The assessment of technical - economic efficiency of Sequencing Batch Reactors in municipal wastewater treatment in developing countries

Tran Ha Quan and Elena Gogina
Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

E-mail address: haquan_891300@yahoo.com

Abstract. The Sequencing Batch Reactors (SBR) is a variation of activated sludge and has been widely applied in wastewater treatment since 1920s. The advantages of this technology are not only the high performance in low or varying flow patterns but also present worth cost for a long time. Therefore, the article evaluates the technical - economic efficiency of this technology in municipal wastewater treatment from combined sewerage system. Based on building and operation pilot SBR with process Nitrification/Denitrification and bio-film in municipal wastewater treatment plan for 1 months, the technical - economic efficiency has been determinates. Firstly, the efficiency removal pollutants is more stable and the quality of pilot’s effluence achieved Russian Standard about treated water. After that, the environmental damage has been decreased for 8 – 11 time, especially damage from nitrogen ammonia and nitrate. At least, the calculation from economic factors of SBR has been showed that the cost of treating 1 m$^3$ wastewater than 0.5 USD when optimized this technology by process Nitrification/Denitrification and bio-film.

1. Introduction
Basically, the production of waste from human activities is unavoidable and a part of this waste, which contains all the materials added to the water during its use by a community will end up as municipal wastewater. Especially in developing countries with combine sewerage systems, human body wastes together with the water used for flushing toilets has been mixed with rain water and industrial wastewater in local area before being treated in municipal wastewater treatment plants (WWTPs). Nowadays, pollution in the urban waterways resulted in frequent occurrences of low dissolved oxygen, fish kills, algal blooms and bacterial contamination [1,2]. Therefore, municipal wastewater is major source of environmental damage, based on the overload of organic matters and nutrients in Ecosystem. Moreover, because of lacking investment in construction, operation and management of municipal wastewater treatment technologies occurs and the danger inherent in access to unsafe treated water. According report of Gotaas (1956), the composition of human faeces and urine in municipal wastewater is given in Table 1 [3]
Table 1. Composition of Human Faeces and Urine

| Approximate composition % | Feaces | Urine |
|---------------------------|--------|-------|
| Moisture                  | 66 – 80| 93 – 96|
| Organic matters           | 88 – 97| 65 – 85|
| Nitrogen                  | 5 – 7  | 15 – 19|
| Phosphorus                | 3.0 – 5.4| 2.5 – 5.0|
| Potassium                 | 1.0 – 2.5| 3.0 – 4.5|
| Carbon                    | 44 – 55| 11 – 17|
| Calcium                   | 4.5    | 4.5 – 6.0|

All around the world, the technology activated sludge – suspended growth process in biological wastewater treatment process has been wide applied in municipal WWTPs [4,5]. According to the report of United States Environmental Protection Agency (USEPA), the advantages of activated sludge in municipal wastewater treatment included: At first, the units necessary for this treatment are relatively small and requiring less space than other technology. In addition, when properly operated and maintained, the process is generally free of flies and odors. However, activated sludge processes are more costly to operate than Attached Growth Processes due to higher energy use to run the aeration system [6,7]. Summarize, suspended growth process in biological reactor is suitable for the conditions when the investment has been shared for the construction and upgrading of other infrastructure in urban area. The present worth of 3 main biological activated sludge reactors: Sequencing Batch Reactor (SBR), Oxidation Ditch (OD) and Aerotank (CAS) has been calculated via EPA’s computer Assisted Procedures for the Design and Evaluation of Wastewater Treatment Facilities program and showed in Figure 1.

![Figure 1](image-url)

**Figure 1.** The present worth cost of biological activated sludge reactors

Firstly, all cost is developed as per January 2020 with present worth computed at 7 3/8 percent interest rate and 20-year life with PWF = 10.29213. Basically, the SBR has an optimal Present worth cost with average flow rates, in range 5 000 – 20 000 m$^3$/d. Because of saving the land using with all of the treatment steps are combined into a single tank, SBR widely applied in the world such as in Europe, China and USA for treated wastewater form municipalities, resorts, casinos or areas characterized by low or varying flow patterns.

