Analysis of Sludge (from Sewage Treatment Plant) Mixing methods in Anaerobic Digesters for Production of Bio-Gas

Man Singh Mirdha[1], Mr. Hemant Kumar Agarwal[2]

[1]M.Tech Student Jagan Nath University, Jaipur
Assistant Professor Department of Civil Engg. Jagan Nath University, Jaipur

***

Abstract - This study investigates the biogas generation of sewage sludge using anaerobic digestion from Delawas Sewage Treatment Plant located in Jaipur city, which is capital city of Rajasthan. In addition, different mixing techniques for anaerobic digestion and pretreatment of sewage sludge is studied and implied for optimum biogas generation. Sludge recirculation, most common mixing technology is combined with plate heat exchanger to heat the sludge going inside the digesters and performance of same has been studied thoroughly. Similarly, most basic pretreatment of sewage sludge i.e. gravity thickening is used to optimize the digesters volume. Several other mixing methods are discussed and used such as, mechanical agitation, gas-sludge ejector & mixing system.

Following the completion of this study, biogas generation with respect to feeding, mixing and pretreatment are discussed thoroughly to pinpoint the optimum inlet parameters and mixing & feeding patterns.

The findings of the scenario analysis show the impact of optimizing OLR and consistency in feeding to digesters are very crucial for optimum biogas generation and health of anaerobic digesters. Also the effect of mixing by implying different mixing techniques shows positive results for enhanced biogas generation.

1. INTRODUCTION

The number of rivers in India's network is as high as 113, and the country's extensive alluvial basins store an abundant supply of groundwater. India has a wealth of water resources. In addition, the Indian subcontinent is endowed with snow-covered mountains in the Himalayan range, which provide the country with a diverse supply of water resources. Many regions of the country's accessible water resources are being depleted, and as a consequence, the quality of the water has degraded. This is due to the country's fast population growth, as well as the necessity to fulfil the rising needs of irrigation, residential consumption, and industrial usage. Domestic sewage, industrial effluents, and agricultural runoff are the primary contributors to water pollution in India.

As the trend toward urbanization continues across the globe, one of the most critical problems to address is urban environmental management. Urban planners are faced with a number of issues, one of which is the requirement to assure the continuous provision of fundamental human services such as water and sanitation. A significant obstacle is presented by the inadequate handling of municipal wastewater in many urban centers located in the south. In major cities, wastewater treatment and disposal is a difficult challenge. The improper disposal of wastewater contributes to the contamination of both aquatic and terrestrial environments. As a result of serving tainted water, it leads to a variety of health concerns as well as epidemics. The water bodies get eutrophicated as a result of its addition, which results in the death of aquatic biological resources. Therefore, treatment plants play an important part in the environmentally responsible use of wastewater since they render the water useful for a variety of applications.

A knowledge of the characteristics of the wastewater being managed is necessary for the efficient treatment of any type of wastewater. Not only is detailed parameterization data for these characteristics required to facilitate the effective design of wastewater treatment and disposal systems, but it is also required to enable the development and application of water conservation and waste load reduction strategies. However, wastewater characteristics must be predicted for the vast majority of existing projects as well as almost every potential construction. (Kumar & Chopra, 2012).

Despite possessing just 4% of the world's fresh water resources, India is responsible for more than 16% of the world's people's well-being. In India, the total quantity of wastewater generated annually by 200 cities is roughly 2,600 Mm3, and the use of sewage effluents for irrigation of agricultural fields is becoming more prevalent, particularly in the peri-urban area. Trace metal concentrations in sewage discharge vary from city to city. These waste fluids include significant amounts of nutrients as well as trace amounts of harmful metals. Despite the fact that the concentration of heavy metals in sewage effluents is generally low, the long-term application of these waste waters on agricultural fields usually leads in the build-up of higher quantities of these metals in the soil. This is true even when heavy metal concentrations in sewage effluents are relatively modest. The quantity of metals that can build in some soils is affected by the length of time waste water is permitted to irrigate soils. Crops produced on polluted soil absorb metals in high enough concentrations to cause clinical problems in both animals and humans who ingest these metal-rich plants.

