

DESCRIPTION

Title of Invention

AEROBIC BIOFILM TREATMENT METHOD AND APPARATUS

Technical Field

[0001] The present invention relates to a method and a device for subjecting wastewater including a pollutant that can be biologically oxidized to a biofilm treatment using a self-granulated granule, a fluidized bed carrier, a fixed bed carrier, or the like, and particularly to control of the aeration intensity thereof. In the present invention, wastewater present outside a biofilm carrying out a microbial treatment is referred to as bulk water.

Background Art

[0002] Examples of a method for treating wastewater including a pollutant that can be biologically oxidized include an activated sludge method that uses suspended sludge and a biofilm method that carries out a treatment in a form in which a microorganism is accumulated and proliferated referred to as a biofilm such as a self-granulated granule method, a fluidized bed carrier method, or a fixed bed carrier method.

[0003] In the former activated sludge method that uses suspended sludge, a microorganism is maintained in a dispersed state in a reaction tank in a form referred to as a microbial floc. By keeping the microbial biomass maintained in the reaction tank constant by the operation of extracting the microorganism that increases in association with a wastewater treatment as excess sludge, the amount of oxygen consumed

generated due to the autolytic process of the microorganism itself can be kept at a constant level. Therefore, the increase or decrease in the amount of oxygen required in the above process changes in proportion to the raw water load. By adding a constant oxygen consumption offset associated with the microbial autolytic process to the above oxygen consumption, the amount of oxygen consumed to be supplied can be determined. In the process, the microorganism is typically retained in the form of a flocculate of the microorganism of about 1 mm referred to as a floc, and a sufficient contact area between the microorganism and the bulk aqueous phase is secured. Because of this, the permeability and diffusivity of oxygen or the pollutant in the floc are not main rate-determining factors in the treatment performance of the pollutant removal rate. Because of this, the aeration air volume to be supplied to the device is considered to be proportional to the amount of oxygen consumed. PTL1 discloses that the load of a pollutant is measured using an instrument and based thereon, the aeration air volume is controlled.

[0004] In the activated sludge method that uses suspended sludge and the biofilm method (self-granulated granule method, fluidized bed carrier method, fixed bed carrier method, or the like), as a method for simply adjusting the amount of oxygen supplied in proportion to the load of raw water, the so-called DO control system that carries out an air volume control that keeps the dissolved oxygen concentration (hereinafter referred to as DO) in a liquid constant is widely used.

[0005] PTL2 discloses that in the self-granulated granule method and the fluidized bed carrier method, the wastewater aeration volume is controlled, using the fluidization of the microbial carrier as a criterion when the BOD volume load is smaller than a predetermined value, and

using the oxygen demand of the wastewater as a criterion when the BOD volume load is larger than the predetermined value.

Citation List

Patent Literature

[0006] PTL1: JP 2001-353496 A

PTL2: JPS 63-256185 A

[0007] In a method that carries out a treatment using a biofilm such as the self-granulated granule method, the fluidized bed carrier method, or the fixed bed carrier method, strictly speaking, it is difficult to appropriately adjust the amount of oxygen supplied based only on the inflow load determined by the product of the flow volume per unit time of raw water and the pollutant concentration of raw water, which are common indexes of the raw water load, or the tank load obtained by dividing the inflow load by the volume of the reaction tank. The reasons for this are as follows.

[0008] In the method using a microbial biofilm, there is no means for keeping the microbial biomass retained in the form of a biofilm in the reaction vessel constant, and as a result, the microbial biomass retained changes with time, and thus the amount of oxygen consumed generated due to the autolytic process of the microorganism itself also changes. Therefore, in the method using a biofilm, the amount of oxygen supplied to the device needs to be determined in consideration of the change in the amount of oxygen consumed that changes in proportion to the load of raw water and also the change in oxygen consumption associated with the change in retained microbial biomass.

[0009] Because of these factors, in the treatment scheme using a biofilm, the amount of oxygen required to oxidize raw water organic matter changes according to the load fluctuation, and the amount of oxygen that needs to be supplied also changes according to the change in the amount of the biofilm retained in the treatment device. Further, in the biofilm method, a microbial biofilm having a film thickness of typically 3 mm or more is generally formed, and the contact area with bulk water per microorganism retained is smaller than that in a suspension method. Because of this, in supplying oxygen to the microorganism in the biofilm, the diffusion phenomenon of oxygen on the contact surface between bulk water and the biofilm is a main rate-determining factor in oxygen supply.

[0010] The diffusion rate of oxygen in the biofilm depends on the DO level of bulk water, and thus it is necessary to adjust the DO level in order to adjust the amount of oxygen supplied. In addition, from the viewpoint of the aeration system, the required aeration air volume changes depending on the difference in the DO level even if the amount of oxygen supplied is the same. It is widely known that when the DO level is high, the required aeration volume increases, and when the DO level is low, the required aeration volume decreases.

[0011] Therefore, when the load increases, the amount of oxygen required to oxidize organic matter in raw water increases. The amount of oxygen that needs to be supplied is determined by taking into account the amount of oxygen consumed due to the autolytic process, which changes according to the change in the microbial biomass retained as the biofilm. It is necessary to adjust the DO of bulk water to be higher according to the increase in the amount of oxygen that needs to be

supplied, and also to increase the aeration air volume in order to achieve the target DO.

