Iranian Journal of Oil & Gas Science and Technology, Vol. 13 (2024), No. 1, pp. 01–14
http://ijogst.put.ac.ir

Operational Analysis: Rotating Biological Contactor–Activated Sludge or Nitrifying Trickling Filter–Activated Sludge?

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Highlights

- This study evaluated the effectiveness of two distinct wastewater treatment plant configurations in terms of their ability to produce high-quality effluent.
- The evaluation was conducted using GPS-X software, specifically the September 2007 (USA, Avg) version.
- The NTF/AS process achieved higher removal efficiencies for biochemical oxygen demand, chemical oxygen demand, and total suspended solids than the RBC/AS configuration.
- With respect to total phosphate removal, the nitrifying trickling filter/activated sludge process demonstrated a removal efficiency comparable to that of the RBC/AS configuration.
- The NTF/AS-based municipal wastewater treatment plant represents a financially viable option.

Received*: May 11, 2025*; revised*: June 17, 2025;* accepted*: June 18, 2025*

Abstract

Municipal and industrial wastewater pose significant environmental hazards if discharged without adequate treatment. Consequently, appropriate treatment processes must be implemented prior to discharge into receiving water bodies, land application, or reuse. Ensuring access to clean water remains a critical global priority. This study aims to contribute to the development of an efficient wastewater treatment plant. The application of process simulation and modeling plays a crucial role in the design, construction, and prediction of operational requirements for wastewater treatment facilities. Simulating a project before full-scale implementation can reduce capital and operational expenditures while enabling comprehensive technical evaluation from multiple perspectives. This study proposes the implementation of a combined nitrifying trickling filter/activated sludge (NTF/AS) process to upgrade a municipal wastewater treatment plant (MWWTP). The performance of the MWWTP was analyzed and compared for two configurations: a combined rotating biological contactor/activated sludge (RBC/AS) process and a combined NTF/AS process. Two treatment scenarios were developed and technically evaluated using operational data from the Ekbatan wastewater treatment plant in Tehran. In these simulations, GPS-X software was employed to investigate the effects of variations in influent characteristics within their minimum and maximum ranges on effluent quality. Considering the variability in influent conditions resulted in more accurate and reliable predictions. Under the fixed-flow scenario, the RBC/AS configuration achieved removal efficiencies of 90.51%, 89.70%, 95.14%, 14.80%, and 76.41% for chemical oxygen demand, total suspended solids, biochemical oxygen demand BOD5, total phosphorus, and ammonia, respectively.

Keywords: Activated sludge, Nitrifying trickling filter, Operational analysis, Rotating biological contactor, Wastewater treatment plant

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How to cite this article
Talaeian, M. and Mirnemati M. S., Operational Analysis: Rotating Biological Contactor–Activated Sludge or Nitrifying Trickling Filter–Activated Sludge? Iran J. Oil Gas Sci. Technol., Vol. 13, No. 1, p. 1–14, 2024. DOI: https://doi.org/10.22050/ijogst.2025.522758.1740

1. Introduction

Wastewater management represents a significant global challenge because it requires compliance with discharge standards, protection of environmental and public health, facilitation of water reuse, and resolution of energy and material recovery issues, including nutrient recovery (Jafarinejad, 2008).

To prevent eutrophication in surface waters, phosphorus discharges from municipal and industrial wastewater treatment plants must be strictly regulated. Phosphate concentrations exceeding 1.0 mg/L can impair the coagulation process in downstream drinking water treatment. Nitrogen also plays a critical role in wastewater management; however, concentrations above the permissible limit of 10 mg/L may lead to adverse ecological and public health effects (Akpor et al., 2011). The principal forms of nitrogen in wastewater include organic nitrogen, ammonia, nitrate, and nitrite. Ammonia, nitrate, and nitrite are classified as inorganic nitrogen species (Hurse et al., 2011). These inorganic forms contribute to eutrophication, particularly when ammonia is oxidized to nitrate, resulting in elevated nitrate concentrations in receiving waters.

For aquatic life, the maximum allowable concentration of ammonia and ammonium compounds at 18 °C and within a pH range of 5–7 is approximately 2 mg/dm^3. Nitrate contamination of drinking water can cause methemoglobinemia, a serious health condition. Hemoglobin normally transports oxygen in the bloodstream; however, in the presence of nitrite, it is oxidized to methemoglobin, which cannot carry oxygen efficiently. In addition, ammonia is toxic to fish and increases oxygen demand in receiving waters through nitrification (Jafarinejad et al., 2017).

Various techniques for ammonium removal from wastewater have been reported in the literature. These include biological nitrification–denitrification processes, ion exchange systems, adsorption using natural or synthetic materials, and membrane-based technologies, particularly pressure-driven membrane processes.

Conventional wastewater treatment typically involves a sequence of physical, chemical, and biological processes designed to remove suspended solids as well as organic and inorganic contaminants from sewage (Crini et al., 2012). These processes are generally categorized into preliminary, primary, secondary, and tertiary or advanced treatment stages.

Biological treatment processes are broadly classified into suspended growth systems and attached growth systems. Suspended growth systems include the activated sludge process, oxidation ditches, contact stabilization, extended aeration, step aeration, pure oxygen activated sludge systems, and aerated lagoons. Attached growth systems include trickling filters and rotating biological contactors. Wastewater treatment plants are inherently complex systems that involve numerous biological, physicochemical, and biochemical processes (Crini et al., 2019). Trikoilidou et al. (2019) similarly classified biological treatment processes into suspended growth and attached growth categories.

