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Assessing the Efficacy of Sewage Treatment Plants (STPs) and optimization in Managing Industrial Waste: A Comparative Study of Biological Processes using USAB Technology

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Brief overview:

This review study examines the comprehensive evaluation of sewage treatment plants (STPs) in India and investigates several biological processes, with specific emphasis on the Upflow Anaerobic Sludge Blanket Reactor (UASB) technology. The UASB technology is the focal point of this study, which aims to analyze the influence of different criteria on its operational effectiveness. Also real time monitoring of an established 111MLD capacity Sewage Treatment plant (Ludhiana, Punjab, India) has been done by comparing the quality of inlet parameters and outlet parameters such as BOD, COD, TSS, Temperature, pH.

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Abstract

This review study examines the comprehensive evaluation of sewage treatment plants (STPs) in India and investigates several biological processes, with specific emphasis on the Upflow Anaerobic Sludge Blanket Reactor (UASB) technology. This study aims to assess the effectiveness of various sewage treatment systems and explore strategies for optimizing their performance in the management of industrial waste. The discourse commences with an examination of the current state of wastewater management in India, underscoring the imperative for the implementation of efficient treatment approaches. Additionally, the present study investigates the many unit activities and processes associated with sewage treatment, which comprise a range of physical, chemical, and biological treatment techniques. The UASB technology is the focal point of this study, which aims to analyze the influence of different criteria on its operational effectiveness. The effects of several factors, including temperature, hydraulic retention time (HRT), pH levels, granulation, and mixing, are comprehensively examined in order to gain a deeper understanding of their impact on the operation of Upflow Anaerobic Sludge Blanket (UASB) reactors. Also real time monitoring of an established 111MLD capacity Sewage Treatment plant (Ludhiana, Punjab, India) has been done by comparing the quality of inlet parameters and outlet parameters such as BOD, COD, TSS, Temperature, pH.

Keywords: sewage treatment plants (STPs), Upflow Anaerobic Sludge Blanket Reactor (UASB), industrial waste, Activated Sludge, biological processes

1 Introduction

Wastewater and sewage are essentially the community's water supply after they have been contaminated by various uses. From the perspective of the sources of generation, wastewater is the mixture of any groundwater, surface water, and storm water that may be present, along with the liquid (or water) carrying wastes taken from homes, institutions, businesses, and industrial establishments (Droste & Gehr, 2018). Sewage/community wastewater is the general word used to describe the wastewater that is released from domestic locations, such as homes, businesses, and institutions. It is 99.9% water and 0.1% solids, and because it contains carbon molecules found in things like paper, vegetable matter, and human waste, it is organic. In addition to sewage from communities, the area also has industrial wastewater. Similar to sewage, many industrial wastes are organic in nature and can be handled physico-chemically, by microorganisms, or both (Prabu et al., 2011).

Water covers 71% of the earth's surface and makes up 65% of human bodies. After using clean water for everything from washing to gardening to cooking, it ends up as wastewater. Contaminated water loses its aesthetic and economic worth and becomes dangerous for human health and the survival of marine life that depends on it [1]. It is believed that between 70% and 80% of the water supplied is wasted as effluent. The produced wastewater is discharged into the natural watercourse. The only way to address the serious problems and health risks associated with wastewater disposal into surface water sources is to treat the wastewater in accordance with regulations [2]. Numerous pathogenic bacteria, germs, suspended particles, nutrients, minerals, poisonous metals, and other substances are present in the wastewater. For a while, lowering the concentration of hazardous bacteria, dissolved inorganic compounds, oxygen-demanding materials, and suspended particles was the main objective of wastewater treatment. But in recent times, there has been a greater focus on enhancing municipal treatment systems for the removal of solid waste. Physical, chemical, and biological processes are used in conventional wastewater treatment to extract particles, nutrients, and organic matter from wastewater [3]. The many stages of treatment are primary, secondary, tertiary, and preliminary. Coarse fines and other big items are removed from wastewater during the preliminary treatment stage. Both organic and inorganic particles are removed during initial treatment by the physical processes of flotation and sedimentation. The purpose of secondary treatment is to eliminate any remaining organic matter and suspended particles from the effluent. All procedures and methods utilised to eliminate pollutants that were not eliminated in earlier stages are included in tertiary treatment. While these actions can enhance the water quality of typical wastewater, they are not a suitable remediation method for wastewater produced by growing industrial operations. There can be other contaminants in the wastewater we are working with that are challenging to eliminate using the traditional approach. It's possible that the wastewater that needs to be treated contains more toxins than can be handled using conventional techniques. The kind of wastewater determines the appropriate treatment procedure, therefore understanding its properties—such as its COD, TS, VS, and salt content—is crucial [4-5].

