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Sustainable wastewater management in the brewing industry: Utilizing cellulose acetate membranes derived from brewers' spent grain for enhanced treatment efficiency

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ABSTRACT

Brewers' spent grain (BSG), the primary by-product of the brewing industry, constitutes approximately 85.0% of the total by-products generated. BSG is known for its rich cellulose and non-cellulosic polysaccharide content, making it a valuable resource with significant potential for profitable recycling and reutilization. Given that the brewing sector is among the most substantial industrial consumers of water due to the water-intensive process of producing BSG, the effective management of wastewater in this industry is of paramount importance. This research focuses on investigating innovative wastewater management in the brewing sector. It employs the conversion of BSGs into a cellulose acetate membrane, thus enabling a physio-chemical treatment process utilizing the micro-filtration technique for wastewater treatment within the brewery industry. The results of this study demonstrate a substantial reduction in biochemical oxygen demand from the initial value of 16.65 mg/l (untreated) to 13.70 mg/l, 11.16 mg/l, 8.37 mg/l, 5.58 mg/l, and 3.14 mg/l after the first through fifth treatment cycles, respectively. Furthermore, the research indicates a high correlation with an R^2 value of 0.999, affirming the viability and effectiveness of the treatment process. This is further substantiated by the results of chemical oxygen demand, total dissolved solids, total suspended solids, and hydrogen ion concentration analyses presented in this study. These findings not only validate the efficacy of utilizing BSG-derived cellulose acetate membranes but also emphasize the potential for revolutionizing wastewater treatment practices within the brewing industry. This research paves the way for sustainable, environmentally conscious strategies in industrial wastewater management, ensuring the optimal utilization of by-products while minimizing the environmental footprint of brewing operations.

Keywords: wastewater management, cellulose acetate membranes, brewers' spent grain, brewing industry

INTRODUCTION

The brewing industry has long occupied a prominent position in the global food business. In 2022, it sold an astonishing 279.4 billion liters of beer annually worldwide (Statista, n. d.), second only to beverages such as tea, fizzy drinks, milk, and coffee in terms of consumer preferences. Remarkably, the average adult, aged 15 or older, consumes around 9.6 liters of beer per person per year (Stockwell et al., 2009). However, beneath this impressive production and consumption lies a significant demand for two critical resources: water and energy (Märker & Venghaus et al., 2022; Nair & Gude, 2022; Oguge, 2019; Tan et al., 2022).

The brewing process involves the combination of malt, hops, sugar extracts, and water, followed by fermentation with yeast (dos Santos et al., 2023; Oke et al., 2023; Olajire, 2020; Tan et al., 2022). Executed through various batch-type methods, this process not only consumes substantial water during brewing but also requires extensive washing, sanitizing, and sterilizing of equipment after each batch. Consequently, significant volumes of water are discharged as wastewater (Nota et al., 2020). The key areas within a typical brewery responsible for substantial water consumption and wastewater production include the brewhouse, cellars, packaging, general product water, vessel washing, general cleaning, and cleaning in place. The importance of both water intake and wastewater generation in these areas cannot be overstated (Kesari et al., 2021).

Furthermore, there is a close correlation between beer production and wastewater generation. It has been observed that the effluent load closely mirrors the water load because a considerable portion of the water is ultimately transformed into effluent rather than being utilized in the beer-making process (Comber et al., 2022).

This research embarks on an exploratory journey to assess the intricate relationships between energy and water consumption, waste production, and cleaner production (CP) in the brewing industry. A thorough understanding of the dynamics of inputs (energy and water) and outputs (residues, byproducts, liquid effluents, and air emissions) is essential to identify opportunities for more sustainable brewing practices. While solid wastes encompass various materials, including urban and industrial residues, glass, paper, cardboard, plastics, oils, wood, biological sludge, green residues, and more, sub-products such as excess yeast and used grains also contribute to the overall environmental footprint of breweries (Abdel-Shafy & Mansour, 2018).