A recent study proposed the implementation of a combined nitrifying trickling filter/activated sludge (NTF/AS) process as a viable strategy for upgrading a municipal wastewater treatment plant. The study evaluated the performance of municipal wastewater treatment plants employing a combined rotating biological contactor/activated sludge (RBC/AS) process and compared it with that of plants utilizing the combined NTF/AS configuration. The assessment considered operational performance, construction requirements, and energy and chemical consumption to determine the overall feasibility of the proposed configurations.

2. Materials and methods

2.1. Case study and influent wastewater

The Ekbatan Wastewater Treatment Plant, located in Tehran, Iran, has been in operation since 1988. The facility occupies an area of approximately 40,000 m² and is situated in the Ekbatan district. The reported overall removal efficiency of the plant is approximately 97%.

Both the NTF/AS and RBC/AS configurations are fixed-bed biological treatment systems that rely on microbial activity to degrade contaminants in wastewater. The primary distinction between these systems lies in the manner in which wastewater contacts the microbial biomass. In the NTF/AS system, wastewater flows over a stationary solid medium, such as rock or plastic packing, on which biofilm develops. In contrast, in the RBC/AS system, wastewater contacts microorganisms attached to rotating discs partially submerged in the wastewater, where a biological film forms on the disc surfaces.

Technical simulation and modeling play a critical role in the design, construction, and prediction of operational requirements for wastewater treatment plants. Simulating a treatment system prior to full-scale implementation can reduce additional costs and allow comprehensive technical evaluation from multiple perspectives. In the present study, a combined nitrifying trickling filter/activated sludge NTF/AS process was proposed to modernize a municipal wastewater treatment plant (MWWTP). The performance of MWWTPs based on the combined RBC/AS and combined NTF/AS configurations was analyzed and compared. Two activated sludge–based treatment scenarios were simulated and technically evaluated using operational data from the Ekbatan treatment plant in Tehran. The effects of variations in influent wastewater characteristics, ranging from minimum to maximum values, on effluent quality were investigated using GPS-X software. Considering the variability of influent conditions resulted in more reliable and accurate predictions.

The objective of this study was to evaluate the performance of two distinct wastewater treatment plant configurations using GPS-X software, specifically the September 2007 (USA, Avg) version. Overall, GPS-X is a valuable tool for the preliminary design and performance assessment of wastewater treatment plants. In recent years, wastewater treatment plants have increasingly been modeled and simulated to evaluate alternative design and operational strategies prior to full-scale implementation (Sirianuntapiboon et al., 2017).

Table 1 presents an overview of the influent wastewater characteristics and key operational parameters of the Ekbatan wastewater treatment plant. It includes the average influent flow rate and the average concentrations of principal pollution indicators. All evaluated configurations were simulated using the data summarized in Table 1. The table also reports the average influent loading over a one-month period at the Ekbatan treatment plant in the Bagheri district.

2.2. Process design description

The examination employs a software tool, GPS-X, developed by Hydromantis, to assess three distinct options for wastewater treatment from both technical and qualitative perspectives. GPS-X is a sophisticated, versatile, and multipurpose modeling platform used to simulate wastewater treatment plants in domestic and industrial settings. The software enables the qualitative evaluation of design, effluent pollutant concentrations, and the removal efficiency of various treatment methods using computational models for carbon, nitrogen, and phosphorus included in the model library.

Table 1

Daily influent and effluent wastewater characteristics of the Ekbatan wastewater treatment plant

Parameter (unit)	Maximum	Minimum	Average	Standard deviation
DO	5.4	0	3.1	0.48
Influent T (°C)	28.5	6	18	2.8
Influent pH	8	6.7	7	0.4
Influent biological oxygen demand (BOD) (mg/L)	236	100	120	47
Influent chemical oxygen demand (COD) (mg/L)	400	80	211	65
Influent TN (mg/L)	57	15.5	29	7
Influent total phosphorus (mg/L)	18.8	9.6	12	3
Influent total dissolved solids (mg/L)	523	270	320	135
Influent total settleable solids (mg/L)	320	150	191	90
Sludge volume index (SVI) (mg/L)	520	170	220	130
Mixed liquor volatile suspended solids (MLVSS) (mg/L)	280	230	720	677
Discharge total settleable solids (mg/L)	34	1.5	10	6
Discharge BOD (mg/L)	21.2	2	7	2.2
Discharge COD (mg/L)	41.6	6	15	7
Discharge total ammonia (mg/L)	16.2	0.4	2	2.1
Discharge total phosphorus (mg/L)	8.3	3.1	4.2	
Total Kjeldahl nitrogen (TKN) (mg/L)	42	17	36	
PO4-P (mg/L)	8.6	5.95	6.93	

The objective of the study is to evaluate the performance of wastewater treatment plants (WWTPs) by analyzing two scenarios representing variations in raw wastewater. The assessment focuses on pollutant levels, including chemical oxygen demand (COD), biological oxygen demand (BOD5), total suspended solids (TSS), and total phosphorus in the effluent. Both scenarios are simulated over a 60-day period, and the results for the considered parameters are presented. Moreover, the study investigates the performance of municipal wastewater treatment plants (MWWTPs) employing the combined rotating biological contactor (RBC)/activated sludge (AS) process and the combined trickling filter (TF)/AS process. Two scenarios are utilized to analyze the aforementioned pollutants in the effluent over a 60-day simulation period. The simulation outcomes are illustrated in figures, and the corresponding parameter values obtained from the software are provided.

The combined RBC/AS process is widely applied for treating domestic and hospital wastewater. The RBC system is renowned for its ability to withstand high hydraulic and organic loadings and for its operational simplicity. Hassard et al. (2019) reported that the RBC system effectively removes nitrogen from wastewater due to its substantial biofilm mass, which provides a large surface area for the bio-drum and facilitates the removal of organic matter and nitrogen. The energy consumption of this process is approximately half that of the AS process, as aeration is not required. The removal efficiency for organic matter is remarkably high, around 99%, while nitrogen removal reaches approximately 90%. Anaerobic RBCs have demonstrated complete nitrification and denitrification capabilities. Due to the abundance of microorganisms available for organic matter digestion, a short hydraulic retention time (HRT) of approximately 4 hours is sufficient for effective organic matter removal.

