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Performance evaluation of a facultative aerated lagoon for the purpose of reviewing the design parameters

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Axial dispersion;
Gorveh wastewater treatment plant.

Abstract. Evaluating the performance of a facultative aerated lagoon in a semi-humid region in Iran shows that the design parameters, used for dimensioning these types of wastewater treatment facility, which were derived from foreign references, do not match the real values. The need to review those parameters to achieve a more realistic and cost effective design is, therefore, obvious. In addition to suggesting more reasonable design parameters to be of benefit for dimensioning these plants in Iran, computing the overall BOD removal rate based on real qualities of wastewater, which can be used in a theoretical approach to dimensioning, ensures a more accurate design compared with a design based on an assumed detention time, as is currently usual in Iran. Accurately designing facultative aerated lagoons, widely used in Iran, would lead to cost saving due to decreasing the dimensions of the downstream lagoons. Thus, the obligation to apply the real quality parameters obtained in this study to new designs is proven.

1. Introduction

In Iran it has been proved that the design procedure, including choosing the initial design parameters, has affected the performance of wastewater treatment plants [1]; besides determining the qualitative parameters according to the climate will enhance the efficiency of the sewage treatment plants [2].

Mechanically aerated lagoons are basically earthen basins, generally 2.5-5 m deep, provided with mechanical aerators installed on a float or fixed columns. Aerated lagoons permit a considerable amount of flexibility in design that includes facultative aerated lagoons (partially mixed), aerobic flow-through (completely mixed) and aerobic with sludge recycling (extended aeration). Facultative aerated lagoons are more efficient than anaerobic ponds while less efficient than extended aeration lagoons [3]. The initial design and economic estimation of small wastewater treatment plants are issues of particular interest since wastewater from most of these accumulations is not yet covered yet [4]. Rural communities generally use a series of aerated lagoons to treat domestic wastewater. Effluents from these systems are typically discharged to receiving watersheds, which leads to a potential transfer of Pharmaceuticals, Personal Care Products (PPCPs) and steroid hormones from sanitary sewage to the surrounding. The discharge of effluents meaningfully increases the PPCP concentrations in the receiving creek and raises their event in the adjacent river [5]. Macleaod and Charles indicated that measured loadings, weighted by a population served by WWTPs, are an excellent predictor of other effluent concentrations, even between different treatment types. Temporal changes in chiral drug EFs were observed in the effluent of aerated lagoons, and some differences in EF were found in WWTPs [6]. Gagné et al. showed that

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the exposure of freshwater mussels to treated aerated lagoon wastewater is harmful, where their immune system is compromised [7]. Kim et el. determined PBDE levels in influent, primary effluent, and final effluent collected from diverse treatment processes, including four aerated lagoons, two facultative lagoons, four primary treatments, eight secondary biological treatments and two advanced treatments [8]. Liu et al. represented a method for the design of a distribution treatment system with a single contaminant. They demonstrated that for a system with only one treatment process, the obtained design with a minimal amount of treatment has minimum cost. Also, for a system with two treatment processes, the key issue is to optimize them, analytically. Additionally, they found that for some systems, when the cost ratio of the treatment processes changes, the optimal system structure changes as well [9]. Pedro et al. presented a new method for the optimal design of wastewater treatment systems [10]. Karuppiah and Grossmann integrated water, using processes and water treatment operations, into total networks, such that the total cost of obtaining freshwater and treating wastewater is minimized [11]. Puig et al. indicated that poor quality of WWTP data leads to large errors in key process parameters, such as SRT and conversion rates. They presented a practical stepwise methodology, in which mass balances and data reconciliation techniques were applied on full-scale WWTP data. Their results showed that by improving the data quality using mass balance calculations, useful new information becomes available for process evaluation, WWTP design and benchmarking [12]. Differences in a ciliate community because of key design parameters, including anoxic/anaerobic stages and suitable bioindicator species for performance evaluation, were determined by Dubber and Gray [13]. A Knowledge-Based Methodology (KBM) for the conceptual design of a wastewater treatment plant (WWTP), Process Flow Diagrams (PFDs) and their application to two scenarios, is presented by Garrido-Baserba et al. [14].

