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KATONAI KÖZLÖNY

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# Estimation of Attached Growth Process Aeration Requirement in Wastewater Treatment[4]

## Kötött biomasszát alkalmazó szennyvíztisztítási eljárások levegőigényének számítása

*Attached growth process in wastewater treatment is widely used in order to achieve the sufficient biodegradation of organic matter and nutrient removal. Since the biofilm is attached to a carrier in this process, the substrate and oxygen shall be transported to the biomass surface and reach the deeper layer of the biofilm via diffusion. The driving force of the process is the dissolved oxygen (DO) concentration difference, therefore at least 4–5 mg/L DO is required in this system, which is relatively high compared to activated sludge, where the DO is 1.8–2.5 mg/L. In the attached growth systems, where the suspended matter concentration is low, the relative oxygen diffusion rate (α) is about 0.7–0.8, which is an elevated value compared to the activated sludge system, where alpha is 0.4–0.5. The aim of this paper is to estimate the aeration requirement of the wastewater system applying biofilm; the above mentioned two properties are to be taken into account and the results will be compared to the conventional activated sludge system aeration need.*

***Keywords:*** *activated sludge, aeration, attached growth, biofilm, wastewater treatment*

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*A kötött biomasszát alkalmazó szennyvíztisztítási módszerek egyre elterjedtebbek, segítségükkel a befogadóra előírt szervesanyag és növényi tápanyageltávolítás megvalósítható. Mivel a biofilm hordozóanyaghoz kötött, a biomassza szubsztráttal és oxigénnel való ellátottságáról gondoskodnunk kell; el kell juttatni a biofilm felületéig, majd diffúzió segítségével a mélyebb biofilm rétegekbe, amelynek hajtóereje az oldott oxigénkoncentráció (DO) különbség. Biofilmes rendszerekben ennek értéke 4–5 mg/l, amely viszonylag magas az eleveniszapos rendszerek 1,8–2,5 mg/l-es koncentrációértékéhez képest. Kötött biomasszát alkalmazó rendszerekben a lebegőanyag-koncentráció nem számottevő, ezért a relatív oxigén beoldódás (α=0,7–0,8) is jobb az eleveniszapos rendszerek 0,4–0,5-es értékeihez képest. A tanulmány célja, hogy a biofilmes rendszerek oxigénigényét meghatározza és összehasonlítsa a hagyományos eleveniszapos rendszerrel.*

***Kulcsszavak:*** *biofilm, eleveniszap, kötött biomassza, levegőztetés, szennyvíztisztítás*

## Introduction

In urban water cycle, wastewater treatment has a significant role in securing the quality of the receiving water bodies. Many technologies have been developed to close the water cycle and besides the treated effluent, the sludge produced can be utilised similarly to a system where biomass is utilised.[5] Sustainable water management is in the centre of all technological advancements.[6]

Pollution of water supplies can influence water both on the surface of the ground and under the ground. Besides anthropogenic polluting activities, the signs of climate change are also visible in the characteristics of future water supplies.[7]

It happens more and more often that extremely low levels of water are coupled with periods of dryness. As a result, the amount of usable water declines. Smaller flow in the water bed results in the deterioration of water quality and slower storage filling; the longer presence in the storages can induce further deterioration of the water quality.[8]

To establish sustainable water supply is also a requirement. To keep the water supply secure, besides building proper control regulations into the water supply, it is necessary to pay special attention to the security of some special activities that are necessary to ensure the proper quality of drinking water. Besides minimalising the pollution of the raw water, the lessening or removal of the pollution guarantees the meeting of national and communal water quality guidelines and regulations. One of these regulations includes the properly sized and established waste water cleaning technology. The choice of the adequate waste water cleaning technology for the pollutants is of key importance to protect the health of the user.[9]

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[5] Berek 2016.
[6] Somlyódy 2011.
[7] Glatz 2009.
[8] Salamon et al. 2018.
[9] Hauber 2016.