Activated sludge is a commonly employed method for the biological treatment of liquid waste, efficiently treating municipal sewage and various types of industrial wastewater (Campbell et al., 2012). Activated sludge WWTPs can remove biological nitrogen, biological phosphorus, and organic carbon compounds, depending on their design and application. Numerous studies have modeled and simulated the activated sludge process. The plug flow-activated sludge process prevents excessive growth of filamentous organisms, which can cause settling problems in the secondary clarifier. In the later stages of the reactor, nitrification and endogenous respiration can consume a significant portion of oxygen once the organic loading ratio decreases sufficiently. Table 2 presents the design criteria and operational conditions for the municipal wastewater treatment plant processes based on the combined trickling filter/AS process.

Table 2

Design criteria and operational conditions for processes used in the MWWTP incorporating the combined trickling filter (TF)/activated sludge (AS) process

Process or unit	Design criteria and operational conditions
Influent pump station	The system required two pumps, both of which were constant-speed types. The influent sewer had a depth of 4.57 meters, and the static head measured 12.19 meters.
Screening	For cleaning, a mechanically operated method was employed, with a cleaning depth of 0.30 meters. The bars used in the cleaning process had a width of 0.63 centimeters and were spaced 3.81 centimeters apart. The system was installed at a slope of 30 degrees, with a shape factor of 2.42. The maximum and average approach velocities to the system were 0.76 meters per second and 0.91 meters per second, respectively.
Grit removal	Grit removal was accomplished using an aerated method, with two units installed. The design specifications for the units included a depth of 1.50 meters and a current allowance of 1.7. The Manning coefficient for the system was 0.035. The grit particles to be removed had a size of 0.2 millimeters and a specific gravity of 2.65. The volume of grit was calculated as 2.99×10^{-5} cubic meters per cubic meter of grit. The detention time for the grit removal process was set at 2.5 minutes. The air supply per unit length of the tank was 0.27 cubic meters per minute per meter. The surface velocity and tank floor velocity were 0.45 meters per second and 0.30 meters per second, respectively.
Primary clarification	For the clarifier, a circular design was selected. The design was based on the average flow. The surface overflow rate was set at 40.74 cubic meters per square meter per day, and the side water depth was 2.74 meters. The weir overflow rate was determined to be 186.3 cubic meters per meter per day. The specific gravity of the clarifier was 1.05. The underflow concentration for the system was 4%, with removal efficiencies of 58%, 32%, 40%, 5%, and 5% for suspended solids (SS), BOD, COD, TKN, and phosphorus, respectively.
RBC	The aerobic unit had a working volume of 2.85 liters and contained 12 fully immersed bio-disks, each with a diameter of 12 centimeters. These disks were connected to a motor via a stainless-steel shaft and rotated at speeds of 5–15 rpm, parallel to the direction of wastewater flow. Additionally, the aerobic unit included 24 fully immersed disks and eight rectangular blades, each 2 centimeters wide, positioned in the disk intervals to enhance mixing. The surface area provided in the anaerobic and anoxic units was 95 square meters per cubic meter, whereas in the aerobic tank, it was 54 square meters per cubic meter. The optimal operating region for the system was determined based on the total hydraulic retention time (HRT) range of 18 to 18.7 hours, with rotational speeds ranging from 5 to 15 rpm. The boundaries of the optimal

Process or unit	Design criteria and operational conditions
	region were defined by the median values of the COD:N:P ratio (1000:83:30) and the R-value (2.5) on average.
Intermediate clarifier and secondary clarifier	For the clarifier, a circular design was selected based on the average flow. The surface overflow rate was set at 20 cubic meters per square meter per day, and the maximum solids loading rate was 117.18 kilograms per square meter per day. The side water depth was 3 meters, and the weir overflow rate was 186.3 cubic meters per meter per day. The specific gravity of the clarifier was 1.03. The underflow concentration was 1%, and the effluent suspended solids (SS) concentration was 20 milligrams per cubic decimeter.
Conventional (plug flow) AS	The process design for the project focused on carbon removal and nitrification. The design specifications included a solids retention time (SRT) of 15 days. Diffused aeration with fine bubbles was selected for the system. The alpha factor for oxygen transfer in wastewater was set at 0.5, and the beta factor for oxygen saturation in wastewater was 0.95. The minimum airflow for the fine-bubble aeration system was determined to be 0.61 cubic decimeters per second per square meter. The standard oxygen transfer efficiency for the system was 20%. The concentration of mixed liquor suspended solids (MLSS) was 2,500 milligrams per cubic decimeter. The maximum heterotrophic specific growth rate was 6 per day, while the heterotrophic decay rate was 0.24 per day. The maximum autotrophic specific growth rate was 0.5 per day, with an autotrophic decay rate of 0.04 per day. The biomass yield for the system was 0.5.
Chlorination	For chlorine dosing, a concentration of 10 milligrams per cubic decimeter was applied. The contact time at peak flow was set at 30 minutes, and the influent coliform count was 10^7 per 100 cubic centimeters.
Gravity thickening	Design Parameters: The system design is based on the following criteria: a mass loading of 50 kilograms per square meter per day, a depth of 3 meters, and an underflow concentration of 5%.
Anaerobic digestion	The specific gravity of the system was 1.05, with 50% of volatile solids destroyed. The concentration in the digester was 5%, and the minimum detention time in the primary digester was 15 days. The location was suitable for moderate-winter conditions, approximately 0 °C. The raw wastewater temperature was 20 °C, while the digester operated at 40 °C. A fraction of the influent flow, specifically 2%, was returned as supernatant, which had concentrations of 6,250 mg/dm³ for suspended solids (SS), 1,000 mg/dm³ for BOD, 2,150 mg/dm³ for COD, 950 mg/dm³ for total Kjeldahl nitrogen (TKN), and 650 mg/dm³ for ammonia.
Belt-filter press	Cake Characteristics: The cake solids content was 19%, and the density of the cake was 1,200 kilograms per cubic meter. The operating schedule was 8 hours per day, 5 days per week. The hydraulic loading per meter of belt press width was 381 cubic meters per day. The polymer dosage was set at 1% of the dry weight. Finally, the filtrate solids concentration was 100 milligrams per cubic decimeter.
Hauling and landfilling	Disposal Considerations: The cost basis for sludge disposal was calculated per ton. The distance to the disposal site was 20 kilometers. The system operated for 8 hours per day. The loading time per vehicle was 0.75 hours, and the hauling time per trip was 1 hour.

