Chapter – I INTRODUCTION

This chapter aims to introduce the background and objectives of the study. It ends with an outline of the thesis structure.

1.1 Background

The world's population continue to grow and increases the energy demand. Non-renewable energy sources are depleting at an alarming rate and causing severe harm to the environment and living beings. The adverse environmental impact of conventional energy sources necessitates a shift towards sustainable alternatives. NITI Aayog, the National Institution for Transforming India, suggests that shifting to renewable energy sources is necessary to fulfil the growing energy requirements and address the unfavourable consequences of climate change. The Urban Local Bodies (ULBs) and Municipal Corporations in India are proactively addressing these challenges by enhancing infrastructure and refining management practices to align with future sustainable goals in Municipal Solid Waste (MSW) management. The composition and quantity of solid waste generation vary from place to place, average income group, population, social behaviour, seasonal condition etc. **(**Khajuria et al., 2010**,** Minghua et al., 2009, Banerjee et al., 2019). By 2050, the estimated solid waste generation rate will be 3.40 billion tonnes (Kaza et al.,2018). This waste mostly comprises 44% food and green waste followed by 17% paper waste and the remaining glass, metal, rubber, wood and other waste material. The rate of production of MSW in India is 160038.9 TPD out of which 50% is treated, 18.4% is disposed-off in landfills and 31% is unaccounted which contributes to the release of greenhouse gases (Annual Report on Solid Waste Management (2020-21)). The accounting of biodegradable waste is significant in Indian cities ranging from 41% to 52% of the total MSW(Saini et al., 2012; Sharma & Jain, 2019a; Singhal et al., 2022). Biodegradable organic matter which is a significant portion of MSW also known as the Organic Fraction of Municipal Solid Waste (OFMSW) (excluding plastic waste). If this biodegradable organic matter is disposed in a landfill without treatment, it will naturally decay and produce greenhouse gases. It is feasible to segregate the OFMSW and process it using composting, vermicomposting, incineration and anaerobic digestion. In major Indian cities, generated biodegradable waste has the potential to be used in anaerobic digestion which can lead to the production of energy.

Increasing population growth increases the sewage generation rate. There are 1093 sewage treatment plants in operational condition in India which can treat approximately 20235 MLD of sewage (CPCB annual report, 2021). Domestic sewage is treated with different treatment technologies like ASP and SBR which are the most prevailing technologies followed by Upflow Anaerobic Sludge Blanket (UASB) which are used by most of the ULBs. In developing nations such as India, the use of UASB treatment technology for sewage treatment presents a strategic advantage owing to its low initial setup costs, economical operational maintenance and potential for energy generation. However, the discharge of treated sewage using UASB necessitates secondary treatment, typically through the ASP to ensure compliance with inland surface water disposal standards specific to Indian conditions. As per the National Inventory of Sewage Treatment Plant (Annual Report CPCB, 2021), 76 sewage treatment plants in India are based on UASB technology. These plants are responsible for treating a total of 3524 MLD of sewage. After the UASB process, when the sewage is treated with the ASP, it results in the production of bio-flocculated sludge which requires proper attention for its treatment and disposal.

1.2 Basic principle of anaerobic digestion process

The intricate process of anaerobic digestion needs a strict anaerobic environment. The processes that bring the entire anaerobic digestion process to a conclusion include hydrolysis, acidogenesis, acetogenesis and methanogenesis (Appels et al., 2008). The first phase of the AD process is hydrolysis, thought to be the rate-limiting step. Lipids, proteins, and nucleic acids are among the organic compounds with the highest solubility and molecular weight at this level. (Li et al., 2011). In the acidogenesis phase, the component formed undergoes additional processing. Here, fermentative or acidogenic bacteria make Volatile Fatty Acids (VFA) which also produce ammonia, CO_2, H_2S and a few other by-products. Acetic acid, CO_2 and H_2 are formed during the acetogenesis phase from organic acids produced during the acidogenesis phase after they have been further digested **(**Esposito et al., 2011**)**. The last phase of anaerobic digestion uses two groups of methanogens to create methane gas. The second group of bacteria use H_2 as an electron donor and CO_2 as a source of energy. The first group of bacteria break down acetate in CH_4 and CO_2 (Figure 1).

