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(54) Title: METHOD FOR RECONSTRUCTION AND OPTIMIZATION OF THE ACTIVATED SLUDGE STAGE OF WASTE WATER TREATMENT PLANTS WITH ONE SUSPENDED BIOMASS

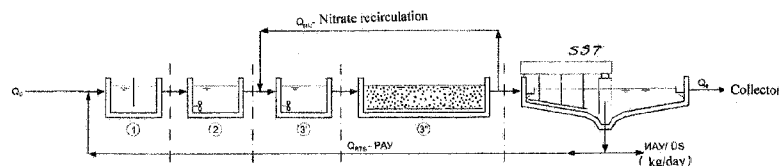


Fig. 1

(57) Abstract: Method for reconstruction and optimization of the activated sludge stage of waste water treatment plants (WWTPs), with one suspended biomass. Method for reconstruction and optimization of waste water treatment plants, wherein the determination of the major dimensioning parameters for real waste waters, like the respiration of heterotrophs' biomass, the respiration of nitrifying bacteria biomass, the specific nitrification rate, depending on the definite temperature, the specific denitrification rate, depending on the respiration of biomass, is performed on site by means of laboratory equipment, upon observance of the law of similarity, while compensating variation of the influence of temperature on the bio basin volumes at different seasons is done by calculation of the sludge age of a real waste water and variation of the biomass concentration within determined limits, under keeping a constant biomass age, and taking into consideration the biomass concentration in the bio basin in accordance with the temperature changes of waste water herein, and the optimization of dimensioning the air blowers for the activated sludge stage is effected by determination of the required oxygen quantity, based on the actual respiration of the real biomass.



METHOD FOR RECONSTRUCTION AND OPTIMIZATION OF THE ACTIVATED SLUDGE STAGE OF WASTE WATER
TREATMENT PLANTS WITH ONE SUSPENDED BIOMASS

FIELD OF THE INVENTION

The invention relates to a method for reconstruction and optimization of the activated sludge stage of municipal and industrial waste water treatment plants (WWTPs) with one suspended biomass, discharged into „sensitive areas”, and is applicable to the construction of new treatment plants in different infrastructural systems, as well as to the optimization of the already existing ones.

BACKGROUND OF THE INVENTION

The most frequently used practices of dimensioning the activated sludge stage of WWTPs, obeying the specific discharge permits of treated waste waters, which reflect the European Directives in this field, are based on the requirements and the recommendations of:

- the domestic (local) generally accepted design standards for sewage systems (the WWTPs respectively) of the respective country;
- the worksheet of the DWA – Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall, Deutschland – ATV-DVWK – A131/ 2000; Dimensioning of Single-Stage Activated Sludge Plants;
- the regulations and standards of the Environmental Protection Agency - USA.

The requirements to the purified waste water for nitrogen (N) and phosphorus (P), as stated in the permits for discharge into ”sensitive areas”, are:

BSB₅ < 25 mg/l (biological oxygen demand BOD₅)
CSB < 125 mg/l (chemical oxygen demand COD)
NS < 35 mg/l (undissolved substances)

In case of WWTPs with EP ≥ 100 000 equivalent populants:

$$\text{TKN} < 10 \text{ mg/l} = \sum [2 \text{ (mg/l) N-N}_{\text{org}} + 3 \text{ (mg/l) N-NH}_4^+ + 5 \text{ (mg/l) N-NO}_3^-] \text{ (total nitrogen)}$$

$$\text{TP} < 1 \text{ mg/l (total phosphorus)}$$

In case of WWTPs between 10 000 and 100 000 EP (equivalent populants):

$$\text{TKN} < 15 \text{ mg/l (total nitrogen)}$$

$$\text{TP} < 2 \text{ mg/l (total phosphorus)}$$

The discharge permits are generally issued by the respective Basin Directorate (BD) according to the current law. The standards for discharge into the water bodies may differ from the generally accepted (enforcement of particular standards for discharge by the BD), because they also depend on the industrial water use. In that case the relevant parameters are limited as a load (kg/d), which leads to lower concentrations in the issued permits, compared to the above-mentioned standards.

The performance of newly built or enlarged (reconstructed and upgraded) waste water treatment plants, with increased requirements for "sensitive areas", is often unsatisfactory.

The difficulties commonly include a non-achievement of the discharge parameters for purified waste water in the recipients, determined by the requirements of the discharge permits. This can be considered as a global problem. The following circumstances can be regarded as major causes:

1. The initial design data are specific for each single WWTP and in case of enhanced requirements, as for the „sensitive areas”, they are practically intransferable to another case, unless the laws of similarity are observed. The currently prevailing dimensioning methods rest on semi-empirical and often subjective methods, due to the subjective acceptance of the initial dimensioning parameters from tables, or using the experience of others from the technical literature.
2. The known high dependence on the media temperature of the microorganism consortium – nitrifying bacteria (autotrophs), facultative heterotrophs, denitrifying bacteria and other new microorganisms.
3. Usually, the up to date project planning is based on the maximum needed bio basin volume during the cold winter months ($t < 10\text{-}12^\circ\text{C}$), which is built of several uniform technological lines

(sections), while in summertime (the volume is up to two times smaller at 20 - 25 °C) the separation of unnecessary volume parts, i.e. to put out of operation some technological lines, is recommended. That causes additional problems during the repeated start-up and commissioning of the facilities, etc.

Similar difficulties also occur at the tourist sites with different seasonal occupation winter / summer, and with different number of equivalent populants respectively. The dimensioning here also concerns the most unfavorable loading and the exclusion of the unnecessary volumes out of the tourist season.

This is related to unjustified high investment costs and equipment, which would be desirable to be avoided.

4. The application of mathematical software / models for dimensioning of WWTPs is very convenient and prevailing in the water and wastewater engineers' everyday. Due to the lack of opportunities, time and financial resources, the measurements on site, recommended in that case for model verification (validation) and calibration, are normally ignored, which leads to significant uncertainty of the final results (volume of facilities, output parameters of WWTPs etc.), due to the incorrectness of the initial data used. Only the outcomes after realization of the project can be utilized in order to check the reliability of a given mathematical model for dimensioning.
5. The insufficient bio basins' mixing due to the unfit combination between their geometrical shape and the stirring devices chosen.
6. At present, the choice of variables is subjectively due to the acceptances chosen out of many alternatives, and the achieved result respectively may be uncertain and not covering all possible situations (modes of operation, necessary for the WWTPs).

