suppression of NOB is not feasible. In this context, we define the term out-selection as an approach to repress NOBs through the achievement of higher rates for AOBs, thus producing nitrite for other organisms.

SUMMARY

[0011] In one aspect, the present disclosure refers to a wastewater treatment apparatus, comprising: a biological nitrogen removal (BNR) reactor having a volume that is equipped with an aeration system; an ammonia sensor for generating an ammonia concentration signal; and a controller for processing the ammonia concentration signal and thereby limiting a growth of nitrite oxidizing bacteria (NOB) under controlled aeration conditions, the conditions being controlled either along the flow-path or along the process time-line, andwherein the wastewater treatment apparatus is configured to set an aeration system activation interval, an upper DO setpoint, or both, and wherein the wastewater treatment apparatus is configured to set the aeration system activation interval, the upper DO setpoint, or both are set such that a measured ammonia concentration is higher than 1.5 mg/L ammonia as nitrogen, for more than 75% of the reactor volume in space or time.

[0011a] In another aspect, the present disclosure refers to a wastewater treatment apparatus, comprising: a biological nutrient removal (BNR) reactor that is equipped with an aeration system; an ammonia sensor in the reactor to generate an ammonia concentration signal; at least one oxidized nitrogen sensor to sense oxidized nitrogen concentration in the reactor to generate an oxidized nitrogen signal for nitrite, nitrate, or combination of nitrite and nitrate; and a controller; wherein the wastewater treatment apparatus is configured to respond to one or more signals representing (A) a ratio of the ammonia concentration to the oxidized nitrogen concentration, on an as nitrogen basis or (B) a sum of the ammonia concentration plus the negative value of the oxidized nitrogen concentration, on an as nitrogen basis; and wherein the controller is configured to generate instructions for increasing, decreasing or maintaining the DO concentration, the duration of the aerobic period, and/or the duration of the anoxic period to maintain (A) the ratio of the ammonia concentration to the oxidized nitrogen concentration, on an as nitrogen basis, from about 0.5 to 1.5 and/or including a defined offset ammonia concentration or (B) the sum of the ammonia concentration plus the negative value of the oxidized nitrogen concentration, on an

as nitrogen basis, from about −3.0 to +1.0 and/or including a defined offset ammonia concentration.

[0011b] In another aspect, the present disclosure refers to a wastewater treatment apparatus, comprising: a biological nitrogen removal (BNR) reactor having a volume that is equipped with an aeration system; an ammonia sensor for generating an ammonia concentration signal; and a controller for processing the ammonia concentration signal and thereby limiting a growth of nitrite oxidizing bacteria (NOB) under controlled aeration conditions, the conditions being controlled either along the flow-path or along the process time-line, and wherein the aeration system activation interval, an upper DO setpoint, or both are set such that a measured ammonia concentration is higher than 1.5 mg/L ammonia as nitrogen, for more than 75% of the reactor volume in space or time, and wherein the wastewater treatment apparatus further includes a high-ammonia-strength reactor for bioaugmentation of anammox organisms to provide microbial competitors for nitrite to limit the growth of NOB.

[0011c] In another aspect, the present disclosure refers to a wastewater treatment method, comprising: providing a biological nitrogen removal (BNR) reactor that is equipped with an aeration system; using an ammonia sensor in the reactor to generate an ammonia concentration signal; using a controller to process the ammonia concentration signal and thereby limiting a growth of nitrite oxidizing bacteria (NOB) under aeration conditions, the conditions being controlled either along the flow-path or along the process time-line; and setting the aeration system activation interval, an upper DO setpoint, or both such that a measured ammonia concentration is higher than 1.5 mg/L ammonia as nitrogen, for more than 75% of the reactor volume in space or time.

