Case Study

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Selection of Wastewater Treatment Plants Toward a Sustainable Design and Water Reuse: (A Case Study in the City of Mashhad)

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Abstract

The need for water reuse application in Mashhad which is the second largest city of Iran has been recognized in recent years. This need has forced local authorities to pursue upgrading the existing or installing the more advanced wastewater treatment plants for potential water reuse applications. However, the selection of suitable wastewater treatment train technologies is complex and may require a user-friendly tool to facilitate decision-making process for authorities, which is the focus of this paper. To advance the main focus of the study, this paper is prepared to develop and simulate various treatment train technologies based on multiple criteria analysis considering technical, social, economic, and environmental issues. The treatment technologies considered for simulations in this study include Moving Bed Bio Reactor, Integrated Fixed Film Activated Sludge, Sequencing Batch Reactor, Anaerobic/Anoxic/Oxic, and Modified Ludzack-Ettinger. At first, multiple simulations were performed and then a multi-criteria analysis was performed in order to select the most appropriate treatment technology. As part of this study, additional simulations were performed with respect to different sludge management alternatives including the utilization of energy produced from biogas. The overall results showed that A^2/O treatment technology is the most suitable treatment for producing a highly reliable effluent quality for sustainable use of water reuse. With additional local data collection, the methods and the preliminary simulations performed in this study can further be improved to enhance the current decision-making tool for possible future practical use in Mashhad and other cities in Iran.

Keywords: Wastewater Treatment Train, Multi-Criteria Approach, Simulations, Decision Support System.

1. Introduction

According to the World Water website (https://worldwater.io/), 41% of Iranian people are living in areas with water scarcity. The water scarcity in Iran is the result of both physical (inadequate natural water resources to supply demand) and economic factors (poor management of the available water resources) (Kayhanian and Tchobanoglous, 2016). To overcome water scarcity challenge, several strategies are proposed including demand-side management, improvement of water infrastructures, water desalination, and water reuse especially for the agricultural and industrial sectors. As part of sustainable water reuse, including potable reuse, several components including technical, regulatory and public outreach must be considered. These issues along with how to move forward with a systematic water reuse application in Iran were discussed in a series of articles by (Kayhanian and Tchobanoglous, 2018a, b, c).

The main technical and regulatory component associated with water reuse application is related to upgrading the existing Waste Water Treatment Plants[1] or selecting new generation of WWTPs for the production of a more reliable and higher effluent quality (Kayhanian and Tchobanoglous, 2018b). Besides the technical and regulatory issues, Kayhanian and Tchobanoglous argued that, for sustainable use of water reuse, Iran must also seriously consider the other important issues such as social and economic issues. Moreover, the importance of using satellite wastewater treatment instead of using the traditional centralized WWTPs was highlighted.

The selection of urban wastewater treatment may involve three levels of decision making (Lemma and Suarez, 2017). The first level of decision making is strategic (i.e., urban planning and general environmental policies), that indirectly affect the design and operation of the water cycle. This level involves high uncertainty and risk. Under the second level of decision making, the combination of appropriate technologies is selected to achieve specific goals and overcome environmental constraints. Finally, under the third level of decision making, the detailed design of treatment plants is performed which has the least uncertainty. The selection of suitable technology for WWTPs is of crucial importance to meet possible demand as well as satisfying regional restrictions and improving ecosystem health (Bertanza et al., 2017). Because of the complexity of decision making process associated with selecting appropriate treatment technology or treatment train technologies, this study is undertaken with the aim of developing a user-friendly decision making support tool for authorities in the city of Mashhad, Iran.

Our literature review revealed that, similar studies were performed in other geographical regions using different criteria. For example, (Hasan et al., 2019) studied different technologies and found Up-flow Anaerobic Sludge Bed[2] reactor followed by an aerobic process such as Down-flow Hanging Sponge[3] process as a promising technology to reach high Biochemical Oxygen Demand[4] removal efficiency with low cost in India. Several technologies such as Integrated Fixed-film Activated Sludge[5], Extended Aeration[6], Aerated Lagoon[7], Sequential Batch Reactor[8], Absorption Bio-oxidation[9] technologies were evaluated by Analytic Hierarchy Process[10] method from technical, economic, and environmental aspects, and IFAS technology was recognized as superior technology in Iran (Karimi et al., 2011a). Moreover, Karimi et al. used the fuzzy order preference by Technique for Order of Preference by Similarity to Ideal Solution[11] and fuzzy AHP methods for selection of the treatment process in Iranian industrial sites. These processes were UASB, Up-flow Anaerobic Fix-Bed Reactor[12], Anaerobic Baffled Reactor[13], Contact process, and Anaerobic Lagoon. The results showed that the UAFB and ABR were the most appropriate anaerobic treatment processes (Karimi et al., 2011b).

