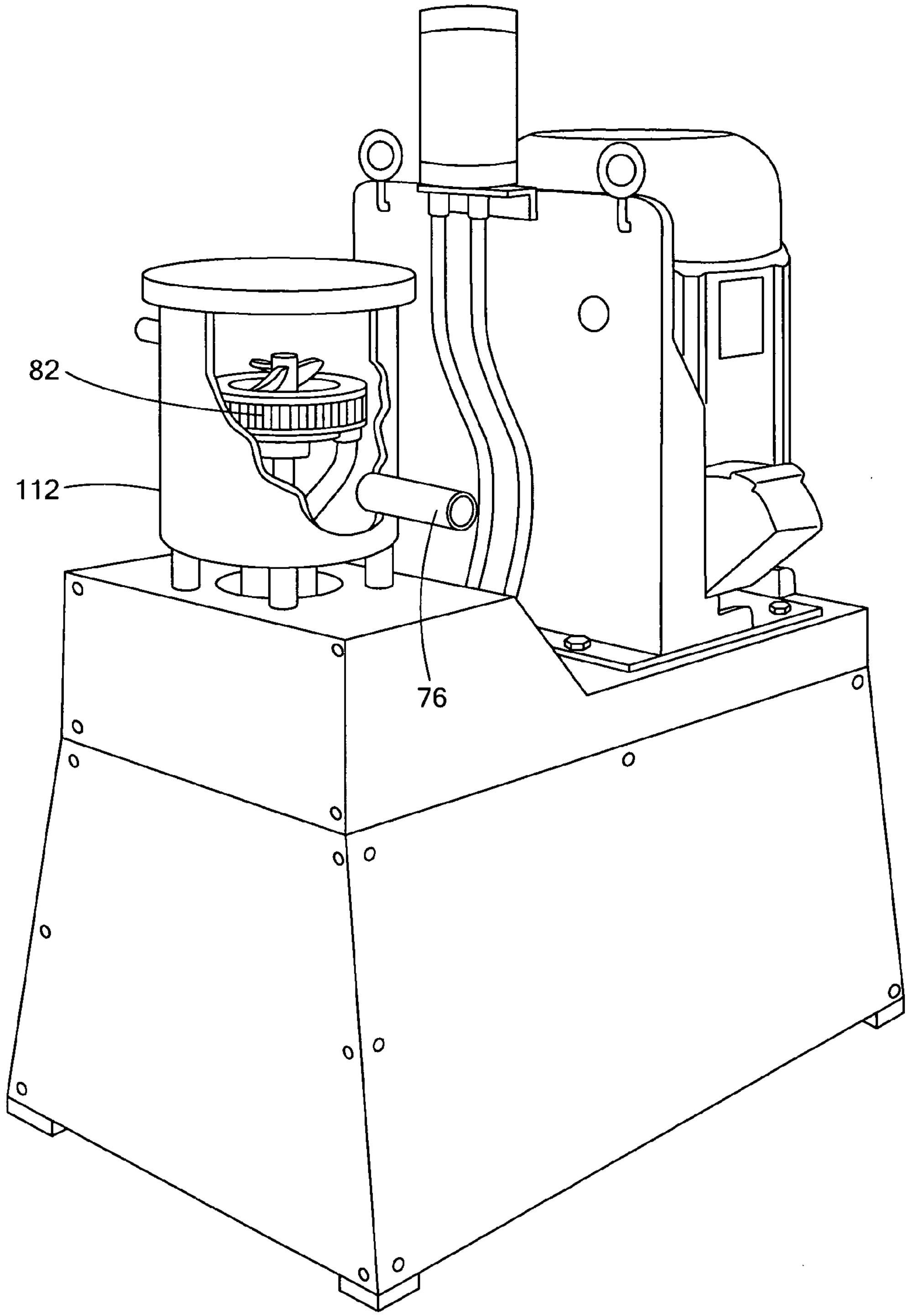



FIG. 5C

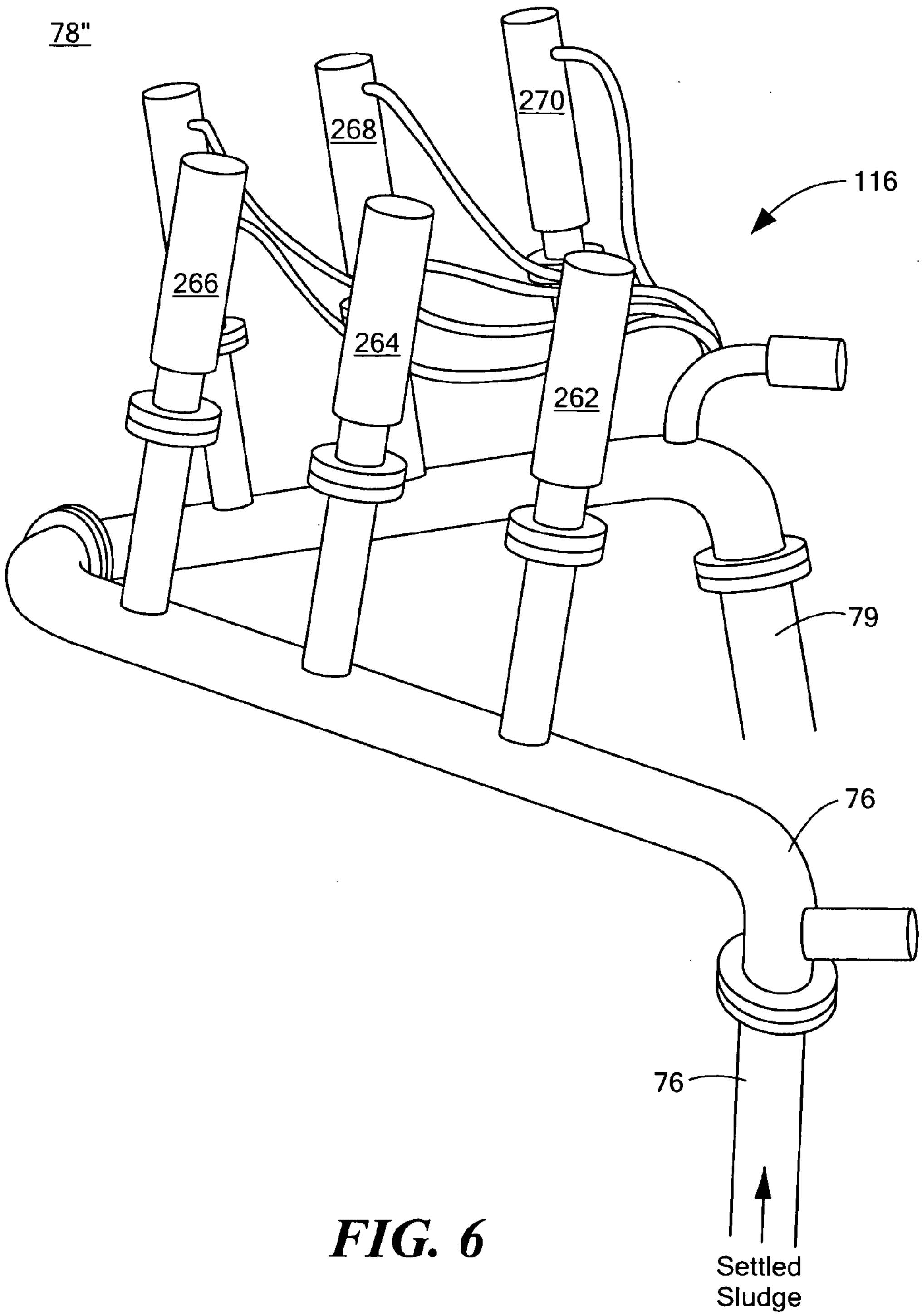



FIG. 6

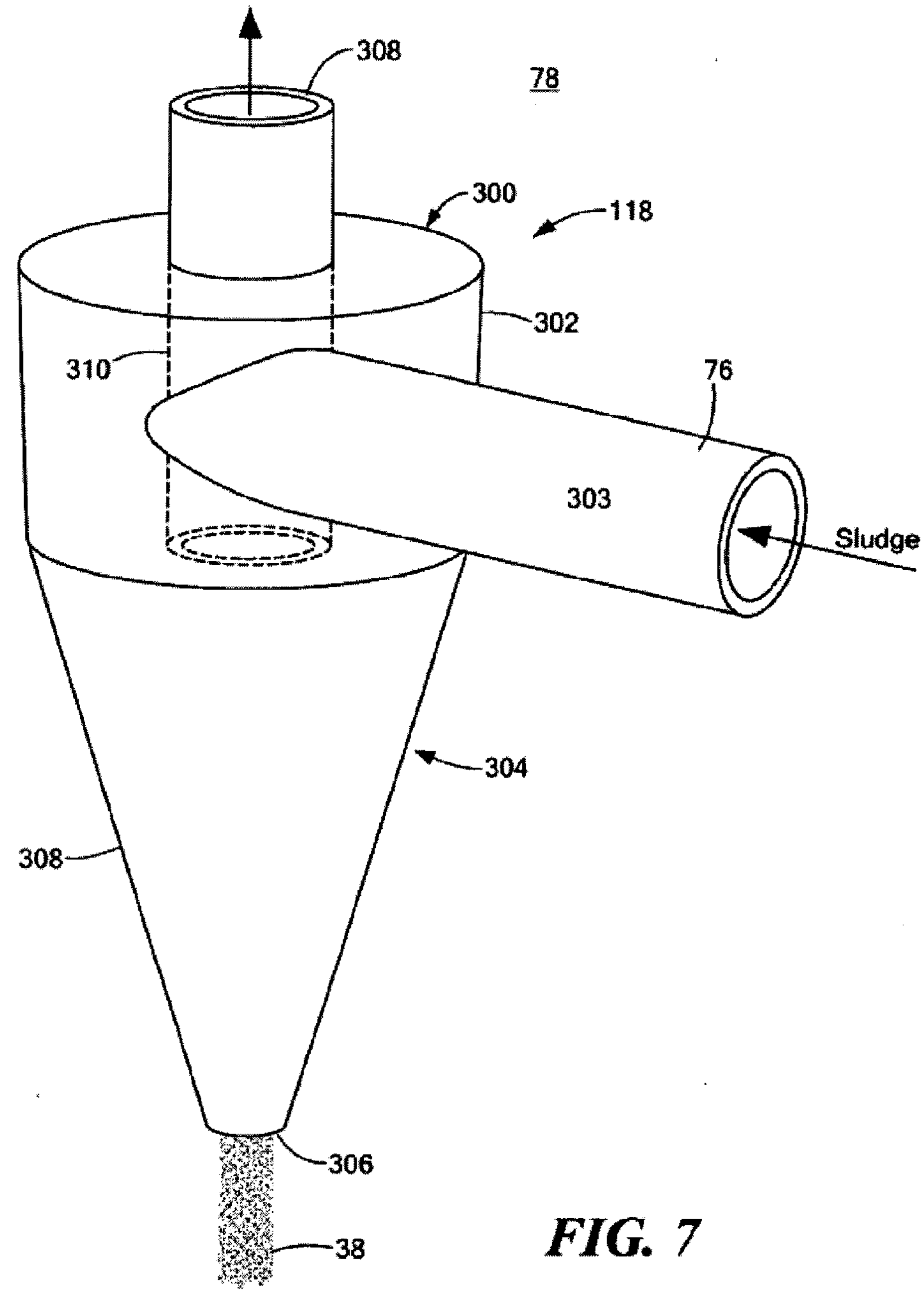