[0012] On the contrary, when the load decreases, the amount of oxygen required to oxidize organic matter in raw water decreases. The amount of oxygen that needs to be supplied is determined by taking into account the amount of oxygen consumed due to the autolytic process, which changes according to the change in the microbial biomass retained as the biofilm. The DO of bulk water can be kept lower according to the decrease in the amount of oxygen that needs to be supplied, and the aeration volume for achieving the target DO also decreases.

[0013] For these reasons, when carrying out an operation that does not adjust or control according to the load of the aeration air volume, it is necessary to carry out a constant air volume operation in a state in which the aeration air volume is excessively increased so that the DO of bulk water can be kept high and the amount of oxygen supplied can be maintained even at the time of a high load.

[0014] Under the constant air volume operation that can maintain the high DO required at the time of a high load, a waste of energy occurs because the air volume is not suppressed according to the decrease in the amount of oxygen consumed when the amount of oxygen consumed decreases when the load decreases. Even when DO control is carried out by assuming oxygen supply at the time of a high load and setting a high DO target value, the DO level can be lowered to keep the load decreases by a biofilm treatment device, and thus if the target DO level of DO control is lowered, the aeration air volume can be reduced. However, the normal DO control does not suppress the air volume due to such a

decrease in the DO target value, and thus a waste of energy consumption still occurs.

[0015] For this reason, the waste of energy consumption becomes particularly remarkable when the load fluctuation is large. However, even if there is a situation in which such a waste of energy consumption occurs, it is difficult to carry out the operation of adjusting the DO level that does not worsen the treated water quality according to the load fluctuation and adjustment of the air volume to the target DO level by a conventional technique. Even when the operator appropriately adjusts the air volume, conventionally a high load is assumed to some extent even if the load is low, and thus conventionally, even if the load is low, excessive DO level setting and aeration are often carried out in order to supply more oxygen than necessary with some margin. Because of this, a waste of energy often occurs.

[0016] When the raw water load, which is a common index of the raw water load, is used to adjust the aeration intensity, it is necessary to measure the concentration of a substance to be removed in raw water. In this case, it is considered, as a measure to be taken, for example, to install a TOC meter, an ammonia sensor, an absorbance system, or the like in the raw water tank as an online measurement device for the organic matter load. However, stable measurement is difficult for a reason such as the high initial cost of the measurement instrument or a large amount of a solid in the organic matter species, and analytical precision cannot be obtained depending on the composition of the organic matter, and in reality, such problems make it difficult to install the online measurement device and make load monitoring by automatic

measurement impossible, and thus as a result, a situation in which it is difficult to determine an appropriate aeration intensity often occurs.

[0017] In addition, when the concentration of an organic substance to be removed in raw water is measured using a TOC meter, an ammonia ion sensor, an absorbance meter, or the like, maintenance work such as cleaning and calibration of the sensor is troublesome. In particular, the TOC meter is equipped with a complicated mechanism and has a high failure probability. Because of this, it is difficult to maintain the stability of the control system using the TOC meter from the aspect of operational control, and there is a concern of malfunction.

Summary of Invention

Technical Problem

[0018] An object of the present invention is to provide a method and a device for appropriately controlling aeration in a wastewater treatment using an aerobic biofilm.

Solution to Problem

[0019] The aerobic biofilm treatment method of the present invention is a method comprising supplying raw water to an aeration tank, aerating the aeration tank using an aeration device, and subjecting a substance to be removed in the raw water to an aerobic biological treatment using a biofilm retaining carrier or granule packed in the aeration tank, wherein a relationship between an oxygen consumption rate per carrier or granule, and a corresponding DO target value and/or a corresponding aeration intensity set value is set in advance, the DO target value and/or the aeration intensity set value is adjusted based on the relationship

according to a fluctuation of a measured value of the oxygen consumption rate per carrier or granule, and the aeration device is controlled such that the DO becomes the target value or the aeration intensity becomes the set value.

[0020] The aerobic biofilm treatment device of the present invention is an aerobic biological treatment device including an aeration tank to which raw water is supplied, an aeration device that aerates the aeration tank, a biofilm-attached carrier or granule packed in the aeration tank, and a controller that controls the aeration device, wherein the device further includes: a setting unit that sets in advance a relationship between an oxygen consumption rate per carrier or granule, and a corresponding DO target value and/or a corresponding aeration intensity set value; and an adjusting unit that adjusts the DO target value and/or the aeration intensity set value based on the relationship according to a fluctuation of a measured value of the oxygen consumption rate per carrier or granule, and wherein the controller controls the aeration device such that the DO becomes the target value or the aeration intensity becomes the set value.

[0021] In one embodiment of the present invention, the oxygen consumption rate per carrier or granule is any of the oxygen consumption rate per packing volume of the carrier, the oxygen consumption rate per total surface area of a carrier group, the oxygen consumption rate per packing volume of the granule, and the oxygen consumption rate per total surface area of a granule group.

[0022] In one embodiment of the present invention, the oxygen consumption rate per carrier or granule is calculated from a measured value of the aeration air volume, a measured value of the concentration of

oxygen in the gas phase released from the aeration tank, or a measured value of the DO of the aeration tank and an experimental value or a calculated value of the oxygen dissolution efficiency of the aeration tank, and a measured value or a calculated value of the packing volume or the surface area of the carrier.

