Original Article

An Investigation on the Efficacy of MBR and SBR in Reducing the Organic Content of Wastewater

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Abstract

Aim- The aim of this research is to compare suspended growth reactors MBR and SBR to calculate the organic content reduction efficacy offered by the reactors for different concentrations of wastewater from the dairy industry. Materials and methods – The secondary treatment reactors, MBR and SBR having an average Organic Loading Rate (OLR) of 0.55 g/m³/d to 1.11 g/m³/d, were compared for their Biological Oxygen Demand (BOD_5) removal efficacy for a period of 5 consecutive days for wastewater effluents from dairy industries such as mixed dairy, cheese, cheese whey, milk permeate, butter, dairy sewage, ice cream. Test samples (N = 14) were taken from the outfall of the experimental group (MBR) and control group (SBR) using G Power software. G power is taken as 0.8.

Results– The performance of an individual MBR reactor at removing the BOD_5 content was 95% compared to an individual SBR reactor which showed only 65%. On the other hand, the treatment plant as a whole which employed MBR reactor showed a removal efficacy of 84% and the plant which employed SBR reactor showed only 70% removal efficacy of BOD_5. The significance value is determined as 0.04 (p is less than 0.027, statistically significant) based on SPSS analysis.

Conclusion - MBR not only showed a better efficacy at removing BOD_5 from the dairy wastewater but was also cost efficient ($7.59) than SBR ($11.53), the only downside to the MBR reactor was that it utilised more power of 62.82 kW than that of SBR (44.71 kW). MBR showed a lesser efficacy of 52% for treating the effluents from ice cream which had an OLR of 0.156 g/m³/d and the reactor showed its highest efficacy of 99.8 % for treating milk permeate effluents of having an OLR of 1.73 g/m³/d .

Keywords: Innovative Membrane BioReactor, Sequencing Batch Reactor, Dairy wastewater, Biological Oxygen Demand, Suspended growth process, Secondary treatment, Wastewater Treatment.

DOI: 10.47750/pnr.2022.13.S04.007

INTRODUCTION

Dairy wastewater is nothing but diluted milk. In a survey conducted by the Environmental Protection Agency of USA in 1950 dairy effluents was classified as the second most polluting effluent (. and Patil . 2014). When buffaloes were fed with wastewater irrigated maize and brassica, the accumulation of toxic metals in the raw milk was observed (Iqbal et al. 2020). It was found that the concentration of toxic heavy metals present in dairy sourced from urban areas were more when compared to the dairy sourced from rural areas, thus such minor changes can lead to drastic impacts on the quality of dairy as well as dairy wastewater (Iftikhar et al. 2014). It is crucial to treat dairy wastewater before it is being disposed of into water bodies otherwise the microbial pathogens and heavy metals present in untreated wastewater can negatively harm human health (Chahal et al. 2016). This research aims to compare two suspended growth process reactors for the BOD_5 removal efficacy. The importance of this research is to determine which reactor works best in real time application of the organic content reduction efficiency, consumption of power and cost were analysed (Al-Shammari et al. 2018). Some of the applications of innovative Membrane BioReactor and SBR are; for the leachate treatment from incineration plants and sanitary landfills, MBRs were advantageous at pollution removal, fouling control, and power mitigation of the whole treatment processes (Zhang, Xiao, and Huang 2020). SBR showed a higher BOD_5 removal efficacy of 90% than conventional activated sludge process which has shown a removal efficacy of 60-70%. The nitrogen reduction content was also high due to the formation of high MLSS concentration(Mahvi n.d.).

More than 1856 articles were published in Google scholar, Springer and Science Direct in the past 5 years. Google Scholar showed 1570 journals, Springer had 89 articles and Science Direct showed 197 articles. The findings of the most cited paper are; The advantages and desirable features of using the MBR reactor was its use for the treatment of wastewater produced from the dairy industry at two different HRT: 6h and 8h, a 99% organic matter removal efficiency was obtained. Only the low molecular weight fraction was efficiently degraded by biomass (Andrade et al. 2013). In the study using MBR as secondary treatment with nano filtration as the tertiary treatment, MBR reactor showed a COD, nitrogen and phosphorus removal efficiency of 98%, 86% and 89% respectively for the treatment of dairy waste water (Andrade et al. 2014).The advantages of SBR are as follows, the grey water when treated with SBR showed a 90% COD reduction rate when the reactor was operated at 2.5 HRT, nitrification rate improved but the phosphorus removal efficiency of the reactor decreased (Lamine et al. 2007). The SBR reactor was filled with milk factory effluent and synthetic wastewater under different conditions. The COD removal efficacy was found to be 90% and the COD concentration varied from 400 to 2500 mg/l, hence this reactor was found to be a good option to treat medium strength industrial wastewater (Mohseni-Bandpi and Bazari 2004). The most cited article is (Wang et al. 2012) MBR required a shorter startup period and the anammox bacteria present in MBR was more ecologically stable and thus was a much more promising reactor than SBR. Our team has extensive knowledge and research experience that has translate into high quality publications(Bhansali et al. 2021; Jayanth et al. 2021; Sudhakar et al. 2021; Sathiyamoorthi et al. 2021; Deepanraj et al. 2021; Raju et al. 2021; Arun Prakash et al. 2020; Kamath et al. 2020; Shanmugam et al. 2021; Rajasekaran et al. 2020; Adhinarayanan et al. 2020; Rajesh et al. 2020; Aurtherson et al. 2021)

