Grenze International Journal of Engineering and Technology, June Issue

Sustainable Management of Dairy Wastewater using Anaerobic Biological Processes

Monika Tiwari[1], Rajesh Bhagat[2], Sandeep Bodkhe[3] and Prajakta Waghe[4]
[1]Research Scholar, Yeshwantrao Chavan College of Engineering, Nagpur (YCCE), India
Email: tiwarimonika634@gmail.com
[2]Assistant Professor, Yeshwantrao Chavan College of Engineering, Nagpur (YCCE), India
[3]Chief Scientist, National Environmental Engineering Research Institute (NEERI), Nagpur, India
[4]Associate Professor, Yeshwantrao Chavan College of Engineering, Nagpur (YCCE), India

***Abstract*— This study presents a critical review of the dairy wastewater characteristics and evaluates applicability of anaerobic treatment process which helps in effective management. Wastewater generated from different dairy products exhibits significant variability in pollutant load, highlighting the need for adaptable and efficient treatment strategies. Among the available treatment methods, anaerobic biological processes are recognized as the most sustainable option due to organic matter removal capacity, energy required is low and renewable energy is produced. Upflow Anaerobic Sludge Blanket Reactors and Anaerobic Fluidized Bed Reactors have demonstrated COD and BOD removal efficiencies exceeding 90% under optimized operating conditions. Hybrid reactor shows COD removal efficiency 5% higher and increase in biogas production by 20% as compared with convection heated reactors. The study identifies the need for hybrid treatment systems, optimization of low-cost packing media, and improved biogas yield to improve efficiency of anaerobic treatment of wastewater produced by dairy industry.**

***Index Terms*— Dairy wastewater; Anaerobic digestion, Biogas production, Organic loading rate (OLR), Dairy effluent treatment, Hybrid reactors.**

I. INTRODUCTION

In the world, dairy industry accounts for high water consumption, generating high amount of wastewater which is directly discharged to aquatic ecosystem [1]. Various operations such as cleaning, manufacturing, heating, cooling, sanitizing are involved in dairy industry which increases wastewater volume [2]. The Dairy wastewater contains high BOD and COD, proteins, oil, fats, detergents, nutrients, lactose and sanitizing agent. Untreated wastewater from dairy industry are directly released into receiving water posing threat to human beings, aquatic lives and plants. Eutrophication is caused due to nutrients present in dairy wastewater which causes odor problems in receiving water [1]. Bacteria such as Salmonella and E. coli spread through contamination released by dairy wastewater affecting human health and animals [3]. There is large variation in characteristics of wastewater produced by dairy industry as given in table 1, selection of different process is important for effective treatment of dairy wastewater.[3]. Due to high cost of coagulant, large volume of sludge production and less efficient in removing COD, process of coagulation and sedimentation is not used. Therefore, biological treatment is generally used for treatment of wastewater produced by dairy Industry.[4]

Grenze ID: 01.GIJET.12.2.179_22

TABLE I: WASTEWATER CHARACTERISTICS PRODUCED BY DAIRY PRODUCTS OF DIFFERENT CATEGORY ([3]

Effluent Produced	pH	BOD (Biological Oxygen demand) in mg/l	COD (Chemical Oxygen Demand) in mg/l	FOG (Fats, Oil and Grease) in mg/l	TS (Total Solids) in mg/l	TSS (Total Suspended Solids) in mg/l	TN (Total Nitrogen) in mg/l	TP (Total Phosphorous) in mg/l
Mixed Dairy	3.38-12.08	240-5900	500-10400	20-1920	710-7000	60-5800	10-660	0-600
Milk	5-9.50	500-1300	950-2400	-	-	-	-	-
Cheese	3.38-9.50	590-5000	1000-63300	330-	2600	1920-53200	190-2500	18-830
Cheese whey	3.92-9.50	27000-60000	50000-102100	900-14000	55000-70900	1270-22150	200-1760	120-530
Whey	9-5	590-1210	1070-2180	-	-	80-440	-	-
Milk Permeate	5.55-6.52	-	52940-57460	-	11610-15390	300-450	300-450	2500
Ice-cream	5.10-6.96	2450	5200	-	3900	3100	-	14
Butter	12.08	220-2650	8930	2880	-	700-5070	-	-
Washing Wastewater	10.37	3470	14640	3110	-	3820	-	-

