

WASTEWATER TREATMENT USING NATURAL SOLID ADDITIVES IN ACTIVATED SLUDGE PROCESS

RELATED APPLICATION(S)

This claims the benefit of U.S. Provisional Application No. 61/509,147, filed
5 on July 19, 2011. The entire teachings of the above application(s) are incorporated
herein by reference.

BACKGROUND OF THE INVENTION

The activated sludge process is a wastewater treatment method that is widely
utilized throughout the world. In the process, primary-treated sewage or wastewater
10 is exposed to air or oxygen and biological microbes, which degrade and consume the
organic content dissolved or suspended in the wastewater.[1] Furthermore, the
activated sludge process is useful for denitrification, phosphate removal, heavy
metal removal, and degasification of the wastewater.

The efficiency of the activated sludge process is partially dependent on
15 having a good separation between the sludge and the treated water of the mixed
liquor in the settling tank. A number of studies have utilized additives in the
activated sludge process and examined their effects. For example, the addition of
talc weights the sludge, improving its sedimentation and lowering the sludge settling
volume. This positive effect is short-lived, however, and therefore requires repeated
20 additions of very large amounts of talc (up to 100% of the mixed liquor suspended
solid (MLSS) concentration). The disadvantage of this practice is a large increase in
the amount of dry solids in the sludge after separation in the settling tank. An
improvement to this process came in the formulation of a multi-component additive
containing talc, a quaternary ammonium salt, and a synthetic polymer, an agent that
25 aids sludge sedimentation with a more long-term effect.[2]

Enhanced sludge settling has also been observed with diatomite-containing
activated sludge system as compared to a normal activated sludge system, one factor
that contributes to greater biomass gained in the diatomite-containing process.
Diatomite particles, however, were found to have a relatively low adsorption

capacity for dissolved and suspended organics in the wastewater. With micrographic evidence, it was determined that diatomite serves as a carrier of sludge microbes, enabling the biodegradation of the organic components of the wastewater.[3]

- 5 The mineral bentonite has been examined in high loading with respect to the oxidation of ammonia into nitrite in landfill leachate treatment.[4] Further studies into Zeolite addition into the activated sludge process has demonstrated that these minerals hold some promise for applications such as enhanced biological phosphorus removal [5] and heavy metal absorption.[6]

10 SUMMARY OF THE INVENTION

The present invention relates to a method to improve efficiency and stability of wastewater treatment in an activated sludge process using one or more natural minerals as solid additives that functions as a sludge carrier.

- 15 The present invention discloses a method for wastewater treatment, comprising:

- 20 a) creating a high density sludge (HDS) comprising at least one solid mineral additive and microorganisms;
- b) exposing wastewater to the HDS of step (a) in an activated sludge tank and agitating the wastewater and HDS to yield a mixture of treated wastewater, normal activated sludge, and HDS; and
- c) separating the HDS from the mixture of step (b) for reuse in the wastewater treatment method.

In another embodiment, the method for wastewater treatment comprises:

- 25 a) mixing at least one solid mineral additive and water in a handling tank to form a mixture;
- b) introducing the mixture of step (a) into a culturing tank that contains an aliquot of a mixed liquor comprising microorganisms, wastewater, and organic waste obtained from an activated sludge tank;
- 30 c) agitating by aerating the mixture and the mixed liquor of step (b) to allow the microorganisms to degrade the organic waste, thereby forming a high-density sludge (HDS);

- d) introducing the HDS from step (c) to the activated sludge tank used in step (b);
- e) agitating by aerating the wastewater and the HDS in the activated sludge tank to allow the microorganisms to degrade the organic waste, and to allow the HDS to bind dissolved and suspended solids, if present, in the waste, for a period of time to yield a mixture of treated wastewater, normal activated sludge (NAS), and HDS;
- f) separating the treated wastewater from the mixture of step (e);
- g) separating the HDS from the NAS of step (f) by density or size; and
- h) transferring at least part of the HDS separated in step (g) to the handling tank of step (a).