Pausta et al. focused on the selection of the optimum Biological Nutrient Removal[14]system that can be applied using the Analytical Network Process[15] considering the economic, technical, and environmental aspects as well as the space requirement. The alternative technologies were A^2/O, 5 Stage Bardenpho (5BP), University of Cape Town[16] Virginia Initiative Plant, SBR, and Membrane Bio-Reactor[17]. Results showed that the SBR was the optimum BNR system in urban areas. To make the decision making tool more robust, we enhanced the excising tool by adding the other important critical topics such as economic, environmental and social criteria (Pausta et al., 2017).

In this regard, an Environmental Decision Support System[18] which was called Novedar_EDSS, integrated

[1] Waste Water Treatment Plants (WWTPs)

[2] Up-flow Anaerobic Sludge Bed (UASB)
[3] Down-flow Hanging Sponge (DHS)
[4] Biochemical Oxygen Demand (BOD)
[5] Integrated Fixed-film Activated Sludge (IFAS)
[6] Extended Aeration (EA)
[7] Aerated Lagoon (AL)
[8] Sequential Batch Reactor (SBR)
[9] Absorption Bio-oxidation (AB)
[10] Analytic Hierarchy Process (AHP)
[11] Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)
[12] Up-flow Anaerobic Fix-Bed Reactor (UAFB)
[13] Anaerobic Baffled Reactor (ABR)
[14] Biological Nutrient Removal (BNR)
[15] Analytical Network Process (ANP)
[16] University of Cape Town (UCT)
[17] Membrane Bio-Reactor (MBR)
[18] Environmental Decision Support System (EDSS)

technical, environmental, economic, and social assessment to support the selection of the most appropriate strategy for WWTPs (Castillo et al., 2016). Different case studies from Italy and the USA were performed to demonstrate and validate the application of the tool for different relevant problems.

Moreover, the costs (investment, operating, and maintenance costs) and environmental criteria (i.e. Chemical Oxygen Demand[1] removed) were previously used to evaluate three different treatment pathways including Oxidation Ditch[2], Intermittent Cycle Extended Aeration System[3], A^2/O (Chen et al., 2018). The ICEAS technology had the lowest investment cost while A^2/O was selected as the best choice by the multi-objective decision model.

Minhas and Bakshi compared three technologies such as Moving Bed Biofilm Reactor[4], SBR, and Soil Bio-Technology[5] by different criteria such as BOD removal, the land area, energy requirement, operational and maintenance issues, sludge characteristics, amounts of excess sludge, extending capacity, and quality of treated water. Results showed that the SBT technology had the highest priority due to low cost, high efficiency in BOD and COD removal, efficient removal of pathogens, low odor, eco-friendly technology, no need for skilled labor, and non-use of chemicals (Minhas and Bakshi, 2017).

On the other hand, the energy efficiency is crucial for WWTPs because of increasing energy costs and concerns about global climate change (Yifan et al., 2017) as well as population growth and increased regulatory control of water quality discharge standards (Alizadeh et al., 2020). Energy optimization can be achieved through energy recovery and utilizing energy-efficient technologies.

Energy self-sufficient WWTPs and carbon-neutral (zero greenhouse gas emissions) WWTPs are different, although carbon neutrality is often referred to in its narrow definition: energy neutrality (Hao et al., 2015). Energy self-sufficient WWTPs commonly refer to WWTPs generating their energy requirement from the energy embedded in the water and wastes (Schaum et al., 2016; Svardal and Kroiss, 2011).

Two complementary aspects are required to realize energy self-sufficiency in WWTPs:

(1) Most wastewater treatment facilities have the potential to reduce their energy input by 30% or more through energy efficiency improvement measures and treatment process modifications (Means, 2004).

