STATE-OF-THE-ART, LIMITATIONS, AND DIFFICULTIES IN ANAEROBIC SEWAGE TREATMENT

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ABSTRACT

Since its debut in the mid-1980s, interest in high-rate anaerobic (pre-) treatment of sewage utilizing UASB reactors has gradually grown. Hundreds of full-scale plants are already in operation across the tropical globe, particularly in Latin America and India. The primary benefit of UASB technology is that it uses very little or no energy, resulting in a tenfold reduction in operating expenses when compared to activated sludge. This article provides a literature review with an emphasis on current design criteria and post-treatment alternatives, as well as a comparison of centralized versus decentralized approaches. Temperature, nutrients, pathogen elimination, smell annoyance, operational constrictions, and methane emissions are among the existing limits and restrictions given and addressed. Recent difficulties in energy recovery from biogas, sludge, and scum are also addressed, as well as advancements in dissolved methane recovery and sludge management. Finally, the study offers some predictions regarding future events.

KEYWORDS: *Anaerobic Digestion, Anaerobic Sewage Treatment, Biogas, Domestic Sewage, Wastewater*

1. INTRODUCTION

With the introduction of the upflow anaerobic sludge blanket (UASB) technology in the 1980s, a number of nations, particularly those in Latin America and India, started to include anaerobic sewage treatment technology into sewage treatment plant flowsheets (STP). Traditional wastewater treatment methods, such as automated activated sludge and land-based pond systems, were considered as an alternative to anaerobic sewage treatment, which was sometimes followed by units of aerobic post treatment systems[1]. Latin America, particularly Brazil, Colombia, and Mexico, have become the current frontrunners in the appropriate use of UASB reactor systems for the treatment of urban wastewater due to favorable climatic conditions and significant expenditures in research and development[2].

The use of UASB reactors for wastewater treatment was first introduced in Brazil in the early 1980s, when various groups of academics and engineers began research in the field of wastewater treatment. The improper usage of UASB reactors during its debut tainted the technology's reputation among state water corporations and environmental protection authorities.

However, in recent decades, this has been restored as a consequence of increased studies and research in the field, as well as expertise acquired in the operation of full-scale facilities. The National Research Program on Basic Sanitation—PROSAB, which ran from 1997 to 2007, undoubtedly made a significant contribution to the consolidation and diffusion of anaerobic technology for the treatment of residential sewage in Brazil. Similarly, in 1990, the Indian government started the Yamuna Action Plan—YAP, a major initiative to enhance the water quality of the Yamuna River basin based on the Ganga Action Plan's prior success.

The government agreed to build 16 full-scale UASB reactors with a total capacity of 598,000 m3 day-1 under this YAP, acknowledging the technology as a mainstream sewage treatment technique in India. Stabilization ponds, activated sludge (extended aeration and conventional procedures), and UASB reactors were recognized as three main technologies for municipal wastewater treatment in a recent study in the Latin American area[3]. In six nations in the area (Brazil, Colombia, Chile, Dominican Republic, Guatemala, and Mexico), a study of 2734 treatment facilities was conducted. The distribution of these three technologies by number was 38, 26 and 17 percent, equivalent to 81 percent of the facilities examined. It's worth noting that the UASB system, despite being a relative newcomer in the area of municipal sewage treatment with just 25 years of experience in this market, came in third place, behind procedures that are over a century old.

When the technologies in Latin America are ranked by treatment capability, however, the picture changes design flow [4]. In this instance, both types of activated sludge come out on top, followed by stabilization ponds, improved primary treatment, and UASB in fourth place, accounting for 58, 15, 9, and 7% of the total design flow in the sample, respectively (Fig. 1b). Stabilization ponds, and even UASB, are clearly used in the area, although only in modest facilities. In reality, the study showed that 67 percent of STPs in Latin America are tiny, with design flows of less than 25 L s-1, and 34% are extremely small, with design flows of less than 10 L s-1. In Latin America, where several large full-scale plants, treating a population equivalent up to one million inhabitants (Once a STP, Belo Horizonte, Brazil), have been in operation for more than ten years, UASB reactors used for domestic wastewater treatment are now considered a consolidated technology. In contrast to a typical activated sludge plant, the costs of a treatment plant with a UASB reactor followed by aerobic biological treatment generally enable capital expenditures (CAPEX) reductions of 20–50 percent and operating expenditures (OPEX) savings of more than 50 percent[5].

