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Techno-economic analysis of a municipal wastewater treatment plant: A comparison among SBR, MLE & A_2O processes

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Abstract

Sequencing Batch Reactor (SBR), Modified Ludzak Ettinger (MLE), and anaerobic/anoxic/aerobic (A_2O), were modeled and simulated using the data of the Konarak-Iran Waste-Water Treatment Plant (WWTP). GPS-X and CapdetWorks software were used for technical and economic evaluation, respectively. The cost of MLE treatment per cubic meter of effluent with a flow rate of 900 cubic meters per day was 0.96$ per cubic meter, which was 36.4% and 12.5% lower than SBR and A_2O, respectively. The removal efficiency of pollutants using the A_2O method was above 90%, which has the best efficiency compared to the other two methods. However, since the quality of the effluent is also met by the MLE method, the choice of the same method can be desirable. Therefore, modeling and technical and economic simulation of wastewater treatment to perform comparisons between different methods lead to better engineering decisions based on the cost and quality of effluent.

1. Introduction

The global population was estimated to be around 7.8 billion in 2020, and there is significant population growth. The availability and consumption of fresh water and the treatment of the resulting effluent are all severely impacted by such rapid growth [1]. Moreover, due to the migration of people from rural to urban areas, the amount of municipal wastewater generation has augmented in cities [2]. According to studies, around 40% of the world's population lacks basic sanitation, and 25% of developing countries' urban dwellers do not have access to sanitation facilities, with a substantially greater number for developing country rural populations of up to 82 percent [3]. In Iran, which is considered a developing country, although nearly half of the population is covered with a wastewater collection system, only 28% of Iran's 82 million people have a wastewater treatment system [4]. These statistics show the need for the appropriate treatment of municipal wastewater.

Municipal wastewater has low organic strength and high particle organic matter. In addition to this, since huge levels of nutrients and organics are present in untreated municipal wastewater, it has been designated as the most dangerous to water ecosystems. Suppose nothing is done to deal with treating this abundant amount of wastewater. In that case, it can have serious repercussions such as increases in water pollution, which can lead to water scarcity, impede economic development, and lead to poverty, starvation, and disease becoming more common [5-7]. This means that there is a need to treat municipal wastewater properly to tackle this issue. Various physical, chemical, and biological processes are used to remove particles, organic matter, and minerals from wastewater throughout the wastewater treatment process. Primary, secondary, and tertiary (or advanced) treatment are the available stages of treatment. The secondary stage of wastewater treatment, which involves the application of diverse microorganisms under regulated conditions, is one of the most critical stages of wastewater

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treatment [8,9]. These processes or wastewater treatment systems can be divided into centralized and decentralized wastewater treatment [10]. As opposed to centralized wastewater treatment systems, decentralized wastewater treatment systems are frequently considered to be more environmentally friendly solutions to choose from. Notwithstanding this, many centralized treatment plants in developing nations are unable to cope with stringent environmental regulations [3].

One of the most famous decentralized systems is biological aerobic treatment. The Activated Sludge Process (ASP), contact stabilization, total oxidation, aerated tanks, and aerated biological filter are some of the aerobic and anaerobic technologies used in secondary treatment. Because of its possible design and operation characteristics, the ASP can be considered the most prevalent biological process compared to the other biological processes [3,11-13]. Activated sludge has serval operating conditions and it can be achieved using a variety of configurations. Design, aeration, and operating conditions can all be altered to optimize system performance. Sludge activation methods include complete mixed activated sludge, extended aerated activated sludge, Integrated Fixed Film Activated Sludge (IFAS), Sequential Batch Reactor (SBR), Modified Lodzak Ettinger process (MLE), anaerobic process/anoxic/aerobic (A_2O), Membrane Bioreactor Method (MBR) and others [5,14].

As can be seen, there are various options to use for Waste-Water Treatment Plants (WWTPs) and it is vital not only to select a process that can meet the effluent discharge standards but also to be economical. However, the decision-making process for selecting the best wastewater treatment technology is often filled with uncertainty and complexity because there are many options and factors to consider, such as investment prices, energy consumption, and odors [15]. However, modeling and simulation can ease the task and make better decisions with their help. Mathematical modeling is an essential tool, especially for simulating biochemical processes in ASP, which requires a significant amount of data on effluent and sludge properties and process kinetics and stoichiometry [16].

The use of dynamic modeling and simulation in wastewater treatment design is now ubiquitous [17]. The models are supported by GPS-X, SIMBA, AQUASIM, BIOWIN, and STOAT. The GPS-X model is one of the best for sewage treatment plant simulation. Unlike other software, this model can simulate treatment plants with excellent accuracy [5]. Also, cost estimation costing software programs, such as CapdetWorks, typically provide faster and better estimates of capital and annual cost (O&M). WWTP design and construction are primarily concerned with determining which wastewater treatment option best meets the effluent permit's requirements considering present conditions and anticipated future situations [12,18].