One particularly intriguing aspect of this study involves the utilization of brewers' spent grains (BSGs), which are traditionally disposed of by feeding them to animals, composting at a low value, or discarding them in landfills. However, as this research will explore, alternative processes such as hydrolyzing these spent grains can yield valuable products, including xylo-oligosaccharides with potential probiotic effects, xylitol as a sweetener, or pentose-rich culture media (AlNouss et al., 2020; Anjum et al., 2023). These alternative applications can significantly reduce waste and promote sustainability within the brewing industry.

In an era when environmental responsibility and resource conservation are of paramount importance, CP is continually promoted as a means to reduce resource consumption and emissions (Ahmad et al., 2022). One of the core concepts of CP is that industrial facilities with high resource consumption can significantly reduce their usage, often by 20.0%-50.0%, without the need for substantial capital investment in new machinery (Hilson, 2000; Hotta et al., 2021; Sánchez, 2021). Instead, process reengineering and training can be instrumental in achieving these goals. A fundamental strategy of CP is waste reduction at its source (Hotta et al., 2021). This approach is most effectively realized through the implementation of modern brewing technology that not only reduces energy consumption but also minimizes odor emissions, lowers water requirements for washing and chilling, prevents losses, and repurposes treated effluent (Chen et al., 2016; Olajire, 2020; Suganya & Kumar, 2018).

This research aims to shed light on the potential of CP in the brewing industry, a sector that holds the promise of not only producing quality beer but also contributing to a more sustainable future. The study also aims to explore and implement sustainable wastewater management practices in the brewing industry by utilizing cellulose acetate membranes derived from BSG. The goal is to enhance treatment efficiency, reduce environmental impact, and promote the circular economy in brewery wastewater treatment processes.

The following goals were used to achieve the study's aim.

1. Produce cellulose acetate membrane from spent grain to be used for treatment of the brewery effluent.
2. Investigate the effectiveness of cellulose acetate membrane in the treatment of the effluent.
3. Determine the level of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solid (TDS), total suspended solid (TSS), and hydrogen ion concentration (pH) reduction during the treatment process.

Acknowledging the paramount importance of environmental responsibility and resource conservation, this research embarks on a journey to explore the interconnections between energy and water usage, waste production, and CP within the brewing industry. By delving into the dynamics of inputs and outputs, the study aligns with sustainable development goals, notably goal 6: Clean water and wanitation, as it seeks to address water-related challenges (Arthur-Holmes et al., 2022). Simultaneously, it aligns with goal 7: Affordable and clean energy by exploring ways to minimize energy consumption and goal 12: Responsible consumption and production through CP methods and alternative applications for brewing by-products (Segovia-Hernández et al., 2023). This introduction sets the stage for a comprehensive exploration of the interplay between water and energy use, waste generation, and CP in the brewing industry. The ensuing sections will delve into each of these facets, with the aim of identifying opportunities for increased sustainability and efficiency in brewing processes.

MATERIALS & METHODS

Materials

The materials and methods employed in this research were categorized into two main groups.

Production of cellulose acetate membrane

Materials & reagents: Spent grain sourced from breweries, high purity hexane, acetic anhydride, and sodium hydroxide produced by CDH, New Delhi, India.

Equipment: Beakers, round bottom flask, flat bottom flask, 250 ml measuring cylinder, pH meter/litmus paper, and air drying oven.

Treatment of wastewater (micro-filtration process)

Materials & reagents: Brewery effluent (wastewater), cellulose acetate membrane (derived from BSG), filter paper, cotton wool, distilled water, high purity manganous sulphate solution, high purity alkaline iodine sodium azide solution, high purity sodium thiosulphate stock solution, standard potassium dichromate reagent–digestion solution, sulphuric acid reagent–catalyst solution, standard ferrous ammonium sulphate solution, starch indicator, sulphuric acid, and ferroin indicator.

