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Bibliometrics of highly cited articles in the research field of volatile organic compounds

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Volatile organic compounds (VOCs) have caused global concerns due to their toxicity and chemical reactivity in photochemical air pollution. Scientific research on the VOCs has been increasing during the past decades. To understand the high impact research, this study conducted a bibliometric analysis of highly cited articles associated with VOCs field based on the Science Citation Index Expanded (SCI-EXPANDED) from 1900 to 2014. Articles with at least 100 citations from the Web of Science Core Collection were selected for analysis. Publication year, authors, institutions, countries/territories, journals, Web of Science categories, and citation life cycles were used to evaluate the publication performance of the highly cited articles. The results show that a total of 295 highly cited VOCs related articles were published in SCI-EXPANDED between 1954 and 2011. The USA was the most productive country in VOCs research, with most VOCs-specialized institutions such as University of Colorado, National Center for Atmospheric Research (NCAR), National Oceanic and Atmospheric Administration (NOAA), and United States Environmental Protection Agency (US EPA). The *Y*-index assessment revealed that S.C. Lee from Hong Kong Polytechnic University and M. Phillips from Menssana Research Inc. had highest publication potential on highly cited articles and were influential scientists in VOCs field. Citation life cycles analysis indicates that the article entitled "A global model of natural volatile organic compound emissions" was the most cited work in VOCs-related studies.

Keywords: *Article Life, VOCs, Y-index, Bibliometric, Web of Science Core Collection*

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1. Introduction

Volatile organic compounds (VOCs) are important ingredients in the atmosphere, involving in a series of atmospheric chemical reactions [1,2]. They contain thousands of chemical species, which can be emitted from natural sources such as vegetation and oceanic emissions [3,4] and anthropogenic sources such as fossil combustion and solvent usage[5,6]. The toxic organics can be poisonous to individuals [7,8] and the chemically reactive compounds can generate severe photochemical air pollution such as haze and ozone episodes [9,10]. The regional and global impacts of VOCs have been causing increasing attentions in the scientific research community [11,12].

The early work about VOCs began with their toxicity impact on organisms [13,14]. As VOCs were recognized as precursors of ozone and organic aerosols, they had been increasingly concerned across the world. Numerous studies of VOC emissions [15], chemical reactions [16], transports [17], removals [18] and risk exposure [19] were conducted. Accordingly, scientific publications have been continually growing during the past decades. Their bibliometirc performance in terms of countries, institutes, and collaborations, and the research trends was firstly characterized by Zhang et al. [20]. However, scientometric analysis of the whole output of VOCs publications only presented a general picture of VOC-related research, while their influential classics and research hotspot might not be well identified and characterized.

High impact articles are more likely to be found among the most frequently cited publications rather than those with less citations [21,22]. Therefore, the highly cited article is a good indicator to characterize the high impact research. Citation characteristics of highly cited papers for subject categories in science, such as chemical engineering [23], environmental science [24], and materials science [25], as well as specified research topics, for example wetlands [26], adsorption [27] and biomass [28] have been investigated. Citation life cycles of most frequently cited articles were deployed to evaluate the history citation characteristics and to predict future citations [29,30]. In addition, top cited papers in total citations in recent year and publication year were discussed [31]. However, few studies have attempted to analyze the highly cited articles in the field of VOCs research.

The main purpose of this study is to identify the high impact research in the VOCs field using the bibliometric method. The articles with at least 100 total citations from time of publication to the end of 2014 were selected for analysis in the Science Citation Index Expanded (SCI-EXPANDED) from 1900 to 2014. The publication number, journals, Web of Science categories, countries, institutions, authors, citation life cycles were used to evaluate publication performance of the highly cited articles. In addition, the Y-index was employed to assess the characteristics and contributions of individual authors with highly cited articles.