Some of the unanswered problems relating to the previous research was that there were no comparison between two suspended growth batch reactors such as MBR and SBR to identify which reactor performed more efficiently in treating various dairy effluents such as mixed dairy, cheese, cheese whey, milk permeate, butter, dairy sewage, ice cream whose BOD_5 ranged between 1508-29580 g/m³; and whether the treated wastewater complies under the government standards. The majority of extant research is based on data obtained from certain ethnic groups and results in less accuracy. The aim of this research is to compare two secondary treatment reactors namely MBR and SBR in treating various dairy effluents to reduce the organic content of these 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. The number of groups taken are two (innovative Membrane BioReactor and SBR), parameters such as mixed dairy, cheese, cheese whey, milk permeate, butter, dairy sewage, ice cream were taken whose BOD_5 is varied for each parameter. Thus, the sample size is 7 and the total sample size is 14. The pre text power value is calculated using GPower 3.1 software (g power setting parameters: statistical test difference between two independent means, α= 0.05, power = 0.80, effect size= 1.4144) and the pre test value is 80% . The software used to conduct this study is GPSx 8.0.1 (Andrade et al. 2013). The GPSx8.0.1 is a water and wastewater treatment plant modelling software which is used to derive the quantity of reduction of organic content based on the given input values. In this study, it is used to calculate the BOD_5 removal efficacy of two suspended growth reactors such as MBR and SBR.

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 MBR reactor. Group 2 was done by analysing various dairy wastewater parameters using the GPSx software to test the BOD_5 treatment efficiency of the SBR.The input parameters for various dairy effluents such as mixed dairy, cheese, cheese whey, milk permeate, butter, dairy sewage and ice cream were taken from (Slavov 2017) and (Tikariha and Sahu 2014) which are mentioned in Table 1 and Table 2. Other values such as organic fractions, phosphorus fractions, organic fractions, inorganic precipitates and soluble gases were maintained at 0.

Membrane Bioreactor

The first sample group preparation was run with the innovative Membrane BioReactor 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 treatment plant layout is made with reference to Fig. 1

The above values were updated at the influent inlet and the simulation was run for a period of 5 consecutive days. Raw wastewater enters the treatment unit and is then passed to the equalisation tank, primary clarifier, MBR 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.Membrane BioReactor (MBR) is a modified conventional activated sludge process which employs biological treatment where the secondary clarifier is replaced by a membrane separator. It is located inside or outside the reactor. The treated effluent from MBR is nitrified and thus can be reclaimed, and hence it can also be used for toilet flushing, car washing and municipal watering. The only downside of this reactor is frequent membrane fouling (Reif et al. 2008; Soylak and Cay 2007; Dufour, Strickland, and Cabelli 1981)). The physical, operational and kinetic parameters of MBR are: Total membrane surface area - 4000m^2, Solids capture rate - 0.999, Colloidal substrate capture rate -0.1, Number of reactors in series - 4, Surface area in final tank - 40.0 m^2, Total maximum volume - 500m^3, Cross air flow - 19000m^3/d, Standard oxygen transfer efficiency - 0.1, Pumped flow - 50 m^3/d, Total air flow into aeration tank - 20000 m^3/d.

Sequencing Batch Reactor

The second sample group preparation was run with the SBR 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 treatment plant layout is made with reference to Fig. 2 The above values were updated at the influent inlet and the simulation was run for a period of 5 consecutive days. Raw wastewater enters the treatment unit and is then passed to the equalisation tank, primary clarifier, SBR 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.Sequencing Batch Reactor (SBR) is a modified activated sludge process, the process of equalisation, biological treatment and secondary clarification takes place in a unit tank. The phases involved in the treatment of dairy wastewater that flows through SBR are fill phase, react phase, settle phase, draw phase and idle phase. Such reactors are used where area is limited and are highly used to remove the nitrogen and phosphate content in wastewater (Kulikowska, Klimiuk, and Drzewicki 2007). The physical, operational and kinetic parameters of SBR are:Surface area- 200m^2, maximum water level (height) - 5m, volume of reactor - 1000m^3, feed point from bottom - 1m, aeration method - diffused air, air flow into aeration tank - 7600 m^3/d, specific adsorption rate - 0.1 1(gCOD/m^3)/d, maximum specific growth rate on substrate3.2 1/d, saturation coefficient for oxygen 0.2 mgO_2/L, saturation coefficient for nitrogen as nutrient - 0.05 mgN/L.