Impact of Sludge mixing on AD process

The effectiveness of the anaerobic digestion (AD) process is strongly dependent on the characteristics of the feed, as well as the feeding pattern, pH, temperature, redox potential, hydraulic retention time (HRT), solids retention time (SRT), and mixing inside the digester. Mixing has an effect on the proximity of microorganisms to available substrates and nutrients, consistent operating temperature and pH, HRT/SRT, and the distribution of metabolic waste, all of which are essential elements in the aerobic decomposition process and the performance efficiency of the system. As a consequence of this, the AD procedure is influenced by the mixing procedure, which is a physical procedure. Stirred tank digesters are built with the goal of providing external physical mixing within the digesters themselves. This is accomplished via the use of agitation.

A continuously stirred tank reactor, also known as a CSTR, is the primary component of a stirred tank digester that is completely assembled. This type of reactor is designed to process organic waste with total solids (TS) contents ranging from 3% to 10%. Its planned range of operation is from 3% to 10%. The HRT that is necessary for this process typically lasts anywhere from 10 to 20 days and is performed at a temperature of 35 degrees Celsius. The substrates are continuously fed into the digester through the intake, and at the same time, an equal number is permitted to exit the device through the device's outflow. There is a widespread consensus that the HRT and the SRT refer to the same entity. The contents of a typical digester are continually mixed using one of the following four methods: gas recirculation, liquid/slurry recirculation, mechanical pumping and mechanical stirring, or a combination of these four techniques. Additionally, the contents can be mixed using a combination of these four methods. This is done in order to maintain the suspension of the solids and to generate a combination that is uniform in consistency. There is a tendency for light particles such as fibre, straw, or feathers to float on the surface of the digester, which hinders the production of biogas. On the other side, heavy solids like stones, eggshells, sand, or other thick lumps descend to the bottom of the digester. This can happen with a variety of different materials. The surface is also a common location for floating liquids and light solids. Stratification, whether it is generated by sedimentation or flotation, reduces the volume of the active digester, causes mechanical problems with pumps and impellers, obstructs the release of biogas from the liquid phase, and may also result in the formation of foam, scum, and crust. Stratification can be induced by either sedimentation or floatation.

The following is a list of some of the advantages that come from mixing:

- allows for effective use of the total capacity of the digester,
- halts the process of stratification, which includes floating and sedimentation,
- stops the formation of foam, scum, and crust,
- avoids pH and temperature fluctuations.,
- responsible for the dispersion of metabolic end products as well as any harmful elements that may be present in the influent,
- increases the rate at which biogas is released from the substrate,
- ensures that the bacteria, bacterial enzymes, and their substrate continue to be in close proximity to one another,
- contributes to the decrease in particle size.

The fundamental purpose of mixing is to promote homogeneity in the fluid mixture and to give an equal platform for anaerobic microbes.

A stable habitat for anaerobic bacteria is one of the most critical criteria for attaining maximal digestion, and proper mixing is the key to meeting this prerequisite. Digesters are less prone to become blocked when enough mixing is undertaken. In classic sludge anaerobic digesters, poor mixing often led to the oversizing of the digesters due to the lower HRT/SRT that it induced. This, in turn, led to decreased interaction of the substrates with the microorganisms, which resulted in poor volatile solids (VS) reduction and low biogas generation. It has been established that improper mixing within the digester is a substantial contribution to the failure of the digester. Uneven mixing, on the other hand, can result in the establishment of initiation zones in which methanogens can emerge and thrive, and from which they can subsequently seed the remaining areas of the digester. It is not yet apparent what degrees of mixing in AD are deemed suitable and what levels are considered inadequate, and it is unknown whether or not it is economically viable to attain 100% homogeneity in the quest to enhance the energy efficiency of AD.

