# Comparison of CAS, MBR, SBR, and Biolak Treatment Systems in Removal of BOD and COD from Municipal Wastewater—Case Study: Ekbatan Wastewater Treatment Plant

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**Abstract** Progressive importance of wastewater treatment and water reclamation due to the limited nature of freshwater resources and growing demand for clean water makes a practical assessment of different treatment technologies essential to engineers. This study aims to provide an evaluation of the performance of activated sludge, membrane bioreactor, sequencing batch reactor, and Biolak treatment systems in removing $BOD_5$ and COD from municipal wastewater. An independent pilot for each treatment system was constructed and set up at Ekbatan wastewater treatment plant in Tehran. An extensive set of tests were performed on the effluent of the pilots under controlled operating conditions to evaluate the performance of each process. The study was conducted over a period of one year. It was found that while the CAS and Biolak pilots reached results in accordance with treatment standards, the highest water quality was achieved by the MBR and SBR pilots. Furthermore, the SBR and MBR pilots reached the maximum $BOD_5$ and COD removal efficiencies, respectively. Finally, it was concluded that high efficiency in conjunction with qualitative advantages such as low land occupation and easy retrofit of old plants makes SBR and MBR technologies among the most viable options for municipal wastewater treatment.

**Keywords:** Biolak process, Biological wastewater treatment, Conventional activated sludge, Membrane bioreactor, Sequencing batch reactor

## 1. Introduction

It is crucial to engineers in the fields of environmental engineering and water and wastewater treatment to acquire a practical assessment of the performance of different treatment processes in order to determine the most efficient option under specific circumstances.

The conventional activated sludge system is one of the most common methods for recycling wastewater, especially in secondary municipal wastewater treatment [1], despite its simplicity compared to more advanced methods. CAS systems have several advantages, such as odorless and colorless recycled wastewater output, and low land occupation. [2, 3, 4] Dorr-Oliver experimented with the process of membrane wastewater treatment, in which suspended growth was externally placed on a rotating cylindrical plate with an ultrafiltration membrane [5, 6]. Membrane bioreactor (MBR) is the combination of a membrane process like microfiltration or ultrafiltration with a suspended growth bioreactor, and is now widely used for municipal and industrial wastewater treatment. [7, 8] The SBR method was first applied in the U.S. in the 1970s. This method is a type of fill activated sludge system for wastewater treatment, which includes five stages—fill, react, settle, decant, and idle—and is only dependent on time, unlike CAS that is also dependent on location [9, 10]. The Biolak method is considered a relatively new method in urban wastewater treatment and includes different models [11, 12], for example, Biolak equipped with phosphorus extraction and Biolak equipped with nitrogen extraction. In this system, the wastewater is collected by the collecting network and subsequently enters into the wastewater treatment plant facilities. [13, 14, 15]

The aim of this study is to introduce four biological wastewater treatment systems, namely conventional activated sludge (CAS), membrane bioreactor (MBR), sequencing batch reactor (SBR), and Biolak and to establish an objective comparison of their performance in removing $BOD_5$ and COD from municipal wastewater. For this purpose and to procure necessary data, a pilot for each treatment system was installed at Ekbatan wastewater treatment plant, as the study area, and an extended set of tests were performed on input and output samples of each system during a period of approximately one year.

## 2. Materials and methods

### *2.1. Methodology*

In order for experiments in this study to represent the characteristics of municipal wastewater treatment, initial wastewater feed was provided from Ekbatan wastewater treatment plant. Ekbatan wastewater treatment plant is located between the first and second phases of Ekbatan town, west of Tehran, with about 4 hectares at its disposal. The plant became operational with extended aeration system, which was later replaced with A2O facilities, with the design capacity of 100,000 population equivalent (P.E.) and consists of two sedimentation tanks, one condensation unit, one sludge stabilization unit, and two centrifuge units.