In some embodiments of the invention, the method further comprises:

- i) adding an effective amount of a viable microbial blend containing strains capable of degrading organic wastes to the culturing tank in case the formation of HDS in step (c) or degradation of waste in step (e) is not efficient.

In further embodiments of the invention, when the wastewater comprises a high concentration of toxic ions, steps (g) and (h) are not performed. In some embodiments of the invention, the wastewater is equalized prior to entering the activated sludge tank. The aeration of step (c) allows aerobic microorganisms to grow inside a porous structure and on the surface of the additives.

In the invention, the solid mineral additives are selected from the list comprising attapulgite, bentonite, diatomaceous earth, montmorillonite, perlite, spilite, vermiculite, zeolite, talc, kaolinite, albite, oligoclase, bytownite, anorthite, olivine, enstatite, diopside, hornblende, and further porous silicate minerals or a combination of these. In some embodiments of the invention, the solid mineral additives are washed with water to dissolve and remove a water soluble contaminant.

In the invention, the separation of the HDS from the NAS of step (f) of the invention occurs in a density selective separation device or a size selective separation device.

In an example embodiment of the invention, the density selective separation device is a centrifuge separator, in which treated wastewater, the normal activated sludge, and the high density sludge to each flow toward a separate outlet, wherein each outlet is positioned at a different height.

5 In some embodiments of the invention, the size selective separation device is a rotating sieve.

The methods described herein help to overcome the limitation of low efficiency in wastewater treatment that uses the activated sludge process for municipal and industrial wastewater, especially when the organic loading is high,
10 when water quality and operational parameters vary significantly, and when toxic ions, e.g., heavy metal ions, are present.

The modified activated sludge process of the invention uses natural additives in wastewater treatment in an efficient, low cost, and novel manner compared with conventional processes. The methods of the invention allow for the use of one or
15 more additives with selectable particle size and porosity that are more versatile and novel compared to conventional processes. All of these advantages provide for improved methods for handling and culturing high density sludge with additives.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing will be apparent from the following more particular
20 description of example embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating embodiments of the present invention.

FIG. 1 shows a schematic of a modified activated sludge process by addition
25 of HDS additives.

FIG. 2 shows a schematic drawing of a preparation module comprising an additive handling tank and a culturing tank.

FIG. 3a is a comparison of Chemical Oxygen Demand (COD) removal
between Normal Activated Sludge (NAS) (No) and High Density Sludge (HDS)
30 with exfoliated vermiculite of different particle sizes (G0: 0.25-0.71 mm, G1: 0.33-

1.00 mm) at initial stage (left) and mature stage (right). FIG. 3b shows the COD removal for different amounts of added exfoliated vermiculite.

FIG. 4 is a comparison of sludge settling between NAS (No) and HDS with exfoliated vermiculite of different particle sizes (G0: 0.25-0.71 mm, G1: 0.33-1.00 mm) at mature stage.

FIG. 5 shows a schematic drawing of the container for culturing sludge.

FIG. 6 shows SEM images taken with JEOL JSM-6701F SEM. FIGs. 6a and 6c are magnified in FIGs. 6b and 6d, respectively. The scale bar is 50 μ m for FIGs. 6a and 6c, taken at x300, and the scale bar is 1 μ m for FIGs. 6b and 6d, taken at x4000.

FIG. 7a is a Thermogravimetric Analysis (TGA) plot of HDS, and FIG. 7b is a TGA plot of NAS.

DETAILED DESCRIPTION OF THE INVENTION

A description of example embodiments of the invention follows.

The activated sludge process is a widely used process in the treatment of wastewater using air or oxygen gas and a biological floc (also called a sludge) to remove organic waste. The efficiency of waste treatment depends largely on the growth, distribution, and handling of the sludge. The invention described herein is directed to a method to improve the activated sludge process for higher treatment efficiency. This method is based on the addition, utilization, and circulation of one or more solid mineral additives with diverse porosity and density in the process. The solid mineral additives house the microorganisms of the floc, and, as described herein, the additives contribute to improved sludge growth and flocculation, stabilized sludge structure, and more efficient interactions with the organic substance. The additives and cultured sludge can also be easily maintained by recycling the high density sludge (HDS) that contains the additives by using a gravity-based density selective separation instrument. Recycling the HDS with additives is highly advantageous in that the process reduces the amount of solid sludge that necessitates disposal, as compared to processes that require repeated additions of supplements. Moreover, the additives exhibit strong ion exchange characteristics which may reduce the impact of toxic ions, including heavy metals.

