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A Systematic Research Trend on Membrane Bioreactor for Treatment of Wastewater: A Bibliometric Analysis

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ABSTRACT

The textile, pulp and paper, printing and dyeing industries cast various concentrated pollutants and contaminants. A membrane bioreactor (MBR) is an advanced treatment technology with a small footprint, low sludge production and gives high-quality water effluent for reuse. In this research, an exhaustive overview of the research trend on MBR technology for wastewater treatment from 2010 to 2022 using bibliometric research was studied. This study was executed on the core collection of the Scopus database. The bibliometrics R-package (version 3.1.4) and VOS viewer software were used to analyze the research trend. A dataset of 8,626 publications was retrieved. Behind screening and extracting identical and irrelevant data, 679 were exported in CSV format. The analysis results showed that the papers were published with an annual growth rate of 14.51%, with a yearly citation rate of each report at 126.70 times. China had produced most publications on MBR treatment technology with more corresponding nodes than other countries and territories. Water research was the maximum cited journal, with the number 2952. The research hotspot for the most often used terms, "Membrane Bioreactor" and "Membrane fouling" were shown in the network visualization map and density visualization. This analysis is an alternative and creative mode of divulging directions in MBR research.

Key words: Membrane bioreactor technology, wastewater treatment, research trend, bibliometric analysis

INTRODUCTION

One of the explicative issues of the 21st century is water dearth, defined as a condition in which available water supplies are insufficient to meet demand (Hussain *et al.,* 2022). One of the most critical international threats that could have an impact on the world over the next 10 years, according to the World Economic Forum 2019, is a lack of access to clean water (World Economic Forum, 2019). The world is fronting a primary global water quality concern due to rapid industrialization, urbanization and population growth (Kitanou *et al.,* 2018). The pulp and paper industry, printing and dyeing industry, and textile industry are some of the primary polluting industries that produce large amounts of wastewater that contains toxic heavy metals (Fe, Cu, As, Cr, etc.), phenolic organic compounds, and other persistent organic pollutants (POP; Thamaraiselvan and Noel, 2015; Kitanou *et al.,* 2018). Reusing treated water imposes an adequate solution for the future to fulfil sustainable development goal. Currently, a great deal of beneficial research on methods for treating industrial wastewater, such as adsorption, has been conducted (Garrone *et al.*, 2018), advanced oxidation process (Arzate *et al.*, 2019), membrane filtration (Konvensional., 2017), membrane bioreactor (Kannan *et al.,* 2023), etc. Among them, the membrane bioreactor is a superior advanced technique for treating industrial wastewater. Low sludge generation, a low carbon footprint, and adaptability in future evolution are further benefits of MBRs. Due to the process's reliability, the use of MBR technology for industrial wastewater treatment has also come to light. To provide high-quality effluent for water reusing Erkan and Engin (2017) claim that MBR, a technique for treating industrial wastewater that substitutes membrane filtration for a sedimentation tank, has been utilized extensively. The MBR's wastewater can be immediately recycled for

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unlimited irrigation (Kalavrouziotis *et al.*, 2015). Two of the essential benefits of MBR technology are high effluent quality and perfect separation of hydraulic retention time (HRT) and solids retention time (SRT; Xiao *et al.*, 2019). In existing years, there have been many studies on MBR for wastewater treatment (Amit *et al.,* 2020; Poojamnong *et al.,* 2020; Vinardell *et al.,* 2020; Rahman *et al.*, 2023). It resolves to be easier to share research successes and identify future research directions unless studies on MBR are systematically evaluated. Examples include those involved in the treatment of industrial wastewater (Erkan and Engin, 2017), municipal wastewater treatment (Ittisupornrat *et al.,* 2023), model development (Shin *et al.,* 2021), and membrane fouling (Hansen *et al.,* 2021). In comparison, quantitative methods are insufficient to systematically outline the entire literature on industrial wastewater treatment techniques. Therefore, the industrial wastewater research hotspot and upcoming advances are challenging to understand from a macro perspective.

