Efficacy of UASB /MBBR in Reducing the Organic Content of Dairy Wastewater: An Investigation

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ABSTRACT
Aim: The objective of this research is to compare between two secondary treatment reactors such as UASB (Upflow Anaerobic Sequencing Batch) and MBBR (Moving Bed Biofilm Reactor) to enhance the quality of the dairy effluents from various dairy processing industries. **Materials and methods:** To conduct this study two attached growth processes reactors such as MBBR and UASB were compared for their BOD_5 (Biological Oxygen Demand) removal efficacy of various dairy effluents such as mixed dairy, cheese, cheese whey, milk permeate, butter, dairy sewage, ice cream for a period of 5 consecutive days. Test samples (N = 14) were taken from the outfall of the experimental group (UASB) and control group (MBBR) using G Power software. G power is taken as 0.8. **Result:** The simulation indicated that UASB showed a higher BOD_5 removal efficiency of 99% when compared to the BOD_5 removal efficacy of MBBR of 87%, the cost and power consumed for UASB was $2050.26, 91.5 kW and that of MBBR $2986.17, 105.72 kW. The significance value is determined as 0.04 (p is less than 0.05, statistically significant) based on SPSS analysis. **Conclusion:** The above analysis concluded that UASB not only treated dairy wastewater effluents having different Organic Loading Rate (OLR) with higher efficiency but with lesser power consumption and cost than that of MBBR, MBBR treated ice cream having low OLR with a lower efficacy and UASB treated cheese[Citation error] whey with the highest efficacy.
Keywords: Biological Oxygen Demand, Innovative Upflow Anaerobic Sequencing Batch Reactor, Dairy wastewater, Attached growth process, Moving Bed Biofilm Reactor, Organic content, Secondary treatment, Wastewater treatment.

INTRODUCTION

Pollution is the after effect of production (van der Ploeg, de Zeeuw, and Brabant 1990), one of the main pollutants released from the dairy processing industry is casein, which is the precipitate formed due to the decomposition of dairy sewage (Tikariha and Sahu 2014). A portion of the adverse consequences on sea-going life forms are immunosuppression, decreased digestion, and harm to gills and epithelia. Hence it is necessary to treat the polluted water before it is being discharged into the surface water bodies. The aim of this research is to compare two attached growth process reactors such as innovative Upflow Anaerobic Sequencing Batch Reactor and MBBR to reduce the organic content such as BOD_5 of different dairy effluents such as mixed dairy, cheese, cheese whey, milk permeate, butter, dairy sewage, ice cream and the treated effluent should comply under the government norms of $BOD_5<50$ g/m^3[Citation error]. The importance of the research is to treat dairy wastewater using two attached growth process reactors namely UASB and MBBR, both reactors replace the conventional activated sludge process [Citation error]. Some of the applications of the innovative Upflow Anaerobic Sequencing Batch Reactor are enhancing the biohydrogen production using Clostridium LS2, which can help to replace fossil fuels, as they do not discharge greenhouse gases such as carbon dioxide [Citation error]. Applications of MBBR include, when inoculated with the novel bacterium Corynebacterium pollutisoli SPH6 helped increase the Total Nitrogen removal efficiency of the reactor by an additional 20%, other microbes that can be used to reduce the TN are Hydrogenophaga, Desulfuromonas, and Desulfomicrobium (Liu, Wang, and Pang 2018).

