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Improvement of Wastewater Treatment Using Lagoons Technology

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Abstract

Wastewater lagoons have proven to be an economically and environmentally beneficial alternative to traditional methods for treating sewage because of their unique properties, which include simplicity of use and inexpensive construction, energy, and maintenance costs. It is a natural wastewater treatment process that exploits the interactions between bacteria, algae, and other microorganisms and their surroundings to remove pathogens, organic matter, suspended particles, phosphates, ammonia, and nitrates.

Stabilization lagoons are widely used throughout the world as they have proved to be a perfectly acceptable and satisfactory treatment system, the effluents produced in tertiary lagoons have been used for irrigation and aquaculture in many countries, indicating the high quality achieved during treatment in these units.

This aim of this research is to overview the literature on lagoons' classification, design, and historical development. It also includes a set of relevant pilot and laboratory-scale experiments. As well as a comprehensive review of factors affecting lagoon performance, including sun's light, DO, pH, temperature, and nutrients. The relationship between these factors and their use in efficient contaminant removal is also discussed.

Keywords: Lagoons technology, Lagoon classification, Wastewater, Efficiency.

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1. Introduction

Today's society tends to centralize and live in urban areas, which implies a greater increase in their standard of living and the consequent increase in energy consumption and eating habits, and it also implies greater development in the industrial and technological area, which causes an increase in water consumption; to meet the new needs and habits of the population. Another significant impact on water availability is that these urban settlements bring greater pollution to the environment; if not well managed, they tend to be discharged mainly into water bodies, reducing their water quality and hence the availability of surface fresh water.

As we have seen, water is one of the most important natural resources for maintaining the population's standard of living. Therefore, collecting and treating wastewater from the community is vital before it is discharged into the environment. To achieve this, various mechanical sewage treatment facilities, including activated sludge, trickling filter systems, and others, are built to handle a large volume of wastewater and treat it efficiently[1].

At the same time, larger communities can only support these treatment facilities due to their high construction costs and the need for highly qualified specialists with practical experience. In addition, these methods to eliminate pathogens are costly and ineffective; Only a tertiary treatment, such as maturation lagoons or chlorination, can do this [2].

Most of the smaller towns and rural areas with little financial resources frequently took advantage of one advantage: the availability of land. In such situations, it is more economical to build an artificial pond in which wastewater is retained with a given depth and generally long residence times (1 to 30 days), in which the sewage is treated by biological degradation of the organic matter and elimination of pathogens Organisms under controlled conditions [1].

These ponds, called stabilization lagoons, are the oldest known wastewater treatment system, with evidence of the use of ponds to store and purify water going back 3,000 years [3]. Many people would be surprised today to learn that there are one thousand lagoons systems in Germany and two thousand pond systems in France, and one-third of all sewage treatment facilities in the USA are lagoons [4].

It is a natural, environmentally friendly, and easiest way to treat wastewater. The self-purification ability of water bodies was the main inspiration for the treatment method of this technology. Lagoon treatment uses the physical, chemical, and biological processes between algae, bacteria, other microorganisms, and their environment to remove organic matter, pathogens, suspended solids, phosphates, ammonia, and nitrates from wastewater[1].

Lagoons systems used for wastewater treatment are inexpensive in terms of construction costs, energy consumption, and maintenance costs, and they are also easy to design and operate. Furthermore, if properly constructed and operated, these facilities should be able to produce effluents that meet environmental and human health standards set by many countries[5].

These benefits result in generally low treatment costs. However, the most important benefit of lagoons is their efficiency in removing harmful bacteria and E.coli, which is typically high and can exceed 99%.[6] Numerous hypotheses explain how pathogens are eliminated in lagoons. According to Parhad and Rao (1974), the high pH of ponds can cause the rapid death of E. coli. They found that wastewater with pH > 9.2 was not suitable for the growth of E. coli. [6,7].

In a study of model ponds in Oklahoma, Gann et al. (1968) concluded that coliform removal in lagoons was closely related to BOD5 removal, indicating that coliforms are removed because they cannot compete successfully for nutrients. The numbers of bacteria and E. coli were reduced by the algae's toxic chemicals, as Caldwell (1956) and Davidson (1961) noted [6,8,9 and 10]

Smallhorst et al. (1953) suggested that detention time and settlement may also significantly impact the removal of bacteria from stabilization lagoons. Hodgson (1964) found that the snails, which serve as vectors of schistosomiasis, could not survive more than ten weeks in a lagoon environment while conducting research in a lagoon in Mandarellas, Southern Rhodesia [6,11and 12].

Often these systems have multiple lagoons designed in series, parallel, or both. It will be because, in most cases, two or more small lagoons can provide better treatment than a single large cell. According to (Yanez, 1993) he found that the lagoons were classified into three categories: anaerobic, facultative, and aerobic, depending on the type of biological activity occurring there, which is a function of the amount of dissolved oxygen (DO) present in them. In addition, water circulates in different environmental conditions caused by differences in depth [1,13].

Therefore, this paper aims to review the history of the lagoon's existence and discuss the types, design considerations, and factors affecting the performance of the lagoon and their use in the efficient removal of pollutants.

2. History Development of Lagoons Technology

Historical records show that the lagoon technique was invented in Texas in 1901, the same year the first documented wetland treatment system was patented [14]. However, Jordão and Pessoa (1995) argue that artificial lagoons have been used for sewage treatment, fish farming, and land irrigation for centuries, but more accidentally than planned [15,16].

It took until the beginning of 1924s for the ability of the accidental lagoons in sewage treatment to be revealed in Santa Rosa, California, where wastewater caused the gravel bed to clog, forming a lagoon. The amount of organic matter and suspended solids (SS) in wastewater decreased after being kept in these holding basins. In California, only about 30 lagoons were constructed to treat sewage then, whereas, in Germany, the first approved lagoon system was designed in the 1920s [14].

Although sewage lagoons have been used for centuries in Asia and other parts of the world, the spread of this technology is only recently being documented in the literature. It is particularly true of the period immediately after World War II when researchers and engineers worked to understand, explain and control the lagoon's stabilization process, to intensify some operational controls to know some parameters of the lagoon. The first wastewater treatment facility in North America was built in Maddock City, North Dakota, in the 1940s.

In 1958, stabilization lagoons became a popular sewage treatment technique in Latin America, and the first experimental lagoon was constructed in the Costa Rican city of Cañas to treat domestic effluents. In 1993, there were already 3,000 of these systems in Latin America and the Caribbean, which Their use became popular, and the vast majority of the built ponds are still in operation.