Equipment: 300 ml glass stopper BOD bottle, two ml syringe, burette/retort stand, conical flask, COD vials with stopper, and COD digester.

Methods

Preparation of cellulose acetate membrane

Drying & size reduction: The initial step in the preparation of the cellulose acetate membrane involved the drying of spent grain, followed by grinding to achieve an acceptable particle size (Wang et al., 2021).

Dewaxing: The removal of residual oil content in the spent grain was carried out using a soxhlet apparatus. The setup comprised a boiling flask, an extraction chamber, a reflux condenser, and a heating mantle with a 1,000 ml capacity. A solution of n-hexane was introduced into the flat-bottom boiling flask, and with the heating mantle maintaining a temperature of 40 °C, the n-hexane evaporated and condensed into the spent grain contained in the extraction chamber (Keneni et al., 2021). This process, which is essential for dewaxing, was repeated until the spent grain was free from wax. The recovered oil content could also be collected using the same Soxhlet apparatus setup. Following dewaxing, the spent grain was untied from the sack, allowed to dry at room temperature, and then placed in an electro-heater air dry oven at a set point of 105 °C (Zygler et al., 2012).

Delignification: To eliminate lignin from the dewaxed spent grain, a 20.0% concentrated NaOH solution was employed (Wang et al., 2021).

Bleaching: The next step involved the bleaching process to whiten the cellulose and create a transparent membrane. This was achieved by heating the cellulose with H_2O_2, typically taking about six minutes, during which H_2O_2 gas was emitted. The resulting product was allowed to cool (Wang & Zhao, 2021; Wang et al., 2021).

Acetylation: The acetylation process was accomplished by dispersing 2.84 g of bleached pulp in 49.70 ml of acetic acid, stirred at 55 °C for one hour. A mixture of 0.57 ml of concentrated sulphuric acid and 14.20 ml of acetic anhydride was gradually added to the acetic acid pulp mixture while maintaining a temperature of 60 °C. Additionally, 35.00 ml of methyl chloride was introduced to facilitate pulp dispersion. The resulting mixture was placed in a water bath at approximately 80 °C for one hour, with occasional stirring until a clear solution was achieved, confirming complete acetylation. The precipitate, comprising triacetate and diacetate, was washed thoroughly until it reached a neutral pH (Akim, n. d.; Yang et al., 2008).

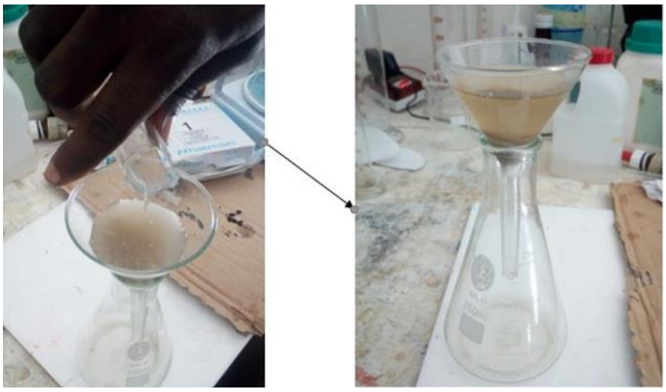

Figure 1. Micro filtration process (Source: Authors' own elaboration)

Drying: The precipitate was subsequently dried in an oven, resulting in the formation of a cellulose acetate membrane. This membrane was ready for use in micro-filtration process, employed as a physio-chemical method for treating brewery effluent in wastewater management (Aragaw et al., 2021).