Statistical Analysis

Statistical Package for the Social Sciences (SPSS) is a statistical analysis tool that is used to analyse the survey data, in this study the efficiency values for both the reactors retrieved from the GPSx software was given as input to the SPSS software for which it gave the significance value. The significance value should be lesser than 0.05 which indicates that the proposed method is better than the existing method. The SPSS (v.26) software is used for the statistical analysis of MBR and SBR reactors. The independent variable is various types of dairy wastewater and the dependent variable is BOD_5. Two independent group analysis tests are carried out to calculate the BOD_5 removal efficiency for both the methods.

RESULT

Table 3 concludes that treatment plant that employed innovative Membrane BioReactor treated dairy effluents such as mixed dairy, cheese, cheese whey, milk permeate, butter, dairy sewage and ice cream with a BOD_5 reduction efficiency of 84.02% and the plant that employed SBR had BOD_5 reduction efficiency of 70.11%. Table 4 shows the individual reactor efficiency for the reduction of BOD_5 in SBR and was found to be 95.07%. Table 5 shows the individual reactor efficiency for the reduction of BOD_5 in SBR and was found to be 65.22%. Table 6 illustrates the standard deviation and significance difference of MBR and SBR. These were utilised to determine whether the method produces substantial results in SPSS. Table 7 shows the independent sample test for MBR and SBR. MBR: t value and mean difference -2.41 and -13.90 and SBR: t value and mean difference -2.41 and -13.90. The quality significance variation among the two groups is 0.027 ($p < 0.05$, statistically significant).

Fig. 1 displays the process flow diagram employed in the treatment of dairy wastewater operating with the MBR reactor. Fig. 2 illustrates the process Flow diagram employed in the treatment of dairy wastewater operating with the SBR reactor. Fig. 3 shows the Sankey diagram depicts the rate flow of dairy wastewater through each component for the treatment plant employing the MBR reactor. Fig. 4 displays the Sankey diagram depicting the rate flow of dairy wastewater through each component for the treatment plant employing the SBR reactor . Fig. 5 displays the total Power in kW for the operation of the treatment plant employing the MBR reactor. Fig. 6 shows the total Power in kW for the operation of the treatment plant employing the SBRreactor. Fig. 7 illustrates the pie chart depicting the total cost acquired for the treatment plant employing the MBR reactor. Fig. 8 shows the pie chart depicting the total cost acquired for the treatment plant employing the SBR reactor. Fig. 9 gives the comparison of MBR and SBR in terms of mean BOD5 reduction efficiency. The mean efficiency of MBR is slightly higher than SBR..

DISCUSSION

The input parameters are the effluents from various dairy processing industries of varying concentration of organic and inorganic substance. The reactor's efficiency to treat the effluent may vary since each effluent from different dairy processing industries has different concentrations of BOD, COD, TN and TP. The BOD_5 values were calculated by the GPSx 8.0.1 software. Table 3 depicts the concentration of the effluent BOD_5 and the BOD5 reduction efficiency of SBR and MBR treatment plants. Table 4 and Table 5 indicated the efficiency of individual reactors of MBR and SBR respectively. The removal efficiency of MBR is 95% and SBR is 64%. The results showed that the MBR had higher removal efficiency than SBR. It was found that MBR was highly efficient at treating loads having BOD_5 varying from 2500 g/m³ to 29580 g/m³ which included effluents from mixed dairy, cheese, cheese whey, milk permeate and butter but failed to treat loads below 1500 g/m³ which were the effluents from ice cream industries, but the overall efficacy of MBR in treating dairy effluents was much higher when compared to that of SBR. SBR was efficient at treating loads below 1500g/m³ but less efficient at treating effluents from the butter industry of BOD_5 concentration of 2598g/m³ (Table 4 and 5). Fig. 3 and Fig. 4 describe the rate of flow of effluents through each reactor which has been retrieved from the GPSx software using the sankey diagram. The power consumed by an individual MBR reactor is 44.51kW and for the treatment plant employing MBR reactor is 62 kW meaning that MBR reactor is power intensive. For the treatment plant employing an individual SBR reactor, it consumed 33.49kW while the power of the entire plant setup came up to only 44.71kW. The SBR treatment plant thus consumed less power than MBR. These values are depicted in the form of a pie chart as shown in Fig. 5 and Fig. 6. The cost required for the MBR treatment plant as a whole is $2345.36 of which the cost of an individual MBR reactor is $7.59. The cost required for the SBR reactor is $11.53 and for the treatment plant is $6942.76. On comparing both the reactors MBR treatment plant required lesser cost to operate than that of SBR treatment plant. Fig. 7 and Fig. 8 depicts the cost acquired for the treatment plant of MBR and SBR in the form of a pie chart. Table 6 Table 7 represents the independent sample test for MBR and SBR reactors, both the reactors showed a t value and mean difference of -2.41 and -13.90. There is a significance between the two groups since $p<0.05$