For evaluate the effectiveness of SBR not only in terms of technology (1), but also economically (2) in municipal wastewater treatment from combined sewerage systems, an experiment on SBR pilot
has been performed at the municipal WWTP, based on the technology of Environment Protect Research Centre, Danang University and National Research Center of Moscow University of Civil Engineering. Therefore, the technology inside SBR has been upgraded to archive the next level of discharge standard with the schedule of experiment in Figure 2 [8,9].

![Diagram of wastewater treatment system](image)

**Figure 2.** The experiment site

2. Material and Method

For assessing technical and economic characteristics of SBR in municipal wastewater treatment, model reactor has been built with fully electronic device such as mixer, sensors, electrical valve/pump... and all of them has been operated and controlled automatically by program in computer. After that, the model has been moved and setup into WWTPs for treating municipal wastewater in practice. Setup process of pilot SBR has been showed in Figure 3 [10,11].
In its most basic form, the SBR model is a set of tanks that operate on the “Fill – Treat – Draw” wastewater and each phase has been operated during a discrete period of time. Through changing the operation parameters of electronic device and duration of each treating period into program (Figure 2D), the biological reactions Nitrification and Denitrification has been added into operation circle for to increase the effectiveness of treating wastewater. The difference between typical operation and modification with Nitrification/Denitrification showed in Figure 4. However, the bio-media also applied into SBR model to ensure performance of activated sludge [12–14].
2.1. Method for evaluating the technical efficiency of SBR
At first, pilot SBR operated continuously for 1 month in municipal WWTP with difference mode: typical – Nitrification/denitrification – modification with bio-film. After analyzing the quality of influence and effluent during 8 – 10 days for each mode, the effectiveness of SBR has been determined. Through comparison concentration BOD₅, COD, N – NH₄, N – NO₃ and T – N in pilot’s effluent and in discharge standard № 552 – Ministry of Agriculture of The Russian Federation about treated water, the technical efficiency of applying SBR has been evaluated [15,16].

2.2. Method for evaluating the technical efficiency of SBR
The most important parameter of assessment economic efficiency wastewater treatment technology is cost of treating per 1 m³ municipal wastewater. Moreover, this article has been used another parameter for economically evaluating SBR in practice – environmental damage. According Order 87 of The Ministry of Natural resources and Ecology Russian Federation, environmental damage of treated waste is the tax of pollutions in treated water, which discharged into the river, lake or ocean after comparing with discharge standard. Therefore, the environmental damage of treated water in Russian Federation determinates by formula [17]:

\[ Y = K_{YG} \times K_V \times K_{IH} \times \left( \sum_{i=1}^{n} H_i \times M_i \right) \times K_{IZ} \]

Where: \( Y \) – environmental damage; \( K_{YG} \) – coefficient of climate conditions, depended on time or season per year; \( K_V \) – coefficient of environmental factor; \( K_{IH} \) – coefficient indexation, based on the inflationary component of economic development; \( K_{IZ} \) – coefficient of the negative impact of pollutants on a water body; \( H_i \) and \( M_i \) – tax level and the mass difference of each pollution when comparing with discharge standard.

3. Results

3.1. The technical efficiency of SBR
The average value of pollutants in influence and effluent after continuous operation pilot SBR in municipal WWTP for 1 month has been showed in Table 2. Moreover, the concentration of pollutants in effluent also compared with Russian discharge standard for evaluate the technical efficiency of technology in practice.
Table 2. The concentration of pollutants in municipal wastewater and effluence of pilot

| Parameters | Municipal wastewater | Typical operation | Nitrification/ Denitrification | Nitrification/ Denitrification with bio-film | Discharge standard of Russian Federation |
|------------|----------------------|-------------------|-------------------------------|---------------------------------------------|----------------------------------------|
| Capacity, l/d | x | 80 | 74 | 88 | |
| BOD$_5$, mg/l | 70 – 86 | 7 – 12 | 6 – 8 | 4.4 – 6.4 | 3 |
| COD, mg/l | 130 – 165 | 13 – 18 | 8 – 11 | 5.8 – 8.8 | 30 |
| N - NH$_4$, mg/l | 28.22 – 31.38 | 7.48 – 9.74 | 0.59 – 0.78 | 0.31 – 0.41 | 0.39 |
| N - NO$_3$, mg/l | 0.43 – 0.65 | 16.09 – 18.33 | 8.05 – 9.68 | 8.92 – 9.46 | 9.1 |
| T - N, mg/l | 78 – 86 | 24.92 – 32.44 | 10.82 – 13.02 | 11.11 – 11.78 | – |