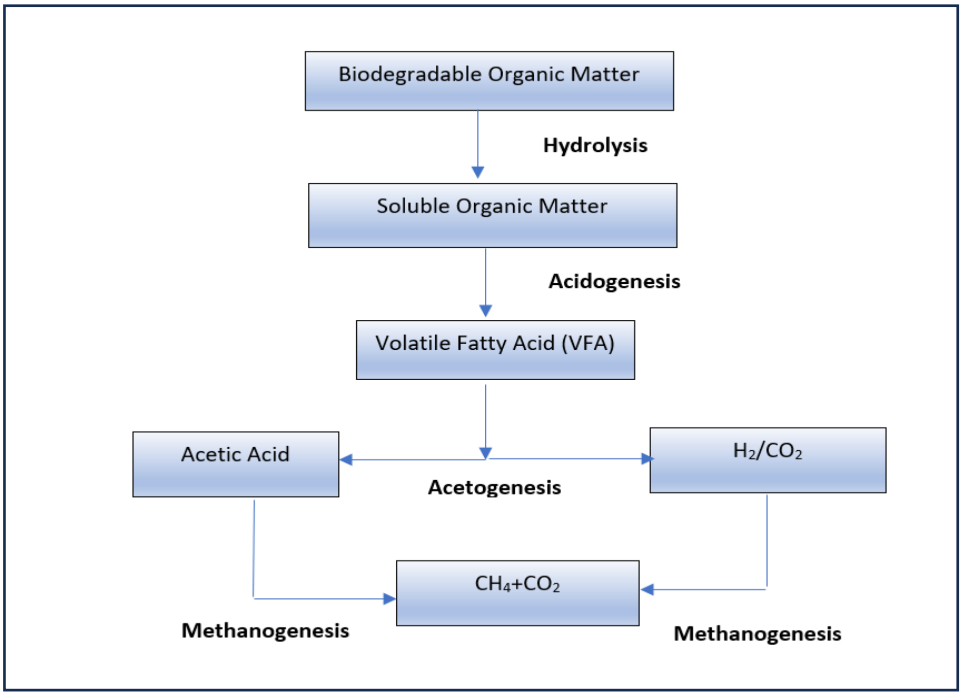

Figure 1 : Anaerobic digestion process, (Appels et al.,2008)

1.2.1 Anaerobic co-digestion – a prominent treatment technology for waste management

Anaerobic co-digestion is when two or more substrates are anaerobically digested, providing balanced nutrients and more stable environmental conditions for anaerobes. Anaerobic co-digestion aims to diversify substrate and enhance the versatility of microbial communities and robustness in the process (Tyagi et al., 2018). The anaerobic co-digestion process is a path of recycling, recovery (in the form of energy) and reduction (digestate use as fertilizer which reduces landfill disposal partially).

Another importance of the anaerobic co-digestion process (Astals et al.,2014; Shah et al., 2015)

- Sustainable bio-waste recycling
- It creates synergy between substrates, improving biogas yield and methane enrichment in biogas composition.
- Biogas yield with anaerobic co-digestion is higher compared to mono digestion of each substrate.
- Improve process stabilization

- Dilutes inhibitory substances
- Helps to balance nutrient
- C/N ratio achievement
- Improve moisture content
- Reduction in greenhouse gas emission
- Economic feasibility for waste management
- Recovery of value-added products

1.3 Need of the study

Anaerobic digestion has emerged as a highly preferred process due to its cost-effectiveness for growing nations like India with low investment and potential for revenue generation. Anaerobic digestion of OFMSW has issues such as large particle size, high solids, slow biodegradation, lignin-rich waste and the heterogeneous nature of the waste makes the process challenging (Hartmann & Ahring, 2005). OFMSW is considered a high Total Solids substrate of approximately 35-50% leads to failure of the reactor performance due to mechanical problems, toxic substance accumulation, process inhibition due to higher acidification, low biogas yield, high C/N ratio, deficiency of macro and micronutrient, low degradation rate increases retention time which requires larger reactor volume (Cecchi et al., 2011). OFMSW must be treated with other co-substrates to enhance the waste-to-energy process. The anaerobic digestion (AD) process allows the OFMSW to be microbiologically digested under anaerobic conditions to produce biogas rich in methane. The digestate can be used as an agricultural fertilizer (Chiu & Lo, 2016)