[0023] In one embodiment of the present invention, the aeration intensity is controlled by controlling the aeration air volume, the aeration stop time, or the aeration suppression time.

[0024] In one embodiment of the present invention, the relationship is set using any of an experimental result, an operation result of an actual machine, and a mechanism model considering the diffusivity of oxygen in the biofilm.

Advantageous Effects of Invention

[0025] In the present invention, aeration control is possible by using the oxygen consumption rate of the aeration tank instead of the raw water load without using a sensor for measuring the raw water concentration such as a TOC meter, and thus the manpower and cost of maintenance can be suppressed and in addition, aeration control can be appropriately carried out even in a case where no TOC meter can be used depending on the on-site facility or the raw water species.

[0026] In addition, in one embodiment of the present invention, a necessary and sufficient oxygen supply suitable for a property of the carrier or the granule in the aeration tank, which changes with time, is estimated using the oxygen consumption rate per carrier or granule, and the DO target value or the aeration intensity set value itself is changed and controlled, and thus more appropriate aeration control is possible.

Brief Description of Drawings

[0027] [Fig. 1] Fig. 1 is a block diagram of a biological treatment device to which the present invention is applied.

[Fig. 2] Fig. 2 is a block diagram of a biological treatment device of a Comparative Example.

[Fig. 3] Fig. 3 is a graph showing results of an Example and a Comparative Example.

[Fig. 4] Fig. 4 is a graph showing results of an Example and a Comparative Example.

[Fig. 5] Fig. 5 is a graph showing results of an Example and a Comparative Example.

[Fig. 6] Fig. 6 is a graph showing the TOC load of raw water.

Description of Embodiments

[0028] Fig. 1 is a block diagram of a biological treatment device to which the present invention is applied.

[0029] Wastewater to be treated (raw water) is introduced into an aeration tank 2 through a pipe 1. A carrier C supporting a biofilm is packed in the aeration tank 2. Diffuser tubes 3a, 3b, and 3c are disposed at the bottom of the aeration tank 2, and air is supplied from a blower 4 through a pipe 5 and branch pipes 5a, 5b, and 5c to carry out aeration. The aeration tank 2 is provided with a top cover 2r.

[0030] The water that has been subjected to an aerobically biological treatment by the biofilm passes through a screen 2a and is taken out as treated water from a pipe 6.

[0031] This biological treatment device is provided with an exhaust gas meter 7 for measuring the oxygen concentration of the gas phase portion gas in the upper portion of the aeration tank 2 and below the top cover 2r, a DO meter 8 for measuring the DO in the aeration tank 2, and an air volume meter 9 for measuring the volume of air supplied from the blower 4 to the diffuser tubes 3a to 3c, as measurement means.

[0032] In the present invention, aeration control is carried out based on the oxygen consumption rate per carrier or granule of the aeration tank, instead of using the raw water load as a control index.

[0033] In general, when the raw water load is large, the oxygen consumption rate of the aeration tank is high, and when the raw water load is small, the oxygen consumption rate is low, and the oxygen consumption rate includes oxygen consumption due to the microbial autolysis process.

[0034] On the other hand, in the biofilm method, a microbial biofilm having a film thickness of typically 3 mm or more is generally formed, and the contact area with bulk water per microorganism retained is smaller than that in a suspension method that uses a microorganism that forms a floc of typically around 1 mm. Because of this, in supplying oxygen to the microorganism in the biofilm, the diffusion phenomenon of oxygen on the contact surface between bulk water and the microbial biofilm is a main rate-determining factor in oxygen supply. In addition, it is also known that the contact area between the microbial biofilm and bulk water is a main factor in the oxygen diffusion rate into the microbial biofilm. The larger the contact area, the higher the oxygen diffusion rate, and the smaller the contact area, the lower the oxygen diffusion rate. In addition, it is known that the diffusion rate of oxygen in the microbial

biofilm depends on the DO level of bulk water, and it is necessary to adjust the DO level in order to adjust the amount of oxygen supplied. In addition, from the viewpoint of the aeration system, the required aeration air volume changes depending on the difference in the DO level even if the amount of oxygen supplied is the same. It is widely known that when the DO level is high, the required aeration volume increases, and when the DO level is low, the required aeration volume decreases. Because of this, a conventional treatment device that uses a biofilm often keeps the DO level of bulk water high so that a sufficient oxygen diffusion phenomenon that satisfies the required oxygen consumption occurs, and as a result, often carries out excessive aeration, and a waste of energy often occurs.

[0035] The root causes of the occurrence of the situation in which a waste of energy related to aeration occurs by keeping the DO level high have been studied, and it has been found that one of the root causes is that the amount of the carrier or the granule packed in the aeration tank that is retained and the contact area between the microbial biofilm and the bulk water that changes in proportion to the amount retained changes to change the oxygen diffusion efficiency.

[0036] For example, when an aeration tank in which a fluidized bed carrier is packed is operated for a long period of time, the carrier is scraped to have a smaller particle size and flows out of the tank as SS through a gap in the screen, the carrier packing ratio in the tank decreases, and the contact area between the biofilm surface and bulk water decreases, which may reduce the treatment performance.