The high initial investment cost, as well as the continuous operational and maintenance requirements of mixing equipment, are some of the negatives associated with stirred tank digesters. In the past, a complete stirred tank digester would function in the same manner as a continuous stirred tank reactor (CSTR), in which the digester would be constantly fed and mixed. It is estimated that the amount of energy required for mixing in a full-scale digester can account for anywhere from eight percent to fifty-eight percent of the overall energy demand. The variances in energy efficiency might be attributable to the varied types of substrates, TS, tank designs, mixing types and their orientations, as well as the operational mode of mixing. Due to the great price required in obtaining absolute homogeneity, the majority of industrial digesters work as a heterogeneous mixture. This is due of the high expense. The economics of AD may be improved to optimize the quantity of energy generated per unit of substrate treated, as well as the quality of the digestate, while concurrently minimizing the amount of money spent on capital and operational expenditures. When compared to the continuous mixing mode of a CSTR, optimum intermittent mixing is reported to minimize the energy consumption and maintenance expense while simultaneously enhancing biogas output. This is the situation from an economic point of view. In an ideal circumstance, mixing should occur at the same time as feeding in order to homogenize the fresh feed that is being delivered, to guarantee that the bacteria, bacterial enzymes, and their substrate are in close touch with one another, and to produce an equal platform for the anaerobes. Therefore, in batch-fed or intermittent feeding modes, the mixing should coincide with the feeding in order to disperse the feed, and then it should be mixed sometimes in between feedings. This is especially critical for daily batch-fed or intermittent feeding modes (Kariyama et al., 2018)

Identification of major processes

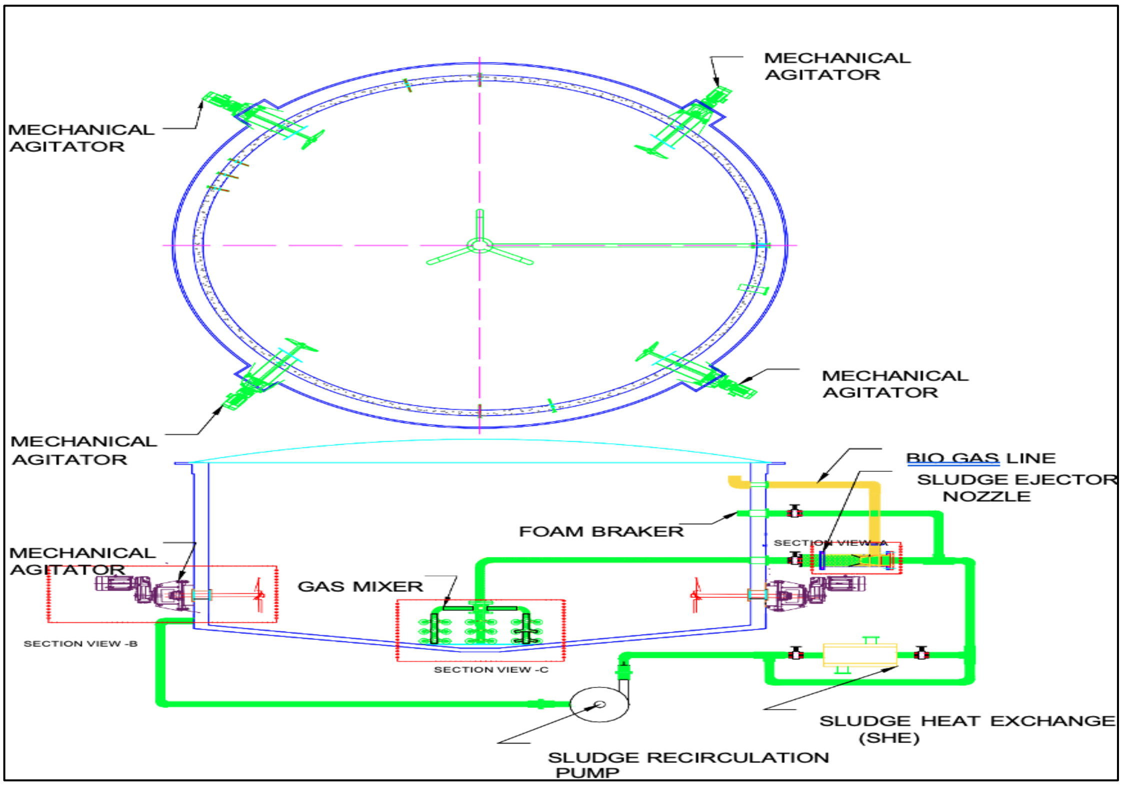
I. Sludge recirculation for Anaerobic sludge digestion.