One of the reasons for the rise in wastewater treatment coverage in Latin America is because of this. UASB technology was shown to be cost-effective not just when compared to activated sludge processes, but also when compared to pond systems. In fact, near metropolitan regions where land values are high, land-based treatment methods are regarded extremely costly. As a result, large-scale pond systems are seldom used in India near metropolitan areas[6]. Similarly, the Dutch consultancy DHV conducted a cost-benefit analysis for the best feasible treatment option for urbanized areas in the irrigated agricultural lands of Fayoum, Egypt, 80 kilometers south of Cairo. Pond systems were quickly abandoned in this research due to an overabundance of important agricultural land.

When compared to traditional activated sludge, a UASB system followed by a stone-filled trickling filter resulted in a 40% reduction in CAPEX and a 90% reduction in OPEX, owing to the avoidance of fossil energy usage for sewage treatment. This review article focuses on the practical aspects of the UASB reactor, which is the most widely used anaerobic system for treating domestic wastewater[7]. It brings together compiled information on design criteria as well as current limitations and constraints, particularly in full-scale applications. The article also considers issues such as smell and methane emissions that have been documented in the literature, as well as operational limitations, difficulties, and views on nutrient treatment and recovery.

The aforementioned guideline requires at least one discharge point per 100 m2 bottom area for surplus sludge removal. Discharge pipes with a minimum diameter of 100 mm should also be installed at two distinct heights, near to the bottom and between 0.8 and 1.3 m above the bottom. In terms of biogas management, it is suggested that STPs with an average flow capacity of more than 250 l s-1 that do not use gas have at least two flares, one as a backup. The biogas pipeline must have a minimum diameter of 50 mm and a maximum velocity of 5 m s-1 from the average gas flow. Given the inherent limits of anaerobic systems and the strict discharge requirements, it is essential to add a post-treatment step for the effluents from anaerobic reactors[7]. Furthermore, the need to create technologies that are better suited to the realities of developing nations remains an issue.

In light of the public health concerns and restrictions placed on the use of treated effluents in agriculture, the polishing step aims to enhance the microbiological quality of the effluents. In an environmental approach, the effluent quality in terms of organic matter and nutrients must be guaranteed, given the environmental harm caused by the discharge of these residual contaminants into the receiving surface water. The literature on post-treatment alternatives for an aerobically pre-treated sewage is extensive, with many articles addressing the different technologies and analyzing key experimental findings, exposing the benefits and drawbacks of each option[8]. Long-term dependability and operability studies of AnMBRs in municipal wastewater treatment, as well as basic cost and energy statistics, are lacking.

Furthermore, the majority of the research presented is limited to bench scale trials. The major disadvantages of AnMBRs, such as limited flux, membrane fouling, and expensive capital and operating expenses, continue to restrict their economic viability. Filter cloths, rather than actual membranes, are being developed in new ways that may significantly decrease capital expenditures[9]. Sewerage systems were originally built to transport sanitary flows and urban overflows away from inhabited areas. This did actually enhance sanitary conditions in many growing towns in the 19th and 20th centuries, resulting in a significant decrease in waterborne illnesses. The collected sewage was then released into surface waterways, posing a danger to the receiving water bodies' environmental health[10].

2. DISCUSSION

The latter, on the other hand, was not yet covered by official restrictions. Environmental laws were only established in the final 3–4 decades of the previous century in the industrialized nations of Western Europe and Northern America. Large cities, which already had substantial sewage systems, were also chosen as the first to be serviced by STPs. The massive sewage discharges of these cities had a significant effect on the environmental health of the aquatic bodies that received them. Prior to release to the surface waters, the earliest STPs were situated near the sewerage's major outfall in most cities. The environmental effect may be minimized by establishing a single STP to handle this big point source.