This design incorporates various components that effectively treat wastewater and ensure its safe discharge into surface water. These components include an influent sewage pumping station, granulation unit, primary settling tank, rotary biological contactor (RBC), secondary settling tank, filtering unit, chlorination disinfection unit, anaerobic digestion tank, and sludge drying unit. It is important to note that the excess sludge generated by biological treatment plants must undergo stabilization to prevent environmental harm prior to disposal (Jafarinejad et al., 2018). Figure 1 illustrates the process flow diagram (PFD) of the MWWTP employing the combined RBC/AS system.

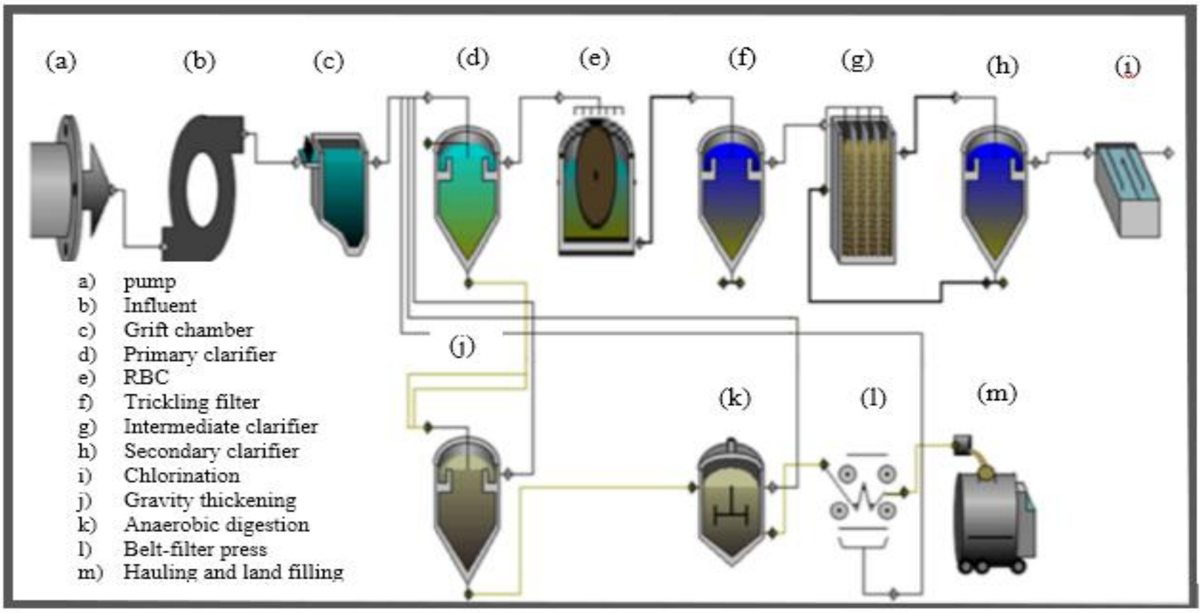

Figure 1

Layout of the MWWTP based on the combined RBC/AS process

The use of immobilized microorganisms in the RBC and AS systems ensures consistent performance, even under low levels of mixed liquor volatile suspended solids (MLVSS). Analysis using response surface methodology (RSM) demonstrated the impacts of various operational factors on system performance and their interactive effects. Among the factors influencing nutrient removal, hydraulic retention time (HRT) and rotation rate (R) were the most significant. Increasing HRT led to higher removal efficiencies of chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP). The effect of R varied by nutrient: it reduced COD removal efficiency, improved TN removal efficiency, and had no impact on TP removal efficiency. The optimal operating conditions were identified within an HRT range of 18–18.7 hours and an R range of 5–15 revolutions per minute (RPM), with average values of COD:N:P of 1000:83:30 and an R-value of 2.5 (Akhbari et al., 2011).

A wastewater treatment plant employing a combination of nitrifying trickling filter and activated sludge processes utilizes nitrification and denitrification to reduce nitrogen levels in the effluent. Various factors influence nitrification dynamics, including organic loading, hydraulic loading, temperature, pH, dissolved oxygen concentration, and filter media characteristics. These factors must be carefully considered in the design and operation of trickling filters to achieve efficient nitrification. To maintain high NH_3-N concentrations, recirculation can be reduced to control biofilm thickness. Studies suggest that the nitrification rate is proportional to the media surface area.

Figure 2 illustrates the arrangement of a municipal wastewater treatment plant (MWWTP) employing the combined NTF/AS (nutrient trickling filter/activated sludge) process. The MWWTP comprises several essential components, including an influent pumping station, preliminary treatment (screening and grit removal), primary clarifier, NTF, intermediate clarifier, conventional plug-flow AS, secondary clarifier, chlorination unit, gravity thickening, anaerobic digestion, belt filter press, and sludge hauling and landfilling. Except for the NTF, all processes follow similar design criteria and operational conditions as the MWWTP based on the combined RBC/AS (rotating biological contactor/activated sludge) process. Parameters that remain constant across all processes include specific surface area, surface loading rate, and influent alkalinity.