The bibliometric tool and VOS viewer were adequate instruments for analyzing scientific research both quantitatively and qualitatively. It has recently attracted much attention for the systematic study of publications. It employs statistical and mathematical methods to analyze the references, the volume of the literature's external characteristics (including articles, books and patents; citations and co-citations) and research tendency in a specific field. The output measurement provides researchers with information on the state of the research to help them to locate and establish new research directions. According to Cooper (2015), scholars have widely used bibliometrics to analyze specific journals and have become an essential method for the research community. Generally, there exist two categories for this procedure. One group is determined by journals, nations with a specific climate, and how much activity there is surrounding a hot issue in that field. The second group is to identify connections and interconnections between keywords, nations and institutions; relationship indicators and social network analysis used. These two categories have demonstrated how issue trends, topics and research methodologies are essential to the research field and how they change over time. The outputs of MBR research from 2010 to 2022 were analyzed bibliometrically in this publication to illuminate underlying trends in annual publications, the geographic distribution of scientific production, and provide publication scenarios of contributing journals, countries, and authors for future research trends related to MBR for wastewater treatment.

MATERIALS AND METHODS

The digital document platform Scopus was created by Thomson Scientific for Elsevier and has a sizable number of peer-reviewed researches pertinent to the subject of this paper. On October 6, 2022, data for this study were retrieved from Scopus' online database. Bibliometric tools, such as the bibliometric R-tool package was used to graphically display the statistical outcomes of an academic text. Firstly, the articles related to pulp and paper industry wastewater treatment using MBR were searched using the keywords "Membrane Bioreactor" and "Pulp and Paper wastewater". Fig. 1 shows the framework for the identification and selection of research activities. The data were acquired from 8,626 publications between the year 2010 to 2022; the language was selected English with the subject of environmental science, material science and multidisciplinary. 679 records remained after filtering and weeding out duplicate and irrelevant data. The search results were produced in CSV and plain text formats with "complete record and reference", along with citation data, abstracts, keywords, etc. CiteSpace then performed an analysis of the data. Fig. 2 provides a summary of the bibliographic statistics of the studies obtained.

RESULTS AND DISCUSSION

According to the bibliometric analysis "Article" was the dominant sort of publication; only articles were analyzed in tardy research for the elaboration of industrial expansion advances, the demand for wastewater treatment and reuse. Due to various deterrents and hindrances, such as inadequate treatment solutions, outrageous costs, lack of basic niceties, insufficient financial assistance and technological expertise, sustainable treatment of industrial

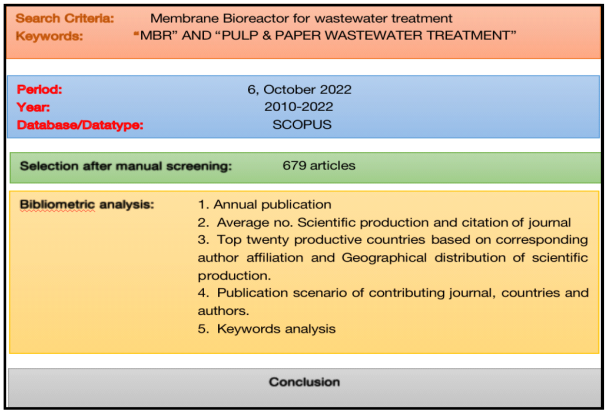

Fig. 1. The frame diagram of identification and selection of research work depicted.

Fig. 2. Summary of the bibliographic statistics of the studies obtained.

effluents became a demanding process in most parts of the world, i.e., MBR advanced treatment technology for a sustainable domestic, industrial and saline wastewater solution. To effectively separate waste mixtures, MBR approaches combined a hybrid biological reactor with membrane units for biodegradation. The first known usage of an MBR was in 1969, when AS was removed from a biological wastewater treatment system's effluent using an ultra-filtration membrane. This technology was used for the treatment of various wastewaters. According to Amit *et al.* (2020), MBR treated dairy wastewater and municipal wastewater. MBR was also used to treat Bleach Pulp Mill Effluent by MF-MBR. MBR permeate water with an incredible effluent quality for water reuse or recycling (Fatima *et al.*, 2021; Han, 2021; Zhang and Liu, 2022).