This study aims to see how using different processes can affect the cost of treating as well as the characteristic of effluent for Konark municipal wastewater. To achieve this, simulation and technical and economic modeling are essential. Technical analysis of this research was performed using GPS-X software. SBR (current case of the Konark municipal WWTP), MLE, and A_2O were analyzed using a simulation technique based on the obtained information and the results were compared to the real data from the plant. The economic estimation of these three projects was done using CapdetWorks software, and fixed, operating, material, and energy costs for the three projects were calculated and compared by this software. This study aims to raise the question if SBR can be a good choice for this plant or if the two other scenarios can perform better.

Table 1. Characteristics of wastewater obtained from the Konarak WWTP.

Parameters	Unit	Influent
Mean flow	m^3/d	900
Maximum flow	m^3/d	1320
Minimum flow	m^3/d	480
TSS	mg/L	302
BOD5	mg/L	251
Total COD	mg/L	452
Total TKN	mgN/L	35
TP	mgP/L	8

2. Methods and material

2.1. Wastewater feed characteristics

This study is based on a case study of sanitary wastewater treatment in Konarak (Sistan and Baluchestan with 25.368, and 60.348 coordinates as shown in Figure 1. Sanitary wastewater (maximum capacity of 900 cubic meters per day) is transferred to the wastewater treatment package through the wastewater collection network. The wastewater is then biologically treated. After this stage, according to the environmental protection organization of Iran, the effluent is eligible for reuse in agriculture. Data on the quality of incoming wastewater are given in Table 1.

2.2. Simulation procedure

GPS-X software has been widely used in the simulation and design of wastewater treatment systems [19-21]. In this study, GPS-X was used to simulate three different cases. Cnplib library is used in GPS-X software and the simple1d clarifier model was used to do qualitative analyses of the design and find the output pollutant concentration [22]. CapdetWorks software version 4 was used in this study to estimate the total cost of systems. This software was used to estimate construction costs and annual costs according to the US equipment cost database (2014) as most of the default values proposed by CapdetWorks. This software was used to compare the effluent output for three different scenarios regarding A_2O, SBR, and MLE for Konarak municipal

Figure 1. Location of the Konarak wastewater treatment plant.

wastewater, and in the end, the results of effluent were compared with the actual effluent data obtained from the laboratory at the WWTP. The economic analysis was also done, and the total cost of the three scenarios was compared. The following assumptions have been used for the simulation:

- The default settings of stoichiometric and kinetic parameters in GPS-X were employed for the WWTP modeling simulation;
- The pH is constant and almost neutral;
- There are enough mineral nutrients to ensure adequate growth;
- Simultaneous hydrolysis of organic and nitrogen compounds exists;
- A constant concentration of Dissolved Oxygen (DO) is maintained, and there is sufficient mixing in the reactor;
- The liquid temperature was assumed to be 20°C.

2.3. Process description

Three different scenarios were used in this study, and the description and the procedure to simulate them are illustrated. These processes are SBR, MLE, and anoxic-anaerobic-oxic (A_2O). The SBR case is the current scenario of this wastewater plant. The aim is to see how MLE and A_2O processes would affect the cost and effluent characteristics.

2.3.1. SBR

SBR is an activated sludge technology that combines biological reactions with solid-liquid separation in a reservoir. This procedure can be changed according to the growing circumstances for different groups of microorganisms to eliminate different toxins from wastewater. Five operational steps make up a typical SBR cycle:

1. Filling: Add raw sewage or primary effluent.
2. Reactions start during aeration filling.

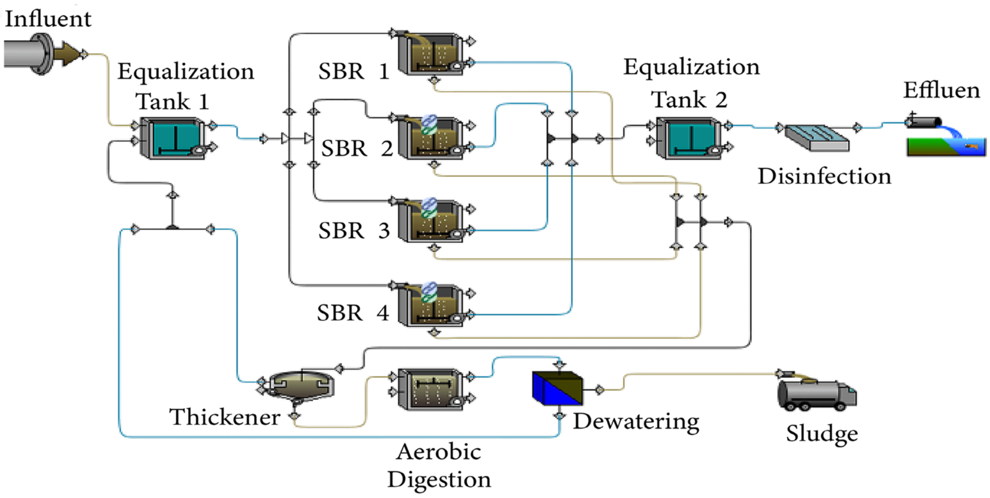

Figure 2. SBR process flow diagram.