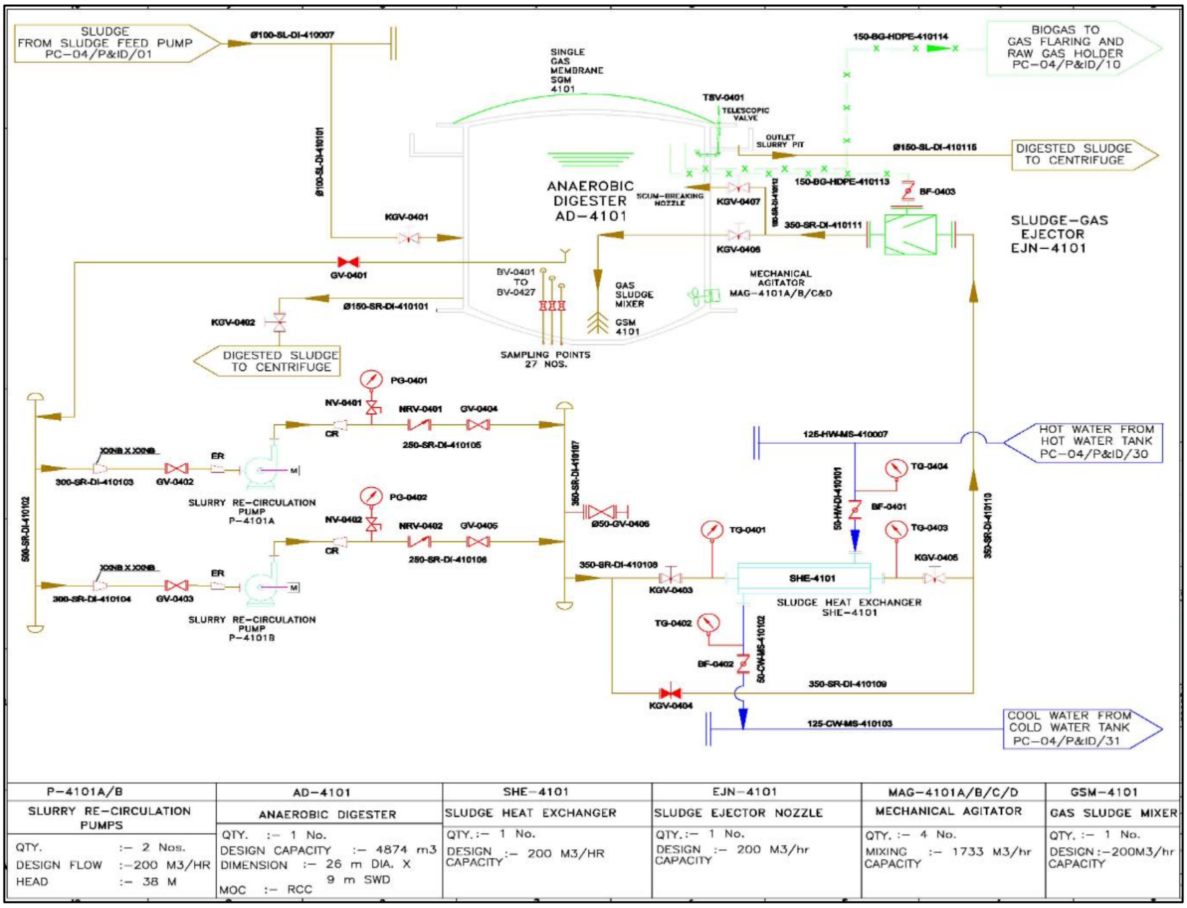
II. Plate heat exchanger for recirculating sludge.