1.1 Status of wastewater in India

The cumulative volume of wastewater produced by 299 cities classified as class 1 amounts to 16,652.5 million litres per day (MLD). Approximately 59% of the total is generated by a group of 23 metropolitan cities. The state of Maharashtra accounts for around 23% of the total wastewater created in class-1 cities, while the Ganga river basin contributes approximately 31% of this effluent. The collection rate for treated wastewater is just 72% of the total amount generated. Among the 299 cities classified as class-1, it has been observed that 160 cities possess a sewerage system that caters to over 75 percent of their respective populations. Additionally, 92 cities have achieved a population coverage exceeding 50 percent. In general, it can be observed that the proportion of the total population residing in class-1 cities with access to sewerage facilities has increased from 48% in 1988 to 70%. There are three main types of sewerage systems: open, closed, and piped.

2 Classification of Sewage Treatment Plant Methods

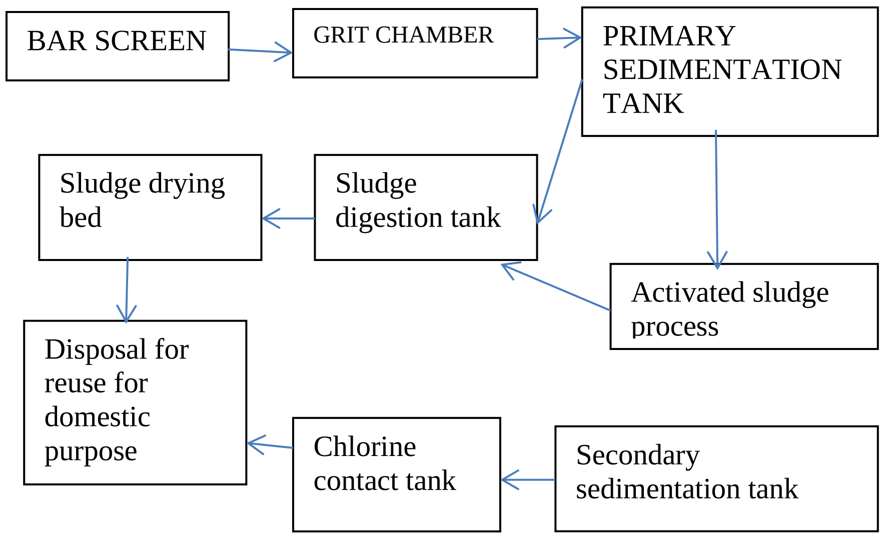


Figure 1.Flow Diagram of STP (Sewage Treatment Plant)

2.1 Preliminary sewage treatment

The application of this particular treatment method results in a reduction of the biochemical oxygen demand (BOD) present in the wastewater, typically ranging from 15% to 30%. Preliminary operations encompass several activities, such as the implementation of screening processes to effectively eliminate garbage and rags. A grit chamber is used to facilitate the separation and subsequent removal of coarse suspended matter, which has the potential to induce equipment wear or obstruction.

2.2 Primary sewage treatment

During the initial treatment stage, a fraction of the suspended particles and organic debris present in the wastewater is eliminated. The process of removing contaminants is often achieved through physical mechanisms, like as sedimentation in settling basins. The liquid effluent resulting from first treatment frequently contains a significant quantity of suspended organic matter and exhibits a high biochemical oxygen demand (BOD), approximately equivalent to 60% of the initial concentration. The organic particles that are extracted during the sedimentation process in primary treatment are commonly subjected to anaerobic decomposition in a digestion tank or burnt. The resulting residue is then utilised for landfill purposes or as a soil conditioner. The major purpose of primary treatment is to serve as a preliminary step preceding secondary treatment. The basic illustration of a Primary treatment can be seen in Figure 1.

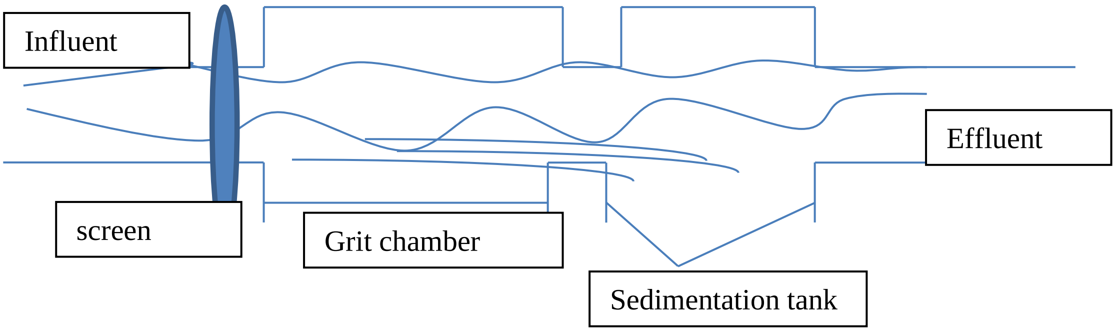


Figure 1: The basic illustration of waste water treatment through Primary treatment[7].

Material and Method

3 Upflow Anaerobic Sludge Blanket Reactor Technology for Sewage Treatment Plant Anaerobic treatment systems, such as Upflow Anaerobic Sludge Blanket (UASB), are being increasingly promoted due to their numerous advantages. These advantages include a simple design, straightforward construction and maintenance, minimal land requirement, low costs for both construction and operation, minimal production of excess sludge, high efficiency in removing chemical oxygen demand (COD), ability to withstand fluctuations in temperature, pH, and influent concentration, rapid recovery of biomass after shutdown, and the generation of energy in the form of biogas or hydrogen [1, 9, 15-19]. The aforementioned characteristics contribute to the widespread adoption of Upflow Anaerobic Sludge Blanket (UASB) as a viable wastewater treatment alternative [20, 21]. Numerous scholars have advocated for the implementation of UASB technology in the treatment of sewage wastewater within tropical and subtropical areas [10–12, 14, 22–24].