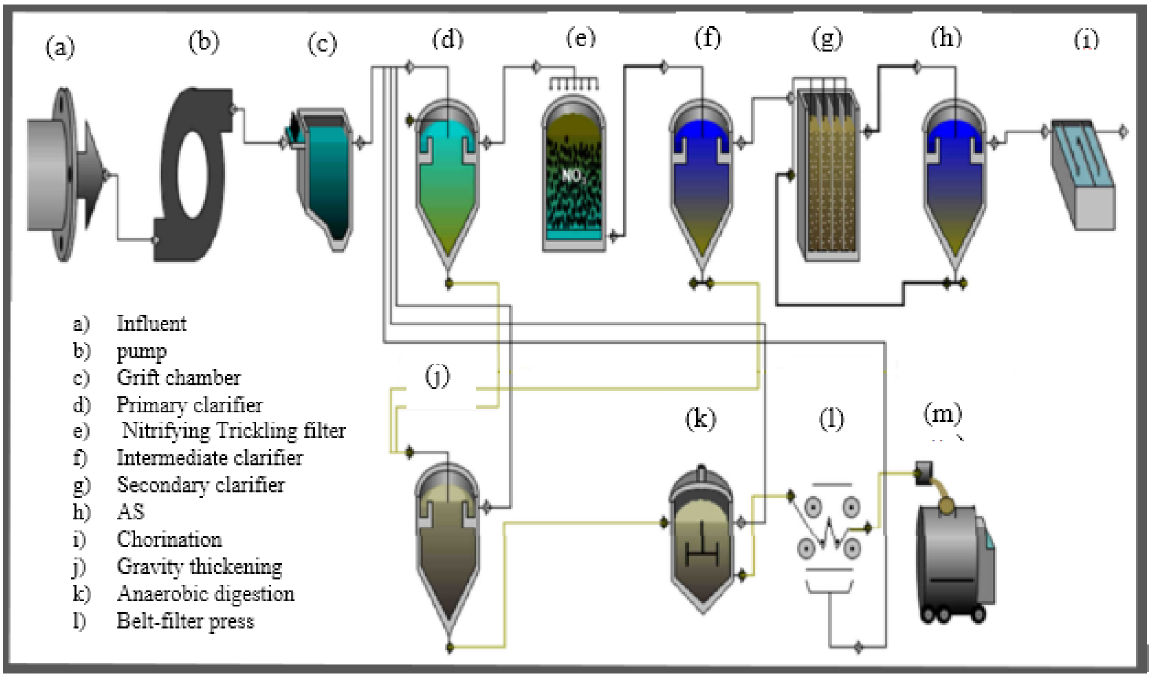

Figure 2

Arrangement of the municipal wastewater treatment plant using the combined NTF/AS process

3. Results and discussion

Two distinct scenarios, described below, based on variations in the raw wastewater flow rate, were considered to assess the effluent quality.

3.1. Scenario 1: Fixed flow rate

The calculated flow rate was 4,500 cubic meters per day. In the given scenario, the influent flow rate varied, as shown in Figure 3. The pollutant concentrations were analyzed over a 60-day period, during which parameters such as chemical oxygen demand (COD), biological oxygen demand (BOD5), total suspended solids (TSS), and total phosphorus (TP) stabilized. The simulation results are presented in Figure 4.

The simulation results for the concentration of BOD5 (mg/L) over the 60-day period are shown in Figure 4(a). The BOD5 concentration initially increases but reaches a steady state after 5–7 days due to microbial proliferation. The daily concentration of total COD is presented in Figure 4(b). COD reaches equilibrium earlier in the NTF/AS method than in the RBC/AS method. The simulation results for total suspended solids (TSS) over time are displayed in Figure 4(c). TSS concentrations initially increase in both methods but stabilize after the twelfth day. The total phosphorus (mg/L) concentrations over the 60 days are shown in Figure 4(d). In the RBC/AS wastewater treatment plant, the microbial growth rate is lower compared to the NTF/AS method, resulting in a longer time to reach equilibrium with phosphorus nutrients. The consumption rate of carbon nutrients exceeds that of phosphorus nutrients, further promoting microbial growth.

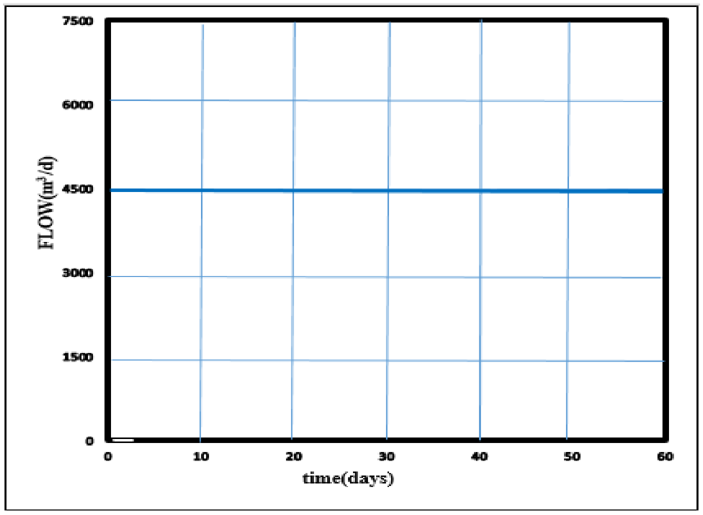

Figure 3

The influent flow of the wastewater treatment plant in scenario 1 is being reconfigured.

