A Scientometric Analysis of Research on Bio Filtration of Waste Gas Streams During 1989-2020

Shanmugam Rajeswari

Anna University

Panchamoorthy Saravanan (✉ pancha_saravanan@yahoo.com)

Anna University <https://orcid.org/0000-0001-9499-0807>

Nagendiran Jaya

Anna University

Mookan Rengasamy

Anna University

Divya Baskaran

Anna University

Viswanathan Saravanan

Annamalai University

Rajan Rajesh kannan

Annamalai University

Manivasagan Rajasimman

Anna University

Research Article

Keywords: Biofilter, Air Pollution Control Technologies, Histcite, VoS Viewer, Bradford's Law, Relative Growth Rate.

Posted Date: August 26th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-672214/v1>

License: This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

A scientometric analysis of research on bio filtration of waste gas streams during 1989-2020

Shanmugam Rajeswari¹. Panchamoorthy Saravanan^{2*}. Nagendiran Jaya².Mookan

Rengasamy².Divya Baskaran³. ViswanathanSaravanan⁴. Rajan Rajesh kannan⁴. Manivasagan

Rajasimman⁴.

¹*Department of Library, UCE - BIT Campus, Anna University, Tiruchirappalli, Tamil Nadu,*

620024, India

^{2, 2*}*Department of Petrochemical Technology, UCE - BIT Campus, Anna University,*

Tiruchirappalli, Tamil Nadu, 620024, India

³*Department of Chemical Engineering, Sri Venkateswara College of Engineering,*

Sriperumbudur, Tamil Nadu, 602117, India

⁴*Department of Chemical Engineering, Annamalai University, Chidambaram, Tamil Nadu,*

608002, India

*Corresponding Author

Dr. P. Saravanan

Assistant Professor

Room No: 24, Academic Block -B,

Department of Petrochemical Technology

University College of Engineering,

Bharathidasan Institute of Technology Campus

Anna University,Tiruchirappalli - 620 024.

Mobile number 9943902025

E. Mail: pancha_saravanan@yahoo.com

Graphical abstract

Abstract

Biofiltration is a superior method of pollution control technologies among the various physical, chemical and biological methods. This process uses active microorganisms and to degrade pollutants produce innocuous end products. Microbes present in the filter materials used in remove of contaminants from the air effectively. A total of 1386 bibliographic records from the Web of Science (WoS) database were extracted and analyzed to report the analysis of scientific state of the authors, journals, countries, and categories. Histcite and VoSviewer software's are used for analyzing records. In the study, we have analyzed annual contribution, authorship pattern, type of document, language, degree of collaboration, Collaborative index, Co-author index, relative growth rate and doubling time, Bradfords law, h-index, subject wise, countries and co-occurrence keywords. The results indicate that USA and China are the most contributing countries in biofiltration. This study therefore, provides an extensive understanding about the trends and research patterns of biofilter of air efforts worldwide. Finally, research gaps and environment pollution issues are highlighted and the scope for future also discussed.

Keywords Biofilter. Air Pollution Control Technologies. Histcite. VoS Viewer. Bradford's Law. Relative Growth Rate.

Introduction

Bio filtration is an acceptable method for waste gas treatment technologies among the various conventional methods (Siswanto et al.2020). This process uses active organisms to filter unwanted gas streams in the polluted air streams (Vikrant et al. 2018). Microbes present in the filter materials used in remove the contaminants from the polluted air through adsorption, diffusion and degradation. (Saravanan et al. 2009; Malakar et al. 2017). The carbon-containing pollutant is shifted into a biofilm applied to the outer wall of the packaging material when the air passes through a reactor (Khanongnuch, 2019; Torpy et al.2018).Biofiltering varies from the other physical and chemical methods in that there is no solvent step involved. Biofilters have shown most cost-effective alternative method in two areas: odour control and the separation of organic solvent vapors from waste air steams (Tiwari et al. 2019; Ashokumar at al. 2015; Barbuinski et al. 2020;Sazakli et al.2021). A humidified stream of polluted air is transferred by porous packing, which automatically immobilizes the microorganisms. Mixed microbial communities form a biofilm on the packaging material's surface, which cause major pollutant biodegradation (Ashokumar at al. 2016; Rajamanickam et al. 2020).

Some of the major factors that stimulus of removal of pollutants from air like, unending operation of biofilters (Rybarczyk et al. 2019), high pollutants loading rate (Kumar et al. 2019), packing material drought (Gopinath et al. 2018), acid or base and significant nutrient (Salgar et al. 2020). Due to in continuing process of biofilter with high pollutants loading rate, high removal of biofilter is connected to various concert parameters such as features of packing material, humidity of packing media(Sun et al. 2020; Cheng et al. 2019; Rahmat et al. 2017; Soret et al. 2018; Luenga et al. 2017), pH of media (Lu et al. 2002; Saucedo-Lucero and Revah, 2018), nutrient application (Son et al. 2005; Dolphen et al. 2020), and temperature (Li et al. 2020; Mohammed et al. 2017).

Biodegradability of particular pollutants depends on its loading rate, provided other factors are satisfactory. The loading rate is measured by the gas velocity through the bed and the concentration of VOC in the influent stream (Leili et al. 2017; Detchanamurthy et al.2012). At low loading the pollutant can frequently be completely removed from the air stream. Pollutant with low solubility and high Henry`s constant in water, are likely to be affected by diffusion limitations due to their low solubility in aqueous phase and hence may require lower loading

(Yang et al. 2018). Similarly, high concentrations of toxic pollutants will inhibit biofiltration performance.

The rate of degradation increases with increasing pollutant concentration until the maximum removal capacity is reached. Further increase in loading rates results in breakthrough (Terry et al. 2018; Lu and Chen 2018). The best loading condition is obtained by the combination of both flow rate and concentration. Gas flow rates through the bed vary considerably. An average velocity through the filter bed is about 10 to 100 m/h. Highly biodegradable pollutants can be treated at much higher superficial velocity. Rene et al. (2018) performed the compost/ceramic biofilter for the removal of gas-phase toluene (or) xylene concentration was varied from 0.1 to 1.5 g/m³. Yang et al. (2018) reported the simultaneous removal of multicomponent volatile organic compounds in biofilter. There are different observations ranging from co metabolism to inhibition of biodegradation for certain hydrocarbons in the presence of other carbon sources or pollutants (Baskaran et al. 2019; Rabbani et al. 2015).