More than 1565 articles were published in Google scholar, Springer and Science Direct in the past 5 years. Google Scholar published 640 journals, Springer had 577 articles and Science Direct showed 348 articles. The findings of the most cited paper are;The advantages and desirable features of UASB are as follows, when mixed liquor and glucose was fed into an UASB at an organic loading rate of 6.2 gCOD/l d the reactor produced a minimum efficiency of 97%, but concentrations above 7.5 gCOD l/d were found to be less safe for COD concentrations above 42 g/l conventional reactors were found to be more useful [Citation error]. When the UASB reactor was given a volume of 120.12m^3 effluent and the OLR varied at different dosages ranging from 0.19g/m^3 /d - 3.84g/m^3/d, the reactor achieved a COD removal efficiency of 87% and a BOD_5 removal efficiency of 94% (Gotmare, Dhoble, and Pittule 2011).The advantages of using MBBR are, as the OLR rates of MBBR was varied and the filling ratio was kept at 40% the reactor showed to be stable, this allowed a reduction time of HRT from 8h to 4h reaching a COD removal efficiency of 95% [Citation error]. MBBR followed by an activated sludge oxidation process resulted in the removal of 97% of COD and 99% of greases, and had a significant residual capacity (Slavov 2017). The most cited article is [Citation error] Combined UASB and MBBR reactor was studied for which aerobic ammonium oxidising bacteria (AOB) and nitrite oxidising bacteria (NOB) were compared for a period of 5, 16 months. It was obvious that the diminishing of influent ammonium concentration led to a reduction of suspended biomass which had a significant commitment to nitrite production.Previously our team has a rich experience in working on various research projects across multiple disciplines(Sathish et al. 2020; Pandurangan, Veeraiyan, and Nesappan 2020)

The unanswered problem in previous research was that there was not enough comparison being made between UASB and MBBR for the BOD_5 removal efficacy for various dairy wastewater effluent concentrations. The research focused on a single reactor's organic content removal efficiency operating at different conditions. The objective of this study is to compare between two attached growth process reactors such as UASB and MBBR to evaluate the BOD_5 removal efficacy of different dairy wastewater effluents.

MATERIALS AND METHODS

The above study was conducted at the Environmental Engineering lab, Department of Energy and Environmental Engineering, Saveetha Institute of Medical and Technical Sciences. To conduct the study two groups, the innovative Upflow Anaerobic Sequencing Batch Reactor and MBBR were taken, the sample size of each group was calculated by keeping threshold alpha 0.05%, g power as 80% confidence interval as 95% and enrollment ratio as 1. According to the above input the sample size is 7, hence the total sample size is 14. The different samples considered in this study are mixed dairy, cheese, cheese whey, milk permeate, butter, dairy sewage and ice cream[Citation error]. Using GPSx 8.0. Software concentration of BOD_5 at the outfall unit was calculated.

The sample preparation of group 1 was done by analysing various dairy wastewater parameters using the GPSx software to test the BOD_5 treatment efficiency of the UASB reactor. Group 2 was done by analysing various dairy wastewater parameters using the GPSx software to test the BOD_5 treatment efficiency of the MBBR.The input values were taken from (Slavov 2017) and (Tikariha and Sahu 2014). Table 1 depicts the different dairy effluents such as mixed dairy, cheese, cheese whey, milk permeates, butter, dairy sewage, ice cream. Table 2 depicts the general input values that are common for all the parameters. Other values such as organic fractions, phosphorus fractions, organic fractions, inorganic precipitates and soluble gases were maintained at 0 and the simulation was run for a period of 5 days.

Upflow Anaerobic Sequencing Batch Reactor

The first sample group preparation was run with the innovative Upflow Anaerobic Sequencing Batch Reactor reactor. The independent parameters given to the simulation are various types of dairy wastewater and the dependent parameter is BOD_5 (Biological Oxygen Demand) in the wastewater. The plant layout was made similar to most of the conventional wastewater treatment units as shown in Fig. 1. Raw wastewater enters the treatment unit and is then passed to the equalisation tank, primary clarifier, UASB and secondary clarifier. The sludge from the previous three reactors are then sent to the dewatering unit. Treated water from the secondary clarifier and dewatering unit is passed for chemical disinfection. The purified wastewater is then discharged through the outfall pipe. UASB (Up-Flow Anaerobic Sludge Blanket) reactor uses anaerobic digestion to convert the dissolved organic matter into settle-able biomass. The effluent to be treated is given at the lower part of the reactor where the organisms in the sludge bed consumes the biodegradable organic matter which later settles to the bottom as sludge, this sludge is dewatered for further use. Since UASB employs anaerobic treatment processes, methane gases are also produced (Wu 1995). The physical and operational conditions for UASB is as follows maximum volume: $400m^3$; headspace volume: $20m^3$; height of volume 15m; height to diameter ratio: 1.5; total gas pressure: 1 atm; temperature: 35°C; average granule size: 0.002 rth; water content in granule 90%, depth of transition zone: 0.5m terminal setting velocity reduction factor: 0.8.