India is a diverse country with significant differences in geographical regions and living standards in these areas, resulting in different patterns of garbage generation (Pal & Bhatia, 2022). Substrate availability, composition, characteristics, geographical condition, climatic condition, economic condition, treatment processes, waste management approach etc. are the key factors for the anaerobic digestion process. The study of the substrate and its efficiency for a particular area is a very important factor for the success of any anaerobic process. Organic matter co-digested with sewage sludge (mixture of PS (60%) and WAS (40%)) operated with an average OLR 0.8kg/m^3/d VSS by increasing OLR by 25% can increase biogas quantity by 80%. (Zupančič et al., 2008). Food waste anaerobically co-digested with septic tank sludge with a mixing ratio of (75:25) shows a negative effect on biogas generation compared to mono digestion of FW. The Septic sludge has an excessive presence of manganese and zinc which creates inhibition in biogas production (Kesharwani & Bajpai, 2020). OFMSW and WAS from dewatering pool anaerobically co-digested can result in low methane yield with high solids (15%-20%) compared to low solids (5%-10%) content and with 5% Total Solids maximum biomethane yield of 337 N mL/g VS achieved (Ahmadi-Pirlou et al., 2017). OFMSW and mixed sludge (pre-thickened primary & secondary sludge) are anaerobically co-digested in a continuous flow reactor have observed that OLR and substrate composition have an impact on the microbial community in the reactor (Keucken et al., 2018). Anaerobically co-digested food waste and sewage sludge from the activated sludge process show maximum methane yield with a mixing ratio of 3:1 under mesophilic conditions that is 0.35L CH_4/gm VSreduce(Arelli et al., 2021). Fruit waste (mango, banana, tomato, papaya) is anaerobically co-digested with sewage sludge digestate (wastewater treatment plant France) and biochar (350℃) with ISR=2 which gives the best result at 1 to 1.5gm VS fruit waste (Ambaye et al., 2020). OFMSW (slurry with 15%TS and 90%VS of TS from a biogas plant, Sweden) with PWASS (Primary and Waste Activated Sludge) from a wastewater treatment plant (Stockholm, Sweden) at a ratio of 3:1 on a VS basis can be operated with 5 gm VS/L/d that has the potential to increase biogas yield four times (Björn et al., 2017a). Municipal Solid Waste and Municipal Sewage (Madurai, Tamilnadu, India) are co-digested under mesophilic conditions with a mixing ratio of 1:4 which can achieve a methane yield of 52% in biogas. (Vasumathi A.M. & Mathuram A., 2015).

The sludge formed in the SST (post-UASB) is less in quantity, has poor porosity is difficult to dewater, is low in solid content and therefore difficult to dispose-off in conventional sludge drying systems. This sludge must go through some process to reduce volume, improve its characteristics, and reduce health problems and hindrances to meet disposal standards and acceptance. The bio-flocculated sludge produced in the SST has an abundance of microorganisms that can enhance the anaerobic digestion process. The prime use of bio-flocculated sludge from SST (post-UASB) for the anaerobic co-digestion process still needs to be focused based on various parameters and availability in Indian conditions to enhance the anaerobic digestion process of OFMSW.

The report published by the Ministry of Housing and Urban Affairs under the flagship of the Swachh Bharat Mission adopting circular economy mission state that bio-methanation of wet solid waste is significantly more profitable than composting. It also highlighted the concern about municipal sewage sludge management as it is being utilized unscientific without regulatory standards in India.

The study of anaerobic co-digestion of OFMSW and bio-flocculated sludge from SST (post-UASB) is required to check the synergistic effect that can arise by using solid-liquid waste to enhance the methanation process and nutrient recovery in the form of digestate which can be used for land application. This study underscores the potential of integrated waste management practices for sustainable and economical solutions (Figure 2). The estimated quantity of OFMSW generation and bio-flocculated sludge generation rate is 600kg/d and 104kg/d respectively, for 1 lakh of the population (Annexure 1).