Conventional biofilters depend on natural microorganisms found in compost, soil, peat or other solid media without microbial inoculation. Recent studies show that inoculation of the filter bed with acclimatized culture, activated sludge or microorganisms isolated from contaminated environments improve biodegradation rates (Das et al. 2019; Zhai et al. 2020; Ralebitso-Senior et al. 2012; Kraakman et al. 2021). The inoculum increases the biomass density, hence high biodegradation rates obtained throughout the treatment process. For that reason, modern biofiltration research uses inoculates to reduce biofilter acclimation time and improve overall biodegradation rates (Kumar et al. 2019).

Ottengraf et al. (1986) studied the moisture content of the filter bed is a serious factor for biofilter performance, because microorganisms require water to carry out their normal metabolic activities. Low humidity content sources for the bed drying, laterally with the enlargement of gaps that cause channeling and short circuiting. This also denies microorganisms of water, producing important decrease in the removal rate. Optimal water levels differ with the various packing media, dependent on surface area of medium, void volume and other few factors (Vergara-Fernandez et al. 2018; Irga et al. 2018).

Temperature regulator is also very vital role in biofiltration to evade heat shocks. The classes of microorganism based on temperature classified as psychrophilic microorganisms with

a temperature range of 10- 20°C; mesophilic microorganisms with a temperature range of 20–40°C and thermophilic organisms having the temperature range of above 45°C(Huber 2004; Singh et al. 2017). Biological activity roughly doubles for each 10°C rise in temperature, up to an optimum of about 37°C for mesophilic bacteria. The recommended temperature range for biofiltration is between 15 and 40°C (Deshusses et al. 1999; Bohn 1999).

Carbon and energy essential for microorganisms may be formation from the pollutant gas, although extra nutrients such as nitrogen, phosphorus, minerals, and trace elements would be complete to microorganisms in the biofilter for better performance (Varma et al. 2018; Kennes et al. 2013). Natural packing media (e.g., peat, compost) cover nutrients to support biomass formation but, in the case of synthetic packing material, nutrients would be providing for good performance. (Chen et al. 2012) reported nitrogen necessities for biofiltration of methanol and create that, the elimination rate oscillation due to level of nitrogen by addition of NH_3 and NO_3 .

In a biofilter, the biomass mains to elimination of pollutants over time, which has been connected to growth in flow rate of air in the bed. Biomass gathering is better at the commencement segments of the biofilters, and leads to a variation in bed features e.g., decrease in inter particle void space, and the compaction of natural packing material like wood chips; these variations source for channeling and better pressure drop (Ryu et al. 2010; Xi et al. 2015;Paull et al. 2019). In overall, there is an around linear growth in pressure drop with growing gas flow rate, which starts to develop exponential at higher flow rates.

(Bohn 1999) reported the populations of microorganism in the packing materials found to be one billion microorganisms per gram of packing material. Many groups of microorganisms are known to be present in the biofiltration of gaseous pollutant. (Ottengraf 1987). There are few reports on utilizing a co-culture of fungi and mites for the biofiltration of hydrophobic pollutants (Prenafeta-Boldu 2001; Zhao et al. 2011; Datta and Allen 2005). For simply biodegradable organic compounds, adaptation can characteristically take less than ten days, and for fewer biodegradable pollutant and those impurities for which the microorganisms are fewer possible to be originally present in the biofilter material, the period can be lengthier (Leson et al. 1991). Microorganisms can endure for honestly long periods of upto 60 days when the biofilter is not loaded (Ottengraf et al. 1983) and if enough nutrients are obtainable from the filter material (Leson et al. 1991; Kam et al. 2011).

140 The packing material would offer better removal features over a period of 2 to 4 years
141 (Dorado et al. 2010). Its cost would be inexpensive when associated to the other asset costs and it
142 would not decay physically so that elimination proceeding to repacking shows expensive.

143 Evidently, more and more scientometric reports on air pollution control production have
144 been published (Ali Hamidi et al. 2020). However, up to now some of the key factors have not
145 yet been discussed such as bio filtration of waste gas streams, contribution of authors and
146 institutions and data on citation with high published journals list in the bio filtration of waste gas
147 streams. Therefore, the present study aimed to explore the growth of published biofilter
148 literatures by scientometric analysis. To find out the high published core journals through
149 evaluation of the productivity distribution of institutes and major contributing countries on this
150 interest.

151 **Methodology**

152 **Application of scientometrics analysis**

Fig. 1 Research framework of this study

Figure 1 depicts a schematic illustration of scientometric analysis of biofilter of polluted air. For scientometrics analysis, we used the “Web of Science” record which is regularly used by investigators worldwide. WoS record is measured as one of the most dependable foundations to

become evidence on the published work in a precise area of research, and later, investigators have been broadly using this record (Li et al. 2018; Schanes 2018).

This database includes peer-reviewed journal articles, conferences, editorials, book chapters, and review papers, among other forms of publications. The scientific output information for this bibliographic review was obtained from Web of Science's Core Collection Data (Rajeswari et al., 2021). Microsoft Excel and BibExcel were used to examine the features of the publications. The frequency analysis was done with (Persson O., 2009) and the network diagrams for the collaboration study were made with Pajek 1.0.0.1 (Batagelj 1998) and VOS viewer (Van Eck 2013).

The literature search was conceded out on the WoS core gathering using the exploration engine, “bio filter of air” presented in the keywords, abstract or title of the article. All articles which had been published between 1989 (1st January) and 2020 (31st December) were included. The search process was carried out on March 26th 2021. Thirteen hundred and eighty-six multilingual bibliographic records were collected. Twelve procedures were used to continue with this investigation among the scientometric analysis approaches, which are defined as the analysis following the data collection. (1) publication history, (2) analysis on the variety of documents, (3) Country analysis, (4) authors’ Contribution’s analysis, (5) keywords analysis, (6) cited authors analysis, (7) cited journals analysis, (8) categories analysis, (9) cited document frequency analysis (10) Relative growth Rate and Doubling Time (11) Degree of Collaboration and Collaborative Index (12) Subject analysis and (12) Authors h-index. As a result, these strategies have been deployed, and significant portions of the software output from Histcite, Bibexcel, and VoS readers have been represented.

Results and discussion

Research on bio filtration of waste gas streams during 1989-2020

In the following, the results obtained from the analysis carried out with the computational tools are presented.