In the future, the majority of our population will live in an urban environment. The high population density, the shrinking living space, and climate change will bring many difficulties that need to be addressed through innovative solutions to mitigate the effects. Increasing residential water consumption in growing cities will increase the volume of waste water. In addition to the growing demand for high-quality clean drinking water, there is an increasing pressure on water resources. Improving the efficiency of different water treatment technologies is therefore crucial. Biofilm technology is a popular method of wastewater treatment. The biofilm, which functions as a reaction surface, is a complex system that allows the degradation of substances with different properties through its different layers of properties. The use of biological wastewater treatment technologies is not new. The development of certain elements of waste water treatment in the last 100 years has been the appearance of plastics and the development of methods for significantly increasing the stability and effective surface of the biofilm. In addition, it is important to determine the aeration needs of different biofilm systems in order to optimise the amount of oxygen that provides aerobic processes and the economy of the water purification process. Due to the increasing load of decreasing high quality water resources, it is necessary to study and develop different wastewater treatment technologies for sustainable water management.

Biodegradation of organic matter in wastewater treatment technologies is based on microorganisms, which favour the aerobic conditions. The liquid phase of the wastewater has a certain amount of dissolved oxygen due to the Henry law, but this is not enough in intensified technologies, where microorganisms consume more than it can be dissolved naturally and may result in anaerobic conditions. As a consequence, an aeration system needs to be installed and oxygen needs to be provided at high efficiency. Aeration is useful for the bioprocesses, but it may also improve the hydraulic conditions within the reactor volume; the introduction of external energy helps in mixing.[10]

Activated sludge systems use a highly concentrated suspended biomass, the MLSS (Mixed Liquor Suspended Solid) is 3.5–5.5 g/L, resulting small reactor volume for the treatment of a certain amount of wastewater discharge. In ideal cases this biomass is perfectly homogenised, the same concentration could be measured at each location within the basin. The biomass forms flocs, which shape and process properties could be determined by environmental factors such as substrate loading, temperature, pH, shearing conditions, etc.

Key parameter in process sizing is the sludge residence time (SRT), which represents the average age of the biomass and determines the rate of degradation. If only organic matter degradation is concerned, SRT of 3–4 days is enough at wastewater temperature of 12°C, but if full nitrification and denitrification also needs to be taken into account, this value is increased to 10 and 14 days respectively.[11] In order to ensure the desirable SRT recirculation of biomass is used; part of the settled sludge is reverted back to the aerated basin.

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[10] Grady et al. 2011.

[11] Clara et al. 2005.

In attached growth process, the biomass is bound to a carrier. This carrier can be moving or stationary. Moving Biofilm Bed Reactors (MBBR) are a good approach to upgrade an existing wastewater treatment plant capacity without building new basins, thus reactor volumes and land area are saved.[12] But it should be noted that the carriers also occupy some water volume. If the carrier is fixed and the biomass does not move, the substrate shall reach the biomass. In this case aeration has to cover the process oxygen demand, as well as the appropriate mixing conditions should be satisfied. It means that the main wastewater flow should transport the substrate evenly to the biofilm. The transport process induced by the main flow is a conductive transport, whereas the transport through the various biofilm layers is a diffusive transport process.

The technologies can apply purely attached biomass and in this case the suspended biomass is negligible or can be hybrid biofilm-activated sludge systems. In this paper, the aeration demand of pure biofilm system is investigated. The starting point of the calculation is the biological oxygen demand, then the influence of environmental parameters is considered in attached growth system, which may provide guideline for process engineers.

## Oxygen Transport Processes

Oxygen demand is independent from the type of biomass, it is the same for the activated sludge and biofilm processes. For the dissolved oxygen concentration, a scalar transport equation can be formulated as follows:

$$\frac{\partial DO}{\partial t} = KLa * (DO_{sat} - DO) - r_m$$

where:
KLa: oxygen transfer coefficient [1/s]
DO: dissolved oxygen concentration [g/m$^3$]
$DO_{sat}$: saturation dissolved oxygen concentration [g/m$^3$]
$r_m$: oxygen consumption by microorganisms [g/(m$^3$s)]

The oxygen transfer coefficient determines the magnitude of the oxygen transfer rate and it has a direct effect on aeration efficiency. Various methodologies have been developed to measure the actual value of Kla online by intermittent or continuous approaches.[13] KLa reflects the diffusion between the gas phase and liquid phase, which has dependence on many factors, but the most significant is the free surface area between the two phases. That fact led the aeration system manufacturers to invent devices, which creates relatively small bubbles with high surface area. In wastewater treatment, fine bubbles with 1 to 3 mm diameter are applied for oxygenation, and

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[12] ANDREOTTOLA et al. 2003.