FIG. 7

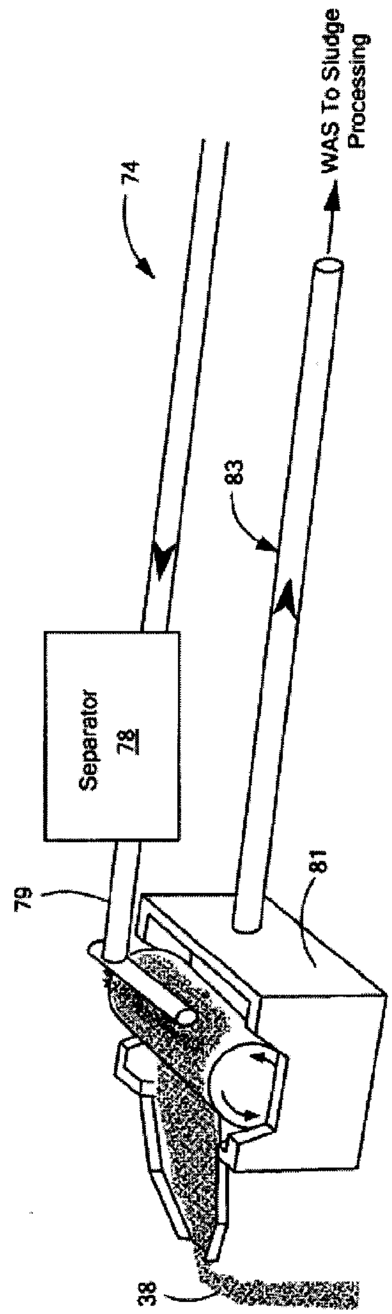



FIG. 8

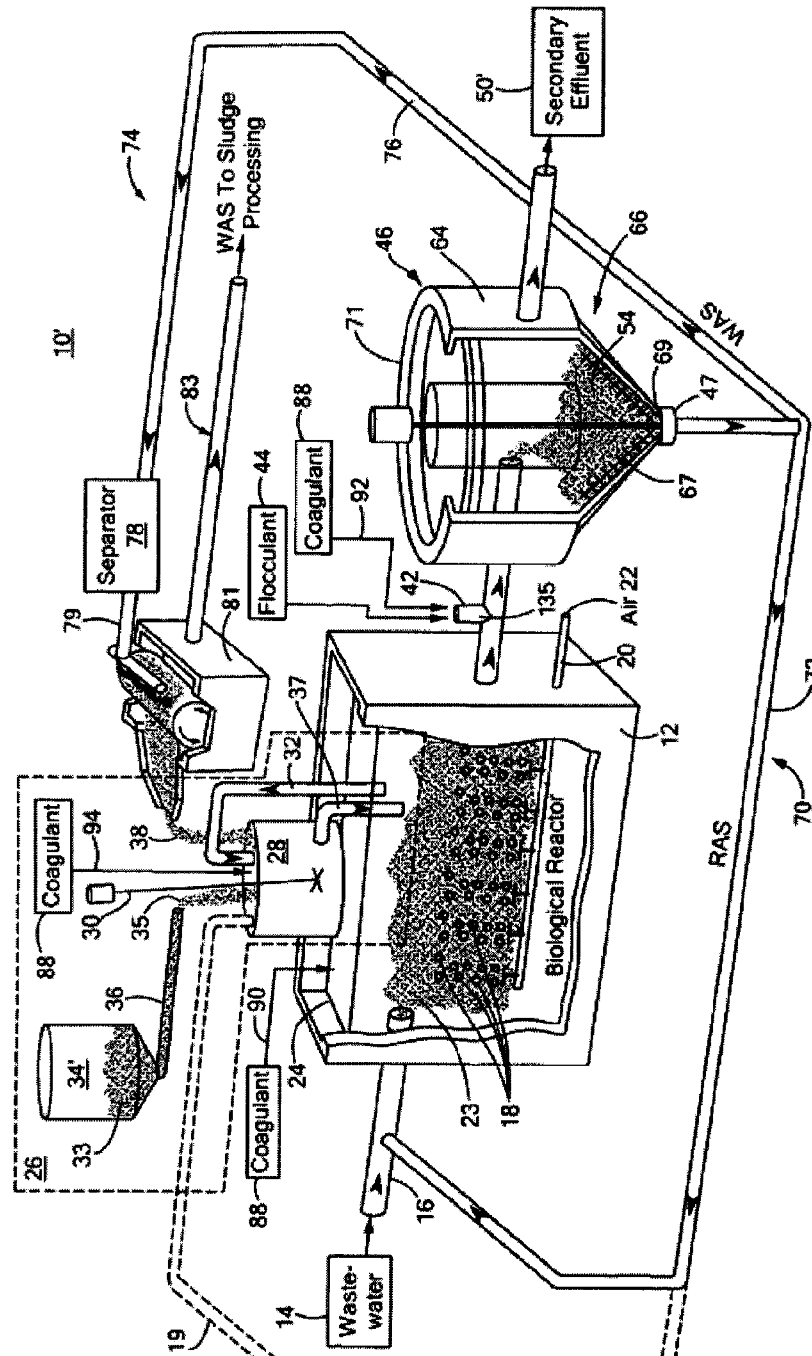

10'
Secondary Effluent