2. Data colletion and methodology

The data were collected from SCI-EXPANDED databases of the Web of Science (updated August 04, 2015). The keywords “volatile organic compound”, “volatile organic

compounds", "VOC", and "VOCs" were searched in title, abstract, author keywords, and *Key Words Plus* in the Web of Science Core Collection for the year of 1900 to 2014[32,33]. In total, 21,967 journal articles were found. The data was further filtered by *TC*year and the "front page" [34]. *TC*year denotes the total number of times that an article is cited from its publication until the end of a certain year. The articles with *TC*2014 ≥ 100 were retrieved as the highly cited articles. In addition, articles that could be found only through *KeyWords Plus* but not through their "front page" information (The "front page" includes the article title, abstract, and keyword section.) were excluded. A total of 309 articles (1.4% of the 21,967 total articles) were selected for next-step analysis.

In order to verify that these articles were related to volatile organic compounds (VOCs), the authors examined the contents of abstracts for the 309 articles, and excluded articles that were not VOCs-related despite that they satisfied the selection criteria mentioned above. Some of the excluded articles used "VOC" in reference to the Pascal Visual Object Classes (VOC), open circuit voltage (VOC), vaso-occlusive crisis (VOC), Scale–vocabulary (WAIS-voc), voltage oriented control (VOC), and vicinal oxygen chelate (VOC). Finally, 295 articles were considered as highly cited articles in VOCs field. These records were downloaded into spreadsheet software, and additional coding was manually performed using Microsoft Excel 2010 for calculation [35].

The Y-index was applied to characterize highly cited articles of authors in this study [36]. The Y-index is defined as:

$$j = FP + RP \tag{1}$$

$$h = \tan^{-1}\left(\frac{RP}{FP}\right) \tag{2}$$

where j is publication potential with first and corresponding author articles only. FP is the numbers of first author articles and RP is the corresponding author articles. h is a publication characteristics constant, which introduces the distribution of the numbers of the first author articles and the corresponding author articles. The Y-index with two parameters (j, h) evaluates both the publication quantity and contribution characteristics as a single index. When h> 0.7854, it means one published more corresponding author articles, and when h<0.7854, it means one published more first author articles. When $h = 0$, j = number of first author articles, and $h = \pi/2$, j = number of corresponding author articles. More details about the methods can be found in Mo et al. [37].

3. Results and discussion

3.1. *Publication Number and Citations of highly cited articles*

A total of 295 highly cited VOCs related articles (*TC*2014 ≥ 100) were published in SCI-EXPANDED covering a period from 1954 and 2011. The maximal value of *TC*2014 was 2,030, and the average value was 169. In recent years, relationship between the number of highly cited articles and their citations per publication (*CPP* = TC2014 per year) was studied in different research topics, such as thermodynamic [38] and pain [39]. Fig. 1 shows

the numbers of highly cited articles by decades, with the 2000s accounting for the most at 180, followed by the 1990s with 101. There were only a few highly cited articles published before 1990s with a total number of ten. This indicates VOCs have caused widely attentions since 1990s. The developments of VOCs sampling and detection techniques were important reasons for increasing investigations related to VOCs [40]. Fig.1 also shows that the trend of *CPP* was different from the number of articles across the decades, with the highest value in the 1950s. Article published by Ray [41] in 1954 was the only highly cited article (*TC*2014 = 192) in the 1950s.This article described the technique of VOCs separation and estimation by gas—liquid partition chromatography, which was used for analysis of many species of VOCs. The CPP in 1990s ranked second, with a value of 188, which was followed by 2000s, 2010s, and 1980s, ranging from 142 to 159. In addition to the most number of highly cited articles in 1990s and 2000s, the high CPP in 1990s and 2000s further indicates that great progress of VOCs research centralized in these two decades.

