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Article

Technology for Up-flow Anaerobic Sludge Blanket (UASB) in Wastewater Treatment: A Mini-Review

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Abstract: The rising contamination of water bodies due to industrial, municipal, and climatic factors has intensified the need for cost-effective and sustainable wastewater treatment technologies. The Up-flow Anaerobic Sludge Blanket (UASB) reactor has emerged as a widely adopted method for treating various types of wastewater, owing to its simplicity, low operational costs, energy recovery potential, and effectiveness in reducing organic loads. This mini-review explores the fundamental principles, operational mechanisms, and advancements in UASB technology. The paper highlights the biological and physical processes underlying pollutant removal, including hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Emphasis is placed on reactor design, microbial dynamics, and operational parameters affecting treatment efficiency. Through a review of recent studies and case applications, the paper evaluates the advantages, limitations, and future prospects of UASB reactors in both industrial and domestic wastewater contexts. The review concludes that while UASB reactors provide notable benefits, especially in warm climates, they require further development to meet stringent effluent standards and adapt to varying wastewater compositions.

Keywords: UASB, wastewater, review, anaerobic digestion

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1. Introduction

The objective of treating wastewater is to reduce the concentration of certain contaminants to a point where the effluent's release will not damage the environment or endanger human health. The best wastewater treatment is one that offers and ensures effluents with the chemical and microbiological quality needed for a particular use at a reasonable cost with little need for upkeep and operation. In addition to reducing organic and suspended particulates, wastewater treatment plants also eliminate biological and chemical components that are primarily of public health concern and may be hazardous to crops [1].

Urbanization and the world's population growth have led to an increase in wastewater production as there is less space available to construct more wastewater treatment facilities. Additionally, stricter regulations have been put in place to limit the discharge of various pollutants, particularly nutrients (TN and TP).therefore, it's critical to develop innovative and alternative technologies for wastewater treatment [2].

The anaerobic treatment offers a desirable potential client to developing countries. Although there are several methods for treating municipal and commercial wastewater, the anaerobic treatment technique seems to be the most promising due to its minimal sludge growth and methane production. The study of the principles of anaerobic digestion has been ongoing for the past few decades, and the development of high-rate anaerobic processes has brought the digestive process to a complete halt. Both the space occupied and the proportional size of the high rate digesters are quite small. High reactors are being employed in place of the flat and short reactors. Because active granular matter is retained, high rate anaerobic digesters have relatively high launching rates [3]. Over the past three decades, a variety of anaerobic systems have been developed, including fluidized expanded bed reactors, baffled reactors, anaerobic filters, and (UASB). Because aeration equipment is expensive, anaerobic procedures are used to treat high-strength industrial wastewater, particularly that produced by the food processing and pulp and paper sectors, became a highly appealing choice in the early stages. Anaerobic processes have just recently been adopted as the primary method for household sewage. The creation of the broader idea of sustainable environmental protection and resource conservation (EPRC) in relation to wastewaters marked the beginning of this [4].

2. Materials and Methods

This paper adopts a qualitative review methodology to examine the development, functionality, and application of UASB reactor technology in wastewater treatment. The research process involved four systematic stages:

Scientific articles, technical manuals, theses, and industry reports published between 1990 and 2024 were collected from reputable academic databases including ScienceDirect, Springer, Scopus, and Google Scholar. Keywords such as "UASB reactor," "anaerobic digestion," "wastewater treatment," "COD removal," and "biogas production" were used to guide the search.The literature was filtered based on relevance, recentness, and the presence of experimental or pilot-scale data. Priority was given to studies that detailed reactor performance, operating conditions (e.g., temperature, HRT, OLR), sludge granulation dynamics, and treatment outcomes across various wastewater types (domestic, agro-industrial, dairy, etc.). The collected materials were categorized into thematic areas: (1) fundamental processes and design principles, (2) performance efficiency and influencing factors, (3) advantages and limitations, and (4) real-world applications and adaptations. Each theme was analyzed to identify trends, challenges, and potential improvements. Key findings were compared across different climatic regions, wastewater characteristics, and reactor configurations to derive a generalized understanding of the operational robustness and limitations of UASB systems. Case studies were used to substantiate the scalability and versatility of the technology.