Table 1 Year-wise distribution of Research Publication

S.No	Publication Years	Records	%	TLCS	TGCS
1	1989	1	0.1	8	10
2	1990	2	0.2	0	0
3	1991	3	0.2	255	459

4	1992	3	0.2	0	0
5	1993	3	0.2	165	246
6	1994	13	0.9	329	619
7	1995	8	0.6	247	411
8	1996	11	0.8	168	347
9	1997	50	3.6	929	1755
10	1998	27	1.9	674	1492
11	1999	32	2.3	456	1010
12	2000	35	2.5	643	1914
13	2001	63	4.5	595	1705
14	2002	37	2.7	315	1178
15	2003	56	4.0	594	1797
16	2004	46	3.3	452	1006
17	2005	69	5.0	946	2526
18	2006	52	3.8	439	1374
19	2007	50	3.6	517	1662
20	2008	59	4.3	456	1743
21	2009	92	6.6	661	2051
22	2010	61	4.4	633	1571
23	2011	58	4.2	368	1127
24	2012	95	6.9	402	1467
25	2013	58	4.2	255	819
26	2014	49	3.5	177	666
27	2015	50	3.6	175	580
28	2016	62	4.5	165	935
29	2017	61	4.4	186	779
30	2018	55	4.0	104	546
32	2019	58	4.2	41	255
33	2020	67	4.8	4	84
Total		1386	100	11359	32134

185 TLCS- Total Local Citation Score; TGCS- Total Global Citation Score

Fig. 2 Annual contribution of research output on biofilter of air

Annual growth of publication

During the study period 1989-2020, Table 1 and Figure 2 show the rise of research papers in the field of biofilter of air literature. In total, 1386 publications were published. The biggest numbers of papers (95, or 6.9%) were published in 2012, while the lowest numbers of research articles (one, or 0.1%) were published in 1989. The year 2009 saw the second largest number of articles published, with 92 (6.6%). The research output of air biofilters has been steadily increasing.

Table 2 Document wise distributions of publications

S.No	Document wise	Records	%	TLCS	TGCS
1	Article	1219	88.0	9455	24927
2	Proceedings Paper	95	6.9	949	2536
3	Review	59	4.2	951	4659
4	Early Access	4	0.3	0	0
5	Editorial Material	3	0.2	4	11
6	Meeting Abstract	3	0.2	0	0
7	Correction	2	0.1	0	1
8	Review; Early Access	1	0.1	0	0
	Total	1386	100	11359	32134

TLCS- Total Local Citation Score; TGCS- Total Global Citation Score

Fig. 3 Type of documents on biofilter of waste gas stream

Publication type analysis

Table 2 and Figure 3 show that from 1989 to 2020, there were eight different types of documents published on biofilter of air. There were a total of 1386 documents published. There were 1219 research articles in this document format, accounting for 88 percent of all published materials. Proceeding papers accounted for 95, review articles for 59, early access for four, editorial material for three, and meeting abstracts for three. Correction and Early Access were published 2 and 1 respectively.

Table 3 Language wise Distributions of publications

S.No	Language wise	Records	%	TLCS	TGCS
1	English	1356	97.8	11304	32021
2	Polish	13	1.0	12	43
3	German	6	0.4	4	14
4	French	5	0.4	31	46
5	Spanish	3	0.2	0	1
6	Korean	2	0.1	6	7
7	Czech	1	0.1	2	2
		1386	100	11359	32134

TLCS- Total Local Citation Score; TGCS- Total Global Citation Score

Fig. 4 Language contribution on biofilter of air

Language contribution on biofilter of air

Table 3 and Figure 4 show that biofilter of air was published in seven languages between 1989 and 2020. There were a total of 1386 documents published. The English language made the most contribution in this language 1359 (97.8 %). Czech was the language with the smallest contribution, 1 (0.1 %).

Table 4 Authorship pattern of Literature

Authors	Records	Percentage
Single	34	2.45
Double	250	18.03
Three	362	26.12
Four	309	22.29
Five	227	16.38
Six	115	8.30
Seven	49	3.54
Eight	21	1.52
Nine	11	0.79
Ten and More than Ten	8	0.58
	1386	100

Fig. 5 Authorship pattern on biofilter of air

Authorship analysis

The authorship pattern of biofilter of air literature is depicted in Table 4 and Figure 5. The authorship pattern up to ten authors results in a total of 1378 research output, with the remaining eight papers published by more than ten authors. During the study period, single author contributions accounted for 2.45 %. Three authors received the greatest percentage of 26.12%; followed by four writers, quadruple authors, five writers, six authors, seven writers, eight writers, and more than 10 authors.

Table 5 Collaborative Measures

Publication Years	Single Author (Ns)	Multi Author (Nm)	Total No. of Articles (Ns+Nm)	Total No. of Authors	DC	CI
1989	-	1	1	3	1	3
1990	-	2	2	9	1	4.50
1991	1	2	3	5	0.67	1.67
1992	-	3	3	20	1	6.67

1993	-	3	3	9	1	3
1994	-	3	13	35	0.23	2.69
1995	1	7	8	21	0.88	2.63
1996	1	10	11	40	0.91	3.64
1997	3	47	50	164	0.94	3.28
1998	-	27	27	90	1	3.33
1999	2	30	32	99	0.94	3.09
2000	-	35	35	119	1	3.40
2001	4	59	63	206	0.94	3.27
2002	1	36	37	131	0.97	3.54
2003	1	55	56	189	0.98	3.38
2004	-	46	46	159	1	3.46
2005	2	67	69	225	0.97	3.26
2006	2	50	52	163	0.96	3.13
2007	2	48	50	182	0.96	3.64
2008	-	59	59	223	1	3.78
2009	3	89	92	348	0.97	3.78
2010	1	60	61	250	0.98	4.10
2011	2	56	58	246	0.97	4.24
2012	3	92	95	391	0.97	4.12
2013	-	58	58	250	1	4.31
2014	-	49	49	234	1	4.78
2015	2	48	50	207	0.96	4.14
2016	1	61	62	248	0.98	4
2017	2	59	61	263	0.97	4.31
2018	-	55	55	270	1	4.91
2019	-	58	58	254	1	4.38
2020	-	67	67	317	1	4.73
Total	34	1352	1386	5381	0.98	3.88

*DC = Degree of Collaboration **CI = Collaborative Index

235

236

Fig. 6 Collaborative measures of biofilter of air

Collaborative Measures

Degree of Collaboration: In order to identify the degree of collaboration, the researcher has adopted Subramanyam formula. The formulae is

$$C = \frac{N_m}{N_m + N_s} \quad \text{Eq (1)}$$

Where,

C = Degree of collaboration in a discipline

N_m = Number of multiple authored papers

N_s = Number of single authored papers

$$\text{Collaborative Index} = \frac{\text{Total Paper}}{\text{Total Authors}} \quad \text{Eq(2)}$$

Table 5 and Figure 6 represent the Degree of Collaboration and Collaborative Index.