For Gorveh city, primarily, it was planned to erect an anaerobic pond, in combination with facultative stabilization ponds. However, afterwards, for various reasons, including fear of the possibility of odor emission, it was basically changed to facultative aerated lagoons by installing floating aerators. Because exact qualitative and quantitative parameters were unavailable while dimensioning the whole sewage plant for Gorveh, they were chosen by referring to foreign references, including Metcalf and Eddy Inc. [15], which did not match the real wastewater quality conducted to the plant.

This study evaluates the performance of the facultative aerated lagoon and subsequently compares it with well-known references to suggest design values that help to produce a more realistic design, ensuring capital cost decreases as well as improvement in the effluent quality.

The results of this study are aimed at supporting experts who undertake the role of dimensioning wastewater treatment plants in the country by correcting various design defects, so that the final goal of establishing environmentally beneficial wastewater treatment plants is achievable.

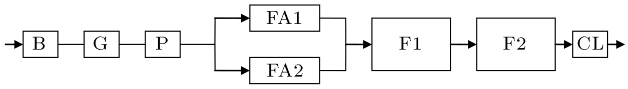
2. Materials and methods

2.1. Specifications of the plant

Gorveh city, in Iran, is categorized as a semi-humid region, having long cold winters and gentle summers. The average maximum annual temperature is +14°C, average minimum annual temperature is 0.8°C, and average annual precipitation amounts to 349 [16]. The plant is supposed to treat 16,000 m^3/d of wastewater, which is equal to 80,000 inhabitants. After screening and degritting, wastewater is conducted to two parallel facultative aerated lagoons followed by two facultative ponds in series. Figure 1 show the flow diagram of the plant which is under operation. Specifications of the units of the plant are included in Table 1.

2.2. Analyzed parameters

The basis for the analyses performed in this study is the laboratory tests conducted by the quality control laboratory of the operating company (Kurdistan Water



B=Bar screen G=Grit chamber P=Parshall flume

Figure 1. Schematic flow diagram of the plant.

Table 1. Specifications of the units of the wastewater treatment plant.

Unit's name	Area	Water depth	Volume	Average hydraulic detention time	Long-time average flow
	(m^2)	(m)	(m^3)	(d)	(m^3/d)
Aerated facultative lagoons	5,000	4	20,000	4.81	4,155
Facultative ponds	50,000	1.5	75,000	9	8,311

and Wastewater Company), which have been fulfilled in accordance with the standard method APHA [17]. With regard to its objective of reviewing the design parameters associated with the facultative aerated lagoons, this study assesses parameters, including BOD, PH, SS, Total Fecal Coliform and Sulfate. Moreover, the overall BOD removal rate constant of the incoming wastewater, which plays an important role in the theoretical approach to dimensioning the facultative lagoons in new designs, is also assessed.

2.3. Basic parameters used for dimensioning the existing plant

As mentioned, primarily, it was planned that the existing facultative aerated lagoon should serve as an anaerobic pond and, thus, the basic design parameters included in the planning report of the plant were chosen accordingly. Mara suggests a BOD loading of 100 g/(m^3.d) for the average temperature of the coldest month, lower than 10°C, as a design criterion for anaerobic ponds [18]. According to the above criterion, the dimensions of the anaerobic pond were determined. Table 2 shows the assumed quality of the influent wastewater which, as previously said, was not obtained by performing pilot studies but derived from foreign references.

2.4. Estimating the overall BOD removal rate (K_L) under field and standard conditions

According to Arceivala, two approaches are available for dimensioning the facultative aerated lagoons [3]. One assumes a detention time which varies from 3 to 12 days, thus the dimensions of the lagoon can be determined. The other one is a theoretical approach which needs the exact overall BOD removal rate. In the theoretical method, the flow may be considered as ideal plug flow or ideal completely mixed. For the plug flow regime, the relation between parameters is as follows [3]:

$$S = S_0 \times e^{(-K_L.t)}, \tag{1}$$

where:

S	effluent BOD (mg/l);
S_0	influent BOD (mg/l);
K_L	overall BOD removal rate (d^{-1});
t	detention time (d).

Table 2. Assumed quality of the raw wastewater as considered in the primary design phase.