*2.2. CAS pilot*

The activated sludge pilot, composed of an aeration tank and secondary sedimentation tank, was installed at Ekbatan wastewater treatment plant. The supply tank with a height of 91.5 cm, diameter of 66 cm, and total volume of 300 lit was shared with the MBR pilot. Moreover, the aeration tank, responsible for oxidation of organic materials and biological removal of ammoniac and designed according to parameters such as hydraulic retention time, MLVSS, and percentage of recycled sludge, was selected of polyethylene with the following dimensions: span length of 76.5 cm, floor length of 67.5 cm, span width of 65 cm, floor width of 50 cm, height of 69 cm, and thickness of 6 mm. The pilot consisted an input from the supply tank, an output, and an input for recycled sludge from the secondary sedimentation tank. Two circular blowers with an internal diameter of 9 cm and external diameter of 12.5 cm and two linear blowers with a width of 1.5 cm and length of 40 cm were used. According to design parameters and required performance, the secondary sedimentation tank was selected as cylindrical with a funnel floor with a height of 110 cm and diameter of 80 cm at the cylindrical section, and a height of 50 cm and outer and inner diameters of 80 and 7.5 cm, respectively, at the funnel section.

*2.3. MBR pilot*

The main components of the membrane bioreactor pilot include the bioreactor tank, aeration system, membrane, and supply tank, with the membrane placed inside the bioreactor tank. According to technical specifications and optimum working conditions of the membrane, in addition to calculations pertaining to biological reactions by micro-organisms, a rectangular polyethylene tank with a span length of 137 cm, floor length of 125 cm, span width of 81 cm, height of 82 cm, and input wastewater tube with a diameter of 0.5 in. was selected. The flow type and filtration flow type were chosen as submerged and cross-flow, respectively, in order to reduce the probability of membrane blockage. In addition, to study the impacts of aeration on the performance of the pilot, two types of central aquarium pumps with aeration capacities of about 90 l/min for medium aeration and 45 l/min for low aeration were utilized. The supply tank with a height of 91.5 cm, diameter of 66 cm, and total volume of 300 lit was responsible for providing wastewater feed to the pilot, stabilizing the properties of the input, and establishing uniform flow.

*2.4. SBR pilot*

The construction of the sequencing batch reactor pilot, in accordance with predetermined design parameters, was completed over a six-month period at the faculty of Civil Engineering of K.N. Toosi University of Technology, Tehran, and transported to Ekbatan treatment plant after satisfactory performance was ensured by sufficient experiments and simulation on the pilot. The cylindrical polyethylene supply tank had a height of 91.5 cm, diameter of 66 cm, and total volume of 300 lit. The aeration unit was designed as a rectangular polyethylene tank with a length of 76.5 cm, width of 65 cm, height of 69 cm, free length of 10 cm, and thickness of 6 mm, according to design parameters including MLVSS, type of blowers, depth, and pattern of blowers. The sequencing batch reactor tank contained one input and two outputs. Furthermore, the clarification process was essentially the same as that of the conventional activated sludge system. The sedimentation tank, the last procedural unit in the pilot, has a height of 110 cm and diameter of 80 cm in the cylindrical section, and a height of 50 cm and outer and inner diameters of 80 and 7.5 cm, respectively, in the funnel section.

*2.5. Biolak pilot*

An exclusive Biolak pilot was designed and constructed independently at Ekbatan wastewater treatment plant for this study in compliance with all required principles and standards. Due to the importance of maintaining treatment performance in the activated sludge process under different operating conditions, principal parameters in the process were closely monitored. The amount of dissolved oxygen (DO) in the pilot was controlled using a portable oximeter, which was determined to be approximately 2 mg/l. The amount of recycled sludge was adjusted by considering the density of microorganisms in the aeration basin of the Biolak pilot, and the excess amount of activated sludge was controlled. The alkaline degree and the pH of input and output samples were examined daily, and were

**Table 1.** Removal efficiency of $BOD_5$ and COD in the CAS pilot

| Hydraulic retention time (hour) | BOD removal (%) | COD removal (%) |
|---|---|---|
| 5 | 84.8 | 88.5 |
| 6 | 90.1 | 92 |
| 7 | 93.2 | 94.4 |
| 8 | 91.9 | 93.3 |

confirmed to be acceptable according to municipal wastewater standards. The wastewater input feed for the pilot was supplied from the divider basin following the grit chamber, which was directed into the pilot using a gas faucet and a special hose after it was pumped in the reservoir tank.The density of microorganisms in input wastewater was negligible; therefore, the pilot was initiated and operated using the mixed liquid in the aeration basin of Ekbatan wastewater treatment plant, with a density of roughly 2500 mg/l. In addition, no need for temperature adjustment was necessary since the pilot was operated during the summer.