[0037] In the case of an aeration tank provided with an expanded bed using a precipitating carrier, which is a kind of fixed bed treatment, it is

necessary to periodically backwash the same to discharge excess sludge and SS between the carriers. At this time, the carriers are worn due to a collision and a shear force between the carriers, the carrier packing ratio gradually decreases, the carrier packing ratio in the tank decreases, and the contact area between the biofilm surface and bulk water decreases, and thereby the contact area between the biofilm and bulk water, which can contribute to the diffusion of oxygen into the biofilm, is reduced, the oxygen transfer rate is reduced, and the treatment performance is reduced.

[0038] In a biological treatment tank using a self-granulated granule, the number and the particle size of the self-granulated granule fluctuate with time, and the amount of the biofilm in the aeration tank increases or decreases, thereby the contact area between the biofilm and bulk water increases or decreases, and thereby the oxygen diffusivity into the biofilm changes, which causes a phenomenon in which the aeration air volume required for a wastewater treatment changes even if the organic matter load is the same.

[0039] For such a reason, load control using the oxygen consumption rate has the advantage of being able to monitor the oxygen demand also including oxygen consumption due to a change in the microbial biomass, but the oxygen transfer rate from bulk water to the biofilm is affected by a change in the amount of the carrier and a change in the contact area. Because of this, even if the oxygen consumption rate is the same, the appropriate DO level and aeration air volume change depending on the change in a property of the carrier or the granule, and thus it is difficult to control the aeration volume that does not cause energy loss while satisfying the oxygen demand. For such a reason, even in the aeration

control using the oxygen consumption rate, it is desirable to carry out aeration control using, as an index, the oxygen consumption rate per carrier or granule in which the aeration can be controlled in consideration of the influence of the increase and decrease in the amount of the carrier or the amount of the granule, as in the case of carrying out the aeration control using the raw water load. This is because the contact area between bulk water and the biofilm per amount of the carrier or the granule can be assumed to be constant, and thus it is not necessary to take into account a change in the oxygen transfer rate associated with a change in the contact area.

[0040] Accordingly, in the present invention, the aeration is controlled using the oxygen consumption rate per carrier or granule, instead of just the oxygen consumption rate, as a control index.

[0041] Examples of the oxygen consumption rate per carrier or granule include an index such as the oxygen consumption rate per packing volume of the carrier or the granule or the oxygen consumption rate per total surface area of the carrier group or the granule.

[0042] <Raw water load>

The raw water load is calculated by the following expression.

[0043] $\text{Load} = Q \cdot \text{Conc}$

Load: Raw water load [kg/d]

Q: Raw water flow rate [m³/d]

Conc: Raw water concentration [kg/m³]

Examples of the raw water concentration include the concentration of TOC, ammoniacal nitrogen, or TOC/N estimated from a UV absorbance.

[0044] <Carrier volume load>

The carrier volume load is calculated by the following expression.

[0045] $\text{Load}_{\text{CarrierVol}} = \text{Load}/V_{\text{Carrier}}$

$\text{Load}_{\text{CarrierVol}}$: Carrier volume load [$\text{kg}/(\text{m}^3 \cdot \text{d})$]

V_{Carrier} : Carrier packing volume in aeration tank [m^3]

[0046] $\langle \text{Carrier surface area load} \rangle$

The carrier surface area load is calculated by the following expression.

[0047] $\text{Load}_{\text{CarrierSurf}} = \text{Load}/S_{\text{Carrier}}$

$\text{Load}_{\text{CarrierSurf}}$: Carrier surface area load [$\text{kg}/(\text{m}^2 \cdot \text{d})$]

S_{Carrier} : Total surface area of the carrier group in the aeration tank [m^2]

[0048] In the aeration tank, the raw water load may fluctuate with time rapidly on a minute basis, but the change with time in a property of the carrier (carrier packing volume in the aeration tank or the total surface area of the carrier group in the aeration tank) changes relatively slowly on a daily to monthly basis. Because of this, it is preferable to frequently update a calculated value of the raw water load. In addition, the carrier packing volume in the aeration tank or the total surface area of the carrier group in the aeration tank is analyzed by sampling the carrier periodically (for example, at a frequency of about once every 1 to 3 months), and data on the carrier packing volume or the total surface area data of the carrier group may be updated.

[0049] [Method for calculating oxygen consumption rate]

$\langle \text{Case 1: Method for calculating oxygen consumption rate from air volume meter and exhaust gas meter} \rangle$

The aeration air volume and the oxygen concentration of the exhaust gas are measured, and the oxygen consumption rate q_{O_2} is directly calculated by the following expression.

[0050]

$$OTE = \frac{Z_0 - Z}{Z_0} \quad \cdot \cdot \cdot (1)$$

[0051]

$$qO_2 = \frac{G_v \cdot Z_0 \cdot OTE}{v_m} \quad \cdot \cdot \cdot (2)$$

[0052] OTE: Oxygen transfer efficiency [-]

Z_0 : Mole fraction of oxygen in blown air [-]

Z : Mole fraction of oxygen in exhaust gas [-]

qO_2 : Oxygen consumption rate [kg/d]

G_v : Blowing flow rate of aeration air converted to standard state

[Nm³/d]

v_m : Specific volume of oxygen [Nm³/kg]

[0053] <Case 2: Method for calculating oxygen consumption rate from DO meter and aeration air volume>

The aeration air volume and the DO are measured, and the oxygen consumption rate qO_2 is indirectly estimated.

(i) (Provision before mounting control device) The oxygen solubility index ϕ required to estimate the oxygen consumption rate is calculated by the following expression.