Australia has conducted an extensive study on pond treatment, making it the pioneer to use ponds in series, often known as Australian ponds. Stabilization ponds were first brought to Brazil in 1960 by engineer Benoit Almeida Victoretti. He built and designed the first stabilization ponds using the so-called Australian system, consisting of an anaerobic lagoon and a facultative lagoon after that. In contrast, lagoon use in Marandellas, Southern Rhodesia, was recorded in 1960 [15].

In their investigations, Nelson et al. (2004) pointed out that most existing wastewater treatment systems in Mexico are stabilization lagoons, which comprise most of the more than 400 wastewater treatment facilities where they began to be implemented in 1980.

Emphasizes a WHO (World Health Organization) report stating that 39 countries used ponds by the middle of 1964 [15,17]. Since then, ponds have been widely used worldwide, particularly in tropical nations where the environment is most conducive to operation.

3. Lagoon Classification, Design, and Performance

In the literature, lagoons are classified according to the predominant metabolic activity involved in the degradation of organic matter, such as anaerobic, facultative, maturing, or aerobic, each with different treatment and design characteristics.

3.1. Anaerobic Lagoon

3.1.1. Description

Anaerobic lagoons are widely used as pre-treatment systems and are particularly effective in treating high organic loads such as industrial, agricultural, dairy, slaughterhouse wastewater, etc. [3]. Can create this environment by applying a high BOD5 loading per unit volume of the lagoon, resulting in an oxygen consumption rate many times higher than oxygen production. [18]. They are typically constructed to be deeper than other lagoons to reduce the possibility that oxygen generated on the surface penetrates other layers, as shown in Fig. 1. [18]

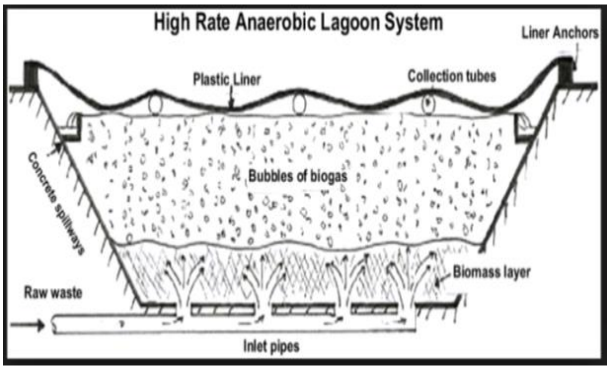

Fig. 1 Cross-Section of an Anaerobic Lagoon [18]

Because these ponds are deeper, resulting in lower soil requirements and generally longer residence time, allowing for particulate settling, digestion of retained sludge, and reduction in BOD5 concentration.

These lagoons use very little energy and require no special equipment other than a pump. Because anaerobic microorganisms are dormant below 15°C, anaerobic processes can require long residence times, especially in cold climates. Because of this, anaerobic ponds are rarely used for municipal wastewater treatment in cold areas. Typically, facultative or aerobic lagoons are placed behind anaerobic ponds to provide additional treatment [3].

In these cells, anaerobic bacteria convert organic matter into stable products such as carbon dioxide, hydrogen sulfide, and methane. Treatment in anaerobic lagoons takes place in two phases [19]:

Organic matter is first broken down by a class of bacteria called acidifiers, producing less complex compounds called organic acids. Second, under strictly anaerobic conditions, methane-producing bacteria feed on organic acids and convert the acid end products mainly into CO2, H2S, and CH4. As a result, the liquid medium becomes carbon-depleted by releasing methane (CH4) into the atmosphere.

The system must operate under conditions that favor the occurrence of methanogenic bacteria. If the proliferation rate of methanogenic bacteria is reduced due to their extreme sensitivity to environmental influences, the acids formed in the first stage accumulate, which leads to the following effects:

a) Stopping the process of removing organic matter, and
b) Produces unpleasant odors because acids are very smelly.

For methanogenic bacteria to multiply, the following requirements must meet:

- Lack of dissolved oxygen (Methanogenic bacteria are raw anaerobes and do not survive in the presence of dissolved oxygen)
- Suitable media temperature (above 15°C)
- pH appropriate (close to or greater than 7)

the system's performance depends on load, temperature, HRT, and keeping the pH in the ideal range. Typical design and capacity values for anaerobic lagoons are given in Table 1. [20]

Table 1. Design criteria for anaerobic lagoons [20]

Source	Optimal depth [m]	Surface loading [kg/ha.d]	Residence Time [d]	BOD5 Removal [%]	Total suspended solids removal [%]	Optimal temperature [ºC]
Metcalfe & Eddy (1993)	2.5-5	225-560	20-50	50-85	20-60	30
WHO EMRO Technical Report No. 10 (1987)	2.5-5	> 1000	5	50-70	NA	25-30
Lagoon Technology International (1992)	2-5	>3000	1-2	75	NA	25
World Bank Technical Paper No. 7 (1983)	4	4000-16000	2	NA	NA	27-30

3.1.2. Merits and Demerits of Anaerobic Lagoons

Anaerobic Lagoons have several advantages:

1. Sludge disposal is rarely required;
2. BOD5 removal can reach 80-90%;
3. The plant requires little or no energy;
4. Operation and maintenance are relatively easy.

However, the disadvantages of anaerobic lagoons include the following:

1. They are not intended to produce good effluent;
2. The lagoons can give off bad smells;
3. Treatment depends on the weather and the season.

3-1-3-Design Criteria

Anaerobic treatment lagoons are often designed based on volumetric loading rate and hydraulic residence time. While this is often the case, the surface loading design probably needs to be revised [3].

Therefore, anaerobic lagoons are designed using a volumetric loading (λv, g/m3.day) given by Equation 1 [21]:

$$\boldsymbol{\lambda_v = {}^{L_i\,Q}/_{V_a}} \quad (1)$$

Where :
Li : Input BOD5 (mg/l),
Q : Flow rate (m^3/day), and
Va: Volume of an anaerobic lagoon (m^3)

The hydraulic residence time criterion (t_{an}) is based on the reproduction time of anaerobic bacteria.

The volume of the lagoon is calculated according to Equation (1) after choosing the volumetric loading of the organic matter (λv).

The hydraulic residence time is then determined from Equation 2 as follows:

$$\boldsymbol{t_{an} = {}^{V_a}/_{Q}} \quad (2)$$

Meiring et al. proposed the construction of anaerobic lagoons in the first stage of treatment to maintain anaerobic conditions. One anaerobic pond in each treatment group is often sufficient if the input sewage Li is less than 1000 mg BOD5/l [21,22].

Up to three anaerobic lagoons can be used in series for high-strength industrial waste. Still, no lagoon with a residence time of less than one day should be used because methanogenic bacteria can flow into effluent longer than their production rate.

Under these conditions, the efficiency of the anaerobic lagoon decreases, and the result is the accumulation of acids in the medium with the formation of unpleasant odors due to the presence of low-density methanogenic bacteria responsible for acidic transformation.