The result of SBR agrees with (Mohseni-Bandpi and Bazari 2004) such that the SBR reactor is used to treat effluents with medium strengths. In a study by (Yee, Rathnayake, and Visvanathan 2019), the BOD_5 removal efficacy of MBR was 97-99% when thermophilic conditions were adapted, the MBR reactor running at the same condition whose reactor temperature was maintained at 50℃ was able to yield 84% BOD_5 removal efficacy. A similar study by (El-Fadel and Hashisho 2014) agrees with the results obtained. MBR was efficient at removing 95% BOD_5 whereas SBR failed to reach such high removal rates. MBR reactors with a capacity of 600L were operated for grey and black water for a period of 50 days. The average COD removal efficiency for black water was 95% and the same for grey water was 96% (Atasoy et al. 2007). Opposing findings are for a SBR reactor made of plexiglass of the volume 22.5L, having input COD concentrations in the range of 400-2500 mg/L was able to achieve 90% COD removal efficiency. It was efficient in treating biological medium strength loads. Future scope includes the usage of biological flocs present in the MBR to improve the fouling level of membranes. The possibility to use MBR for dairy wastewater reclamation is also high.

Limitations of this study include the fact that there might be differences in efficiency of the output derived using the software and the output of real life implementation of the plant. Future scope of this study aims at comparing the innovative Membrane BioReactor reactor with other suspended growth process reactors that treat dairy effluents effectively.

CONCLUSION

This analysis illustrated that, MBR not only showed a higher efficacy (84%) at treating various dairy effluents than SBR (70%) but also proved to be cost efficient. The SPSS value of both the reactors came upto 0.027 indicating that the proposed reactor is more efficient at removing BOD_5 than the existing reactor. Based on the independent T test the significance value is 0.027 ($p < 0.05$) 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.

Acknowledgments

The authors would like to express their gratitude towards Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences (Formerly known as Saveetha University) for providing the necessary infrastructure to carry out this work successfully.

Funding

We thank the following organisations for providing financial support that enabled us to complete the study.

1.Hubert Enviro Care Systems Pvt. Ltd.

2. Saveetha University

3. Saveetha Institute of Medical and Technical Sciences

4. Saveetha School of Engineering

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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 from various dairy industries

Parameters	BOD5 (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 the treated wastewater in g/m^3 and its resultant efficiency for SBR and MBR

reactors respectively. The BOD5 reduction efficiency of MBR is 84% which is comparatively higher than SBR reactor of 70%

Parameter	SBR-effluent (g/m^3)	SBR Reactor (%)	MBR effluent (g/m^3)	MBR reactor (%)
Mixed dairy	883.11	70.71	233.88	92.24
Cheese	5389.3	70.64	1455.20	92.07
Cheese whey	9184.876	68.94	1938.45	93.44
Milk permeate	5590.24	66.45	1234.76	92.58
Butter	851.63	67.10	300.62	88.38
Dairy sewage	858.89	73.28	746.03	76.79
Ice cream	379.23	73.65	714.47	52.62
Overall Efficiency		70.11		84.02

Table 4. Individual reactor efficiency of MBR reactor for the treatment of different dairy wastewater and its resultant efficiency is 95.07%

Parameter	Influent (g/m^3)	Effluent (g/m^3)	Efficiency (%)
Mixed dairy	4051.37	41.79	98.96
Cheese	78365.90	562.94	99.28
Cheese whey	49516.90	610.89	98.76
Milk permeate	68336.07	96.84	99.85
Butter	7987.36	237.69	97.02
Dairy sewage	6972.39	330.56	95.25
Ice cream	5224.60	1233.10	76.39
Overall Efficiency			**95.07**

Table 5. Individual reactor efficiency of SBR reactor for the treatment of different dairy wastewater and its resultant efficiency is 64.46%

