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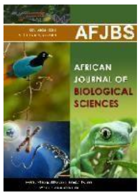

Assessing the Efficacy of Sewage Treatment Plants (STPs) and optimization inManaging Industrial Waste: A Comparative Study of Biological Processes

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Abstract

The present study examines the evaluation of Sewage Treatment Plants (STPs), specifically emphasizing their effectiveness in the treatment of industrial wastewater. This study investigates a range of biological processes, encompassing aerobic, anoxic, and anaerobic treatments, with the aim of assessing their efficacy in the treatment of both inorganic and organic industrial wastewater. Furthermore, the research examines the application of several treatment methods, including the Activated Sludge Process (ASP), Extended Aeration (EA), Moving Bed Biofilm Reactor (MBBR), and Sequential Batch Reactor (SBR), within Sewage Treatment Plants (STPs). This study seeks to offer significant insights into the optimizationof sewage treatment plants (STPs) to enhance the efficiency of industrial waste management. This will be achieved through a thorough investigation and comparison of relevant data and information.

Keywords: Sewage Treatment Plants (STPs), biological processes, Sequential Batch Reactor (SBR), aerobic, industrial wastewater

1 Introduction

According to the Asian Development Bank (ADB) in 2019, metropolitan regions account for 55% of the global population, a figure projected to increase to 60% by the year 2030. The substantial growth in population in close proximity to urban regions places significant strain on essential resources and services (Kumar & Tortajada, 2020). The provision of safe drinking water and sustainable sanitation is fundamental for the enhancement of health and hygiene. The 2015 Millennium Development Goal aims to eradicate open defecation, and among the 17 Sustainable Development Goals, it places significant emphasis on the priority of 'clean water and sanitation' with a focus on sustainable infrastructure (Roy & Pramanick, 2019). The Indian government has implemented various initiatives, including the Swachh Bharat Mission, Atal Mission for Rejuvenation and Urban Transformation, and Namami Gange, among others, with the aim of establishing sustainable water supply networks, resilient sewerage systems, and effective sewage treatment plants (STPs).

A sewage treatment plant (STP) effectively removes hazardous contaminants, rendering the resulting effluent suitable for safe disposal or potentially beneficial for subsequent usage. A Short-Term Plan (STP) is a dynamic system in which the entirety of the treatment process must operate in accordance with the designated specifications in order to enhance its reliability. Every individual unit of Sewage Treatment Plant (STP) is specifically engineered to handle the inflow of sewage and effectively remove the targeted pollutants. The removal efficiency (RE) of each individual unit or the entire plant refers to the proportion of the pollutant that is eliminated during the treatment process. According to (Khan et al., 2014), there have been reports suggesting that the use of RE can provide a more accurate estimation of the specific pollutant reduction, hence serving as a reliable indicator of the efficacy of a STP. The integration of several pollutants was found to enhance the efficiency of RE, as demonstrated by (Jamwal et al., 2009). Additionally, it has been noted that the removal efficiency (RE) is subject to temporal variations due to the stochastic character of influentand effluent pollutant parameters. The efficacy of a Sewage Treatment Plant (STP) in attaining the intended effluent standard has been examined through the use of several distribution functions, including normal, log-normal, and Weibull distributions (Padalkar & Kumar, 2018).

The review paper is organized as follows. Section 1 is the introduction and background of thesewage treatment and the industrial waste. Section 2 is about the industrial wastewater characteristics and the types. Biological process in STPs are discussed in the section 3. Performance evaluation of STPs are investigated in section 4. Technologies in the Sewage treatment plant was studied in section 5.

2 Industrial Wastewater Characteristics

Water pollution was generally restricted to tiny, localized areas until the middle of the 18th century. Then followed the Industrial Revolution, the advancement of the internal combustion engine, and the chemical industry's meteoric rise propelled by petroleum. A massive volume of fresh water is used as a raw material, as a production method (process water), and for cooling reasons due to the rapid development of many industries. Water thatis used in an industrial process comes into contact with a wide variety of raw materials, intermediate products, and trash. Wastewater is, thus, an "essential by-product" of contemporary industry and one of the main sources of contamination in the water environment (Shindhal et al., 2021).

2.1 Types of industrial waste water

Based on the many sectors and contaminants, there are numerous forms of industrial wastewater; each sector generates a unique combination of pollutants (see Table 1) (Arashiro et al., 2020).

Table 1: Water Pollutants by the Industrial Sector

Sector	Pollutant
Iron and steel	BOD, COD, oil, metals, acids, phenols, and cyanide
Textiles and leather	BOD, solids, sulfates and chromium
Pulp and paper	BOD, COD, solids, Chlorinated organic compounds
Petrochemicals and refineries	BOD, COD, mineral oils, phenols, and chromium
Chemicals	COD, organic chemicals, heavy metals, SS, and cyanide

Non-ferrous metals	Fluorine and SS
Microelectronics	COD and organic chemicals
Mining	SS, metals, acids and salts

Chromium, nickel, zinc, cadmium, lead, iron, and titanium compounds are released by the metal-working sectors; the electroplating sector is one of the major distributors of these pollutants. Printing plants discharge inks and dyes, dry cleaners and auto repair companies produce waste from solvents, and photo processing shops produce silver. Pulp and paper mill effluents comprise suspended particles, organic wastes, dioxins, and chloride organics because the business is primarily dependent on chlorine-based materials (Noor et al., 2020). Phenols and mineral oils are released in large quantities by the petrochemical sector. Also, there is a lot of organic material and suspended sediments in the effluent from food processing facilities. The treatment of industrial wastewater needs to be specifically tailored to the type of effluent generated, much like the wastewater's diverse properties. The two categories of industrial wastewater that are often distinguished are inorganic and organic processes (Nidheesh et al., 2020).