Factor	Unit	Value
BOD	mg/l	250
SS	mg/l	330
Fecal coliform	MPN/100 ml	10^7

For the completely mixed flow, the equation is as follows [3]:

$$S = S_0/(1 + K_L.t), \tag{2}$$

where the terms are as defined previously. Within this study, the value of K_L is estimated considering the influent and effluent quality of the wastewater, as has been described, in order to achieve a more realistic design when dimensioning new facultative aerated lagoons. The following steps were taken for estimating the K_L.

2.5. Estimating the BOD values at field condition

Since measuring the BOD was fulfilled under standard conditions (20°C and 5 days), BOD values have been computed under field conditions, which refer to BOD at wastewater temperature in the lagoon. For the purpose of estimating the K_L at the temperature of wastewater in the lagoon, K_L(TW), Eqs. (3) and (4) were used as follows [19]:

$$\text{BOD}_{\text{TW}} = 0.68 \times \text{BOD}_5(1 - e^{(-K1\times5)}), \tag{3}$$

$$\text{TW} = (A \cdot f \cdot T_a + Q \cdot T_i)/(A \cdot f + Q), \tag{4}$$

where:

TW	wastewater temperature at lagoon (°C);
BOD_{TW}	BOD at the temperature of wastewater in the lagoon (mg/l);
$K1$	first order reaction constant = 0.31 d^{-1} [19];
A	lagoon surface area = 4,000 m^2;
f	proportionality factor = 0.49 m/d [19];
T_a	ambient temperature (°C);
T_i	influent wastewater temperature (°C);
Q	flow (m^3/d).

2.6. Estimating the K_L

The values of K_L were obtained using Eqs. (1) and (2). After obtaining the K_L at the temperature of TW, it was also calculated at 20°C for the purpose of comparing the calculated value with the values cited in the literature. Eq. (5) was used for this purpose [3]:

$$K_L(TW) = K_L(20) \times 1.035^{(TW-20)}, \tag{5}$$

where the parameters were introduced as before. At the next step, for a more realistic estimation of K_L, it was also calculated, considering the real flow regime in the tank. The flow regime was determined by obtaining the dimensionless ratio, $D/(U.L)$, as follows:

$$D/(U.L) = (D.t)/L^2, \tag{6}$$

Table 3. Derivation of the statistical parameters for examined factors.

Factor	Mean	Standard deviation	Coefficient of Kortosis	Coefficient of Skewness	Coefficient of variation	Distribution pattern
BOD (mg/l)	220	64	0.8	-68	0.29	Normal
SO_4^{-2} (mg/l)	45	36	14	3.06	3.06	Log-normal
SS (mg/l)	400	260	2.8	1.5	0.65	Normal
Fecal coliform (MPN/100 ml)	1.2×10^{11} (Geo-metric)	4.5×10^{12}	4.4	2.39	35.7	Normal
PH	7.7	0.18	0.09	-0.1	0.0228	Normal

where:

- L the length of the tank (m);
- t the detention time (m/d);
- U fluid velocity (m/d);
- D coefficient of axial dispersion (m^2/d) which, according to Arceivala [3], can be estimated by Eq. (7) for a lagoon with a width of W less than 30 m:

$$D = 16.7 \times W. \tag{7}$$

3. Results

3.1. *Statistical investigation of the influent constituents of wastewater*

With regard to the objectives of the study, statistical analysis of the factors mentioned previously was performed and the results are included in Table 3. Once the types of statistical distributions around the median were determined, it was understood that all parameters are following a normal distribution pattern except for the Sulfate concentration, which follows a logarithmic pattern.

3.2. *Evaluating the variation of the influent and effluent constituents at the facultative aerated lagoon*

Figure 2 shows the variations of the influent BOD versus the effluent BOD of the facultative aerated lagoon. The possible relationship between influent and effluent BOD was assessed by obtaining the correlation factor, R^2, the result of which is shown in Figure 3. The effect of temperature on BOD removal efficiency was also assessed, the result of which is included in Figure 4. Along with this assessment, the BOD removal efficiency was compared with the expected values for an aerated facultative lagoon as reported by Arceivala [3], as is also illustrated by Figure 4. The performance of the existing facultative aerated lagoon was compared with a similar anaerobic pond, which, as described, was initially planned to be erected but was afterwards modified to an aerated lagoon, the result of which is illustrated in Figure 5. The efficiency of the facultative aerated lagoon, with regard to coliform removal, was