It should be noted that the appearance of algae while working in these lagoons is a sign of under-loading. Under these conditions, the algae's oxygen can inhibit digestion's methanogenic phase. Therefore, truly anaerobic conditions must be restored by an organic overload of at least 100 g BOD5/m^3. [21]

3.2. Facultative Lagoons

3.2.1. Description

Facultative lagoons are commonly used as secondary lagoons, where an anaerobic lagoon is used as a pre-treatment to reduce organic overload therein [23]. These lagoons can be adapted to most climates using aerobic and anaerobic processes for natural wastewater treatment. The operating costs are much cheaper than other treatment processes due to the simple construction, which primarily involves earthwork. System performance is generally acceptable, and values align with many secondary treatment systems. In facultative lagoons, sewage is often deposited in three distinct levels or zones [24]. Fig.2, illustrates the different conditions and the wastewater treatment in each zone [18].

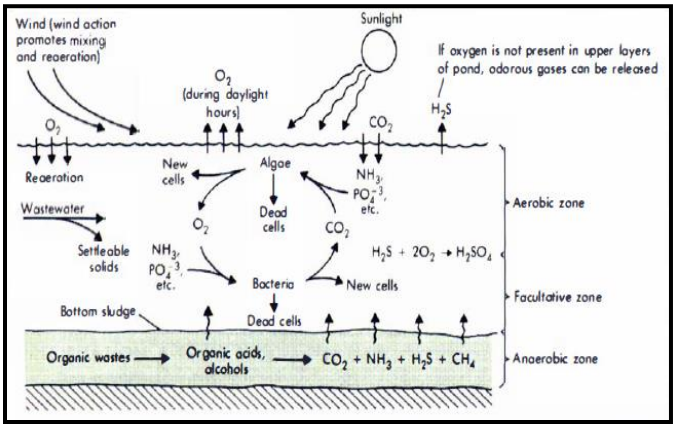

Fig. 2 Processes involved in facultative lagoons [18]

The oxygen zone is the upper layer of the facultative lagoon as it contains most of the oxygen produced naturally by wind re-aeration and by the presence of algae during photosynthesis.

Because algae produce oxygen, aerobic heterotrophic bacteria use it as an electron acceptor to break down organic matter and turn it into carbon dioxide and water. Thus, we observe a mutual relationship between algae and bacteria, with the former providing the energy necessary for metabolic activities and the latter providing the food necessary for these actions. During the photosynthetic process, algae assimilate CO2, reducing the acidity of the medium and increasing the pH, which can reach values above 10, which leads to reduce a large part of the ammonium ion (NH4+) in the form of ammonia (NH3), which itself is released into the atmosphere due to its volatility.

Furthermore, high pH values favor the inactivation of fecal coliform bacteria. Climate, solar radiation, wind, and the number of algae in the water affect the depth of the aerobic zone. The aerobic zone is home to various organisms, including aerobic bacteria, contributing to wastewater treatment. Moreover, this region is a barrier for gases emitted during treatment procedures in the lower layers. The layer at the bottom of the lagoon where there is no oxygen is called the anaerobic zone. Sludge accumulates here as a layer of all solids deposited from the wastewater [25]. Anaerobic bacteria slowly break down the sludge into CO2, H2S, NH4, and other gases in the anaerobic zone. After a while, the bottom layer contains only the inert (non-biodegradable) part. As the hydrogen sulfide that forms in the lower layer is oxidized by chemical and biological processes in the higher layer, there are no odor problems. The zone between the aerobic and anaerobic zones sometimes contains free oxygen and sometimes only oxygen in combined forms such as nitrates. Under these changed conditions, facultative bacteria will prevail and dominate. The biological activity of these bacteria is essentially the same as that of aerobic bacteria, except they can use bound oxygen when free oxygen is unavailable, which should not be underestimated the importance of this area [25].

Changes happen in every lagoon, not only from season to season but also from light to dark, day to day. But even under these changing conditions, facultative bacteria break down organic compounds over a long period until the pond can restore aerobic conditions. Most lagoons that are not mechanically aerated are classified as facultative lagoons due to the significance of this region. Temperature and wind conditions are very important in these lagoons as they promote the mixing of the contents and help prevent short circuits. Wind mixing is necessary to prevent thermal stratification causing anaerobic conditions and subsidence [21]. In general, facultative lagoon systems are easy to use, but performance may vary; There is some variation in the literature, but this is mainly due to their relationship to different geographic locations and, thus, different climatic conditions. In the winter, it can successfully eliminate pathogens and coliform bacteria depending on the temperature and humidity and remove roughly 50% of the phosphorus under high pH circumstances.

Limits to consider include the possibility of algae in the effluent raising the TSS level above the 30 mg/l TSS limit[3] . The design criteria for facultative lagoons are listed in Table 2 [20]

Table 2. Facultative Lagoon Design Criteria [20]

Source	Optimal Depth [m]	Surface Loading [kg/ha.d]	Residence Time [d]	BOD5 Removal [%]	Total Suspended solids removal [%]	Optimal Temperature [ºC]
Metcalfe & Eddy (1993)	1.2-2.5	60-200	5-30	80-95	70-80	20
WHO EMRO Technical Report No. 10 (1987)	1.5-2	200-400	NA	80	NA	20-30
Lagoon Technology International (1992)	1-2	100-400	NA	70-80	NA	NA
World Bank Technical Paper No. 7 (1983)	1-1.8	200-600	NA	NA	NA	15-30

3.2.2. Merits and Demerits of Facultative Lagoons

One of the benefits of facultative lagoons is;

1. Rare need for sediment removal;
2. Another benefit is the effective removal of pathogens, coliforms, BOD5, solid sediments, and to a lesser extent, ammonia;
3. They're easy to use and energy efficient, especially when they're made for works with gravity flow

The drawbacks include the following:

1. Increased accumulation of sediments in cold regions or shallow lagoons.
2. Control of emerging vegetation is necessary to prevent the development of mosquitoes and other vectors.
3. Shallow lagoons take up a lot of space.
4. In the spring, unpleasant smells can occur from time to time.

3-2-3-Design Criteria

Facultative lagoons require an area of enough sun exposure to produce algae growth through photosynthesis. The goal of ensuring photosynthesis and algae growth is to provide enough oxygen. Although numerous methods are available for designing these lagoons, Mara (1976) recommended that facultative lagoons be designed based on surface organic loading rate for the abovementioned reasons, as given in equation 3:[21,26]

$$\boldsymbol{\lambda_s = {10L_i\,Q}/{A_f}} \quad (3)$$

Where

Li :The concentration of influent sewage (mg/L),

ʎs : Surface loading rate kg /ha.day, and

A_f : Surface area required for the facultative lagoon (m^2).