From the statistic given highest collaboration index found in 1992. It was 6.67. The average

254 collaborative index was 3.88. Degree of Collaboration was 1.00. In the year 1989, 1990, 1992,
 255 1993, 1998, 2000, 2004, 2008, 2013, 2014 the degree of collaboration is much similar.

256 **Table 6** Co-Authorship Index

Publication Years	Single Author (N _s)	Multi Author (N _m)	CAI	Total No. of Articles (N _s +N _m)
1989	-	1	102.56	1
1990	-	2	102.56	2
1991	1	2	68.38	3
1992	-	3	102.56	3
1993	-	3	102.56	3
1994	-	3	23.67	13
1995	1	7	89.74	8
1996	1	10	93.24	11
1997	3	47	96.41	50
1998	-	27	102.56	27
1999	2	30	96.15	32
2000	-	35	102.56	35
2001	4	59	96.05	63
2002	1	36	99.79	37
2003	1	55	100.73	56
2004	-	46	102.56	46
2005	2	67	99.59	69
2006	2	50	98.61	52
2007	2	48	98.46	50
2008	-	59	102.56	59
2009	3	89	99.22	92
2010	1	60	100.88	61
2011	2	56	99.03	58
2012	3	92	99.32	95
2013	-	58	102.56	58
2014	-	49	102.56	49

2015	2	48	98.46	50
2016	1	61	100.91	62
2017	2	59	99.20	61
2018	-	55	102.56	55
2019	-	58	102.56	58
2020	-	67	102.56	67
Total	34	1352	100	1386

CAI- Co-Authorship Index

Fig. 7 Co-author Index of biofilter of air

Co-Authorship Index (CAI)

Co-authored articles have been found to be mentioned more frequently, and the biofilter of air research is no exception. The results of the analysis demonstrate that the CAI value has risen over time. This means that in the biofilter of air, teamwork is characterized by multi-authored contributions rather than single-authored contributions. For calculating Co-Authorship Index (CAI), Garg and Padhi (2001) proposed a formula-

268

269

$$CAI = ((\frac{N_{ij}}{N_{io}})/(\frac{N_{oj}}{N_{oo}}))100 \quad \text{Eq(3)}$$

271 Where

272 N_{ij} = number of papers having j authors in block i 273 N_{io} = Total output of block i 274 N_{oj} = No. of papers having j authors for all blocks.275 N_{oo} = Total number of papers for all authors in all blocks276 $J = 1, 2, (3, 4) \text{ and } (\geq 5)$

277 Table 6 and Figure 7 exhibit the results of the analysis, which reveal that multiple author
 278 papers have a higher impact than single author studies. As a result, it's safe to assume that
 279 collaborative research is common in biofilter research. The data shows that CAI has been
 280 increasing and decreasing during the study period. This means that multi-authored articles, rather
 281 than solo contributions, are the primary source of collaboration in biofilter of air research.

282 **Table 7** Relative Growth Rate and Doubling Time

Publication Years	Records	W1	W2	RGR	Dt
1989	1	-	0	0	0
1990	2	0	0.69	0.69	1
1991	3	0.69	1.10	0.41	1.69
1992	3	1.10	1.10	0	0
1993	3	1.10	1.10	0	0
1994	13	1.10	2.56	1.46	0.47
1995	8	2.56	2.08	0.48	1.44
1996	11	2.08	2.40	0.32	2.17
1997	50	2.40	3.91	1.51	0.46
1998	27	3.91	3.30	0.61	1.14
1999	32	3.30	3.47	0.17	4.08
2000	35	3.47	3.56	0.09	7.70
2001	63	3.56	4.14	0.58	1.19
2002	37	4.14	3.61	0.53	1.31

2003	56	3.61	4.03	0.42	1.65
2004	46	4.03	3.83	0.20	3.47
2005	69	3.83	4.23	0.40	1.73
2006	52	4.23	3.95	0.28	2.48
2007	50	3.95	3.91	0.04	17.33
2008	59	3.91	4.08	0.17	4.08
2009	92	4.08	4.52	0.44	1.58
2010	61	4.52	4.11	0.41	1.69
2011	58	4.11	4.06	0.05	13.86
2012	95	4.06	4.55	0.49	1.41
2013	58	4.55	4.06	0.49	1.41
2014	49	4.06	3.89	0.17	4.08
2015	50	3.89	3.91	0.02	34.65
2016	62	3.91	4.13	0.22	3.15
2017	61	4.13	4.11	0.02	34.65
2018	55	4.11	4.01	0.1	6.93
2019	58	4.01	4.06	0.05	13.86
2020	67	4.06	4.20	0.14	4.95
1386

Fig. 8 Relative Growth Rate and Doubling Time

Relative Growth Rate and Doubling Time

The researcher has applied the relative growth rate and doubling time model developed by Mahapatra (1985) to examine the growth rate.

A specified period of the interval can be calculated from the following equations:

$$R(1 - 2) = \frac{W_2 - W_1}{T_2 - T_1} \quad \text{Eq(4)}$$

Where $R(1-2)$ = mean relative growth rate over the specified period of interval;

$W_1 = \log W_1$ (Natural log of initial number of publications/pages);

$W_2 = \log W_2$ (Natural log of initial number of publications/pages);

$T_2 - T_1$ = The unit difference between the initial time and final time.

The relative growth rate for both publications and pages can be calculated separately.

Therefore,

$R(a)$ = Relative growth rate per unit of publications per unit of time (year);

$R(p)$ = Relative growth rate per unit of pages per unit of time (year)

Doubling Time

Based on the calculations, it is discovered that the relative growth rates and doubling time have a direct equivalency. If the number of publications/pages on a specific subject doubles over time, the difference between the logarithms of the numbers at the start and end of the period must be the logarithms of the number 2. If one uses a natural logarithm, this difference has a value of 0.693.

The corresponding doubling time for publications and pages can be calculated by using the following formula: Doubling time (D_t) = $0.693 / R$ Eq(5)

The RGR value for the year 1990 is 0.69, as shown in Table 7 and Figure 8, and the relative growth rates have reduced to 0.14. The Doubling Time for publication of all sources in biofilter of air research output, on the other hand, has grown from 1.00 to 4.95. It climbed from 1.00 to 4.95 in 1990, and it continued to rise until 2020.