This methodology ensures a comprehensive understanding of UASB technology as a sustainable solution for wastewater treatment, enabling critical evaluation and highlighting areas for future research and innovation.

In the 1970s, the Up- flow anaerobic sludge blanket (UASB) concept was created. The UASB reactor is currently the most widely used high-rate reactor for wastewater treatment worldwide. Both the amount of active biomass retained and the contact between biomass and wastewater determine the UASB reactors' treatment capability. Chemical oxygen demand (COD) reduction and methane yield are both improved when a sufficient number of methanogenic bacteria are maintained in UASB [5]. The UASB is One type of reactor that has a high loading capacity. Its design simplicity sets it apart from other methods. UASB combines biological and physical processes. The main feature of biological processes is the breakdown of decomposable organic matter in anaerobic environments, whereas the main characteristic of physical processes is the separation of solids and gases from liquids. Anaerobic sludge has good settling qualities, For this reason ,UASB reactors typically do not use mechanical mixing. The production of biogas ensures sufficient contact between the biomass and substrate at high organic loading rates [6]. The original purpose of the UASB idea was to treat wastewaters from industry with medium to high BOD and COD rates anaerobic. The main purpose is that when a moderate up flow velocity is applied, anaerobic bacteria fbocs will prefer to settle under gravity. This eliminates the need for a separate sedimentation tank. In essence, the reactor compartment is a place where anaerobic bacteria can proliferate and settle, while the bacteria consume the organic compounds in the wastewater as it passes through the sludge layer. Since the early 1980s,The popularity of the UASB reactor has grown .It has been widely utilized, particularly for the treatment of highly concentrated wastewaters with COD value up to (30,000 mg/L) from agricultural like the sugar and potato processing industries. The most commonly method for Anaerobic treatment of industrial wastewater at the moment is this one[7].

Over the past 20 years, the UASB technique for wastewater treatment has been developed. Mesophilic methanogenic bacteria grow in tropical countries due to the relatively high ambient temperature. A lot of work was done during this time to comprehend the kinetic and mass transfer processes occurring inside the anaerobic reactor [8].

Nowadays, The world offers a vast array of wastewater treatment technology. Anaerobic procedures, however, replaced the typical and aerobic methods used to treating wastewater from domestic, municipal and industrial. Large amounts of organic material have been eliminated by anaerobic reactors [9]. However, due to the high levels of residual COD and BOD, nutrients, and pathogens, UASB reactors typically unable to satisfy almost all of current effluent discharge rules. UASB wastewater treatment is a crucial area of study where new ideas and advancements are required to solve the issue [10].

3. Results and Discussion

1. Anaerobic digestion and wastewater treatment systems

For a broad variety of extremely diverse industrial effluents, particularly those containing hazardous or inhibiting substances, UASB wastewater treatment systems represent a tested and sustainable technique. The method can also be used to treat household wastewater at temperatures as low as C and perhaps even lower. The anaerobic treatment procedure simply provides advantages over traditional aerobic treatment systems. This is especially true with regard to the startup rate. For practical purposes, the knowledge now available on the immobilization (granulation) of anaerobic sludge and the development of granular anaerobic sludge is adequate. A balanced microbial community must be immobilized in order to maintain a low enough intermediate concentration during anaerobic treatment. Excellent opportunities for process control, such as the anaerobic treatment of wastewaters containing primarily methanol, are made possible by the increased understanding of the roles of constituents like nutrients and trace elements, as well as the impact of metabolic intermediates and end products. The thermophilic and psychrophilic temperature ranges are also suitable for the profitable application of anaerobic wastewater treatment. Additionally, mesophilic conditions can be utilized with thermophilic anaerobic sludge.