The selection of the permissible design value of λs is usually based on the temperature. Since the increase in temperature combined with a larger area of sun exposure causes an acceleration of degradation of the organic material in area units, thus causing higher rates of surface organic loading rate of the lagoon.

The earliest relationship between λs and temperature was given by McGarry and Pescode (1970) and later by Mara (1976) [23,27and 26]. The Mara (1976) equation is as shown in Equation 4:

$$\boldsymbol{\lambda_s = 20T - 120} \quad (4)$$

In 1987s, Mara presented an appropriate relationship for λs with temperature so that lagoon presents well works[25,28], as given by:

$$\boldsymbol{\lambda s = 350[1.107 - 0.002T]^{(T-20)}} \quad (5)$$

And the mean hydraulic retention time in the facultative pond (tf in days) is calculated from Equation 6:

$$\boldsymbol{t_f = {A_f D_f}/{Q}} \quad (6)$$

The hydraulic residence time will usually be between 20-40 days in a properly designed facultative lagoon. Moreover, with a lagoon depth (Df) of roughly 1. 5 meters, the necessary surface area for a facultative lagoon is noticeably more extensive than that for an anaerobic lagoon. They usually avoid depths less than one meter to avoid the possibility of vegetation growth [21].

3-3-Maturation Lagoons

3-3-1-Description

Maturation lagoons usually constitute the final stage of treatment, also called polishing lagoons, which have the purpose of polishing the treated effluent from a primary or secondary facultative lagoon or a conventional treatment plant. [3]

Recently, the effluents produced in the lagoons tertiary sewage treatment plants have been used in many countries in irrigation and aquaculture, indicating that the high quality achieved during treatment in these units, as well as the availability of inorganic nutrients, which can use in irrigation of vegetables and, the high densities of phytoplankton and zooplankton that can feed many species of fish. This type of lagoon's main objective is to eliminate pathogenic bacteria contained in sewage. In addition to their disinfecting effect, the maturation ponds fulfill other objectives, such as removing nitrogen and phosphorus, some organic matter, polishing the effluent, and achieving a well-oxygenated effluent. [25]

Maturation lagoons are generally built in series with a minimum residence time of 5 days. The typical design values and effectiveness of maturing lagoons are sown in Table 3 [20] . The number of maturation ponds is determined by the retention time necessary to provide the required removal of fecal coliforms. Despite there is general agreement regarding the function of retention hydraulic time in eliminating harmful bacteria, HRT alone is insufficient to achieve satisfactory inhibition of microorganisms in ponds, with the need to join the action with other factors, such as temperature, sedimentation, detention time hydraulic, sunlight, pH, DO, and food shortage, among others.

Table 3. Maturation Lagoon Design Criteria [20]

Source	Optimal Depth [m]	Surface Loading [kg/ha.d]	Residence Time [d]	BOD5 Removal [%]	Total Suspended Solids Removal [%]	Optimal Temperature [ºC]
Metcalfe & Eddy (1993)	1-1.5	≤ 17	5-20	60-80	NA	20
WHO EMRO Technical Report No. 10 (1987)	1-1.5	NA	5-10	50-60	NA	NA
Lagoon Technology International (1992)	1-1.5	NA	NA	NA	NA	NA
World Bank Technical Paper No. 7 (1983)	1.2-1.5	NA	5	NA	NA	NA

3.3.2. Merits and Demerits of Maturation Lagoons

The benefits of maturation lagoons are as follows:

1. Pathogenic bacteria in wastewater are disinfected;
2. They significantly aid in the removal of phosphate and nitrogen. Ammonia removal is generally more than 90 percent. Phosphorus removal in lagoons is lower (usually about 50 percent);
3. Applied to enhance the final effluent's bacteriological quality after conventional sewage treatment works. Maturation ponds only achieve a small additional removal of BOD5

3-3-3-Design Criteria

Maturation lagoons are designed mainly for removing pathogens (for which fecal coliform bacteria are commonly used as indicator organisms [23].

According to Pearson et al. (1996), they reduced the removal of fecal coliforms when the depth of ponds was increased to rise HRT. [25,29]Therefore, the literature reports that the reductions of fecal coliforms result from the synergistic effect of all these factors, being, therefore, difficult to quantify and model.

Generally, the method Marais (1970) used to design fecal coliform bacteria removal in any lagoon (anaerobic, facultative, and maturation) has been represented by first-order kinetic models in completely mixed reactors. The resulting Equation for a single lagoon is given below [21, 30].

$$N_e = \frac{N_i}{(1+K_b t)} \quad (7)$$

Where
Ne : Number of fecal coliforms/100 ml of effluent,
Ni : Number of fecal coliforms/100 ml of influent,
Kb: First-order rate constant for FC removal, d-1 and
t : Retention time in any pond, d.

The stabilization lagoons are idealized when they are designed together, taking into account the lagoon's sequence of anaerobic, facultative, and maturation cells; Equation (4) becomes:

$$N_e = \frac{N_i}{(1+K_b t_{an}).(1+K_b t_{fa}).(1+K_b t_{m1}).(\ (1+K_b t_{mn})} \quad (8)$$

The sub-scripts, an, fa, and m1, refer to the anaerobic, facultative, and maturation lagoons, tmn = retention time, and n is the number of maturation ponds.

The value of kb is highly temperature dependent and was shown by Marais (1970) to be given by:

$$K_{b(T)} = 2.6(1.9)^T - 20 \quad (9)$$

The recommended design parameter for Ni in the context of wastewater treatment is 1 x 10^ fecal coliforms/100 ml, representing a value slightly above typical practical level.

The value of Ne should obtain by substituting the appropriate levels of variables in equation (8) while assuming a residence time of 7 days in each of the two maturation lagoons for wastewater. If the calculated value of Ne does not meet the reuse effluent standard. In that case, it becomes necessary to augment the number of maturation ponds to at least three, each with a 5-day retention period, followed by recalibration of the calculation.

Maturation lagoons are aerobic, where the oxygenation is more homogeneous throughout the water column during daylight period compared to the facultative ponds, and the pH will rise above 9.0. In addition, there is a greater diversity of algae concerning the facultative lagoons with a predominance of non-motile genera.

The presence of minimal quantities of algae within a maturation lagoon may serve as a strong indication of Zooplankton predation on algae. Such an occurrence is likely to negatively impact the pathogen die-off process, which is closely correlated with the activity of algae [21].