Moving Bed Biofilm Reactor

The second sample group preparation was run with the MBBR reactor. The independent parameters given to the simulation are various types of dairy wastewater and the dependent parameter is BOD_5 (Biological Oxygen Demand) in the wastewater. The plant layout was made similar to most of the conventional wastewater treatment units as shown in Fig 2. Raw wastewater enters the treatment unit and is then passed to the equalisation tank, primary clarifier, MBBR and secondary clarifier. The sludge from the previous three reactors are then sent to the dewatering unit. Treated water from the secondary clarifier and dewatering unit is passed for chemical disinfection. The purified wastewater is then discharged through the outfall pipe.MBBR (Moving Bed Biofilm Reactor) uses high density plastic such as polyethylene, the microorganisms grow and digest the organic matter present in the effluent water to biomass, this biomass attaches onto the media, due to the lack of oxygen at the inner portion of the media and continuous agitation it breaks off from the media and settles at the bottom of the reactor which can then be dewatered and used for future purposes. MBBR is used mainly for the treatment of milk and yoghurt effluents (Boyle 2019). The physical and operational conditions for MBBR is tanks in series: 4; tank depth: 4m; maximum volume: $1000m^3$; specific surface of media: 500 1/m; specific density of media: 940000 mg/l; water displaced by media: 0.18.pump efficiency: 0.7; static head: 1.0m, combined blower/ motor efficiency: 0.7.

Statistical Analysis

Statistical Package for the Social Sciences (SPSS) is a complex statistical data analysis software which is used to compare between the existing group and the proposed groups efficiency to determine the significance value. The significance value should be less than 0.05 for the real time implementation of the proposed reactor. The SPSS (v.26) software is utilised for the statistical investigations of UASB and MBBR reactors. The independent variable is various types of dairy wastewater and the dependent variable is BOD_5. Two independent group analysis tests are done to work out the BOD5 removal efficiency for both the strategies.

RESULT

Table 3 indicates that UASB showed greater reactor performance by having a higher BOD_5 removal efficacy of 99% on the other hand MBBR showed 87% BOD_5 removal efficacy for the treatment of various dairy effluents. Table 4 illustrates the standard deviation and significance difference of UASB and MBBR. These were utilised to determine whether the method produces substantial results in SPSS. Table 5 shows the independent sample test for UASB and MBBR. UASB: t value and mean difference 3.078 and 12.35 and for MBBR: t value and mean difference 3.078 and 12.35. The quality significance variation among the two groups is 0.04 ($p < 0.05$, statistically significant).

Fig. 1 displays the process flow diagram employed in the treatment of dairy wastewater operating with a UASB reactor. Fig. 2 illustrates the process Flow diagram employed in the treatment of dairy wastewater operating with the MBBR reactor. Fig. 3 shows the Sankey diagram depicting the rate flow of dairy wastewater through each component for the treatment plant employing UASB reactor. Fig. 4 displays the Sankey diagram depicting the rate flow of dairy wastewater through each component for the treatment plant employing MBBR reactor. Fig. 5 displays the total Power in kW for the operation of the treatment plant employing UASB reactor. Fig. 6 shows the total Power in kW for the operation of the treatment plant employing MBBR reactor. Fig. 7 illustrates the pie chart depicting the total cost acquired for the treatment plant employing UASB reactor. Fig. 8 shows the pie chart depicting the total cost acquired for the treatment plant employing MBBR reactor. Fig. 9 gives the comparison of UASB and MBBR in terms of mean BOD_5 reduction efficiency. The mean efficiency of UASB is slightly higher than MBBR..