The mesophilic methanogenic bacteria thrive in tropical nations due to the favourable ambient temperature, which is close to the optimum for their growth [11, 13]. Considerable endeavours have been undertaken over the past two decades to investigate the mass transport and kinetic phenomena occurring within the reactor. This study aims to examine the merits and drawbacks of anaerobic and aerobic bioreactors. Additionally, it seeks to compare the UASB (Upflow Anaerobic Sludge Blanket) method with alternative sewage treatment approaches, in order to assess their viability and effectiveness in treating household wastewater. Furthermore, the study aims to suggest potential topics for future research in this field. This study presents an analysis of the impact of key process parameters, including temperature, hydraulic retention time (HRT), organic loading rate (OLR), pH, granulation, and mixing, on the operational efficiency of upflow anaerobic sludge blanket (UASB) reactors and hydrogen generation. The objective is to identify the ideal conditions for bacterial growth and system performance. Potential posttreatment solutions suitable for implementation in poor countries with suitable climatic conditions are also identified. Figure 1 presents a simplified depiction of a UASB reactor. The wastewater is introduced into the reactor at its lowermost point and proceeds to ascend through a region known as the "sludge blanket," which is comprised of a bed of granular sludge [13]. The UASB structure facilitates a highly efficient mixing process between the biomass and the wastewater, resulting in a fast anaerobic breakdown [13]. The functioning of a UASB reactor is primarily centred around its granular sludge bed, which undergoes expansion when the wastewater is directed to flow in a vertical upward direction through it [14]. The microorganisms that are attached to the sludge particles have a crucial role in the removal of pollutants present in wastewater. Therefore, the quality of the biofilm and the level of contact between the sludge and wastewater are important parameters that determine the performance of an Upflow Anaerobic Sludge Blanket (UASB) reactor [14]. The biogas produced aids in the facilitation of the mixing and interaction between sludge and wastewater. Additionally, a three-phase gas-liquid-solid separator, positioned in the upper section of the reactor, enables the extraction of biogas by effectively separating it from the liquid effluent and residual sludge particles [13]. The UASB reactor is characterised by typical geometrical and operating features, such as a height to diameter ratio ranging from 0.2 to 0.5 and an up-flow velocity between 0.5 and 1.0 m/h [12].

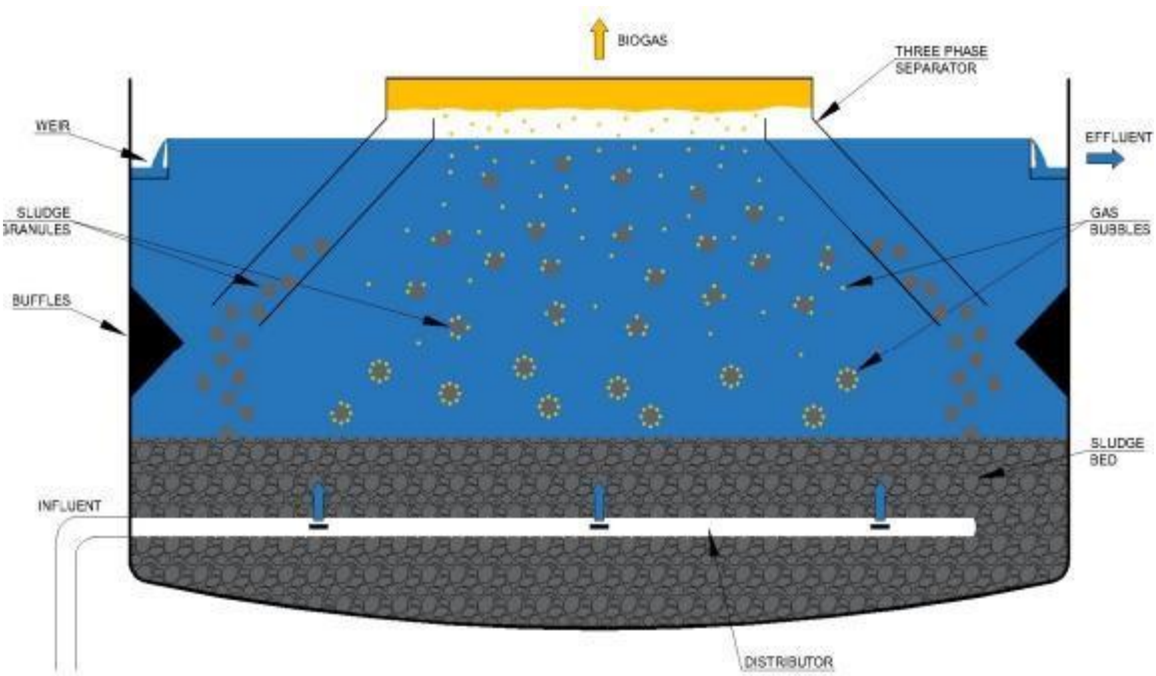


Figure 1. Up-flow anaerobic sludge blanket (UASB) reactor process scheme.