The present invention provides an effective method for automatic handling, utilization, and recycling of additives. The method can be incorporated into existing activated sludge processes.

The activated sludge process is an aerobic method for biological wastewater treatment. The success of the activated sludge process depends on establishing a mixed community of microorganisms that will degrade and consume organic waste material, and that will aggregate and adhere to form sludge. Part of the sludge is then discharged, and the remainder (return activated sludge, or RAS) is returned to the system for recycling. In conventional activated sludge processes, the separation of the sludge from the treated wastewater is performed by gravitational settling, but it may also be done by other methods, such as filtration or centrifugation. Both the biodegradation and separation processes depend largely on the bioactivity and overall physical structure of the sludge, or flocs. The major components of flocs are gelatinous structures of Zoogloea, comprising slimy capsules of bacterial cells. The adsorption and oxidation properties of Zoogloea play important roles in the activated sludge process. Their bioactivity and structure can be affected by many factors including, but not limited to, dissolved oxygen (DO), organic load, and pH. However, these factors are variable due to the properties of the influent wastewater or due to incidents like erroneous operation. A sudden and intense variation in any of these factors may lower the treatment efficiency or even damage the whole sludge system. For improved efficiency of the treatment of wastewater, it is essential to improve the bioactivity and stability of the sludge flocs.

Bacteria adhere to each other to form dense Zoogloea for efficient oxidation of organics. Zoogloea can only tolerate certain variations in environmental factors, or sludge bulking occurs, in which sludge turns into loosened structure with lower density. In this invention, one or more solid mineral additives is introduced into the activated sludge. These additives have various particle sizes and porous structures. Bacteria grow out of the porous structure of the additive core, and extend over the surface area of the additive to form Zoogloea. The result is that high density sludge (HDS) with core-cell cluster-like structures is constructed. In such structures, Zoogloea will be cross-linked through the growth of their constituent bacteria between the porous core structures of the additives. This structural feature enables

formation of a stabilized sludge structure that is more tolerant to environmental impacts than in normal activated sludge. As a further advantage of the invention, the porous structure of additives provides a high surface area which will increase the exposure of bacteria to organic contents in wastewater so that the biological interactions and bioactivity of bacteria are enhanced. The HDS can be easily separated from water, with reduced time required for settling and reduced volume of sludge for disposal. The HDS can also be easily isolated from normal activated sludge (NAS) by gravity which facilitates recycling of the additives.

The selection of additives should be based on a number of the following criteria:

1. Naturally available, without any synthetic chemical;
2. Higher density than water;
3. Not soluble in water;
4. Easily machinable to particles with various particle size ranging from microns to a few millimeters;
5. Easily machinable to particles with various porosities and pore sizes;
6. Stable structure and strength to survive the physical, chemical and biological conditions in activated sludge process;
7. Low cost.

In some embodiments of the invention, examples of such additives include, but are not limited to, attapulgite, bentonite, diatomaceous earth, montmorillonite, perlite, spilit, vermiculite, zeolite, talc, kaolinite, albite, oligoclase, bytownite, anorthite, olivine, enstatite, diopside, hornblende, and further porous silicate minerals and combinations of these. In preferred embodiments of the invention, the additives used are selected from vermiculite, zeolite, or bentonite. In some embodiments of the invention, a single additive is used. A mixture of at least one, at least two, at least three, at least four, or four or more solid natural additives is used. In an embodiment where there are at least two or more additives, the ratio of the additives is selected by considering sludge volume, dissolved oxygen, and wastewater loading in the activated sludge process. The ratio of the two additives ranges from 1:1 to 100:1, and preferably 1:1 to 10:1, and more preferably 1:1 to 2:1. The factors of bulk density, particle size, and porosity are similar across many of the

solid mineral additives that may be used with the invention. The combination of additives used in the invention, and ratios thereof, are selected by a person of ordinary skill in the art based on the factors of material availability, price, and system compatibility.