2. Basic Treatment Process of UASB

The wastewater runs upward through a dense sludge bed with strong anaerobic microbial activity in the UASB reactor. Figure (1) show a UASB schematic. the sludge bed, which is made up of granules or highly sediment able flocs, takes up around half of the reactor's volume. The solids profile in the reactor ranges from more scattered and light particles toward the top to extremely dense and granular particles near the bottom. The UASB reactor's bottom receives wastewater, while the top settling zone allows the effluent to exit the reactor. Therefore, all reaction zones experience the elimination of organic material. Through the top, the generated gas exits the reactor[11]. UASB reactor efficiency and stability are largely dependent on its initial start-up, which is influenced by a variety of (physical, chemical, biological) factors, including the wastewater type, operating conditions, and the traits of the active microbial populations present and growing in the inoculum or seed sludge. Before using full design organic loading rates, In order to introduce the seed sludge to the operational conditions, an acclimatization time is necessary [12]. The (UASB) reactor was created to address the inherent drawbacks of the traditional septic tank [13,14]. Because of its high solid retention time , low hydraulic retention time (HRT), potential for energy recovery, and low sludge production, it has also gained widespread adoption on an industrial scale. It is the anaerobic reactor that is most frequently used to treat industrial wastewater [15].

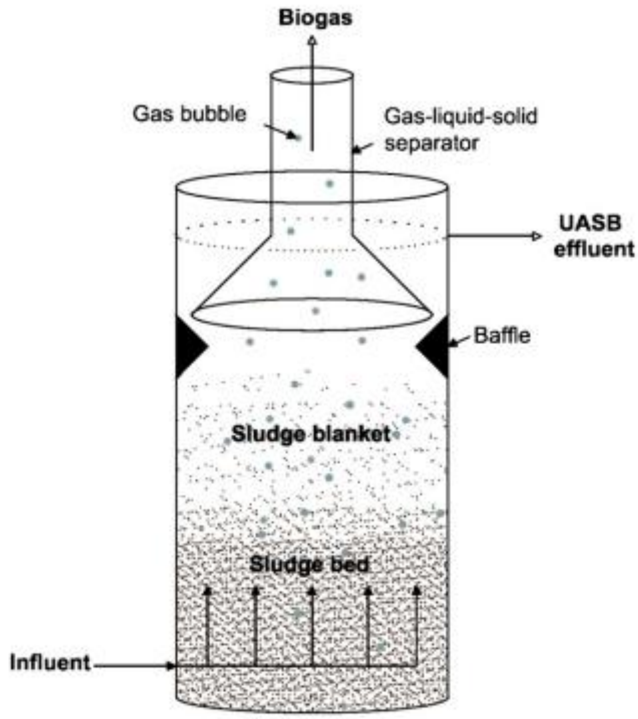

Figure (1) Schematic of the UASB [16]

3. **Advantages and Disadvantages Of UASB Reactor Technology**

   There are many Advantages and disadvantages of UASB [17].

3.1 Advantages of using UASB technique

1. It has good efficiency in elimination even at low temperatures and high OLR, and it requires a smaller reactor.
2. Due to The availability of building supplies and other components, construction is simple and requires little maintenance and operation.
3. Sludge generation is lower than in aerobic processes. As used as an inoculum to seed UASB reactor, the resulting sludge is stable, and may be held for a long time.
4. Resistance to organic shock loading .
5. Utilizing granular anaerobic sludge as seed allows for a rapid startup time (about one week).
6. Methane/hydrogen gas is produced as energy. The boilers can be heated using the energy generated, which lowers operating expenses
7. Treatment efficiency that is robust and broadly applicable from very small to very large scales .

3.2 Disadvantages of using UASB technique

1. Need post-treatment because the pathogen are not totally eliminated. incomplete nutrient removal, needing post-treatment needling.
2. If activated sludge is not easily obtainable, a lengthy startup time because microorganisms grow slowly [18].

3. Anaerobic digestion generates H2S, particularly if wastewater involves significant levels of sulfate. The biogas needs further suitable processing for avoiding odor, toxicity, and corrosion issues.
4. For steady state performance in cold climates, the temperature must be kept between (15 and 35)°C.

4. UASB Process

The UASB process primarily consists of four chemical and biological stages:

1. Hydrolysis: Wastewater has complex organic compounds. the initial stage in converting these compounds to basic sugars, amino acids, and fatty acids is Hydrolysis. The hydrogen and acetate produced in the initial phases can be utilized right away by methanogens.
2. Acidogenesis: This causes acidogenic bacteria, also known as fermentative bacteria, to further break down the remaining chemicals(Ammonia, hydrogen sulfide, carbon dioxide, and other byproducts) are produced here.
3. Acetogenesis: The third step is acetogenesis. Here, the simple molecules created by acidogenesis are further broken down by acetogens, mostly producing acetic acid, carbon dioxide, and hydrogen.
4. Methanogenesis:It is the last stage in anaerobic digestion. Methanogens generate carbon dioxide, water, and methane from the intermediate products of earlier phases.