The UASB treatment method, in comparison to aerobic stabilisation, has advantages such as reduced energy consumption, increased efficiency at handling larger loading rates, and a decreased requirement for micro and macro-nutrients. Additionally, the UASB treatment process results in a smaller quantity of sludge, which possesses improved dewatering properties [12]. Indeed, it has been observed that a mere 5-10% of the organic matter present in wastewater is effectively transported to the sludge fraction [12]. However, it should be noted that the UASB treatment has been found to have a restricted impact on nutrients, such as nitrogen and phosphorus, as well as on micro-pollutants [15]. The utilisation of Upflow Anaerobic Sludge Blanket (UASB) treatment for the management of high-strength industrial wastewater has been found to effectively decrease energy costs associated with aeration in wastewater treatment plants (WWTPs), particularly when UASB is implemented as a preliminary treatment preceding secondary biological processes [16]. The UASB reactor demonstrates effective treatment capabilities for a range of high-strength industrial wastewaters, including brewery wastewater [17], sugarcane vinasse [18], paper mill wastewater [16], and dairy wastewater [16]. These wastewaters are characterised by elevated concentrations of chemical oxygen demand (COD) and significant biodegradability, as indicated by a high biochemical oxygen demand (BOD)/COD ratio. The utilisation of Upflow Anaerobic Sludge Blanket (UASB) treatment for high-loaded substrates has been found to yield substantial amounts of methane while requiring less energy compared to aerobic stabilisation. Additionally, UASB treatment results in a greatly reduced creation of surplus sludge [19]. Moreover, it has been demonstrated that Upflow Anaerobic Sludge Blanket (UASB) technology is effective in treating diluted streams, including municipal wastewater [12], even when operated at ambient temperature.

The study conducted by [20] evaluated the efficacy of UASB treatment and aerobic open lagoon in the treatment of wastewater generated from ethanol production. The findings of the study emphasised that the environmental impact associated with the use of open lagoon is higher when compared to the utilisation of UASB reactor. The UASB reactor and anaerobic membrane bioreactor (AnMBR) have been identified as suitable options for the treatment of chemical-industrial wastewater [21]. However, the full potential of anaerobic treatment is limited by the inefficient breakdown of organic substrates that are resistant to degradation [21]. Therefore, it is necessary to implement an appropriate pre-treatment method in order to improve the degradability of these substances in anaerobic conditions.

The critical factors that require regulation during the implementation of a UASB treatment include the initiation of the reactor and the improvement of granulation. It is advisable to integrate the anaerobic section with a subsequent treatment unit to effectively reduce organic matter, nutrients, and pathogens [10]. In order to mitigate potential downsides such as process sensitivity, vulnerability, odour emission, and protracted start-up periods, it is imperative to administer a enough inoculation at the commencement of operations [12]. The initiation of UASB operation normally necessitates the inoculation of 10-30% of the system's volume with active granular biomass [12]. The constraints of long start-up times and slow granulation, especially when dealing with complex and refractory wastewater, have been identified as significant challenges. However, recent research has demonstrated that the addition of chemicals, such as calcium sulphate, can stimulate granulation. This stimulation leads to an increased rate of granulation and improved methanogenic activity [22]. A study Found that the addition of CaSO4 to a UASB reactor resulted in an increase in granule formation (>0.25 mm) ranging from 7% to 40% after 90 days, compared to a control group. Additionally, the reactor exhibited an improved COD removal efficiency of 3% to 9% at a moderate organic loading rate (OLR) of 2.89 kg COD/m3d [22]. It has been observed that granular biomass is more resilient to higher concentrations of hazardous and toxic compounds compared to traditional flocculent sludge. For instance, UASB has demonstrated a higher tolerance to organic loading rates (OLR) than anaerobic membrane bioreactors (AnMBR) when treating N, N-dimethylformamide [23].

Discussion

4 Effect of Different Parameters on the Efficiency of UASB Reactor

The efficiency of Upflow Anaerobic Sludge Blanket (UASB) reactors is influenced by various factors, such as the characteristics of the wastewater, the acclimatisation of the seed sludge, pH levels, nutrient availability, the presence of toxic compounds, the loading rate, the upflow velocity (V_{up}), the hydraulic retention time (HRT), the liquid mixing, and the design of the reactor. These factors have been found to impact the growth of the sludge bed, as indicated by previous studies [16, 67–69].

4.1 Effect of Temperature

The development and survival of microorganisms are significantly impacted by temperature. The potential for anaerobic treatment exists within all three temperature ranges, namely psychrophilic, mesophilic, and thermophilic. Nevertheless, it is widely observed that lower temperatures tend to result in a reduction of the maximum specific growth rate and methanogenic activity [39, 70, 71]. The methanogenic activity at this particular temperature range exhibits a decrease of 10 to 20 times compared to the activity observed at 35∘ C. To compensate for this decrease and achieve a similar level of COD removal efficiency as observed at 35∘ C, two approaches can be taken: either increasing the biomass in the reactor by a factor of 10 to 20, or operating the system at higher sludge retention time (SRT) and hydraulic retention time (HRT) [3, 67].