Table 8 Ranking of journal according to Bradford's Law

No. of Journals	No. of Publication	Cumulative No. of Publication	Rank	Core
-----------------	--------------------	-------------------------------	------	------

1	98	98	1	I
1	72	170	2	I
1	65	235	3	I
1	57	292	4	I
1	56	348	5	I
1	52	400	6	I
1	48	448	7	I
1	36	484	8	I
2	32	548	10	II
1	31	579	11	II
1	28	607	12	II
2	27	661	14	II
1	25	686	15	II
1	22	708	16	II
2	19	746	18	II
2	18	782	20	II
4	14	838	24	II
1	12	850	25	II
3	11	883	28	II
4	10	923	32	II
2	9	941	34	III
2	8	957	36	III
6	7	999	42	III
9	6	1053	51	III
7	5	1088	58	III
11	4	1132	69	III
22	3	1198	91	III
40	2	1278	131	III
108	1	1386	239	III

Table 8a Bradford Law of journals scattering zone

Zone	No of Journals	No. of Articles
------	----------------	-----------------

1 st Zone	8 Journals	484 Articles
2 nd Zone	24 Journals	439 Articles
3 rd Zone	207 Journals	463 Articles

Fig. 9 Bradford Law of journals scattering zone

Ranking of journal according to Bradford's Law and Scattering Zone

Bradford's Law is a mathematical formula that outlines how journals and the publications they publish interact. It claims that just a small number of core journals will provide the nucleus of papers on a given topic, accounting for a major fraction (1/3) of the articles, with a broader group accounting for the remaining third. The latter third was picked up by a considerably broader set of journals. Bradford's law was not accompanied by a mathematical model. Following that, Brookers³⁷ and Leimkuhler³⁸ proposed the models, and other authors have constructed a variety of Bradford's Law models to explain the dispersion of publications in journals. Leimkuhler devised the following model based on Bradford's verbal formulation:

$R(r) = a \log(1+br)$ Gupta (1991) has given the theoretical aspect of Bradford's Law and studied its applicability using the above method. According of Brookes to test the conformity of Bradford's Law. One should meet the following three implicit conditions:

- (i) The number of articles in each zone must remain constant when splitting the journals into zones.
- (ii) The Bradford multiplier k must be > 1 .

(iii)The Bradford multiplier must remain approximately constant.

The goal of core journals ranking studies is to help with journal selection and evaluation of the worth of one or more journals in a certain topic. The journals are listed in descending order of frequency. The journal that contributes the most articles is scored first, followed by the second-most-article-contributing journal, and so on.

Figure 8a and Table 8 There are 8 journals mentioned in zone I that cover 1/3 of the articles (484) and are considered core journals. Zone II is a slightly larger zone that covers the following 1/3 of the articles, i.e. 439. The final and most expansive zone has 207 journals and 436 articles.

Table 9 Authors h-index and Citations Contribution of biofilter of air

Authors	h-index	Citation sum within h-core	Citations	Articles
Kennes C	26	1515	1723	43
Heitz M	25	1408	1770	54
Veiga MC	25	1283	1470	40
Deshusses MA	20	1575	1611	25
Rene ER	18	738	841	30
Sorial GA	18	719	826	31
Brzezinski R	17	685	710	19
Revah S	16	862	931	25
Gabriel D	15	589	633	19
Munoz R	14	674	762	25
Allen DG	13	464	479	16
Gabaldon C	13	286	322	19
Bibeau L	13	631	645	15
Van Langenhove H	13	412	460	19
Alvarez-Hornos FJ	12	270	311	18
Martinez-Soria V	12	256	272	15
Lafuente J	12	446	465	14
Moe WM	12	368	406	17
Suidan MT	12	576	594	14
Yang CP	11	670	678	13
Le Cloirec P	11	314	332	14
Malhautier L	11	458	493	17
Ramirez AA	11	323	349	16
Delhomenie MC	10	628	638	11
Paca J	10	203	292	26

Fanlo JL	10	433	456	14
Gamisans X	10	390	399	11
Zilli M	10	358	368	12
Lebrero R	10	448	462	14
Wang C	10	233	271	20

346

347

348 **Fig. 10** Authors h-index and Citations Contribution of biofilter of air

349 Author's h-index

350 The contribution of the individual author h-index has been analyzed by Bibexcel
 351 software. The outputs from this investigation are shown in Table 9 and Figure 10. In this figure,
 352 it is evident that “Kennes C” is ranked top in the list with 26 h-index and 43 publications.
 353 Following him, “Heitz M,” “Veiga MC,” and “Deshusses MA” are also ranked in the list.

354 **Table 10** Subject wise contribution of biofilter of air

S.No	Subject	Records
1	Engineering	743
2	Environmental Sciences & Ecology	694
3	Biotechnology & Applied Microbiology	377
4	Meteorology & Atmospheric Sciences	140
5	Chemistry	123
6	Agriculture	122

7	Water Resources	114
8	Energy & Fuels	76
9	Science & Technology – Other Topics	43
10	Biochemistry & Molecular Biology	34
11	Microbiology	20
12	Marine & Freshwater Biology	17
13	Public, Environmental & Occupational Health	16
14	Construction & Building Technology	13
15	Materials Science	10
16	Toxicology	6
17	Polymer Science	4
18	Food Science & Technology	4
19	Fisheries	4
20	Forestry	3
21	Life Sciences & Biomedicine – Other Topics	3
22	Urban Studies	2
23	Plant Sciences	2
24	Instruments & Instrumentation	2
25	Electrochemistry	2
26	Architecture	2
27	Thermodynamics	1
28	Automation & Control Systems	1
29	Urology & Nephrology	1
30	Astronomy & Astrophysics	1
31	Physics	1
32	Mechanics	1
33	Infectious Diseases	1
34	Research & Experimental Medicine	1
35	Geology	1

355

356

357

Fig. 11 Subject wise contribution of biofilter of air

Subject wise contribution of biofilter

Bib excel Software studied the contributions of several subjects in this sector. Table 10 summarizes the findings of our investigation. The contributions of many subjects were presented in Figure.11. With 743 publications, engineering is at the top of the list. The Environmental Sciences & Ecology makes its position second in the list with 694 publications and Biotechnology & Applied Microbiology is ranked in third place in the list with 377 publications.