5. History and applications of UASB

Alawadi, evaluated the UASB technique, a method of biological treatment. that produced biogas as a byproduct using anaerobic bacteria to break down the organic matter in wastewater.. This method has the capacity to remove more than 80% of organic debris from wastewater, making it extremely effective. The UASB reactor design is a common option for treating industrial wastewater because it enables the separation of treated water and sludge. This technology's advantages such as (low running costs, energy recovery, high treatment efficiency) make it a desirable choice.

Elmitwali et al. [20], investigated the use of small sludge particles with a mean diameter of 0.73 mm. The treatment of sewage at 13°C utilizing two anaerobic hybrid (AH) reactors, a UASB, and three reactors (each 3.84 L) with tiny Running the reactors at an (up flow velocity of 1.8 m/d) .the UASB reactor's efficiency in eliminating suspended COD. also, compared to the UASB, the AH reactors' use of sheets greatly improved the suspended COD removal efficiency, which for pre-settled sewage treatment reached 87%.

Nidal Mahmoud , studied the (UASB) reactor In tropical countries such (Brazil and India), this commonly used for sewage treatment. These countries have year-round temperatures between 20 and 30 °C, and their sewage are weak to moderate [21]. Anaerobic technology development's main challenge is to adapt the municipal sewage treatment system in dire circumstances. As an instance, sewage in Palestine and Jordan contains elevated COD levels of over 1000 mg/L.

Jeong et al. [22], Organic-inorganic hybrid polymers were created and fed into the UASB reactors. Granular sludge was discovered to form in just five minutes. Even up to 18 g COD/L/d of OLR, the granules remained stable during the operation. and the COD removal reached 90%.

Al-Shayah and Mahmoud, use a UASB-septic tank. With a gas-liquid separator and an upward flow, this enhanced septic tank design treats sewage at 24°C and a two day of HRT. For suspended COD (COD) and total COD (CODs), they obtained removal efficiencies of 87% and 56%, respectively [23].

Thenmozhi and Uma [24], proposed The UASB approach for the paper industry Several methods have been used to treat wastewater biologically. Up flow is a solution to the problems with attached and suspended growth systems. Sludge Anaerobic There are blanket reactors. A common hybrid reactor type is the UASB, which uses both attached and suspended growth processes. The treatment of wastewater from the dairy sector using a UASB ,is included in this study by varying the retention periods in days for a particular organic loading rate. Its connected growth and suspended growth processes have effectively eliminated BOD, COD, and other criteria.

Nada evaluated the UASB reactor For 20 months to treating raw home sewage. This included the initial, steady-state, and low-temperature phases. After operating for roughly 20 weeks, the first UASB was successfully started. the (COD, BOD, TSS) removal efficiencies were found to be high and nearly consistent. average removal efficiencies at steady state were 85.56% for TSS, 70.05% for total COD, and 70.35% for total BOD. The findings show that in nations with warm climates, using a UASB as an advanced primary treatment stage is a wise decision. Due primarily to the low energy requirements, it is also discovered that the O&M expenses are (30–60)% lower than those of conventional systems.

Goodwin,Using the UASB process, removed 86% of the organic carbon from a synthetic ice cream effluent at HRTs of 18.4 hours. 3.06 kg of (TOC) per m3 day was the highest OLR [25].

De Man, accomplished when the UASB was running at 16 hr of HRT, an OLR of 49.5 kg COD/m3 day, a 33000 mg/L COD in plant wastewater, and 86% COD removal rate for a cheese factory in Wisconsin, USA.

Cammarota [26], used fermented cake enzymatic preparations that contained lipases generated by a Penicillium restrictum strain that hydrolyzes FOG in Wastewater from dairy processing. High removal efficiency of COD and higher-quality effluents were shown using a laboratory scale Hydrolyzed dairy processing wastewater is treated in a UASB. The UASB dealing with the same wastewater without any prior enzymatic hydrolysis treatment was used to compare the results [27].