III. Gas-Sludge Ejector for recirculating sludge.

IV. Gas-Sludge Mixer for recirculating sludge.

V. Mechanical Mixing.





P–4101A/B	AD–4101	SHE–4101	EJN–4101	MAG–4101A/B/C/D	GSM–4101
SLURRY RE–CIRCULATION PUMPS	ANAEROBIC DIGESTER	SLUDGE HEAT EXCHANGER	SLUDGE EJECTOR NOZZLE	MECHANICAL AGITATOR	GAS SLUDGE MIXER
QTY. :– 2 Nos. DESIGN FLOW :–200 M3/HR HEAD :– 38 M	QTY. :– 1 No. DESIGN CAPACITY :– 4874 m3 DIMENSION :– 26 m DIA. X 9 m SWD MOC :– RCC	QTY.:– 1 No. DESIGN CAPACITY :– 200 M3/HR	QTY.:– 1 No. DESIGN CAPACITY :– 200 M3/hr	QTY. :– 4 No. MIXING CAPACITY :– 1733 M3/hr	QTY. :– 1 No. DESIGN CAPACITY :–200M3/hr

Piping and Instrumentation of Digester A

Biogas Generation and Composition

The amount and quality of biogas are crucial markers for assessing anaerobic digestion sufficiency. As previously stated, the biogas output of each anaerobic digester was recorded independently by an individual gas counter during a certain time period (approximately 24 hours), and the average gas flow for each system is determined every day. It should be noted that the biogas flow may vary between feed cycles (which occur every 24 hours). For example, increased output may be observed right after feeding, followed by a drop in output after a few hours. As a result, the average biogas flow per day is more consistent and reliable for estimating biogas output. The gas trap was used to catch biogas while the gas in valve was open and the gas out valve was closed. When enough biogas had been stored (about 700 mL), a portable gas analyzer was attached to the air lock with the gas out valve open to measure biogas composition. The gas analyzer computes the percentages of CH4, CO2, O2, and H2S, as well as the ppm of H2S.

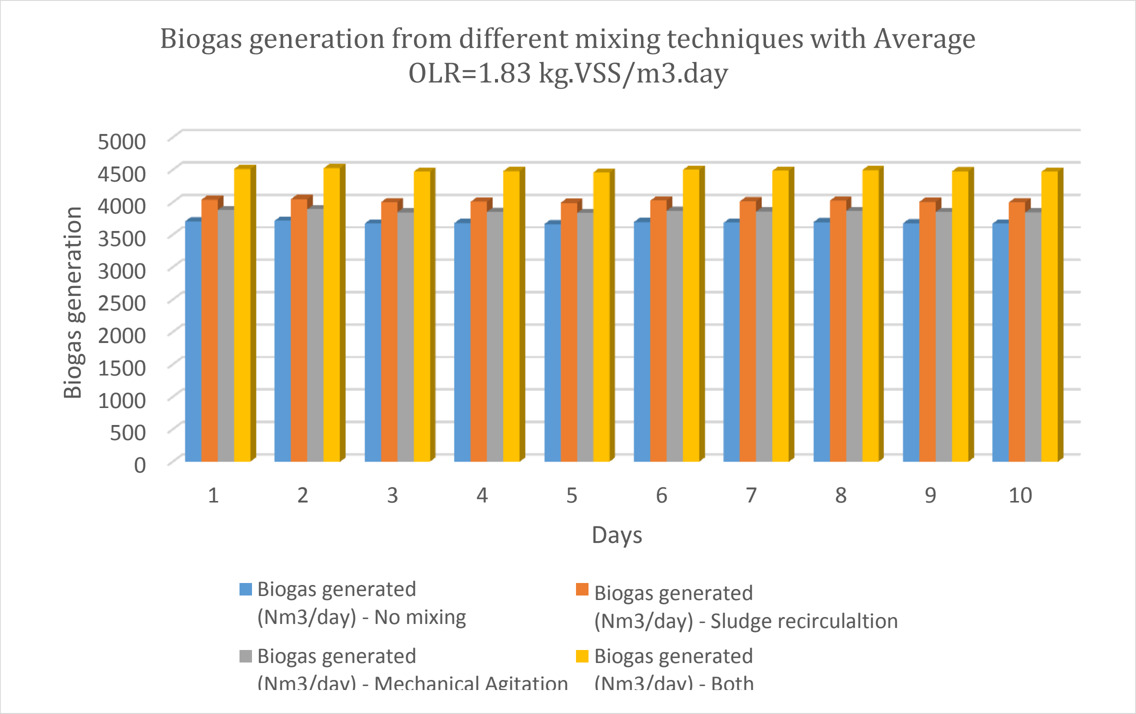
The following tests were carried out to characterize the parameters of the sludge sample. (APHA, 1981)

Comparison of different mixing techniques in respect to biogas production

Thickened sludge is fed into the digesters at constant rate (Appendix A), with different mixing methods utilized to pen out the optimum biogas generation.