Table 11 Leading Countries contribution of biofilter of air

Country	Documents	Citations	Total link strength
USA	281	7811	3988
Peoples R China	159	2680	2623
Spain	150	4225	3202
Canada	143	4024	2570
South Korea	75	1125	974
India	71	2298	1653
Taiwan	70	1120	991
Iran	66	757	1126
France	63	1493	1222
Mexico	59	1700	1231
Poland	50	412	612
Australia	38	1264	431

Netherlands	36	1659	892
Italy	35	848	685
Belgium	33	706	494
Czech Republic	28	297	487
Japan	22	320	400
Denmark	21	253	191
Germany	19	484	261
Thailand	19	309	238
England	17	227	326
Chile	15	489	395
Lithuania	14	126	168
Singapore	14	537	224
New Zealand	12	145	256
Brazil	11	181	199
Malaysia	11	118	181

Fig. 12 Leading Countries contribution of Bio filter of air

Contributing Countries analysis

Different countries' contributions to this domain have been examined. Table 11 summarizes the findings of our investigation. The contributions of several countries were indicated in Figure.12. With 281 publications, the United States is at the top of the list. With 159 publications, the People's Republic of China is rated second on the list, followed by Spain in

third place in the list with 150 publications. Following them, Canada (143), South Korea (75), India (71), Taiwan (70), and Iran (66) have shown their respective research outputs in terms of the number of publications. Using VOS viewer, 59 countries, 7 clusters, 478 links and 13426 total links strengths were identified. Each node represents a country and every publication creates a link between the co-authors. Node size represents the country's comprehensive impact. Thus, bigger the node is the higher collaborative capability and impacts the country. Within the countries that have most related with the author, it is noteworthy that three countries who are highlighted were countries leaders in the biofilter of air segment, providing the investment in research in this area is a way to develop this kind of control air pollution source.

Table 12 Leading Co-occurrence keywords of biofilter of air

Keyword	Occurrences	Total Link Strength
Biofiltration	402	850
Biofilter	245	542
Biodegradation	109	277
Toluene	105	297
Biotrickling Filter	97	220
Volatile Organic Compounds	66	144
Voc	53	156
Elimination Capacity	52	156
Hydrogen Sulfide	51	127
Ammonia	45	106
Removal Efficiency	45	132
Vocs	43	133
Biofilters	41	93
Biofilm	39	112
Compost	39	121
Air Pollution	32	91
Styrene	32	82
Air Pollution Control	31	72
Benzene	29	83
Fungi	29	90
Methanol	29	94
Volatile Organic Compound	25	70
Methane	21	53
Modeling	21	62
Nitrification	20	40
Odor	20	39

Fig.13 Leading Co-occurrence keywords of Biofilter of air

Keyword analysis

The contributions of different Co-occurrence keywords in this domain have been analyzed. The results from our investigations are depicted in Table 12. In Figure.13, the contributions of different Co-occurrence keywords were depicted. Biofiltration is ranked top in the list with 407 publications. The biofilter makes its position second in the list with 245 publications and Biodegradation is ranked in third place in the list with 109 publications. Using VOS viewer, 2335 keywords, 11 clusters and 478 links were identified. By the analysis of the network, where we get 157 nodes 3683 connection between them, it can be observed that the network of co-occurrence of keywords clearly showed the main aspects addressed in the area and also provides an approximate view for future research. .

Conclusions

Biofilter is a potential alternative bioreactor for the treatment of polluted air. Based on 1386 papers from the Web of Science on the evolution and growth of biofilter of air research, we conducted a scientometric study using HistCite, Bibexcel, and VoS viewer. The following are some useful conclusions drawn from the preceding studies: In the last 33 years, there have been

236 journal articles about air biofilters. People are paying increased attention to this subject of study, according to articles published between 1989 and 2020. Furthermore, the United States is the leading contributor, with more articles than any other country, China is second, and India is sixth. Engineering, on the other hand, is the most popular subject. Different approaches can therefore be implemented to efficiently examine the air of biofilter. The analysis on the types of document light on the fact that the articles had a major portion of over 1219 papers, with the highest output of language is English. Several countries have become the focus of attention in recent years. According to the aforementioned visualization study and review of biofilter of air output research papers, it is simple for readers to gain a better knowledge of their future growth patterns.

Declarations

Ethical approval and consent to participate

‘Not applicable’

Consent of publication

‘Not applicable’

Availability of data and materials

The dataset generated and/or analysed during the current study are available from the corresponding author [P.Saravanan], upon reasonable request.

Competing interest

The authors declare that there is no conflict of interest

Funding

‘Not applicable’

Author contribution

Conceptualization/idea for the article: Shanmugam Rajeswari, Panchamoorthy Saravanan, Viswanathan Saravanan. Methodology: Shanmugam Rajeswari, Nagendiran Jaya. Formal analysis and investigation: Panchamoorthy Saravanan, Rajan Rajeshkannan. Writing-original draft preparation: Viswanathan Saravanan .Shanmugam Rajeswari, Panchamoorthy Saravanan. Writing- review and editing: Divya Baskaran.Manivasagan Rajasimman, Mookan Rengasamy. Supervision: Manivasagan Rajasimman.

Acknowledgements

The authors are thankful to Bharathidasan Institute of Technology (BIT) Campus, Anna University, Trichirapalli-620 024 and Annamalai University, Annamalai nagar, Chidambram, India for the technical support.

Reference

- Ashok Kumar S, Nair AS, Saravanan V, Rajasimman M (2015) Modeling of kinetics approach on the removal in methyl ethyl ketone using pressmud based biofilter systems. *Modeling earth systems and environment* 1(1-2): 1-10
- Ashokkumar S, Nair AS, Saravanan V, Rajasimman M, Rajamohan N (2016) Kinetics studies on the removal of Methyl ethyl ketone using cornstack based biofilter. *Ecotox Environ Safe* 134: 377-382
- Barbusi ński K, Urbaniec K, Kasperczyk D, Thomas M (2020) Biofilters versus bioscrubbers and biotrickling filters: State-of-the-art biological air treatment. In *From Biofiltration to Promising Options in Gaseous Fluxes Biotreatment. Recent Developments; New Trends; Advances; and Opportunities*; Soreanu, G., Dumont, E., Eds.; Elsevier: Cambridge, MA, USA 29–51.
- Baskaran D, Rajamanickam R, Pakshirajan K (2019) Experimental studies and neural network modeling of the removal of trichloroethylene vapor in a biofilter. *J Environ Manage* 250:109385
- Batagelj V, Mrvar A (1998) Pajek-program for large network analysis. *Connections* 21(2): 47-57
- Bohn HL, Bohn KH (1999) Moisture in biofilters. *Environ Prog* 18(3):156-161
- Bradford SC (1985) Sources of information on specific subjects 1934. *Journal of Information Science* 10(4): 176–180
- Brokes BC (1977) Theory of Bradford's Law. *Journal of documentation* 27(5): 292-306.
- Chen H, Yang C, Zeng G, Luo S, Yu G (2012) Tubular biofilter for toluene removal under various organic loading rates and gas empty bed residence times. *Bioresour Technol* 121: 199-204

Cheng Z, Feng K, Xu D, Kennes C, Chen J, Chen D, Dionysiou DD (2019) An innovative nutritional slow-release packing material with functional microorganisms for biofiltration: Characterization and performance evaluation. *J Hazard Mater* 366: 16-26

Das J, Rene ER, Dupont C, Dufourny A, Blin J, van Hullebusch ED (2019) Performance of a compost and biochar packed biofilter for gas-phase hydrogen sulfide removal. *Bioresour Technol* 273: 581-591

Datta I, Allen DG (2005) Biofilter technology. In *Biotechnology for odor and air pollution control* (pp. 125-145). Springer, Berlin, Heidelberg.