5 One key advantage of the invention is that the solid natural additives are machinable to particles with selectable size and porosity, a feature that contributes to the versatility of the method. In some embodiments of the invention, the particle size is from about 0.01 mm to about 2 mm. In preferred embodiments of the invention, the particle size is from about 0.1 mm to about 1 mm, and in a more
10 preferred embodiment of the invention, the particle size is from about 0.25 mm to about 0.75 mm. In another aspect of the invention, the porosity of the natural solid additives is about 10% to about 90%, and preferably about 50% to about 90%, and most preferably the porosity is about 70% to about 90%.

 The present invention is directed to improving the efficiency of the activated
15 sludge process for the treatment of wastewater through the addition of mixed natural solid additives. The method comprises (1) creating HDS comprising at least one solid mineral additive and microorganisms; (2) exposing wastewater to the HDS in an activated sludge tank to yield treated wastewater, normal activated sludge, and high density sludge; and (3) separating the treated wastewater from the HDS,
20 wherein the HDS is reused in the wastewater treatment method. The overall process is depicted in FIG. 1 and further described below.

Preparation of HDS with additives

 In some embodiments of the invention, the high density sludge is prepared
25 by first mixing one or more selected additives of optimal particle sizes and porosities with an amount of a handling solution sufficient to suspend the additives. In the invention, the handling solution may be selected from water, seawater, or an aqueous solution of an ionic salt. Collectively, these are referred to herein as "water." In some embodiments of the invention, the selected additives are freshly
30 added into the handling tank. In another aspect of the invention, the additives are introduced into the handling tank through an inlet that delivers HDS with mineral additives from a density selective separation device.

Next, the mixture of selected additives and handling solution is subjected to soaking, stirring, and rinsing in a handling tank, to obtain hydrated and evenly distributed mixtures and to remove contaminants. In some embodiments of the invention, the contaminants are dissolved in the handling solution and/or suspended in the handling solution (e.g., the contaminants present are dissolved in handling solution, suspended in handling solution, or both dissolved in and suspended in handling solution). In embodiments of the invention utilizing newly introduced additives, the contamination comprises dirt, dust, paper chips, or plant leaves. In another embodiment that utilizes recycled high density sludge from the activated sludge process, the contamination comprises toxic heavy metals or organic matter. In some embodiments of the invention, the rinsing process is followed by decanting off the solution containing the contaminant. In other embodiments of the invention, the contaminants are removed by sonication. The washed additive mixture is added to a culturing tank at up to about 50Kg/m^3 . The culturing tank, as shown in FIG. 2, is equipped with inlets for addition of additives and mixed liquor from activated sludge (AS) tank. The mixed liquor comprises wastewater, organic waste, microorganisms, and activated sludge. The culturing tank further comprises an outlet for transferring the prepared HDS to the AS tank and necessary pumping systems to maintain certain levels of sludge and water. In further embodiments of the invention, the additives described herein can be freshly added and/or include those minerals that are recycled from HDS. A total amount of minerals are present in the culturing tank such that a certain density of the mixed liquor is maintained, regularly checked as MLSS (mixed liquor suspended solid), and fresh additives are only topped up when recycled HDS is not sufficient to maintain this density. In the present invention, the volume of the culturing tank is sufficient to supply prepared HDS to the AS tank continuously. The culturing tank is filled with water and sludge from the same source as the AS tank. The mixture of solid mineral additives in water and mixed liquor is agitated by aeration to facilitate formation of HDS through degradation of organic waste by microorganisms present in the mixed liquor. The aeration persists for a period of time sufficient to obtain maximum sludge density. The maximum sludge density is determined by measuring the weight of an aliquot of the upper portion of the settled sludge. The aliquot is of a specific volume. The

sludge density is at a maximum when the sludge weight of the aliquot reaches a maximum and begins to level off. In order to facilitate initial bacteria growth on the additives in the HDS process of the present invention, the dissolved oxygen (DO) level in the culturing tank is higher than in a conventional AS process.