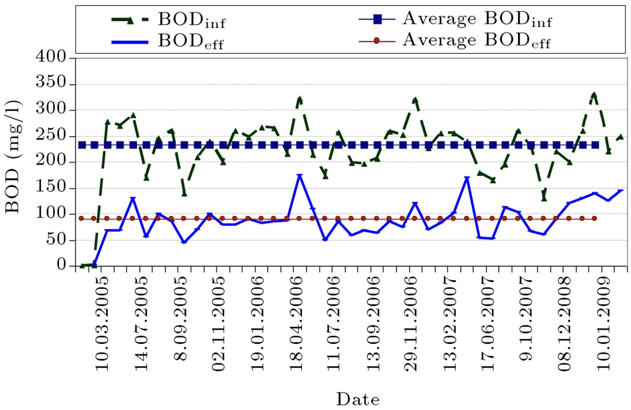


Figure 2. Variations of influent BOD versus effluent BOD of the lagoon.

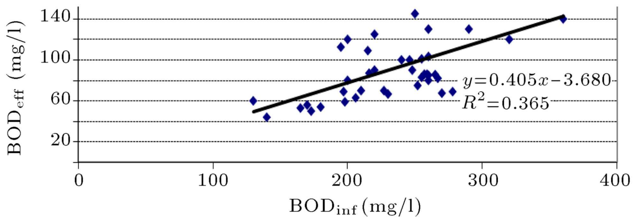


Figure 3. Correlation between influent BOD and effluent BOD of the lagoon.

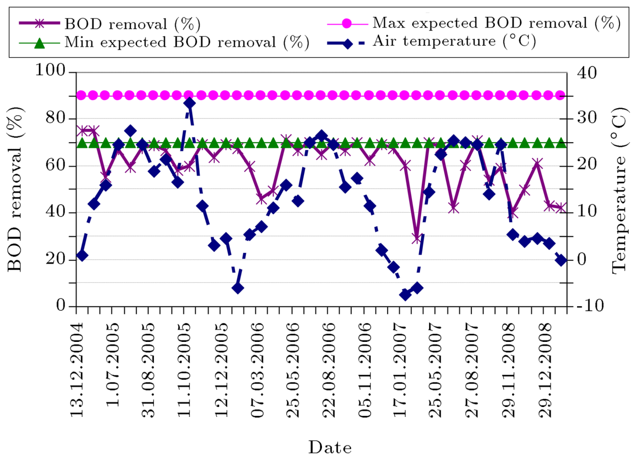


Figure 4. BOD removal efficiency versus temperature compared to values reported by Arceivala [3] for facultative aerated lagoons.

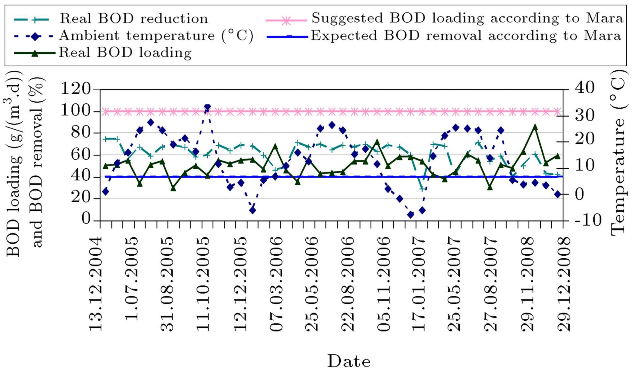


Figure 5. Comparison of the performance of the lagoon with an anaerobic one under similar conditions.

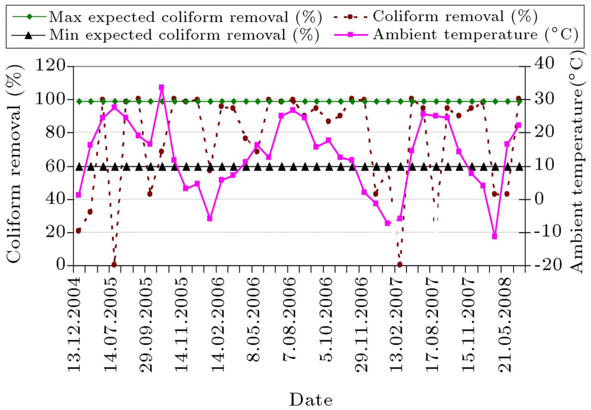


Figure 6. Coliform removal efficiency at facultative aerated lagoon and a comparison with the values reported by Arcievala [3].