DISCUSSION

The efficiency of treating various dairy wastewater of different strengths such as mixed dairy, cheese, cheese whey, milk permeate, butter, dairy sewage, ice cream were calculated for both the reactors. The parameter used to compare both the reactors is BOD_5, it indicates the amount of oxygen required by the microorganisms to digest the sludge and convert dissolved organic matter into biodegradable biomass. Table 3 depicts the average BOD_5 collected at the output for a period of 5 days as well as the efficiency of the plant in treating the wastewater. The BOD_5 removal efficacy of the treatment plant employing UASB reactor was summed up to be 99.77% and the same for the treatment plant employing MBBR reactor is 87.41%. UASB treated cheese whey having its initial BOD_5 concentration as 29,580g/m^3 with a 100% efficiency, in real time application no reactor was proved to produce results of such high efficacy, which portrayed that UASB is efficient at treating high organic loads. Generally, when the concentrations of COD exceeded 1000 mg/l MBBR showed a reduced treatment efficacy but in this study, the result from GPSx showed that MBBR was efficient at treating loads above 4,000g/m^3 and less efficient at loads below 1500g/m^3 . The study conducted by (Tawfik, Sobhey, and Badawy 2008) UASB showed a reduced efficacy of 69% for higher loads, this value contradicts the findings by us. In this work, the removal efficacy of BOD_5 was found to be higher for USAB than MBBR. The rate of flow of effluents at the input was maintained at 4500m^3/d, UASB has a reactor volume of 400m^3 thus the rate of flow of effluent entering and leaving the reactor was 1130m^3/d and 3710m^3/d while MBBR had a reactor volume of 1000m^3 and the rate of effluent entering and leaving the MBBR reactor was 6173m^3/d and 9466m^3/d, this is depicted using the Sankey diagram as shown in Fig. 3 and Fig. 4. Comparative studies were also done for the power consumption of both the reactors. Fig. 5 and Fig. 6 depicts the power consumed by each process. It was found that UASB consumed comparatively lesser power of 91.5 kW power than that of MBBR which consumed 105.72 kW of power. Thus, the total cost for UASB plant layout is $2050.26 which is much lower than MBBR whose plant layout cost $2986.17 is depicted in Fig. 7 and Fig. 8. Table 4 and Table 5 represents the independent sample test for UASB and MBBR reactors, both the reactors showed a t value and mean difference of: 3.78, 12.35. There is a significance between the two groups since $p<0.05$**.**

The derived results agree with the findings of other research papers such that aerobic process is used for the treatment of low strength effluents having COD less than 1000mg/l while anaerobic process can be used to treat highly polluted effluents having COD more than 4000 mg/l (Gotmare, Dhoble, and Pittule 2011). When comparing the efficiency of leachate treatment by MBBR and UASB reactors, UASB reactors showed better performance at treating newly formed leachate than MBBR [Citation error]. Higher volumes of biogas were produced when the concentration of COD was maintained at 1600 mg/L. Similarly 89 % of COD reduction efficacy was observed in UASB reactors when compared to MBBR whose reduction efficiency was only 80% [Citation error]. Opposing results were obtained and are mentioned as follows, when wastewater from Sao Thai Duong Pharmaceuticals has high concentrations of BOD and COD and the BOD/COD ratio being 0.3. The BOD_5 removal efficiency of MBBR and UASB was studied for which MBBR (85-90%) treated wastewaters with a higher treatment efficiency than UASB (60-65%) [Citation error]. For a full scale UASB reactor the removal percentage of COD was just 70% yet that of MBBR on a half order kinetics was of 80% as UASB are reasonable for treatment of overloaded effluents with COD higher than 42 g/L (Falletti et al. 2015).

Limitations of this study include the fact that there might be differences in efficiency of the output derived using the software and the real life implementation of the plant. Future scope of this study aims at comparing the innovative Upflow Anaerobic Sequencing Batch Reactor with other anaerobic reactors that treat dairy effluent effectively.

CONCLUSION

The above analysis portrayed that UASB proved to have a higher BOD_5 removal efficacy of 99% than MBBR having 87% removal efficacy for the treatment of wastewater from various dairy processing industries. UASB also utilised less power than MBBR and thus it is a cost efficient approach for wastewater treatment. Based on the independent T test the significance value is 0.04 ($p < 0.05$) statistically significant within the limit of study.

DECLARATION

Conflict of interests

No conflict of interest in this manuscript.

Author Contributions

Author AJ was involved in data collection, data analysis, and manuscript writing. Author AM was involved in data validation and review of manuscripts.