4. Lagoon Configurations

Most lagoon systems use more than one lagoon, and sometimes several different lagoons are used simultaneously. Wastewater can also undergo different stages of treatment before entering the lagoon, such as preliminary treatment to remove large and heavy solids. In multi-lagoon systems, lagoons can run simultaneously in series or parallel. When lagoons are arranged in series, sewage flows from one lagoon to another. A facultative lagoon may follow another facultative lagoon or a maturing lagoon. When further pathogen reduction is required, maturation lagoons offer a tertiary treatment. The effluent contains relatively few bacteria and algae when lagoons are used in series. Series short circuits are also reduced. However, a large load on the first lagoon is one of the main disadvantages of serial work. During high loading, the first lagoon can become anaerobic and release odors. When lagoons are built in parallel, the flow is shared between them. Compared to series lagoons, effluent quality in parallel lagoons may be less, but they can withstand higher loads without going anaerobic. Another benefit of parallel lagoons is the ability to shift flow to the other lagoon when one is closed for cleaning or maintenance. Figure 3 below shows different stabilization lagoons configurations [21].

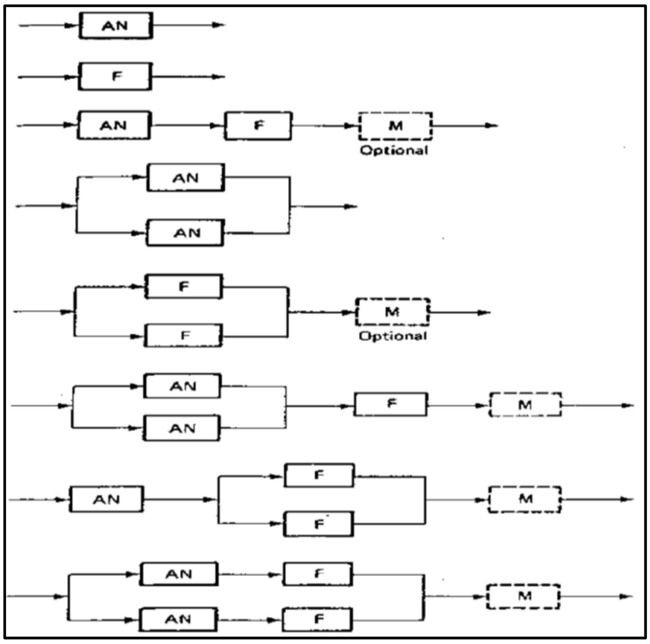

Fig.3 Waste stabilization lagoon arrangements: AN = anaerobic lagoon; F = facultative lagoon; M = maturation lagoon [21]

5. Factors Affecting Lagoon Performance

The success of the waste stabilization process entering the lagoons depends not only on the kinetics of the biological processes but also on the environmental impacts that can be caused by factors affecting the performance of the lagoons that the operator cannot control. These common factors are:

5.1. Sunlight

The water temperature in the lagoons is influenced by sunlight, which is also necessary for the algae to photosynthesize. The lagoons depend on the light that reaches the water's surface and the light that penetrates the water column [19]. Indeed, since the medium is normally very turbid due to the higher concentrations of suspended matter, microbes, and organic matter, sunlight entering the lagoon weakens and disappears quickly a short distance from the surface. In addition, light intensity varies throughout the day and year, as does the algae growth rate [31]. These changes cause two main effects: the dissolved oxygen DO and the pH in the lagoon water reach minimum values at the end of the night and increase during the daylight hours until they reach maximum values at midnight. From that time, the values decrease again through the night.

It has been shown that sunlight generally kills E. coli bacteria and that the extinction rate is related to the intensity of sunlight, and the response of different bacteria to damage caused by sunlight can vary significantly. A survey by Mezrioui et al. (1995a, 1995b) found that sunlight has a much greater impact on the survival of coliform than V. cholera because the concentrations of coliform in the lagoon systems of Marrakesh, Morocco, are significantly eliminated, especially in the warmer seasons [32,33,34]

5.2. Temperature

Lagoon liquid temperature is the parameter that has the greatest impact on lagoon performance. Temperature affects all physical, chemical, and biochemical reactions in the ponds. It is a variable factor related to solar radiation and affects the metabolic rate of algae and bacteria responsible for eliminating organic matter.

As the temperature increases to a certain limit, the total residence time required to achieve the BOD reduction decreases. Seasonal temperature variations in the tropics have little impact on BOD reduction, and high year-round BOD loading rates are possible without developing anoxic conditions. About anaerobic lagoons, the methanogenic bacteria essential for anaerobic digestion are more sensitive to low temperatures, especially below 17ºC. Prompting careful consideration of the desirability of anaerobic units in a treatment system for areas where the liquid lagoon temperature is below 15C for more than a few months of the year [31].

Gloyna (1971) observed that optimum oxygen production for some kinds of algae in facultative lagoons is obtained at a temperature range of 20 to 25ºC. [19,35].

According to reports, some bacteria respond differently to temperature changes, suggesting that mortality from fecal coliform bacteria in stabilization lagoons is highly temperature dependent. The higher the temperature, the more microorganisms are killed.

On the other hand, Pearson and Mara (1987) concluded that there is no connection between FC die-off and temperature and that the maturation lagoon showed higher FC elimination than anaerobic and facultative lagoons when worked at the same temperature. [32,36]

5.3. pH

In lagoon systems, pH, significantly impacted by algae, is critical in eliminating pathogens [32]. The photosynthetic activity requires high carbon dioxide (CO_2) uptake by algae and O2 released by algae, leading to periods of high dissolved oxygen concentration and pH levels in facultative or aerobic lagoons, especially in the last hours of the day when pH levels occurring above 9 can be observed.

A pH range of neutral to slightly acidic (between 6.5 and 7.5) has been identified as the best range for the growth of fecal coliform while raising the pH above 8.5 has been demonstrated to be effective against E. coli. But studies have revealed that Enterococci are more resistant to high pH values, up to 9, than acidic environments. The difference in the behavior of these organisms when exposed to high pH may be caused by various response mechanisms or sensitivity to sunlight. Damage to bacterial cytoplasmic membranes caused by sunlight can make the organisms more susceptible to other conditions, such as high pH levels [32].

In countries with a tropical climate, anaerobic lagoons with a residence time of 1 to 5 days and depths of more than 3 meters are acceptable, where the optimal pH is between 7 and 7.2, with the methane phase predominating over the acidic phase of the formation volatile acids.

There is substantial disagreement in the literature regarding the importance of pH vs. sunlight as a pathogen-removing process. There are inconsistent findings regarding how much each of these two factors contributes.

5.4 Dissolved Oxygen (DO)

As mentioned above, the levels of dissolved oxygen, DO, in the lagoon reflect the intense photosynthetic activity of the algae. Depending on each pond, the surface oxygen layer for an optional lagoon will show fluctuations in dissolved oxygen during the day, and the oxygen level may drop significantly during the night; However, it can also happen that oversaturated concentrations of DO are observed during the day, up to certain values [19]. According to Sweney et al. (2007) observed dissolved oxygen concentrations of up to thirty mg/l during summer in the lagoon system of the Bolivar sewage treatment plant in Adelaide, South Australia [32,37].