There is large variation in characteristics of wastewater produced by dairy industry as given in table 1, selection of different process is important for effective treatment of dairy wastewater.[3]. Due to high cost of coagulant, large volume of sludge production and less efficient in removing COD, process of coagulation and sedimentation is not used. Therefore, biological treatment is generally used for treatment of wastewater produced by dairy Industry.[4]

A. Dairy Wastewater Characteristics

In dairy Industry, various products are made from raw milk such as butter, sour and pasteurised milk, cheese, creams, yoghurts are made from raw milk. Dairy wastewater has high COD and BOD concentration as compared with other agro-industries which becomes the problem to water source where wastewater is discharged. Cheese whey is most important waste product because of its high generated volume and high COD and BOD content. [5].

Wastewater of dairy industry does not contain any chemical which is toxic in nature. It comprises of lactose, whey proteins, fats, nutrients which causes bad odours during degradation stage.[2]. Carbohydrates and protein in high proportion are present in effluent in manufacturing process of cheese and lipid is present during ghee manufacturing process.[2]. Dairy Industry wastewater mainly contains lactose and less biodegradable proteins and lipids. Lactose, lactate, protein and fat in cheese wastewater contributes to 97.7% of total COD.[4].Dairy wastewater is highly polluted due to high COD Content.[6][4].Milk and milk products mainly contains organic compounds in dairy wastewater. Nitrogen is mainly present in organic as well as ionic form in milk products [4].Phosphorous are present in organic as well as inorganic form like orthophosphate and Polyphosphate .Coagulated milk, cheese curd and flavouring ingredients contains suspended solids such as sodium, potassium, calcium, Magnesium, iron , cobalt and nickel .[4]. In milk and dairy effluent composition ,major protein is Casien .Fast degradation of Casien occurs in anaerobic reactors and products of degradation are non-inhibitory in nature .[6].

Lipids compounds are inhibitory which causes difficulties in anaerobic treatment process. Degradation of lipids results in glycerol and LCFAs (long fatty acids) followed by beta oxidation which produces hydrogen and acetate. Glycerol was found to be non-inhibitory compound while LCFAs are inhibitory to methanogenic bacteria. Presence of LCFAs postpones production of methane .[6].Colour of dairy wastewater is white or Yellow . Milk is alkaline in nature but during the process of fermentation it becomes acidic by which lactic acid is formed from lactose .[2].

Water pollution due to dairy effluent is one of the major cause for water pollution due to large amount of organic matter present which source of food for micro-organisms.[2]. Dairy wastewater mainly generates due to storage and processing as well as cleaning operations. During the process of milk cooling, generation of milk processing contains milk droplets and whey droplets. This requires minimum treatment and can be discharged along with stormwater. Cleaning wastewater is highly polluted due to equipment cleaning , milk and whey spillage cleaning which requires further treatment .Shower and Toilets generates Sanitary wastewater having composition similar to municipal wastewater contains good nitrogen source which can be used for stabilization of nutrient .[5].Dairy wastewater has different variation in characteristics, the selection of appropriate methods is important for achieving effective treatment [3].

II. METHODOLOGY

A. Anaerobic Methods of Dairy Wastewater

Aerobic treatment method utilizes high energy due to aeration which is less efficient for the growth of micro-organisms.[2] and odour problem and sludge disposal are major drawback of aerobic treatment process.[7].Anaerobic treatment is an effective method for the degradation of organic content in absence of oxygen which reduces waste and helps in controlling the pollution .When compared with aerobic process this process is best considered by different researchers. Acidogenic and methanogenic bacteria are generally involved in anaerobic process having varieties of environmental conditions. Through this process, renewable energy can be produced which has attained high relevance .[2].Anaerobic treatment process is best method due to simple as compared to other treatment method, low cost and have higher energy efficiency .[8] which is beneficial in generating income and reduces greenhouse gas emissions .[9].