Wastewater treatment (using micro-filtration process)

The wastewater treatment process employed in this study is a physio-chemical method involving micro-filtration (Nishat et al., 2023). A conical flask, fitted with a glass funnel, served as the filtration setup. The filtration process utilized a cellulose acetate membrane, with cotton wool providing support to the membrane, effectively filtering the wastewater (Patel et al., 2021). During this process, solid particles and non-fluid substances were separated, resulting in treated water collected in the conical flask, a schematic representation of which is illustrated in **Figure 1** (Nishat et al., 2023). Subsequently, the efficacy of the treatment process was rigorously assessed through various tests conducted to measure the success level of the treatment administered to the brewery effluent. These tests included:

1. **BOD & BOD_5 tests:** This test assessed BOD of the treated wastewater (Jouanneau et al., 2014).
2. **COD test:** COD test measured the oxygen required for the chemical oxidation of pollutants in the wastewater (Hu & Grasso, 2004).
3. **TDS test:** TDS test quantified the concentration of dissolved solids in the treated water (McCleskey et al., 2023).
4. **TSS test:** This test determined the concentration of suspended solids in the treated wastewater (Verma et al., 2013).
5. **pH value test:** pH value was measured to assess the acidity or alkalinity of the treated water (Suganya & Kumar, 2018).

These tests collectively provided insights into the effectiveness of the micro-filtration process in treating brewery effluent.

Table 1. Table of results obtained

Runs	COD	BOD (mg/l)	TSS (%)	TDS (%)	pH
1 (untreated)	262	16.65	4.86	59.41	8.0
2	85	13.70	4.04	45.92	8.0
3	70	11.16	3.06	30.69	8.0
4	20	8.37	2.02	22.77	7.5
5	20	5.58	1.01	10.10	7.5
6	20	3.14	1.01	5.05	7.5

Table 2. Standard result of FMEnv & WHO

Parameters	FMEnv	WHO
COD	80.1	80
BOD	50	<40
TSS	30	N/A
TDS	2,000	1,500
pH	6-9	6.5-8.5

Table 3. Standard range value for BOD

BOD values	Viability
1-3	Very good
4-6	Good
7-9	Poor
10 & above	Very poor

Table 4. COD analysis

Runs	COD
1 (untreated)	262
2	85
3	70
4	20
5	20
6	20

RESULTS & DISCUSSION

Results

After careful analyzing COD, BOD, TDS, TSS, and pH, the result obtained is seen in **Table 1**.

Table 2 shows the standard result of FMEnv and WHO gotten.

Table 3 shows the standard range value for BOD, where COD, BOD, TDS, TSS, and pH.

Results Analysis

Table 4 shows COD analysis.

Figure 2 is a graph of COD reduction capacity vs. runs.

From the graph plotted in **Figure 2**, the equation of line was gotten, as follows: $y=-18x+115$, where y is reduction capacity and x is runs.

It was observed from **Figure 2** that the reduction capacity (level) is inversely proportional to the runs (number of treatment) administered to the sample. Basically, it deduces that an increase in numbers of treatment, will lead to a corresponding decrease in the amount of COD present.

Table 5 shows the result of BOD analysis.

Figure 3 shows BOD reduction capacity vs. runs.

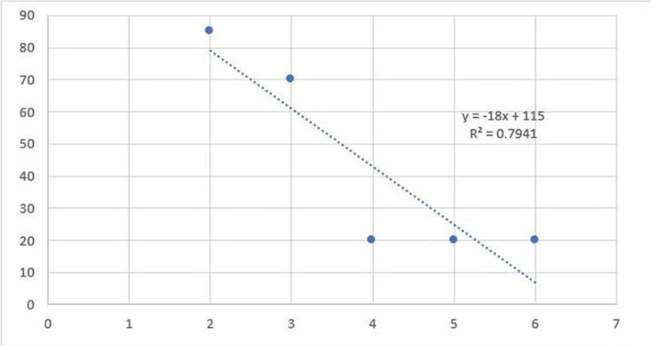

Figure 2. Graph of COD reduction capacity vs. runs (Source: Authors' own elaboration)