DISCLOSURE OF THE INVENTION

The aim of the present invention is to create a method of reconstruction and optimization of the activated sludge stage (at the water line) of municipal and industrial waste water treatment plants (WWTPs), with one suspended biomass, discharged into „sensitive areas” by means of secure (reliable, well provided) dimensioning in the particular case, with covering the possible modes of plant operation, while low investment

costs, budget-friendly electric power consumption and acceptable price per cubic meter purified water are targeted.

The task is solved by method of reconstruction and optimization of the activated sludge stage of waste water treatment plants (WWTPs) with one suspended biomass, whereby according to the invention, the major dimensioning parameters, like:

- the respiration (breathing) of the heterotrophic biomass A_h [mgO₂/l.h];
- the respiration (breathing) of the nitrifying biomass without and with a substrate A_{NI} [mgO₂/l.h] or A_0 [mgO₂/g.h];
- the specific nitrification rate depending on the concrete temperature, v_{NI} [mg N-NH₄/l.h] or v_{NI} [mg N-NH₄/g_{TS}.h], [kg N-NH₄⁺/ kg_{TS}.d] and concentration of oxygen saturation in the bio basin, depending on the temperature and the partial pressure C_s , [mg/l];
- the specific heterotrophic denitrification rate, which depends on the biomass respiration A_o

$$v_{DN} = A_o \cdot 2,3 \text{ [mg}_{NO_3^-}\text{/l.h]} \text{ or [kg}_{NO_3^-}\text{-N / kg}_{TS}\text{.d]}$$

wherein: 2,3 (recommended by the practical experience) is the equivalent of (1 mg NO₃⁻-N = 2,9 mgO₂ – stoichiometrically calculated) of the nitrate as dissolved oxygen (upon their respiration the nitrates are a homologue of the dissolved oxygen);

- the concentration of substances filtered through a membrane filter 0,45 μm and dried at 105 °C, i.e. biomass concentration based on the dry matter content - X_{TS} [kg/m³] in the relevant zones (for nitrification, denitrification);
- others, if applicable;

are measured on site at the WWTPs by means of laboratory equipment with the particular waste water, observing the law of similarity.

Compensating variation of the influence of temperature on the biological stage volumes during different seasons is performed by means of:

- sludge age t_{TS} , [d] calculation of the real waste water through determination of the actual growth velocity of the nitrifying bacteria at different temperatures μ_{max} , [d^{-1}], employing the Arrhenius equation, respectively the loading, depending on the temperatures at different seasons and taking them into consideration during the operation;
- variation of the biomass concentration in the bio basin within determined limits (from 2,0 kg_{TS}/m³ to 5,0 kg_{TS}/m³), keeping a constant biomass age, depending on the temperature variations of the waste water at different seasons and taking them into consideration during the operation through the quantity of the surplus activated sludge ($\dot{U}_{S_d}$) taken out;

The optimization of dimensioning the air blowers for the biological stage is done through determination of the necessary quantity oxygen (O₂), respectively air, based on the actual respiration of a real biomass (of heterotrophic and autotrophic microorganisms).

According to the provided method, the dimensioning of required volumes for nitrification (NI) and denitrification (DN) in case of an activated sludge stage with one aggregate biomass is done separately.

In accordance with the same method, where required (primarily in case of the erection of new WWTPs), the biomass, necessary for the research, is created on site through the “fill & draw” method.

Following improvements are achieved by means of the provided method:

- Reducing investment costs and area necessary for WWTP due to decreasing the bio basin volume, required for performing the nitrification and denitrification processes;
- Optimization of electric energy costs for aeration, owing to the controlled feeding of oxygen, respectively air, required only for degradation of BOD₅ and running the nitrification process, and

without an uncontrolled aerobic sludge stabilisation, in case of foreseen anaerobic stabilisation;

- Optimization and facilitation of operating personnel work, because there is no necessity anymore to include / exclude new sections (bio basin volumes) and to put them into operation / out of operation respectively. The periods, required for creation and adaptation of the respective biomass, are avoided;
- Ensuring the observance of the requirements for discharged waste waters at the WWTP outlet according to the valid discharge permit (regulatory requirements);
- Energy efficiency achievement and sustainable development in the erection of new and / or the reconstruction and modernization of already existing WWTPs, and obtaining a socially acceptable price per cubic meter purified water respectively.

EXPLANATION OF ENCLOSED FIGURES

The present invention is explained by means of enclosed figures, wherein:

Figure 1 illustrates a WWTP “cascade type” having three sections (anaerobic, anoxia and aerobic) with or without a primary sedimentation tank and with one selector. The system has one aggregate biomass for the three particular processes (biological removal of phosphorus, denitrification and nitrification);

- Figure 2: Method for determination of the sludge respiration – A_0 (mg/l.gTS);
- Figure 3: Method for determination of the specific nitrification rate;
- Figure 4: Method for determination of the specific denitrification rate;
- Figure 5: „Fill & draw” method.

EXAMPLES OF EMBODIMENTS ACCORDING TO THE INVENTION

Owing to the increased ecological awareness of environment protection during the last 30 years, the standards for discharge of treated waste waters have been improved consistently. Depending on the importance of the collectors, they are divided into „nonsensitive areas”, remained with the old requirements, without removal of biogenic elements – nitrogen and phosphorus, and „sensitive areas” - with additional standards for reducing concentration of phosphorus $P_{\text{tl}} \leq 1 \div 2$ (mg/l) and nitrogen $N_{\text{tl}} \leq 10 \div 15$ (mg/l). Another increasing the requirements for total phosphorus and total nitrogen is expected, up to $P_{\text{tl}} \leq 0,5$ (mg/l) and $N_{\text{tl}} \leq 5$ (mg/l) respectively.