The entire distribution of studies for treating wastewater using MBR from 2010 to 2022 has been shown in Fig 3. The frequency of papers that have been published can be a valuable predictor of future emerging trends along with variations in research topics over time. The vertical axis indicated the number of published papers, and the horizontal axis displayed the year of publication. The publication level has

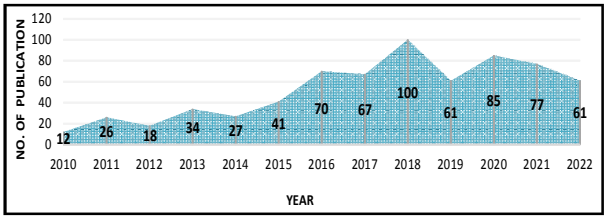

Fig. 3. Temporal distribution of annual publication.

fluctuated over time from the annual scientific production perspective. The number of yearly publications on treating wastewater using MBR was 679. In 2010, only 12 papers were published. From 2011, the number of published articles showed a gradual upward trend and reached a peak in 2018 (100 papers) and sanked in 2022 (61 papers) with an annual growth rate of 14.51%. However, the annual growth rate of published articles mostly stayed the same. It remained the same because of the advantage of MBR for treating different types of wastewater and the limitation of the membrane, such as membrane fouling, the membrane's life span, and membrane production technology.

The average annual number of citations for documents has been shown in Fig. 4 employing the bibliometrix tool (version 3.1.4). The average number of citations appears to have peaked in 2014. The bibliometrix software was used to obtain the information in Table 1 (version 3.1.4). There were a total of 27 publications published in 2014, and each one received an average of 126.70 total citations. Each article received an average of 3.44 total citations per year. The overall citation pattern for this subject, as shown in Fig. 4, has a diagonal tendency and has received more attention from academics in recent years.

Table 2 depicts the geographical distribution of scientific publications based on all authors' associations. Accordingly, China, Australia, Spain, Italy and Japan are the countries that have published the most documents on MBR treatment technology. The quantity of scholarly works from various countries where the related authors reside was utilized to rank the productivity of those nations. Accordingly, Table 3 lists the top 20 nations that have investigated the use of MBR for treating wastewater from the pulp and paper industry. China was at the top of the list with 113 pieces, spread among 76 publications in one country and 37 productions across several nations. Additionally, scholars from India published 11