(2) The use of biogas for digester heating and electricity generation is a sustainable way of recovering energy from WWTPs with subsequent sludge reduction (Wett et al., 2007; Bennett, 2007). Compared with WWTPs without sludge digestion, WWTPs with sludge digestion consume 40% less net energy on average (Scott et al., 2011). Combined Heat and Power[6] using biogas from the anaerobic digestion of sludge may be adopted in the existing energy self-sufficient WWTPs (Movahed and Avami, 2020).

Due to high electricity consumption, the Combined Cooling, Heating, and Power[7] system fueled by biogas generated in Anaerobic Digester[8] has been utilized (Silvestre et al., 2015).

The micro-scale fuel cells, reciprocating engines, and gas turbines are used as prime movers in CHP plants. Many researchers endeavored to integrate the cogeneration systems with AnD in WWTPs. Silvestre et al. investigated five WWTPs in California to supply 39-76% of total electric energy demand from the biogas with a payback time of 2-3 years (Silvestre et al., 2015).

Helal et al. compared a hybrid power system of AnD and fuel cell, micro-turbine, wind turbine, and photovoltaic system for the WWTP in Egypt (Helal et al., 2013). The fuel cell had the lowest emission. When the integrated fuel cell with the micro gas turbine system was utilized, the power to heat ratio was maximized to the value of 5.076.

Nowak et al. studied two advanced self-sufficient WWTPs in Austria that employed the CHP system, heat pump, and a co-digestion system fed with organic waste and concentrated wastewater. As a result, the energy generated surpassed up to 180% of energy generation compared to ordinary WWTP (Nowak et al., 2015). Another analysis studied the integrated CHP system containing micro gas turbine, heat exchanger, Heat Recovery Steam Generator[9], and AnD in a WWTP (Lee et al., 2017). Therefore, it is necessary to optimize the integrated AnD-CCHP system in a real WWTP in terms of energy and economics, and the environment.

In summary, besides the technical component, the aim of selecting wastewater treatment systems for water reuse in developing countries may also focus on reducing energy consumption, decreasing environmental impact, while minimizing costs. The economic parameters (i.e., investment costs) are widely considered to compare treatment pathways in the literature. Concerns about sustainability during the decision-making process involve environmental issues (Garrido-Baserba et al., 2015).

[1] Chemical Oxygen Demand (COD)
[2] Oxidation Ditch (OxD)
[3] Intermittent Cycle Extended Aeration System (ICEAS)
[4] Moving Bed Biofilm Reactor (MBBR)
[5] Soil Bio-Technology (SBT)
[6] Combined Heat and Power (CHP)
[7] Combined Cooling, Heating, and Power (CCHP)
[8] Anaerobic Digester (AnD)
[9] Heat Recovery Steam Generator (HRSG)

However, technical and environmental parameters such as removal efficiency and quality of treated water and sludge production are highly dependent on the influent characteristics, weather conditions, and environmental regulations. These aspects are not previously studied in the city of Mashhad, Iran. Moreover, social parameters such as acceptability and ease of use of technologies are less considered in the literature. Different technical, economic, social, and environmental aspects interact with each other in the wastewater treatment. It is necessary to engage with other stakeholders to meet different goals. Thus, a decision support tool is here required to study the complex situation in the city. This work investigates different pathways for WWTPs and proposes a framework to select the optimal choice regarding the specific conditions in the city which is not previously studied. Thus, the focus of this study is to perform multiple analyses using different treatment alternatives through a multi-criteria approach, including technical, operational, environmental, social, energy use, and cost issues using both quantitative and qualitative information. Some critical parameters like the influent specifications, the weather condition (the air temperature, humidity, the number of rainy days), available land, and the affordability and acceptability of treatment technologies should be investigated to determine the priority of technologies in the region. Then, the assessment of the sludge management technologies to increase the degree of energy self-sufficiency of the WWTP is evaluated.

In the rest of the paper, the case study is introduced at first. Then, Section “Materials and Methods” describes the methodology. The results are then discussed while Section “Conclusion” concludes the work briefly.