Inorganic industrial wastewater

The primary producers of inorganic industrial wastewater are the steel and coal sectors, the nonmetallic minerals sector, and commercial businesses that treat metals on the surface (such as electroplating facilities and iron picking works). A significant amount of suspended debris can be removed from these wastewaters by sedimentation, which is frequently combined with chemical flocculation achieved by adding flocculation agents, iron or aluminum salts, and some types of organic polymers (Ambaye et al., 2021).

Organic industrial wastewater

Large-scale chemical operations and chemical enterprises that primarily employ organic materials for chemical reactions produce organic industrial wastewater. The organic materials in the effluents have a range of sources and characteristics. Only a specific wastewater pretreatment followed by biological treatment will be able to eliminate these. Industries and plants that produce pharmaceuticals, cosmetics, organic dye-stuffs, glue and adhesives, soaps, synthetic detergents, pesticides, and herbicides, as well as tanneries and leather factories, textile factories, cellulose and paper manufacturing plants, oil refining industry factories, brewery and fermentation factories, are the main producers of organic industrial wastewaters.industry that processes metals (Ajiboye et al., 2021).

3 Biological Process of STPs

Biological processes are categorized based on the primary metabolic pathways exhibited by the predominant microorganisms that are actively involved in the treatment system. Biological processes are categorized into aerobic, anoxic, and anaerobic based on the presence and utilization of oxygen (Chen et al., 2020).

3.1 Aerobic Processes

Aerobic processes refer to treatment activities that take place in the presence of molecular oxygen (O2) and utilize aerobic respiration to produce cellular energy. These organisms exhibit a high level of metabolic activity, which therefore results in the production of a greater amount of leftover solids in the form of cellular mass.

3.2 Anoxic Processes

These are aerobic respiration-based systems that provide energy when free molecular oxygen (O2) is not present. The combined oxygen from inorganic waste materials, such as nitrate, serves as the terminal electron acceptor for microorganisms. Common biological mechanismsfor removing nitrogen through denitrification are anoxic reactions (Kanujiya et al., 2019).

3.3 Anaerobic Processes

The aforementioned activities take place in an environment devoid of free or mixed oxygen, leading to the decrease of sulphate and the production of methane. Typically, these systems generate biogas, specifically methane, as a valuable secondary product, while exhibiting a tendency to yield lesser quantities of biosolids during the treatment process. In addition to being classed based on microbial metabolism and/or oxygen utilization, biologicalwastewater treatment procedures can also be categorized according to the growth conditions within the reactor (refer to Figure 1) (Saleh et al., 2020). In the present scenario, the two primary classifications encompass suspended growth and attached growth methodologies.

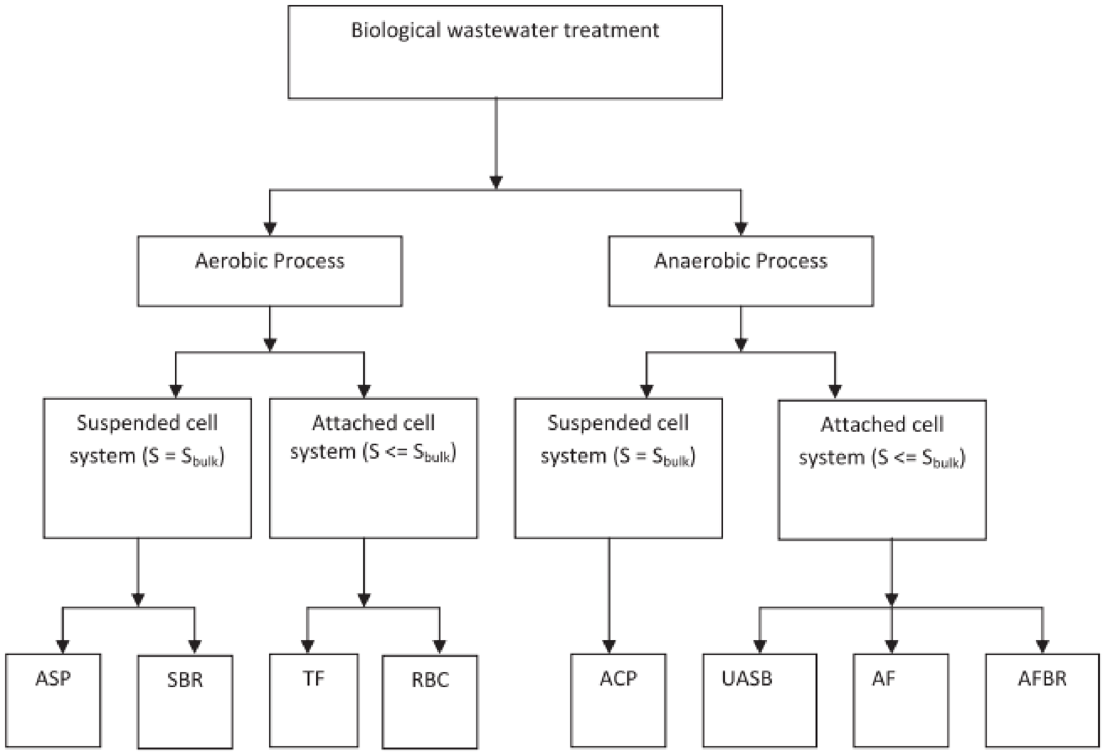


Figure 1: Different biological treatment processes

3.4 Aerobic Biological Waste Treatment Processes

Conventional aerobic waste treatment systems are designed to facilitate the exposure of microorganisms to molecular oxygen (O2) in order to facilitate the oxidation of complex organic compounds found in the waste. This process results in the production of carbon dioxide, simpler organic compounds, and the generation of new cellular biomass. The activated sludge process (ASP) is widely recognized and extensively employed as a predominant biological treatment method in developed nations (Goli et al., 2019).