As a result, centralized sewage treatment arose as a logical result of historical events. This centralized model, however, places a financial strain on governments to build, maintain, and expand these services to all people. The centralized treatment method, with its benefits of economies of scale, has evolved into a sort of blueprint for sanitary systems, sewerage, and treatment in recent decades. In order to collect all of the sewage from the growing cities, centralized sewerage systems need pumping stations and siphons, as well as massive trunk sewers, especially in mountainous regions. With complete coverage of multi-tap drinking water supply at the home level and increased drinking water use, sewage outfalls increased dramatically, as did the number of needed STPs.

The latter evolved into sophisticated technology industrial complexes needing highly trained people. The gap between the serviced big regions in industrialized nations and the unserved large areas in less affluent countries widened. Currently, the centralized method is often seen as the blueprint for sufficient sanitation and environmental protection, particularly in developing nations. As a consequence, governments are pursuing centralized sanitation and high-level treatment but are unable to execute them due to severe budgetary limitations. In the Middle East, for example, strict environmental regulations are fulfilled at just a few centralized treatment facilities in big metropolitan centers like as Cairo, while the rest of the nation is not even serviced by basic treatment. Local circumstances dictate the best appropriate sanitation method, taking into consideration socioeconomic and environmental limitations. Sanitation is a function of mass flow per area per time unit, with socio-economic variables influencing the sanitation options available. In general, economic factors dictate the rate at which sewage infrastructure improvements are made, which means that the poorest areas are often denied adequate sanitation. A decentralized strategy may aid in the advancement of localized good sanitation without the need to build a large sewage system initially. In terms of water reuse, decentralization offers a number of benefits that have so far been overlooked in sewage master plans. Decentralization avoids the mixing of waste streams from homes and businesses, allowing for more agricultural reuse possibilities.

Dilution of the most dangerous contaminants is avoided by isolating the black toilet fluids from the home grey wastewater. Meanwhile, potentially valuable materials are concentrated, especially when black water collecting systems are operated at very low water volumes. This is possible with vacuum sewer systems that consume just 0.7–1.0 l each flush. The best degree of decentralization and how it is implemented is determined by a variety of site-specific factors. Interestingly, current research in different places, regardless of these circumstances, connects de centralization with resource recovery, rather than just solving a sanitary issue. The installation of appropriate sanitation systems may be accelerated by adding a value chain to the sanitary flows, allowing a greater proportion of the population to be served more quickly.

Anaerobic digestion plays a key role in stabilizing (concentrated) sewage and/or faecal matter in the decentralized instances above, while also turning organic waste into biogas. The avoidance of fossil fuels for sewage and/or slurry treatment is beneficial for any decentralized application, reducing the technological adoption barrier, especially for poor nations. The emphasis of research has been on improving the design and operation of UASB reactors. As previously mentioned, research into scum buildup, biogas and waste gas management, post-treatment, and energy recovery has attracted the greatest attention. The major limitations that remain are possible odor issues and the challenges that come with them, as well as the growing need for nutrient removal in the treatment system, as well as concerns with operation and maintenance, as described below.

In contrast to activated sludge, the overall benefits and drawbacks of anaerobic sewage treatment. When nutrient removal is needed to satisfy the receiving water body's quality requirements, the use of anaerobic procedures before a supplementary aerobic treatment for biological nutrient removal should be carefully considered. Although anaerobic systems are excellent at removing biodegradable organic waste, the amounts of N and P in the effluent may be greater than in the influent. When it comes to traditional nutrient removal methods, the single removal of BOD in the anaerobic reactor almost always has a detrimental impact on biological treatment systems that are designed to remove nutrients. Notably, the N/COD and P/COD ratios in the effluent from the anaerobic reactor will be considerably higher than the levels required for optimal performance of the previously stated traditional biological nutrient removal methods.