Deshusses M, Johnson CT, Leson G (1999) Biofiltration of high loads of ethyl acetate in the presence of toluene. *J Air Waste Manage* 49(8): 973-979

Detchanamurthy S, Gostomski PA (2012) Biofiltration for treating VOCs: an overview. *Rev Environ Sci Biotechnol* 11:231–241

Dolphen R, Treesubsuntorn C, Santawee N, Setsungnoen A, Thiravetyan P (2020) Modified coir pith with glucose syrup as a supporter in non-external nutrient supplied biofilter for benzene removal by *Bacillus megaterium*. *Environ Technol* 41(27): 3607-3618

Dorado AD, Lafuente FJ, Gabriel D, Gamisans X (2010) A comparative study based on physical characteristics of suitable packing materials in biofiltration. *Environ Technol* 31(2):193-204

Garg KC, Padhi P (2001) A study of collaboration in laser science and technology. *Scientometrics* 51(2):415-427

Gopinath M, Pulla RH, Rajmohan KS, Vijay P, Muthukumaran C, Gurunathan B (2018) Bioremediation of volatile organic compounds in biofilters. In *Bioremediation: Applications for Environmental Protection and Management*. Springer, Singapore 301-330.

Gupta DK (1991) Application of Bradford's Law to Citation data of Ethiopian Medical Journal. *Annual of Library science and Documentation* 38(3): 85-98

Hamidi A, Ramavandi B (2020) Evaluation and scientometric analysis of researches on air pollution in developing countries from 1952 to 2018. *Air Qual Atmos Health* 13:797–806

Huber J A (2004) Phylogenetic and physiological diversity of subseafloor microbial communities at deep-sea seamounts. University of Washington.

Irga PJ, Pettit TJ, Torpy FR (2018) The phytoremediation of indoor air pollution: a review on the technology development from the potted plant through to functional green wall biofilters. *Rev Environ Sci Biotechnol* 17:395–415

Kam JW, Dao E, Farley J, Fitzpatrick K, Smallwood J, Schooler J W, Handy TC (2011) Slow fluctuations in attentional control of sensory cortex. *J Cogn Neurosci* 23(2): 460-470

Kennes C, Veiga MC (Eds.). (2013). *Bioreactors for waste gas treatment* (Vol. 4). Springer Science & Business Media.

Khanongnuch R (2019) Hydrogen sulfide removal from synthetic biogas using anoxic biofilm reactors.

Kraakman NJR, González-Martín J, Pérez C (2021) Recent advances in biological systems for improving indoor air quality. *Rev Environ Sci Biotechnol* 20:363–387

Kumar M, Giri BS, Kim KH, Singh RP, Rene ER, López ME, Singh RS (2019) Performance of a biofilter with compost and activated carbon based packing material for gas-phase toluene removal under extremely high loading rates. *Bioresour Technol* 285: 121317

Kumar M, Giri BS, Kim KH, Singh RP, Rene ER, López ME, Singh RS (2019) Performance of a biofilter with compost and activated carbon based packing material for gas-phase toluene removal under extremely high loading rates. *Bioresour Technol* 285 121317

Leili M, Farjadfard S, Sorial GA, Ramavandi B (2017) Simultaneous biofiltration of BTEX and Hg from a petrochemical waste stream. *J Environ Manage* 204: 531-539

Leson G, Winer AM (1991) Biofiltration: an innovative air pollution control technology for VOC emissions. *J Air Waste Manage* 41(8): 1045-1054

Li K, Rollins J, Yan, E (2018) Web of Science use in published research and review papers 1997–2017: A selective, dynamic, cross-domain, content-based analysis. *Scientometrics* 115(1): 1-20

Li L, Chai F, Liang C, Wang Y, Zhang X, Yang K, Xiao B (2020) Comparison and application of biofilter and suspended bioreactor in removing gaseous o-xylene. *Environ Res* 188:109853

Lu C, Lin MR, Chu C (2002) Effects of pH, moisture, and flow pattern on trickle-bed air biofilter performance for BTEX removal. *Adv Environ Res* 6(2): 99-106

Lu L, Chen B (2018) Enhanced bisphenol A removal from stormwater in biochar-amended biofilters: Combined with batch sorption and fixed-bed column studies. *Environ Pollut* 243:1539-1549.

Luengas AT, Hort C, Platel V, Elias A, Barona A, Moynault L (2017) Removal of traces of toluene and p-xylene in indoor air using biofiltration and a hybrid system (biofiltration+ adsorption). *Environ Sci Pollut R* 24(11): 10674-10684

Mahapatra M (1985, July). On the validity of the theory of exponential growth of scientific literature. In *Proceedings of the 15th IASLIC conference, Bangalore* (pp. 61-70).

Malakar S, Saha PD, Baskaran D, Rajamanickam R (2017) Comparative study of biofiltration process for treatment of VOCs emission from petroleum refinery wastewater—A review. *Environ Technol Inno* 8: 441-461

Mohammad BT, Rene ER, Veiga MC, Kennes C (2017) Performance of a thermophilic gas-phase biofilter treating high BTEX loads under steady-and transient-state operation. *Int Biodeter Biodegr* 119: 289-298

Ottengraf SP (1987) Biological systems for waste gas elimination. *Trends Biotechnol* 5(5):132-136

Ottengraf SPP, Van Den Oever AHC (1983) Kinetics of organic compound removal from waste gases with a biological filter. *Biotechnology and Bioengineering* 25(12): 3089-3102

Ottengraf, SPP, Van Den Oever AHC (1983) Kinetics of organic compound removal from waste gases with a biological filter. *Biotechnology and Bioengineering* 25(12): 3089-3102

Paull NJ, Irga PJ, Torpy FR (2019) Active botanical biofiltration of air pollutants using Australian native plants. *Air Qual Atmos Health* 12:1427–1439

Persson O, Danell R, Schneider JW (2009) How to use Bibexcel for various types of bibliometric analysis. *Celebrating scholarly communication studies: A Festschrift for Olle Persson at his 60th Birthday*, 5, 9-24.