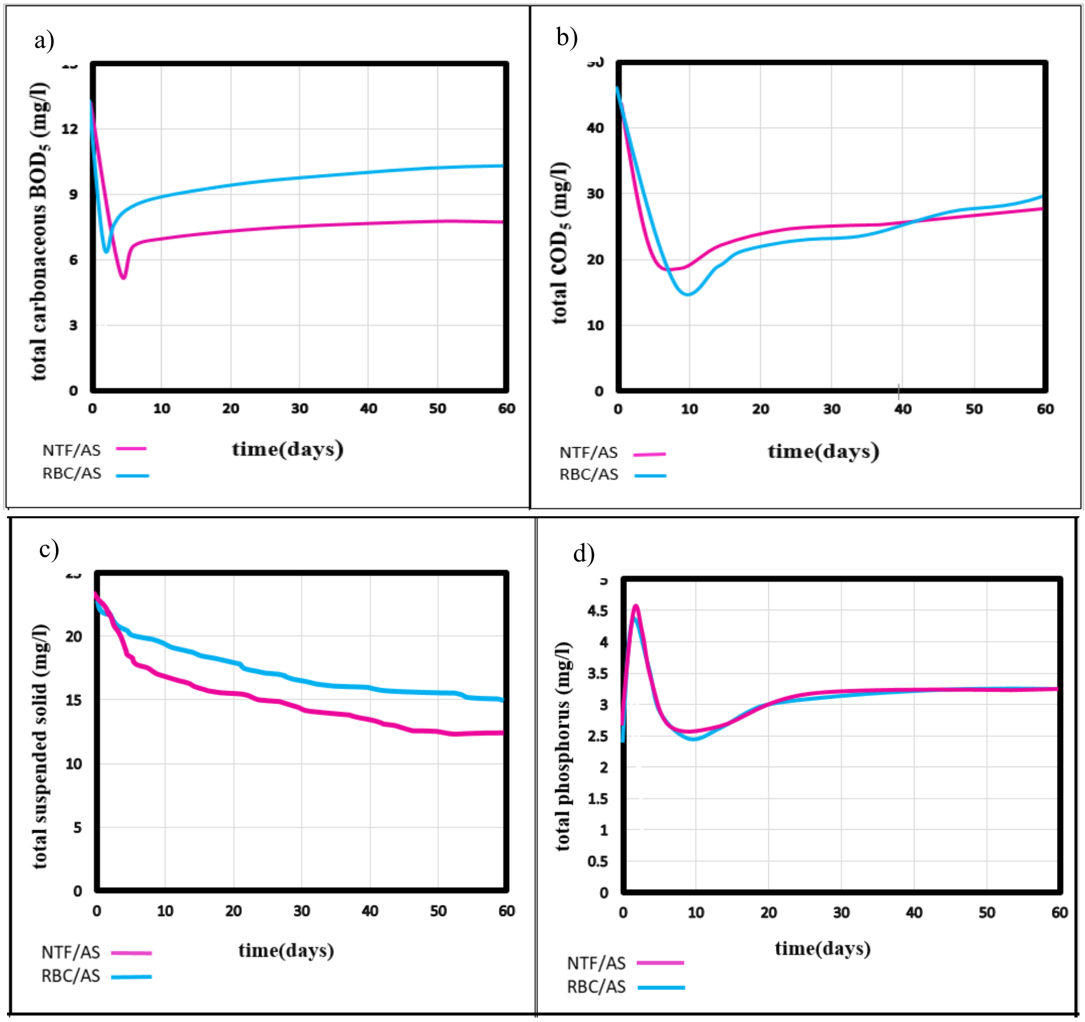

Figure 4

The daily concentration of total suspended solids can be determined using two methods: the RBC/AS method and the NTF/AS method

The software output values for Scenario 1, using both NTF/AS and RBC/AS methods, are summarized in Table 3. In this scenario, TSS initially increases and eventually stabilizes. BOD5 and COD display similar trends, with initial increases followed by decreases before reaching equilibrium. The total phosphorus concentration exhibits a gentler slope in the RBC/AS method. Removal efficiencies for COD, TSS, BOD5, total phosphorus, and ammonia in the RBC/AS system are 90.51%, 89.7%, 95.14%, 14.8%, and 76.41%, respectively. Corresponding values for the NTF/AS method are 93.61%, 82.75%, 90.90%, 15.0%, and 91%, respectively. Both methods comply with Iranian regulations for the discharge of treated wastewater into the environment.

Table 3

Software simulation outcomes for the examined parameters are presented, with discharge values corresponding to a fixed flow rate

Parameters	NTF/AS	RBC/AS	Iranian standards for wastewater discharge (Farzadkia et al., 2016)
Flow (m^3/d)	4500	4500	
TSS (mg/L)	10.25	15	<40
Volatile suspended solids (VSS) (mg/L)	11.2	13	
BOD_5 (mg/L)	7.8	9.23	<30
COD (mg/L)	27.3	29.2	<60
Ammonia N (mgN/L)	3	7	
Nitrite/Nitrate N (mgN/L)	17	22	
Total TKN (mgN/L)	4.1	7	
TN (mgN/L)	19	25	
PO4–P (mgP/L)	6.0	7.2	
TP (mgN/L)	3.15	3.2	
Alkalinity ($mgCaCO_3/L$)	151.67	163.4	

Initially, the concentration of BOD5 increased further during the simulation. After 5–7 days, it reached equilibrium due to microbial growth. The GPS-X software provided output values for Scenario 1 for both the NTF/AS and RBC/AS methods, which are presented in Table 3. In this scenario, total suspended solids (TSS) initially increased but eventually stabilized over time. Biological oxygen demand (BOD5) and chemical oxygen demand (COD) exhibited similar patterns during the early stages of the simulation, showing an initial increase, followed by a decrease, and ultimately reaching equilibrium.