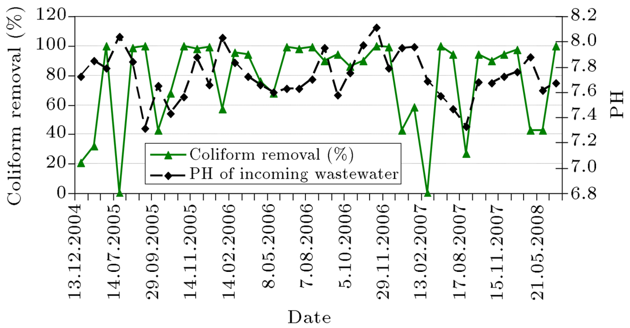


Figure 7. Effects of PH on coliform removal at facultative aerated lagoon.

also assessed, the results of which are included in Figure 6. The effect of PH on the coliform removal efficiency was investigated too (Figure 7). Variations of SO_4^{-2} were also evaluated, the results of which are included in Figure 8.

3.3. Values of overall BOD removal rate (K_L) under field and standard conditions

Having applied the methodology described before, values of K_L (TW) and $K_L(20)$ for both ideal flow regimes were calculated, the final results of which are inserted

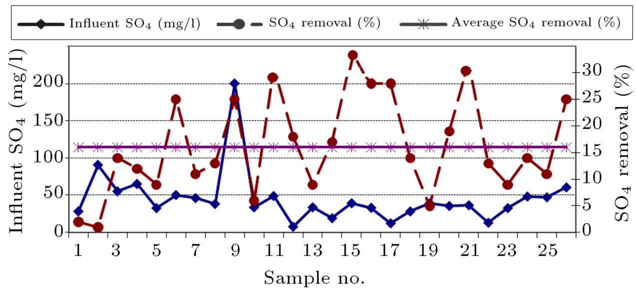


Figure 8. Variation of influent SO_4^{-2} at facultative aerated lagoon.

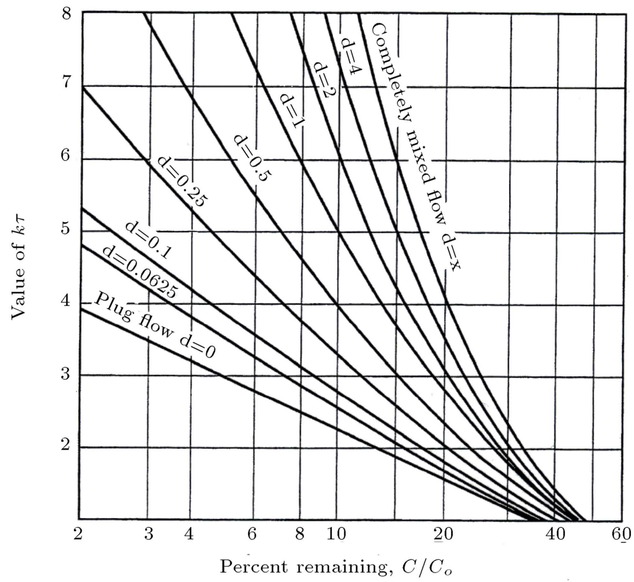


Figure 9. Determination of substrate removal efficiency using the dispersed flow model.

in Tables 4 and 5. Considering the flows recorded while taking samples, K_L was estimated under real field conditions, as inserted in Table 6. In this table, having obtained $K_L.t$, by referring to the curve developed in Figure 9 [20], K_L was obtained.