3. Sedimentation: Solids separate from liquids when they are stationary.
4. Decant: Remove treated effluent.
5. Idle: Sometimes, a reactor is given time to complete its filling step before switching to another unit in a multi-tank system [19].

To simulate the process, the following steps were done. The flow first enters a balancing tank to reduce suspended solids and prevent possible shocks. In the SBR reactor, in the filling phase, the mixing is done without aeration, which, in addition to removing nitrogen, improves the sedimentation properties of the sludge. This phase is anoxic for denitrification. In the aeration stage, oxidation and nitrification occur, and with settling, the treatment process in the reactor ends. The balancing unit after the reactor is to store water and prevents possible shocks. Finally, bypassing the disinfection unit, wastewater of the desired quality is obtained. Residual sludge from water treatment in SBR reactors enters the digestion process. The process flow diagram of the process is shown in Figure 2.

2.3.2. MLE

The MLE process is sequentially anoxic-aerobic. The entering wastewater was denitrified anoxically, then nitrified aerobically. This method involves sequential recirculation of nitrate generated in the aerobic zone to the anoxic zone, which is accompanied by recirculation of Returned Activated Sludge (RAS) to the anoxic zone and that is because there is only one way for RAS to get nitrate into the anoxic area: by injecting it into anoxic zone [23]. To simulate the process, the following steps were done.

A portion of the suspended solids is first separated in the primary clarifier tank as part of the MLE treatment process. Denitrification and nitrogen removal takes place in the anoxic portion, whereas other pollutants in the wastewater are removed using aerobic microorganisms in the aerobic portion. The sedimented sludge can be separated from the desired quality wastewater with enough retention time in the secondary clarifier. Increasing the removal effectiveness of nitrogen is made possible by utilizing a return flow from the aerobic to the anoxic unit in this operation since it provides sufficient oxygen for microorganisms. A return sludge flow from the secondary clarifier to the anoxic unit helps maintain the microorganism-to-organic-matter ratio, and hence more effective wastewater treatment happens. The digestion section receives the settling sludge from the sedimentation tanks and processes it to remove the remaining sludge and purify the wastewater. The process flow diagram of the process is shown in Figure 3.

2.3.3. Anoxic-anaerobic-oxic (A2O)

As one of the world's most commonly utilized biological treatments, the A2O process (anaerobic/anoxic/aerobic) is well-known.

Also, before wastewater may be discharged into the environment, the A2O process is used to remove nitrogen, phosphorus, and organic carbon from the water [24]. To simulate the process, the following steps were done. The A2O process consists of three-level of biological treatments. Anaerobic treatment is used to remove phosphorus and denitrification, which removes ammonia and reduces nitrate loading; anoxic treatment, which removes ammonia and reduces nitrate loading; and aerobic treatment to remove Biological Oxygen Demand (BOD). Following this, a secondary clarifier and a sand filter are used to purify the wastewater physically. An internal return flow from the aerobic tank to the anoxic one is used to remove nitrate with increased efficiency, and a return sludge flow from the secondary clarifier to the anaerobic tank is used to boost phosphorus removal efficiency in this process. In the simulated process, sediment sludge from the clarifier tanks goes to the digestion section for sludge treatment. The process flow diagram of the process is shown in Figure 4.

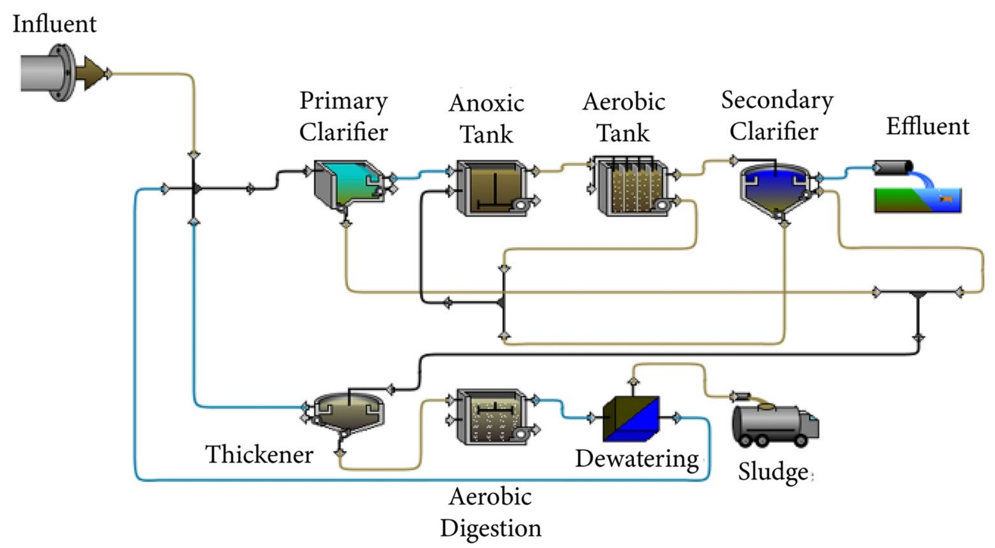

Figure 3. MLE process flow diagram.