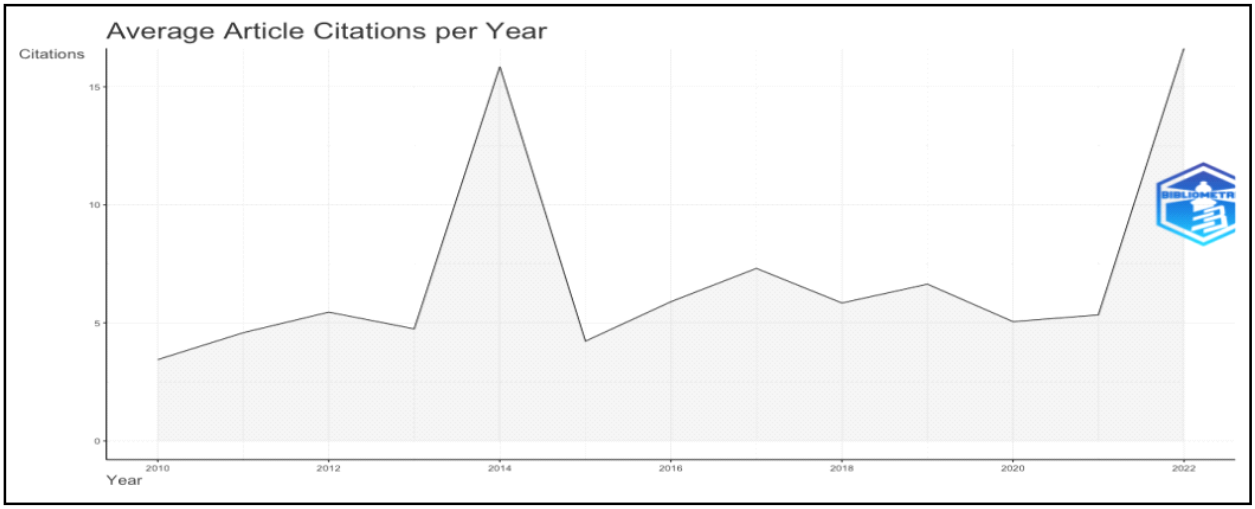

Fig. 4. Annual average of article citations.

Table 1. Average annual citations

Year	N	Mean TC per art	Mean TC per year	Citable years
2010	12	41.33	3.44	12
2011	26	50.42	4.58	11
2012	18	54.56	5.46	10
2013	34	42.71	4.75	9
2014	27	126.70	15.84	8
2015	41	29.56	4.22	7
2016	70	35.37	5.90	6
2017	67	36.54	7.31	5
2018	100	23.37	5.84	4
2019	61	19.92	6.64	3
2020	85	10.11	5.05	2
2021	77	5.34	5.34	1
2022	61	0.75		0

Note: Citable years are the period of time from the publication year of an article to the present. Mean TC per article is average number of citations for each article. Mean TC per year is the average annual number of citations for each publication.

Table 2. The geographical distribution of scientific publications

Rank	Country	Frequency	Rank	Country	Frequency
1	China	729	11	Canada	86
2	Australia	330	12	Belgium	85
3	USA	300	13	Germany	80
4	Japan	292	14	Turkey	65
5	Spain	288	15	Netherlands	61
6	Italy	208	16	Saudi Arabia	61
7	UK	156	17	Greece	45
8	France	122	18	India	43
9	Singapore	116	19	Denmark	39
10	South Korea	103	20	Finland	38

articles, seven of which were produced in a single nation and four of which were produced in multiple nations. In conclusion, the research on the treatment of wastewater using MBR varies from nation to nation. China had

Table 3. Top 20 nations based on associations of corresponding authors

Country	Articles	SCP	MCP	Freq.	MCP ratio
China	113	76	37	0.166	0.327
Australia	56	28	28	0.082	0.5
Spain	45	38	7	0.066	0.156
Italy	41	22	19	0.06	0.463
Japan	40	33	7	0.059	0.175
USA	36	24	12	0.053	0.333
Singapore	23	11	12	0.034	0.522
United Kingdom	23	14	9	0.034	0.391
France	19	14	5	0.028	0.263
Korea	18	11	7	0.027	0.389
Canada	16	12	4	0.024	0.25
Germany	14	3	11	0.021	0.786
Saudi Arabia	14	6	8	0.021	0.571
Turkey	14	9	5	0.021	0.357
India	11	7	4	0.016	0.364
Finland	10	5	5	0.015	0.5
Thailand	10	3	7	0.015	0.7
Belgium	9	5	4	0.013	0.444
Malaysia	8	5	3	0.012	0.375

more equivalent nodes than other countries and territories, making it the most productive country. The top 10 most productive nations in terms of publications on MBR wastewater treatment technology are China, Australia, Spain, Italy and Japan. There are many cooperative organizations between countries, particularly between China, Australia, Spain and Italy.

Table 4 depicts the top 20 most cited journals on MBR, along with titles, authors and journals. Water Research, “Bioresource Technology, Membrane Science, Environment Science and Technology, Environment Chemical Engineering, etc., were found to be paramount journals publishing research articles on MBR technology for pulp and paper wastewater

Table 4. Top 20 most cited documents on MBR along with authors, title and journal