For total phosphorus, the RBC/AS method in the wastewater treatment plant demonstrated a slower approach to equilibrium, indicated by a lower slope. The removal efficiencies for COD, TSS, BOD5, total phosphorus, and ammonia in the RBC/AS system were 90.51%, 89.7%, 95.14%, 14.8%, and 76.41%, respectively. In comparison, the NTF/AS method achieved removal efficiencies of 93.61%, 82.75%, 90.90%, 15.0%, and 91%, respectively. According to Iranian guidelines, the effluent quality achieved by both treatment approaches was acceptable for discharge into the environment.

3.2. Scenario 2: Sinusoidal flow rate

To capture a complete daily sinusoidal flow, the flow rate should vary between 3,500 and 5,500 cubic meters per day. The analysis period was set at 60 days to allow the pollution parameters to reach a steady state. Figure 5 illustrates the influent flow variations over the 60-day period.

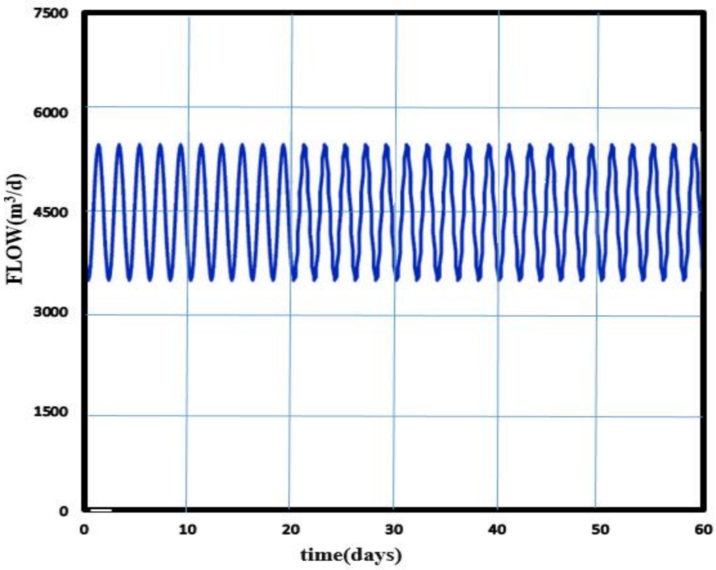

Figure 5

The wastewater treatment plant in scenario 2 processes the incoming wastewater flow.

The discharge output values for a sinusoidal flow rate and the final treated effluent characteristics of the MWWTPs based on the RBC/AS and NTF/AS processes are presented in Table 4. The parameters examined in this scenario include concentrations of chemical oxygen demand (COD), biological oxygen demand (BOD5), total suspended solids (TSS), and total phosphorus (TP). Following the simulations, the results are illustrated in Figure 6. The figure demonstrates a direct correlation between TSS concentration and variations in the plant's influent flow rate: as the flow rate increases, TSS concentration rises, whereas a decrease in flow rate results in a reduction in TSS concentration. Figure 6(a) shows that BOD5 concentrations follow a pattern similar to TSS in response to changes in the influent flow. In this scenario, the microbial growth rate cannot fully adapt to the increased load of organic pollutants, resulting in elevated BOD5 concentrations. Despite the increased loading of bio-contaminants and carbonaceous substances, the microorganisms are unable to compensate for the continual rise in carbon pollutants.

Figure 6(b) shows that changes in microbial growth and COD concentrations mirror the patterns observed for BOD5. However, in the NTF/AS treatment plant, a sudden surge occurs during the transition from lower to higher flow rates, which is less pronounced in the RBC/AS process. Microbial activity patterns are altered, and excessive chemical or hydraulic stress may inhibit growth. In the NTF/AS process, the growth rate of microorganisms exhibits a shallower slope due to a lower intrinsic growth rate, resulting in a longer time to reach equilibrium with phosphorus nutrients. The rate of carbon nutrient consumption exceeds that of phosphorus, further promoting microbial proliferation. Once microbial populations reach sufficient levels, as observed in contact stabilization systems, phosphorus concentrations decline sharply, and flow conditions stabilize.

The GPS-X software output values for this scenario are summarized in Table 4. The NTF/AS wastewater treatment plant achieved reductions of 94.58% for COD, TSS, BOD5, total phosphorus, and ammonia in the effluent. The RBC/AS method achieved reductions of 92.2%, 90.83%, 97.22%, 17.8%, and 73.76% for the same parameters, respectively. According to Iranian regulations, the effluent quality produced by both treatment methods is suitable for discharge into the environment.

