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SIZING OF A DECENTRALIZED WASTEWATER TREATMENT UNIT SUPPORTED BY BIOKINETIC MODELING

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Abstract: Decentralized wastewater systems treat, dispose and reuse the wastewater in the vicinity of source, reducing the sewage transportation cost to minimal. As an alternative to centralized systems it can function as a satellite system or an individual wastewater treatment unit. Design an onsite facility applies the same sizing procedure compared the conventional large scale systems, whereas the input flow data and its variability, the model parameters could differ. In this study a small size treatment unit was designed by biokinetic modeling, where the model parameters were estimated using analytical methods. As a result of the calculation the biomass build-up and the quality of the treated effluent was predicted and the operation parameters were determined in summer and winter operation.

Keywords: Activated sludge model**,** Biokinetic modeling**,** Decentralized wastewater system, Onsite sewage treatment

1. Introduction

The need for sustainable water management is growing due to increasing pollution and emerging water supply shortages. The environment suffers from repetitive and high pollutant load due to inadequate wastewater treatment. Solutions shall focus on the accessibility and efficiency of sewage treatment processes. Treatment technologies must not only be efficient and reliable, but they should have low investment and maintenance costs.

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Centralized systems could handle large quantity of wastewater, while the majority of the investment cost belongs to the installation and operation of the wastewater collection system. Elevated residence time in sewage system may cause undesirable biological processes or sedimentation and it has effect on quality of wastewater entering the treatment plant [1].

Decentralized solutions could be an option to reduce the size of sewage channel system and treat the wastewater locally, especially in regions, where the population density is low and/or the system could serve less than 2000 Population Equivalent (PE) [2].

Individual wastewater treatment facilities include the treatment and/or final disposal or temporary collection and storage of municipal wastewater with 1 to 25 population equivalent. Depending on the environmental and water management aspects and the building density, these may include: onsite sewage facilities, individual small wastewater treatment units and closed wastewater storages. Disposal and handling of liquid, sludge, and construction waste from individual wastewater treatment facilities must be carried out in accordance with separate legislation.

Onsite sewage treatment facility is an installation that serves for the non-utility drainage and disposal of municipal wastewater, and provides an environmental solution equivalent to the municipal wastewater drainage and treatment. The individual wastewater treatment plant carrying out the treatment of the sewage by means of energy input and ensures the removal of the pollutants, the recipient of the treated wastewater can be surface water or soil. Closed wastewater storage is an installation consisting of one or more closed and watertight tanks; for the non-hazardous collection of wastewater and for the temporary storage of municipal liquid waste.

At international level, in the 1990s, a lack of development in decentralized wastewater treatment was recognized and, in response, DEcentralized WAstewater Treatment System (DEWATS) was created [3].

DEWATS systems are suitable for the treatment of both domestic and industrial wastewater with a flow rate of 1 - 1000 m^3/day. A comprehensive system can only be appropriate if it provides a reliable and efficient treatment of residential and technological wastewater in a variety of local conditions, requires fast design and execution process, has medium investment costs, and has limited maintenance and operational requirements. It is confirmed that individual systems may perform unsatisfactory due to inappropriate operation: the organic matter degradation is low; the activated sludge systems are less efficient compared to biofilm systems since the floc wash-out could remove the active biomass from the system [4]. This deficiency could be overcome by application of post-treatment: e.g. flow from anaerobic baffled reactor is treated by a constructed wetland. The performance for organic matter degradation is 90%, whereas the nutrient removal is also satisfactory (NH_4-N: 70%) [5].

The importance of field data was highlighted, since the per capita values determined by the developed countries are not always in accordance with actual data measured. In most cases the actual 5-day Biological Oxygen Demand (BOD_5) load is overestimated [6].

In individual wastewater treatment units all type of biomasses (suspended or attached) and hybrid methods could be applied [7], also the calculation of the operation parameters (aeration intensity, excess sludge removal) are the same as in large scale plants [8].

The aim of this research is to design a small wastewater treatment unit that fulfills the effluent quality requirement.