2. Some relevant information about the case study area

The city of Mashhad is the capital of Khorasan Razavi province of Iran, which has about 204 square kilometers in the area; this city is located between Binalood and Hezaran Masjed Mountains and in the Kashaf basin. The altitude of this city from sea level is 985 m (Alizadeh et al., 2020). The climate of the city is temperate, cool, and dry. The average annual precipitation in the statistical period of (1997-2017) is 230 mm per year (Iranian Weather Organization, 2018). The total rainfall of the city in 2017 is reported to be 238 millimeters while the minimum and maximum values of relative humidity are 26.7 percent and 63.1 percent in this year, respectively. The average relative humidity is 53% (Iranian Weather Organization, 2018). The average annual temperature of Mashhad city is 15.7 °C during 1997- 2017 (Iranian Weather Organization, 2018). The values of mean, absolute maximum, and minimum temperatures in 2017 are -13 °C, 42.2 °C, and 16.2 °C, respectively. Meanwhile, the average annual number of ice days in Mashhad is 85 days (Iranian Weather Organization, 2018).

This city with about a 3 million population is the second most populated city in Iran (Statistical Center of Iran). In addition, this city attracts millions of tourists annually. The influent characteristics of the wastewater are presented in Table 1. Regarding the high organic load of wastewater and the presence of nutrients in this wastewater, the development of advanced methods for wastewater treatment, removal of harmful substances, as well as the recovery of its useful materials is necessary (Alizadeh et al., 2020).

Table 1. Wastewater influent characteristics

Parameter	Unit	Values [present work]	Global range (Metcalf and Eddy, 2014)
Average flow rate	m^3/day	75000	-
COD	mg/L	761	250-800
TSS	mg/L	279	120-400
NH_3	mg/L	71.5	20-70
BOD	mg/L	379	110-350

3. Materials and Methods

The decision-making process for proper selection of new WWTPs technologies to be considered for sustainable water reuse application in the city of Mashhad is presented here by the following four steps.

3.1. Step 1: construct the superstructure

In the superstructure, a variety of treatment pathways are considered to choose the final technology for the city of Mashhad. They include SBR, MLE, A^2/O, MBBR, and IFAS processes for wastewater treatment and Gravity Belt Thickener[1], AnD, Belt Filter Press[2], Centrifuge, Multiple Hearth Incineration[3], Fluidized Bed Incineration[4] for sludge management. Fig. 1 shows the superstructure of present work to select the best possible WWTPs pathway for the city of Mashhad. Generally, the sewage passes through multi-stage screens: it first enters the primary treatment followed by secondary and then enters to advanced treatments. The primary and secondary clarifiers and two equalization tanks are required for some technologies as shown in the Fig. 1. The equalization tanks have been used in SBR technology to increase the shock resistance. Although additional treatment is costly, it is environmentally very

[1] Gravity Belt Thickener (GBT)
[2] Belt Filter Press (BFP)
[3] Multiple Hearth Incineration (MHI)
[4] Fluidized Bed incineration (FBI)

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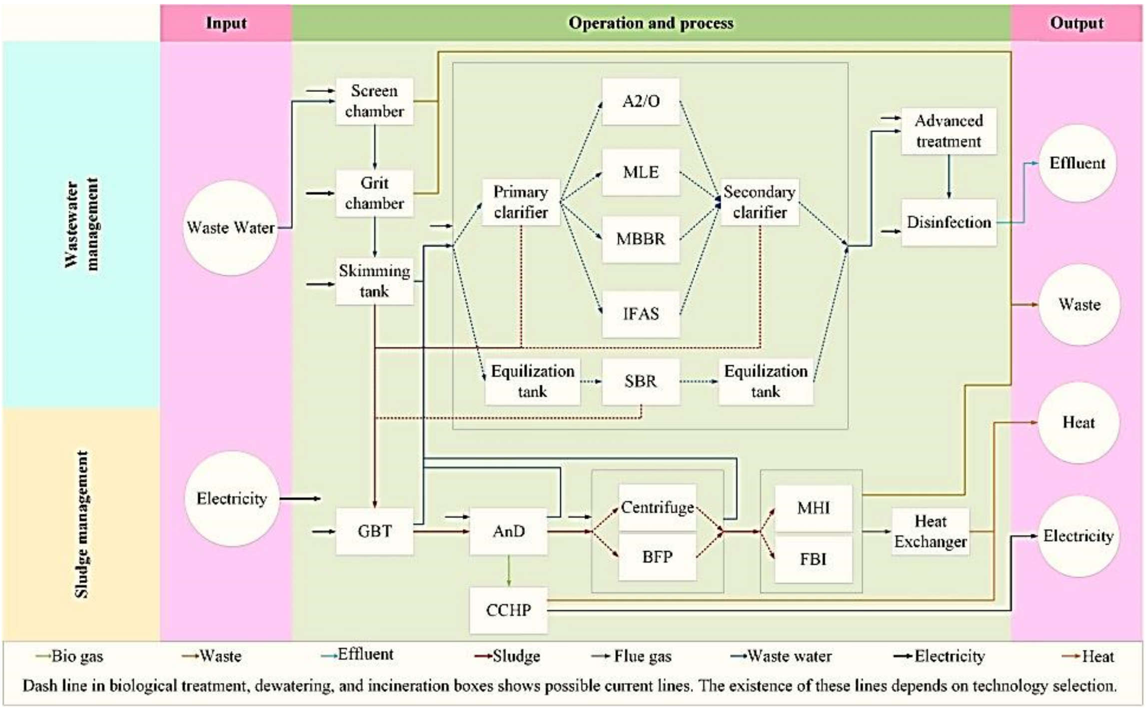