4.2 Effect of Hydraulic Retention Time (HRT)

The hydraulic retention time (HRT) is a critical factor that significantly influences the reactor's performance, particularly in the context of municipal wastewater [76, 77]. The upward flow velocity (Vup) exhibits a direct correlation with hydraulic retention time (HRT) and assumes a significant function in the entrapment of suspended solids. A reduction in the upward velocity (Vup) results in an elevation in hydraulic retention time (HRT), leading to an enhancement in the efficiency of removing suspended solids (SS) in the system [1, 78, 79]. The efficiency of chemical oxygen demand (COD) removal in an Upflow Anaerobic Sludge Blanket (UASB) reactor is shown to decrease as the upflow velocity is increased.

4.3 Effect of pH

The maintenance of pH within the range of 6.3-7.8 is crucial in anaerobic reactors due to its direct impact on the pace of the methanogenesis process [110]. The pH of domestic sewage typically remains within a certain range due to the buffering capacity of the acid-base system, specifically the carbonate system. As a result, there is no need for the addition of chemicals [1]. The UASB reactors utilised for sewage treatment in tropical and subtropical regions have been documented to exhibit remarkable stability in relation to pH and buffering capacity [10– 12, 14, 22, 24, 111]. Enhancements in the rates of hydrolysis and acidogenesis are observed in the treatment of residential wastewater through the utilisation of anaerobic reactors. It has been determined that maintaining a pH level of 7 creates an ideal operational setting for anaerobic digestion, leading to the removal of over 80% of total organic carbon (TOC) and chemical oxygen demand (COD) [111].

4.4 Effect of Granulation

According to previous studies [107, 112], it has been observed that extended hydraulic retention times (HRTs) in UASB reactors can impede the formation and growth of granular sludge. On the other hand, the utilisation of extremely brief hydraulic retention times (HRTs) results in the depletion of biomass. Both scenarios are deemed unsatisfactory in terms of attaining optimal outcomes from the Upflow Anaerobic Sludge Blanket (UASB) reactor. While granulation has traditionally been seen as a crucial factor in achieving good treatment of residential wastewater in Upflow Anaerobic Sludge Blanket (UASB) reactors, recent studies have demonstrated that these reactors can still exhibit satisfactory performance in the absence of granules.