Yu, Used 7.3 L UASB reactor to treat synthetic wastewater with 4,000 mg/L of COD in the influent, researchers successively investigated the effects of a few particular multivalent cations on granulation. the granulation process was found to be accelerated at optimal iron (Fe2þ) concentrations of 300 and 450 mg/L; higher Fe2þ concentrations in the feed (greater than 450 mg/L) led to excessive mineral deposition on the granules.

Agrawal, showed that lowering the temperature from 27 °C to 10 °C reduced the rate of gas production by 78% and the removal of COD by 25% respectively, When treating diluted sludge. Because of this, tropical nations with temperatures between 20 and 40 C are the first to use UASB reactors. One of the main obstacles to the widespread deployment of UASB technology is resolving issues brought on by regional climate change [28], [29], [30].

Halalsheh, demonstrated With HRT three to four times greater than those in tropical nations that it was nevertheless possible to operate UASB reactors in Jordan to treat strong sewage (at typical winter temperatures of 18°C and summer temperatures of 25°C). A single stage UASB reactor operating at long HRT is recommended under Jordanian climate circumstances, according to their comparison of a single-staged and a two-staged UASB, which revealed no discernible gain in COD removal efficiency.

A´lvarez et al. [31],One hydrolytic unit the hydrolytic up flow sludge blanket (HUSB) reactor and one methanogenic unit(UASB) reactor would make up a two-step UASB system that would exceed a UASB alone for TSS and COD removal efficiencies at low temperatures of (17–21)°C and HRT of 9.3–17.3 hr. This is because the HUSB reactor self-regulating mechanism allowed for relatively independent TSS removal from temperature influences.

Singh et al. [32], utilized UASB system to treat municipal wastewater at low temperatures. They found that 70% of the COD was removed at 11 C and 30 to 50% at 6 °C.

Kalogo and Verstraete [33], discovered that the COD removal efficiency at temperatures between 10 and 15 °C was less than that at 35 °C.

Seghezzo [34], ran a pilot-scale UASB reactors and achieved a maximum 63% COD removal efficiency at a low temperature of 17°C, as well as an OLR of 0.6 kgCOD/m3 ·day (HRT of 6 hours and COD infuent = 153 mg/L).

Zhang et al.[35],Used an anaerobic reactor to treat residential wastewater improves both the hydrolysis and acidogenesis rates. The ideal pH for anaerobic digestion is 7, that leads to the elimination of more than 80% of TOC and COD.

Leitao [36], reported as OLR relies on the reactor's capacity, up flow velocity, and wastewater strength; as a result, it also depend on the HRT. So, the effect of OLR impact on reactor performance is complicated since it relies on other factors that have conflicting effects on the removal efficiency of UASB. such (The feed concentration increased from 98 to 818 mg/L. as well as the OLR from 0.4 to 3.3 kg COD/m3 ·day, up to a certain limit (OLR of 1.2 kg COD/m3 ·day), increased the removal efficiency from (50 to 64)%, while increasing the flow rate and, consequently, the OLR from 3.3 to 17.6 kg COD/m3 ·day, reduced the overall COD efficiency from 57 to 36%.

Sandra Anijiofor et al. [37], studied mix aerobic-anaerobic systems are more effective at treating household sewage. the wastewater treatment are being solved by use high-rate bioreactors, such UASB-AS, as a hybrid system of aerobic and anaerobic. Sludge generation may be decreased, energy and chemical consumption can be improved, and organic matter can be removed more effectively at a shorter (HRT). Anaerobic and aerobic digestion must still be combined in more sophisticated and innovative integrated systems.

4. Conclusion

Several researchers have utilized the UASB technology as an alternative to conventional method for wastewater treatment processes to remove high levels of contaminants from different wastewater types. The current research reviewed a current projects that addressed the use of this method to treat different wastewater types. The results of this study show the efficacy of UASB in treating a wide variety of wastewater types and its reliability. there are Significant advantages of UASB reactor technology (biogas production, high organic removal rates, and inexpensive capital and maintenance costs). To maintain optimal conditions for UASB operation, however, proper operational parameter monitoring and control are needed. The UASB reactor can be become an effective option for treatment industrial wastewater by adjusting its operational parameters. Any type of wastewater with high strength can be treated by the UASB reactors. It can be used on wastewaters (home wastewater treatment systems) or large-scale wastewaters (agro-industrial wastes).

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