Activated Sludge Process

Classic ASPs refer to aerobic suspended cell systems. The process of mineralization of waste organic molecules is often accompanied by the generation of new microbial biomass and, in certain cases, the elimination of inorganic chemicals like ammonia and phosphorus. The occurrence of these outcomes is contingent upon the specific design of the process. The concept of activated sludge operations originated in the early 1900s, wherein the term "activated" was used to denote the presence of particles that facilitate the breakdown of waste materials (Waqas et al., 2020). It was eventually determined that the component responsible for the activation of the sludge consisted of an intricate combination of microorganisms. The aqueous component within activated sludge systems is sometimes referred to as the "mixed liquor," encompassing both the incoming wastewater and the resident microorganisms (Wei et al., 2019).

Multiple iterations of the ASP have been seen. The prevalent designs employed in this context encompass conventional, step aeration, and continuous-flow stirred-tank reactors. According to the second source, A typical activated sludge process (ASP) comprises of customary pre-treatment procedures, an aeration tank, and a secondary clarifier. An illustration of the latter can be observed in Figure 2. The aeration tank can be aerated by the use of sub-surface or surface aerators, which are specifically designed to provide sufficient dissolved oxygen to support the growth and activity of microorganisms in the water (Based etal., 2020). The wastewater traverses the tank, where resident microorganisms engage in the consumption of organic substances present in the effluent. The effluent from the aeration tank is directed to the clarifier, where the microorganisms are subsequently separated and eliminated. The supernatant containing the clarifier is subsequently conveyed through disinfection or treatment facilities, and ultimately released into the receiving water body. The biosolids derived from the settler are either recycled back to the first stage of the treatment system or directed to digesters for subsequent processing (Buaisha et al., 2020).

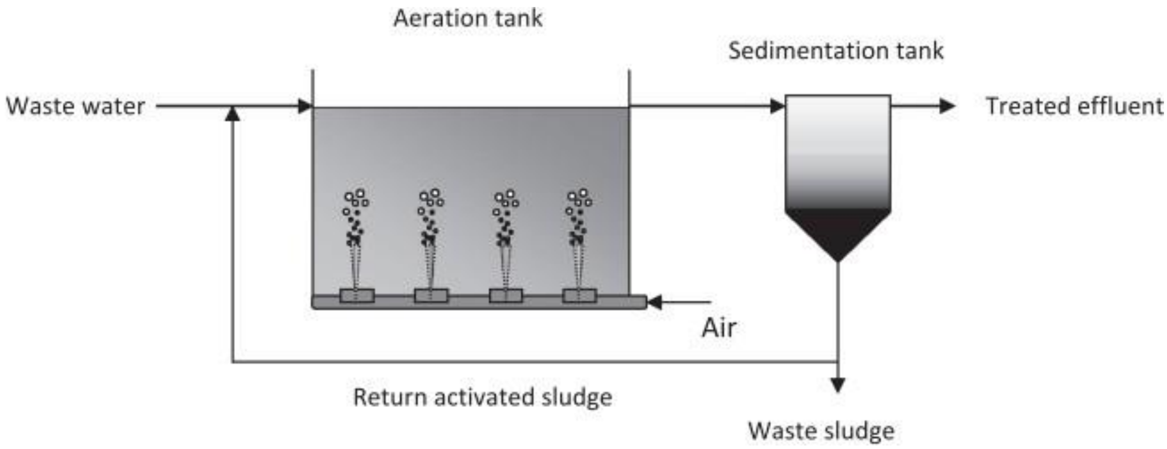


Figure 2: Activated sludge process

Aeration Tanks

Typically, aeration tanks are created in an uncovered manner, allowing them to be open to theatmosphere. The microorganisms receive air through two main mechanisms: mechanical aerators or diffusers. Mechanical aerators, including surface aerators and brush aerators, facilitate the mechanical aeration of water surfaces, thereby enhancing the passage of oxygen from the atmosphere into the water. The manipulation of rotor speed enables regulation of the concentration of dissolved oxygen in the liquid (Jagaba et al., 2021). Both mechanical aerators and diffusers are significant energy consumers in aerobic biological wastewater treatment processes. Diffusers are devices that introduce air into the tank at a certain depth, and they are generally favored due to their superior efficiency in transferring oxygen. As mentioned earlier, aeration facilitates the provision of oxygen to microorganisms and additionally aids in the homogenization of the liquid within the tank. While it is ideal to achieve total mixing, it is common for "dead zones" to form within the tank when anaerobic/anoxic conditions occur due to inadequate mixing in certain locations. Minimizing the number of these zones is preferable in order to mitigate both the presence of unpleasant odors and issues related to sludge thickening, which can impede the settling efficiency in secondary clarifiers (Jasim, 2020).

Attached Growth Processes

Trickling filters, exemplified in Figure 3, are a type of attached growth processes that have the capability to attain treatment objectives comparable to those of activated sludge systems. The conversion mechanisms observed in these systems are commonly constrained by mass transport limitations. It has been observed that bacteria residing in the outer layers of the biofilm play a significant role in the overall removal of the substrate (Machineni, 2020). The selection of support material in trickling filters is based on the requirement for pore spaces of adequate size to facilitate the passage of air through the filter, irrespective of the formation of biofilm and the downward flow of water. The distribution of wastewater is achieved through the utilization of rotary arms positioned at the uppermost section, followed by a subsequent downward trickle through the filter medium. Trickling filters are primarily employed for the purpose of carbon and ammonia oxidation, although they can also facilitate denitrification under optimal convection of air inside the system (Silva et al., 2019).