The present patent provides a method for reconstruction and optimization of the activated sludge stage of WWTPs with one suspended biomass, discharging their purified waste waters into „sensitive areas”, i.e. with increased requirements for the biogenic elements in the purified waste water, whereby according to the invention the determination of the major dimensioning parameters for real waste waters is done on site by means of laboratory equipment, under observance of the law of similarity. The method mainly considers the removal of nitrogen.

The selection of the treatment scheme is of primarily importance for achieving the intended purifying ability at the WWTP outlet. Taking into account the previous practical experience (not so very long) with new WWTPs, the cascade system with three separated cascades and one aggregate biomass wins more and more recognition.

The competent dimensioning of the chosen process scheme follows with regard to the real case with measured on site, and not with accepted parameters.

The specified dimensioning method is valid for process schemes, for example with bio basins cascade type (Fig.1), with separated volumes for primary denitrification, followed by nitrification, with one aggregate biomass.

1. In accordance with the provided method, object of the present invention, the first step is to check the existing technological scheme / the

WWTP concept, pursuant to the submitted/ existing project, as per its technology part.

According to the enclosed Fig.1, the depicted WWTP represents a technological scheme of purification – activated sludge stage, with one aggregate biomass for the three separated processes (biological removal of phosphorus, denitrification and nitrification). The bio basin is cascade type with one selector 1 and three separated sections – anaerobic 2, anoxia 3' and aerobic 3", with or without primary sedimentation tank (depending on the chosen scheme for the sludge treatment).

2. The next step is to check the capability of the aggregate biomass (with heterotrophic denitrification – about 80 % of the aggregate biomass) to remove the nitrogen:

$BSB_5 : TKN_0 \geq 3,00 \div 4,00$, wherein:

$3,00 \div 4,00$ - threshold value;

BSB_5 - BOD₅ value of inlet waste water [kg/d];

TKN_0 - total nitrogen value of inlet waste water [kg/d].

3. A laboratory determination of the respiration (breathing) of nitrifying bacteria biomass A_{NI} [mgO₂/l.h] or A_0 [mgO₂/g.h] follows by means of the laboratory test stand, as shown in Fig. 2, whereby the active sludge with a volume $V = 250$ ml is poured in a laboratory tank 4, placed over a magnetic stirrer 5, whilst a substrate (allyl-thioharn, interfering the nitrification) 6 is feeded into the tank 4, and one thermometer 7, one electrode for a dissolved oxygen 8, one measuring device 9 and one recording device 10 are connected with the tank 4.

The laboratory measurement is performed initially with a substrate with "genuine" waste water under concrete local conditions, whereupon a repeated measurement with addition of ammonium salts (up to 20 mg/l), $/A_{BSB}$ and $A_{NH_4^+ - N}/$ is performed.

The required biomass for planned laboratory investigations in case of a newly establishing WWTP can be taken from a similar plant, or it can be cultivated by means of the „fill & draw” method (filling and drawing) within 3 to 4 weeks.

4. The next step includes a laboratory determination of the specific nitrification rate, depending on the concrete temperature, specific for the WWTP, e.g. at $10-12\text{ }^{\circ}\text{C} \div 15\text{ }^{\circ}\text{C} \div 20-25\text{ }^{\circ}\text{C}$. For that purpose an exemplary laboratory stand is used, which is shown in Fig. 3 and illustrated with respective charts:

$$v_{NI} [\text{mg N-NH}_4/\text{l.h}] \text{ or } v_{NI} [\text{mg N-NH}_4/\text{g}_{TS}.\text{h}], [\text{kg N-NH}_4/\text{kg}_{TS}.\text{d}]$$

5. The next step represents a laboratory determination of the specific denitrification rate, which depends on the biomass respiration A_0/A_{BSB} and $A_{\text{NH}_4^+-\text{N}}$, according to the exemplary stand in Fig.4:

$$v_{DN} = A_{\sigma} 2,3 [\text{mg}_{\text{NO}_3^-/\text{l.h}}] \text{ or } [\text{kg}_{\text{NO}_3^-/\text{N}}/\text{kg}_{TS}.\text{d}]$$

wherein: 2,3 (recommended by the practical experience) is the equivalent of $(1\text{ mg NO}_3^-/\text{N} = 2,9\text{ mgO}_2\text{—stoichiometrically calculated})$ of the nitrate as dissolved oxygen (during their respiration the nitrates are a homologue of the dissolved oxygen);

6. A sludge age t_{TS} , [d] calculation of the real waste water follows through determination of the actual growth velocity of the nitrifying bacteria μ_{max} , $[\text{d}^{-1}]$, employing the Ahrrenius equation, respectively the loading, depending on the temperatures at different seasons and taking them into consideration during the operation;

The follwing known method is used in order to find the nitrification and denitrification volume:

F : M (food : microorganisms), known as a biological loading or BOD₅-decomposition rate – $B_{TS,BSB}$.

$$B_{TS} = \frac{B_{d,BSB} [\text{kg}_{BSB_5} / \text{d}]}{TS_{BB} [\text{kg} / \text{m}^3] \cdot V_{BB} [\text{m}^3]}, [\text{kg}_{BSB_5} / \text{kg}_{TS}.\text{d}]$$

$B_{TS} = F : M$, i.e. the biomass reproduction is depending on that ratio, which also depends on the influence of temperature;

$$t_{TS} = 1 / \mu_t, [\text{d}]$$

wherein:

t_{TS} – sludge age [d],

μ_t – coefficient of the reproduction rate, calculated according to the Monod equation, but with $\mu_{\max}$, calculated according to the Van't Hoff equation, modified by Svante Arrhenius:

$$\mu_t = \mu_{\max} \cdot e^{K(T_1 - T_2)} \text{ or } \mu_t = \mu_{\max} \cdot e^{-kt}, [\text{d}^{-1}]$$

$$\mu_{\max^x} = \mu_{\max^{15}} \cdot e^{K(T_1 - T_2)}$$

wherein:

$\mu_{\max^{15}} = 0,45, [\text{d}^{-1}]$ - specific growth rate, known and standardised for pure cultures from *Nitrosomonas* at 15 °C;

T_1, T_2 – the relevant waste water temperatures, °C;

K – Van't Hoff factor (function of the temperature, in tabular form);

Monod equation:

$$\mu_t = \mu_{\max} \frac{(NH_4^+ - N)}{K_N + (NH_4^+ - N)} \cdot \frac{O_2}{K_O + O_2}, [\text{d}^{-1}]$$

The sludge age is connected with the quantity of the produced new (surplus activated sludge), which is taken out of the bio basin. Since the nitrifying bacteria do not form flocules, they utilize the biomass, formed by the heterotrophs as carriers, wherein they take 1 ÷ 3 % of the total mass. In order to avoid their taking out together with the aggregate mass, the reproduction rate of the heterotrophs (from 2 to 4 times higher) has to be equal to the reproduction rate of the nitrifying bacteria: $\mu_t = \mu_{\text{nitr.}}$. This is possible only in that case, if the heterotrophs go on a “diet”, i.e. the loading as per BSB₅ (F : M) is in ratio less than $B_{TS} < 0,10 \div 0,005$ (mg BSB₅/kg_{TS}.d). Since the nitrifying bacteria are determinative of the biomass reproduction of heterotrophic microorganisms, the whole dimensioning is concentrated on the nitrification by means of laboratory investigations with real waste water.

7. The next step is a determination of the volume for nitrification.

The following equation is used for dimensioning of the nitrification volume:

$$V_{NI} = \frac{\Delta(NH_4^+ - N)}{v_{NI} \cdot TS_{BSB}}, [m^3], \text{ for already existing WWTPs;}$$

$$^*V_{NI} = \frac{\eta \cdot N_0^*}{v_{NI} \cdot TS_{BSB}}, [m^3], \text{ for new WWTPs;}$$

wherein:

$\Delta(NH_4^+ - N)$ is the difference between the concentration of amonium ions at the WWTP inlet and outlet, respectively the inlet and outflow at NI-stage for already existing WWTPs, [kg/d];

or

η is the coefficient of nitrified total nitrogen (N_0), $\eta \approx 80\%$

*N_0 is the total nitrogen at the WWTP inlet, which is expected to be fully nitrified (for new WWTPs);

v_{NI} – nitrification rate (NI), [kg $N-NH_4$ / kg $_{TS}$.d], from laboratory investigations at different temperatures, specific for the concrete WWTP; TS_{BSB} is the biomass concentration by dry matter [kg $_{TS}$ /m³], determined through laboratory investigations of the waste water at the WWTP inlet, or through the NI-stage of existing WWTPs (at determined temperature, oxygen concentration, amonium ions and pH).

8. The determination of the volume for denitrification follows.

Dimensioning of the volume for denitrification:

$$V_{DN} = \frac{\Delta(NO_3^- - N)}{v_{DN} \cdot TS_{BSB}}, [m^3]$$

wherein:

$\Delta(NO_3^- - N)$ is the difference between the concentration of nitrate ions at the WWTP inlet and outlet, respectively the inlet and outlet at DN-stage for already existing WWTPs [kg/d];

TS_{BSB} is the biomass concentration by dry matter [kg $_{TS}$ /m³], determined through laboratory investigations of the waste water at the WWTP inlet, or through the DN-stage of existing WWTPs (at determined temperature, pH, etc.).

v_{DN} is the denitrification rate (DN) [$\text{kg}_{\text{NO}_3\text{-N}}/\text{kg}_{\text{TS}}\cdot\text{d}$] - from laboratory investigations, at different temperatures, specific for the actual WWTP; For determination of v_{DN} a preliminary measurement of the biomass respiration A_o [$\text{mg}/\text{l}\cdot\text{h}$] is used, while the same is divided by an equivalent of (NO_3^-) for oxygen – 2,3.

$$v_{DN} = A_o \cdot 2,3 \text{ [mg}_{\text{NO}_3\text{-}} / \text{g}_{\text{TS}}\cdot\text{h}] \text{ or } [\text{kg}_{\text{NO}_3\text{-N}} / \text{kg}_{\text{TS}}\cdot\text{d}]$$

9. A determination of the total bio basin volume follows.

Determination of the total bio basin volume for NI u DN:

$$V_{BB} = V_{NI} + V_{DN}, [\text{m}^3]$$

10. The next step is to determine the quantity of the surplus activated sludge ($\dot{U}S_d$)

$$\dot{U}S_d = \frac{V_{BB} \cdot TS_{BB}}{t_{TS}}, [\text{m}^3 / \text{d}]$$

wherein:

V_{BB} = total bio basin volume [m^3];

TS_{BB} = biomass concentration by dry matter [$\text{kg}_{\text{TS}}/\text{m}^3$];

t_{TS} = sludge age, calculated according to paragraph 6 [d].

11. Finally, the report preparation follows with actual operating instructions and recommendation of measures (operating etc.) for WWTP optimization, depending on the achieved outcomes.

A training course for the operating personnel follows, e.g. in case of eventual change of the waste water temperature and measurement of TS_{BB} (for example each month), what a quantity surplus activated sludge is required to be taken out ($\dot{U}S_d$, m^3/d), how much and what a quantity of oxygen respectively air is required for the nitrification area etc.

All above-described steps (as per paragraphs 3, 4, 5, 6, 7, 8 and 9) are determined at different temperatures: 10 °C, 15 °C and 25 °C $\pm$ 2-5 °C, which are specific for the seasons of the concrete climate region, where the respective WWTP is located.

It is striven during the operation to keep the sludge age t_{TS} (d) constantly, whilst with such given bio basin volume V_{BB} (m³) the biomass concentration varies in accordance with the temperature influence on the reproduction factors:

$$\mu_x = \mu_{nitr.} \text{ (d}^{-1}\text{) nitrifying bacteria} = \text{heterotrophs.}$$

12. In case the WWTP is not built yet and an existing project needs to be optimized, the required parameters are determined according to the present optimization method, while the required biomass for laboratory investigations is produced on site by means of the “fill & draw” method, in accordance with the laboratory test stand, as shown in Fig. 5.

