The nitrifying rate of Sequencing Batch Reactor when apply bio-carrier the Biochip to municipal wastewater treatment

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Abstract. All around the world, the biofilm is the typical method for modification the municipal and industrial wastewater treatment plant. In the activated sludge reactor, the biofilm carries more suspended bacterial through the attached and growth of microorganisms on the surface of bio-carrier. Therefore, the article evaluates the performance of bio-carrier Biochip 25 in the Sequencing Batch Reactor (SBR) – a variation of activated sludge and has been wide applied in municipal wastewater treatment plant. The experiment proceeded in 2 phases, based on 2 main kind of pollutants in wastewater: 1. Organic matters in typical model SBR; and 2. Nutrients, especially ammonia – nitrogen in modification model with anoxic step. The quality of treated water from the model SBR with Biochip shows that, the efficiency of biological treatment stabilizes in range 80 – 90% with organic matter and 75 – 85% with Ammonia – Nitrogen. In modification model SBR, the specific denitrification rate stabilizes in range 0.3 – 0.4 N_red/kg sludge/day and the nitrification rate in range 0.18 – 0.20 kg N_ox/kg sludge/d. Moreover, the specific rate and the balance of nitrogen in reactor got optimal value when the ratio of loading rate from 1.5 – 2.5 kg BOD +TKN/kg sludge/day.

1. Introduce
A microbial biofilm is an ‘aggregate of microbial cells surrounded by a self-produced polymer matrix’, the term ‘film’ referring to the bacterial adhesion, aggregation and multiplication on their surfaces [1]. So, it is also defined as a well-organized, cooperating community of microorganisms and associated cells with reduced growth rate, regulation of gene and generation of extracellular polymeric matrix [2]. In biological wastewater treatment, the process of pollutants removal in wastewater through biofilm is shown in Figure 1.
Figure 1. Schedule of biological treated water in the surface of biofilm

The substrate in the bulk liquid is consumed within a biofilm and separated by the stagnant liquid layer, then flow over the surface. Substrates, oxygen, and nutrients diffuse across the stagnant liquid layer to the biofilm, and products of biodegradation from the biofilm enter the bulk liquid after diffusion across the stagnant film [3,4]. Therefore, the 2 main applications of biofilm is trickling filter and modifying the activated sludge process, increasing the performance of pollutants removal in wastewater [2].

Nowadays, The Mutag Biochip 25\textsuperscript{TM} has been widely applied in MBBR and IFAS technology for biological wastewater treatment in Russia. According to producer Multi Umwelttechnologie AG, it is a high-performance carrier for biofilms, made of virgin PE, has a diameter of approx. 25 mm, a thickness of approx. 1.1 mm [5]. The active surface area of them is more than 4 000 m\textsuperscript{2}/m\textsuperscript{3} with a large number of closely spaced, open pores in the surface for immobilization of microorganisms.

Figure 2. Applying Biochip in Activated Sludge

However, this article is going to evaluate the application of media Biochip 25 in the Sequence Batch Reactor (SBR), a variation of the Conventional Activated Sludge (CAS) with all step of treating water proceeding into only 1 tank. The difference between them is caused by the hydraulic conditions of the wastewater’s flow in the structures: while the CAS operated with constant hydraulic loadings
for each tank, the SBR is filled during a discrete period of time and then operated as a batch reactor. Since 1920, the SBR have been used successfully to treat wastewater from municipalities, resorts, casinos or areas characterized by low or varying flow pattern [6,7]. The difference between CAS and SBR, and the operated circle of a typical SBR has been showed in Figure 3.

| Phase | 1 Fill | 2 React | 3 Settle | 4 Draw | 5 Idle |
|-------|--------|---------|----------|--------|--------|
| Operation | Mixer and Air | Mixed or Aerated | Effluence | Waste sludge |

![Figure 3. Principle of SBR and Comparison with Conventional activated sludge](image)

According to the Manual guide of BioChip and Summary report of SBR by USEPA, the application of Biochip 25 in SBR has some advantages: First, the reactor operates by phases during the fixed periods, so the situation of the media does not depend on the hydraulic flow of the wastewater. Second, the clarifier and return pumps is not required in SBR and the mixed liquor with Biochip is always kept inside the reactor. Also, the media has a density of 0.95 kg/l, suspended in the reactor and is appropriate for the Fill and Mixing phases of the reactor [8,9].