S. No.	Title and journal	Total citations	TC per year
1.	Lares *et al.* (2018). Occurrence, identification and removal of microplastic particles and fibers in conventional activated sludge process and advanced MBR technology. *WATER RES.*	468	93.60
2.	Tadkaew *et al.* (2011). Removal of trace organics by MBR treatment: The role of molecular properties. *WATER RES.*	346	28.83
3.	Kovalova *et al.* (2012). Hospital wastewater treatment by membrane bioreactor: Performance and efficiency for organic micropollutant elimination. *ENVIRON. SCI. TECHNOL.*	339	30.82
4.	Krzeminski *et al.* (2017). Membrane bioreactors - A review on recent developments in energy reduction, fouling control, novel configurations, LCA and market prospects. *J. MEMBR. SCI.*	284	47.33
5.	Judd (2016). The status of industrial and municipal effluent treatment with membrane bioreactor technology. *CHEM. ENG. J.*	168	24.00
6.	Verrecht *et al.* (2010). The cost of a large-scale hollow fibre *MBR. WATER RES.*	150	11.54
7.	Jang *et al.* (2013). Effects of salinity on the characteristics of biomass and membrane fouling in membrane bioreactors. *BIORESOUR. TECHNOL.*	146	14.60
8.	Skouteris *et al.* (2015). The effect of activated carbon addition on membrane bioreactor processes for wastewater treatment and reclamation - A critical review. *BIORESOUR. TECHNOL.*	140	17.50
9.	Arefi-Oskoui et al.(2019). A review on the applications of ultrasonic technology in membrane bioreactors. *ULTRASON. SONOCHEM.*	133	33.25
10.	Wijekoon *et al.* (2013). The fate of pharmaceuticals, steroid hormones, phytoestrogens, UV-filters and pesticides during MBR treatment. *BIORESOUR. TECHNOL.*	132	13.20
11.	Luo *et al.* (2017). Osmotic versus conventional membrane bioreactors integrated with reverse osmosis for water reuse: Biological stability, membrane fouling and contaminant removal. *WATER. RES.*	130	21.67
12.	Hai *et al.* (2011). Removal of micropollutants by membrane bioreactor under temperature variation. *J. MEMBR. SCI.*	127	10.58
13.	Nguyen *et al.* (2012). Removal of trace organic contaminants by a membrane bioreactor-granular activated carbon (MBR-GAC) system. *BIORESOUR. TECHNOL.*	126	11.45
14.	Huang *et al.* (2015). A novel composite conductive microfiltration membrane and its anti-fouling performance with an external electric field in membrane bioreactors. *SCI. REP.*	115	14.38
15.	Holloway *et al.* (2014). Removal of trace organic chemicals and performance of a novel hybrid ultrafiltration-osmotic membrane bioreactor. *ENVIRON. SCI. TECHNOL.*	112	12.44
16.	Ren *et al.* (2010). Novel membrane bioreactor (MBR) coupled with a non-woven fabric filter for household wastewater treatment. *WATER RES.*	110	8.46
17.	Li *et al.* (2011). Simultaneous activated carbon adsorption within a membrane bioreactor for an enhanced micropollutant removal. *BIORESOUR. TECHNOL.*	103	8.58
18.	Deng *et al.* (2016). Biofouling and control approaches in membrane bioreactors *BIORESOUR. TECHNOL.*	96	13.71
19.	Merayo *et al.* (2013). Assessing the application of advanced oxidation processes and their combination with biological treatment to effluents from pulp and paper industry. *J. HAZARD MATER*	87	8.7
20.	Luo *et al.* (2014). High retention membrane bioreactors: Challenges and opportunities. *BIORESOUR. TECHNOL.*	86	9.56

treatment. According to Lares *et al.* (2018) Water Research had the highest citation in the article occurrence, identification and removal of microplastic particles and fibres in conventional activated sludge process and advanced MBR technology. Krzeminski *et al.* (2017) proposed that journal of Membrane Science provided a review on membrane bioreactors on recent developments in energy reduction, fouling control, novel configurations, LCA and market prospects. According to Poojamnong *et al.* (2020) Environment Chemical Engineering journal informed that fluorescence regional integration was used to characterize reversible and irreversible foulants in a membrane bioreactor (MBR) for the treatment of wastewater from eucalyptus pulp and paper mills. As per Scholes *et al.* (2019) Journal of Environmental Chemical Engineering, provided colloidal carbon interference in the treatability of pulp and paper wastewater by MBR.