[0054]

$$OTE = \frac{Z_0 - Z}{Z_0} \quad \cdot \cdot \cdot (3)$$

[0055]

$$\phi = \frac{v_m \cdot h \cdot (C_s - C)}{Z_0 \cdot OTE} \quad \cdot \cdot \cdot (4)$$

[0056] OTE: Oxygen transfer efficiency [-]

Z₀: Mole fraction of oxygen in blown air [-]

Z: Mole fraction of oxygen in exhaust gas [-]

φ: Oxygen solubility index [m]

v_m: Specific volume of oxygen [Nm³/kg]

h: Water depth of diffusion device [m]

C_s: Saturated dissolved oxygen concentration [kg/m³]

C: Dissolved oxygen concentration of mixed liquid [kg/m³]

[0057] (ii) (When the device is in operation) Changes with time in oxygen consumption rate are continuously measured.

[0058] The oxygen consumption rate qO₂ is continuously estimated by the following expression from continuous measurement data from the DO meter and on the aeration air volume, and the oxygen solubility index φ determined in advance.

[0059]

$$qO_2 = \frac{G_v \cdot h \cdot (C_s - C)}{\phi} \quad \cdot \cdot \cdot (5)$$

[0060] qO₂: Oxygen consumption rate [kg/d]

G_v: Blowing flow rate of aeration air converted to standard state [Nm³/h]

h: Water depth of diffusion device [m]

C_s: Saturated dissolved oxygen concentration [kg/m³]

C: Dissolved oxygen concentration of mixed liquid [kg/m³]

ϕ : Oxygen solubility index [m]

[0061] In the present invention, the relationship between the oxygen consumption rate per carrier or granule of the aeration tank and the corresponding DO target value or the corresponding aeration intensity set value is set in advance, and the corresponding DO target value or aeration intensity set value is adjusted based on the above relationship according to the fluctuation in a measured value of the oxygen consumption rate.

[0062] Then, the aeration device is controlled such that the DO becomes the target value or the aeration intensity becomes the set value.

[0063] [the relationship between oxygen consumption rate and DO target value and/or aeration intensity set value]

The relationship between the oxygen consumption rate and the DO target value and/or the aeration intensity set value is set using data on a result of a preliminary experiment, data on an operation result of an actual machine, a simulation result of a mechanism model considering the diffusivity of oxygen in the biofilm, or the like.

[0064] This relationship may be any of a calibration curve (approximate function), a control table, and the like.

[0065] [Biofilm mechanism model for creating calibration curve or control table]

As one method for finding the relationship between the raw water biofilm load and the DO target value or the aeration intensity set value, a dynamic model that estimates a decrease in a pollutant and an increase or a decrease in the activated sludge microbiomass in a biofilm when the biofilm comes into contact with the bulk aqueous phase in a fluid state including the pollutant and oxygen (hereinafter sometimes referred to as

a biofilm mechanism model) can be used. Such a dynamic model needs to be built also in consideration of a situation in which microbe proliferation and pollutant consumption/oxygen consumption occur simultaneously in the biofilm, and a phenomenon in which oxygen is dissolved in bulk water by diffusion of dissolved oxygen in the bulk aqueous phase into the biofilm and aeration. In addition, the expansion and contraction of the biofilm occur because of an increase and a decrease in the volume of the microbial population associated with the proliferation and the death of a microbe, or the attachment of the microbe from bulk water and the detachment of the microbe to the bulk water. When using a dynamic model for a biofilm utilization treatment, these phenomena need to be mathematically modeled. Such phenomena are phenomena that originally occur in a three-dimensional space, and thus the model expression is complicated, but the simulation can be carried out relatively easily by expressing the expansion and contraction of the biofilm by a one-dimensional model expression that considers a change only in the thickness direction. As a mathematical model for simulating a wastewater treatment with activated sludge, for example, a series of mathematical models proposed by a Task Group of the International Water Association [Reference 1] can be utilized. [Reference 2] and the like can be used as an example of a mathematical model for a biofilm. [Reference 1] M Henze; IWA. Task Group on Mathematical Modeling for Design and Operaton of Biological Wastewater Treatment; et al [Reference 2] Boltz, J.P., Johnson, B.R., Daigger, G.T., Sandino, J., (2009a). "Modeling Integrated Fixed-Film Activated Sludge and Moving Bed Biofilm Reactor Systems I: Mathematical Treatment and Model Development". Water Environment Research, 81(6), 555-575

[0066] By using a mathematical model, for example, a mathematical model of a fluidized bed carrier can be built. In general, such a mathematical model is often described in the form of simultaneous ordinary differential equations, and a dynamic behavior of the target process can be simulated using numerical integration software for ordinary differential simultaneous equations. For example, it is possible to predict the treated water quality according to the DO situation of the bulk aqueous phase, which changes depending on a specific device configuration, load assumption, or aeration intensity.

[0067] By using a mathematical model, it is possible to predict, for example, the TOC concentration of the treated water when the treatment is carried out with various aeration intensities under various load conditions. Based on a simulation result, the minimum DO target value and aeration intensity adjustment that does not worsen the treatment can be studied, and a table that organizes the simulation result can be created and utilized for the control table used in the control system of the present patent.

