The Operation of Anaerobic Lagoons
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Abstract
The operation of the anaerobic lagoon adjacent to Isfahan Wastewater Treatment Plant was studied over a 12-month period. The rate of organic loading, BOD and SS removal efficiencies and their relationships with organic reductions and ambient temperature were studied. A high correlation was found to hold among temperature, organic loading rate, and BOD$_5$ removal. A correlation coefficient of 87% was obtained for temperature and BOD$_5$ removal efficiency and that for temperature and organic loading was 83%. The lowest atmospheric temperature during the study period was 4°C (per day) when BOD$_5$ removal efficiency reached 25%.

A model was developed to predict SS removal efficiency against atmospheric temperature variations in which small increases were observed in removal efficiency with increasing atmospheric temperatures. The BOD$_5$ reaction constant ($K_t$) at 20°C was equal to 0.4895 d$^{-1}$. A model was also developed a correlation coefficient of 83% with a standard error of 6.3%. According to the observations and studies carried out, the quantity of per capita sludge in the anaerobic lagoon was estimated to be 0.06 to 0.08 per person/year.

KEY WORDS
Anaerobic lagoons; reaction constant; operation; per capita sludge; loading rate.

INTRODUCTION
It should not be surprising that the most common wastewater treatment method should also be the simplest one: the stabilization pond. The pond process operates naturally and therefore does not have the common formidable problems of energy and electromechanical devices faced with in most other processes. Stabilization ponds find application in both small and large communities but sparsely-populated areas are more suitable for their application due to inexpensive land available in these areas. Treatment in stabilization ponds occurs as a result of a series of natural physicochemical and biological reactions in an aquatic environment, removing pathogenic agents, BOD, ammonia, nitrates, suspended solids and phosphorous. Stabilization ponds lacking any aerating systems can be classified into anaerobic, facultative, and aerobic ponds [1,2]. This paper will only discuss the design and operation of anaerobic ponds.
Anaerobic decomposition consists in the biological degradation of organic matter in the absence of free oxygen. In the process, organic matter is destroyed in the absence of oxygen to produce methane, carbon dioxide and a few other gases. According to a general theory, the decomposition takes place in two stages: in the first stage, the organic matter is converted into short-chained acids under the effect of acidogenic bacteria and the acids thus produced are further converted, in the second stage, into methane and carbon dioxide by methanogenic bacteria.

The destruction of organic matter not only produces the products from chemical decomposition but also generates biomass. The quantity of each product can be affected by a host of factors such as atmospheric temperature, detention time, pH, and the substrate type and concentration.

Anaerobic ponds can be compared with the conventional treatment units such as primary settling tanks, sludge concentration units, anaerobic digesters, sludge drying beds and sometimes with grit removal facilities [3].

The following is a list of the events while wastewater passes through the anaerobic lagoons during a detention time of several days:

a. A high percentage of the suspended solids present in water is removed;

b. Some of the pathogenic elements are reduced;

c. Floating matter such as grease, oil, plastics, cigarette butts and similar material from the scum on the surface of the flow;

d. Gases such as CO₂, CH₄, and H₂S are dissipated into the atmosphere from the surface of the lagoon as a result of metabolic reactions. With these gases some of the settled material may also rise to the surface and leave the lagoon in the effluent. In warm seasons this process becomes more acute and adversely affects pond effluent quality [3].

The quantity of sludge accumulated in anaerobic lagoons has been reported to be from 40 to 80 lit/person/year [3 and 4]. The effluent from anaerobic lagoons requires further treatment for which facultative lagoons are commonly used. BOD5 removal has been reported to be 40 to 85 per cent under favorable conditions [3, 5 and 6].

Anaerobic lagoon design is usually based on detention time and loading volumes, the latter, of course, has recently become of greater concern to designers. The suggested detention times in different references show great variations, for instance 5 days (Oswald et al 1976), 1-5 days at varying atmospheric temperatures (Arceivala, 1973), 20-50 days (Metcalf & Eddy, 1976), a minimum of 3 days (Gloyna, 1989), and at least 1 day (WHO, 1987). A number of figures have also been suggested concerning loading volumes including 42-283 for Canada (Fisher et al, 1968), 125 for warm areas (Gloyna, 1971), 100-400 (Mara, 1976), 50-134 for India depending on atmospheric temperature (Arceivala, 1981), and a maximum of 400 g BOD5/ m³.d (WHO, 1987) [6].