Oxygen concentration greater than 0.5mgL-1 has been shown to help eliminate fecal bacteria, and mild inhibition of E. coli and Enterococci with increased dissolved oxygen has been reported. At the same time, both pH and light intensity was constant. Indicating that the endogenous photo inactivation of Enterococci and E. coli was substantially dissolved oxygen-dependent [32].

5.5 Nutrients

Domestic wastewater always contains all the nutrients necessary for bacterial, algal, and microorganism growth and survival, such as carbon, organic nitrogen, phosphorus, sulfur, etc. [21]. While industrial wastewater is often deficient in nitrogen, phosphorus, or both and contains toxic substances, in stabilization lagoons, proteins are broken down by hydrolysis into amino acids, which are broken down by bacteria into ammonia. Soluble ammonia then combines with the hydrogen ion H+ to form ammonium ion NH4+, oxidized by nitrifying bacteria to produce nitrite and nitrates. Algae use most ammonia NH_3 as a nitrogen source to build cellular material. In municipal wastewater, the phosphorus content is usually sufficient for the development of algal growth, thanks to the use and assimilation of inorganic phosphorus in its cellular synthesis; Bacteria and algae are a source of organic phosphorus through respiration and decomposition. Sulfur is a major nutrient in lagoons; sulfates are usually the only form present and are reduced to sulfides by bacteria. This conversion takes place in anaerobic lagoons but can also occur in the anaerobic layer of the lagoons facultative [31].

Many researchers have reported that high nutrient concentrations generally reduce the removal rate of pathogens from sewage systems. According to Boutilier et al. (2009) observed that E. coli has long lived in dairy sewage, which typically contains more nutrients levels than municipal wastewater [32,38]

5.6 Hydraulic Residence Time

The properties of the water circulation influence Biological activity in lagoons. When designing a lagoon, the time required to reach a certain level of purification is calculated. What matters from a purification perspective is all the material entering the lagoon, staying there during that time, or if there is a significant difference between the time that any portion of the liquid stays in the lagoon. The fraction that flows quickly through the basin achieves a lower degree of stabilization than the fraction that has stagnated for a longer period. These fluctuations in effective residence time always lead to a reduction in removal efficiency. The water circulation in a lagoon is affected by its shape and size, the position of the inlet and outlet, the speed and direction of the prevailing winds, and density differences in the basin. The wastewater distribution in the lagoon must be as homogeneous as possible so that the entire volume of the planned lagoon can be used for treatment and the ideal residence time is therefore achieved [31].

Residence time gives suspended particles more time to settle, which pathogens can attach. Furthermore, among all the parameters mentioned in the study (pH, nutrients, sunlight, temperature, DO), residence time was the factor with the biggest influence on the effectiveness of E. coli elimination. In domestic wastewater, Feacham et al. (1983) suggest a period of 30 to 60 days for the elimination of harmful bacteria. [32,39]. According to Jimenez et al. (2001), depending on the initial concentration, a residence time of at least five to twenty days was required to effectively remove worm eggs, while would be required 38 days for helminth cyst (oo) protozoa removal [32,40].

5.7 Wind

The wind is an important factor affecting the performance of wastewater stabilization lagoons. The wind aerates the surface layer and causes material mixing throughout the basin.

The movement is particularly interesting because it overcomes stratification, transfers the oxygen created in the upper layers to the bottom levels, enhances algae growth, and increases the organic capacity of the cells. During periods of excessive wind speed, the deposited solids can remain in suspension, reducing light penetration and, therefore, photosynthetic activity. Too high wind speed can also cause erosion at pond edges [6]. To avoid short circuits between inlet and outlet and to delay the normal flow, the lagoon should be designed in a way that prevent the direction of the prevailing wind along the line of flow. The direction of the prevailing winds is also an important factor in the position of the lagoons relative to the buildings.

6. Elimination of Pathogens, Organic Matter and Nutrients

Pathogens present in the wastewater are considered harmful to health and are therefore removed in a targeted manner by mechanical wastewater treatment plants. Traditionally, these methods use chlorination-based disinfection to remove pathogens, which is expensive and requires significant technical expertise. As noted above, developing countries are unable to use traditional treatments. Therefore, stabilization lagoons are used. One of the benefits of lagoons is their ability to eliminate pathogens [20].

The conventional system can only compete in pathogen removal efficiency with that obtained in lagoons unless you add the effluent disinfection process. Removal efficiencies for pathogenic bacteria and coliform are typically high, with values up to 99% being reported [6]. There are many hypotheses in the literature regarding pathogen destruction in lagoons. Still, it has been found that the best elimination of pathogens from lagoons is facilitated by long residence times, low turbidity, high pH, high temperature, and low BOD levels. Food competition was cited by McKinney (1962) as the primary factor in the removal of coliform in lagoons [6,42], followed by a series of studies by Almasi and Pescod (1996), Boutilier et al. (2009), and Diaz et al. (2010) have since documented the significance of nutrient availability for microbial survival and growth. [32,43,38,44]

It is well known that solar radiation may contribute to the killing of microorganisms as turbidity drops and light penetration rises. Von Sperling (1996) found that polishing lagoons are shallower than other types of lagoons, their depth making the coliform degradation mechanism more efficient in increasing light penetration [15,45] . Regarding helminth eggs, due to their density, the mechanism of sedimentation is frequently used to remove the eggs in primary facultative lagoons or anaerobic lagoons. Sedimentation in lagoons is generally retention time-dependent; the use of high retention times provides not only more period for the settlement of suspended matter to which harmful bacteria can attach but also a long time for the pathogen to be inactivated by disinfecting factors such as sunlight, pH, dissolved oxygen and temperature, and associated with achieving low values of BOD concentrations in the effluent [23]. Depth can increase residence time but also reduce sunlight's ability to penetrate algal lagoons, which would lead to misleading information regarding disinfection mechanisms.

Brandão (2000) added that when four or more lagoons are used in series, the effluent from the stabilization lagoon can be of good quality for unlimited reuse in irrigation and exceed WHO standards for E. coli and helminth eggs [15,46]. Anaerobic and facultative lagoons are evaluated for organic compound removal, usually expressed as biochemical oxygen demand (BOD5) at 20°C for five days. As for the maturation of the lagoons, they are designed to eliminate the pathogen, but in some cases, the elimination of the BOD also takes place in these cells [23].