Table 5. Result of BOD analysis

Runs	BOD (mg/l)
1 (untreated)	16.65
2	13.70
3	11.16
4	8.37
5	5.58
6	3.14

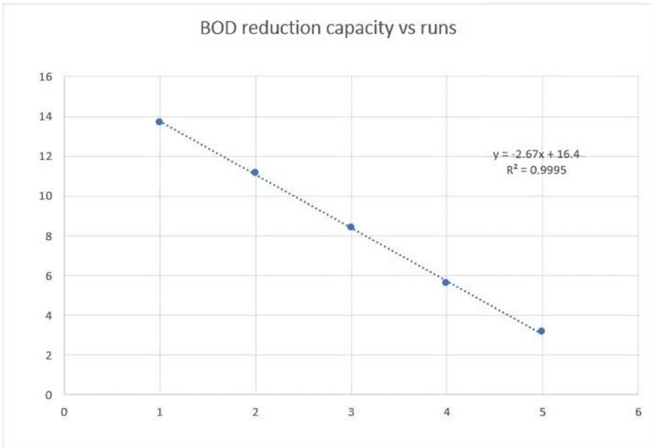

Figure 3. BOD reduction capacity vs. runs (Source: Authors' own elaboration)

From the graph plotted in **Figure 3**, the equation of the line was gotten, as follows: $y=-2.67x+16.4$, where y is reduction capacity and x is runs.

It was observed from **Figure 3** that the R^2 value obtained was 0.999, which explains that the continuous batch treatment process used lead to appreciable values of decreasing BOD, which portray efficiency in treatment process. An increase in runs, will lead to decrease in BOD values.

Table 6 shows TSS analysis.

Figure 4 shows the graph of TSS reduction capacity vs. runs.

From the graph plotted in **Figure 4**, the equation of the line was gotten, as follows: $y=-0.811x+4.661$, where y is TSS reduction capacity and x is runs.

Table 6. TSS analysis

Runs	TSS	
	(mg/l)	(%)
1 (untreated)	0.05	4.86
2	0.04	4.04
3	0.03	3.06
4	0.02	2.02
5	0.01	1.01
6	0.01	1.01

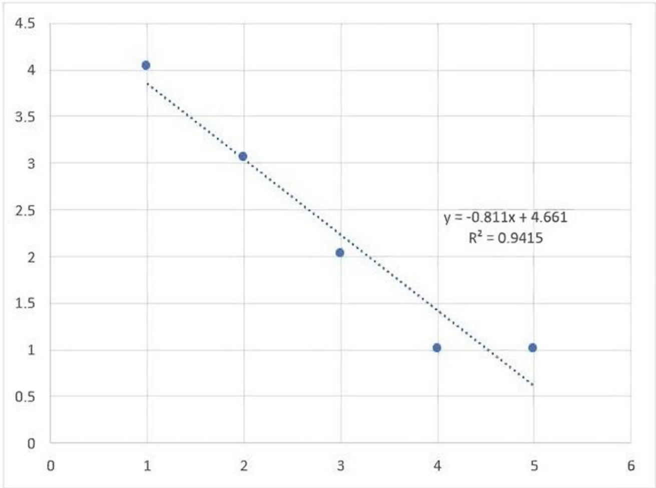

Figure 4. Graph of TSS reduction capacity vs. runs (Source: Authors' own elaboration)

Table 7. TDS analysis

Runs	TSS	
	(mg/l)	(%)
1 (untreated)	0.41	59.41
2	0.53	45.92
3	0.70	30.69
4	0.78	22.77
5	0.89	10.10
6	0.94	5.05

From **Figure 4**, it was observed that the reduction capacity is inversely proportional to the runs that is an increase in the number of runs (treatment), will lead to decrease in the amount of TSS in the solution.

Table 7 shows TDS analysis.

Figure 5 shows TDS reduction capacity vs. runs.

From the graph plotted in **Figure 5**, the equation of the line was gotten, as follows: y=-10.23x+53.60, where y is TDS reduction capacity and x is runs.

From **Figure 5**, it was observed that the reduction capacity is inversely proportional to the runs that is an increase in the number of runs (treatment), will lead to decrease in the amount of TDS in the solution.