- 5 In some embodiments of the invention, an amount of a viable microbial blend (*e.g.* commercially available) is added to the culturing tank. The microbial blend contains strains capable of degrading organic waste. The microbial blend is added to the culturing tank when the formation of HDS is not efficient, meaning that the minimum amount of HDS to achieve a healthy activated sludge has not formed.
- 10 The amount of microbial blend that is added to the culturing tank is gradually increased at a rate by which the sludge volume reaches about 200 mL/L to about 500 mL/L in about two to about 4 days. In some embodiments of the invention, an amount of a viable microbial blend is added to the culturing tank after a process failure or an emergency. In other embodiments, the viable microbial blend is added
- 15 at the beginning of a new activated sludge process. In yet other embodiments of the invention, a viable microbial blend is added when an accelerated sludge growth is required.

- In another aspect of the invention, the wastewater to be treated is analyzed for content of chemical oxygen demand (COD), biochemical oxygen demand
- 20 (BOD), oil and grease, heavy metals, nitrogen-based species, and phosphorus-based species. Based on the analytical tests performed, additives are selected based on density, particle size, porosity, and ease of bacterial growth in order to form an efficient high density sludge.

- In some embodiments of the invention, the selected additives comprise crude
- 25 vermiculite, exfoliated vermiculite, zeolite, and bentonite. In another embodiment, the additives comprise zeolite and bentonite. In yet another embodiment, the additives comprise bentonite.

Application of HDS with additives to AS process

- 30 HDS with additives is added to the AS tank through an inlet connected to the HDS outlet of the culturing tank. The HDS flow rate is optimized in such a way that it does not significantly affect the sludge volume of about 300 to about 500 mL/L in

the activated sludge tank, and the concentration of additives are maintained at about 20 kg/m³. In preferred embodiments of the invention, the HDS inlet is positioned in the near proximity of the inlet of wastewater for thorough mixing and long retention time in the AS tank. In one aspect of the invention, the mixing occurs by agitation
5 through aeration of the mixture. In one aspect of the invention, the retention time of the wastewater in the AS tank is from about 1 to about 48 hours. In a preferred embodiment, the retention time of the wastewater in the AS tank is from about 2 to about 10 hours, and in a more preferred embodiment, from about 3 to about 5 hours. In some embodiments of the invention, the wastewater to be treated in the AS tank,
10 or influent, is equalized, or pre-treated to buffer the pH of the wastewater or remove macrosolids.

A preliminary study was done with two types of additives with different particle sizes. Compared to the conventional AS process, COD removal rate and sludge settling are improved by HDS with additives. FIG. 3a shows that at both the
15 initial and mature stage of HDS formation utilizing exfoliated vermiculite, COD removal rates with HDS are higher than with normal activated sludge (NAS) and the improvement is more significant at a mature stage. The time required for maturing of HGS could be up to about 7 days. The COD removal rate is dependent on the amount of additives present in the HDS, as shown in FIG. 3b. FIG. 4 graphs the
20 volume of sludge against time in the settling process in the density selective separation tank. It shows that HDS formed with exfoliated vermiculite additives settled faster with a small volume of sludge production than normal AS. Moreover, these additives consist of minerals and inorganic salts of sodium, potassium, calcium, magnesium, and aluminum, which allow ion exchange with toxic and
25 heavy metal ions, including, but not limited to lead, mercury, manganese, cadmium, chromium, copper, nickel, and zinc, in wastewater.

Recycling of HDS with additives

Regeneration of bacteria leads to increase of sludge particle size. Excessive
30 Zoogloea will detach from HDS and form NAS in the mixed liquor. Aged Zoogloea will also be replaced by newly grown ones and join the NAS community. Both

NAS and HDS suspended in the mixed liquor overflow to a density selective or size selective separation instrument where water, NAS, and HDS are separated.

In certain embodiments of the invention, the treated water, the NAS, and the HDS are separated based on the difference in gravity. In a preferred embodiment, the water, the NAS, and the HDS are separated by a density selective separation instrument. In some embodiments of the invention, the density selective separation device is based on differences in responses of different materials to gravity, centrifugal force, or flow patterns due to differences in the density of the materials.