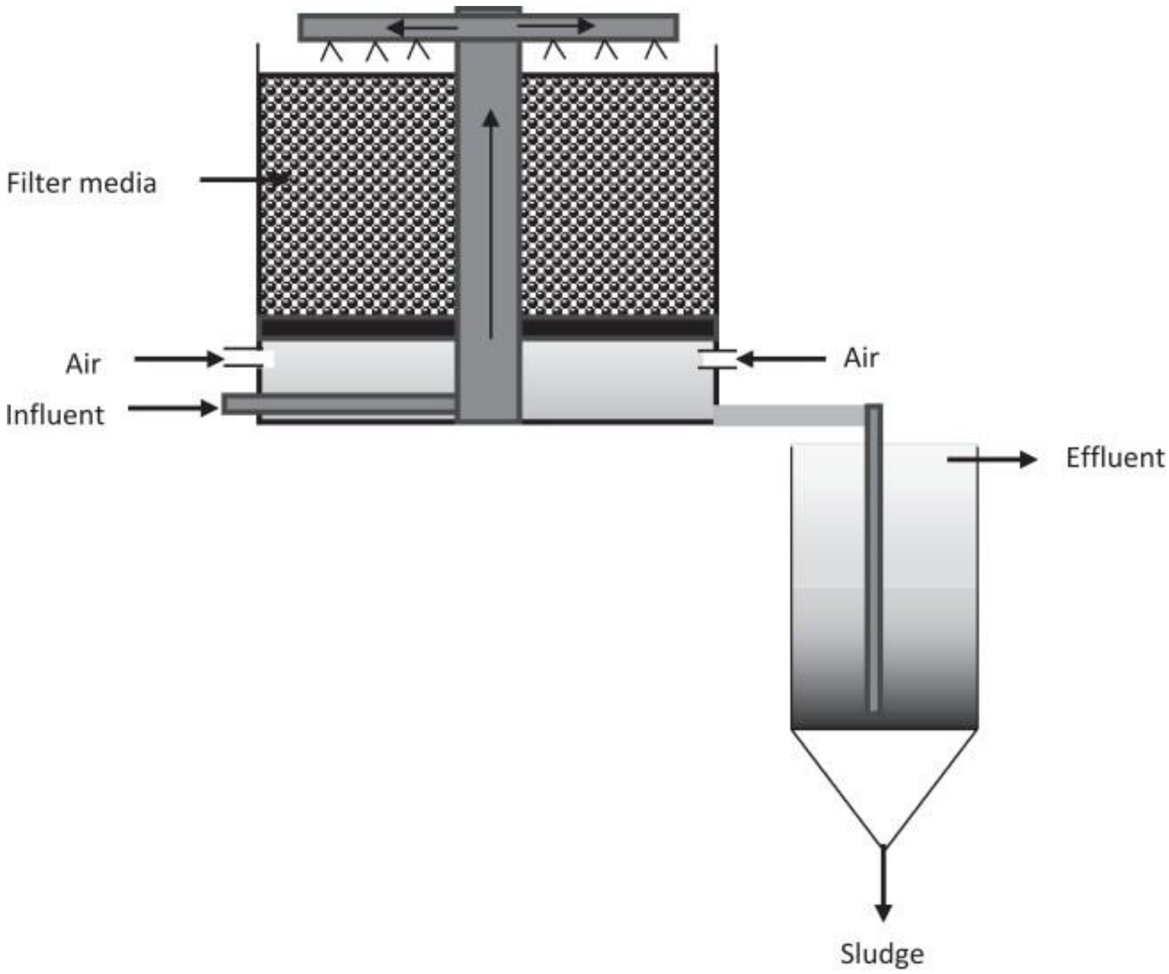


Figure 3: Aerobic trickling filter.

3.5 Anaerobic Wastewater Treatment Processes

Anaerobic treatment technologies are widely used in various sectors based on their applicability and requirements. The sequential and syntrophic metabolic interactions of different trophic groups of prokaryotes, such as fermenters, acetogens, methanogens, and sulfate-reducing bacteria (SRB), break down organic materials under anaerobic conditions (Chen et al., 2020). These microbial communities interact metabolically to convert complex organic chemicals into simpler ones like ammonia, carbon dioxide, hydrogen sulphide, and methane. In (Sayara et al., 2020)There are four main reaction phases that comprise the digestion process, and each stage involves a different type of microbe.

Stage 1: Dehydrogenation----The primary constituents of the organic waste material are lipids, proteins, and carbohydrates. Because of the action of extracellular enzymes secreted by these microorganisms, complex and big molecules are broken down into simpler components. Hydrolytic microorganisms including Lactobacillus, Bifidobacterium, Clostridium, and Bacteroides are primarily responsible for the process of hydrolysis or solubilization. These microbes hydrolyze complex organic compounds (lipids, proteins, lignin, and cellulose) into soluble monomers like glycerol, glucose, amino acids, and fatty acids. In the following stage, the fermentative acidogenic bacteria utilise these hydrolysis products (Ahmad et al., 2022).