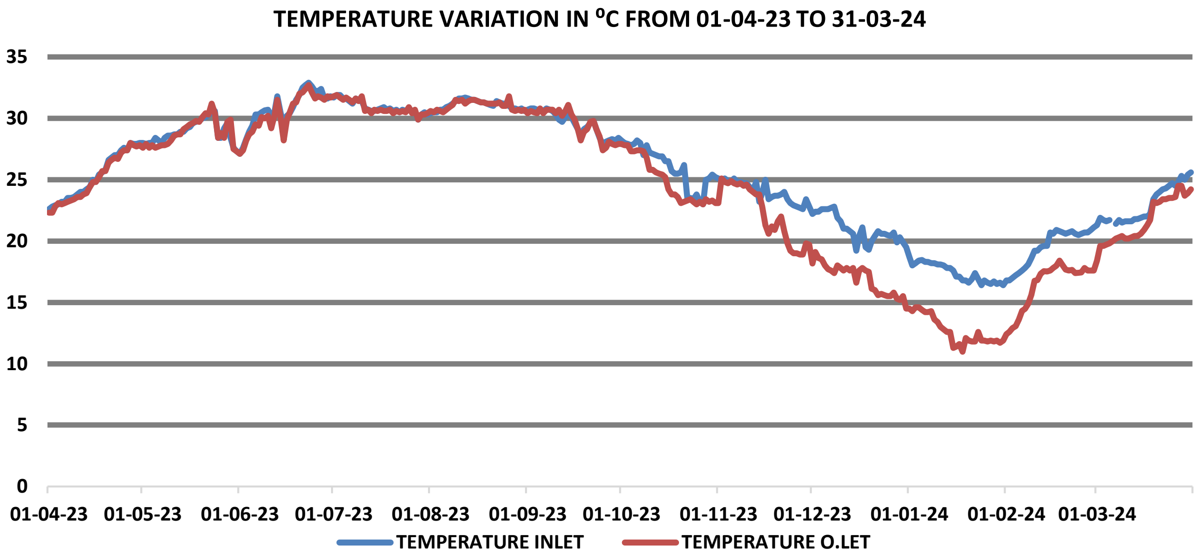
4.5 Effect of Mixing

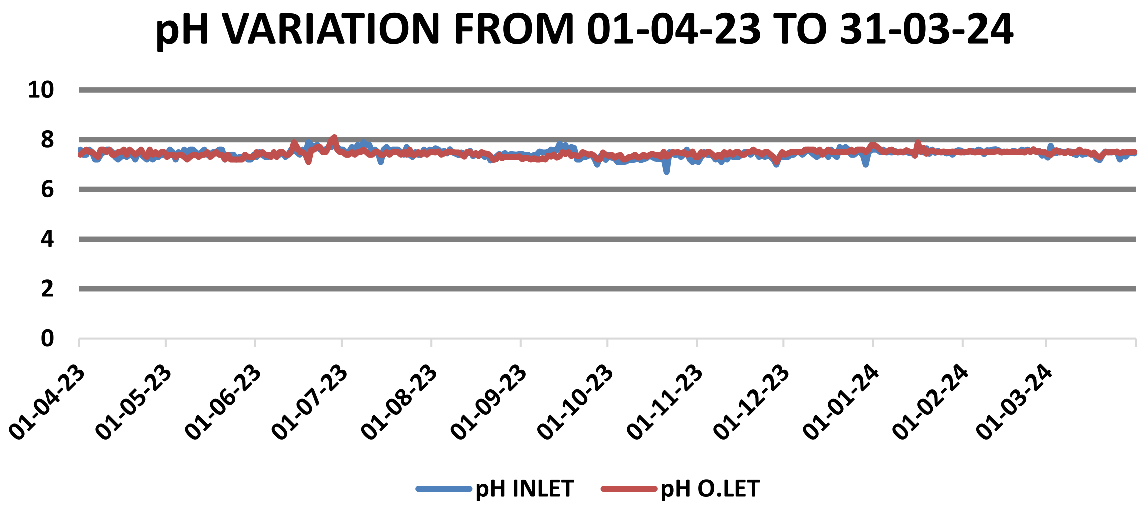
The combination of offers a significant advantage in terms of facilitating contact time between microorganisms and wastewater, reducing barriers to mass transfer, mitigating the formation of inhibitory by-products, and ensuring consistent environmental conditions. Inadequate mixing can impede the primary process rate due to the presence of substrate pockets at distinct phases of digestion, resulting in pH and temperature fluctuations at each stage [119]. The process of mixing can be accomplished through mechanical means or by employing the recirculation of methane gas or slurry.

5 Result

a) Real time monitoring of 111MLD STP based on UASB technology at Bhattian Village Ludhiana Punjab India

The analysis was conducted in the site lab of 111 MLD UASB based STP at village Bhattian Backside METRO MALL, Ludhiana. This STP was established under SATLUJ ACTION PLAN GOI. Co-ordinates of this STP are 30^0 57’52.7724’’N, 75^0 49’41.1852’’E. This STP was commissioned in year 2007 by Punjab Water Supply & Sewerage Board. Results were performed from April 2023 to March 2024 continuously and variations in the results of Temperature variation, pH variation, BOD, COD, TSS variation of inlet sample vs outlet sample is presented in graphical representation.