4. Discussion

4.1. BOD removal efficiency

Figure 2 shows that, excluding some samples taken from the start of the operating of the lagoon, BOD_{eff} is a function of BOD_{inf}, since, as the BOD_{inf} increases, the BOD_{eff} increases too, and vice versa. This is an indication of establishing an aerobic biological process at the upper aerobic layer, regardless of the small value of input energy. The correlation between BOD_{inf} and BOD_{eff} was investigated, as shown in Figure 3. It cannot be claimed that a strong correlation exists, since R^2 was estimated to be only 0.36. The average BOD concentration of the influent observed during the period was 220 mg/l. Thus, with regard to a standard deviation of 64 mg/l (Table 3), with a probability of

Table 4. Steps taken to calculate the overall BOD removal rate (K_L) at field conditions (plug flow regime).

$\mathbf{BOD_{int}}$ at TW (mg/l)	$\mathbf{BOD_{eff}}$ at TW (mg/l)	Flow ($\mathbf{m^3/d}$)	Detention time (d)	K_L TW ($\mathbf{d^{-1}}$)	K_L (20) ($\mathbf{d^{-1}}$)
SO	S	Q	$t = 20,000/\mathrm{Q}$	K_L = -LN(S/S0)/t	
99	29	4320.0	4.62	0.259	0.223
103	35	4492.8	4.45	0.239	0.184
105	31	4406.4	4.53	0.265	0.219
124	36	4147.2	4.82	0.254	0.237
117	33	4320.0	4.63	0.271	0.272
138	47	4492.8	4.45	0.241	0.268
85	22	4406.4	4.53	0.299	0.427
90	24	4579.2	4.38	0.306	0.474
83	25	4579.2	4.37	0.276	0.409
84	43	4492.8	4.45	0.149	0.236
77	23	4665.6	4.29	0.286	0.333
76	26	4579.2	4.37	0.247	0.252
96	57	4665.6	4.29	0.119	0.107
102	33	4752.0	4.20	0.266	0.289
66	25	4752.0	4.21	0.210	0.213
Average				0.246	0.282

Table 5. Steps taken to calculate the overall BOD removal rate (K_L) at field conditions (completely mixed flow regime).

$\mathbf{BOD_{int}}$ at TW (mg/l)	$\mathbf{BOD_{eff}}$ at TW (mg/l)	Flow ($\mathbf{m^3d}$)	Detention time (d)	K_L TW ($\mathbf{d^{-1}}$)	K_L (20) ($\mathbf{d^{-1}}$)
SO	S	Q	$t = 20,000/\mathrm{Q}$	K_L = (S0-S)/(S*t)	
99	29	4320.0	4.62	0.5	0.432
103	35	4492.8	4.45	0.427	0.329
105	31	4406.4	4.53	0.521	0.423
124	36	4147.2	4.82	0.498	0.466
117	33	4320.0	4.63	0.453	0.545
138	47	4492.8	4.45	0.434	0.497
85	22	4406.4	4.53	0.635	0.908
90	24	4579.2	4.38	0.643	0.997
83	25	4579.2	4.37	0.537	0.952
84	43	4492.8	4.45	0.211	0.335
77	23	4665.6	4.29	0.56	0.654
76	26	4579.2	4.37	0.445	0.455
96	57	4665.6	4.29	0.155	0.140
102	33	4752.0	4.20	0.489	0.529
66	25	4752.0	4.21	0.338	0.342
Average				0.462	0.534

90%, it can be claimed that the long-term incoming BOD concentration is about 300 mg/l or less. Compared with a BOD concentration of 250 mg/l, which was considered as the design value when dimensioning the plant (Table 2), it shows that considering the BOD concentration equal to 300 mg/l is more realistic. This is, therefore, the suggested value, on condition that it is not intended to perform long-term BOD measurements for new designs, since this would be more accurate.

The study showed that the BOD removal efficiency in the lagoon is also influenced by variations in temperature (Figure 4). This also shows the existence

Table 6. Steps taken to calculate the K_L with regard to real dispersion number at field conditions.