Stage 2: Acidogenesis—Simple organic materials like sugars, amino acids, and long-chain fatty acids are converted by fermentative acidogenic bacteria into short-chain organic acids like lactic, succinic, butyric, valeric, isobutyric, and propionic acids; alcohols and ketones (such as ethanol, methanol, glycerol, and acetone); carbon dioxide; and hydrogen. In any anaerobic digester, ac idogenic bacteria are typically the most prevalent and multiply at rapid rates (Rabii et al., 2019). These organisms' strong activity suggests that the anaerobic digesting process's acidogenesis is never its rate-limiting stage. Microorganisms specific to the acetogenesis stage further process the volatile acids generated in this stage.

Step 3: Acetogenesis ---During this phase, organic acids and alcohols are converted by obligate hydrogen-producing bacteria, or acetogenic bacteria. The resulting acetate, hydrogen, and carbon dioxide are then utilized by meth anogens and SRB. The symbiotic link between methanogens and acetogenic bacteria is very robust. Hydrogen is used by metha nogens and SRB to help attain the low hydrogen pressure levels necessary for acetogenic conversions (Zhao et al., 2019).

Step 4: Methanogenesis – Methanogenic archaea produce methane during this last step of aerobic digestion, which is the result of the production of hydrogen, acetate, methanol, methylamines, formate, and acetate during previous stages. Although there are certain instances when hydrolysis is rate-limiting, the majority of the time this step of the anaerobic process is thought to be the one where methanogen growth is very slow (Pramanik et al., 2019).

4 Performance Evaluation of Sewage Treatment Plants (STP)

Most STPs are built to ensure a healthy environment and to lessen the pollution load on receiving water bodies, which in turn lessens the degradation of the water quality. The technique of performance evaluation aids in comprehending the operating challenges and design of every plant unit. An analysis of the influent and effluent pollutant levels at the treatment plant provides evidence of the effectiveness of STPs (Wakode & Sayyad, 2014). In Ludhiana at Bhattian location, two STPs, one of 50 MLD capacity on SBR technology and the other on UASB technology of 111 MLD capacity are built on same site, both these STPs are fed with influent from a common pumping station. Throughout the course of twelve months, daily samples were taken from the STP's inlets and outlet. Temperature, pH, Total Suspended Solids (TSS), Chemical and Biological Oxygen Demands (BOD and COD), were measured in wastewater samples. According to results obtained from the test conducted at the Laboratory the parameter removal efficiency for TSS, COD and BOD, were 98.6 %, 91.2 % and 97.6 respectively. The results of STP on SBR technology were compared with the results obtained from UASB based STP for the same parameters during the same period of observation, while using the common influent, where the parameter removal efficiency for TSS, COD and BOD were 91.6%, 76.2 % and 81.6 % respectively. Also on SBR technology, Kaithal Town's STP was built. Throughout the course of three months, daily samples were taken from the STP's inlets and output. pH, Total Suspended Solids (TSS), Chemical and Biological Oxygen Demands (BOD and COD), Turbidity, Nitrate, Phosphate, Total Nitrogen (TN), and Total Phosphorous (TP) were measured in wastewater samples. According to (Koppad, 2014) the parameter removal efficiency for TSS, COD, BOD, and turbidity were 97.2%, 92.0%, 97.8%, and 93%, respectively. In order to handle and treat home wastewater, (Showkat & Najar, 2019) studied the effectiveness of STP based on the cutting-edge aerobic BIO FOR technology located in Delhi. pH, TSS, BOD, COD, Mixed Liquor Suspended Solids (MLSS), Total Coliform (TC), and Faecal Coliform (FC) were the characteristics that were taken into consideration. The results of STPs based on BIO FOR Technology show that the technology was relatively excellent in the removal of FC from the wastewater but not sufficiently efficient in the removal of TC. BOD, COD, and Suspended Solids (SS) removal efficiencies were 95.2%, 93.4%, and 97%, respectively.

5 Treatment Technologies used for Sewage Treatment

5.1 Activated Sludge Process (ASP)

The activated-sludge technique is a sewage-treatment procedure that involves the introduction of sludge, which is a collection of microbe-rich deposits from settling tanks and basins, into the incoming wastewater. This mixture is then agitated for a period of time ranging from 4 to 8 hours, while ensuring the presence of a sufficient air supply. The sludge effectively adsorbs suspended solids and a variety of organic substances, while microorganisms present in the sludge facilitate the oxidation of organic materials. The selection of air and sludge measures can be varied in order to regulate the degree of treatment received. The sludge is subsequently separated and collected in a settling tank (Hussain et al.,2021).

The activated sludge plant encompasses many key processes. Firstly, it involves the aeration of wastewater in the presence of a microbial suspension. This promotes the growth and activity of microorganisms responsible for the breakdown of organic matter. Following aeration, the next step is solid-liquid separation, which separates the treated wastewater from the suspended solids. The clarified effluent is then discharged. Additionally, surplus biomass is removed through a process known as wasting, while the remaining biomass is returned to the aeration tank to maintain the microbial population.

5.2 Extended Aeration (EA)

The traditional activated sludge plant has undergone modifications to remove the primary sedimentation tank and sludge digesting tank, resulting in a technique known as Extended Aeration. This method is designed to enhance the aeration tank by extending the duration of aeration. According to a study conducted by (Awasthi et al., 2022), it has been found that for populations of up to 150,000, an alternative method proves to be more cost-effective compared to a traditional activated sludge facility.

5.3 Moving Bed Biofilm Reactor (MBBR)

The system comprises a combination of the activated sludge process, which involves suspended growth, and biofilter operations, which involve attached growth. The utilization of the full tank space for biomass development is a key characteristic of the Moving Bed Biofilm Reactor (MBBR) method. The system employs fundamental floating medium that serve as carriers for the formation of biofilms. The displacement of air bubbles is responsible for the motion of biofilm carriers. The efficacy of this basic treatment framework has been demonstrated in the removal of BOD, nitrogen, and phosphorus, while also promoting effective solids separation (Oliveira, 2014).