Fig. 5 shows the top 10 most cited journals with number of local citations for treatment of

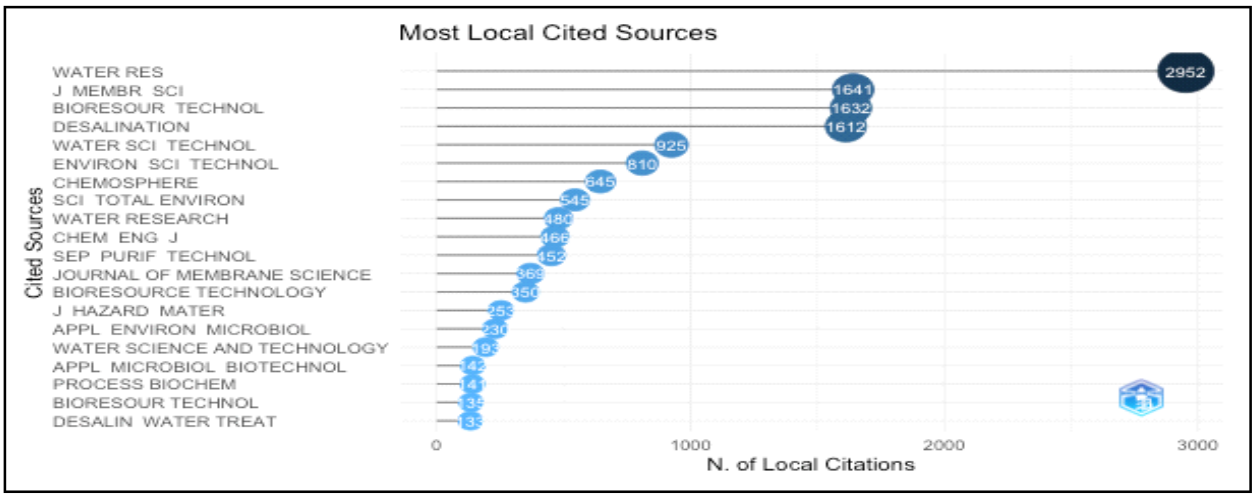

Fig. 5. Top 20 most cited journals.

wastewater using MBR. Journal of Water Research was first with maximum citation numbers 2952, Journal of Membrane Science second with 1641 and Journal of Bioresource Technology third with 1632.

CONCLUSION

Water scarcity stands as one of the explicative challenges of the 21st century and one of the most significant international risks that could influence the world over the next decade. Therefore, reusing treated water imposes an adequate solution for the future to fulfil the demand. Many researchers have conducted a vast amount of helpful research on industrial wastewater treatment techniques. The Membrane Bioreactor (MBR) was a superior advanced technology for treating industrial wastewater. Using bibliometric tools such as the bibliometric R-tool package and VOS viewer software, the research was aimed at studying the research trend in MBR for the treatment of industrial wastewater. The analysis was found on October 6, 2022, and data were retrieved from the Scopus database. Firstly, the articles related to pulp and paper industry wastewater treatment using MBR were searched using the keywords Membrane Bioreactor and Pulp and Paper Wastewater. The conclusion of the temporal distribution of an annual publication was classified into three significant types with rapid growth period 2010-2022. Thus, the number of papers published showed the change in annual scientific production year by year with an annual growth rate of 14.51%. The average citation of documents indicated a zigzag trend and payed more attention to a scholar in the wastewater treatment field. Furthermore, the geographical distribution of scientific publications concluded that China, Australia, Spain, Italy and Japan published more articles on MBR treatment technology. Water Research, Bioresource Technology and Membrane Science were the most cited journals on MBR. The results presented in this article were also dynamic and changed over time, and research trends on MBR for wastewater treatment overgrow. Therefore, a systematic study is required to locate and thoroughly assess existing MBR technology for wastewater treatment.

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