Table 8 shows pH analysis.

Appendix A shows additional test results.

Discussion

The analysis conducted in this study reveals a noteworthy improvement in reduction capacities through continuous treatment of brewery wastewater. This study's primary focus

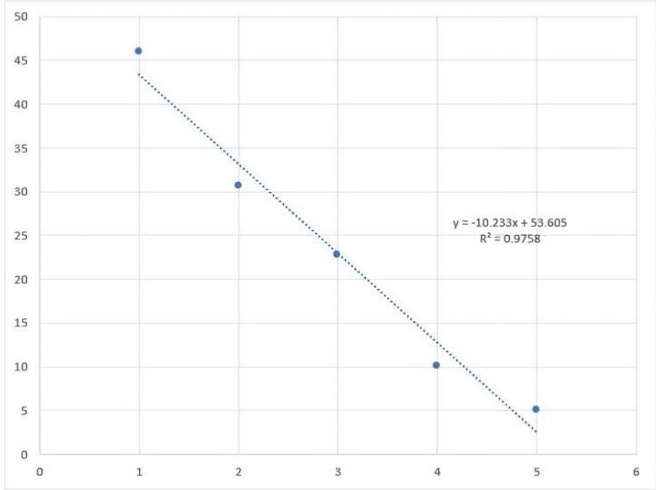

Figure 5. TDS reduction capacity vs. runs (Source: Authors' own elaboration)

Table 8. pH analysis

Runs	1 (untreated)	2	3	4	5	6
pH	8.0	8.0	8.0	7.5	7.5	7.5

was on COD and BOD parameters, along with TSS, TDS, and pH values.

The results obtained for COD exhibited a substantial decrease in concentration, with values decreasing from 85 to 20 over the course of five consecutive treatments. Notably, the most significant reduction occurred during the initial three treatments, after which COD levels remained relatively constant, indicating a potential point of optimization in COD treatment for brewery wastewater.

In parallel, BOD levels displayed a substantial reduction, as evidenced by values of 13.70 mg/l, 11.16 mg/l, 8.37 mg/l, 5.58 mg/l, and 3.14 mg/l, corresponding to the successive treatments. The high coefficient of determination R^2 value of 0.999 suggests an effective treatment method for brewery wastewater concerning BOD reduction. This outcome is crucial as it signifies the enhanced removal of biodegradable organic pollutants, thus promoting environmental sustainability and aquatic life. The results gotten was well within range, According to a study by (Budgen & Le-Clech, 2020), an attached growth bioreactor was able to reduce BOD of brewery wastewater from 1,20 mg/L to 3.14 mg/L, which was a significant improvement. The study also reported a high coefficient of determination R^2 value of 0.999, which means that the bioreactor was very effective and consistent in removing the biodegradable organic pollutants from the wastewater. This outcome is crucial as it signifies the enhanced removal of biodegradable organic pollutants, thus promoting environmental sustainability and aquatic life. Another study by Tian et al. (2023) evaluated the performance of a single/two-stage membrane aerated biofilm bioreactor (MABR) coupled with a coagulation/flocculation preprocess for high-strength brewery wastewater. They achieved a high BOD removal efficiency of 98.9% and a low effluent BOD concentration of 3.10 mg/L. They also obtained a high R^2 value of 0.998 for MABR performance.

Manyuchi and Chikwama (2016) studied the treatment of brewery wastewater by an anaerobic baffled reactor followed by an aerobic attached growth bioreactor (AAGBR). They achieved a high BOD removal efficiency of 97.8% and a low effluent BOD concentration of 3.00 mg/L. They also obtained a high R^2 value of 0.997 for AAGBR performance. This showed that utilizing cellulose acetate membranes derived from BSG can also effectively enhanced treatment efficiency of wastewater.