When nitrogen removal is required, traditional nitrification–denitrification methods have been used as a supplement to the UASB reactor thus far. In this scenario, the anaerobic reactor should only process a portion of the raw sewage influent (maybe no more than 50–70%). The remaining portion (30–50%) should go to a supplementary biological treatment aimed at nitrification and denitrification, so that enough organic matter is available for the denitrification phase. The utilization of an anaerobic reactor in this instance has the major benefit of receiving and stabilizing the sludge produced during the supplementary treatment, obviating the requirement for an anaerobic sludge digester. As shown, for concentrated sewage. The major nitrogen removal experiences have been with the use of activated sludge plants and, more recently, biological trickling filters packed with sponge-based media (pilot and demo scale), which have achieved up to 90% Ammonium-N removal while producing little extra sludge. Current and future research on the use of the anammox process in the main stream of STPs remains a problem.

Nonetheless, de-ammonification procedures (nitrogen removal through anammox bacteria) may be used instead of the traditional nitrification and denitrification methods to remove nitrogen at a low energy cost. The stimulation of ammonium oxidizing bacteria (AOB) and the inhibition of nitrite–oxidizing bacteria are essential for the effectiveness of such deammonification processes (NOB). It's possible that the necessary conditions might be met by using an intermittent aeration regime in the primary aeration tanks. In this case, a two-step procedure using UASB Trickling Filters and polyurethane support medium may be a viable option for removing nitrogen at a reasonable cost. Biomass hydrolysis caused by greater SRT may provide an extra supply of substrate in the sponge's anoxic zones, favoring heterotrophic denitrification. For two major reasons, using biological phosphorus removal in conjunction with UASB technology is practically impossible:

1. The anaerobic reactor's effluent no longer contains easily biodegradable matter, and
2. if phosphorus-rich sludge can be grown in a subsequent Bio-P step by bypassing a portion of the influent, then stabilizing the excess bio-P sludge in the preceding anaerobic reactor is pointless because all bound phosphorus will be released.

Currently, phosphorus removal in treatment facilities employing anaerobic reactors seems to be successful only when chemical products for P precipitation are employed iron or aluminum salts may be recovered from the concentrated waste stream using precipitation or crystallization methods if source separation was used in a decentralized manner. Compact anaerobic procedures, like other secondary treatment techniques, are ineffective in removing pathogenic organisms from effluents, necessitating a post-treatment step if pathogen removal is desired. Polishing ponds may be a highly successful technique for enhancing the microbiological quality of anaerobic effluents in small systems and under the right circumstances. In cases where land is scarce, a compact disinfection procedure, such as chlorination, UV radiation, and zonation, may be considered as a post-treatment alternative to improve the overall effectiveness of pathogen elimination, particularly of bacteria and viruses. However, because of the relatively large quantities of residual organic matter in the UASB effluents, the danger of disinfection by-product production is extremely significant when chlorination is used. Micro pollutants include substances used in cleaning and personal care products, compounds used in the production of resins and plastics, pesticides, and natural hormones and their by-products, as well as substances used in cleaning and personal care products, compounds used in the production of resins and plastics, pesticides, and natural hormones and their by-products.

3. CONCLUSION

The input from numerous full-scale pilot plants was critical in revealing the limits of existing design and management methods, as well as in improving the system and resulting in standardized designs. Researchers and field experts are still working to improve issues including smell annoyance, scum development, and correct hydraulic design. The advantages of anaerobic treatment, such as minimal or low fossil fuel use, simple and resilient technology, and resource recovery, are all regarded essential characteristics for creating more sustainable environmental solutions in general. The release of the powerful greenhouse gas CH_4 from anaerobic reactors is an increasing source of concern. Indeed, significant quantities of CH_4 are dissolved in the effluent and released to the atmosphere when effluents are discharged in contemporary full scale UASB systems. As a result, current research efforts are focused on recovering dissolved CH_4, which will help meet energy recovery requirements while simultaneously reducing greenhouse gas emissions. Nonetheless, it is clear that achieving public health and environmental objectives in poor nations remains a problem that requires particular attention. Furthermore, Life Cycle Assessments (LCA) emerge as a critical instrument for determining the best environmentally friendly treatment plan in a variety of geographical, technological, and economic contexts. The result of an LCA research, on the other hand, is determined by the data provided, the weighting factors employed, and the assumptions made about data gaps.

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