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TABLES AND FIGURES

Table 1. Concentration of BOD_5, COD, TN, TP and pH of various dairy waste water effluents in g/m^3 except for pH

Parameters	BOD_5 (g/m^3)	COD (g/m^3)	TN (g/m^3)	TP (g/m^3)	pH
Mixed dairy	240	104000	660	600	11
Cheese	5000	63300	830	280	9.5
Cheese whey	60000	102000	1760	530	6.5
Milk permeates	5900	57460	400	450	6.25
Butter	2650	8930	220	300	12
Dairy sewage	3215	4958	79.6	18	7.3
Ice cream	2450	5200	2	14	6.9

Table 2. Concentration of chemical parameters of dairy wastewater effluent in g/m^3 of the effluent dairy wastewater

Parameter	Concentration (g/m^3)
Ammonia nitrogen	2.1
Nitrite	0.0375
Nitrate	10.24
Orthophosphate	2
Calcium	40.4
Magnesium	10.1
Potassium	5
DO	0.38

Table 3. Output concentration of BOD_5 of the treated wastewater in g/m^3 and its resultant efficiency for UASB and MBBR reactors respectively. The average BOD_5 reduction efficiency of UASB reactor is 99% and that of MBBR reactor is 87%

Parameters	UASB Output (g/m^3)	UASB Efficiency (%)	MBBR Output (g/m^3)	MBBR Efficiency (%)
Mixed dairy	2.69	99.91	300.67	90.03
Cheese	3.35	99.98	1779.32	90.30
Cheese whey	0.000000384	100	2710.49	90.83
Milk permeate	2.330	99.98	1659.36	90.04
Butter	2.79	99.89	187.79	92.74
Dairy sewage	14.27	99.86	183.00	94.30
Ice cream	18.66	98.76	548.54	63.62
Overall Efficiency		99.77		87.41

Table 4. Mean Output Voltage, Standard Deviation and Standard error values are obtained for 14 sample data sets. When compared treatment plant employing UASB reactor has better performance than the treatment plant employing MBBR reactor

	Group	N	Mean	Std. Deviation	Std. Error Mean
Efficiency	UASB	7	99.77151	0.447857	0.169274
	MBBR	7	87.41365	10.612361	4.011095

Table 5. Independent sample T-test t is performed for the two groups for significance and standard error determination. Since the value of significance is 0.04 ($p < 0.05$) which is considered to be statistically significant.

Levene's Test for Equality of Variances				**t-test for Equality of Means**						
		f	**sig**	**t**	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**95% Confidence Interval of the Difference**	
									LOWER	**UPPER**
Efficiency	**Equal variances assumed**	5.04	0.04	3.07	12	0.01	12.35	4.01	3.61	21.10
	Equal variances not assumed			3.07	6.02	0.02	12.35	4.01	2.54	22.17

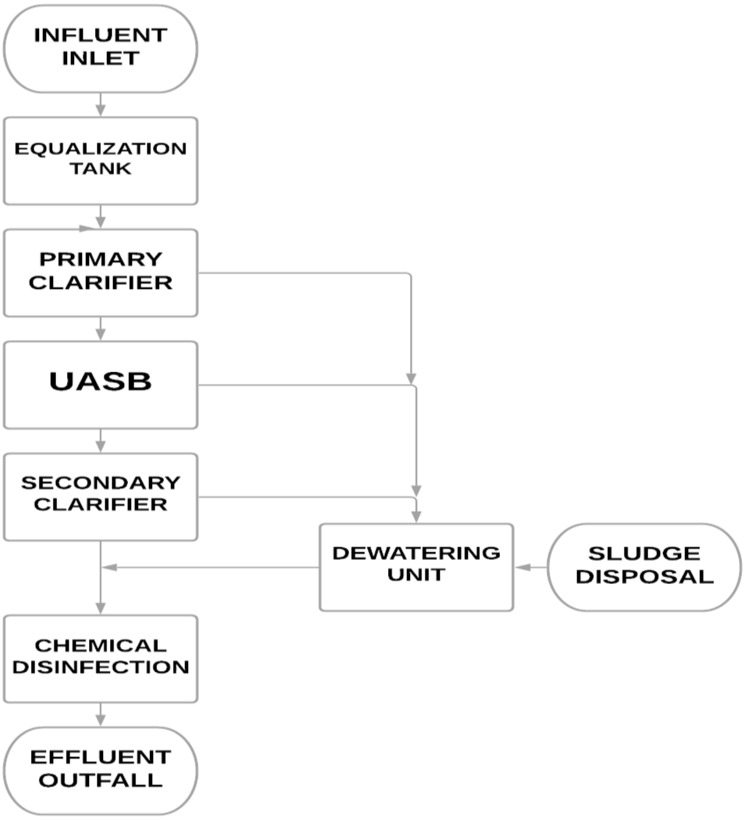

Fig. 1. Process Flow diagram employed in the treatment of dairy wastewater operating with UASB reactor