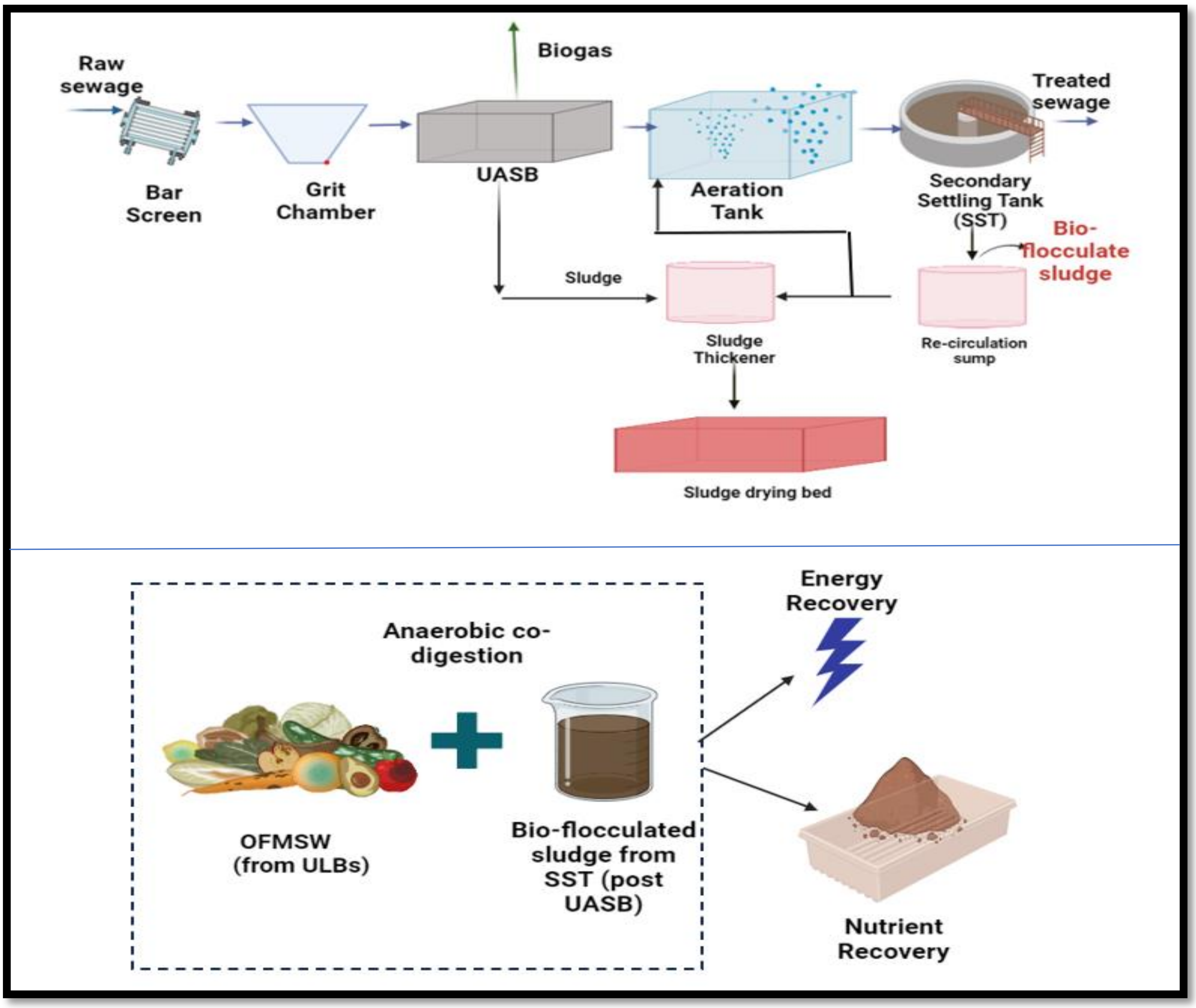

Figure 2: Substrate for anaerobic co-digestion process

1.4 Objectives of the present study

- **To Check the feasibility of an anaerobic process for the co-digestion of OFMSW & bio-flocculated sludge generated in ASP (post-UASB) of conventional sewage treatment in Indian conditions.**

  Composition and Characteristics of OFMSW and bio-flocculated sludge are analyzed with different parameters. The feasibility of anaerobic co-digestion of OFMSW and bio-flocculated sludge is checked using a lab-scale batch experimental study with different mixing ratios under mesophilic conditions. The batch anaerobic co-digestion process is validated with kinetic modelling to develop kinetic constants for the anaerobic co-digestion process. The mixing ratio is optimized according performance anaerobic reactor based on different operating parameters, biogas yield and kinetic modelling.

- **To identify optimum conditions for various parameters to achieve satisfactory degradation and gas production for the co-digestion process.**

  Optimized mixing ratio from the batch experimental study is used to check the robust and reliance performance of anaerobic co-digestion of OFMSW & bio-flocculated sludge when operated at different OLRs under semi-continuous flow to optimize the operational condition for biogas yield.

- **To scale up an analytical model for running a treatment scheme as suggested.**
  A prediction model using an Artificial Neural Network (ANN) is developed. The developed prediction model using lab-scale experimental data, can be useful for the operation and performance enhancement of the anaerobic co-digestion process when replicated on actual field conditions.

1.5 Organization of the Thesis

Thesis includes:

Chapter I presents a brief overview of the need for anaerobic co-digestion of OFMSW and bio-flocculated sludge and states the scope of research. The motive of the thesis is to improve the efficiency of the anaerobic digestion process using bio-flocculated sludge as co-substrate to maximize the generation of biogas from locally available OFMSW.

Chapter II presents a literature review on influencing the anaerobic co-digestion process using different substrates, reactor types, pretreatment technology, operational conditions and biogas production. The chapter also presents strategies that can be considered for enhancing the process performance by using different kinetic modelling and prediction modelling techniques.

Chapter III presents the preparation of substrates for the anaerobic co-digestion process, analytical methods, experimental work, kinetic modelling and prediction modelling techniques used in the study.

Chapter IV presents the feasibility study of anaerobic co-digestion of OFMSW and bio-flocculated sludge using lab-scale experimental work with the performance of batch and semi-continuous flow anaerobic reactors. It also presents the developed kinetic models to validate lab-scale experimental work and prediction modelling with Artificial Neural Network (ANN) using lab-scale experimental data.

Chapter V presents the significant findings from the research study and recommendations for additional research.

At the end of the report, a list of references cited in the Thesis is provided.

At the end of the report, there is a list of publications resulting from the current research.