[0011d] In another aspect, the present disclosure refers to a wastewater treatment method, comprising: providing a biological nutrient removal (BNR) reactor that is equipped with an aeration system; providing wastewater in the reactor; while the wastewater is in the reactor, using an ammonia sensor in the reactor to generate an ammonia concentration signal; while the wastewater is in the reactor, using at least one oxidized nitrogen sensor or measurer in the reactor to sense oxidized nitrogen concentration in the reactor to generate an oxidized nitrogen signal for nitrite, nitrate, or combination of nitrite and nitrate; causing a controller to process the ammonia and oxidized nitrogen concentration signals, and control DO

concentration, duration of an aerobic period, and/or duration of an anoxic period, in the reactor, based on ammonia concentration and oxidized nitrogen concentration; and subsequently, removing the wastewater from the reactor.

[0011e] In another aspect, the present disclosure refers to a wastewater treatment method comprising: providing a biological nutrient removal (BNR) reactor that is equipped with an aeration system: using an ammonia sensor in the reactor to generate an ammonia concentration signal; using at least one oxidized nitrogen sensor or measurer to sense oxidized nitrogen concentration in the reactor to generate an oxidized nitrogen signal for nitrite, nitrate, or combination of nitrite and nitrate, and wherein a controller processes the ammonia and oxidized nitrogen concentration signals, and controls DO concentration, duration of an aerobic period, and/or duration of an anoxic period, in the reactor, based on ammonia concentration and oxidized nitrogen concentration; and feeding ammonia and oxidized nitrogen into an anoxic reactor where anammox bacteria are selectively grown and retained.

[0011f] In another aspect, the present disclosure refers to a wastewater treatment method, comprising: providing a biological nutrient removal (BNR) reactor that is equipped with an aeration system; using an ammonia sensor in the reactor to generate an ammonia concentration signal; using at least one oxidized nitrogen sensor or measurer to sense oxidized nitrogen concentration in the reactor to generate an oxidized nitrogen signal for nitrite, nitrate, or combination of nitrite and nitrate, and wherein a controller processes the ammonia and oxidized nitrogen concentration signals, and controls DO concentration, duration of an aerobic period, and/or duration of an anoxic period, in the reactor, based on ammonia concentration and oxidized nitrogen concentration; and causing the controller to generate instructions for increasing, decreasing or maintaining the DO concentration, the duration of the aerobic period, and/or the duration of the anoxic period to maintain (A) a ratio of the ammonia concentration to the oxidized nitrogen concentration, on an as nitrogen basis, from about 0.5 to 1.5 and/or including a defined offset ammonia concentration; or (B) a sum of the ammonia concentration plus the negative value of the oxidized nitrogen concentration, on an as nitrogen basis, from about −3.0 to +1.0 and/or including a defined offset ammonia concentration.

[0011g] In another aspect, the present disclosure refers to a wastewater treatment method, comprising: providing a biological nitrogen removal (BNR) reactor having a volume that is

equipped with an aeration system; using an ammonia sensor in the reactor to generate an ammonia concentration signal; using an oxidized nitrogen sensor to sense oxidized nitrogen in the reactor, and to generate concentration signals for nitrite, nitrate, or combination of nitrite and nitrate; using a controller to process the ammonia and oxidized nitrogen concentration signals, and to control DO concentration, duration of an aerobic period, and/or duration of an anoxic period, in the reactor, based on the ammonia concentration and an oxidized nitrogen concentration, wherein the controller generates instructions for increasing, decreasing or maintaining the DO concentration, the duration of the aerobic period, and/or the duration of the anoxic period in the reactor based on a ratio or sum of the ammonia concentration and oxidized nitrogen concentration and/or including a defined offset ammonia concentration.

[0011h] The present disclosure achieves a proper and measured control of maintaining high AOB oxidation rates while achieving NOB out-selection, using various control strategies, including: 1) aeration control ensuring nearly saturated ammonia concentration and DO profiles varying from a high set-point rapidly depleting close to zero for maximized AOB-rates during aerobic phases; 2) an innovative aeration control strategy based on the ratio of on-line measured NH_4- and NOx signals in order to maximize total nitrogen removal and to provide an optimum stoichiometric substrate ratio for the anammox reaction; 3) aggressive aerobic SRT management for wash-out pressure on NOB; and 4) bioaugmentation of anammox and lighter flocculant AOB fraction. The use of such control strategies provides important advantages over prior art strategies.