III. RESULTS AND DISCUSSION

A. Anaerobic Filter (AFs)

As per literature, Anaerobic filters are mainly used process for the treatment of dairy wastewater having low strength. It consists of two filtration chambers and degradation of organic material takes place by biomass which helps in efficient solid removal. Selection of proper packing media is important because it has critical effect on performance of reactor .Anaerobic filter diagram is shown in figure 1.[2] [4] [10]. Different packing material can be used such as seashell , charcoal , plastic materials , polymers , stones , granular activated carbon and quartz.[10].Packing material holds the micro-organisms which are present in the voids which helps in treating high organic loading rate (OLR) wastewater.[2].Studies shows dairy wastewater treatment using AFs reduces 90% COD but removal rate of Fat, oil and grease (F.O.G) is low upto 47%.Addition of SBR helps in removing 99% FOG .[3]

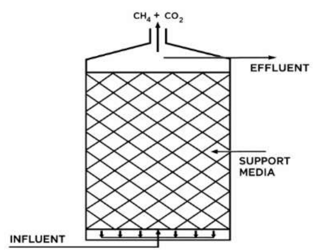

Figure 1: Anaerobic Filter with packaging material

B. Up-Flow Anaerobic Sludge Blanket Reactor (UASBRs)

In Dairy wastewater treatment, UASBRs are mostly used. In this reactor, bottom part is packed with anaerobic sludge granules through which wastewater is passed. From the top part , treated effluent is extracted and methane gas is separated from the vent pipefrom top.[3]. According to literature review , Plastic materials are more effective packing media when compared with other materials .[11].UASBRs is shown in figure 2. Studies shows that UASB reactor reduces the amount of BOD and COD with the increase level of pH and total Solids. [11].

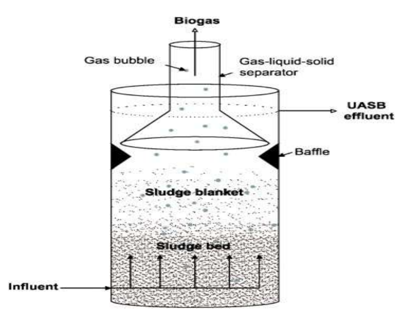

Figure 2. Upflow Anaerobic Sludge Blanket Reactor (UASBRs)with vent pipe (Siewhui Chong, Tushar Kanti Sen, Ahmet Kayaalp, Ha Ming Ang, 2012)

UASB technology is highly efficient in treatment having COD content upto 40000 mg/l .96.3% of COD reduction was achieved at hydraulic retention time(HRT) of 3 h.[3]. As shown in Figure 3 below Biogas production has been increased with the increase in OLR.[12]

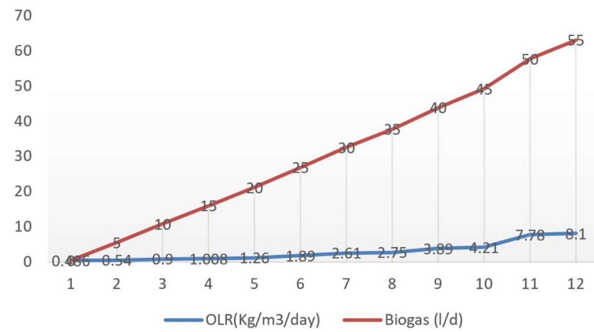

Figure 3. Biogas production vs OLR

C. Continuous Stirred Tank Reactor

Due to Limitation in HRT this reactor is widely practiced on lab scale but not used in Industry. For the high production of methane and decomposition of organic matter , studies has been done on this reactor.[2].CSTR are efficient in treating diluted dairy wastewater containing suspended solids and COD values above 30,000 mg/L.[14]. Mixed system is a good option, CSTR combine with Anaerobic baffled reactor (ABR) removes 82% COD with a biogas production of 0.26m3/Kg.[1].Conditions of parameters is given in table II below[2].