50'
WAS To Sludge Processing
74
76
Separator 78
79
81
83
Flocculant
44
Coagulant
88
92
42
135
Air 22
20
46
64
71
66
54
69
47
67
WAS
72
70
RAS
12
37
32
28
38
94
Coagulant
88
30
35
36
34'
33
26
Biological Reactor
90
Coagulant
88
24
23
18
16
Waste-water
14
119

FIG. 9

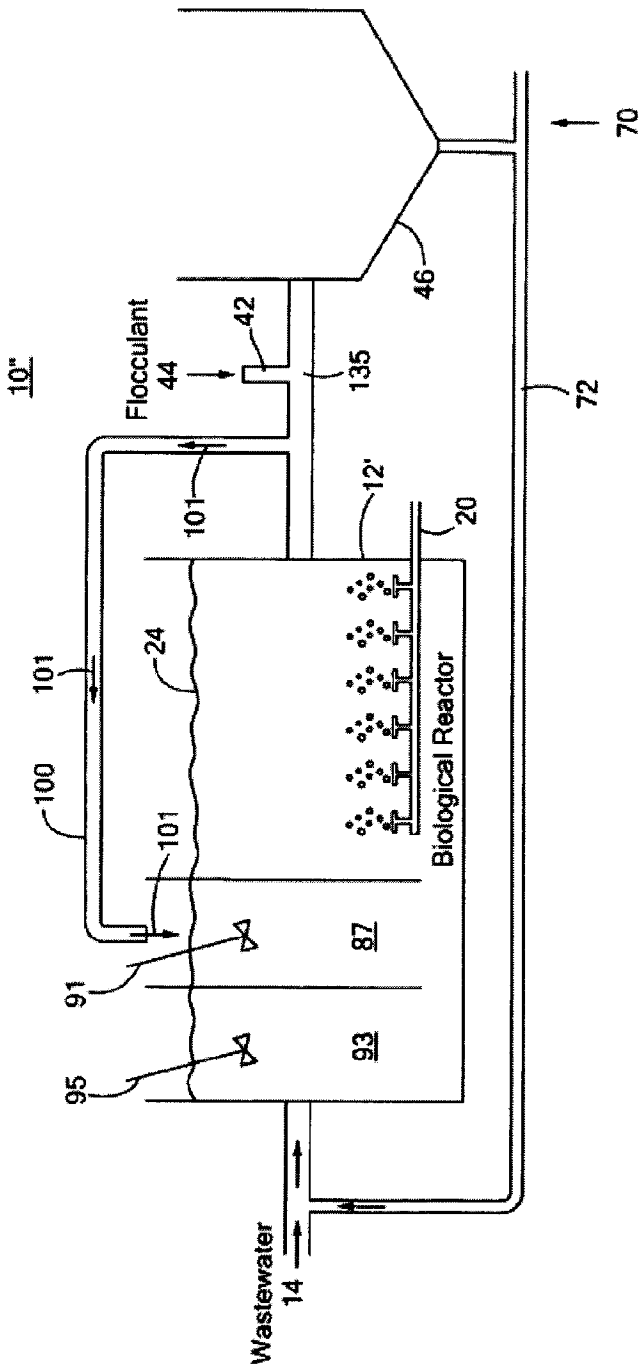

10"
Flocculant
44
42
135
46
70
72
101
12'
20
24
100
101
101
Biological Reactor
91
87
95
93
Wastewater
14