[0068] [Control of aeration intensity]

The aeration intensity can be controlled, for example, by changing the aeration air volume (supply air flow rate), or the aeration stop time or the aeration suppression time (weak aeration time) for each fixed time cycle. The aeration stop time refers to the time during which inner aeration of a fixed time cycle in the so-called intermittent aeration is stopped. The aeration suppression time is the time of weak aeration in an operation in which strong aeration and weak aeration are alternately repeated.

[0069] The aeration air volume, the aeration stop time, and the aeration suppression time are controlled continuously or stepwise according to the raw water load.

[0070] <Oxygen diffusivity index>

In the case of a biofilm treatment using a biofilm attached to a self-granulated microbial granule or a fluidized bed or fixed bed carrier to remove a pollutant, the contact area between the liquid phase in a fluid state and a microorganism in contact with each other is smaller than that in the suspension method, oxygen and a pollutant need to diffuse and permeate inside the biofilm (in the thickness direction) for the biodegradation of the pollutant, and the rate of this diffusion and permeation process is slower than the microbial proliferation rate and the oxygen consumption rate, and thus the diffusion and permeation process is one of the main factors determining the treatment performance.

[0071] The surface area between the biofilm and bulk water in contact with each other is a factor affecting the diffusion and permeation process. When the surface area is narrowed, even if the DO of the bulk water is the same, the total amount of oxygen diffused into the biofilm relatively decreases, the treatment performance decreases, and the water quality of the treated water tends to be worsened. On the contrary, when the surface area is widened, even if the DO of the bulk water is the same, the total amount of oxygen diffused into the biofilm relatively increases, the treatment capacity increases, and the treated water quality tends to become good. In addition, even if the DO is low, sufficient treatment performance can be exerted, and the aeration volume and the electric power related to aeration can be reduced.

[0072] In the case of a device that uses a self-granulated microbial granule, when the granule is enlarged by a long-term operation, the specific surface area in contact with bulk water per volume of the self-granulated microbial granule decreases, and the surface area in contact with bulk water per volume of the device decreases.

[0073] In the case of a device that uses a carrier, when the amount of sludge retained by the carrier is increased by a long-term operation, a void space inside the carrier is blocked by the microbial biofilm itself and a solid having no biological activity such as a scale component, and thus the contact area between bulk water and the biofilm is reduced. As a result, the specific surface area in contact with bulk water per carrier packing volume decreases, and the surface area in contact with bulk water per aeration tank volume decreases.

[0074] In particular, in the case of a treatment using a biofilm attached to a fixed carrier, an excess of the biofilm tends to be retained in a space between the carriers when the period of operation is long. In such a situation, the volume of the bulk aqueous phase relatively decreases according to the increase in the amount of the biofilm retained. In addition, when this state progresses further, the space between the carriers is blocked by the microbial biofilm, and a space into which bulk water cannot flow is generated. As a result, the contact area between the bulk aqueous phase and the biofilm gradually decreases, and the penetrability and permeability of oxygen and the pollutant into the biofilm tends to decrease with time.

[0075] [Biological treatment other than fluidized bed]

Although a biological treatment using a fluidized bed carrier has been illustrated in Fig. 1, the present invention can be practiced by the same method even when a fixed bed carrier or a granule is used.

[0076] Although in the present embodiment, use of the present invention when wastewater including organic matter is treated by an aerobic biofilm treatment involving aeration, additionally, even when carrying out a biological treatment including an aerobic treatment step using a biofilm in an aeration tank, such as a biological nitrification and denitrification treatment using a biofilm, the present invention can be practiced by the same method.

[0077] [Sensor maintenance]

For air volume measurement, it is common to use a micro differential pressure gauge combined with an orifice, a micro differential pressure gauge combined with a Pitot tube, or a hot wire type air volume meter. The measurement stability of the micro differential pressure gauge and the hot wire type air volume meter, which are industrial instruments, is high, and measurement using such an instrument is measurement targeting the atmosphere and has less risk of reduced precision due to sensor contamination than measurement targeting wastewater including a pollutant, and thus stable measurement is possible if regular maintenance is typically carried out once per year.

[0078] Measurement of the oxygen concentration of the exhaust released from the aeration tank does not require regular cleaning work because the measurement unit does not come into direct contact with wastewater that is highly likely to pollute the sensor, and stable measurement is possible if typically, regular calibration using

atmospheric oxygen concentration is carried out once per day and regular maintenance is carried out once per year.

[0079] As a dissolved oxygen concentration meter in the aeration tank, a fluorescence type DO meter having a theoretically small deviation in a measured value due to pollution has been used in recent years, and the precision can be maintained typically by regular cleaning and calibration work using air oxygen concentration once per month.

Example

[0080] [Experimental Example 1: Method for calculating oxygen consumption rate from air volume meter and exhaust gas meter]

(1) In the biological treatment device of Fig. 1, the oxygen consumption rate qO_2 was calculated from online data on the aeration air volume and the oxygen concentration of the exhaust gas.

(2) Evaluation of calibration frequency of exhaust gas meter 7 (exhaust gas oxygen concentration meter) required for continuous measurement

Once a day, O_2 standard gas having a known concentration was passed through an exhaust gas meter 7, the indicated value of the exhaust gas meter 7 was checked, and when the difference between the standard gas concentration and the indicated value of the exhaust gas meter 7 was 0.2% or more, the exhaust gas meter 7 was calibrated. The required calibration frequency was once every 7 days. The present calibration operation can be automated.