TABLE II: CONDITIONS OF REACTOR WHILE PERFORMING EXPERIMENT

Wastewater Type	Volume of Reactor (L)	pH	Temperature (degree celsius)	HRT (days)	(OLR)
Wastewater containing cheese whey	6	7	55	10	0.95kg/m^3/day
Cheese whey	25	-	35	18	4.9g/L/Day
Cheese whey and Dairy manure	26.6				
-	34	10	-		
Solid waste of dairy Industry	-	5.5	37	6	-

D. Anaerobic fluidized bed reactors (AFBR)

AFBR can treat wastewater with high organic loading rate (OLR). The fluidized bed reactor has attached biomass which helps to treat wastewater in small HRT and it has high mass transfer characteristics .In this reactor , microbes are attach to support media through which effluent is pass .Support media such as pieces of charcoal, sand and clay particles, glass beads, plastic granules.[2]. The support media remains continuous in suspension mode with the liquid recirculation.[4]. Due to improvement in mass and heat exchange rates and equal recirculation of liquid , this reactor has capacity to handle high solid content. Reactor avoids the biological film thickness and no channeling and plugging occurs.[4].84% of COD removal achieved from 35kg/m3 /day by using support media as perlite having excellent biomass attachment .High power requirement, lengthy start-up time is some disadvantages of this reactor.[2]. AFBR figure is shown below.

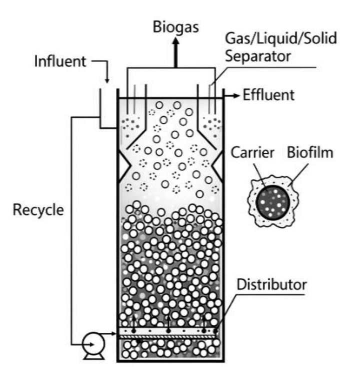

Figure 3: Anaerobic Fluidized bed reactor with support media (https://www.ever-clear.com.tw/en/capability/detail-a)

E. Anaerobic Packed bed digesters (APBR)

APBR is similar to trickling filter containing support material in the biofilm form consists of porus materials such as ash, zeolite, small pieces of wooden, micro-organisms, polymers, plastics which remain in tight contact with effluent. APBR works in upflow or downflow mode.This reactor is efficient and used widely for the treatment of dairy effluent as it has ability to hold biomass which increases contact between biomass and wastewater results in generation of biogas.[2].A lab scale study was carried by APBR uses polypropylene pall rings at OLR and HRT of 12 h and 5.4 kg/m3/day results in COD removal of 87%.APBR can operate at temperature (22-26 degree celsius) and HRT of 3 days.[2]. Study suggests two upflow anaerobic packed bed reactors (UAPBR) is highly feasible in treating cheese whey with a COD removal of 94-96%.APBR is shown in figure 4 [2].

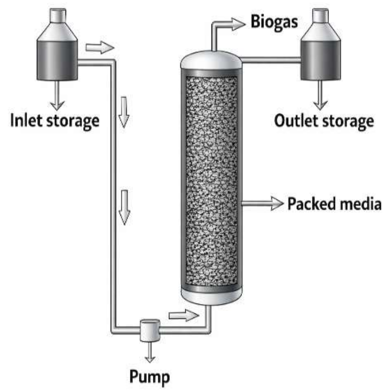

Figure 4: Anaerobic Packed bed digester with support media

IV. RESEARCH GAP

There is a lack of comprehensive research on hybrid anaerobic systems (e.g., AF–SBR, UASB–APBR combinations) to improve overall treatment efficiency, especially for FOG and nutrient removal. Combination of process is feasible for treatment of Dairy wastewater. Although various packing materials have been tested, comparative studies on low-cost, locally available, and sustainable media for AFs and APBRs are limited, especially under real industrial conditions. Anaerobic systems primarily target organic matter removal, while nitrogen and phosphorus removal remains insufficient. Integrated nutrient recovery or post-treatment options are underexplored. Although biogas generation is a major advantage, optimization of methane yield, biogas quality, and energy balance has not been adequately addressed in existing studies.

V. CONCLUSION

Anaerobic biological treatment method is an environmentally friendly solution for the treatment of dairy wastewater. UASB are most extensively used for treatment of dairy wastewater as they can treat high volume of wastewater in a short time. Among these technologies, UASBRs and packed-bed systems have shown particularly promising performance in treating high-strength dairy effluents, achieving COD removal efficiencies exceeding 90% under optimized operating conditions. UASB integrated with AFBR is a good technology when space required is less. To lower cost of operation, different research is required which helps in reducing the environmental impact.

