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Application of Anaerobic Digestion in Addressing Unsanitary Conditions of Lavatories in Tertiary Institutions of North-Western Nigeria: A Review

Adam Salihu Kila [a*], Sa'idu Hassan Musa [a], Umar Aliyu Ahmed [a], Bello Suleiman Muhammad [a], Haruna Musa [b], Abubakar Danjuma Maiwada [c] and Kasim Mohammed [d]

[a] Centre for Renewable Energy and Sustainability Transitions, Bayero University Kano, Nigeria.
[b] Department of Pure and Industrial Chemistry, Bayero University Kano, Nigeria.
[c] Material Science and Engineering Department, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.
[d] Department of Civil Engineering, Bayero University Kano, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

North-western Nigeria is a climate-vulnerable area characterized by seasonal rainfall and hot weather. The region is faced with various challenges, including inadequate water supply, making sanitation practice the topic of discussion among various stakeholders in the environmental and

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**Corresponding author: Email: asalhassan.crest@buk.edu.ng;*

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public health sectors. The aim of this paper is to review the applications of anaerobic digestion in addressing the sanitary issues in the tertiary institutions in North-Western Nigeria. Most important on this issue is the unsanitary conditions of lavatories at dormitories in these institutions. A report by the International Centre for Investigative Report posted that "life in most tertiary institutions in north-western Nigeria is quite unbearable for students, due to the level of discomfort and poor sanitary conditions of public toilets in their hostels. In view of this, it is suggested that various sanitation technologies that would prevent the spread of communicable diseases with less application of water should be considered in these institutions. Anaerobic digestion technology can play a significant role in addressing sanitary challenges and can also be integrated with other technologies such as urine-diverting flush toilet and waterless urinals, among others, to address the issue of inadequate water and energy supply, as well as sanitary conditions of students' lavatories in higher institutions in north-western Nigeria.

Keywords: Sanitation technologies; anaerobic digestion; lavatories; tertiary institutions; waterless urinals.

1. INTRODUCTION

Waste generation is a natural consequence of human life. The way these wastes are handled, stored, collected and disposed of, can pose risks to the environment and to public health (Ross et al., 2022). Management of these wastes is one of the major challenges worldwide and is an important concern in developing countries where waste management infrastructure and services are lagging behind the basic standards in terms of hygiene, efficient collection and disposal (Workman et al., 2021). When people do not have access to sanitation, their biological waste is left in the open, providing a means to transmitting gastrointestinal diseases (Nakamya et al. 2020; Cid et al., 2022). Untreated waste is responsible for several diseases like cholera, gastroenteritis, dysentery, typhoid, hepatitis and intestinal parasites, taking the life of millions of people each year and infecting hundreds of millions more (Hossain et al., 2013). These conditions, overrepresented in developing countries, further hamper quality of life in populations that already lack access to clean water, sufficient food and energy (Workman et al., 2021).

The World Health Organization (WHO) and United Nations Children's Fund (UNICEF) Joint Monitoring Programme (2019) estimated that there are more than 670 million people practicing open defecation in the world, especially in rural communities of developing countries (Ross et al., 2022; Boyd et al., 2022). In urban settings, the situation is more pronounced at the institutional level such as prisons, students' hostels, among others. Water shortage is the main cause of unsanitary conditions of lavatories since adequate water needs to be used to flush the faecal waste down the sewer system; otherwise, the faecal matter floats on the water seal, covering the opening of the toilet trapways (Hossain et al., 2013). Sanitation is one the most serious problems facing the world today. Almost 40% of the world's population (about 2.6 billion people) lacks access to adequate sanitation hence, open defecation becomes a usual practice (WHO/UNICEF, 2019). This leads to increased transmission of intestinal parasites and various infectious diseases. On the current development trajectory, it is unlikely that the United Nations Sustainable Development Goals (SDGs), particularly goal 3 (good health and well-being), goal 6 (clean water and sanitation), goal 11 (sustainable cities and communities), be met (WHO/UNICEF, 2019). Sub-Saharan African countries are particularly at high risk of this sanitary challenges, where the effects of climate change and socio-economic hardship are well-pronounced.