*2.6. Tests*

For this study, a comprehensive set of tests were used to determine various characteristics of influent and effluent samples, and pH, temperature, DO, $BOD_5$, COD, MLSS, MLVSS, ammonium, nitrate, nitrite, and phosphate were measured as the following for all pilots according to standards at Ekbatan wastewater treatment plant. pH and temperature were measured on site using a digital meter and a mercury thermometer, respectively. DO-meter was used to determine the amount of dissolved oxygen in aeration units of the pilots. BOD-meter was used to measure biochemical oxygen demand [16]. Chemical oxygen demand was measured using the titration method [16]. The density of nitrate and phosphate in influent and effluent samples, spectrophotometer was used, and corresponding vials were measured. MLSS and MLVSS were measured by the evaporation method according to the recommended guidelines; additionally, the oven was set to 600 c [16].

## 3. Results and discussion

Although extended tests were performed on samples from the pilots, only results directly relative to the aims of this paper are discussed. The following tables present, in summary, the results obtained from experiments performed on samples from CAS, MBR, SBR, and Biolak pilots.

*3.1. CAS pilot*

The results of the experiments performed on samples from this pilot at Ekbatan wastewater treatment plant are available in Table 1. Hydraulic retention times (HRT) of 5, 6, 7, and 8 hours with intermediate aeration and cellular retention time of 20 days have been used to determine the removal of $BOD_5$ and COD in the conventional activated sludge pilot. For each cycle of operation, three specimens have been used. In addition, the typical value of MLSS for the CAS pilot was determined to be between 1200 to 1500 mg/l.

*3.2. MBR pilot*

The membrane bioreactor pilot was operated under hydraulic retention times of 3, 4, 5, and 6 hours with intermediate aeration and cellular retention time of 20 days. The experiments were conducted on samples at Ekbatan wastewater treatment plant, and the results are presented in Table 2. To ensure accuracy and reduce associated errors, three separate specimens for each test were used. In addition, pH values of input and output flows were determined to be 7.15-8.

*3.3. SBR pilot*

In order to determine optimum aeration and sedimentation time, the filling time was initially set to 1 hour, and samples were taken after 4, 6, and 8 hours of aeration. Moreover, samples were taken after 1, 2, and 3 hours of sedimentation. At this stage, tests were performed on 10 specimens. According to values of $BOD_5$, COD, MLSS, and MLVSS, the optimum aeration time was determined as 6 hours. Similarly, the optimum sedimentation time was determined as 3 hours.

**Table 2.** Removal efficiency of $BOD_5$ and COD in the MBR pilot

| Hydraulic retention time (hour) | BOD removal (%) | COD removal (%) |
|---|---|---|
| 3 | 90.3 | 93.2 |
| 4 | 93.5 | 95 |
| 5 | 95.6 | 97.1 |
| 6 | 95.3 | 96.7 |

**Table 3.** Removal efficiency of $BOD_5$ and COD after 6 hours of aeration and 3 hours of sedimentation for different filling times and input discharges in the SBR pilot

| | Test | 1 hour filling time | Removal efficiency | 2 hours filling time | Removal efficiency | 3 hours filling time | Removal efficiency |
|---|---|---|---|---|---|---|---|
| BOD | Input | 139.33 | | 159.33 | | 148.33 | |
| | After 6 h aeration | 16.67 | 88.04 | 15.33 | 90.38 | 16.33 | 88.99 |
| | After 3 h in sedimentation tank | 2.67 | 98.09 | 2 | 98.54 | 2.33 | 98.43 |
| COD | Input | 269.33 | | 240.33 | | 246.33 | |
| | After 6 h aeration | 38.33 | 80.2 | 37.67 | 84.33 | 39.33 | 81.06 |
| | After 3 h in sedimentation tank | 11 | 95.17 | 10.33 | 95.7 | 11.33 | 94.32 |

At the next stage, sample collection was carried out after 1, 2, and 3 hours of filling time, with the aeration and sedimentation times set to their optimum values. Average values of $BOD_5$ and COD, performed on three specimens for each filling time, as well as the input discharge is shown separately after 6 hours of aeration and 3 hours of sedimentation in Table 3. pH measurements indicated that input and output flows were stable between 7.26 and 8.17.