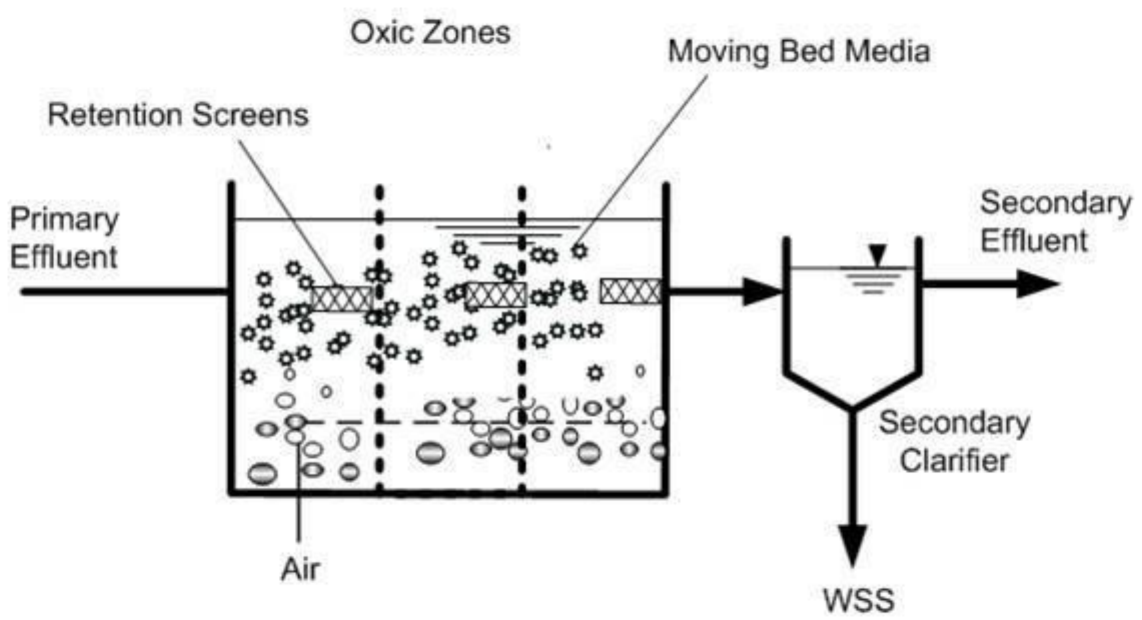


Figure 4: Typical Representation of Moving Bed Biofilm Reactor

5.4 Sequential Batch Reactor (SBR)

The sequencing batch reactor (SBR) process is a suspended growth (active sludge) technique that operates in a single tank, with each key step occurring sequentially. The reduction of the overall impact occurs through the occurrence of five consecutive phases within a single reactor. Submerged biological reactors (SBRs) have the potential to be strategically engineered and effectively utilized in order to optimize the elimination of nitrogen, phosphorus, and ammonia, while concurrently addressing the reduction of total suspended solids (TSS) and biochemical oxygen demand (BOD) (Rangari et al., 2022). The five stages of Sequential Bayesian Reasoning (SBR) are as follows:

- The tank is filled with wastewater, which then mixes with biomass that settles duringthe previous cycle.
- In the process of React, the introduction of air into the tank serves to facilitate thegrowth of biological organisms and enhance the reduction of trash.
- During this stage, the process of mixing and aeration ceases in order to facilitate thesettling of solids.
- The process of discharging clarified water is depicted by a drawing.
- During this step, it is possible to remove sludge.

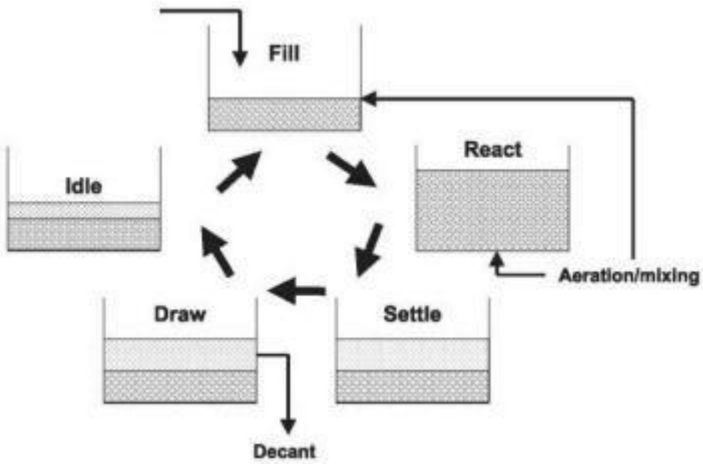
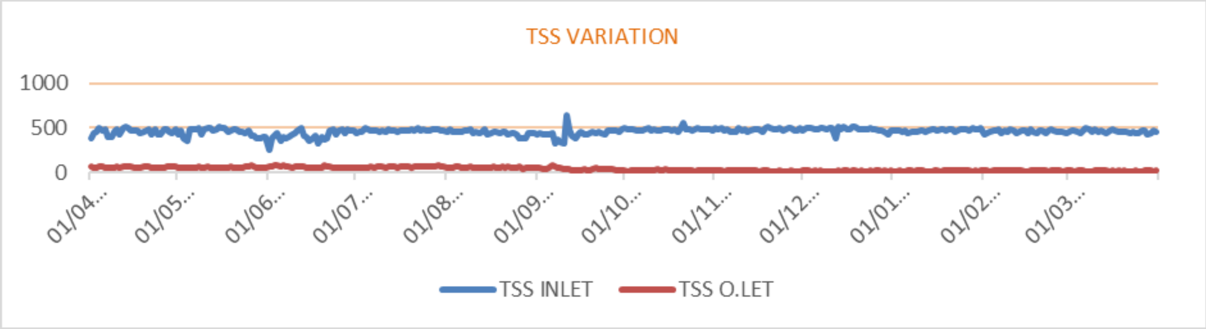
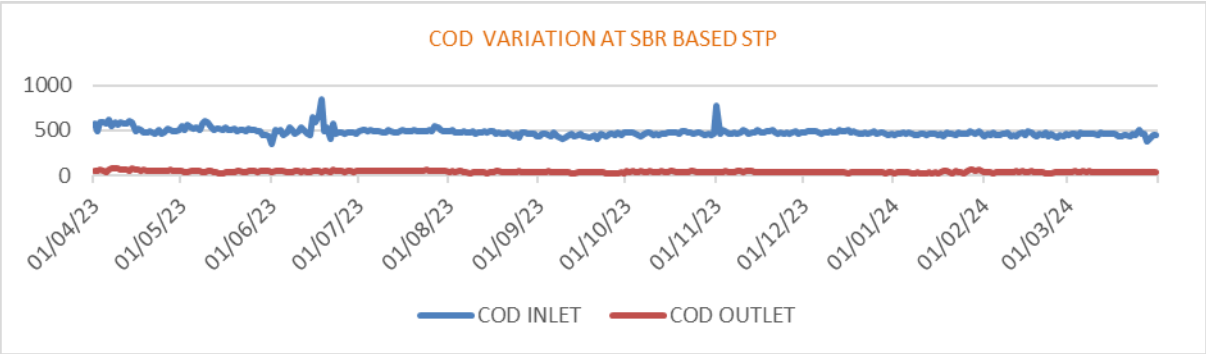