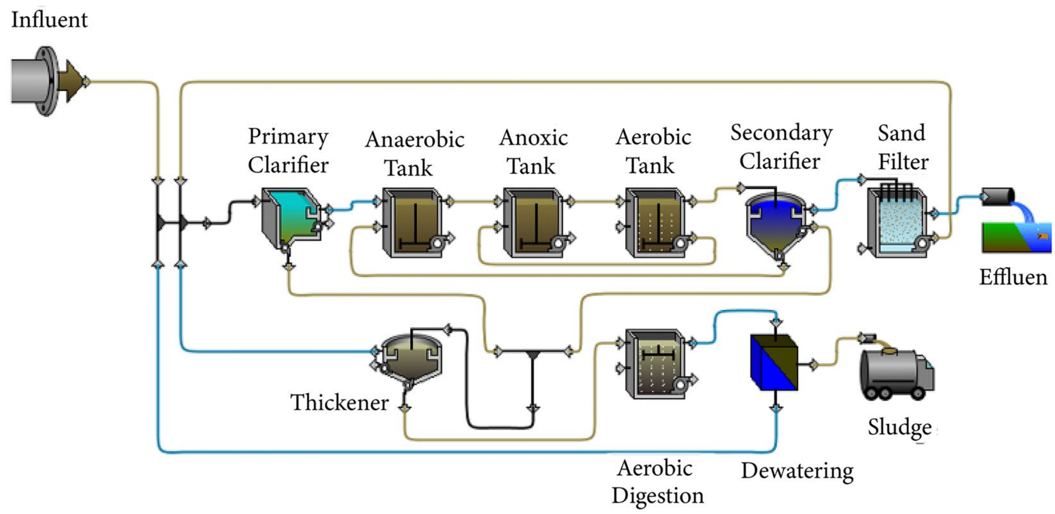

Figure 4. A_2O process flow diagram.

For sludge disposal, first, the water and sludge are separated and sent back to the beginning of treatment in the thickener tank. The sludge is sent to the aerobic digestion tank, where aerobic microorganisms break down the sludge. Finally, the dewatering step, like a press filter, separates the water from the sludge and sends it back to the beginning of the treatment process. The sludge is then thrown away.

2.4. Design parameters

The following tables depict the design criteria for three different processes. In the MLE process, the return flow rate from the aerobic unit to the anoxic is 1000 m^3/d and the sludge flow rate from the secondary clarifier to the anoxic unit is 600 cubic m^3/d. In the A_2O process, the return flow rate from the aerobic unit to the anoxic is 1000 m^3/d and the sludge flow rate from the secondary clarifier to the anaerobic unit is 800 m^3/d. Tables 2, 3, and 4 give the values related to the design parameters.

Table 2. Design criteria for SBR.

Unit process	Design criteria	Value	Unit
Equalization Tank 1	Maximum volume	105	m^3
SBR	Tank depth	3	m
	Airflow	95	m^3/h
	Surface area	70	m^2
	Maximum water level	3	m
	Feed points from the bottom	1	m
SBR (cycle time)	Airflow	480	m^3/h
	Fill	0.5	h
	Aeration	3	h
	Settle	1	h
	Decant	1	h
	Idle	0.5	h
Equalization Tank 2	Maximum volume	105	m^3
Disinfection	Tank depth	3	m
	Airflow	95	m^3/h
	Volume	30	m^3
	Chlorine dosage (mg/l)	1	mg/l
	HRT lower limit	0.005	d
	HRT upper limit	0.2	d

Table 3. Design criteria for MLE, A_2O.

Unit process	Design criteria	Value		Unit
	`	MLE	A_2O	
Primary clarifier	Surface area	35	35	m^2
	Maximum water level	3	3	m
	Feed point from the bottom	1	1	m
	Lamella located in layer	2	2	
	Plate angle	60	60	Degree
	Plate spacing	0.1	0.1	m
Anaerobic tank	Maximum volume	-	100	m^3
	Tank depth	-	3	m
Anoxic tank	Maximum volume	180	125	m^3
	Tank depth	3	3	m
Aerobic tank	Maximum volume	300	300	m^3
	Tank depth	3	3	m
	Aeration type- fine bubble	Diffused aeration	Diffused aeration	
	Airflow into the aeration tank	481	481	m^3/h
Secondary clarifier	Surface area	45	45	m^2
	Maximum water level	3	3	m
	Feed point from the bottom	1	1	m
	Lamella located in layer	2	2	
	Plate angle	60	60	Degree
	Plate spacing	0.1	0.1	m
Sand filter	Diameter		1.25	m
	Height		1.8	m
	Backwash flow fraction		0.02	

Table 4. Design criteria for sludge treatment.