: Comparison of modes of mixing for biogas production

Day	Experiment-I (None)		Experiment-II (Recirculation)		Experiment-III(Agitation)		Experiment-IV (Both)	
	OLR (kg.VSS/m^3.day)	Biogas generated (Nm^3/day)	OLR (kg.VSS/m^3. day)	Biogas generated (Nm3/day)	OLR (kgVSS/m^3. day)	Biogas generated (Nm3/day)	OLR (kgVSS/ m^3.day)	Biogas generated (Nm^3/day)
Day-1	1.84	3705	1.85	4037	1.85	3879	1.84	4512
Day-2	1.85	3717	1.85	4050	1.85	3891	1.84	4526
Day-3	1.83	3671	1.83	4000	1.83	3843	1.82	4470
Day-4	1.83	3680	1.83	4009	1.84	3852	1.82	4481
Day-5	1.82	3661	1.82	3989	1.83	3832	1.82	4458
Day-6	1.84	3695	1.84	4026	1.84	3868	1.83	4500
Day-7	1.83	3685	1.84	4016	1.84	3858	1.83	4488
Day-8	1.84	3692	1.84	4023	1.84	3865	1.83	4496
Day-9	1.83	3676	1.83	4006	1.83	3849	1.82	4477
Day-10	1.83	3672	1.83	4001	1.83	3844	1.82	4472
Average	**1.83**	**3686**	**1.836**	**4016**	**1.838**	**3859**	**1.83**	**4488**



Impact of intermittent mixing on anaerobic digestion

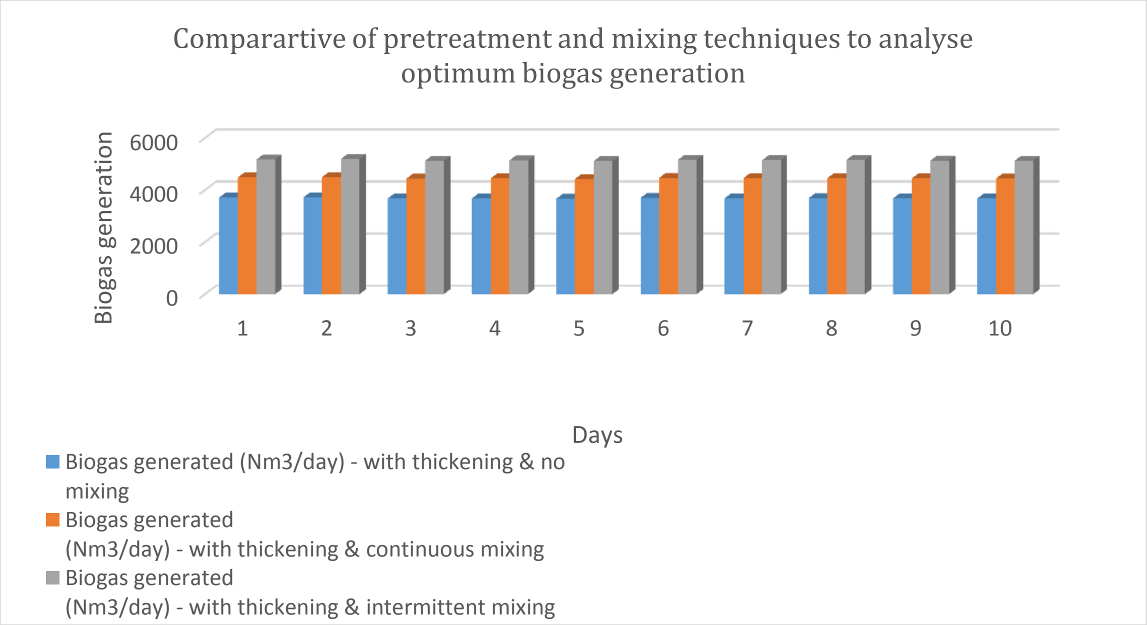
Day	Experiment-I		Experiment-II		Experiment-III	
	OLR (kg.VSS/m^3.day)	Biogas generated (Nm^3/day)	OLR (kg.VSS/m^3.day)	Biogas generated (Nm^3/day)	OLR (kg.VSS/m^3.day)	Biogas generated (Nm^3/day)
Day-1	1.85	5173	1.83	4991	1.86	4572
Day-2	1.86	5189	1.83	5006	1.87	4586
Day-3	1.83	5125	1.81	4944	1.84	4529
Day-4	1.84	5137	1.82	4956	1.85	4540
Day-5	1.83	5111	1.81	4931	1.84	4517
Day-6	1.84	5159	1.82	4977	1.86	4560
Day-7	1.84	5145	1.82	4964	1.85	4547
Day-8	1.84	5155	1.82	4973	1.86	4556
Day-9	1.84	5132	1.81	4951	1.85	4536
Day-10	1.83	5127	1.81	4946	1.85	4531
Average	**1.84**	**5146**	**1.818**	**4964**	**1.853**	**4548**