[0081] [Experimental Example 2: Method for estimating oxygen consumption rate from DO meter and air volume meter]

(1) In the biological treatment device of Fig. 1, the oxygen concentration of the gas phase portion at the upper portion of the aeration tank 2 was

obtained using an exhaust gas meter, the aeration air volume in the reaction tank, the oxygen concentration of the exhaust gas, and the DO in the reaction tank were measured, and the oxygen solubility index ϕ was calculated based on the measurement results thereof.

(2) Based on the oxygen solubility index ϕ measured in advance, the oxygen consumption rate qO_2 was continuously calculated from online measurement data from the DO meter and on the aeration air volume.

(3) Evaluation of calibration frequency of DO meter required for continuous measurement

Once a day, the DO in the reaction tank was measured using a portable DO meter calibrated with saturated water, then the difference between the measured value and the indicated value of a DO meter 8 was checked, and when the difference was ± 0.5 mg/L or more, the DO meter 8 was calibrated. The required calibration frequency was once every 15 days.

[0082] [Experimental Example 3: Calculation of raw water load from TOC meter and flow rate meter]

Using the biological treatment device shown in Fig. 2, the maintenance frequency when carrying out aeration control based on the raw water load using a measured value of the TOC concentration of raw water was examined.

[0083] In the biological treatment device of Fig. 2, wastewater to be treated (raw water) is introduced into an aeration tank 11 through a pipe 10. A carrier C supporting a biofilm is packed in the aeration tank 11. A diffuser tube 13 is disposed at the bottom of the aeration tank 11, and air is supplied from a blower 14 through a pipe 15 to carry out aeration.

[0084] The water that has been subjected to an aerobic biological treatment by the biofilm passes through a screen 12 and is taken out as treated water from a pipe 16.

[0085] This biological treatment device is provided with a flow rate meter 17 and a TOC meter 18 for measuring the flow rate and the TOC concentration of raw water flowing through the pipe 10, a DO meter 19 for measuring the DO in the aeration tank 11, and an air volume meter 20 for measuring the volume of air supplied from the blower 14 to the diffuser tube 13, as measurement means, and values detected by these are input to a controller 21. The aeration intensity is controlled by causing the motor rotation speed of the blower 14 to be controlled by the controller 21.

[0086] The TOC load was calculated by measuring the raw water flow rate using the flow rate meter 17 and measuring the TOC concentration of the raw water using the TOC meter 18.

[0087] Once a day, the raw water was sampled and filtered through a 0.45 μm filter, and then the TOC concentration of the filtrate was measured using a TOC meter in an analysis chamber. When the difference between the indicated value of the TOC meter 18 and the indicated value of the TOC meter in the analysis chamber was 5% or more, the TOC meter 18 was calibrated. The required calibration frequency was once every 3 days.

[0088] [Table 1]

	Calibration frequency required to maintain precision
Exhaust gas meter of Experimental Example 1	7 days (automatable)
DO meter of Experimental Example 2	15 days
TOC meter of Experimental Example 3	3 days

[0089] As shown in Table 1, Experimental Examples 1 and 2 directly or indirectly calculating the oxygen consumption rate in the aeration tank were found to be less troublesome in calibrating the instrument than Experimental Example 3 measuring the TOC of the raw water using the TOC meter 18.

[0090] [Example 1]

<Creation of control table>

Using a biofilm mechanism model, the influence of the oxygen consumption rate per carrier packing volume and the corresponding DO target value and weak aeration time on the treated water quality was simulated, and the relationship between the oxygen consumption rate per carrier packing volume and the DO target value and weak aeration time set value that could realize the minimum aeration air volume that could maintain the target treated water quality for each oxygen consumption rate per carrier packing volume was determined in advance and created as the control table shown in Table 2.

[0091] [Table 2]

Oxygen consumption rate per carrier volume	[kgO ₂ /(m ³ ·d)]	0.5	0.8	1.2	1.5	2.0	2.5	2.7	3.0	3.2
DO target value	[mg/L]	3.1	3.1	3.1	3.1	3.1	3.8	3.9	4.4	4.8
Weak aeration time set value	[minutes/2 hours]	110	90	80	60	40	20	0	0	0

[0092] The oxygen consumption rate per carrier packing volume was calculated by the measurement and calculation of Experimental Example 2, and according to the resulting numerical value, the DO target value and the weak aeration time set value were adjusted every 2 hr.

[0093] In this control table, for example, when the TOC carrier volume load ($\text{kgC}/(\text{m}^3 \bullet \text{d})$, hereinafter, the unit may be omitted) is 0.5 or more and less than 2.5, a DO target value of 3.1 mg/L is set,

when the TOC carrier volume load is 2.5 or more and less than 2.7, a DO target value of 3.8 mg/L is set,

when the TOC carrier volume load is 2.7 or more and less than 3.0, a DO target value of 3.9 mg/L is set,

when the TOC carrier volume load is 3.0 or more and less than 3.2, a DO target value of 4.4 mg/L is set, and

when the TOC carrier volume load is 3.2 or more, a DO target value of 4.8 mg/L is set,

as an appropriate value,

when the TOC carrier volume load is 0.5 or more and less than 0.8, a weak aeration time set value of 110 minutes every 2 hours is set, and

when the TOC carrier volume load is 0.8 or more and less than 1.2, a weak aeration time set value of 90 minutes every 2 hours is set, when the TOC carrier volume load is 1.2 or more and less than 1.5, a weak aeration time set value of 80 minutes every 2 hours is set, when the TOC carrier volume load is 1.5 or more and less than 2.0, a weak aeration time set value of 60 minutes every 2 hours is set, when the TOC carrier volume load is 2.0 or more and less than 2.5, a weak aeration time set value of 40 minutes every 2 hours is set, and when the TOC carrier volume load is