[0012] Accordingly, the present disclosure describes a system and method of removing nitrogen from wastewater in a reactor for biological nitrogen removal, wherein an aerobic-anoxic duration and/or a concentration of dissolved oxygen in the reactor is controlled based on a ratio of an ammonia concentration to a concentration of oxidized nitrogen (NOx, sum of nitrite and nitrate concentrations) measured in real time. Typically, the aerobic-anoxic duration and/or the concentration of dissolved oxygen in the reactor is controlled to achieve a ratio of ammonia concentration to a concentration of oxidized nitrogen that is within a range of 0.5 to 1.5, preferably between 0.7 to 1.0. By employing the system and method of the present disclosure, overall nitrogen removal is maximized because denitrification (dependent on chemical oxygen demand (COD) input) and subsequent ammonia oxidation balance each other while also favoring AOB over NOB. Alternatively, instead of applying a ratio, the difference between ammonia concentration and concentration of oxidized nitrogen can be controlled to a value near 0 which leads to an equivalent control performance.

CLAIMS

1. A wastewater treatment apparatus, comprising:

a biological nitrogen removal (BNR) reactor having a volume that is equipped with an aeration system;

an ammonia sensor for generating an ammonia concentration signal; and

a controller for processing the ammonia concentration signal and thereby limiting a growth of nitrite oxidizing bacteria (NOB) under controlled aeration conditions, the conditions being controlled either along the flow-path or along the process time-line, and

wherein the wastewater treatment apparatus is configured to set an aeration system activation interval, an upper DO setpoint, or both, and wherein the wastewater treatment apparatus is configured to set the aeration system activation interval, the upper DO setpoint, or both are set such that a measured ammonia concentration is higher than 1.5 mg/L ammonia as nitrogen, for more than 75% of the reactor volume in space or time.

2. The apparatus of claim 1, further comprising an oxidized nitrogen sensor for sensing oxidized nitrogen in the reactor, and for generating concentration signals for nitrite, nitrate, or combination of nitrite and nitrate and wherein the controller processes the ammonia and oxidized nitrogen concentration signals, and controls DO concentration, duration of an aerobic period, and/or duration of an anoxic period, in the reactor, based on the ammonia concentration and an oxidized nitrogen concentration.

3. The apparatus of claim 2, wherein the controller generates instructions for increasing, decreasing or maintaining the DO concentration, the duration of the aerobic period, and/or the duration of the anoxic period in the reactor based on a ratio or sum of the ammonia concentration and oxidized nitrogen concentration and/or including a defined offset ammonia concentration.

4. The apparatus of claim 1, wherein the BNR reactor receives bioaugmentation of ammonia oxidizing bacteria (AOB) from a high-ammonia-strength reactor, having a reactor feed concentration greater than 200 mg/L ammonia as nitrogen, and wherein a less dense, more compressible, or unattached sludge fraction is selected from the high-ammonia-strength reactor for the bioaugmentation, and fed to the BNR reactor such that retention time of the bioaugmentation fraction is less than 10 days in the high-ammonia-strength reactor.

5. The apparatus of claim 1, wherein anoxic conditions supporting anaerobic ammonia oxidizing bacteria are promoted in space in the reactor using a biofilm or granular zone within a geometry of the reactor or in time in the reactor with a floc, biofilm, or granule.

6. A wastewater treatment apparatus, comprising:
a biological nutrient removal (BNR) reactor that is equipped with an aeration system;
an ammonia sensor in the reactor to generate an ammonia concentration signal;
at least one oxidized nitrogen sensor to sense oxidized nitrogen concentration in the reactor to generate an oxidized nitrogen signal for nitrite, nitrate, or combination of nitrite and nitrate; and
a controller;
wherein the wastewater treatment apparatus is configured to respond to one or more signals representing (A) a ratio of the ammonia concentration to the oxidized nitrogen concentration, on an as nitrogen basis or (B) a sum of the ammonia concentration plus the negative value of the oxidized nitrogen concentration, on an as nitrogen basis; and
wherein the controller is configured to generate instructions for increasing, decreasing or maintaining the DO concentration, the duration of the aerobic period, and/or the duration of the anoxic period to maintain (A) the ratio of the ammonia concentration to the oxidized nitrogen concentration, on an as nitrogen basis, from about 0.5 to 1.5 and/or including a defined offset ammonia concentration or (B) the sum of the ammonia concentration plus the negative value of the oxidized nitrogen concentration, on an as nitrogen basis, from about −3.0 to +1.0 and/or including a defined offset ammonia concentration.