Fig. 1. The superstructure of treatment trains used for present simulation study

beneficial due to water and energy saving gained from water reuse (Awad et al., 2019). Therefore, an advanced purification step for de-nitrification is considered for all pathways. Consequently, the concentration of ammonium and nitrite will be negligible.

Since AnD has several advantages in comparison to aerobic digestion to stabilize the sludge both economically and environmentally in the city (Movahed and Avami, 2020, Rostami et al., 2020), this process is considered as the stabilization technology and for energy production from sludge after thickening process. The CCHP systems are considered after AnD to burn biogas and generate heat and power. The digested sludge from AnD enter to dewatering stage and then are incinerated to reduce the volume of waste.

3.2. Step 2: simulate pathways

Each path is simulated by Capdetworks4 software to provide the data for the next steps. The following assumptions are considered:

- Influent specifications are the same for all routes as shown in Table 1, since this study is aimed at the second level of decisions to select the best choice under the equal land conditions, the geographical constraints are not considered to design the plants,
- The intermediate pumping stations are not considered for the second level of decisions,
  The CCHP technology is modeled according to the Capstone microturbine catalog. The Capstone C200 microturbine is an adaptable, low-emission, and low-maintenance power generation system.
- According to the currents temperature and overall heat transfer coefficient, the area of the heat exchanger, and then the purchased cost is calculated (Peters and D.Timmerhaus, 1991).

3.3. Step 3: define criteria

After each path is simulated, the results are evaluated from a technical, economic, environmental, and social perspective, and then the treatment technologies are prioritized. The criteria are defined from expert opinions, consultation with the representatives of the WWTPs participating in this case study, and from other studies reported in the literature. The criteria were selected in a manner that they have the least overlap with each other. Some questionnaires were also prepared and distributed among experts representing different stakeholders whom we assumed to be most familiar with the regional conditions. The information gathered were organized under technical, economic, environmental, and social criteria to perform situations.

3.4. Step 4: determine the weights and final score

The values for each criterion which were estimated in the simulation step, were normalized by dividing them by the least value of each criterion. This is a common procedure to ensure that the measuring units of each

Table 2. Weighted results based on multiple prioritization decision criteria

Priority	Criteria	Weight
1	Operation and maintenance costs	0.23
2	Effluent characteristics	0.21
3	Investment cost	0.2
4	Ease of use	0.15

criterion do not affect the results. Thus, we have a dimensionless scale for each criterion in all pathways in which its value varies between 0 and 1. Once they are normalized, different weights may be assigned to them to incorporate the preferences of stakeholders and decision-makers. To determine the weights, we ask the experts to prioritize the criteria. The results of this survey are shown in Table 2. The best alternative is the one that has the highest score. This methodology was found to be the most useful method for choosing the best technology pathway based on the preferences selected by stakeholders and decision-makers.

As can be noted in Table 2, the operation and maintenance costs are among the highest priority and the need for additives is the least priority according to this survey.

The Capdetworks4 software was also used to simulate the sludge management. For these simulations, four scenarios were used that include BFP and MHI (first scenario), the BFP and FBI (second scenario), the Centrifuge and MHI (third scenario), and the Centrifuge and FBI (fourth scenario). These scenarios were compared in terms of economic and total electrical energy required for each system.

According to Capstone C200 microturbine characteristics, the heat and power efficiency are derived as 40% and 33% with the average temperature of Mashhad city, respectively. For incineration technology, the exhaust gas heat can be recovered through a heat exchanger.