The removal of BOD in wastewater systems includes the physical settling of its particulate fractions and the biological treatment of its soluble components. Aerobic heterotrophic bacteria oxidize and assimilate the soluble constituents through their metabolism to deal with the soluble BOD—leading increase in the bacterial mass, which is then separated into settled biosolids. The biological process is supported by providing DO, soluble, biodegradable fractions of BOD (from wastewater), and nutrients [47]. There needs to be more data on nutrient removal in the lagoon system; although nitrogen removal is generally good, phosphorus removal is more unpredictable [4].

Nitrogen and ammonia removal in lagoons can reach 95% or more and appears related to pH, temperature, organic load, residence time, and wastewater characteristics. The main elimination mechanisms are the volatilization of ammonia and sedimentation of organic nitrogen in the form of microbial biomass.

Nitrification and Denitrification only sometimes occur because there are few physical attachment sites in the aerobic region, resulting in a limited population of nitrifying bacteria [23]. The elimination of nitrogen in the lagoons is, mainly due to the elimination of ammonia, both by being incorporated into the algal biomass and by volatilization on the basin surface, the latter being promoted by the high pH levels developed in ponds by algal photosynthesis [23]. More research is needed to understand the nitrogen cycle in lagoons built for nitrogen removal.

Removal of phosphorus in lagoon systems involves uptake by algal biomass and some organisms. Algae represent the largest component of the organic fraction of phosphorus in lagoon fluid as they contain large amounts of orthophosphates. At the same time, part of the phosphate is constantly lost to the sediments, where it is stored in the lower zone by storage in slowly decomposing organic matter and then released into the water column by anaerobic processes [23].

Phosphorus removal rates in lagoons are generally low, typically less than 40%, with removal ranges of up to 15-25% reported [47]. Houng and Gloyna (1984) developed two mathematical models of phosphorus degradation and cycling in lagoons and operated the two lagoon systems under three loading conditions over 22 months. System I consisted of an anaerobic lagoon, a facultative intermediate lagoon, and a polishing lagoon. Similar to System I, System II did not have an anaerobic lagoon. They showed that facultative ponds with 90% BOD removal would remove only about 45% of all phosphorus present. They argued that increasing the number of cells maturing would result in greater phosphorus removal [48].

7. Current Development of Lagoon

Mara, D. et al. (2000) researched to assess the performance of a lagoon system for treating wastewater from the Providencia sugar refinery in Colombia. This system includes 2 lagoons: an initial anaerobic lagoon and a subsequent anoxic lagoon. Providencia lagoon systems are shown in Fig. 3 with sample site locations [49]. The lagoons were monitored for up to 3 years by analyzing the main parameters: BOD, COD, pH, TSS, temperature, and flow. They found that the entire system removes 73-82% of the BOD, of which 53-70% is present in the secondary anoxic cell, which is satisfactory despite the prevailing organic overload conditions. However, TSS removal was small compared to BOD removal.

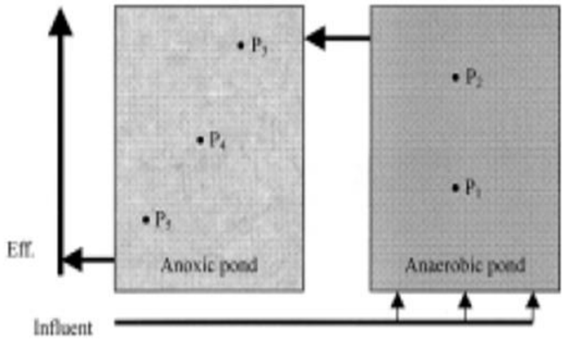

Fig. 4: Sampling points P1-P5 in the Providencia WSP

Almasi et al. (2009) studied the performance of lab-scale anaerobic and secondary anoxic lagoons to treat petroleum refinery effluent with a medium level of organic matter for eighteen (18) months in Kermanshah, Iran. Two laboratory-scale lagoons with a volume of 0.18 m^3 were designed, but with different shapes and configurations. The arrangement of the lab-scale lagoons is shown in Fig. 4, [50]. They tested the efficiency of the system at a temperature at three different temperature levels (10, 10-20, and >20 0C), two different volumetric organic loading levels (65 and 100 $g/m^3.d$), and two different levels of HRT (3.5 to 5 days). The study showed that the lagoon system performed well with BOD5 and COD removal rates of 72.64%, 61%, and 79.49%, 71% in anaerobic and anoxic lagoons, respectively.

Fig.5: Lab scale anaerobic-anoxic lagoon system

Egwuonwu et al. (2014) designed and built a laboratory model to evaluate the efficiency of a real lagoon system treating wastewater from the FUTO dormitories at the Federal University of Technology, Owerri, Nigeria, before re-discharging it into the Otamiri River. The model is a small-scale replica of the real system consisting of a facultative lagoon and three maturation lagoons, all connected in series. The design of the laboratory model of the basins was based on the Froude number (Fr) similarity between the model and the real structure. Table 4 includes the sizes of the laboratory models and the discharge of the facultative and maturation lagoons [51]. The final effluent cell of the system is filtered in a sandy loam medium. The lagoon system reduced the BOD concentration in the effluent from 356 mg/l to 22 mg/l, showing an elimination efficiency of 93.8%, while the fecal coliforms count provided a removal efficiency of approximately 99.99%. Consequently, the process of filter media can be useful to validate their use as an ideal and effective option after the lagoon system.These agents can be useful in reducing the TS content from 150 mg/l for incoming wastewater to 26 mg/l for treated wastewater. They concluded that the lagoon's effluent met the FEPA standard (Table5) [51]

Table 4: Lists the sizes of the laboratory models and the discharges of the facultative lagoons and maturation lagoons

Parameter	Facultative lagoon prototype	Facultative lagoon model	Maturation lagoon prototype	Maturation lagoon model
Area of lagoon, (m^2)	1140.73	1.267	520	0.578
Flow (m^3/s)	1.99×10^{-2}	4.04×10^{-6}	1.99×10^{-2}	4.04×10^{-6}
Residence time, (d)	11	4	4	3
Length, (m)	58.5	1.95	39.6	1.32
Width, (m)	19.5	0.65	13.2	0.44
Depth, (m)	1.5	0.75	1.2	0.6

Table 5: View the results of laboratory tests conducted on treated wastewater

Parameter	Input sewage	Output sewage	FEPA standard	Measured Elimination (%)
BOD5 mg/L	356	22	30	93.8
FC count (fc/100 mL)	1×10^8	10	400	99.9
Total suspended solids (mg/L)	155	26	30	82.7

Almasi A. et al. (2014) published a study using a laboratory scale consisting of anaerobic lagoons (0.2, 1, 1 m) and facultative lagoons (0.2, 1, 1 m) with 400 L capacity to assess the effects of (4) different phenol concentrations and various residence times to determining the efficiency of lagoons at the Kermanshah refinery in Iran. The inlet to the lagoon was 30 cm below the water surface. Fig. 6 shows the full properties of the test cells used [52]. The hydraulic residence times in the anaerobic lagoon were 2 and 5 days, and in the facultative lagoon, 5 and 10 days. In a lab-scale test, they used oily grease effluent from the Kermanshah refinery as the raw effluent. It was discovered that increasing retention time and reducing phenol concentration significantly enhanced lagoon performance. According to the author's result, the mean efficiency of the lagoon system for removing SCOD, TCOD, SBOD, TBOD, and phenol was the highest, with a residence of five days in the anaerobic lagoon, ten days in the facultative lagoon and a phenol concentration of 100 mg/l was 91.2, 93.3, 91.7, 93.7, and 98.0% removal, and a minimum residence of two days in the anaerobic lagoon, five days in the facultative lagoon and a phenol concentration of 400 mg/L give 71.9, 76.4, 68.4, 75.9, and 77.6% removal, respectively. (Fig.7 and Fig.8) [52].