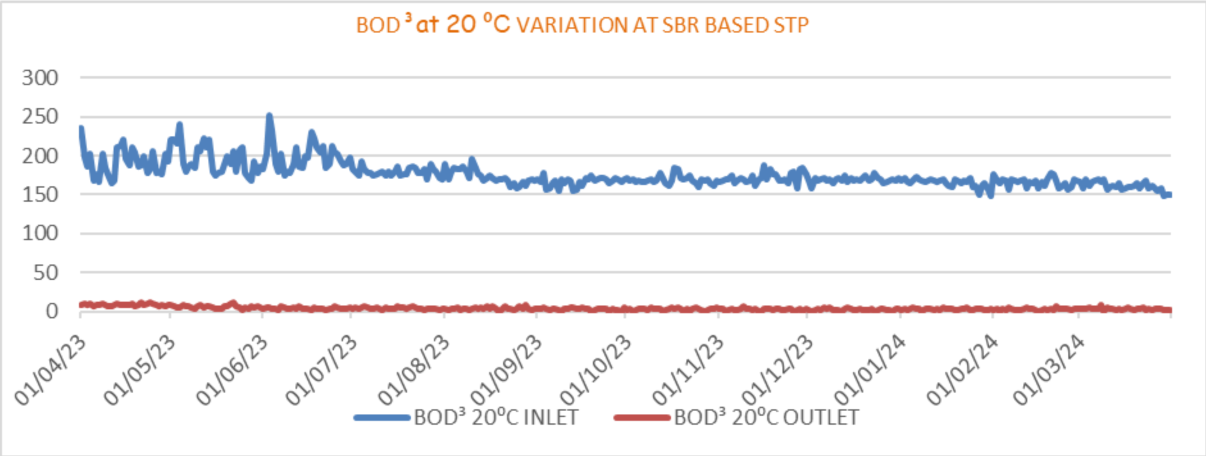
Figure 5: Typical Cycle in SBR (USEPA 1999)

Data Analysis

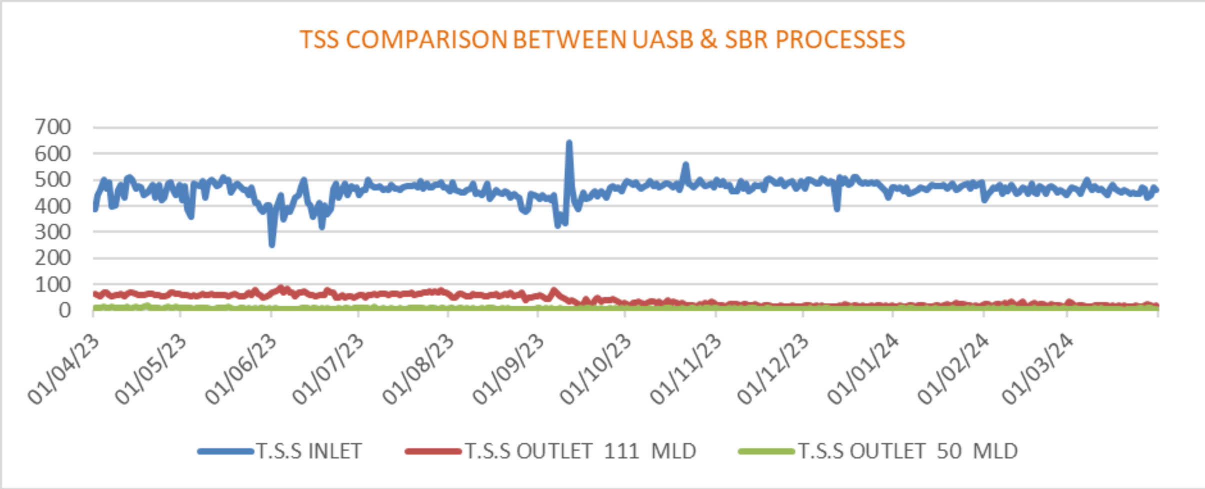
a) Following graphs shows the reduction in in different parameters at STP based on SBR technology during twelve month period







b) Comparison between treated parameters received from SBR and UASB technology are being shown herewith through following graphs