4. Results and Discussion

The criteria for sustainable assessment are the economic issues and environmental parameters such as removal efficiency (Alizadeh et al., 2020). The removal efficiency of some important characteristics which are of great importance for water reuse such as BOD, COD, and NH_3/NH^{4+} is shown in Fig. 2. The removal efficiencies are high enough such that the quality of treated water is in agreement with regional standards and restrictions. In all cases, the addition of advanced treatment has improved the quality of effluent.

Fig. 3 shows the comparison of different treatment train technologies in terms of different normalized cost criteria. As shown in Fig. 3, there is a slight difference between the investment cost of A^2/O, MLE, and MBBR

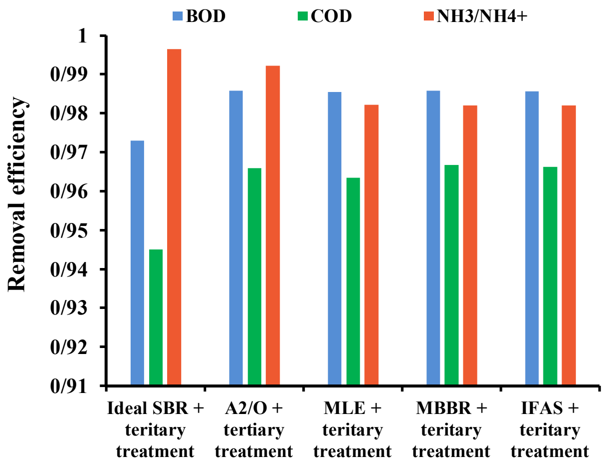

Fig. 2. Results of removal efficiency for selected constituents under different treatment train pathways

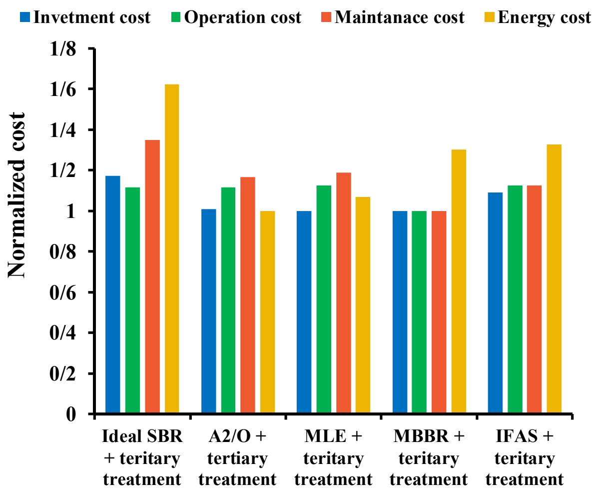

Fig. 3. Results of normalized cost for different treatment train pathways

technologies. The most attractive wastewater treatment technologies based on investment cost are

$$\text{MLE}, \text{MBBR}, \ A^2/\text{O} > \text{IFAS} > \text{SBR} \qquad (1)$$

The required land and indirect costs like technical cost and engineering design for SBR are more than other processes. Because of batch structure of SBR technology, the need for more technical labor and its high energy requirements, its operation and maintenance costs are more than other processes. The operation and maintenance costs are very close to each other for both A^2/O and MLE technologies. The most attractive technologies based on the operation and maintenance costs are

$$\text{MBBR} > \text{IFAS} > A^2/\text{O}, \text{MLE} > \text{SBR} \qquad (2)$$

The use of chemical additives leads to adverse environmental effects. Therefore, new WWTPs are aimed to minimize them. The most attractive sewage treatment technologies based on the use of chemical additives are

$$A^2/O > MLE > SBR > MBBR > IFAS \quad (3)$$

The greater the energy consumption, the higher the indirect Green House Gas[1] emissions. The SBR technology requires more energy than other processes and consequently, more GHGs will be emitted indirectly by utilizing this technology. Based on this criterion, the most attractive technologies are as follows

$$A^2/O > MLE > MBBR > IFAS > SBR \quad (4)$$

The lower the amount of sludge production, the lower the cost of sludge management and the less environmental effects of sludge production. The most attractive technologies with respect to sludge management are

$$MBBR > SBR > MLE > A^2/O > IFAS \quad (5)$$

Since AnD is used for the stabilization of sludge in all pathways, biogas is produced in WWTP. The amounts of energy produced from biogas depend on the characteristics of produced sludge from different technologies. The most attractive technologies for biogas production are

$$IFAS > MLE > A^2/O > MBBR > SBR \quad (6)$$

The organic sludge content of the sludge produced from the MLE process is larger than the A^2/O process. So, the amount of energy production is higher. Although the SBR sludge production is moderate (Eq. 5), the potential for energy production is the lowest among all pathways because of its low quality for energy production (Eq. 6).