Parameter	Influent (g/m^3)	Effluent (g/m^3)	Efficiency (%)
Mixed dairy	3429.02	1137.43	66.82
Cheese	77315.53	28192.52	63.53
Cheese whey	115444.77	44555.37	61.40
Milk permeate	19042.41	7366.94	61.31
Butter	12828.39	4337.78	66.18
Dairy sewage	6508.51	2099.12	67.74
Ice cream	6108.52	2185.98	64.21

Overall Efficiency			64.46

Table 6. Mean Output Voltage, Standard Deviation and Standard error values are obtained for 14 sample data sets. When compared treatment plant employing MBR reactor has better performance than the treatment plant employing SBR reactor

	Group	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
Efficiency	SBR	7	70.1163	2.80177	1.05897
	MBR	7	84.0232	15.01085	5.67357

Table 7. Independent sample T-test t is performed for the two groups for significance and standard error determination. Since the value of significance is 0.027 ($p < 0.05$) 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**	6.355	.027	-2.410	12	0.033	-13.90	5.77	-26.48	-1.33
	Equal variances not assumed			-2.410	6.418	0.050	-13.90	5.77	-27.80	-0.0041

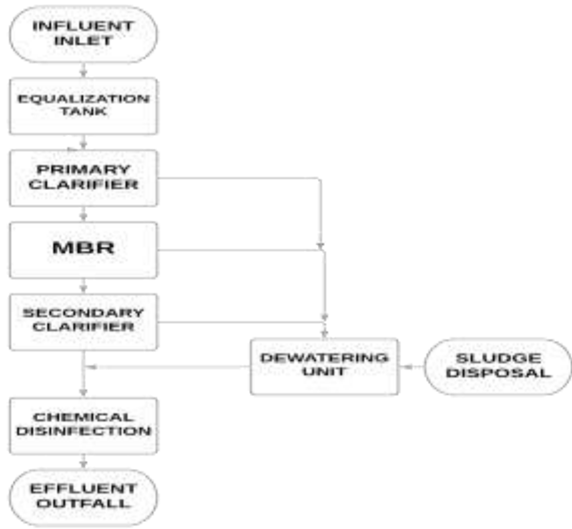

Fig. 1. Process Flow diagram employed in the treatment of dairy wastewater operating with MBR reactor

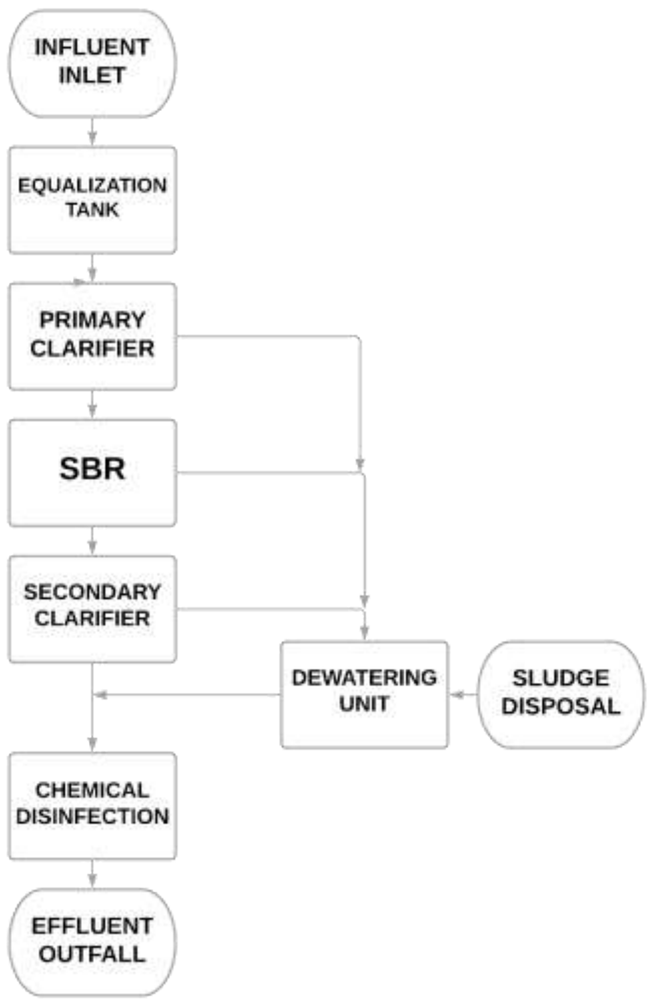

Fig. 2. Process Flow diagram employed in the treatment of dairy wastewater operating with SBR reactor