pH VARIATION FROM 01-04-23 TO 31-03-24
10
8
6
4
2
0
01-04-23
01-05-23
01-06-23
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01-08-23
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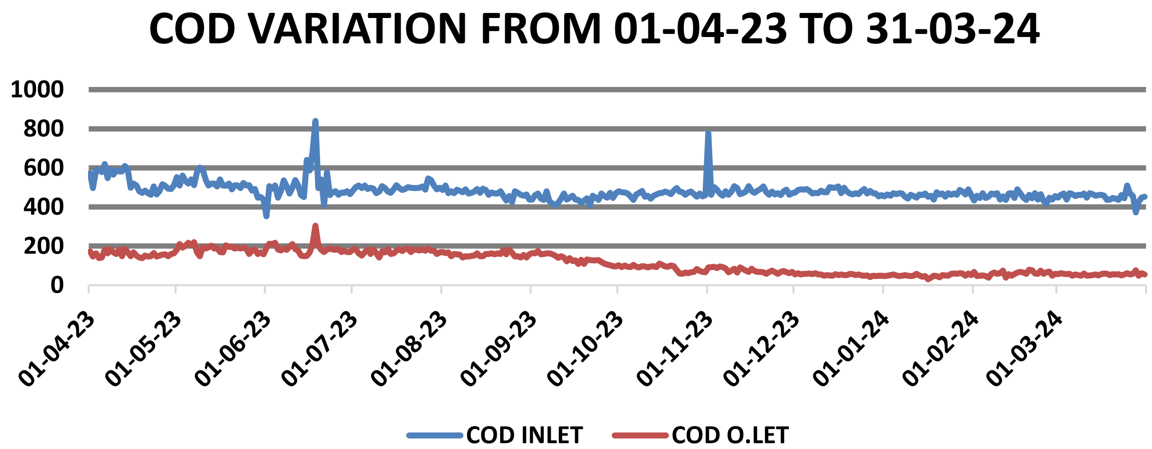
COD VARIATION FROM 01-04-23 TO 31-03-24
1000
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600
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01-08-23
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COD INLET
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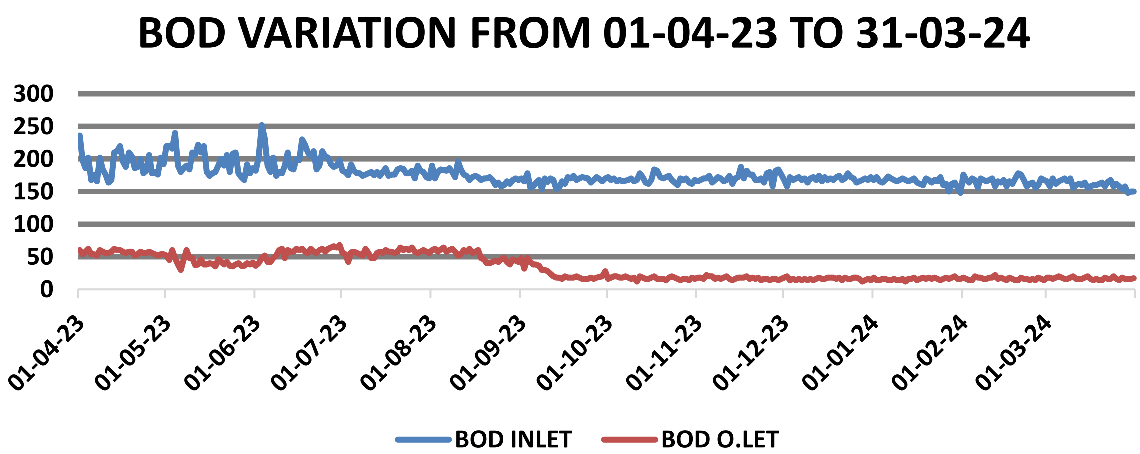
BOD VARIATION FROM 01-04-23 TO 31-03-24
300
250
200
150
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01-04-23
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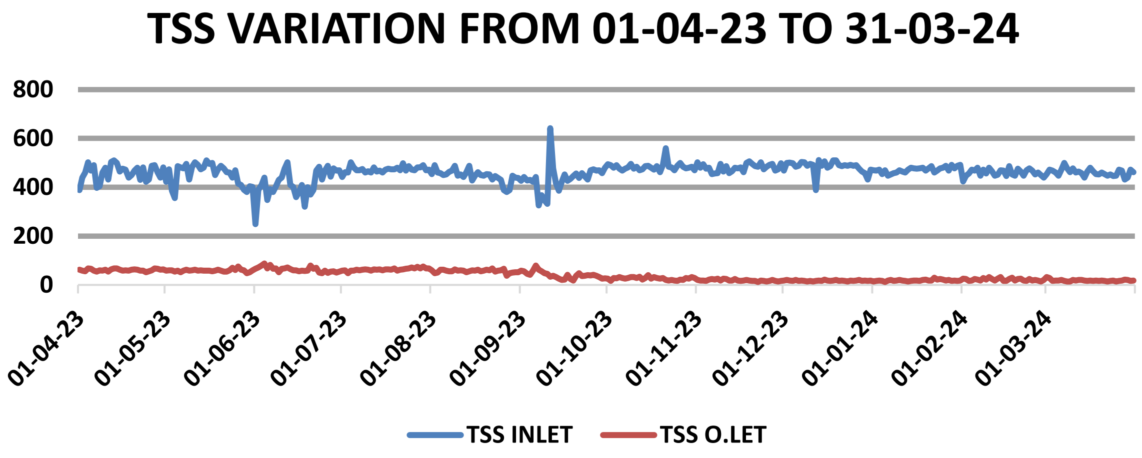
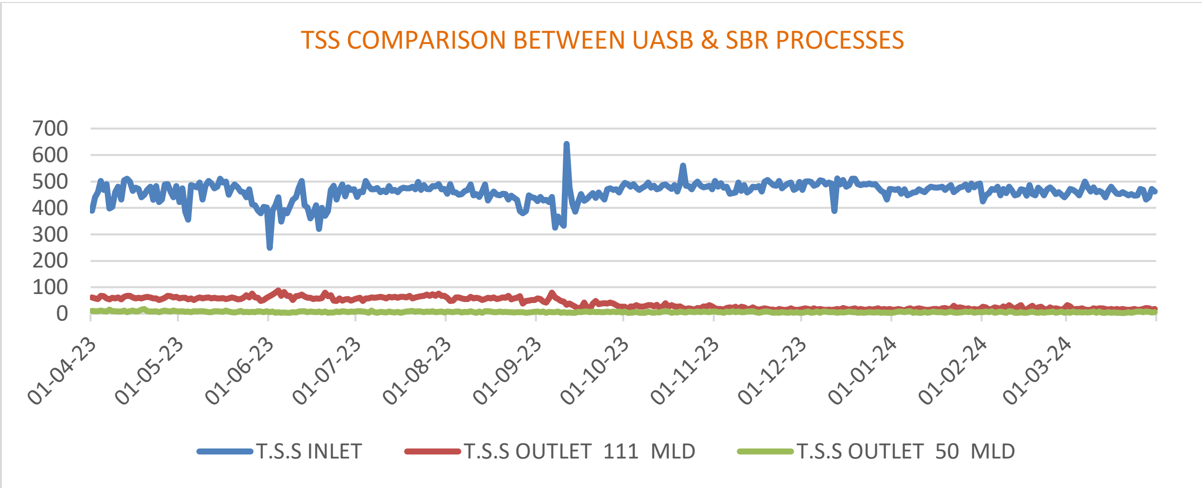
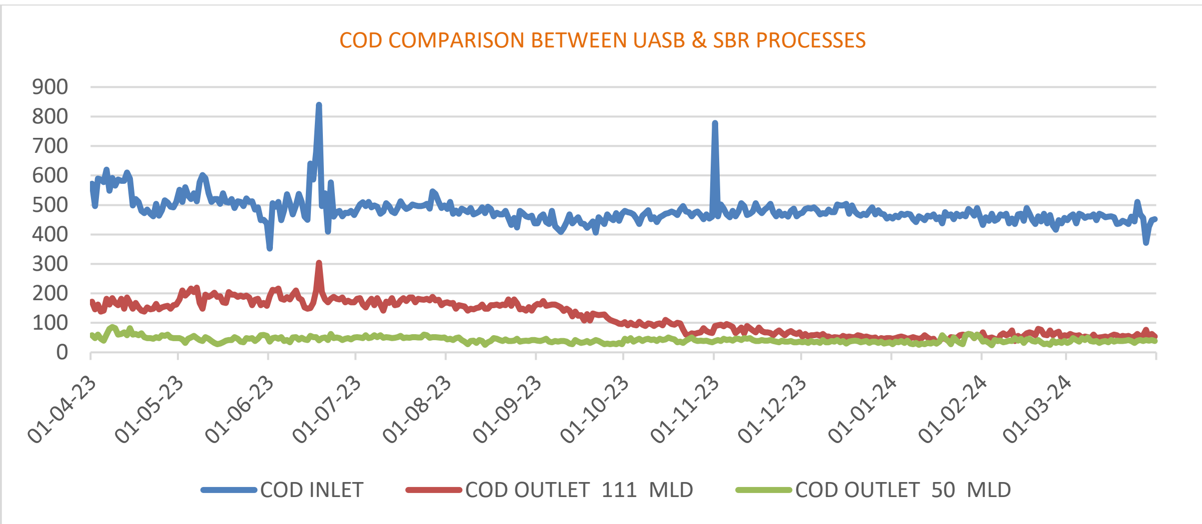
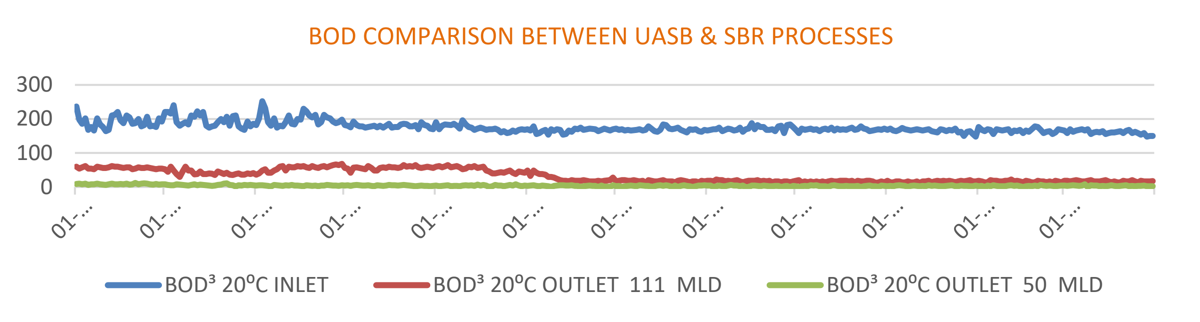