According to a recent observation by International Centre for Investigative Report (2021), life in most tertiary institutions in North-West Nigeria is quite unbearable for students, due to the level of discomfort and poor sanitary conditions of public toilets in their hostels. Modern toilets need a lot of water and septic systems; and to tackle this issue, the development of waterless toilet was found useful (Affam and Ezechi, 2021). However, waterless toilet also comes with its own challenges. These include the perception of odour from the system and cleaning and replacement of broken parts are other challenges (Opidi, 2020). Other options include the use of septic tank and anaerobic digestion technology. These also come with their challenges as about 13 to 15 litre of water is required to flush the human excreta down the sewer system to the digester or septic tank. To address such challenges, a holistic approach needs to be employed (Affam and Ezechi, 2021).

Some of the existing improved mechanisms used in addressing challenges related to wastes from human excreta include ventilated improved pit latrines, compost toilets, toilets connected to the conventional septic tanks onsite, toilets linked to the public sewage system, among others (Affam and Ezechi, 2021). Some of these systems have not, however, performed to expectations due to intrinsic issues with respect to location, construction quality, as well as operation and maintenance (Orner and Mihelcic, 2018). Additionally, there are obvious disadvantages associated with the use of pit latrine in addressing sanitary issues, some of which are contamination of surface and underground waters, as well as collapsing of the latrine, especially during the rainy season. As such, the use of natural treatment of the human excreta and other biodegradable wastes through the application of anaerobic digestion technology using biodigesters is attracting renewed attention (Almansa et al., 2023). This is a technology that can be applied at household and institutional levels, as well as in industrial and agricultural sectors. Therefore, this paper reviews the application of anaerobic digestion in addressing unsanitary conditions of lavatories in developing countries.

2. ANAEROBIC DIGESTION TECHNOLOGY

There are about 50 tertiary institutions in North-western Nigeria, with an estimated students and staff population of 225,000 (Hile, 2023). With variation of dietary intake of food, which determines the rate and quantity of defecation, an average of 128 g of fecal waste per capita per day has been reported to be produced by a healthy person (Ross et al., 2015; Shukla et al. (2023), with a range of 51 to 796 g/capita/day. One gramme of human excreta generates 0.04 – 0.05 cubic meter (40 - 50 liter) of biogas (Tilley et al., 2014; Donacho et al., 2023). With an average of 5000 students in hostels, particularly in first and second generation universities in north-western Nigeria, an estimated 640 kg of human excreta is generated on daily basis. Based on the data from Tilley et al. (2014), 32000 liter of biogas can be generated daily using anaerobic digestion technology.

Anaerobic digestion involves a series of biochemical reactions where microorganisms. Mainly bacteria breakdown the organic matters of any substrate into gaseous mixture (CH_4, CO_2, H_2, H_2S, etc.) in the absence of free oxygen (Deng et al., 2017; Bakkaloglu et al., 2022). Some groups of microorganisms involved in the biodegradation of organic matter in an anaerobic digestion process cannot survive in the presence of oxygen (Nakamya et al. 2020), thus anaerobic (oxygen-free) environment is required (Almansa et al., 2023). Anaerobic digestion breakdowns complex organic substrates through a multi-step processes, involving various classes of bacteria (Ferronato and Torretta, 2019). The process can be described in four various stages, including *hydrolysis*, *acidogenesis*, *acetogenesis* and *methanogenesis* (Bakkaloglu et al., 2022). At hydrolytic stage, the complex organic compounds, such as carbohydrate, protein and lipid, are broken down by the action of microbial extracellular enzymes into simple monomeric and dimeric compounds such as simple sugars, amino acids and long chain fatty acids, which can absorbed by microbial cellular membranes (Boyd et al., 2022). In the acidogenic stage, these simple compounds are anaerobically oxidized into alcohol, ammonia, and volatile fatty acids (VFAs). Alcohols and VFAs are converted to acetic acid, hydrogen and carbon dioxide in the acetogenic stage. In methanogenesis, these products undergo various biochemical processes (hydrogenotrophic and acetocalystic pathways) for methane production (Almansa et al., 2023).

Anaerobic digestion is considered as one of the most effective and desirable sanitation options (Deng et al., 2017); it is the technology that offers on-site waste treatment, elimination of pathogen and recovery of resources such as biogas and biofertilizer (Ferronato and Torretta, 2019; Almansa et al., 2023). Biogas contains about 60% methane and 40% carbon dioxide, and is usually used in generating heat and electricity in large scale production plants, while at household level, it is used for cooking and lighting (Boyd et al., 2022). Anaerobic digestion can be employed in addressing various environmental challenges such as deforestation and indoor air pollution in developing countries through the provision of alternative source of energy for cooking instead of firewood, which releases toxic gases resulting from incomplete combustion (Watabe et al., 2023; Malet et al., 2023). Anaerobic digestion also provides nutrients-rich biofertilizer, which can be applied in agriculture to improve soil fertility and boost food production (Watabe et al., 2023).