7. The apparatus of claim 6, wherein the aerobic sludge retention time associated with the reactor is controlled by adjusting flow rate or the frequency of the operation of a flow device

wasting the sludge to maintain a certain aeration intensity or an aerated fraction by sensing and measuring dissolved oxygen and/or aerated duration that is suitable for maximizing process rates of desired microorganisms within the reactor.

8. A wastewater treatment apparatus, comprising:
a biological nitrogen removal (BNR) reactor having a volume that is equipped with an aeration system;
an ammonia sensor for generating an ammonia concentration signal; and
a controller for processing the ammonia concentration signal and thereby limiting a growth of nitrite oxidizing bacteria (NOB) under controlled aeration conditions, the conditions being controlled either along the flow-path or along the process time-line, and
wherein the aeration system activation interval, an upper DO setpoint, or both are set such that a measured ammonia concentration is higher than 1.5 mg/L ammonia as nitrogen, for more than 75% of the reactor volume in space or time, and
wherein the wastewater treatment apparatus further includes a high-ammonia-strength reactor for bioaugmentation of anammox organisms to provide microbial competitors for nitrite to limit the growth of NOB.

9. A wastewater treatment method, comprising:

providing a biological nitrogen removal (BNR) reactor that is equipped with an aeration system;

using an ammonia sensor in the reactor to generate an ammonia concentration signal;

using a controller to process the ammonia concentration signal and thereby limiting a growth of nitrite oxidizing bacteria (NOB) under aeration conditions, the conditions being controlled either along the flow-path or along the process time-line; and

setting the aeration system activation interval, an upper DO setpoint, or both such that a measured ammonia concentration is higher than 1.5 mg/L ammonia as nitrogen, for more than 75% of the reactor volume in space or time.

10. The method of claim 9, further comprising decreasing an NOB net observed growth rate by exposure to an inhibitor, a nitrogenous metabolic intermediate, or a toxic substance.

11. The method of claim 9, further comprising using a growth factor to increase ammonia oxidizing bacteria (AOB) and anammox net growth rates.

12. The method of claim 9, further comprising the step of feeding ammonia oxidizing bacteria (AOB) to the BNR reactor from a high-ammonia-strength reactor, having a reactor feed concentration greater than 200 mg/L ammonia as nitrogen, and wherein a less dense, more compressible, or unattached sludge fraction is selected from the high-ammonia-strength reactor, and is fed to the BNR reactor such that retention time of the fraction is less than 10 days in the high-ammonia-strength reactor.

13. The method of claim 9, further comprising the step of providing a high-ammonia-strength reactor for bioaugmentation of anammox organisms, and using the high-ammonia-strength reactor to provide microbial competitors for nitrite to limit the growth of NOB.

14. The method of claim 9, further comprising promoting in space anoxic conditions in the reactor using a biofilm or granular zone within a geometry of the reactor or in time anoxic conditions in the reactor with a floc, biofilm, or granule.

15. The method of claim 9, wherein the apparatus is configured to cause a dissolved oxygen (DO) profile to switch between a lower DO setpoint of less than 0.1 mg/L and an upper DO setpoint of greater than 1.0 mg/L.

16. A wastewater treatment method, comprising:

providing a biological nutrient removal (BNR) reactor that is equipped with an aeration system;

providing wastewater in the reactor;

while the wastewater is in the reactor, using an ammonia sensor in the reactor to generate an ammonia concentration signal;

while the wastewater is in the reactor, using at least one oxidized nitrogen sensor or measurer in the reactor to sense oxidized nitrogen concentration in the reactor to generate an oxidized nitrogen signal for nitrite, nitrate, or combination of nitrite and nitrate;

causing a controller to process the ammonia and oxidized nitrogen concentration signals, and control DO concentration, duration of an aerobic period, and/or duration of an anoxic period, in the reactor, based on ammonia concentration and oxidized nitrogen concentration; and

subsequently, removing the wastewater from the reactor.