2. Methodology

Removal of the wastewater constituents are based on biological processes, microorganisms consume the carbon, nitrogen and phosphorous forms to build up their cells. Therefore, the basic element of sizing a wastewater treatment plant is to estimate the required biomass amount in the system. Biomass is defined as the bacterial mass of various species capable of decomposing dissolved and colloidal organic matter. The bacterial mass and microorganisms involved in the wastewater treatment process break down and transform to small and simple molecules. Growth can be seen as an enzyme-catalyzed microbiological reaction [9].

The growth of the microorganism can be described by Monod type kinetics as follows:

$$\mu = \mu_{max} \frac{S}{K_S + S}, \tag{1}$$

where: μ is specific growth rate $[t^{1}]$; $\mu_{\max}$ is maximum specific growth rate $[t^{1}]$; S is substrate concentration [mg/l].

Monod kinetics describes the production of biomass in function of substrate concentration. If the substrate concentration is low, the growth rate is linear; if the substrate concentration is high the bacteria growth follows zero-order (concentration independent) kinetics. Introducing the yield (Y), the relation between the substrate consumption and biomass growth can be explained as follows:

$$\frac{dX}{dt} = Y \frac{dS}{dt}, \tag{2}$$

where X is the amount of biomass produced per day [kg/d]; S is the daily incoming substrate amount [kg/d]; Y is the biomass yield [kg/kg].

By using (1) and (2) the mass transport for the substrate can be written as follows:

$$\frac{dS}{dt} = -\frac{1}{Y} \mu_{max} \frac{S}{K_S + S} X\ . \tag{3}$$

Biokinetic modeling is based on Activated Sludge Models (ASM). All types of ASM models - ASM1 [10], ASM3 [11] - describes the basic processes of carbon oxidation, nitrification and denitrification, the concept differs in the description of the heterotrophic growth and decay and it shall take into account the actual purpose of the modeling [12].

For this study the ASM2D model was selected as it is widely used comprehensive model, where the model parameter calibration procedure is not unique allowing the user the find the optimal subset of parameters for the tuning procedure [13]. The applied simulation tool was GPS-X 6.5 commercial software.

First step of the biokinetic simulation is the influent characterization, where the fractions of the raw wastewater were analyzed. It follows the creation of the model layout in accordance with the actual treatment unit setup (*Fig. 1*). The raw influent flows to a buffer zone, where the flow is equalized, and then it is directed to the biological zones, which are the anaerobic, anoxic and aerobic zone.

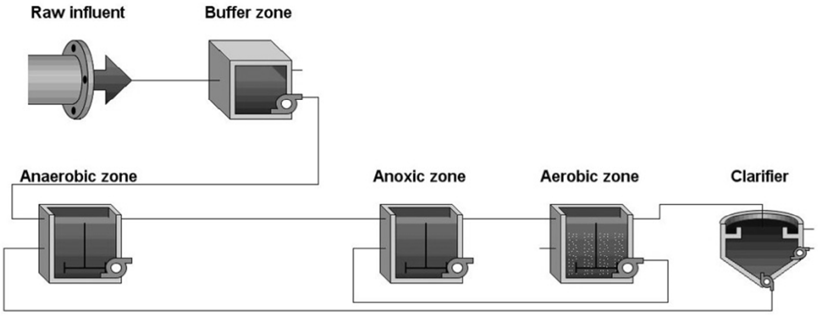

Fig. 1. Model layout of a small size wastewater treatment unit

Aerobic zone is aerated by depth diffusers; the part of the flow is directed back to anoxic zone (internal recirculation) in order to transport the nitrate back to the denitrifying microorganisms to reduce the Total Nitrogen (TN) in the system. Solid particles are separated in the clarifier. Some part of the sludge is reverted back to the anaerobic zone to maintain the biomass concentration in the system and excess sludge is taken out from the system at a predefined rate in order to ensure the solid retention time required for the biological processes.

3. Results and discussion

The incoming flow is 6 m^3/d, which has a diurnal variation; the peak flow factor is 3. As for operational aspects the dry matter content of reactor is: $MLSS$=3.5 g/l, where MLSS denotes the Mixed Liquor Suspended Solid. The Dissolved Oxygen (DO) in the aerobic reactor is 2 g/m^3. The Standard Oxygen Transfer Rate (SOTE) is 12%, which is a realistic value for a 2.0 m depth reactor. The nitrate recirculation rate is 400%. The clarifier area is 0.5 m^2, the maximum surface load is designed to be 0.47 $m^3/m^2\cdot h$. The sludge recirculation rate is 100%.