Prenafeta-Boldú FX, Kuhn A, Luykx DM, Anke H, Van Groenestijn JW, De Bont JA (2001) Isolation and characterisation of fungi growing on volatile aromatic hydrocarbons as their sole carbon and energy source. *Mycol Res* 105(4): 477-484

Rabbani KA, Charles W, Cord-Ruwisch, R (2015) Recovery of sulphur from contaminated air in wastewater treatment plants by biofiltration: a critical review. *Rev Environ Sci Biotechnol* 14:523–534

Rahmat AN, Zaman NQ, Tajarudin HA (2017) Biomass as packing material for biofiltration of gaseous streams. *Eng Heritage J* 1(1): 45-48

Rajamanickam R, Baskaran D, Kaliyamoorthi K, Baskaran V, Krishnan J (2020) Steady State, transient behavior and kinetic modeling of benzene removal in an aerobic biofilter. *J Environ Chem Eng* 8(2): 103657

Rajeswari S, Saravanan P, Kumaraguru K, Jaya N, Rajeshkannan R, Rajasimman M (2021) The scientometric evaluation on the research of biodiesel based on HistCite and VOSviewer (1993–2019). *Biomass Conversion and Biorefinery* <https://doi.org/10.1007/s13399-021-01461-6>

Ralebitso-Senior TK, Senior E, Di Felice R, Jarvis K (2012) Waste gas biofiltration: advances and limitations of current approaches in microbiology. *Environ Sci Technol* 46(16): 8542-8573

Rene ER, Sergienko N, Goswami T, López ME, Kumar G, Saratale GD, Swaminathan T (2018) Effects of concentration and gas flow rate on the removal of gas-phase toluene and xylene mixture in a compost biofilter. *Bioresour Technol* 248: 28-35

Rybarczyk P, Szulczyński B, Gębicki J, Hupka J (2019) Treatment of malodorous air in biotrickling filters: A review. *Biochem Eng J* 141: 146-162

Ryu HW, Cho KS, Chung DJ (2010) Relationships between biomass, pressure drop, and performance in a polyurethane biofilter. *Bioresour Technol* 101(6): 1745-1751

Salgar-Chaparro SJ, Lepkova K, Pojtanabuntoeng T, Darwin A, Machuca LL (2020) Nutrient level determines biofilm characteristics and subsequent impact on microbial corrosion and biocide effectiveness. *Appl Environ Microbiol* 86(7): e02885-19

Saravanan V, Rajamohan N (2009) Treatment of xylene polluted air using press mud-based biofilter. *J Hazard Mater* 162(2-3): 981-988

Saucedo-Lucero JO, Revah S (2018) Monitoring key organic indoor pollutants and their elimination in a biotrickling biofilter. *Environ Sci Pollut R* 25(10): 9806-9816

Sazakli E, Leotsinidis M (2021) Odor nuisance and health risk assessment of VOC emissions from a rendering plant. *Air Qual Atmos Health* 14:301–312

Schanes K, Dobernig K, Gözet B (2018) Food waste matters-A systematic review of household food waste practices and their policy implications. *J Clean Prod* 182: 978-991

Singh K, Giri BS, Sahi A, Geed SR, Kureel MK, Singh S, Singh RS (2017) Biofiltration of xylene using wood charcoal as the biofilter media under transient and high loading conditions. *Bioresour Technol* 242: 351-358

Siswanto D, Permana BH, Treesubsuntorn C (2020) *Sansevieria trifasciata* and *Chlorophytum comosum* botanical biofilter for cigarette smoke phytoremediation in a pilot-scale experiment—evaluation of multi-pollutant removal efficiency and CO₂ emission. *Air Qual Atmos Health* 13:109–117

Son HK, Striebig BA, Regan RW (2005) Nutrient limitations during the biofiltration of methyl isoamyl ketone. *Environ Prog* 24(1): 75-81

Soret R, Fanlo JL, Malhautier L, Geiger P, Bayle S (2018) Investigation of removal capacities of biofilters for airborne viable micro-organisms. *Int J Environ Res Public Health* 15(3): 551

Subramanyam K (1983) Bibliometric studies of research collaboration: A review. *J Inf Sci* 6(1): 33-38

Sun Z, Ding C, Xi J, Lu L, Yang B (2020) Enhancing biofilm formation in biofilters for benzene, toluene, ethylbenzene, and xylene removal by modifying the packing material surface. *Bioresour Technol* 296: 122335.

Terry LG, Summers RS (2018) Biodegradable organic matter and rapid-rate biofilter performance: A review. *Water Res* 128:234-245

Tiwari A, Alam T, Kumar A, Shukla AK (2019) Control of odour, volatile organic compounds (VOCs) and toxic gases through biofiltration—an overview. *Int J Tech Innov Mod Eng Sci* 5: 1-6.

Torpy F, Clements N, Pollinger M (2018) Testing the single-pass VOC removal efficiency of an active green wall using methyl ethyl ketone (MEK). *Air Qual Atmos Health* 11:163–170

Van Eck NJ, Waltman L (2013) *VOSviewer* manual. Leiden: Univeriteit Leiden, 1(1), 1-53

Varma VS, Muthusamy S, Rajendran K (2018) Organic waste and pollutants reduction through composting. In *Waste Bioremediation* (pp. 141-164). Springer, Singapore.

Vergara-Fernández A, Revah S, Moreno-Casas P, Scott F (2018) Biofiltration of volatile organic compounds using fungi and its conceptual and mathematical modeling. *Biotechnol Adv* 36(4):1079-1093

- Vikrant K, Kailasa S K, Tsang DC, Lee SS, Kumar P, Giri BS, Kim KH (2018) Biofiltration of hydrogen sulfide: trends and challenges. *J Clean Prod* 187:131-147
- Xi J, Kang I, Hu H, Zhang X (2015) A biofilter model for simultaneous simulation of toluene removal and bed pressure drop under varied inlet loadings. *Front Environ Sci Eng* 9(3):554-562
- Yang C, Qian H, Li X, Cheng Y, He H, Zeng G, Xi J (2018) Simultaneous removal of multicomponent VOCs in biofilters. *Trends Biotechnol* 36(7): 673-685
- Yang C, Qian H, Li X, Cheng Y, He H, Zeng G, Xi J (2018) Simultaneous removal of multicomponent VOCs in biofilters. *Trends Biotechnol* 36(7): 673-685
- Zhai J, Jiang C, Long C (2020) Two-step method for the construction and start-up of a fungal–bacterial biofilter for treating gaseous toluene. *Environ Prog Sustain Energy* 39(5): e13404
- Zhao HW, Zhou D, Haddad GG (2011) Antimicrobial peptides increase tolerance to oxidant stress in *Drosophila melanogaster*. *J Biol Chem* 286(8): 6211-6218