Q (m^3/d)	**TW** (°C)	**D/UL = 24467.1 Q**	**SO** (mg/l)	**S** (mg/l)	**Percent removed**	$K_L.t$	**Detention time** (d)	K_L **at TW** (d^{-1})	K_L **at 20°** (d^{-1})
		-			(1-S/S0)	-	$t = 20000/Q$		
4320	24	5.66	99	29	0.7	2.35	4.63	0.508	0.438
4492.8	27	5.45	103	35	0.66	1.8	4.45	0.404	0.312
4406.4	25.5	5.55	105	31	0.7	2.34	4.54	0.515	0.426
4147.2	22	5.9	124	36	0.71	2.35	4.82	0.488	0.456
4320	20	5.66	117	33	0.72	2.36	4.63	0.51	0.512
4492.8	16	5.45	138	47	0.66	1.8	4.45	0.404	0.463
4406.4	9.5	5.55	85	22	0.74	2.38	4.54	0.524	0.749
4579.2	7	5.34	90	24	0.74	2.38	4.37	0.545	0.845
4579.2	3	5.34	83	25	0.7	2.34	4.37	0.535	0.949
4492.8	6.5	5.45	84	43	0.48	1.35	4.45	0.303	0.482
4665.6	15.5	5.24	77	23	0.71	2.35	4.29	0.548	0.639
4579.2	19	5.34	76	26	0.66	1.8	4.37	0.412	0.421
4665.6	23	5.24	96	57	0.4	1.25	4.29	0.291	0.262
4752	18	5.15	102	33	0.67	1.75	4.21	0.416	0.449
4752	20	5.15	66	25	0.59	1.6	4.21	0.38	0.384
Average								0.4522	0.519

of an aerobic biological process which is influenced by temperature. According to Mara [18], 70-90% BOD removal efficiency is expected at these lagoons, whilst, in this case, BOD removal efficiency is higher than the minimum reported only for 7% of cases. This can be attributed to three facts as follows:

1. According to the re-engineering study carried out by a German consulting engineering company, 2.7 W/m^3 energy was required for the purpose of preventing possible odor emission, but, this was not applied in reality [21].
2. While selecting the type of surface aerator, the temperature and altitude of the site were not taken into account. Thus, a real aerobic process at the top layer was not established, leading to lower efficiency compared with a well-functioning lagoon.
3. An average detention time of about 5 days, for dimensioning the facultative aerated lagoon, compared with 3-12 days suggested by Arceivala [3], is rather low and has led to lower efficiency compared with the 70% to 90% BOD removal efficiency reported by Arceivala [3]. Now that the value of overall BOD removal efficiency for the wastewater in question is estimated ($K_L(20°\mathrm{C}) = 0.52$ d^{-1}, Table 6), and considering the influent quality of the wastewater (S_0 = BODin = 300 mg/l), as well as the average temperature of incoming flow ($T_{\text{avg}} = 6°\mathrm{C}$), the required detention time of the aerated facultative lagoon for BOD removal efficiency of 80% (the average suggested by Arceivala [3]), would be as $t = 12.5$ d. This is almost equal to the highest value suggested by Arceivala [3]. If there are no limitations regarding land availability, it would be necessary to increase the volume of the lagoon to achieve the desired level of treatment. If there are limitations, it would be necessary to increase the power of the aerators to compensate for the low temperature effects.

Considering the above, it is suggested that the level of energy applied at the tank be increased, according to the recommendations of ATV-A 201E [22], to 3 W/m^3, in order to achieve higher BOD removal efficiency. It is recommended that the modeling of the plant, for which the performance data is now available, to be performed, since this leads to finding the optimum energy required for economically achieving the desired effluent quality, as stressed by Ifak [23] and Moradhasseli [24]. Mara [18] reported that, for an anaerobic lagoon similar to the existing facultative one, in terms of dimensions, where the average ambient temperature is lower than 10°C but BOD loading is less than 100 g/(m^3.d), a BOD removal efficiency of 40% may be achievable. In this case study, regardless of aeration, the average BOD loading was 51 g/(m^3.d), while the average BOD removal efficiency was 61% (Figure 5). It was, therefore, concluded that the efficiency of the facultative aerated lagoon is higher when compared with an anaerobic one, as expected. This is because applying energy at the top layer of the lagoon increases the BOD removal efficiency.