TSS COMPARISON BETWEEN UASB & SBR PROCESSES
700
600
500
400
300
200
100
0
01/04/23
01/05/23
01/06/23
01/07/23
01/08/23
01/09/23
01/10/23
01/11/23
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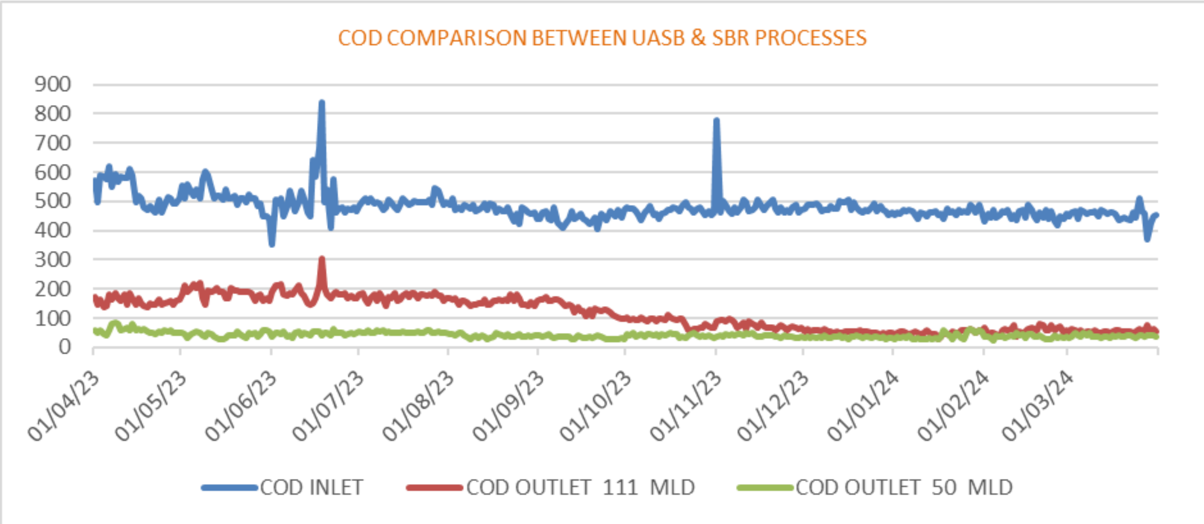
T.S.S INLET
T.S.S OUTLET 111 MLD
T.S.S OUTLET 50 MLD


COD COMPARISON BETWEEN UASB & SBR PROCESSES
900
800
700
600
500
400
300
200
100
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01/04/23
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COD INLET
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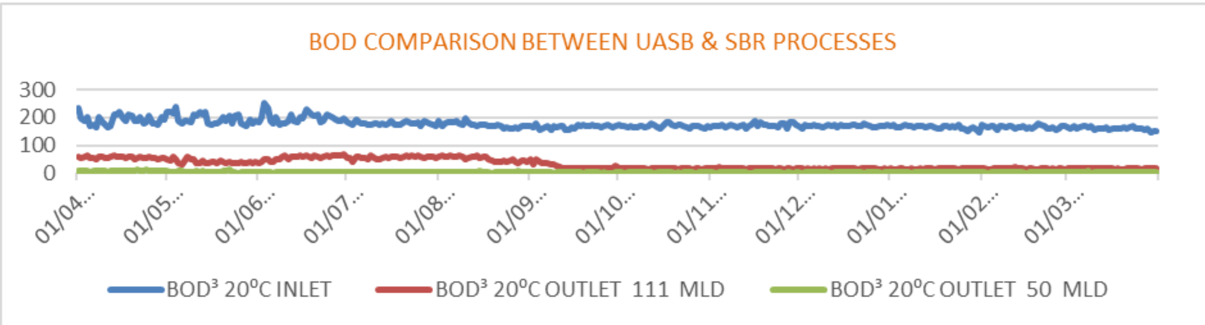
COD OUTLET 50 MLD


BOD COMPARISON BETWEEN UASB & SBR PROCESSES
300
200
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01/04...
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01/03...
BOD³ 20⁰C INLET
BOD³ 20⁰C OUTLET 111 MLD
BOD³ 20⁰C OUTLET 50 MLD

Conclusion

The present study investigates the efficacy of diverse biological mechanisms employed in Sewage Treatment Plants (STPs) for the purpose of managing industrial wastewater. Aerobic techniques, such as the Activated Sludge Process, have demonstrated encouraging outcomes in the treatment of both inorganic and organic wastewater. The achievement of optimal outcomes in anoxic and anaerobic processes necessitates the meticulous evaluation of operational factors. The Moving Bed Biofilm Reactor (MBBR) and Sequential Batch Reactor (SBR) have demonstrated promising capabilities in improving the efficiency of Sewage Treatment Plants (STPs) as a result of their inherent flexibility and adaptation to varying operational conditions. The research highlights the importance of adopting a comprehensive methodology for developing and managing sewage treatment plants (STPs), taking into account the unique attributes of industrial wastewater and carefully choosing suitable biological techniques and treatment methodologies. The present study establishes a fundamental basis for the subsequent investigation and enhancement of STP optimization strategies, hence making a valuable contribution towards the promotion of environmental cleanliness and improved public health.

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