In one embodiment, density selective separation occurs in a centrifuge separator, in which a conical container is equipped with NAS outlets at a middle level, HDS outlets on the bottom, and a spinning mechanism. Mixed liquor is pumped into the instrument from bottom to top. Effluent is spun off from the top. As the apparatus spins, NAS is collected at a middle level, and HDS at the bottom. Pumping systems for effluent discharging, sludge disposal, and HDS recycling are not shown in details.

In another aspect of the invention, the treated water, the NAS, and the HDS are separated based on the difference in size (*e.g.* particle size). In an example embodiment, a size selective separation device is a rotating sieve, in which treated wastewater, normal activated sludge, and high density sludge are separated based on their abilities to pass through the pores of the sieves while moving through a rotating sieve.

In another embodiment of the invention, the wastewater contains large concentrations of toxic ions that are higher than what is allowed for discharge. In this embodiment, used HDS is disposed. In another embodiment of the invention in which the wastewater contains high concentrations of toxic ions, recycled HDS should be soaked with concentrated salt solutions in the handling tank. Then, the solution containing the contaminants is decanted, and the remaining HDS is returned to the culturing tank for reuse.

The process of the present invention, utilizing mineral additives to form a high density sludge, can be applied in wastewater treatment operations that use an activated sludge process for municipal and industrial wastewater. Furthermore the process can be applied in treatment of wastewater from food production and

processing operations, to other industrial applications in the textile or coke production industry. The process is especially useful with wastewater in which:

1. organic loading is high;
2. operational parameters and water quality varies significantly; or
- 5 3. toxic ions, e.g., heavy metal ion are present.

DEFINITIONS

The terms “wastewater” or “waste water” mean water that is adversely affected in quality by anthropogenic influence. Wastewater can originate from municipal or industrial sources. In some embodiments of the invention, wastewater
10 comprises water and a variety of other components, including, but not limited to, pathogens such as viruses and bacteria, non-pathogenic bacteria, organic particulate matter, soluble organic material, inorganic particulate matter, soluble inorganic material, animals, macro-solids, gases, pharmaceuticals, and toxins.

“Flocculation” is a process by which colloids come out of a suspension to
15 form a cluster of particulate matter.

A “floc” is a cluster of particulate matter that comes out of suspension during the process of flocculation.

In some embodiments of the invention, a “toxic ion” may be a heavy metal ion. In more particular embodiments of the invention, the toxic ion is cadmium,
20 chromium, copper, nickel, or zinc.

“Equalized wastewater” is wastewater that has undergone a pretreatment prior to entering a wastewater treatment system. The pretreatment process of equalization is a means of buffering the wastewater prior to wastewater treatment. In some embodiments of the invention, the equalization process is the removal of
25 inorganic and organic macrosolids from the waste mixture. In another embodiment of the invention, equalization is pH neutralization by chemical addition. In another embodiment of the invention, equalization occurs through regulation of temperature, flow rate, or pressure of the wastewater.

EXAMPLES

The following examples are provided to illustrate one or more preferred embodiments of the invention, but are not limited embodiments thereof. Numerous variations can be made to the following examples that lie within the scope of the invention.

Example 1: Culturing of sludge with additives: The culturing container.

A culturing container with volume of 20 liters is shown in FIG. 5. An inlet and an outlet for mixed liquor were added in the upper portion of the container. An outlet for cultured high-density sludge (HDS) was added near the container bottom. One divider, having the height of two-thirds to three-quarters of that of the container was vertically centered in the container, where the divider was not fully submerged. The divider ensured that the inlet and outlet for mixed liquor were not in the same compartment, so that mixed liquor was kept in the container for a long retention time before flowing through the outlet. An air diffuser was installed at the bottom of the container, which was linked to air blower.

Example 2: Culturing of a High Density Sludge with additives: The culturing process.