Anaerobic digestion has been described as an option for treatment of blackwater and kitchen wastes within the sustainable sanitation concepts (Deng et al., 2017), and based on experimental and simulation results, it was found that anaerobic digestion of combined blackwater and other wastes play a crucial role in addressing sanitary and energy issues (Wells et al., 2022). In a study, van Eekert et al. (2019) evaluated the potential of anaerobic digestion processes with respect to rate and extent of degradation of the organic matter in pit latrine using experimental procedures (Ferronato and Torretta, 2019). Based on the findings, the study concluded that pit latrine is the most suitable option for sanitation regarding management of human excreta, particularly in communities around the developing world; and that anaerobic digestion is the dominant pathway through which organic matter is broken down in the system (Watabe et al., 2023).

Different types of anaerobic digestion technology have been widely implemented in addressing sanitary issues around the world (Wells et al., 2022) including the fixed dome digester, the floating drum and plug flow or tubular digester models (Almansa et al., 2023). For example, as at 2014, China had over 40 million household-scale biogas plants, which was expected to double in 2020, while India developed over 90000 household-size biogas digesters between 2017 and 2021. In some countries around Asia, Africa and Latin America, moreover, financial incentives have been provided to households that connected their toilet to an anaerobic digestion system for energy and sanitary purposes (Watabe et al., 2023). Paliwal (2012) reported the construction of 100,000 bio-digester toilets by the Indian Central government to curb open defecation through total sanitation mission programme.

In assessing the potentials of anaerobic digestion in addressing sanitary issues at institutional level, particularly schools, prisons and camps, Butare and Kimaro (2002) described the case of Cyangugu biogas pilot project in Rwanda, where a fixed-dome type of anaerobic digester was set up to manage the faecal waste at Cyangugu prison. The pilot project was implemented by the Kigali Institute of Science, Technology, and Management (KIST) between 2001 and 2002, after the wars and genocide in 1994, when the prisons in Rwanda accommodated inmates ten times their actual holding capacity, which resulted in excessive generation of faecal waste that was a threat to the sanitary conditions of the environment. According to Rao and Doshi (2018), the project was funded by the International Committee of Red Cross (ICRC) through its Institutional Biogas Sanitation System. Similar projects were also implemented in Nepal and Philippines by the ICRC. The Rwandan government also launched a programme to install anaerobic digesters in schools and health facilities, as well as in organisations that have restaurants. About 86 organizational biogas digesters were built in prisons and high schools, and up to 10,647 residential biogas digesters of different sizes were constructed for households.

Zuo et al. (2021) investigated the applicability of anaerobic digestion technology in recycling of dry toilet generated blackwater using biomethane potential test. It was found that anaerobic digestion processes is affected due to rise in the level (3673.3 mg/L) of total ammonium nitrogen (TAN). The biomethane potential of dry toilet blackwater obtained was 402.36 mL CH_4/gVS after 55 days retention time at a temperature of 38 ^oC. Pseudomonas aeruginosa was found to keep multiplying in dry toilet blackwater fermentation broth during the first 8 days, and the growth stabilized thereafter. The study demonstrated the self-adjustment process and pathogen growth dynamics in the dry toilet blackwater during the anaerobic digestion processes. The study also revealed the significance of considering the characteristics of dry toilet blackwater when designing and maintaining the anaerobic digestion for sanitary treatment and reuse systems.

Osei-Marfo (2022) assessed the sanitary efficiency of three existing biogas plants at Mfantsipim Senior High School (Mfantsipim), University of Cape Coast (UCC), and Ankaful Maximum Security Prisons (Ankaful), through wastewater characterization and examination of effluent quality in Ghana. The results of the study indicated significant differences between effluent qualities from the three biohas plants, with most of the quality parameters falling within the Environmental Protection Agency (EPA) guidelines of Ghana. However, the study reported under-performance of the biogas plants, which was attributed to inadequate maintenance, design deficiencies, poor environmental conditions and organic loads higher than the capacities of plants.