Brief description of the method

One cylinder with a capacity of 2÷5 liters is filled with raw waste water from the respective residential area (the main inlet sewer collector), while the waste water in the cylinder is aerated steadily over 24 hours ($O_2 > 3\div6$ mg/l), whereupon it precipitates for about 0,5 h. Every day after the precipitation about 50 % of the waste water is discharged and the remaining 50 % are supplemented with raw water. The creation of own biomass may take place at different temperatures within 3 to 4 weeks, whereupon it is proceeded according to the present method.

The provided method for optimization of WWTPs for „sensitive areas” , object of the present patent application, helps to a great extent to avoid the subjective acceptance from the literature of missing data, which rarely match the concrete climate and other local conditions for WWTPs. Thus the erection of a prototype pilot facility with one-year investigation period is avoided. Each WWTP is particular and the designer can take it into consideration.

We will support the proposed method by means of one definite exemplary solution:

- Base data
- Population - 100 000 EP (GEW);
- $Q_{dr.} = 150$ l/W.d - drain standard per resident per day, incl. infiltrated waters;

- Waste water temperature = 20 °C;
- $Q_d = 15000 \text{ m}^3/\text{d}$ – average twenty-four-hour inflow;
- $Q_t = 1127,50 \text{ m}^3/\text{h}$ – maximum quantity per hour;
- Specific loading at the WWTP inlet:

$$\text{BSB}_5 = 60 \text{ g/EP.d}$$

$$\text{TKN}_o = 11 \text{ g/EP.d}$$

$$\text{TP} = 1,8 \text{ g/EP.d}$$

- Requirements at the WWTP outlet

Anticipated requirements, stated in the discharge permit according to the applicable legislation:

$$\text{BSB}_5 < 25 \text{ mg/l}$$

$$\text{CSB} < 125 \text{ mg/l}$$

$$\text{NS} < 35 \text{ mg/l (undissolved substances)}$$

$$\text{TKN} < 10 \text{ mg/l} =$$

$$= \sum [2 (\text{mg/l}) \text{ N-N}_{\text{org}} + 3 (\text{mg/l}) \text{ N-NH}_4^+ + 5 (\text{mg/l}) \text{ N-NO}_3^+]$$

$$\text{TP} < 1 \text{ mg/l}$$

*TKN – total nitrogen

*TP – total phosphorus

- Solution

1. Check of the the existing technological scheme / the WWTP concept, pursuant to the submitted project, as per its technology project part.

The preferred system for nitrogen removal from the waste water is the cascade one, with separated bio basins for nitrification and denitrification.

Major dependencies upon checking, which are to be observed with regard to the nitrogen elimination run:

- No denitrification without nitrification;
- No nitrification without a dissolved oxygen;
- No nitrification without nitrifying bacteria;

- No denitrification without breathing of heterotrophs (A_0) with ($\text{NO}_3^- + \text{NO}_2^-$) as a homologue of the dissolved oxygen.

2. Check if the biological nitrogen removal is possible:

$$\text{BSB}_5 : \text{TKN}_0 \geq 3,00 \div 4,00,$$

Total loadings at the WWTP inlet:

$$\text{BSB}_5 = 100\,000 \times 0,060 = 6000 \text{ kg/d}$$

$$\text{TKN}_0 = 100\,000 \times 0,011 = 1100 \text{ kg/d}$$

$$6000 : 1100 = 5,45 \geq 3,00 \div 4,00$$

3. Laboratory determination of the respiration (breathing) of nitrifying bacteria biomass A_{NI} [$\text{mgO}_2/\text{l.h}$] or A_0 [$\text{mgO}_2/\text{g.h}$], (FIG.2)

$$A^1_o = 0,02 \text{ kgO}_2/\text{kg.d} \quad - \text{ from laboratory investigations;}$$

$$A^2_o = 0,06 \text{ kgO}_2/\text{kg.d} \quad - \text{ from laboratory investigations upon addition of methanol as a substrate;}$$

4. Laboratory determination of the specific nitrification rate, depending on the definite temperature, specific for the WWTP (e.g. at $10\text{-}12^\circ\text{C} \div 15^\circ\text{C} \div 20\text{-}25^\circ\text{C}$);

$$v_{\text{NI}} = 0,1 [\text{kg N-NH}_4/\text{kg}_{\text{TS.d}}] \quad - \text{ from laboratory investigations;}$$

$$\text{TS}_{\text{BSB}} = 2,5 [\text{kg/m}^3] \quad - \text{ from laboratory investigations.}$$

5. Laboratory determination of the specific denitrification rate, which depends on the respiration of biomass A_0 (FIG.4)

$$v_{\text{DN},1} = A_0 \times 2,3 = 0,02 \times 2,3 = 0,046 [\text{kg N-NH}_4/\text{kg}_{\text{TS.d}}];$$

$$v_{\text{DN},2} = A_0 \times 2,3 = 0,006 \times 2,3 = 0,138 [\text{kg N-NH}_4/\text{kg}_{\text{TS.d}}], \text{ /upon addition of substrate/}.$$

6. Sludge age t_{TS} , [d] calculation of the real waste water through determination of the actual growth velocity of the nitrifying bacteria at different temperatures μ_{max} [d^{-1}], employing the Arrhenius equation, respectively loading, depending on the temperatures at different seasons and taking them into consideration during the operation.

$$t_{TS} = 1/\mu_r = 1/0,314 = 3,2 \text{ d, at temperature } t = 20 \text{ }^{\circ}\text{C}$$

$\mu_{\max}$ – according to the Van't Hoff equation, modified by Svante Arrhenius:

$$\mu_t = \mu_{\max} \cdot e^{K(T_1 - T_2)} \text{ or } \mu_t = \mu_{\max} \cdot e^{-kt}, (d^{-1})$$

$$\text{For } t=20 \text{ }^{\circ}\text{C}, \mu_{\max 20} = \mu_{\max 15} \cdot e^{K(20-15)}$$

$$\mu_{\max 20} = 0,45 \cdot e^{0,098(20-15)}$$

$$\mu_{\max 20} = 0,45 \cdot e^{49}, (d^{-1})$$

$$\mu_{\max 20} = 0,45 \cdot 1,568 = 0,7056 \text{ d}^{-1}$$

$\mu_{\max 15} = 0,45(d^{-1})$ - specific growth rate, known and standardised for pure cultures from Nitrosomonas at 15 °C;