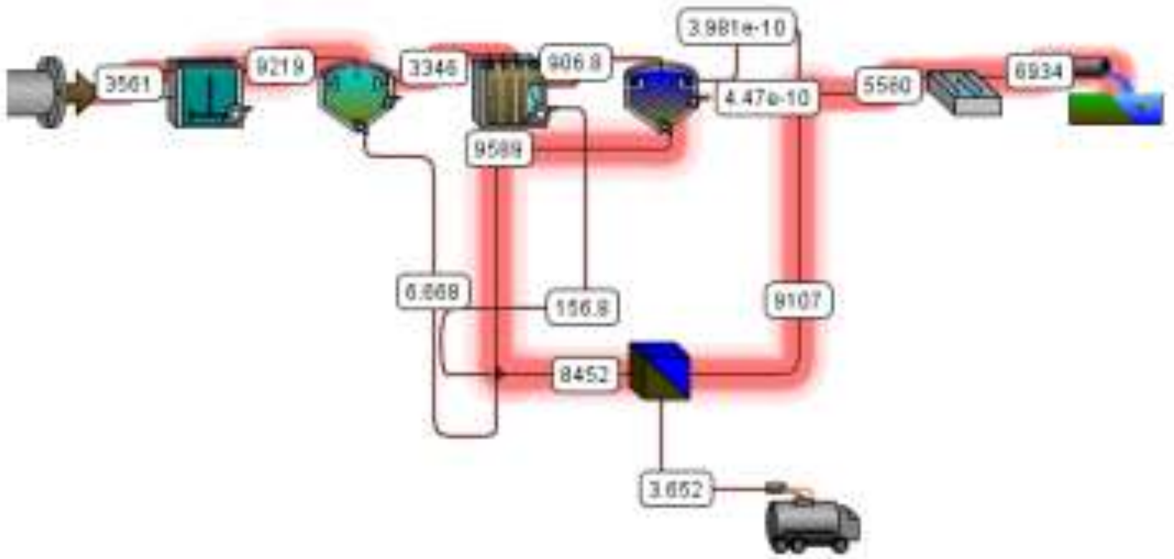

Fig. 3. The Sankey diagram depicts the rate flow of dairy wastewater through each component for the treatment plant employing MBR reactor

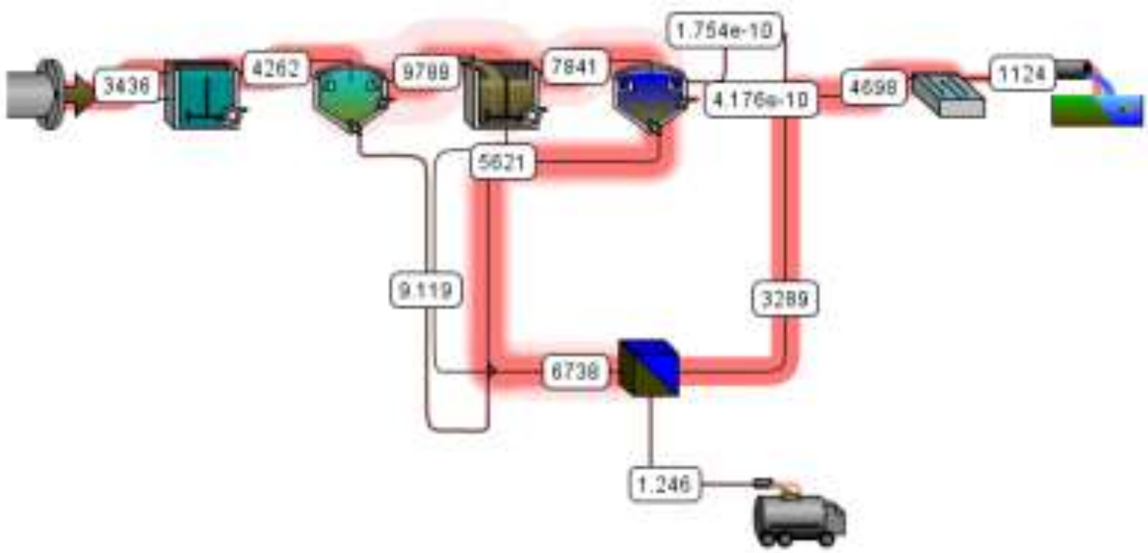

Fig. 4. The Sankey diagram depicts the rate flow of dairy wastewater through each component for the treatment plant employing SBR reactor