Unit process	Design criteria	Value	Unit
Thickener	Surface area	9	m^3
	Depth	3	m
Aerobic digestion	Maximum volume	27	m^3
	Tank depth	3	m
	Airflow into the aeration tank	48.6	m^3/h
Dewatering	Filter press surface	0.36	m^2

3. Result and discussion

The results and discussion sections are divided into two main sections. The first part is the technical comparison and study of the efficiency of removal of pollutants from wastewater in the three proposed methods, while the second part is the economic comparison of WWTPs and also the calculation of the present value, taking into account capital and operating costs throughout the life of the plant.

3.1. The effluent characteristics

Table 5 shows the water output quality information for the three treatment processes, which shows that treated wastewater has reached below the allowable characteristic limit.

According to Table 5, the percentage of removal of COD, Total Suspended Solids (TSS), BOD5, Total Phosphorus (TP), and nitrogen in SBR is equal to 89, 94.8, 95.2, 61.9, and 95.1. The parameters mentioned in the MLE method are equal to 93.5, 94.7, 97.9, 75.1, and 93.7, respectively. The values for the A_2O process are equivalent to 94.6, 99.2, 98.4, 91.7, and 94.4, respectively. According to the report of the environmental protection organization of Iran, the quality of effluent in all three treatment methods is suitable for reuse in agriculture. According to EPA reports [27], the BOD and COD removal efficiency of SBR varies from 85-95% which in our case was 89%. In the case of A_2O process, COD removal efficiency of 92% was reported [28] which is near this study. In other studies, a TP removal efficiency of 93.5% was observed by Mohammad and Thamir Hamad [29] for A_2O process which is near to the simulation result of this study. The nitrogen removal efficiency of 90.7% was seen for MLE process in [30] which is almost near to the simulation result of MLE in this study (93.7%).

The results show that most phosphorus and nitrogen removal occur in the A_2O process due to the return of part of the activated sludge in the sedimentation tank to the beginning of the anaerobic zone where the biological removal of phosphorus will take place. The effluent from the aerobic tank

Table 5. Quality of wastewater effluent from different treatment processes.

Parameters	Unit	SBR	MLE	A_2O	Laboratory tests from the plant	Iranian standards for agriculture reuse [26]	EPA standards for discharge [25]
Flow	m^3/d	898.0	898.5	898.5	898.5		
TSS	mg/L	15.63	15.8	2.426	15	100	50
VSS	mg/L	7.36	5.605	0.8876			
BOD5	mg/L	11.87	5.058	4.005	8	100	50
COD	mg/L	49.57	29.31	24.24	40	200	250
Ammonia N	mgN/L	0.1557	0.04219	0.2841			
Nitrite N	mgN/L	0.07691	0.02772	0.1191			
Nitrate N	mgN/L	18.55	4.566	7.639			
TKN	mgN/L	1.71	2.202	1.944			
TN	mgN/L	20.33	6.795	9.702			50
Soluble PO_4^-	mgP/L	0.2785	0.172	0.2199	0.28		
TP	mgP/L	3.05	1.99	0.6568			2
BOD5/COD		0.23	0.1739	0.16	0.2		

to the second anoxic zone leads to nitrate mixing with the effluent and denitrification and its conversion to nitrogen gas, which reduces the nitrogen in the effluent.

The anoxic zone is deficient in DO. However, oxygen is produced by chemical bonding in the form of nitrate and nitrite by the flow of a return mixture, nitrified from the aerobic region. Performing a denitrification reaction in the anoxic zone reduces the amount of nitrate entering the anaerobic zone by returning activated sludge.

In the SBR process, nitrification, denitrification, and phosphorus removal are performed continuously. The design of SBR wastewater treatment systems can be based solely on the removal of carbon BOD or the combined removal of carbon BOD and nitrogen. An appropriate amount of nitrification and carbon removal can also be achieved by applying several stages of the anoxic process during sedimentation. So, in general, the removal efficiency of SBR reactors is less than MLE and A_2O methods, but concerning phosphorus removal, SBR performance is better with 89% removal from MLE with 75.1%, which is due to the absence of anaerobic reactions in the MLE process, and it reduces the phosphorus removal efficiency.

By increasing the return flow from the aerobic unit to the anoxic in the MLE, the inlet flow rate to the reactor increases and the retention time decreases, and the Feed-to-Microorganism ratio (F/M) decreases, given that this return flows to supply required oxygen by microorganisms. Also, the F/M ratio decreases with increasing backflow sludge flow in MLE and A_2O processes. It is also important to note that this flow maintains the ratio of microorganisms to organic matter.