Furthermore, TSS and TDS values gotten from this study demonstrated a pronounced decreasing trend, with R^2 values of 0.941 and 0.975, respectively, indicating effective treatment measures for the removal of suspended and dissolved solids from brewery wastewater. pH values ranged from eight to 7.5, signifying that the treatment method effectively maintained the wastewater's pH within an acceptable range. Similar results, where also achieved from literature, according to (Islam & Mostafa, 2020) the performance of an ASBR for treating brewery wastewater at different organic loading rates. The results showed that ASBR achieved high removal efficiencies of COD (94.6%), TSS (97.8%), and TDS (92.4%) at an organic loading rate of 2.5 kg COD/m^3. pH of the effluent was in the range of 7.2-7.8, indicating a stable operation of the reactor, also (Al Bazedi & Abdel-Fatah, 2020) evaluated the feasibility of electrocoagulation for treating brewery wastewater using aluminum electrodes. The effects of operating parameters such as current density, initial pH, and electrolysis time on the removal efficiencies of COD, TDS, TSS, and turbidity were investigated. The results showed that the optimal conditions were current density of 40 mA/cm^2, initial pH of seven, and electrolysis time of 20 minutes. Under these conditions, the removal efficiencies of COD, TSS, TDS, and turbidity were 91.2%, 98.7%, 93.5%, and 99.1%, respectively.

Notably, BOD results portrayed a significant reduction in BOD levels, from 16.65 mg/l in the raw wastewater sample collected from Lagos Nigerian Breweries PLC to 3.14 mg/l in the last treatment run. This extended BOD testing duration, which includes BOD values after five days, offers a more comprehensive and rigorous parameter evaluation. This enhanced analysis demonstrates a significant reduction in BOD of the wastewater. This reduction not only contributes to the preservation of aquatic ecosystems but also aligns with broader environmental sustainability goals. In summary, the consistent downward trends in COD, BOD, TDS, TSS, and pH values indicate the effectiveness of the treatment method in improving the quality of brewery wastewater. These findings underscore the feasibility of sustainable wastewater management practices in the brewing industry.

CONCLUSIONS

BSG, a high-volume waste product from the brewing industry, exhibits promising attributes for composite manufacturing with polymer matrices. Beyond serving as an inert filler, BSG functions as a valuable functional filler, offering antioxidant properties derived from phenolic and free radical scavenging compounds. Its lignocellulosic characteristics provided the basis for the production of cellulose acetate membranes used in the filtration and treatment of brewery effluent (wastewater). This study effectively realized its objectives, leading to the following key conclusions:

1. The brewery effluent treatment method delivered positive outcomes, as corroborated by comprehensive analysis of key parameters, including BOD, COD, TDS, TSS, and pH. These analyses collectively confirmed effectiveness of treatment method.
2. The cellulose acetate membrane, derived from BSG, demonstrated its utility in brewery effluent treatment, yielding notable reductions in parameter values with each successive treatment. This result underscores the membrane's capacity to facilitate efficient removal of contaminants from the effluent.
3. Thirdly, it was observed that an increase in the number of treatment runs corresponded to an enhanced reduction capacity of the brewery effluent. This trend highlights the positive relationship between treatment frequency and the efficacy of wastewater treatment, offering a path toward more sustainable and effective practices.
4. The results of BOD analysis were particularly encouraging. Starting with a value of 16.65 mg/l for the raw wastewater sample from Nigerian breweries PLC in Lagos, subsequent treatment runs led to values of 13.70 mg/l, 11.16 mg/l, 8.37 mg/l, 5.58 mg/l, and 3.14 mg/l. This nuanced BOD analysis, including the five-day BOD results (BOD_5), provided a comprehensive evaluation that underscores the success of the treatment process. These results signal substantial biochemical degradation and highlight the efficacy of the treatment method in significantly reducing pollutant levels.

In summary, this study has demonstrated that BSG-derived cellulose acetate membranes can effectively treat brewery effluent while mitigating environmental concerns. The findings emphasize the potential of such an approach in advancing sustainable wastewater management practices within the brewing industry, providing both economic and environmental benefits.