An experiment on SBR reactor with BioChip has been performed at the Laboratory for Biological wastewater treatment, National Research Center of Moscow University of Civil Engineering to calculate the performance of reactor. During the experiment, the SBR model has been upgraded to optimize the effectiveness of biofilm and raise the quality of treated water. Additionally, the parameters of wastewater, activated sludge and treated water have been analysed to determine the specific rate of substrate utilization as well as the nitrification and denitrification of reactor [10–12].

2. Objectives, contents and methods

In the laboratory, the SBR model has been operated based on the “Fill – Treat – Draw” wastewater process [13]. With the research purpose to optimize the BioChip application in SBR, the experiment has been divided in 2 period. First, the BioChip is used in a typical SBR model, and the substrate utilization rate of the biofilm has been calculated to compare the quality of treated water in a model with/without a media carrier. From the results, the model was modified to increase the efficiency of removing pollutants, especially nutrients in wastewater. By changing and upgrading the operation mode of the model, specific nitrification and denitrification rate in the biological wastewater treatment have been calculated. The schedule of the experiment is shown in Figure 4.
In the first period, 2 models of SBR reactor are operated in parallel and one of them used a BioChip. After analyzing the quality of influence and effectiveness of each model, including BOD$_5$, COD, N – NH$_4$, N – NO$_3$, the performance of the model with BioChip is determined [14,15]. From these results, the rate of utilization of soluble substrate in each reactor is calculated. The rate can be modeled using Monod expression and because the mass is decreasing with time due to utilization process, a negative value is used [3,4]. The formula for utilization rate is shown in table 1.

**Table 1. The 1st period of experiment**

| The experiment schedule of 1st period | The substrate utilizations rate |
|--------------------------------------|--------------------------------|
| SBR with Biochip                     | $r_{su} = \frac{kSX}{K_s + S}$ |
| Effluence 1                          | $r_{su}$ – rate of substrate concentration change due to utilization, g/m$^3$*d |
| Effluence 2                          | $k$ – maximum specific substrate utilization rate, g substrate/g microorganisms*d |
| SBR                                  | $S$ – growth-limiting substrate concentration in solution, g/m$^3$ |
| SBR                                  | $X$ – biomass concentration, g/m$^3$K$_s$ |
| SBR                                  | – half-velocity constant, g/m$^3$ |

From the results of 1st period, the SBR has been upgraded and the anoxic phase has been added into the model. With the “inside pump” used in the reactor, the anoxic phase has been proceeded inside the SBR. Therefore, the efficiency of ammonia removal rises, through nitrification and denitrification. From analysis of the quality of wastewater and treated water, the main parameters determined in the 2nd period of experiment are the Specific Nitrification and Denitrification rate (table 2) [16–19].
Table 2. The 2nd period of experiment

The experiment schedule of 2nd period

![Diagram of experiment setup]

### The rate of Nitrifications and Denitrification

\[
SDNR = \frac{NO_3 \times V_{anox}}{MLVSS}
\]

\[
\mu_n = \left( \frac{\mu_{nm} \times N}{K_n + N} \right) \left( \frac{DO}{K_o + DO} \right)
\]

- **SDNR** – Specific denitrification rate;
- **NO\textsubscript{3}** – Nitrate removed;
- **V\textsubscript{anox}** – Anoxic tank volume, in this condition is the volume of model;
- **MLVSS** – Mixed liquor volatile suspended solids