Monod equation:

$$\mu_t = \mu_{\max} \frac{(NH_4^+ - N)}{K_N + (NH_4^+ - N)} \cdot \frac{O_2}{K_O + O_2}, (d^{-1})$$

$$\mu_{\max 20} = 0,7056 \frac{1}{0,5 + 1,0} \cdot \frac{2}{1,0 + 2,0} = 0,3136 \text{ d}^{-1} \quad (\text{Monod} + \text{Arrhenius equation})$$

7. Determination of the volume for nitrification:

$$V_{NI} = \frac{\Delta(NH_4^+ - N)}{v_{NI} \cdot TS_{BSB}} = \frac{1100}{0,1 \cdot 2,5} = 4400 m^3$$

8. Determination of the volume for denitrification:

$$V_{DN,1} = \frac{\Delta(NO_3^- - N)}{v_{DN} \cdot TS_{BSB}} = \frac{770}{0,046 \cdot 2,5} = 6696 m^3$$

$$V_{DN,2} = \frac{\Delta(NO_3^- - N)}{v_{DN} \cdot TS_{BSB}} = \frac{770}{0,138 \cdot 2,5} = 2232 m^3$$

9. Determination of the total bio basin volume:

$V_{BB,1} = V_{NI} + V_{DN,1} = 4400 + 6696 = 11096 m^3$, without addition of substrate;

$V_{BB,2} = V_{NI} + V_{DN,2} = 4400 + 2232 = 6632 m^3$, upon addition of methanol as a substrate.

10. Determination of the quantity of the surplus activated sludge ($\ddot{U}S_d$)

$$t_{TS} = \frac{V_{BB} \cdot TS_{BB}}{Q_{\ddot{U}S,d} \cdot TS_{\ddot{U}S} + Q_d \cdot TS_e} = \frac{V_{BB} \cdot TS_{BB}}{\ddot{U}S_d}, [d]$$

wherein ($Q_e \times TS_e$) is considered as negligible and therefore it is not calculated.

$$\ddot{U}S_d = Q_{\ddot{U}S,d} \times TS_{\ddot{U}S}$$

$$3,2 = 6632 \times 2,5 / Q_{\ddot{U}S,d} \times TS_{\ddot{U}S}$$

$$Q_{\ddot{U}S,d} \times TS_{\ddot{U}S} = 16580 / 3,2 = 5181,25 \text{ kg/d}$$

$$\ddot{U}S_d = 5181,25 / 2,5 = 2072,50 m^3/d$$

The difference:

$\Delta \ddot{U}S$ is used for corrections in the operation!

The measurement of TS in the bio basin is performed every month and depending on the sludge age as a function of the waste water temperature, whereupon the quantity of surplus activated sludge, which has to be taken out, is determined ($\ddot{U}S_d$).

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CLAIMS

1. Method for reconstruction and optimization of the activated sludge stage of waste water treatment plants (WWTPs) with one suspended biomass, **characterised in that** the determination of the major dimensioning parameters for the real waste waters, like:

- the respiration (breathing) of the heterotrophic biomass A_h [mgO₂/l.h];
- the respiration (breathing) of the nitrifying biomass without and with a substrate A_{NI} [mgO₂/l.h] or A_0 [mgO₂/g.h];
- the specific nitrification rate depending on the concrete temperature, v_{NI} [mg N-NH₄/l.h] or v_{NI} [mg N-NH₄/g_{TS}.h], [kg N-NH₄⁺/kg_{TS}.d] and the concentration of oxygen saturation in the bio basin, depending on the temperature and the partial pressure C_s , [mg/l];
- the specific heterotrophic denitrification rate, which depends on the biomass respiration A_o

$$v_{DN} = A_o \cdot 2,3 \text{ [mg}_{NO_3^-} / \text{l.h]} \text{ or [kg}_{NO_3^-} \text{-N / kg}_{TS} \cdot \text{d}]}$$

wherein: 2,3 (recommended by the practical experience) is the equivalent of

(1 mg NO₃⁻-N = 2,9 mgO₂ – stoichiometrically calculated) of the nitrate as dissolved oxygen (upon their respiration the nitrates are a homologue of the dissolved oxygen);

- the concentration of substances filtered through membrane filter 0,45 µm and dried at 105 °C, i.e. biomass concentration based on the dry matter content - X_{TS} [kg/m³] in the relevant areas (for nitrification, denitrification);
- others, if applicable;

is performed on site by means of laboratory equipment, upon observance of the law of similarity, while compensating variation of the influence of temperature on the activated sludge stage volumes during different seasons is effected by means of:

- sludge age t_{TS} , [d] calculation of the real waste water through determination of the actual growth velocity of the nitrifying bacteria μ_{max} , [d⁻¹] employing the Arrhenius equation, respectively the loading, depending on the temperatures at different seasons and taking them into consideration during the operation;
- variation of the biomass concentration (in the bio basin) within determined limits (from 2,0 kg_{TS}/m³ to 5,0 kg_{TS}/m³), keeping a constant biomass age, depending on the temperature variations of the waste water herein at different seasons and taking them into consideration during the operation through the quantity of an surplus activated sludge ($\dot{U}_d$);

and the optimization of dimensioning the air blowers for the activated sludge stage is done through determination of the necessary quantity oxygen (O₂), respectively air, based on the actual respiration of a real biomass (of heterotrophic and autotrophic microorganisms).

2. Method for dimensioning and optimization of the activated sludge stage of municipal and industrial waste water treatment plants (WWTPs), with one suspended biomass according to Claim 1, **characterised in that** the dimensioning of the required volumes for nitrification (NI) and denitrification (DN) in case of an activated sludge stage with one aggregate biomass, is done separately.