REFERENCES

[1] K. Zhao, Y. W. Wu, S. Young, and X. J. Chen, “Biological Treatment of Dairy Wastewater: A Mini Review,” J. Environ. Informatics Lett., vol. 4, no. 1, pp. 22–31, 2020, doi: 10.3808/jeil.202000036.

[2] G. Janet Joshiba, P. Senthil Kumar, C. C. Femina, E. Jayashree, R. Racchana, and S. Sivanesan, “Critical review on biological treatment strategies of dairy wastewater,” Desalin. Water Treat., vol. 160, pp. 94–109, 2019, doi: 10.5004/dwt.2019.24194.

[3] J. Ramsuroop, L. Gutu, W. B. Ayinde, M. Basitere, and M. S. Manono, “A Review of Biological Processes for Dairy Wastewater Treatment and the Effect of Physical Parameters Which Affect Their Efficiency,” Water (Switzerland), vol. 16, no. 4, 2024, doi: 10.3390/w16040537.

[4] A. Goli, A. Shamiri, S. Khosroyar, A. Talaiekhozani, R. Sanaye, and K. Azizi, “A review on different aerobic and anaerobic treatment methods in dairy industry wastewater,” J. Environ. Treat. Tech., vol. 7, no. 1, pp. 113–141, 2019.
[5] G. Smetana and A. Grosser, “The Application of an Upflow Anaerobic Sludge Blanket Reactor in the Treatment of Brewery and Dairy Wastewater: A Critical Review,” Energies, vol. 17, no. 6, 2024, doi: 10.3390/en17061504.
[6] B. Demirel, O. Yenigun, and T. T. Onay, “Anaerobic treatment of dairy wastewaters: A review,” Process Biochem., vol. 40, no. 8, pp. 2583–2595, 2005, doi: 10.1016/j.procbio.2004.12.015.
[7] A. N. Al-Tayawi, E. J. Sisay, S. Beszédes, and S. Kertész, “Wastewater Treatment in the Dairy Industry from Classical Treatment to Promising Technologies: An Overview,” Processes, vol. 11, no. 7, pp. 1–15, 2023, doi: 10.3390/pr11072133.
[8] P. S. Arunadevi and M. Saravanaraja, “Two Phase Upflow Anaerobic Sludge Blanket (Uasb) Reactor on the Reduction of Chemical Oxygen Demand in Dairy Effluent,” Orig. Res. Artic. Asian J. Adv. Res., vol. 3, no. 1, pp. 86–94, 2020.
[9] Y. Nleya, B. Young, E. Nooraee, and S. Baroutian, “Opportunities and Challenges for Anaerobic Digestion of Farm Dairy Effluent,” ChemBioEng Rev., vol. 10, no. 6, pp. 924–940, 2023, doi: 10.1002/cben.202300021.
[10] S. R. Hassan, H. M. Zwain, and I. Dahlan, “Review Article Development of Anaerobic Reactor for Industrial Wastewater Treatment : An Overview , Present Stage and Future Prospects,” vol. 4, no. 1, pp. 7–12, 2013.
[11] A. S. Tanksali, “Treatment of sugar industry wastewater by upflow anaerobic sludge blanket reactor,” Int. J. ChemTech Res., vol. 5, no. 3, pp. 1246–1253, 2013.
[12] I. Factor- and C. K. K. Reddy, “G Lobal J Ournal of E Ngineering S Cience and R Esearches Design and Implementation of a Web-Based Hospital,” vol. 5, no. C, pp. 301–308, 2019, doi: 10.5281/zenodo.1320963.
[13] Siewhui Chong, Tushar Kanti Sen, Ahmet Kayaalp, Ha Ming Ang, “The performance enhancements of upflow anaerobic sludge blanket (UASB) reactors for domestic sludge treatment – A State-of-the-art review,” Water Environ. Res., 2012.
[14] P. Singh, S. S. Mohanty, and K. Mohanty, “Comprehensive assessment of microalgal-based treatment processes for dairy wastewater,” Front. Bioeng. Biotechnol., vol. 12, no. August, pp. 1–31, 2024, doi: 10.3389/fbioe.2024.1425933.