The BOD5/COD ratio for treated wastewater in all three methods as well as the lab test is all in the range of 0.11-0.31 which is confirmed by past studies [31]. This can show the accuracy of the models.

3.2. *Sensitivity test*

Figure 5 Shows the variation of output COD for different influent flowrate. The results are illustrated and as it can be seen, the MLE process is highly sensitive to the flow rate of

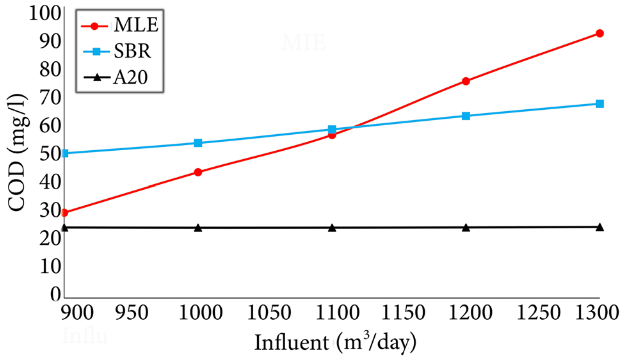

Figure 5. The variation of COD vs input flowrate for different case studies.

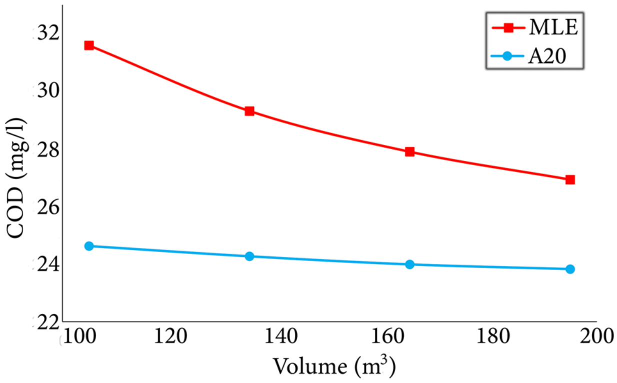

Figure 6. The effect of clarifier volume on output COD.

input wastewater, and it can be said that the MLE process cannot tolerate it, and it cannot meet the minimum required effluent discharge characteristic.

Figure 6 shows the effect of clarifier volume on output COD. The test was done for MLE and A_2O methods since the SBR is not competitive in terms of COD removal with these two methods. The results indicate that for MLE process the best volume for the clarifier to choose for design is 165 m^3 However, increasing the volume will result in more cost so this can only benefit if it results in higher COD removal. For A20 process, as it can be seen the volume of the clarifier does not have much impact so working with a lower volume will result in lower investment cost and the same removal efficiency.

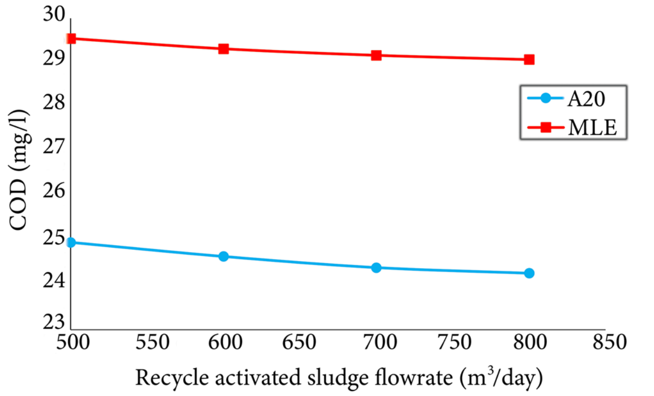

Figure 7. The effect of recycle-activated sludge flowrate on output COD.

Figure 7 illustrates the effect of recycle-activated sludge on the COD. As it is shown, the RAS does not have much impact on reducing/ increasing the output COD and any increase in the RAS to the tank will just increase operating costs.

3.3. Economic evaluation

CapdetWorks software was used to obtain the cost of each project, which estimated a good approximation of all construction and operating costs, as well as labor costs, material, maintenance, energy, chemicals required, and depreciation. The wastewater treatment schemes studied in this study was compared economically using the US equipment cost database (2014) as most of the default values proposed by CapdetWorks. To adjust the default costs at present (as costs in Iran), several cost indicators (start-up costs, construction, wages) are used as input costs (Table 6). All input data in the software, including the dimensions and physical shape of the units, type of aeration, the amount of nutrient removal, etc. have been extracted and entered according to the information obtained from GPS-X. Therefore, the technical and economic estimates of the plans are sufficiently compatible with each other. We also used the cost index for the year 2021 [32].