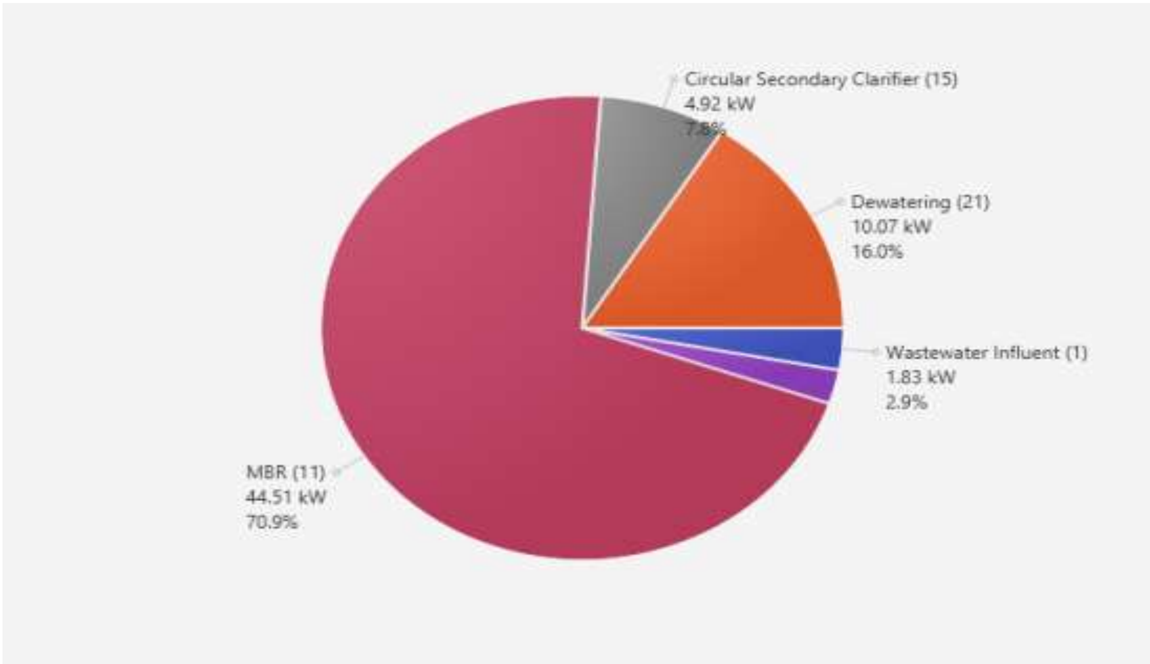

Fig. 5. Pie chart indicating the Total Power consumed by the treatment plant employing MBR reactor along with the power consumed by individual treatment operations

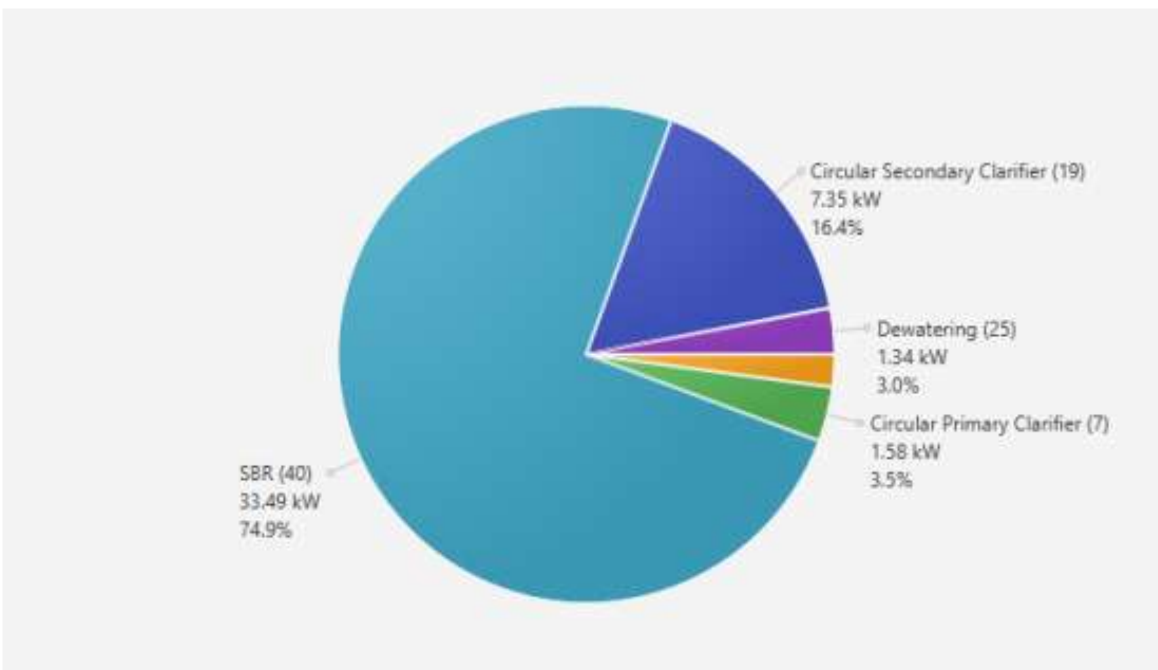

Fig. 6. Pie chart indicating the Total Power consumed by the treatment plant employing SBR reactor along with the power consumed by individual treatment operations