FIG. 10

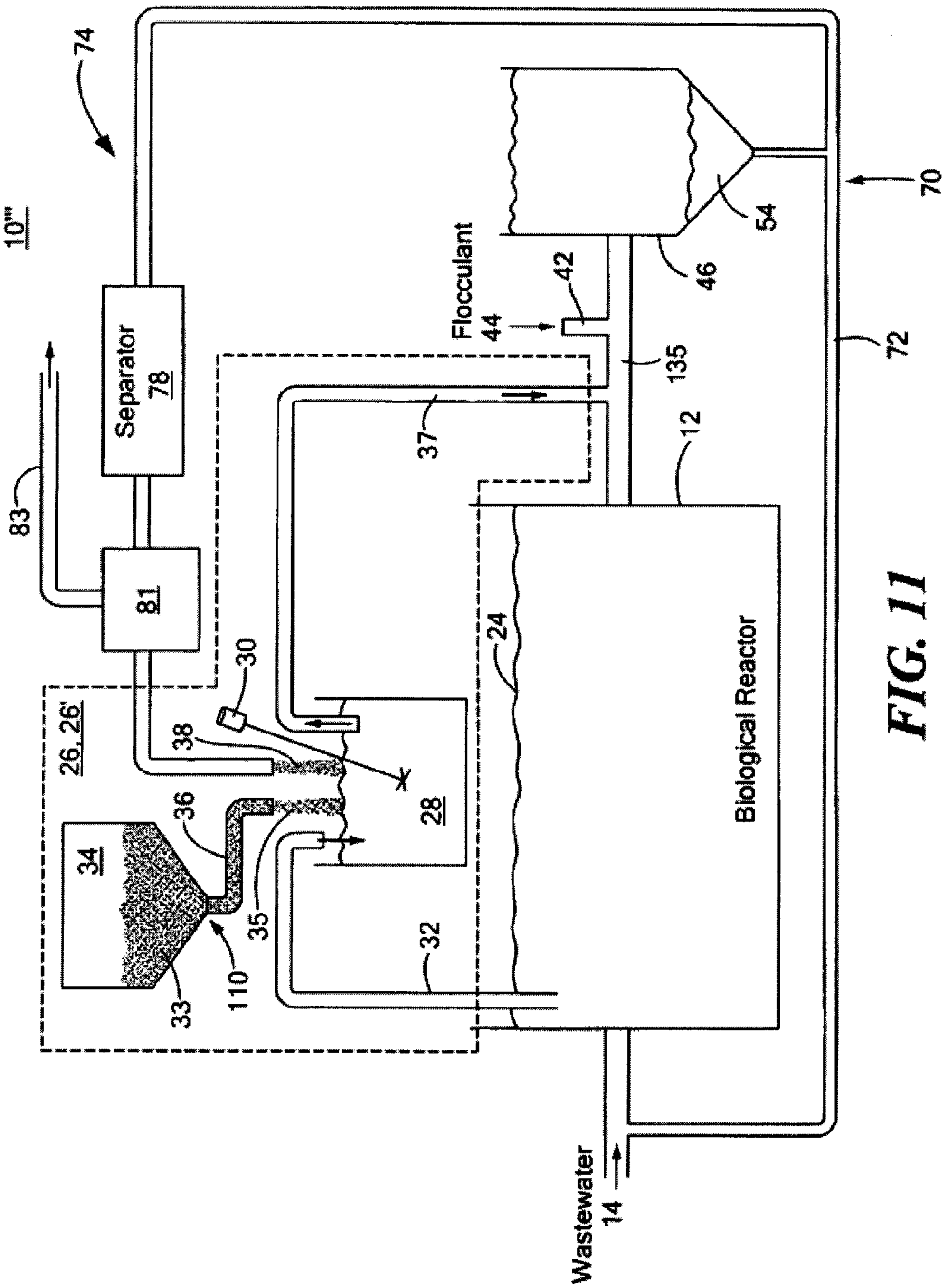

10'''
74
Separator
78
83
81
26, 26'
34
33
110
36
35
38
30
28
32
37
24
Biological Reactor
12
135
Flocculant
44
42
46
54
70
72
Wastewater
14