[13] SUNDARAMURTHY et al. 2009.

coarse bubbles with a diameter of 5 to 8 mm are applied, when oxygen transfer is not important and the aeration is applied only for mixing purposes.

Standard KLa measurements are performed in clean water in order to predict the aeration efficiency of the installed mechanical equipment at field conditions. The initial dissolved oxygen is used up by chemicals then the recovery of DO is detected and a concentration curve in function with time is registered. From this curve the diffusion rate and thus the KLa can be predicted.[14]

The free surface area is reduced if suspended solid concentration is high, since the small floc size particles are "clogging" the air bubbles surface. Since the difference in oxygen transfer is detectable between clean water and wastewater, an alpha factor is introduced, which shows the ratio of KLa in wastewater and clean water. Its value is 0.4–0.5 in activated sludge systems and 0.7–0.8 in attached growth system. This value could be further reduced if surfactant concentration is elevated in a biological reactor, therefore the effective fat, oil and grease removal has an importance prior the biological processes, practically in grit chambers.

The driving force of the diffusion is the difference of the saturation DO and the actual DO concentration. The saturation concentration is in function with salinity, temperature and pressure. The description of the dependence on these factors can be found in the literature.[15] The microorganism oxygen uptake will be detailed in the next section.

## Biological Oxygen Demand

Microorganisms in wastewater treatment consumes dissolved or chemically bound oxygen. For the degradation of organic matter, the dissolved form is necessary. The amount of the oxygen required is based on the influent primary treated wastewater constituents. If BOD5 (Biological Oxygen Demand measured for 5 days) load is known, with the help of specific oxygen demand of organic matter, the total oxygen (OUc) demand per day can be determined.

Autotrophic bacteria are responsible for nitrification, which consumes a relatively high amount of oxygen. If the TKN (Total Kjeldahl Nitrogen) in the incoming wastewater is 1000 kg/d, the oxygen requirement is 4.3 times higher, 4,300 kg/d. The two-step nitrification process is the most common procedure to transform ammonium to nitrate and then with the use of heterotrophic denitrifying bacteria, the nitrate can be converted to gaseous nitrogen by a reduction.[16] This latter process applies the chemically bound oxygen and by the conversion from nitrate to nitrogen releases oxygen, therefore it is gained (2.9 times the denitrifying nitrogen amount) in the mass balance equation as follows:

$$OC = (f_c \cdot (OU_c - OU_d) + f_n \cdot OU_n)$$

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[14] Heijnen et al. 1980.

[15] Tchobanoglous et al. 2014.

[16] Oh–Silverstein 1999.

where:
OC: total biomass oxygen demand [kg/d]
$OU_c$: oxygen demand for organic matter biodegradation [kg/d]
$OU_d$: oxygen gained via denitrification [kg/d]
$OU_n$: oxygen demand for nitrification [kg/d]
$f_c$: safety factor of heterotrophic organisms [-]
$f_n$: safety factor for autotrophic organisms [-]

The safety factors are determined by SRT and the incoming load based on ATV-131, a German guideline for wastewater treatment sizing.[17] The logic behind the role of the incoming load is that the diurnal pattern of the receiving raw wastewater from a large agglomerate is more evenly compared to a small size plant, where the load may show huge variability.

## Aeration Requirement in Attached Growth System

Whereas the biological oxygen demand is the same in suspended growth and attached growth processes, the difference in aeration need is in the environmental factors. The biological oxygen demand calculated in the previous sections is the amount of oxygen that the biomass should uptake. The microorganisms could only take oxygen, which is in water phase, but our aeration system introduces bubbles and not exactly at the location where the biomass is. Therefore, the transport of oxygen consists of the following:

- oxygen transfer between the gas and liquid phase
- oxygen transport by fluid flow
- oxygen transfer between the liquid phase and microorganisms