It is worth mentioning that there were previous experiences utilizing SBR and MLE-based WWTPs in the city of Mashhad (Alizadeh et al., 2020). However, the optimal use of the SBR process requires advanced and specialized operational knowledge and hence makes it less attractive compared with MLE. Considering this fact, the most attractive options for the city are

$$MLE,\ A^2/O > SBR > MBBR,\ IFAS \quad (7)$$

The summary of score of all treatment train pathways based on different criteria is presented in Table 3. The most attractive treatment train technologies in each criterion get scores of 5 and the other treatment rain technologies get an increment of one lower score. Combining all scoring criteria, the most attractive treatment train technologies for the city of Mashhad are as follows

$$A^2/O > MLE > MBBR > IFAS > SBR \quad (8)$$

The SBR technology has been used in 1.3% of Germany's sewage treatment plants (Lemma and Suarez, 2017). These units are suitable for small refineries. Their experience of using them demonstrates that the SBR is suited for small sizes with skilled personnel (Lemma and Suarez, 2017) and with high controlled equipment (Means, 2004). On the other hand, the MBBR technology produces less sludge (Table 4). But it is necessary to separate the media for cleaning and to make the refinery more qualitative. Due to the lack of previous operating experiences in the city of Mashhad and other parts of Iran, the use of this technology is not recommended at present time. In general, the performance of MLE and A^2/O treatment train technologies are fairly the same and hence they were given the same preference. However, since the presence of phosphorus compounds will help to reduce the consumption of fertilizer, the MLE treatment train technology is considered more suitable treatment for reuse of effluent water in the agricultural sector. In all other water reuse applications, more preference is given to A^2/O treatment train technology since it will bemore reliable with higher effluent water quality.

In the sludge management section, the scenarios have been compared in terms of economic and total electrical energy required of the system. The first scenario has been selected and Fig. 4 and 5 show the results.

Therefore, optimal treatment train technologies based on sludge management are GBT, AnD, BFP, and MHI, respectively. The heat exchanger system is considered after the incineration process to recover heat from the hot gases of the stack. If the efficiency of heat recovery is assumed to be 80 percent, approximately 4975 kW of heat will be recovered from the exhaust gases.

According to the capacity of the system, 5 Capstone C200 microturbines are required for this system after AnD. Heat recovery and power generation from CCHP are 1158 kW and 955 kW. Total electricity requirement of the system is approximately 4480 kW.

Thus, 41.5% power requirement of the plant can be supplied with electricity generation from biogas. All of the recovered heat is 6133 kW. The required heat of AnD is 598 kW that can be supplied by recovered heat. The excess heat can be used for space heating of buildings. Finally, the capital and operation and maintenance costs of the sludge management without heat recovery (first phase) and with heat recovery (second phase) were compared. The result of this comparative analysis is shown in Fig. 6.

[1] Green House Gas (GHG)

Table 3. Summary score for treatment train pathways simulated for the city of Mashhad

Criteria	Weights	SBR	MLE	A^2/O	MBBR	IFAS
Operation and maintenance cost	0.23	2	3	3	5	4
Effluent characteristics	0.21	5	5	5	5	5
Investment cost	0.2	3	5	5	5	5
Ease of use	0.15	1	5	4	3	2
Energy requirement	0.14	1	4	5	3	2
Use of additive	0.07	3	4	5	2	1
Total score	1	2.61	4.33	4.39	4.21	3.42

Table 4. Comparison of different treatment train technologies based on various environmental and social criteria

Criteria	SBR	MLE	A^2/O	MBBR	IFAS
Greenhouse gas (GHG) emissions	1	4	5	3	2
Biogas production	1	4	3	2	5
Volumetric flow of sludge produced	4	3	2	5	1
Level of available expertise	2	3	3	1	1
Technology acceptance	2	1	3	1	1
The ability for domestic construction of technology	3	3	2	1	1