FIG. 11

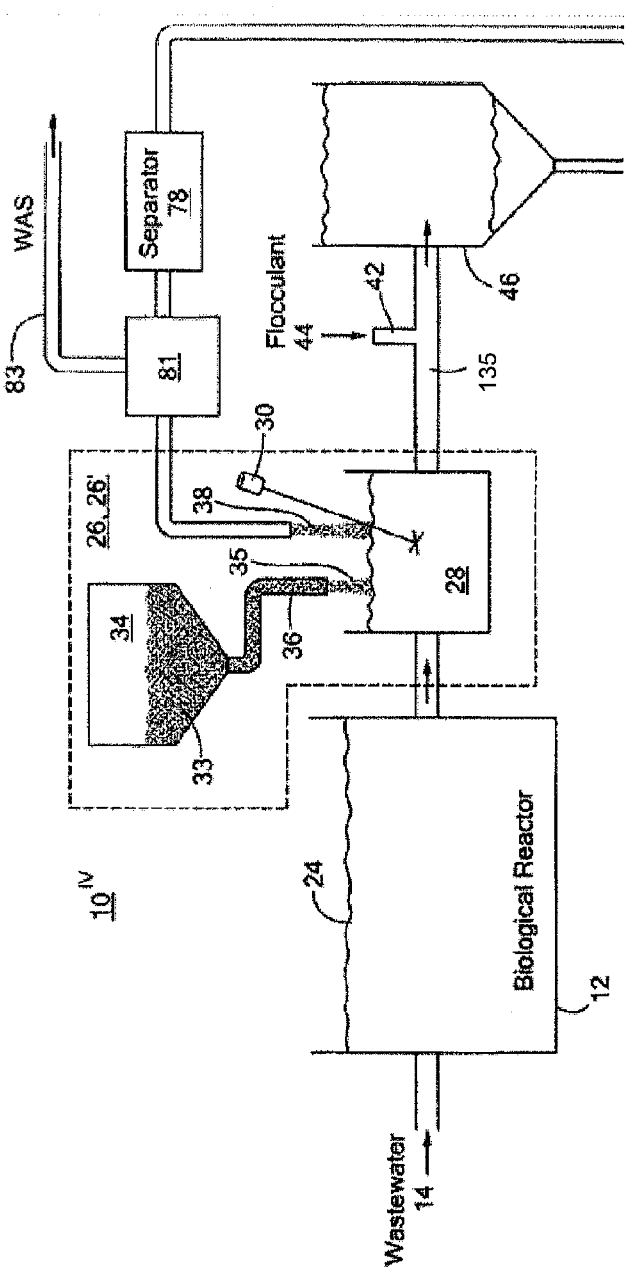

WAS
Separator
78
83
81
Flocculant
44
42
46
135
30
38
26, 26'
35
28
34
36
33
10^IV
24
Biological Reactor
12
Wastewater
14