Each process works at different efficiencies and many environmental factors affect the overall transfer process. It can be seen that more oxygen needs to be introduced compared to what is theoretically required. The following formula shows the relation between the theoretical and actual oxygen requirement:

$$AOTR = SOTR \cdot \beta \cdot \frac{DO_s - DO}{DO_s} \cdot 1.024^{T-20} \cdot \alpha \cdot F$$

where:
AOTR: Actual Oxygen Transfer Rate [kg/d]
SOTR: Standard Oxygen Transfer Rate [kg/d]
β: ratio of saturation dissolved oxygen concentration in wastewater and clean water (0.95)
T: wastewater temperature [°C]
α: oxygen diffusion rate [-]
F: fouling coefficient

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[17] ATV-DVWK-A 131 2000.

AOTR is the daily amount of oxygen needed for the biology (calculated in the previous section), SOTR is the oxygen amount that needs to be provided by the aeration system. In the equation there is a temperature correction factor, the impact of DO and α are already detailed previously. The fouling coefficient depends on the free surface of the diffuser element, where the bubbles are released. If the diffuser is clean, its value is generally 0.9, but if clogging occurs, the value can be reduced significantly.[18]

The estimation of oxygen demand in attached growth system can be performed in relation to the conventional activated sludge (CAS) system as follows:

$$\frac{SOTR_{biofilm}}{SOTR_{CAS}} = \frac{(DO_s - DO)_{CAS}}{(DO_s - DO)_{biofilm}} \cdot \frac{\alpha_{CAS}}{\alpha_{biofilm}}$$

Assuming DOs of 9.0 mg/L and substituting DO: 2 mg/L for CAS and 5 mg/L for biofilm, and the previously discussed alpha values, it can be predicted that, theoretically, the biofilm system has a 10–15% less oxygen demand. This estimation assumes the process oxygen need and does not take into account the requirement of mixing.[19]

As the next step, the oxygen need can be converted to actual airflow need by applying the SOTE (Standard Oxygen Transfer Efficiency). This parameter reflects the amount of oxygen dissolved in 1 m of the rising bubble. General practice is to assume 5–6 %/m, which means 25–30% oxygen transfer efficiency if 5 m deep reactor is assumed.[20] However, state-of-the-art researches revealed that SOTE can be 8–9%/m in novel aeration systems.[21] SOTE does not only has dependence on the equipment itself, but diffuser density also has a significant role. The following formula presents the calculation of actual air flow:

$$Q_{air} = \frac{SOTR}{SOTE \cdot \rho_{air}}$$

where:
$Q_{air}$: aeration demand [$m^3/h$]
SOTE: Standard Oxygen Transfer Efficiency [-]
$\rho_{air}$: air density [$kg/m^3$]

The calculated air flow is an average airflow for the process, an indicative number. The diurnal and seasonal patterns also have to be incorporated in the design. This result is appropriate for blower sizing, but the distribution of diffusers, the exact location should be known for diffuser sizing since the oxygen consumption is not even. At the beginning of the reactors, oxygen uptake is rapid since the heterotrophic organism is responsible for organic matter degradation,

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[18] Kim–Boyle 1993.

[19] Karches 2018a.

[20] Karches 2018b.

[21] Behnisch et al. 2018, 195–196.

whereas in the second half of the reactor, the nitrification is the dominating process, which speed is slower compared to the biodegradation of organic compounds.

The actual value shall be set at on-site by observing the field parameters and the treated wastewater quality. The control of aeration can be performed by DO control or ammonium control, which is a high level of automation and provides economically sound aeration systems.

## Conclusion

In this paper a calculation procedure was presented in order to help practitioners in wastewater industry to predict the aeration demand of fixed biofilm systems. Since the biological process does not show difference compared to conventional systems, the guidelines elaborated for activated sludge systems can be applied as a basis. The biofilm systems differ from CAS systems in two ways: an increased diffusion driving force is needed, which increases the applicable DO concentration, but as the suspended matter is not present, the oxygen transfer between gas and liquid is more efficient. In this study both phenomena were taken into account and as a result it can be stated that from a process point of view, the biofilm system needs 10–15% less air compered to CAS system. The specialities in hydraulics in biofilm systems were mentioned, but it is simplified in this study. As a next step, the reactor hydraulics will be detailed and its effect on aeration demand will be investigated.

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