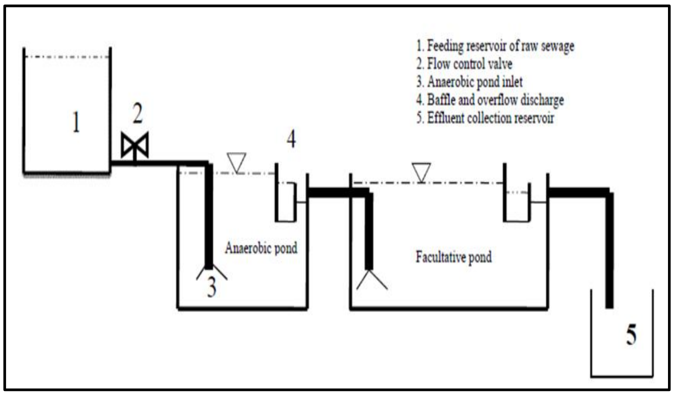

Fig. 6 : A schematic diagram of the anaerobic and facultative lagoon laboratory setup

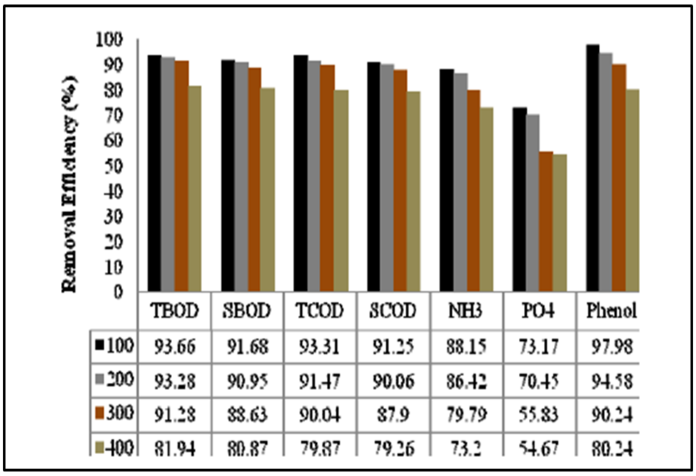

Fig. 7 : Mean removal efficiency of parameters measured at different phenol concentrations and residence time of five days in anaerobic lagoon, ten days residence time in facultative lagoon

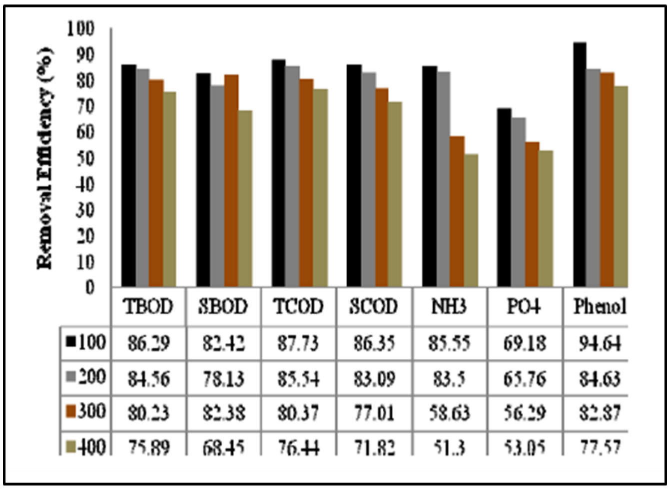

Fig. 8 : Mean removal efficiency of parameters measured for two days residence time in anaerobic lagoon, five days in facultative pond and various amounts of phenol

Nwankwo, I.H., et.al. (2022) designed and fabricated a laboratory model using lagoon systems to treat sewage generated from the kwata slaughterhouse in Awka, Anambra state, Nigeria. A model is a scaled-down replica of the real facility with three different-sized lagoons operating in series: an anaerobic lagoon, a facultative lagoon, and a maturation lagoon. The aspect ratio (L/W) of all lagoons is 3:1, and the

Froude number (Fr), which measures the degree of similarity of the model to the real facility, was used to build a model of the lagoons in the laboratory. Results from the model demonstrated high system performance in reducing COD, NO3, COD, TS, TDS, TSS, and PO4 at the respective concentrations of 4.93 mg/l, 10 mg/l, 250 mg/l, 180 mg/l, 70 mg/l, and 3.95 mg/l. They also noted that total coliforms bacteria and Fecal coliforms are now 4.04 Cfu and 3.98 Cfu each, less than before. They concluded that the final discharges met WHO sanitation standards.

For the treatment of various types of wastewater, previous studies have demonstrated the effectiveness of using lagoon systems, which traditionally consist of an anaerobic lagoon, followed by a facultative lagoon, and then a maturation lagoon in series. Lagoons provide many advantages over mechanical wastewater treatment facilities, including typically reliable systems that do not require energy sources, chemical requirements, and minimal operational requirements. However, despite the widespread use of lagoons where land availability is not a problem, this technique still needs to overcome significant obstacles in the form of odors, overloading, and sometimes excessive concentrations of all suspended particles (present in the form of algae). Many cities have upgraded the lagoons to enhance the effluent from lagoon systems due to these limitations, for example, adding rock filters to catch suspended algae released from traditional lagoons or enriching stabilization lagoons with activated sludge, etc.

8. Conclusions

The lagoon technique is becoming more popular worldwide, especially in remote and small-town where financial resources are limited. It is a widespread and relatively old wastewater treatment technology used successfully to remove organic matter, nutrients, and pathogens with acceptable results. It also has the advantages of being inexpensive to build, efficient in energy use, and efficient in maintenance. It's also easy to create and use.

In general, the lagoons technology is one of the technologies that can be used to perform partial treatment of wastewater, and it can be combined with other technologies to achieve an integrated treatment.

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