According to Table 3, the performance of the pilot to remove $BOD_5$ and COD corresponding to filling times of 1 and 2 hours fall within the allowable limits; nevertheless, the output flow with a filling time of 2 hours exhibits slightly better results in comparison with that of 1 hour filling time. Therefore, the optimum filling time was determined to be 1-2 hours.

### *3.4. Biolak pilot*

The sample collection for BOD, COD, and pH tests was performed under two different operating conditions of the Biolak pilot with densities of 3500 mg/l and 4500 mg/l. Results have been presented in Table 4. pH values were determined to be 7.31-7.76 for all tests.

### *3.5. Discussion*

In order to objectively argue the performance of each treatment technology, relevant data from experiments, in addition to other criteria, has been considered. Maximum $BOD_5$ and COD removal efficiency for each pilot has been determined as the following:

- $BOD_5$ and COD removal efficiency for the activated sludge and MBR pilots was selected at the calculated optimum retention time.
- $BOD_5$ and COD removal efficiency for the SBR pilot was selected at the optimum values of hydraulic retention time, sedimentation time, and filling time, obtained from performed experiments.
- $BOD_5$ and COD removal efficiency for the Biolak pilot was selected as the average values of two input conditions, under which the pilot was operated.

Maximum removal efficiency of BOD and COD was achieved by the SBR and MBR pilots, respectively. It can be concluded that the MBR and SBR treatment systems can achieve the highest efficiency in the treatment of municipal wastewater with regard to water quality; furthermore, according to qualitative assessments, the SBR method has the added advantage of simplicity and lower cost compared to the MBR process, while MBR can achieve higher water quality within a relatively smaller space [14]. CAS is a simple system that can satisfy water quality standards at comparatively low cost, and results demonstrate that the CAS pilot exhibited an acceptable efficiency in removing BOD and COD; however, high space occupation in comparison with other systems may limit the use of this method. Although results from the Biolak pilot implies less efficiency compared to other pilots, due to operational simplicity, low cost, and low land occupation, it is widely used worldwide [14].

## 4. Conclusions

In this study, the performance of conventional activated sludge, MBR, SBR, and Biolak wastewater treatment systems in removing BOD and COD from municipal wastewater was investigated at pilot scale. For this purpose, four independent pilots were designed and installed at Ekbatan wastewater treatment plant, located west of Tehran. The Biolak pilot was the first pilot of its kind installed in Ekbatan treatment plant. The wastewater feed for the pilots was supplied from Ekbatan treatment plant to ensure the accuracy of results for municipal treatment applications. An extended set of tests were performed according to standards on samples from each pilot, and characteristics of influent and effluent were closely monitored; furthermore, pH values were controlled to be within acceptable range through the whole process.

The performance of each pilot in removing BOD and COD was determined. The CAS pilot did not reach the highest efficiency; nevertheless, results were within the same range as the MBR and SBR pilots, and water quality satisfied required standards. Although within

**Table 4.** Removal efficiency of $BOD_5$ and COD in the Biolak pilot at different hydraulic retention times for densities of 3500 mg/l and 4500 mg/l

| **HRT (h)** | **Density of 3500 mg/l** | | **Density of 4500 mg/l** | |
|---|---|---|---|---|
| | **BOD removal (%)** | **COD removal (%)** | **BOD removal (%)** | **COD removal (%)** |
| 17 | - | - | 85.62 | 86.77 |
| 19.1 | 85.08 | 85.55 | - | - |
| 23 | 88.55 | 89.43 | 90.14 | 90.75 |
| 24.8 | 89.34 | 90.07 | 90.75 | 91.62 |
| 25.8 | 89.18 | 90.25 | 90.81 | 91.73 |
| 32.9 | 89.35 | 90.86 | 91.81 | 92.22 |

accepted range, the water quality achieved by the Biolak pilot was not as high as other processes; however, advantages such as operational simplicity, low cost, and low land occupation makes it a widely used system. It was found that the highest water quality was achieved by the MBR and SBR pilots; more specifically, the maximum $BOD_5$ removal of 98.54% was achieved by the SBR pilot, while the MBR pilot reached the highest COD removal of 97.1%. Therefore, it can be concluded that SBR and MBR systems are among the most suitable options for municipal wastewater treatment with regard to water quality.

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