- **\mu_n** – Specific nitrification rate;
- **\mu_{nm}** – Maximum specific nitrification rate;
- **N** – Nitrogen concentration;
- **K_n** – Half-velocity constant, substrate concentration at one-half the maximum specific substrate utilization rate;
- **DO** – Dissolved oxygen concentration;
- **K_o** – Half-saturation coefficient for DO

### 3. Results and discussion

#### 3.1. The first period of experiment:

The efficiency of pollutants removal has been showed in each chart on Figure 4: the Biochip increase the typical SBR’s organic matter removal performance by 10 to 15%, process nitrification and ammonia removal also increase 5% and reach the maximum value at 75%. After that, the substrate utilization rate, with the Biochip media carrier applied, increases from 20 to 30%. Therefore, the process biological reactions into the Biochip – SBR more stabilizes and the quality of treated water raise, especially with BOD and COD concentration.
3.2. The second period of experiment:
The 2\textsuperscript{nd} period of experiment has been divided into 2 phases with the difference is the order of biological reaction. In the 1\textsuperscript{st} phase, the SBR operated 5 hours Aerobic and 3 hours Anoxic; and reversed: 3 hours Anoxic and 5 hours Aerobic in 2\textsuperscript{nd} phase. The results of 2 phases has been showed in Figure 6.

Due to reactor has 2 difference of operated mode, the treatment of organic matter of SBR model is the same with the efficiency removal, calculated based on BOD and COD is mostly stable and staying between 80 – 85\%. However, the performance of process ammonia removal in 1\textsuperscript{st} phase is better than 2\textsuperscript{nd} phase. When analysing the concentration ammonia and Total Kjeldahl Nitrogen of treated water, the efficiency of the 1\textsuperscript{st} phase is higher 5 – 10\% for N – NH\textsubscript{4} and 10 – 15\% for TKN. On the other hand, the efficiency of ammonia removal stabilizes in range from 75 – 85\%, increases 5 – 10\% before upgrade (in the 1\textsuperscript{st} period of experiment.

Additionally, in this period, the concentration of Nitrate in reactor also determined the Specific nitrification (SNR) and denitrification rate (SDNR) of reactor when applying the BioChip and operated with Anoxic step.

At first, SNR in the 2 phases remains mostly the same, with variable range from 0.18 – 1.20 kg Nox/kg sludge/d. So, the denitrification rate is the main reason to raise the performance of ammonia removal in experiment. The value of SDNR in 1\textsuperscript{st} phase is higher than 2\textsuperscript{nd} phase 0.1 kg Nred/kg sludge/d and it take the efficiency of ammonia removal increase 5\%. When proceed Aerobic before
Anoxic step, nitrate has been created by Nitrifying and it is also a main material for process Denitrification later. For this reason, the SDNR in phase 1 reaches value from 0.3 – 0.4 kg Nred/kg sludge/d. Figure 7 has been showed the changing of all the rate by experiment phase and by loading of reactor.

![Figure 7. Nitrogen in reactor and Specific rate of Nitrification and Denitrification](image)

On the other hand, when analysis the results of SNR and SDNR with the rate of loading BOD/TKN of reactor, basically the value of SNR inversely proportional and SDNR proportional with the loading. The curves in Figure shows that, with the same activated sludge in reactor, the BOD/TKN rate in reactor decrease to 1.6 – 2.2 kg BOD-TKN/kg sludge/d and still ensure ammonia treatment performance. The optimal range of this rate is from 1.7 - 1.8 kg BOD-TKN/kg sludge/d with BioChip apply.

4. Suggestions
Application of BioChip in SBR technology is one of the way to modify and upgrade municipal wastewater treatment plant. With the advantages of low cost, ease of transportation and use, combine with operated cycle, the efficiency of ammonia removal can reach 85% with the loading rate from 1.6 – 2.2 kg BOD-TKN/kg sludge/d. Summarize, the recommendation of operated SBR reactor with
BioChip for treated municipal wastewater treatment has been showed in Figure 8 through the formulation of Nitrogen balance.

![Figure 8. Nitrogen in reactor and Specific rate of Nitrification and Denitrification](insert_image)

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