The culturing container described in Example 1 was filled with mixed liquor from the activated sludge (AS) tank in the wastewater treatment plant for inoculation. The settled sludge volume was measured to be 300 – 400 ml/L. 1 kg-additives were added to the container after wetting with water. The container was aerated to maintain the dissolved oxygen (DO) level at 3 mg/L. After one week, the following steps were repeated every 6 hours.

- 1) Stop aeration and close the mixed liquor inlet;
- 2) After 30 minutes, replace 12 L upper portion of the mixed liquor and close the inlet;
- 3) Start aeration.

Example 3: Culturing of sludge with additives: Application of HDS to Activated Sludge Process.

When needed, HDS generated in Example 2 was taken from the HDS outlet described in Example 1 after aeration was stopped for 30 minutes. An amount of

HDS was added to the AS tank so that the concentration of additives ranged from 2 to 10 g/L. Several lab scale AS tanks were used simultaneously and operational parameters of normal AS process were maintained.

Example 4: Evaluation of the Activated Sludge Process as improved by HDS.

5 A preliminary study was done with two types of additives with different particle sizes, namely G for 0.25-0.71mm and G1 for 0.33-1.00mm. The COD of wastewater was around 1000 mg/L. At initial stage (Day 1) and mature stage (Day 7), COD removal after 4 hours of treatment using HDS was compared with normal AS without HDS. As shown in FIG. 3 (A), COD removal rate was improved from
10 19% to above 50% by HDS at the initial stage, as a result of the much higher adsorption capacity of the additives. At mature stage, COD removal rates of HDS were still at least 10% higher than normal AS. Smaller particles showed slightly better performance due to the higher surface area. FIG. 3 (B) shows that the COD removal is dependent on the amount of additives used for culturing of HDS.

15 *Example 5: Sludge Settling Volume with HDS in AS Process.*

FIG. 4 shows the volume of the settled sludge over time in the settling process. This was tested using 25 mL measuring cylinder filled with mixed liquor with normal AS and with HDS. While normal AS requires more than 30 minutes of settling time, HDS settled in 10 minutes. Moreover, the sludge volume was reduced
20 by 30-40% for the case of HDS.

Example 6: Observation of Sludge Growth in the Vacancy Structure of Additives

SEM images of vermiculite loaded with activated sludge are shown in FIG. 6. The vacant spaces between the layers of vermiculite ranged from 10 to 20 μm , which was sufficient for the sludge bacteria, with an average size of 1 μm , to grow
25 within the vermiculite. Clusters of growth were found within the vacant spaces between layers of vermiculite. The magnified view suggested that the clusters were aggregates of bacterial growth. It is known that activated sludge has a mean floc size of about 20 μm . Hence, the aggregates observed in the SEM images were activated sludge floc grown within the vermiculite, generating HDS.

Example 7: Composition of HDS

Thermogravimetric Analysis (TGA) was performed to gauge the percentage of vermiculite present in HDS by removal of water and combustion of all of the organic compounds contained within the HDS. Samples were heated to 550 °C and 1000 °C, and showed differences in appearance of the vermiculite, with the former appearing dull and dark brown, and the latter appearing shiny and bright yellow. These physical characteristics indicated that the activated sludge was completely removed at 1000 °C, but only partially removed at 550 °C. Hydrated vermiculite is known to have greater than 90% weight loss with TGA. However, as shown in FIG. 7, the HDS lost 82.2% of its weight, demonstrating that there were substances other than water in between the layers of vermiculite. This result explained the different levels of sludge volume decrease with HDS as compared to NAS, which loses 98.7% of its weight in TGA.

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5 The teachings of all patents, published applications and references cited herein are incorporated by reference in their entirety.

While this invention has been particularly shown and described with references to example embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention encompassed by the appended claims.