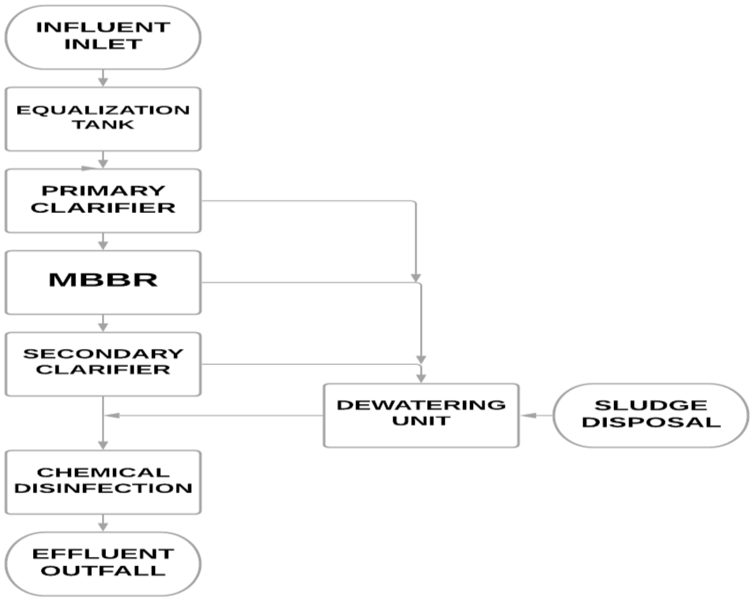

Fig. 2. Process Flow diagram employed in the treatment of dairy wastewater operating with MBBR reactor

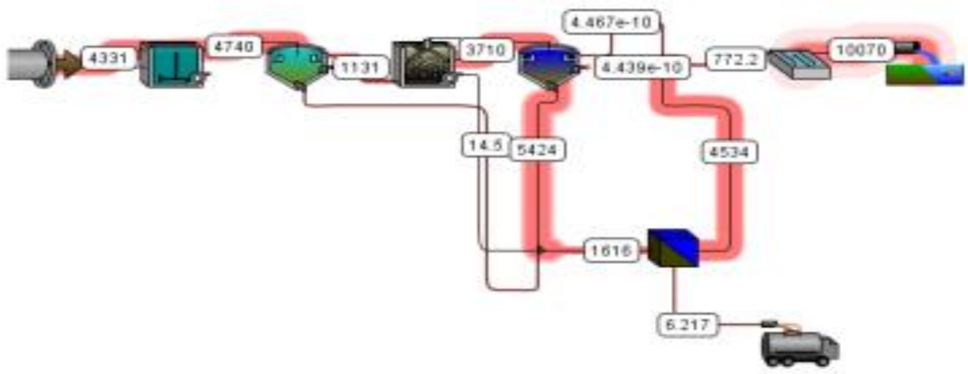

Fig. 3. The Sankey diagram depicts the rate flow of dairy wastewater through each component for the treatment plant employing UASB reactor