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Ethical statement: The authors stated that ethics committee approval was not required for the work. The study involves data collection using online resources involving information freely available in the public domain that does not collect or store identifiable data. All related laws, rules, and regulations required for the study's implementation have been followed. The authors further stated that the article is the original study of the authors, and it has not been published elsewhere.

Data sharing statement: Data supporting the findings and conclusions are available upon request from corresponding author.

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APPENDIX A: CALCULATIONS

1. Determination of COD in the given water sample is tabulated in **Table A1**.

Table A1. COD test values

S/N	Volume of blank (ml)	Volume of sample (ml)	Volume of 0.1N FAS blank (ml)	Volume of 0.1N FAS sample (ml)
1	5	5	14.20	1.10
2	5	5	4.50	0.25
3	1	1	2.70	2.00
4	1	1	3.90	3.70
5	1	1	4.70	4.50
6	1	1	4.30	4.10

From the test result in **Table A1** calculated COD values using this formula, as follows: $COD=(A-B)\times N\times 1{,}000/V_s$, where A is volume of ferrous ammonium sulphate for blank, B is volume of ferrous ammonium sulphate for sample, N is normality of ferrous ammonium sulphate, and V_s is volume of sample used. Therefore, the values of COD treatment were obtained starting with the second run to help for easy identification of the change observed from the first run as indicated untreated and then recorded as shown in **Table 4**.

2. Determination of BOD

Table A2. BOD test values

S/N	Volume of blank (ml)	Volume of sample (ml)	Volume of titrate blank (ml) $Na_2S_2O_3$	Volume of titrate sample (ml) $Na_2S_2O_3$	Dissolved oxygen blank (mg/l)	Dissolved oxygen sample (mg/l)
1	327	333	0.40	1.10	0.40	1.10
2	327	274	0.60	1.10	0.60	1.10
3	328	279	0.60	0.80	0.60	0.80
4	327	279	0.50	0.60	0.50	0.60
5	274	279	1.70	1.90	1.70	1.90
6	274	285	1.50	1.60	1.50	1.60

Table A3. BOD_5 (five days) test values

S/N	Volume of blank (ml)	Volume of sample (ml)	Volume of titrate blank (ml) $Na_2S_2O_3$	Volume of titrate sample (ml) $Na_2S_2O_3$	Dissolved oxygen blank (mg/l)	Dissolved oxygen sample (mg/l)
1	328	324	0.20	0.40	0.20	0.40
2	285	314	0.10	0.10	0.10	0.10
3	328	274	0.30	0.10	0.30	0.10
4	327	319	0.30	0.10	0.30	0.10
5	327	314	0.10	0.10	0.10	0.10
6	327	331	0.10	0.10	0.10	0.10

3. Calculation of TSS

Table A4. TSS test values

S/N	Volume of sample (ml)	Volume of filtrate (ml)	Mass of sample (g)	Mass of filtrate (g)	Density of sample (g/ml)	Density of filtrate (g/ml)	TSS (percentage difference in density) (%)
1	1	1	1.03	0.98	1.03	0.98	4.85
2	1	1	0.99	0.95	0.99	0.95	4.04
3	1	1	0.98	0.95	0.98	0.95	3.06
4	1	1	0.99	0.97	0.99	0.97	2.02
5	1	1	0.99	0.98	0.99	0.98	1.01
6	1	1	0.99	0.98	0.99	0.98	1.01

4. Calculation of TDS

Table A5. TDS test values

S/N	Volume of sample (ml)	Mass of sample (g)	Mass of sample (after dryness) (g)	TDS (percentage dissolved solids) (%)
1	1	1.01	0.60	59.41
2	1	0.98	0.45	45.92
3	1	1.01	0.31	30.69
4	1	1.01	0.23	22.77
5	1	0.99	0.10	10.10
6	1	0.99	0.05	5.05