The impact of intermittent mixing for AD process is examined to determine the optimal biogas production in comparison to extent of savings in operational cost of digesters.

In a digester cycle of 4 hours, the break in mixing or settling time of 60 min, 75 min & 90 min is provided for Experiment I, II & III.

Sludge recirculation pumps (2 Working + 2 Standby) with bkW of 35kW and mechanical agitators (8 Working – 4 for each digester) with BkW of 5.5 kW. Total power consumption for 24 hour operation turns out to be 2736 kWh/day which in comparison to 1 hour settling over a digester cycle of 4 hours comes down to 2052 kWh/day.

With 25% power savings, optimum biogas generation is achieved during Experiment I.



Comparative of pre-treatment and mixing techniques to analyse optimum biogas generation

Conclusion

Anaerobic Digestion of primary sludge has been studied thoroughly during this project and following are the major conclusions: -

- For completely mixed anaerobic digesters, an OLR of 1.75 to 1.90 kg.VSS/m3.day shows maximum biogas generation. Due to a lack of raw sludge, biogas generation is restricted by a low OLR, while VSS escapes undigested at high OLR from digesters or the acetogenic process takes over methanogenic bacteria during high loading rate causing the digester to turn sour.

- Effect of pre-treatment of sludge (Gravity thickening) is noticed during this study which clearly shows the pretreatment of sludge positively affect the AD process. With thickening the same volume of sludge varies with different VSS concentration effecting the OLR considerably and finally leading to hamper the biogas generation. Biogas generation with thickening of raw sludge decreases the volume requirement of Anaerobic digesters.

- Sludge recirculation and mechanical agitation combined shows 17-18% increase in biogas production as compared to no mixing.

- Continuous mixing shows better biogas generation (4488 Nm3/day) as compared to no mixing (3686 Nm3/day), but the study for extent of mixing required to achieve the maximum biogas generation with respect to operation cost of mixing shows intermittent mixing increases biogas generation (5146 Nm3/day) and lowers the operational cost by upto 38%.

REFERENCES

Adekunle, K. F., & Okolie, J. A. (2015). A Review of Biochemical Process of Anaerobic Digestion. Advances in Bioscience and Biotechnology, 06(03), 205–212. https://doi.org/10.4236/abb.2015.63020

APHA. (1981). Standard Methods for the Examination of Water and Wastewater. American Public Health Association.

Bai, S., Srikantaswamy, S., & Shivakumar, D. (2010). Urban Wastewater Characteristic and its Management in Urban Areas—A Case Study of Mysore City, Karnataka, India. Journal of Water Resource and Protection, 02(08), 717–726. https://doi.org/10.4236/jwarp.2010.28082

Balasubramanian, M. (2018). Municipal solid waste management in India: Status, problems and challenges. International Journal of Environment and Waste Management, 21(4), 253–268. https://doi.org/10.1504/IJEWM.2018.093435

Bernard, S., & Gray, N. F. (2000). Aerobic digestion of pharmaceutical and domestic wastewater sludges at ambient temperature. Water Research, 34(3), 725–734. https://doi.org/10.1016/S0043-1354(99)00234-1