b) Real time comparison of UASB technology (111MLD STP) vs. SBR technology (50MLD STP) at Bhattian Village Ludhiana Punjab India







Conclusion

The present review paper examines the effectiveness of sewage treatment plants (STPs) and the optimization of industrial waste management through biological processes, with a specific focus on the Upflow Anaerobic Sludge Blanket Reactor (UASB) technology. This study provides valuable insights into key components of wastewater treatment in the context of India. By conducting an investigation of diverse sewage treatment technologies, unit operations, and biological processes, this study has yielded significant findings regarding the current status of sewage treatment and its prospects for enhancement. The discourse pertaining to the UASB technology has underscored its importance in the treatment of sewage and has showcased its ability to be utilized in diverse environmental contexts. Furthermore, the analysis of crucial variables such as temperature, hydraulic retention time (HRT), pH levels, granulation, and mixing has demonstrated their significant impact on the operation of the Upflow Anaerobic Sludge Blanket (UASB) reactor. These observations enhance the advancement of sewage treatment methods that are both more effective and environmentally friendly. This review study highlights the pressing need to address wastewater management in India, with a specific focus on industrial waste. The promotion of sophisticated biological processes, such as UASB technology, is advocated for in order to enhance treatment efficiency. This advocacy takes into account the impact of important parameters on the overall effectiveness of the treatment process. Through the utilization of the acquired knowledge from this research, stakeholders have the capacity to strive towards enhanced sewage treatment practices, ultimately leading to a more pristine and salubrious environment for the collective populace.

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