The important point to bear in mind while designing the anaerobic lagoon is that the effective volume of the lagoon reduces due to gradual accumulation of sludge deposits and that the design should be based on the real lagoon volume. Furthermore, as anaerobic lagoons have great capabilities in the treatment of high concentration industrial waste, it is recommended that volumetric loadings be used in such designs.
Methods and equipment
Site description
Isfahan is one of the most important historical cities and tourist centers in Iran. Part of the wastewater collected from the city is treated in an activated sludge plant in the north of the city which can receive the waste from 400,000 persons. In a plot of land adjacent of this plant, an anaerobic lagoon was set up in order to study its operation in organic and solid removal with varying parameters including inflow rates and atmospheric temperature variations. The lagoon was ready for operation in July 1996. The specifications of the lagoon are as follows:
* Effective volume = 61 m$^3$
* Effective depth = 2.5m
* Wall sloping = 1 : 1.5
A 4-inch line was used to allow domestic wastewater from the neighboring plant into the lagoon. The influent was controlled through a valve and entered entered the lagoon on the surface. The effluent left the lagoon from under the surface through an outlet line. Figure (1) shows a schematic view of the lagoon.

![Fig 1: A schematic view of the lagoon](image)

Start-up and study stages
After the lagoons had been erected by August 1996, raw wastewater was allowed to enter the lagoon through connection lines. Sampling and the study of the lagoon operation started after the system had reached stable operation.
The anaerobic lagoon was operated and tested in three stages. The flowrate and detention time parameters were varied against variations in atmospheric temperature in all stages of the study. In each stage, samples were collected from specified points at least once a week and BOD$_5$, COD, SS, and atmospheric temperature measurements were carried out according to standard Methods Manual APHA, 18th Edition [7].

**Results and discussion**

**Influent characteristics:**
The minimum, maximum, average and standard deviation of the influent water parameters are reported in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Quantity</th>
<th>Minimum</th>
<th>Average</th>
<th>Maximum</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bod$_5$ (mg/lit)</td>
<td>111</td>
<td>228</td>
<td>460</td>
<td>94</td>
<td></td>
</tr>
<tr>
<td>PH</td>
<td>7</td>
<td>7.49</td>
<td>7.9</td>
<td>0.224</td>
<td></td>
</tr>
<tr>
<td>Turbidity (F.T.U)</td>
<td>78</td>
<td>190</td>
<td>500</td>
<td>121</td>
<td></td>
</tr>
<tr>
<td>Suspended Solids (mg/lit)</td>
<td>57</td>
<td>193</td>
<td>500</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>Volatile Suspended Solids (mg/lit)</td>
<td>44</td>
<td>115</td>
<td>250</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>Total Solids (mg/lit)</td>
<td>115</td>
<td>953</td>
<td>1896</td>
<td>348</td>
<td></td>
</tr>
</tbody>
</table>

**BOD and SS removals**

According to recommendations by Barbosu and Santanna (1989), the operation of the reactor can be measured in one of the following three ways [8]:

1. Total influent and total effluent;
2. Filtered influent and filtered effluent;
3. Total influent and filtered effluent.

Organic removal in the anaerobic lagoon was measured according to number 1 above and the operation of the lagoon with regards to SS and BOD removals was then evaluated.

The effect of organic loading rates on BOD$_5$ removal efficiency is shown in Fig. 2. It should be noticed that the organic loading is calculated on a volumetric basis. BOD$_5$ removal efficiency increases with increasing organic loading rate. It is evident that BOD$_5$ removal efficiency is a function of the hydraulic detention time and the loading rates but atmospheric temperature and influents BOD$_5$ Concentrations also exercise a remarkable effect on the removal efficiency. Wastewater temperature variations in figure 2 are in the range $15 \pm 4.5$.

BOD$_5$ removal efficiency increases with increasing loading rates until the biomass in the anaerobic lagoon reaches its maximum growth when the removal...
efficiency sharply decreases as a result of the activities of acid-forming bacteria \[ 8 \].