3. Method for dimensioning and optimization of the activated sludge stage of waste water treatment plants (WWTPs), with one suspended biomass, according to Claim 1, **characterised in that** the required for the investigations biomass for new WWTPs is created on site through the "fill & draw" method, if applicable.

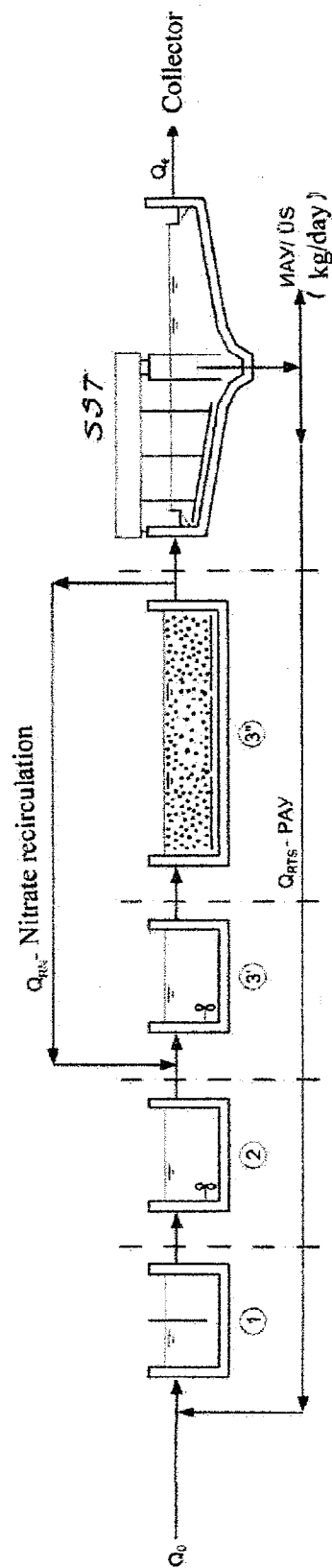
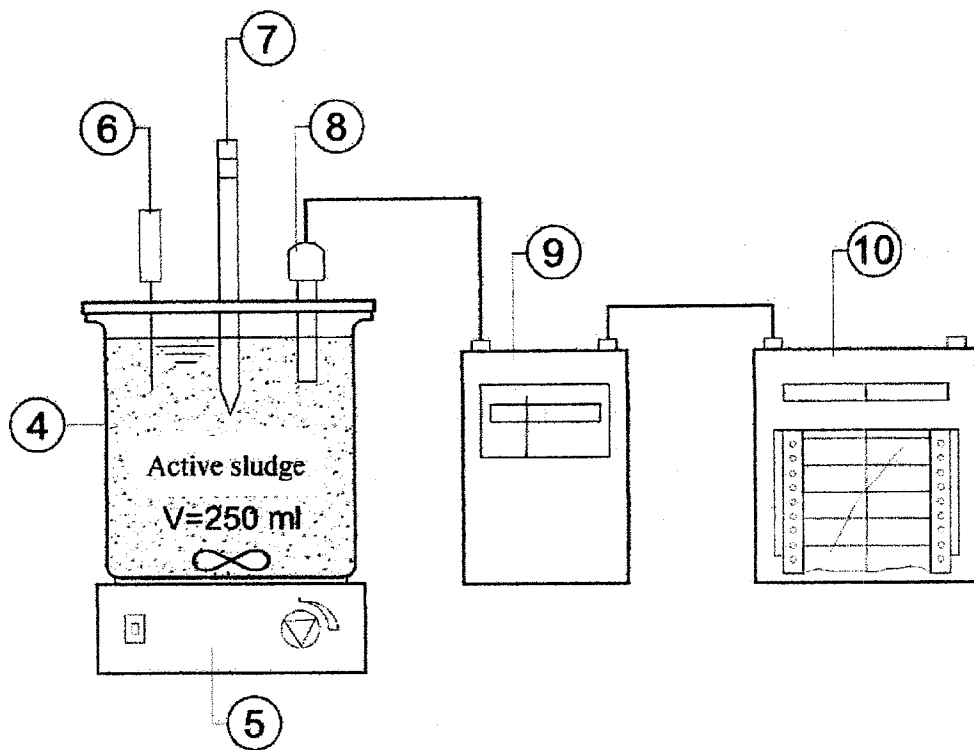
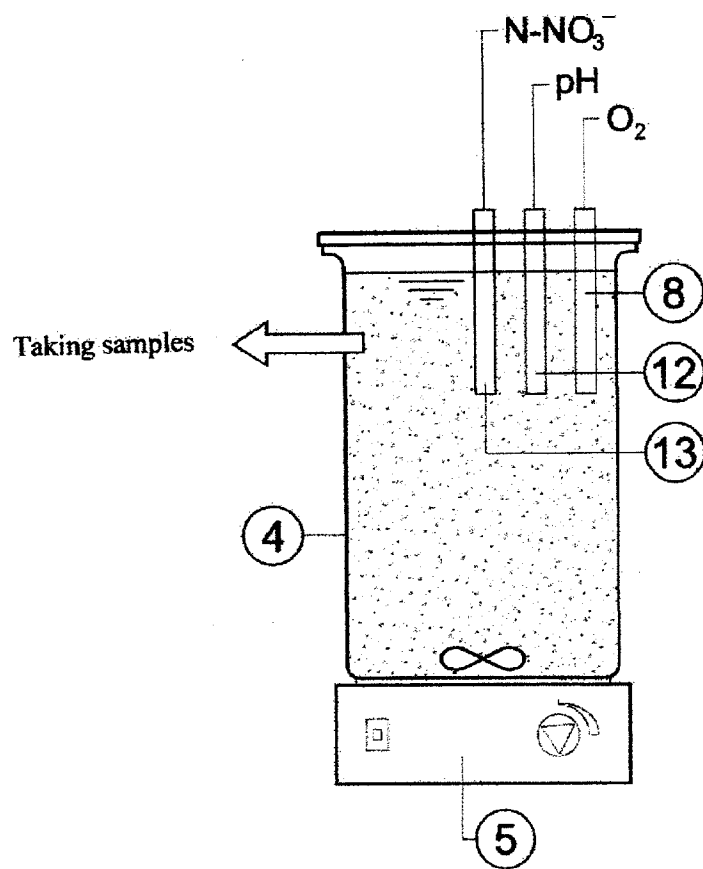