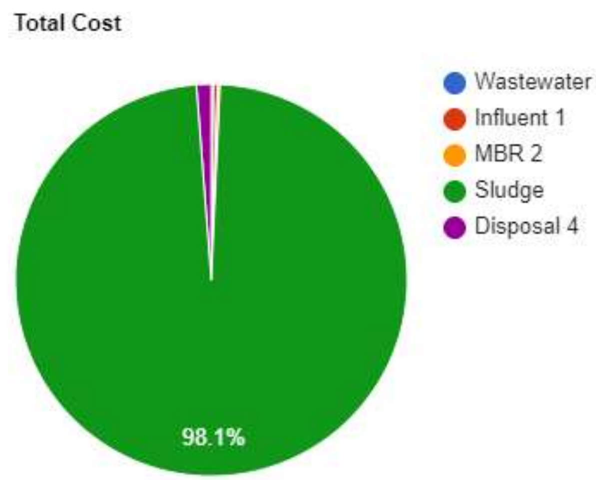

Fig. 7. Pie chart depicting the total cost acquired for the treatment plant employing MBR reactor

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

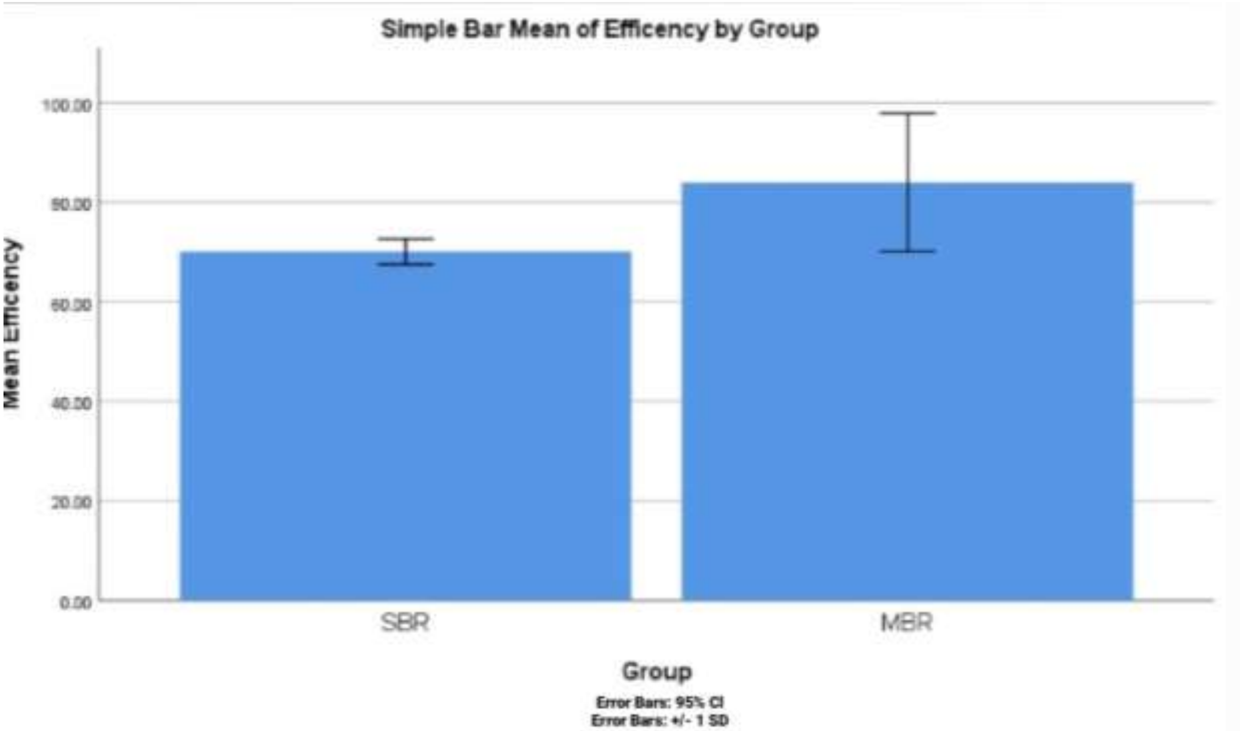

Fig. 9. Comparison of MBR and SBR reactors in terms of BOD5 reduction efficiency, MBR reactor was able to achieve 84% BOD5 reduction efficiency when compared to SBR reactor 70% for various dairy wastewater effluents. X- axis: MBR and SBR reactors. Y-axis: Mean BOD_5 reduction efficiency ± 1 SD