![Graph showing the relationship between BOD\textsubscript{5} removal efficiency and organic loading rate.](image)

**fig.2:** The relationship between BOD\textsubscript{5} removal efficiency & organic loading rate

Fig. 3 shows the suitable loading rates for anaerobic lagoon designs at various atmospheric temperatures. A relation is developed on this basis for the loading rate using the least squares method in which \( L_v \) is the loading rate and \( T_a \) is the ambient temperature (\( T_a = 15 \) to \( 35 \)). It should be reminded that the average BOD\textsubscript{5} removal efficiency in this case is taken to be \( 45 \pm 7\% \) in Equation 1.

\[
(1) \quad L_v = 7.222 \times T_a + 32
\]
A mathematical model obtained through SPSS and TSP softwares to be used in the description of the relationship between BOD$_5$ removal efficiency and temperature.

$$E_{BOD_5} = 0.936 \times Ta + 22.422 \quad (Ta = 4 \text{ to } 35^0C)$$

$r = 78\%$

In (2), $E_{BOD_5}$ in the removal efficiency and Ta is the atmospheric temperature. According to this relation, the BOD$_5$ removal efficiency will be 25\% at a minimum temperature of 4$^0C$

In Equation (3), the relationship between SS removal efficiency and temperature is shown through a linear regression among the data :

$$E_{SS} = 0.295 \times Ta + 29.346$$

where $E_{SS}$ is SS removal efficiency.

It can be deduced from (3) that increases in temperature lead to small increases in SS removal efficiency, a situation which stems from anaerobic activities within the lagoon causing the production of gas bubbles which in turn increase the amount of SS in the effluent in such a way that the detention time rather than atmospheric temperature will have greater effects on SS removal efficiency.

It should also be mentioned that the examination of the anaerobic lagoon revealed that the per capita sludge accumulated in the lagoon was between 0.06 to 0.08 m$^3$, a measure that can be applied in the determination of sludge volumes in anaerobic lagoons across Iran.

In Figure (4), Variations in BOD$_5$ removal efficiency in anaerobic lagoons are plotted against variations in atmospheric temperature.
Fig. 4: The relationship between BOD$_5$ removal efficiency & temperature

In Figures (5) show the relationships between SS removal efficiency and temperature, respectively.
**BOD removal kinetics**

According to the simulations by Ferrara (1981) and Harleman (1981), organic removal is based on complete-mix model and in some cases the plug flow model becomes predominant in the operation of anaerobic lagoons. Also Moreno (1990) has observed the complete-mix model for anaerobic lagoons. Therefore, the existing anaerobic lagoons can be considered as complete-mix reactors in which mixing takes place as a result of anaerobic processes at the lagoon bottom producing gas bubbles rising to the surface. It should be remarked that in our observations also the complete-mix was found to be predominant in most cases, verifying Moreno’s viewpoint.

For a complete-mix reactor without recirculation a first-order kinetic equation can be developed for BOD removal as follows:

\[
C = \frac{C_0}{1 + K_t * t}
\]

Where \( C \) and \( C_0 \) are influent and effluent, mg/lit; \( t \) is hydraulic detention time, days; and \( K_t \) is a first order constant at temperature \( T(d^{-1}) \).

A mathematical model was then developed from the analysis of the data obtained from the anaerobic lagoon in order to estimate the value for \( K_t \) at various temperatures. The correlation coefficient for the equation was 83%.

\[
K_t = 0.022 * T_a + 0.049
\]

Where \( K_t \) is the reaction constant at temperature \( T(d^{-1}) \).

In order to determine \( K_t \) with \( T \) and organic loading rate with using multiple regression a mathematical model obtained as equation (6). In this equation correlation coefficient was 82%.

\[
K_t = 0.019 * T_a + 0.006 * L_v + 0.029
\]

\[r=\%82\]
The relationship between temperature and the reaction constant $K$ as well as the relationship between the loading rate on the lagoon and the reaction constant are shown in Figures (6) and (7). As is clear from Figure (7), the reaction constant increases with increased loading rates.

Finally, using the least squares method, the relationship between $K_t$ and BOD removal efficiency in the anaerobic lagoon was determined. The correlation coefficient for this equation was found to be 88% and the error percentage was calculated 6.3%.

$$E\text{ BOD}_5 = 39.9 \cdot K_t + 20$$

where $E\text{ BOD}_5$ and $K_t$ are BOD removal efficiency and reaction constant, respectively.

Fig 6: Relationship between temperature & reaction constant.

Fig 7: Relationship between organic loading & reaction constant.
6. A reaction constant of 0.489/d\(^{-1}\) was obtained for an anaerobic lagoon at a temperature of 20\(^0\)C which increased with temperature and organic loading rate.
7. The per capita sludge for Iran was suggested to be 0.06 to 0.08 m\(^3\)/year.
8. In most cases, anaerobic lagoons are complete-mix particularly at warmer times; in order to prevent the discharge of suspended solids, technical considerations must be taken into account in the design of the anaerobic lagoon geometry.

References
1. “Lagoon system can Provide Low-cost Wastewater Treatment “, (1997), Pipeline, 8, No.2.