Fig. 1

*Fig. 2*

*Fig. 3*

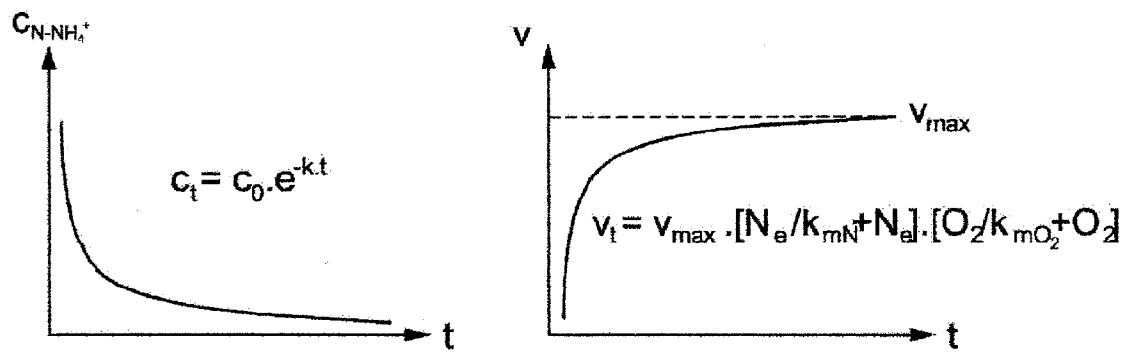
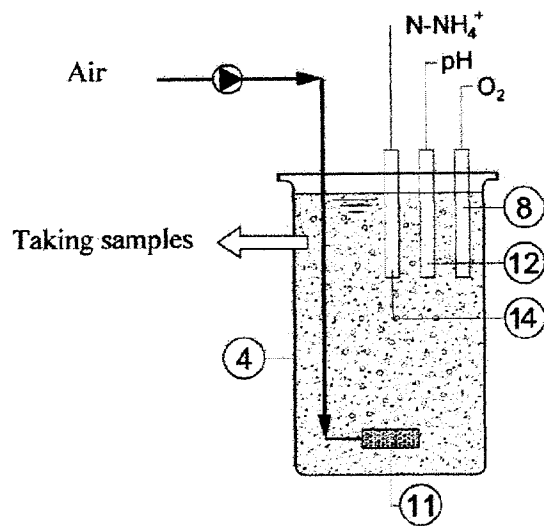
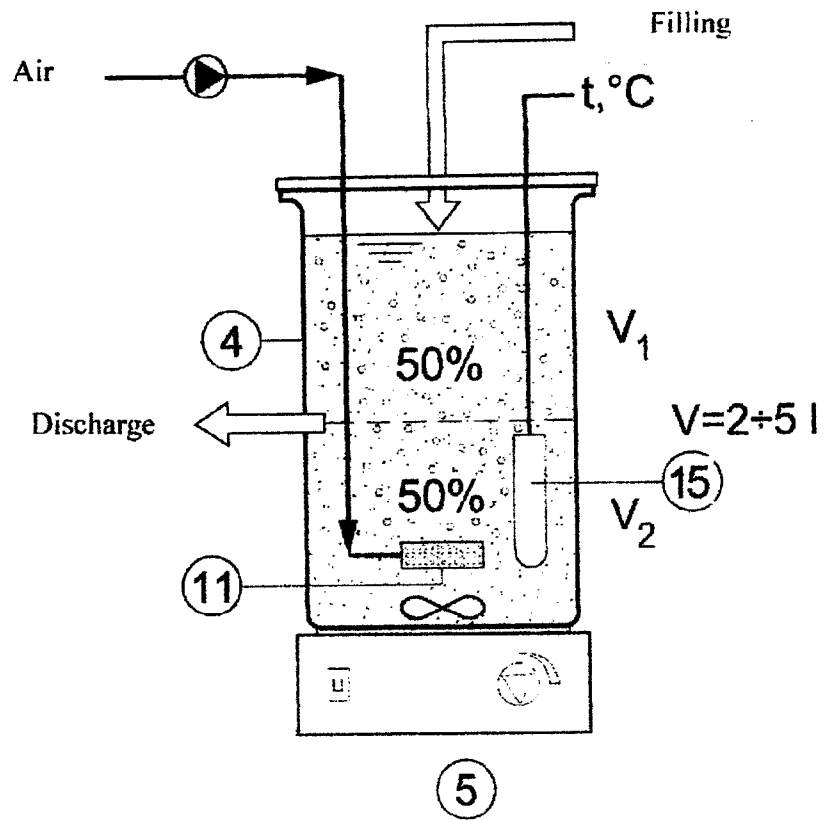


Fig. 4

*Fig. 5*

INTERNATIONAL SEARCH REPORT

International application No

PCT/BG2014/000042

A. CLASSIFICATION OF SUBJECT MATTER

INV. C02F3/12 C02F3/30 C02F3/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	Helmut Kapp: "Bemessungsspielräume bei Belebungsanlagen nach ATV-DVWK-A 131" In: Frank Wolfgang Günthert: "Kommunale Kläranlagen: Bemessung, Erweiterung, Optimierung, Betrieb und Kosten", 2009, expert Verlag, XP002738045, vol. Band 510, pages 67-69, the whole document	1-3
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☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

21 May 2015

Date of mailing of the international search report

11/06/2015

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INTERNATIONAL SEARCH REPORT

International application No

PCT/BG2014/000042

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	US 2002/148779 A1 (SHIEH WEN K [US] ET AL) 17 October 2002 (2002-10-17) paragraph [0038] paragraph [0045] - paragraph [0047] paragraph [0086] - paragraph [0107]; example 3 -----	1-3
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Information on patent family members

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