4.2. Coliform removal efficiency

Coliform removal efficiency is influenced by temperature, as depicted by Figure 6. As Arceivala reported [3], for a detention time between 3-12 days, coliform removal efficiency of 60-90% is expected. For the studied case, for 79% of samples taken, the efficiency was higher than the maximum level reported by Arceivala [3]. Low efficiency is because of the relatively low detention time (4.5 d), which inhibits the proper settling of the particles. The geometric mean of the number of coliforms in the incoming flow was about 13,000 times higher than the value assumed when dimensioning the plant (10^7 MPN/100 ml). It was concluded that, with a probability of 48%, the number of coliforms in the incoming wastewater will be higher than 10^7 MPN/100 ml. Thus, consideration must be given to this fact in new designs. It was understood that the variations in coliform removal efficiency follow the variations in PH (Figure 7).

4.3. Sulfate removal efficiency

Average SO_4^{-2} removal efficiency was 16%, which is mostly as a result of gravity settlement in the tank (Figure 8). The mean concentration of incoming SO_4^{-2} was estimated to be 45 mg/l with a standard deviation of 36 mg/l. Since, for SO_4^{-2}, the distribution of the data around the median was found to be log-normal, it was concluded that, with a probability of 95%, the concentration of SO_4^{-2} is less than 78 mg/l, while, with a probability of 9%, it will be higher than 100 mg/l. According to Mara [18], because the concentration of SO_4^{-2} is less than 500 mg/l, and BOD loading is less than 300 g/(m^3.d), under the climatological conditions of Gorveh, regardless of other reasons (e.g. process requirements), it will not be necessary to aerate the top layer of anaerobic lagoons to overcome the probable negative effects associated with odor emission. This will lead to significant cost saving, although, if higher efficiencies are desired, aerating the top layer may be necessary, as proved in this study.

The calculated quality parameters (watery parameters) were compared with the well-known reference, Metcalf and Eddy Inc. [19], as shown in Table 7. Table 7 includes the suggested values of the quality parameters of domestic wastewater, as cited by Metcalf and Eddy Inc. [19]. As seen, those calculated quality

Table 7. Typical composition of untreated domestic wastewater (adopted from Metcalf and Eddy [15]).

Concentration	Unit	Low strength	Medium strength	High strength
Solids, total (ts)	Mg/l	390	720	1230
Dissolved	Mg/l	270	500	860
Fixed	Mg/l	160	300	520
Volatile	Mg/l	110	200	340
Suspended solids, total (tss)	Mg/l	120	210	400
Fixed	Mg/l	25	50	85
Volatile	Mg/l	95	160	315
Settle able solids	Ml/l	5	10	20
Biochemical oxygen demand, 5-d, 20°C (BOD5, 20°C)	Mg/l	110	190	350
Total Organic Carbon (TOC)	Mg/l	80	140	260
Chemical Oxygen Demand (COD)	Mg/l	250	430	800
Nitrogen (total as n)	Mg/l	20	40	70
Organic	Mg/l	8	15	25
Free ammonia	Mg/l	12	25	45
Nitrogen	Mg/l	0	0	0
Phosphorus (total as p)	Mg/l	4	7	12
Organic	Mg/l	1	2	4
Inorganic	Mg/l	3	5	10
Chlorides	Mg/l	30	50	90
Oil and grease	Mg/l	20	30	50
Volatile organic compounds (voc_5)	Mg/l	50	90	100
Total coliform	Mg/l	< 100	100 - 400	> 400

parameters match the values mentioned by Metcalf and Eddy Inc. [19], which shows a high level of confidence in the study.

4.4. Suggested overall BOD removal rate (K_L) for new designs

The values of $K_L(20°\text{C})$ for plug flow and a completely mixed regime were estimated to be 0.282 d^{-1} and 0.534 d^{-1}, respectively, which matches those reported by Arceivala [3]. This varies between 0.3-0.5 d^{-1} for unfiltered samples. The importance of estimating the $K_L(20°\text{C})$ in this study is that an exact estimation of $K_L(20°C)$ will result in, as said, both cost economic designs and the certainty of achieving a higher effluent quality.

4.5. Need for more study

Within this study, the performance of facultative aerated lagoons in semi-humid regions in Iran was assessed. Also, the values of qualitative parameters, as well as the overall BOD removal rate constant for the wastewater in question, were estimated. By paying attention to these achievements, a more realistic dimensioning will be achievable in new designs. However, it is suggested that these qualitative and quantitative online measuring data be performed within a period of at least one year.

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