17. The method of claim 16, further comprising removing ammonia, nitrite or nitrate using autotrophic organisms in a post polishing aerobic and/or anoxic reactor.

18. The method of claim 16, wherein optimized control of anoxic duration improves a growth of anammox organisms or heterotrophic denitrifiers.

19. A wastewater treatment method comprising:

providing a biological nutrient removal (BNR) reactor that is equipped with an aeration system:

using an ammonia sensor in the reactor to generate an ammonia concentration signal;

using at least one oxidized nitrogen sensor or measurer to sense oxidized nitrogen concentration in the reactor to generate an oxidized nitrogen signal for nitrite, nitrate, or

combination of nitrite and nitrate, and wherein a controller processes the ammonia and oxidized nitrogen concentration signals, and controls DO concentration, duration of an aerobic period, and/or duration of an anoxic period, in the reactor, based on ammonia concentration and oxidized nitrogen concentration; and

feeding ammonia and oxidized nitrogen into an anoxic reactor where anammox bacteria are selectively grown and retained.

20. The method described in claim 19, further comprising adding an organic or inorganic substrate or combination of substrates to accomplish selective reduction of nitrate to nitrite by anammox, heterotrophic organisms, or other microorganisms and subsequent nitrite and ammonia removal by anammox.

21. A wastewater treatment method, comprising:

providing a biological nutrient removal (BNR) reactor that is equipped with an aeration system;

using an ammonia sensor in the reactor to generate an ammonia concentration signal;

using at least one oxidized nitrogen sensor or measurer to sense oxidized nitrogen concentration in the reactor to generate an oxidized nitrogen signal for nitrite, nitrate, or combination of nitrite and nitrate, and wherein a controller processes the ammonia and oxidized nitrogen concentration signals, and controls DO concentration, duration of an aerobic period, and/or duration of an anoxic period, in the reactor, based on ammonia concentration and oxidized nitrogen concentration; and

causing the controller to generate instructions for increasing, decreasing or maintaining the DO concentration, the duration of the aerobic period, and/or the duration of the anoxic period to maintain (A) a ratio of the ammonia concentration to the oxidized nitrogen concentration, on an as nitrogen basis, from about 0.5 to 1.5 and/or including a defined offset ammonia concentration; or (B) a sum of the ammonia concentration plus the negative value of the

oxidized nitrogen concentration, on an as nitrogen basis, from about −3.0 to +1.0 and/or including a defined offset ammonia concentration.

22. The method of claim 21, further comprising limiting an aerobic sludge retention time for the reactor by controlled extension of anoxic periods or volume and by controlling the sludge wasting rate, to increase DO beyond a setpoint in the case of DO intensity control, or to increase the ratio aerobic duration to anoxic duration beyond a setpoint in the case of aerobic/anoxic duration control.

23. A wastewater treatment method, comprising:

providing a biological nitrogen removal (BNR) reactor having a volume that is equipped with an aeration system;

using an ammonia sensor in the reactor to generate an ammonia concentration signal;

using an oxidized nitrogen sensor to sense oxidized nitrogen in the reactor, and to generate concentration signals for nitrite, nitrate, or combination of nitrite and nitrate;

using a controller to process the ammonia and oxidized nitrogen concentration signals, and to control DO concentration, duration of an aerobic period, and/or duration of an anoxic period, in the reactor, based on the ammonia concentration and an oxidized nitrogen concentration, wherein the controller generates instructions for increasing, decreasing or maintaining the DO concentration, the duration of the aerobic period, and/or the duration of the anoxic period in the reactor based on a ratio or sum of the ammonia concentration and oxidized nitrogen concentration and/or including a defined offset ammonia concentration.

24. The method of claim 23, further comprising setting an aeration system activation interval, an upper DO setpoint, or both such that a measured ammonia concentration is higher than 1.5 mg/L ammonia as nitrogen, for more than 75% of the reactor volume in space or time.