Anaerobic digestion system has great potentials to improving sanitation in areas where water supply is not adequate (Almansa et al., 2023). This technology plays a key role in achieving some of the UN SDGs including zero hunger, through the generation of efficient and sustainable fertilizer for food production; good health and well-being, through the elimination of pathogens and other risk factors in wastewater treatment plants (Ross et al., 2022); gender equality, by reducing the workload on women in water and energy (Malet et al., 2023); clean water and sanitation, through the microbial degradation of faecal and other anthropogenic waste, reducing the contamination of surface and groundwater; and climate action, through the generation of renewable energy such as cooking gas and electricity, as well as biofertilizer to improve agricultural productivity, especially in climate-vulnerable areas around the world (Bakkaloglu et al., 2022).

3. INTEGRATION OF ANAEROBIC DIGESTION WITH OTHER SANITATION TECHNOLOGIES

There are various sanitation technologies that can be applied for safe management of human excreta coming from the toilet to prevent or reduce exposure of the community to communicable diseases (UNICEF, 2017; Wells et al., 2022). These sanitation technology options can be any available and feasible means related to use of facilities, conveyance of the human excreta, its treatment and disposal in possible hygienic ways (Gros et al. 2020). The system can be on-site sanitation or off-site, depending on the population size and location, design option, land availability, operation and maintenance costs. The sanitation concepts in on-site systems are similar to that of off-site; only that the treatment is carried out at different location (Almansa et al., 2023).

On-site sanitation options include single-use toilet, in which the collection and storage of the human excreta are done in one place. The excreta and urine, as well as the washing water go directly into the storage tank (Tan et al., 2021). The issue with this system is that it is susceptible to permeation of leachates, which can percolate into groundwater and surrounding environment when full or densely loaded (Affam and Ezechi, 2021). In this case, anaerobic digestion technology can be employed to avoid percolation and contamination of the groundwater with pathogenic microorganisms (Moerland et al., 2020). Biogas and biofertilizer can also be recovered when anaerobic digestion technology is integrated with this system (Almansa et al., 2023).

However, the biogas production processes can be affected by the amount of urine flowing into the storage tank and producing ammonia through the conversion of urea by the enzymes urease (Tan et al., 2021). This can be addressed by employing the use of urine-diverting flush toilet, in which the urine is separately collected without mixing with the faecal matter, or waterless urinals, in which no water is needed to flush the waste into the storage tank, while the urine is collected separately (Tilley et al., 2014; Affam and Ezechi, 2021). Several scientific studies have been conducted to assess waterless urinals and urine-diverting and flush toilets.

Noteworthy is the work of Francis et al. (2016), who assessed the sanitation practices of traders in Kuje market, Federal Capital Territory (FCT), Abuja. A novel toilet complex comprising of 8 toilet units (for males and females), with urine diversion, gender-segregated urinal, urine storage tank, used menstrual absorbents disposal facility for women, bathing facility and a composting chamber, was designed and developed. There is also a provision of small spray system for anal cleansing and another for hand-washing. The toilet design serves as a model for other public institutions where sanitation is a challenge.

The integration of anaerobic digestion with waterless urinals can be achieved using dry digestion technology, in which the system can carry a total solid above 15% in the slurry, and without the need for dilution (Affam and Ezechi, 2021). However, in the integration of anaerobic digestion with urine-diverting flush toilet, wet digestion should be considered (Spuhler et al., 2018; Tan et al., 2021). A wet digester or low solids anaerobic digestion system generally processes feedstock with less than 15% solids content. The feedstocks for a wet digester are typically in slurry form and can be pumped. A dry digester or a high solids anaerobic digestion system generally processes feedstock with greater than 15% solids content. The feedstocks for a dry digester are often described as stackable (Almansa et al., 2023).

4. CONCLUSION

Anaerobic digestion is an important technology that can be applied, especially when integrated with other related technologies, to address various sanitary issues affecting lavatories in students' hostels in higher institutions, particularly in north-western Nigeria. The unsanitary conditions are the result of inadequate water supply that make the lavatories unbearable, leading to open defecation and spread of infectious diseases. Integration of anaerobic digestion with urine-diverting flush toilets or waterless urinals will also address energy issue, in addition to saving more water for sanitation.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The authors hereby declare that no generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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