As in the Section 2 was described, first the amount of the biomass in the system was determined by analytical way based on the literature [9] and from that value the initial volumes of the reactor zones were calculated: the buffer, anaerobic, anoxic, aerobic zones have a volume of 3 m^3, 1 m^3, 1 m^3, 3.9 m^3 and 1.1 m^3 respectively.

A Central-European municipal wastewater average was assumed with total Chemical Oxygen Demand (COD) COD=700 mg/l, Total Suspended Solid (TSS)

TSS=400 mg/l, BOD_5=310 mg/l, TN=80 mg/l, Total Phosphorous (TP) TP=12 mg/l. Influent characterization performed was COD-TSS based; which required the influent COD and TSS as input variables. The COD fractions calculated were the following:

- inert soluble COD: 20 mg/l;
- particulate inert COD: 210 mg/l;
- slowly biodegradable COD: 330 mg/l;
- easily biodegradable COD: 140 mg/l.
- The organic part of the suspended solid was 75%.

Unsteady simulations were performed in order to estimate the time required for biomass build up. *Fig. 2* shows that the Sludge Retention Time (SRT) is 12 days in the system, allowing the organic matter degradation and the complete nitrification. At initial period there was no sludge removal, after reaching the desired SRT the excess sludge was removed resulting constant sludge amount in the reactor. As the simulation revealed, the sludge produced has a dry solid concentration of 6700 g/m^3, which resulted 0.32 m^3/d un-thickened excess sludge.

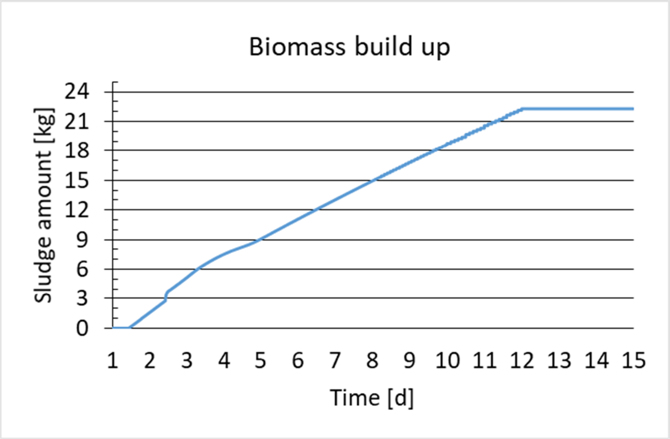

Fig. 2. Biomass builds up in the system

Numerical simulation also added that the oxygen demand is 0.096 kg/h, whereas the analytical estimations (based on stoichiometric calculations of organic matter and ammonium oxidation modified by safety factors) gave 0.164 kg/h. The difference could be caused by safety factors built in the analytical methods, since peak loads and extremities are also taken into account. In numerical model the actual daily and seasonal variations could be applied.

If the pollutant distribution is analyzed in the various reactor zones, it can be observed that there is a constant concentration value at each compartment since the reactor zones are considered as completely mixed. This assumption could be valid in an individual wastewater treatment unit due to the dimensions applied.

As *Fig. 3* shows the NH_4-N concentration decreases steadily as the residence time (sludge age) and the received oxygen advances. Nitrification took place mostly in aerobic reactors, but the recirculation (internal and sludge recirculation) may directs oxygen back the other reactor zones. The aim is to achieve complete nitrification, which allows maximum 2 mg/l NH_4-N at the end of the process.