2.0 or more and less than 2.5, a weak aeration time set value of 20 minutes every 2 hours is set as an appropriate value, and when the TOC carrier volume load is $2.7 \text{ (kgC/(m}^3\text{•d))}$ or more, the weak aeration time set value is set to zero (that is, no intermittent aeration was carried out). [0094]

Raw water whose TOC load fluctuated as shown in Fig. 6 was used as wastewater to be treated.

[0095] Based on the 2-hour moving average of the carrier volume load, once every 2 hours the DO target value was adjusted and the weak aeration time in a 2-hour cycle was adjusted based on the control table in Table 2, and a low air volume ($3 \text{ m}^3\text{/(m}^2 \text{ of bottom area} \cdot \text{hr))}$ was fixed during the weak aeration, and the blower motor rotation speed was controlled in such a way as to reach the set DO target value during the time other than during the weak aeration.

[0096] The changes with time in the duration of the weak aeration time are shown in Fig. 3, and the changes with time in DO are shown in Fig. 4. In addition, the changes with time in the electric power consumption by the blower are shown in Fig. 5.

[0097] [Comparative Example 1]

The conditions were the same as in Example 1 except that the DO target value was fixed at 3.5 mg/L and the weak aeration time was kept constant at 10 minutes/2 hours. Results are shown in Figs. 3 to 5.

[0098] <Discussion>

In Example 1, the DO target value and the weak aeration time were adjusted according to the oxygen consumption rate per carrier, and thus the amount of electric power used by the blower is smaller than that in Comparative Example 1. That is, the electric power consumption of

Comparative Example 1 was about 1150 kWh/day, whereas the electric power consumption of Example 1 was about 950 kWh/day, which is about 17% less.

[0099] There was almost no difference in the treated water quality between Example 1 and Comparative Example 1.

[0100] Although the present invention has been described in detail using specific embodiments, it will be apparent to those skilled in the art that various modifications can be made without departing from the intent and scope of the invention.

The present application is based on Japanese Patent Application No. 2020-063032 filed on March 31, 2020, which is incorporated herein by reference in its entirety.

Reference Signs List

- [0101] 2, 11 Aeration tank
- 2a, 12 Screen
- 3a, 3b, 3c Diffuser tube
- 4, 14 Blower
- 7 Exhaust gas meter
- 8, 19 DO meter
- 9, 20 Air volume meter

CLAIMS

[Claim 1]

An aerobic biofilm treatment method comprising supplying raw water to an aeration tank, aerating the aeration tank using an aeration device, and subjecting a substance to be removed in the raw water to an aerobic biological treatment using a biofilm retaining carrier or granule packed in the aeration tank, wherein
a relationship between an oxygen consumption rate per carrier or granule, and a corresponding DO target value and/or a corresponding aeration intensity set value is set in advance,
the DO target value and/or the aeration intensity set value is adjusted based on the relationship according to a fluctuation of a measured value of the oxygen consumption rate per carrier or granule, and
the aeration device is controlled such that the DO becomes the target value or the aeration intensity becomes the set value.

[Claim 2]

The aerobic biofilm treatment method according to claim 1, wherein
the oxygen consumption rate per carrier or granule is any of an oxygen consumption rate per packing volume of the carrier, an oxygen consumption rate per total surface area of a carrier group, an oxygen consumption rate per packing volume of the granule, and an oxygen consumption rate per total surface area of a granule group.

[Claim 3]

The aerobic biofilm treatment method according to claim 1 or 2, wherein
the oxygen consumption rate per carrier or granule is calculated from
a measured value of an aeration air volume,

a measured value of a concentration of oxygen in a gas phase released from the aeration tank, or a measured value of the DO of the aeration tank and an experimental value or a calculated value of an oxygen dissolution efficiency of the aeration tank, and

a measured value or a calculated value of a packing volume or a surface area of the carrier.

[Claim 4]

The aerobic biofilm treatment method according to any one of claims 1 to 3, wherein the aeration intensity is controlled by controlling an aeration air volume, an aeration stop time, or an aeration suppression time.

[Claim 5]

The aerobic biofilm treatment method according to any one of claims 1 to 4, wherein the relationship is set using any of an experimental result, an operation result of an actual machine, and a mechanism model considering diffusivity of oxygen in the biofilm.

[Claim 6]

An aerobic biofilm treatment device comprising an aeration tank to which raw water is supplied, an aeration device that aerates the aeration tank, a biofilm-attached carrier or granule packed in the aeration tank, and a controller that controls the aeration device, wherein the device further comprises:

a setting unit that sets in advance a relationship between an oxygen consumption rate per carrier or granule, and a corresponding DO target value and/or a corresponding aeration intensity set value; and

an adjusting unit that adjusts the DO target value and/or the aeration intensity set value based on the relationship according to a

fluctuation of a measured value of the oxygen consumption rate per carrier or granule, and

wherein the controller controls the aeration device such that the DO becomes the target value or the aeration intensity becomes the set value.