According results of experiment and chart in table 2, the efficiency removal organic matter in municipal wastewater, which calculated by BOD$_5$ and COD increases 2 – 5% when apply process Nitrification and Denitrification. Additionally, concentration pollutants in effluence of pilot approximate reached Russian discharge standard through combine bio-film in SBR reactor. Efficiency removal nitrogen of reactor, especially ammonia higher than 93% and treated water can be reused for agriculture.

However, it is necessary to assess the technical efficiency through daily performance of pilot. At first, the capacity of pilot decreased 5 – 7% in operating Nitrification and Denitrification; and therefore, efficiency removal ammonia increased from 70 – 75% to 93 – 95%. On the other hands when apply bio-film into SBR, the efficiency removal pollutants more is stable and the performance of pilot also increases 7 – 10%. Due to using bio-film in biological reactor, concentration activated sludge raises with cooperating community of microorganisms and associated cells. Therefore, the
loading of reactor has been decreased and efficiency removal pollutants of pilot also has been ensured in a short period.

3.2. The economic efficiency

Basically, the present worth cost and environmental damage of SBR reactor proportional to the flow rate of wastewater in municipal WWTPs. So, the economic efficiency of technology has been determine through comparison between environmental damage of each components and cost of treating 1 m$^3$ wastewater. Graphics in Figure 5 presented results from calculation of these parameters for 20 years project building and operating WWTP with SBR technology.

![Components of environmental damage from treated water](image)

**Figure 5.** The environmental damage and its components in SBR

Based on applying process Nitrification/Denitrification and bio-film into reactor, the damage of treated water to environmental has been reduced. At first, the amount of damage decreases 6 – 7 times with process Nitrification/Denitrification and 10 – 11 times while optimal operation by bio-film. Moreover, by the percentage of these harm, the damage by ammonia, which has the highest tax, decreases 60 – 75% and the damage by nitrate tends to 0. The damage by organic matters also decreases through the mass difference of BOD$_5$ with Russian discharge standard in range 1.4 – 3.4 mg/l.

![Cost eliminated, environmental damage and cost treated water](image)

**Figure 6.** Cost eliminated and environmental damage in SBR
According the Figure 6 about compare cost between cost eliminated and environmental damage, the present worth cost of project building and operating the municipal WWTP with SBR technology for 20 years from 8 – 28 million USD. However, in typical operation, the tax from treated water is higher than cost of project from 5 to 25 million USD, that proportional to the flow rate of wastewater in municipal WWTP from 5000 m$^3$/d. However, the environmental damage also reduces 0.2 to 0.3 times when compare with present worth cost, corresponding apply process Nitrification/Denitrification and bio-film into reactor. After that, the cost of treating 1 m$^3$ decreases from 0.25 – 0.35 USD/m$^3$ wastewater when modification SBR and characterized by a logarithmic form. At least, the technology SBR with Nitrification/Denitrification and bio-film has been optimized for municipal WWTPs, which has flow rates from 5000 to 20000 m$^3$/d through ensure the price of treating 1m$^3$ wastewater lower than 0.5 USD.

4. Conclusion
Applying technology SBR in municipal wastewater treatment with biological process Nitrification/ Denitrification is a major opportunity and good chance for developing countries to reach the sustainable development and ecological balance in their urban area. Moreover, the reactor’s modification with bio-film will raise the performance of WWTPs and the treated water can be reused for agriculture or other industries. At least, the most important things of this technology are the cost of treating 1 m$^3$ wastewater is lower than 0.5 USD when the flow rates of plant higher than 5000 m$^3$/d.

On the other hand, the disadvantages of SBR is complicated operation and maintenance, such as ensure the performance of reactor under the climate change for a short time. The overload of flow rates and concentration of pollutants in municipal wastewater treatment from combine sewerage system requires highly qualified personnel in WWTPs. Moreover, it is necessary to calculate the hydraulic conditions in the wastewater treatment system for strategies continuously operating a set of parallel tanks.

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