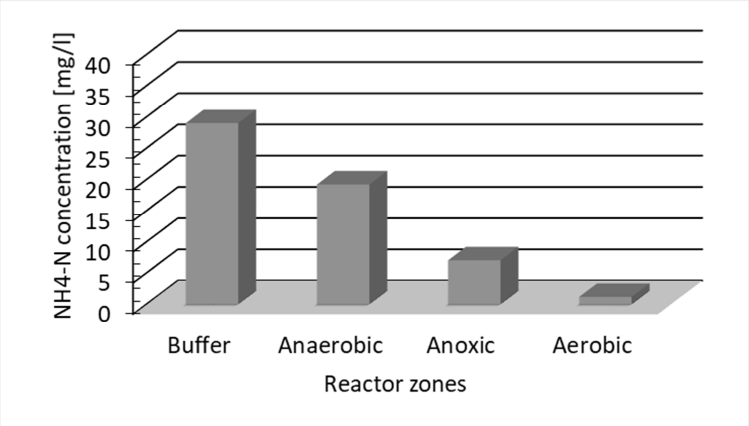

Fig. 3. NH_4-N concentration in the reactor zones

Fig. 4 presents the nitrate-nitrogen concentration in the various reactor zones. Simulation results confirmed that at the end of the nitrification process nitrate is produced in the aerobic zones. Internal recirculation reverts it back to the anoxic zone, where the nitrate-nitrogen concentration shall be below 2.0 mg/l.

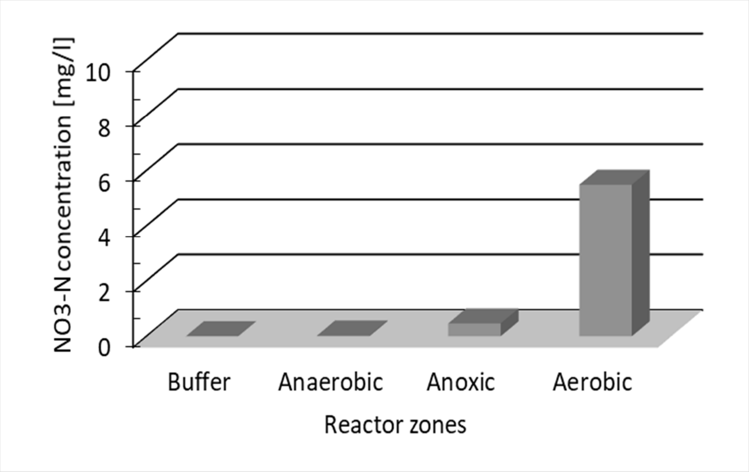

Fig. 4. NO_3-N concentration in the reactor zones

Based on the simulation result, it can be stated that there is biological excess phosphous removal in the system. The settled sludge and raw sewage passes through the anaerobic zone, where the anaerobic microorganisms release phosphorous, in oxic zone phosphorous is stored as a polimer inside the microorganism cells. Excess biomass is removed by the sludge removal.

Treated wastewater effluent quality is summarised in *Table I*. Following conclusions can be drawn:

- appropriately operated individual treatment system can reduce the organic matter significantly and nutrient removal (TN, TP) is achieved at average temperature (20 °C) without chemical addition;
- if the DO setpoint of 2.0 mg/l and the MLSS setpoint of 3.5 g/l is not changed in winter operation (12 °C), nitrification is only partial;
- if operational parameters were adjusted (DO=4mg/l, $MLSS$=6.0 mg/l) at low temperature, nitrification was full;
- organic matter removal is not effected by temperature at this system, since the bottleneck in the design is the nitrogen removal, the applied SRT is higher than the residence time required for heterotrophic microorganisms responsible for organic matter removal;
- enhanced biological phosphorous removal efficiency did not changed with the temperature significantly, while the Phosphorous Accumulating Organisms (PAOs) are meso- and psychrofilic [14].

Table I

Average flow properties at various scenarios

	Influent wastewater [mg/l]	Effluent at 20°C [mg/l]	Effluent at 12°C – standard operation [mg/l]	Effluent at 12°C – adjusted operation [mg/l]
COD	700	29	30	30
BOD_5	310	2.4	3	2.8
TSS	400	9	14	11
NH_4-N	55	1.1	20.6	1.3
NO_3-N	0	5.4	1.7	6.5
TN	80	8	24	9.4
TP	12	1.1	0.7	0.8

Buffer tank is designed to be able to equalize the diurnal load variation, in case of higher load e.g. due to wastewater production by guests in a certain household could have effect on the treated effluent. For example, if the load increases by 100%, only partial equalization is achievable, the peak factor downstream of the buffer tank is 2, resulting COD effluent between 30-45 mg/l, and TN effluent of 8-16 mg/l in the adjusted operation. It is also can be suggested to increase the aeration if higher load is estimated in order to maintain the full nitrification. Appropriate maintenance and operation shall handle the extremities in load may occur.