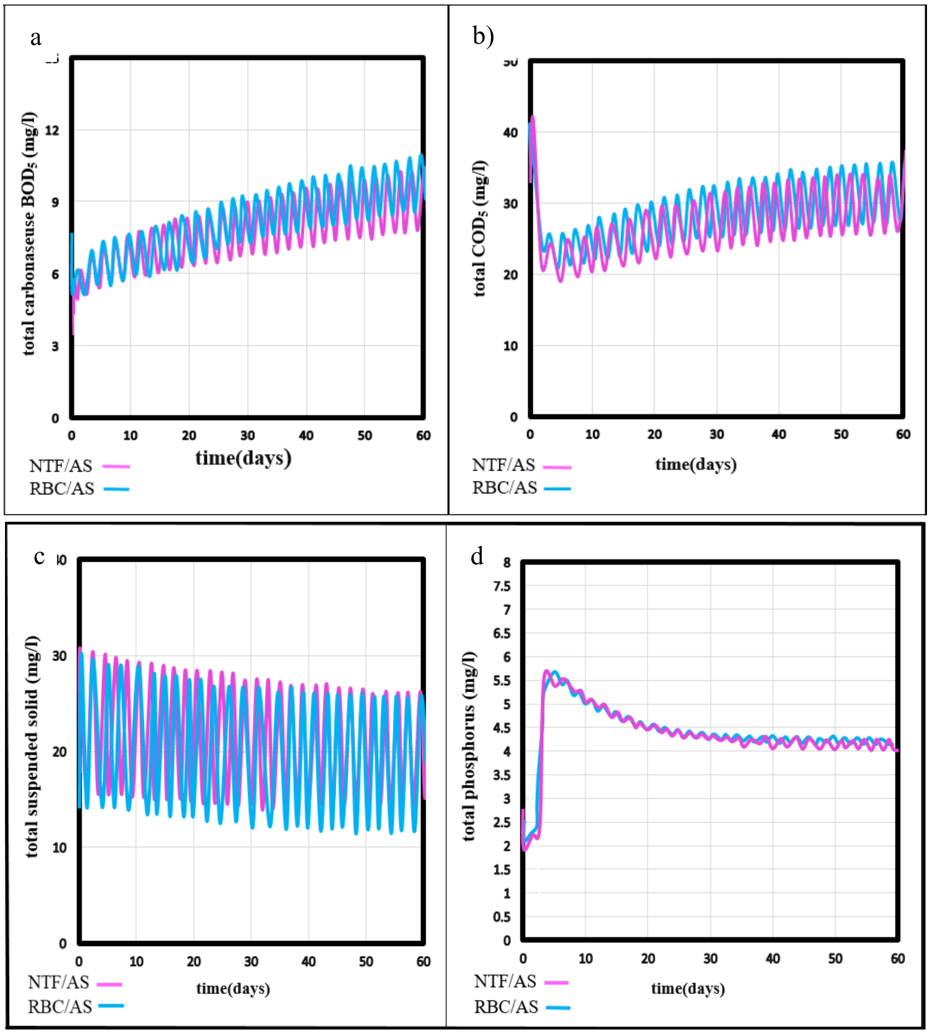

Figure 6

The Daily concentration of total suspended solids is measured using the RBC/AS and NTF/AS methods.

Table 4

Software simulation outcomes for the examined parameters, with discharge values corresponding to a sinusoidal flow rate

Parameters	NTF/AS	RBC/AS	Iranian standards for wastewater discharge (Farzadkia et al., 2016)
Flow (m^3/d)	4500	4500	
TSS (mg/L)	18	11.2	<40
Volatile suspended solids (VSS) (mg/L)	30	23	
BOD_5 (mg/L)	8	12	<30
COD (mg/L)	16.7	21.2	<60
Ammonia N (mgN/L)	4.1	7.1	
Nitrite/Nitrate N (mgN/L)	16.7	21.2	
Total TKN (mgN/L)	4.1	7.1	
TN (mgN/L)	20	25	
PO4–P (mgP/L)	5.8	7.2	
TP (mgN/L)	3.8	4.02	
Alkalinity ($mgCaCO_3/L$)	148.6	150.2	

4. Conclusions

This study evaluated the effectiveness of two configurations of a municipal wastewater treatment plant (MWWTP) in terms of their efficiency in producing high-quality effluent. The assessment was performed using GPS-X Software, Sept 2007 (USA, Avg) version. GPS-X proved to be a valuable tool for analyzing preliminary designs of wastewater treatment plants and for evaluating facility performance under varying operational conditions. Validating development plans remains a complex task, but design guidelines combined with detailed process simulations play a critical role in understanding the influence of different variables on treatment performance.

Based on the results from the first scenario, the nitrifying trickling filter/activated sludge (NTF/AS) method was found to be more effective than the RBC/AS method due to its higher pollutant removal capacity. In both the fixed and sinusoidal flow scenarios, the NTF/AS process achieved higher removal percentages for BOD5, COD, and TSS compared to the RBC/AS method. However, total phosphorus removal was comparable between the two methods. This similarity can be attributed to the comparable microbial growth rates, which require similar durations to establish equilibrium with phosphorus nutrients.

In the fixed flow scenario, the RBC/AS system achieved effluent removal efficiencies of 90.51%, 89.7%, 95.14%, 14.8%, and 76.41% for COD, TSS, BOD5, total phosphorus, and ammonia, respectively. The NTF/AS system achieved corresponding values of 93.61%, 82.75%, 90.90%, 15.0%, and 91%. Under a sinusoidal flow scenario, the NTF/AS system achieved removal efficiencies of 94.58%, 92.79%, 95.6%, 17.6%, and 88.65% for the same parameters, while the RBC/AS system achieved 92.2%, 90.83%, 97.22%, 17.8%, and 73.76%, respectively. Both methods comply with Iranian standards, confirming that the effluent quality is suitable for discharge into the environment.

One notable advantage of the NTF/AS configuration is the reduction in sludge production. This reduction provides potential cost savings in downstream units, including intermediate clarifiers, plug-flow AS tanks, and sludge treatment facilities such as gravity thickeners, anaerobic digesters, belt-filter presses, and hauling and landfilling operations. Consequently, the NTF/AS-based MWWTP represents a financially advantageous option.

Comparing the fixed and sinusoidal flow scenarios, the fixed flow condition in both methods generally achieved 10–15% higher removal efficiencies for COD, TSS, BOD5, total phosphorus, and ammonia. An exception was observed for ammonia, where the sinusoidal flow scenario in both methods exhibited slightly higher removal efficiency, approximately 0.2%, than the fixed flow scenario.

Nomenclature

BOD5	Biological oxygen demand
TKN	Total Kjeldahl nitrogen
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
VSS	Volatile suspended solid

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