3.3.1. Construction cost

CapdetWorks software offers construction costs related to construction items in three categories: unit process costs, other direct construction costs, and indirect project costs [33,34]. Figure 8 shows a comparison of capital expenditure categories for these three processes. According to the figure, the construction costs of SBR units are more than the A_2O unit, and the A_2O unit is more than the MLE unit. This may be due to the number of SBR reactors, which will increase pumps, blowers, and rotating equipment in addition to the increased manufacturing cost. Also, indirect construction costs, including land, miscellaneous, legal, engineering design, potential, technical, and profit during construction, for the SBR system are more than MLE and A_2O. A comparison of total capital costs showed that the total capital cost of the A_2O system was approximately 7.5% lower than the SBR and 3.25% higher than the MLE.

Table 6. Investment cost and operating cost for different units.

Parameter process and financial	Units	Value
Building cost	\$/m	500
Excavation	\$/m^3	5
Wall concrete	\$/m^3	100
Slab concrete	\$/m^3	50
Crane rental	\$/h	100
Canopy roof	\$/m^2	100
Electricity	\$/kWh	0.2
Handrail	\$/m	50
Land costs	\$/ m^2	15
Construction labor rate	\$/h	2
Operator labor rate	\$/h	3
Administration labor rate	\$/h	3
Laboratory labor rate	\$/h	3
Hydrated lime- [Ca (OH)2]	\$/kg	0.4
Al2(SO4)3*14H_2O Ferric	\$/kg	0.6
chloride	\$/kg	0.79
Polymer	\$/kg	2.87
Citric acid 50%	\$/kg	1.146
NaOCL 14%	\$/m^3	344.68
Interest rate	%	8
Construction period	Year	1
Operating life of plant	Year	25
Engineering design fee	%	15
Miscellaneous	%	5
Administration/Legal	%	2
Inspection	%	2
Contingency	%	10
Technical	%	2
Profit and overhead	%	15

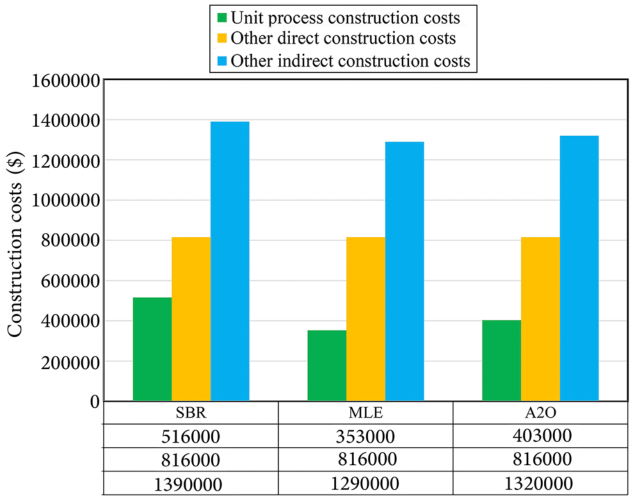

Figure 8. Construction costs for three different processes.

3.3.2. Operating and maintenance costs

The economic analysis should include the annual costs of operating and maintaining (operating costs) of the WWTP. CapdetWorks software includes operating and maintenance costs, including labor, energy, materials, and chemicals.

Table 7. Estimate costs and cost estimates per cubic meter.

Cost item	Value			Unit
	SBR	MLE	A_2O	
Total project costs	2730000	2460000	2540000	$
Total operation and maintenance costs	204000	110000	145000	$/yr
Annualized project cost	226863	204426	211074	$/yr
Annualized project cost + annual O & M cost	430863	314426	356074	$/yr
Cost/m^3	1.31	0.96	1.08	$ /m^3

Table 8. General comparison of minor costs in each process.

	Project	Operation	Maintenance	Material	Chemical	Energy	Amortization
SBR	2,730,000	26,800	5,870	117,000	4,710	49,200	738,000
MLE	2,460,000	19,500	3,450	72,400	0	14,600	648,000
A_2O	2,540,000	21,000	4,320	99,400	0	20,400	744,000

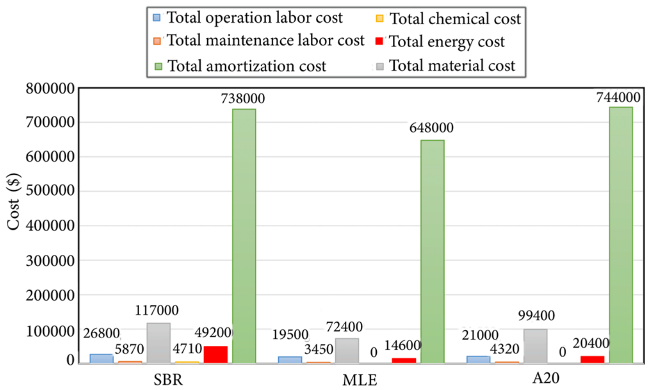

Figure 9. Operating and maintenance costs for different process.