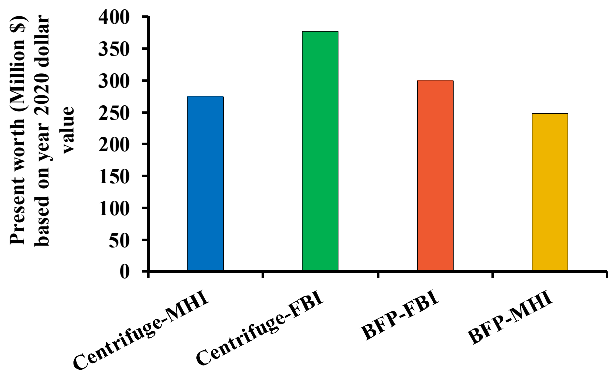

Fig. 4. Comparison of four different treatment train technologies simulated based on present worth values

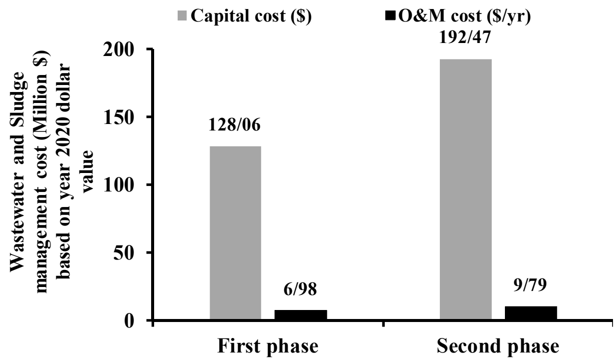

Fig. 6. Cost comparison for sludge management under two scenarios: without heat recovery (phase 1) and with heat recovery (phase 2)

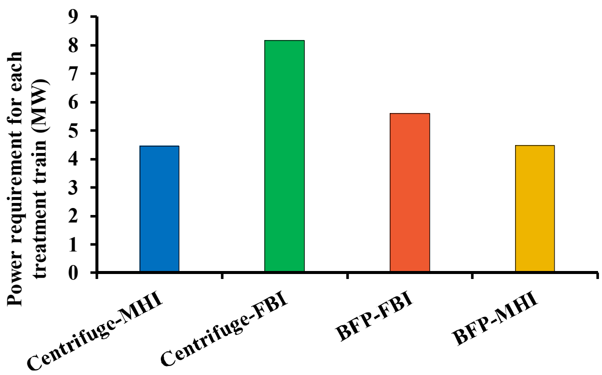

Fig. 5. Electrical energy requirement for four different simulated treatment train technologies

5. Conclusions

This work investigates different wastewater treatment train pathways to select the optimal choice for water reuse application in the city of Mashhad based on specific criteria. Various simulations were performed under various technical, economic, operational, environmental, and social perspective, and the results were compared and prioritized. When prioritizing each treatment train technology, sludge management issues were also considered. Sludge management treatment considered include GBT, AnD, BFP, and MHI.

The heat exchanger system is considered after the incineration process to recover heat from the hot gases of the stack. Total recovered heat and generated power from CCHP are 1158 kW and 955 kW. Total electricity requirement of the system is approximately 4480 kW. With this explanation, the 41.5% power requirement of the plant can be supplied and supported with electricity generation from biogas.

Total recovered heat from CCHP and heat exchanger is 6133 kW and the required heat of AnD is 598 kW that can be supplied by recovered heat. Sewage sludge management has eliminated sludge flow from the treatment plant. Another advantage of sewage sludge management is that the WWTP is self-sufficient in supplying a significant portion of its energy needs. Based on the above multi-objective criteria, our numerous simulations results revealed the following priority ranking for the selective treatment train technologies

$$A^2/O > MLE > MBBR > IFAS > SBR$$

It is worthwhile to note that if the wastewater treatment effluent is only intended for agricultural irrigation use, then there may be no need for employing the phosphorus removal technologies. Under this scenario, the use of MLE is as favorable as A^2/O.

This preliminary decision-making tool presented in the current study demonstrated that it is possible to compare the overall performance of various treatment technologies and select the most suitable treatment trains before implementing them on a large scale within urban cities. However, the simulations results require a much more reliable local data related to treatment, maintenance, operation, cost, social and environmental issues collected in Iran for practical purposes.

The other issue that is worthwhile to pursue and was not considered in this paper is to compare the performance and practical use of centralized treatment train technologies versus multiple satellite treatment trains.

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