*FIG. 12*

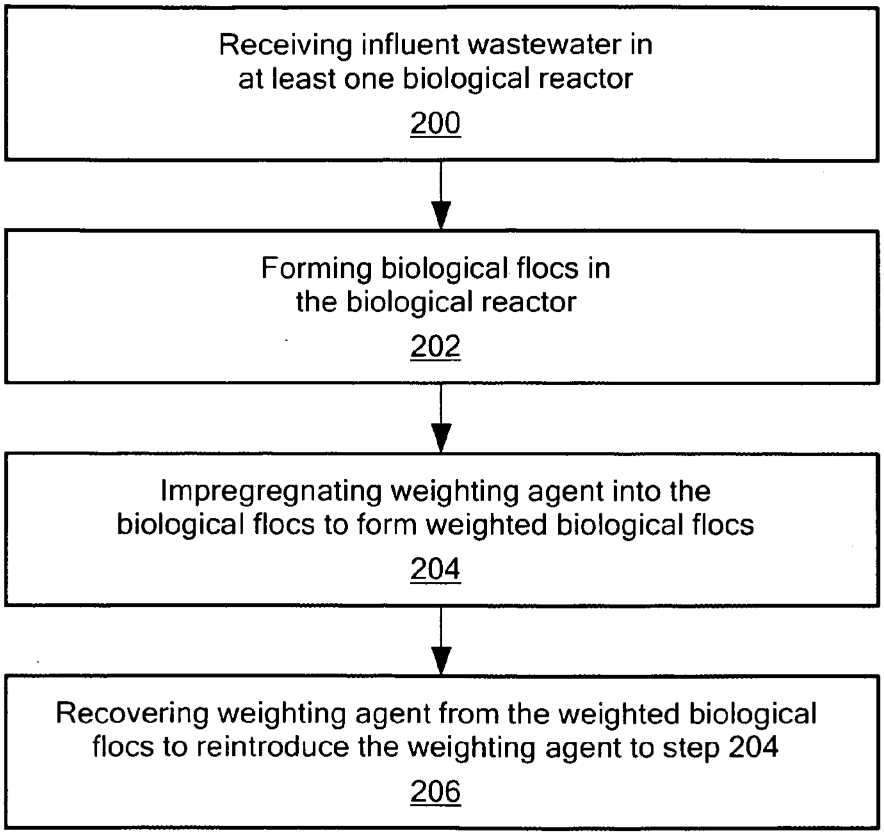
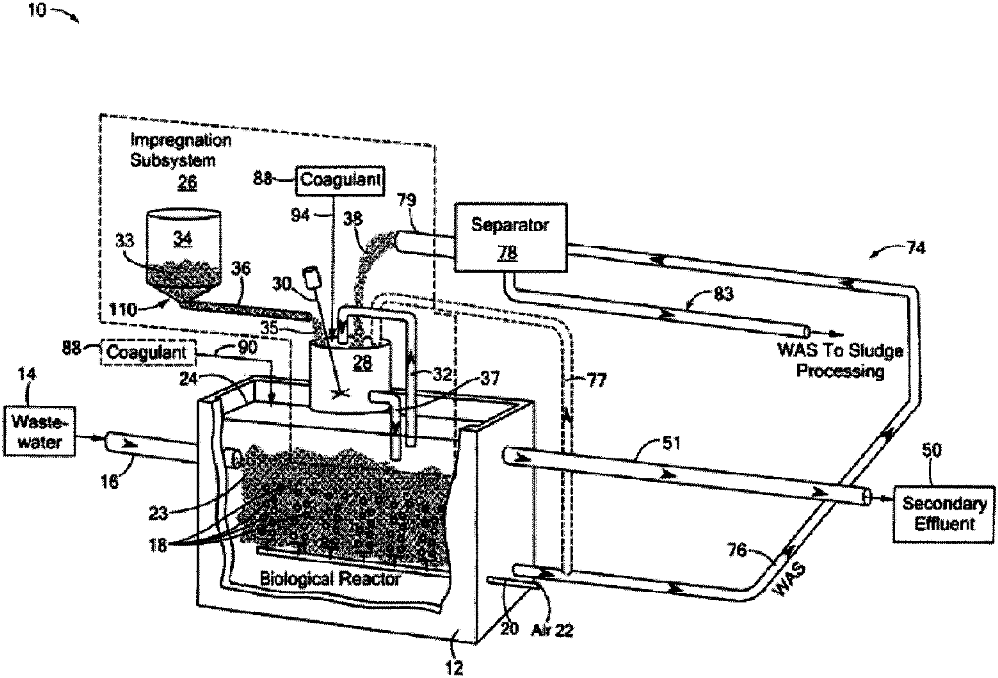

Receiving influent wastewater in
at least one biological reactor
200
Forming biological flocs in
the biological reactor
202
Impregregnating weighting agent into the
biological flocs to form weighted biological flocs
204
Recovering weighting agent from the weighted biological
flocs to reintroduce the weighting agent to step 204
206

*FIG. 13*


10
Impregnation Subsystem
26
88
Coagulant
79
94
38
Separator
78
74
33
34
36
30
83
110
35
88
Coagulant
90
28
WAS To Sludge Processing
14
24
32
37
77
Waste-water
51
50
16
23
Secondary Effluent
18
76
WAS
Biological Reactor
20
Air 22
12