4. Conclusion

Decentralized wastewater treatment options are adequate alternatives to centralized wastewater treatment. The design procedures could be easily adapted to onsite sewage treatment systems. Biokinetic models could predict the treatment unit performance and could provide guidelines for optimal operations. In these systems the flow and load variations are common, but with the help of simulations performed the set-point of operation parameters could be obtained in advance. Furthermore, the biomass build up could be estimated, which is key information on commissioning or in cases, where the biomass washed out and the recovery time shall be predicted. In activated sludge systems it is about 1.5 weeks based on our calculation. In addition, it can be stated that onsite sewage treatment unit perform at high rate even without any chemicals dosed if it is maintained properly.

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Open Access statement

References

[1] Ebtehaj I., Bonakdari H., Sharifi A. Design criteria for sediment transport in sewers based on self-cleansing concept, *Journal of Zhejiang University, Science A*, Vol. 15, No. 11, 2014, pp. 914–924.

[2] Libralato G., Ghirardini A. V., Avezzù F. To centralise or to decentralise: An overview of the most recent trends in wastewater treatment management, *Journal of Environmental Management*, Vol. 94, No. 1, 2012, pp. 61–68.

[3] Gutterer B., Sasse L., Panzerbieter T., Reckerzügel T. *Decentralized wastewater treatment systems (DEWATS) and sanitation in developing countries*, Water, Engineering and Development Centre, Loughborough University of Technology, UK, 2009.

[4] Moelants N., Janssen G., Smets I., Van Impe J. Field performance assessment of onsite individual wastewater treatment systems, *Water Science and Technology*, Vol. 58, No. 1, 2008, pp. 1–6.

[5] Singh S., Haberl R., Moog O., Shrestha R. R., Shrestha P., Shrestha R. Performance of an anaerobic baffled reactor and hybrid constructed wetland treating high-strength wastewater

in Nepal - A model for DEWATS, *Ecological Engineering*, Vol. 35, No. 5, 2009, pp. 654–660.

[6] Reynaud N., Buckley C. Field-data on parameters relevant for design, operation and monitoring of communal decentralized wastewater treatment systems (DEWATS), *Water Practice and Technology*, Vol. 10, No. 4, 2015, pp. 787–798.

[7] Sándor D. B., Szabó A., Fleit E., Bakacsi Z., Zajzon G. PVA-PAA hydrogel micro-carrier for the improvement of phase separation efficiency of biomass in wastewater treatment, *Pollack Periodica*, Vol. 12, No. 2, 2017, pp. 91–102.

[8] Karches T. Effect of aeration on residence time in biological wastewater treatment, *Pollack Periodica,* Vol. 13, No. 2, 2018, pp. 97–106.

[9] Inc. Metcalf & Eddy, Tchobanoglous G., Stensel H. D., Tsuchihashi R., Burton F. *Wastewater Engineering: Treatment and Resource Recovery*, McGraw-Hill, 2013.

[10] Smets I. Y., Haegebaert J. V., Carrette R., Van Impe, J. F. Linearization of the activated sludge model ASM1 for fast and reliable predictions, *Water Research*, Vol. 37, No. 8, 2003, pp. 1831–1851.

[11] Gujer W., Henze M., Mino T., van Loosdrecht M. Activated sludge model No. 3, *Water Science and Technology*, Vol. 39, No. 1, 1999, pp. 183–193

[12] Meister M., Winkler D., Rezavand M., Rauch W. Integrating hydrodynamics and biokinetics in wastewater treatment modeling by using smoothed particle hydrodynamics, *Computers & Chemical Engineering*, Vol. 99, 2017, pp. 1–12.

[13] Brun R., Kühni M., Siegrist H., Gujer W., Reichert P. Practical identifiability of ASM2d parameters - Systematic selection and tuning of parameter subsets, *Water Research*, Vol. 36, No. 16, 2002, pp. 4113–4127.

[14] Lopez-Vazquez C. M.; Oehmen A., Hooijmans C. M., Brdjanovic D., Gijzen H. J., Yuan Z., van Loosdrecht M. C. M. Modeling the PAO-GAO competition: Effects of carbon source, pH and temperature, *Water Research*, Vol. 43, No. 2, 2009, pp. 450–462.