Figure 9 compares the three wastewater treatment methods mentioned, with the highest operating costs related to the SBR process and the lowest costs related to MLE, which was an expected result. The higher costs of the SBR method can be due to the high energy consumption, the use of chemicals, and the need for a more intelligent system for timing units and controls compared to other systems. SBR system maintenance costs are higher due to intelligent controllers, automatic switches, and automatic valves. MLE and A_2O methods are closer to each other in terms of cost, which is due to the similarity of their process, with the difference that A_2O has an anaerobic unit, which increases the fixed and operating costs in this system.

3.3.3. Total cost

The total project cost ($) of WWTPs with SBR, MLE, and A_2O processes is shown in Figure 10. In terms of total shape, MLE costs are lower than SBR and A_2O, which is consistent with the results of the previous two tables, including operating and maintenance costs and manufacturing costs.

3.3.4. Comparison of cost per unit volume of wastewater flow

Table 7 summarizes the cost estimates of treated wastewater in mentioned methods. Eqs. (1)-(3) are applied to determine the plant cost and the cost per cubic meter of treated wastewater. The cost of project capital is multiplied by the cost of return The Capital Recovery Factor (CRF), which is

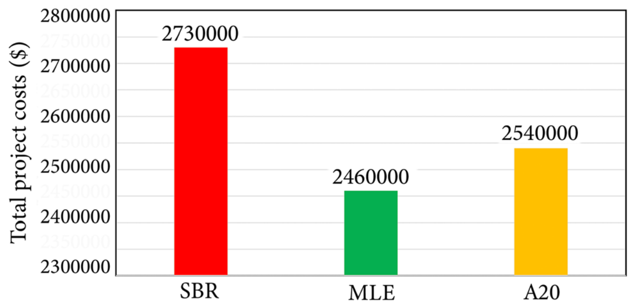

Figure 10. The total cost of different processes.

used to divide the total cost obtained by a set of parts equal to the interest rate (i = 8%) over the design year n = 25, leading to the annual cost of the project as below:

$$CRF = \frac{i(1+i)n}{(1+i)n-1} = \frac{0.08(1+0.08)25}{(1+0.08)25-1} = 0.0831 \quad (1)$$

$$\text{Annualized project cost } (/\text{yr.}) = \text{Total project cost} * \text{CRF} \quad (2)$$

$$\text{Cost/m}^3 = (\text{annualized project cost} + \text{annual Operational \& Maintenance cost}) \frac{\frac{1}{yr}}{\frac{(\text{average design flow} \times 365)\text{m}^3}{yr}} \quad (3)$$

Economic indicators for the choice of the method are the cost of construction and operation of plants, and Capital costs (Capex) and Operating costs (Opex) are the most commonly used indicators [32,35]. Using the proposed formulas and calculations, the data in Table 7 lead to the fact that the price per cubic meter of flow in the SBR process at 900 cubic meters per day is equal to 1.31$ per cubic meter. MLE and A_2O plants with the same capacity cost 0.96$ per cubic meter and 1.08$ per cubic meter, respectively. It should be noted that the method of calculating the cost of treated wastewater per cubic meter is the same as that used by Zahid [36].

The total costs of WWTPs, including construction, operation, maintenance, materials, chemicals, energy, and depreciation ($/year), are listed in Table 8. The cost-effective method is the method that has the lowest cost per cubic meter of wastewater treatment. Therefore, the MLE process is more cost-effective than the other two processes due to its lower cost.

4. Conclusion

This study has been performed for the technical and economic evaluation of three different wastewater treatment methods. For wastewater treatment in terms of quality from GPS-X software and economics of design from Capdetworks software according to the US equipment cost database (2014) and an estimate of construction costs in Iran was used. In this study, the Konark municipal Waste-Water Treatment Plant (WWTP) was analyzed. The current treatment method in this plant is Sequencing Batch Reactor (SBR). With help of simulation software, SBR and two other cases ((MLE) & A_2O) were designed and simulated to have a comparison. It was found that the current system SBR method has the highest costs among the three methods studied, and the MLE method has the lowest costs. Moreover, the removal efficiency of SBR reactors is less than MLE and A_2O methods. The Chemical Oxygen Demand (COD) removal for SBR, MLE, and A_2O was 89, 93.5, and 94.6%, respectively. However, SBR performance is better with 89% concerning phosphorus removal, while removal using MLE was 75.1%.

Considering that the A_2O method has the best removal efficiency and the MLE method is the most cost-effective method, it is reasonable to choose the optimal method. All three methods meet the desired wastewater quality at the outlet and are suitable for use in agriculture. So, the economic perspective, which is to choose a cost-effective method, will be a priority, so in this case, MLE was a better choice than SBR and it can be the best option to choose as it also meets desired wastewater quality at the outlet. However, it should be noted that MLE was so sensitive to the influent flow rate (sensitivity test result) so it should be borne in mind that in case of rising the inflow of wastewater, MLE cannot meet the demands. In general, economic considerations are a crucial factor in any plant design. Therefore, proper planning in process design and accurate cost estimation can lead to better engineering decisions.

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Conflict of interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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