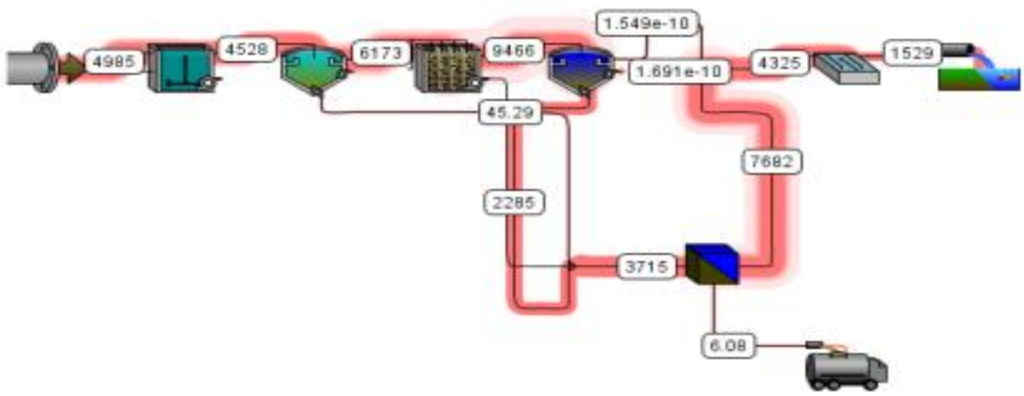

Fig. 4. The Sankey diagram depicts the rate flow of dairy wastewater through each component for the treatment plant employing MBBR reactor

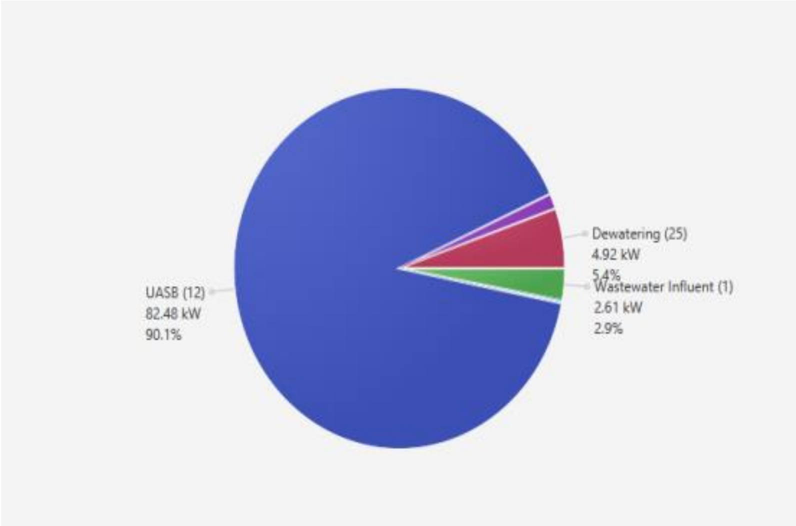

Fig. 5. Total Power in kW for the operation of the treatment plant employing UASB reactor

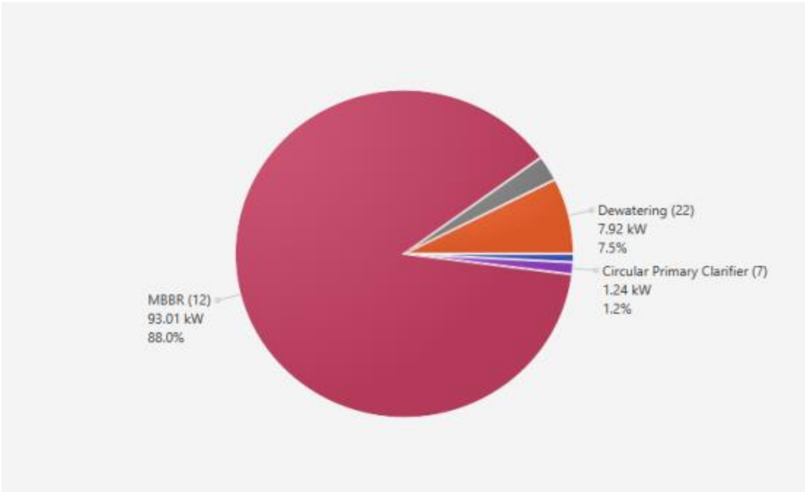

Fig. 6. Total power in kW for the operation of the treatment plant employing UASB reactor