CLAIMS

What is claimed is:

1. A method for wastewater treatment, comprising:
 - a) creating a high density sludge (HDS) comprising at least one solid mineral additive and microorganisms;
 - b) exposing wastewater to the HDS of step (a) in an activated sludge tank and agitating the wastewater and HDS to yield a mixture of treated wastewater, normal activated sludge, and HDS; and
 - c) separating the HDS from the mixture of step (b) for reuse in the wastewater treatment method.
2. The method of claim 1, wherein step (a) comprises:
 - d) mixing at least one solid mineral additive and water in a handling tank to form a mixture;
 - e) introducing the mixture of step (d) into a culturing tank that contains an aliquot of a mixed liquor comprising microorganisms, wastewater, and organic waste obtained from an activated sludge tank;
 - f) agitating by aerating the mixture and the mixed liquor of step (e) to allow the microorganisms to degrade the organic waste, thereby forming the HDS.
3. The method of claim 1 or claim 2, wherein step (b) comprises:
 - g) introducing the HDS from step (a) to the activated sludge tank used in step (e);
 - h) agitating by aerating the wastewater and the HDS in the activated sludge tank to allow the microorganisms to degrade the organic waste, and to allow the HDS to bind dissolved and suspended solids, if present, in the waste, for a period of time to yield a mixture of treated wastewater, normal activated sludge (NAS), and HDS.
4. The method of any one of claims 1-3, wherein step (c) comprises:
 - i) separating the treated wastewater from the mixture of step (h);
 - j) separating the HDS from the NAS of step (i) by density or size; and

- k) transferring at least part of the HDS separated in step (j) to the handling tank of step (d).

5. A method for wastewater treatment, comprising:

- 5 a) mixing at least one solid mineral additive and water in a handling tank to form a mixture;
- b) introducing the mixture of step (a) into a culturing tank that contains an aliquot of a mixed liquor comprising microorganisms, wastewater, and organic waste obtained from an activated sludge tank;
- 10 c) agitating by aerating the mixture and the mixed liquor of step (b) to allow the microorganisms to degrade the organic waste, thereby forming a high-density sludge (HDS);
- d) introducing the HDS from step (c) to the activated sludge tank used in step (b);
- 15 e) agitating by aerating the wastewater and the HDS in the activated sludge tank to allow the microorganisms to degrade the organic waste, and to allow the HDS to bind dissolved and suspended solids, if present, in the waste, for a period of time to yield a mixture of treated wastewater, normal activated sludge (NAS), and HDS;
- 20 f) separating the treated wastewater from the mixture of step (e);
- g) separating the HDS from the NAS of step (f) by density or size; and
- h) transferring at least part of the HDS separated in step (g) to the handling tank of step (a).

25 6. The method of claim 5, further comprising:

- i) adding an effective amount of a viable microbial blend containing strains capable of degrading organic wastes to the culturing tank in case the formation of HDS in step (c) or degradation of waste in step (e) is not efficient.

7. The method of claim 4 or claim 5, wherein separating the HDS from the NAS by density or size occurs in a density selective separation device or a size selective separation device.
- 5 8. The method of any one of claims 1-7, wherein the at least one solid mineral additive is selected from attapulgite, bentonite, diatomaceous earth, montmorillonite, perlite, spilitite, vermiculite, zeolite, talc, kaolinite, albite, oligoclase, bytownite, anorthite, olivine, enstatite, diopside, hornblende, porous silicate minerals, or combinations thereof.
- 10 9. The method of claim 4, wherein steps (j) and (k) are not performed when the wastewater being treated comprises a high content of toxic ions.
- 15 10. The method of claim 5, wherein steps (g) and (h) are not performed when the wastewater being treated comprises a high content of toxic ions.
11. The method of claim 2 or claim 5, wherein the aeration allows aerobic microorganisms to grow inside a porous structure of the additives and on a surface of the additives to form an HDS cluster.
- 20 12. The method of claim 7, wherein the size selective separation device is a rotating sieve.
13. The method of claim 7, wherein the density selective separation device is a centrifuge separator.
- 25 14. The method of claim 13, wherein the centrifuge separator allows treated wastewater, the normal activated sludge, and the high density sludge to each flow toward a separate outlet, wherein each outlet is positioned at a different height.
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15. The method of any one of claims 1-14, wherein the wastewater is equalized prior to entering the activated sludge tank.
16. The method of any one of claims 1-15, wherein the at least one solid mineral
5 additive is washed with water to dissolve and remove a water-soluble contaminant prior to use in the method.