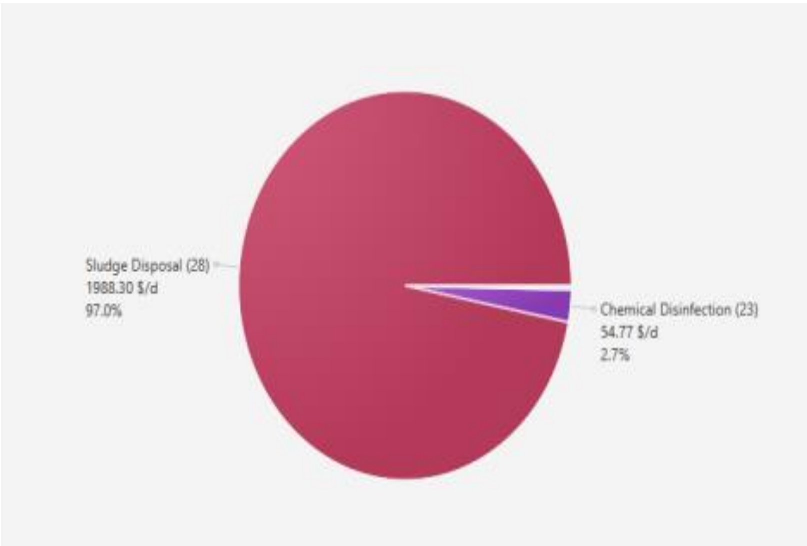

Fig. 7. Pie chart depicting the total cost acquired for the treatment plant employing UASB

reactor

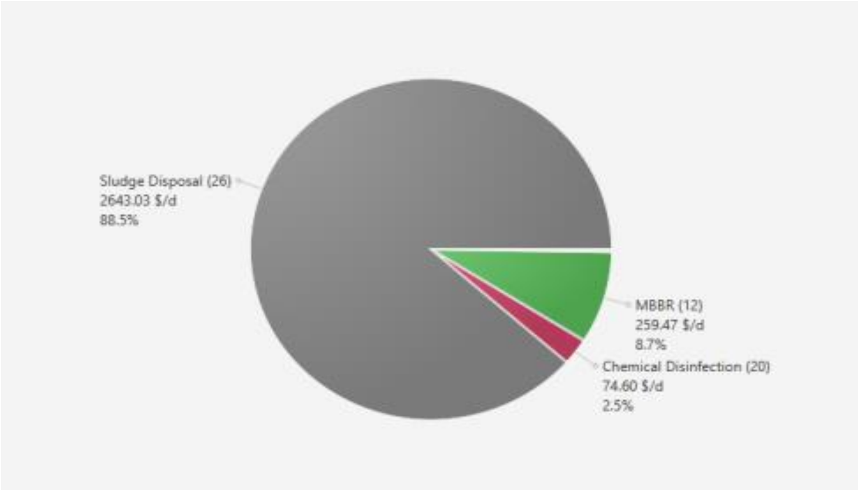

Fig. 8. Pie chart depicting the total cost acquired for the treatment plant employing UASB reactor

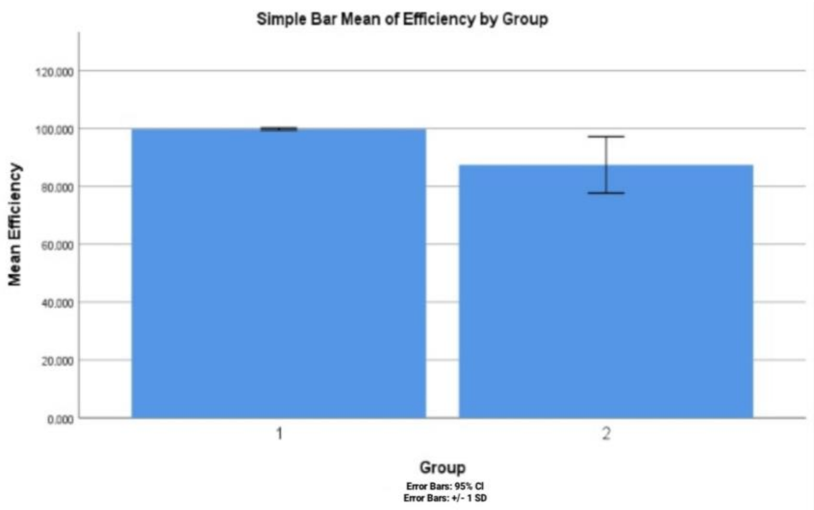

Fig. 9. Comparison of UASB or MBBR reactors in terms of BOD_5 reduction efficiency, the plant operating with UASB reactor was able to achieve 99% (approximately) BOD_5 reduction efficiency when compared to the plant employing MBBR reactor 87% (approximately) for various dairy wastewater effluents. X- axis: UASB and MBBR reactors. Y-axis: Mean BOD_5 reduction efficiency ± 1 SD