3.2. *Citation Life Cycles of Highly Cited Articles*

Citation life cycles of individual articles are commonly used to assess the scholarly impact of publications in research topics. Two indicators proposed by Ho [23], the total citations from publication years to the latest year (*TC*year) and the citations in latest year (*C*year), were used to illustrate the citation performance of highly cited VOCs articles. Table 1 lists the 20 most frequently cited articles in VOCs field in 2014 and their *TC*2014 and

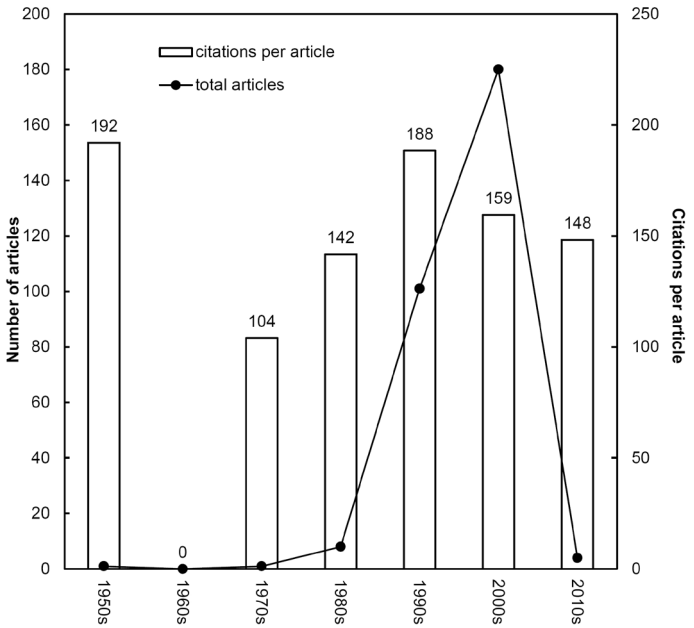

Figure 1

Number of the highly cited articles and citation per publications by decade of publication.

*C*2014. Guenther's article had the highest number of citations in 2014 (*C*2014 = 118), as well as highest number of citations from its publication year to 2014 (*TC*2014 = 2,030). It was followed by Tian et al. and Grell et al. with *C*2014 equal to 102 and 87, respectively. Ervens' article was the 4th most cited article in 2014 (*C*2014 = 71), but ranked 81st on TC2014 (*TC*2014 = 169). This article was published recently and needs time to accumulate total citations, while has caused great attentions in the latest year. The phenomenon was also found for the articles of Kampa and Castanas (5th on *C*2014, 42nd on *TC*2014); Peng et al. (6th on *C*2014, 31st on *TC*2014);Virtanen et al. (10th on *C*2014, 74th on *TC*2014); "Peng et al. (13rd on *C*2014, 127th on *TC*2014); and Zhang et al. (17th on *C*2014, 247th on *TC*2014). These articles can be regarded as potential classics in the future. Among the top 20 highly cited articles in 2014, twelve were published in the USA, which implied the dominance of USA in VOCs search. Additionally, two articles were published in Nature.

The citation life cycles of six highly cited articles in VOCs studies ranked in both top 10 *TC*2014 and *C*2014 are illustrated in Fig. 2. These articles were regarded as classics in VOCs research because they had most citations since its publication year but also caused attentions in recent year. Four of the six articles published between 2001 and 2005, and two published in 1995. The most influential article was "A global model of natural volatile organic compound emissions" written by A. Guenther, with the top ranking of *C*2014 and *TC*2014. The annual citations of this article showed an early rapid rise in the first four years and remained steady at a level of 90 citations between 1999 and 2004. A secondary growth appeared from 2005 to 2008, reaching 150 citations. Although the citations fell down to 118 in 2014, it still ranked top of *C*2014in VOCs field. This article developed an original model estimating global natural VOCs, which had been successfully applied in many studies since 1990s. As biogenic emission is a dominant source of VOCs at global scale, understanding the magnitude and species of natural VOCs is essential to the study of atmospheric chemistry and air pollution [42]. Therefore, the 3-D global computational model proposed by Guenther et al. (Table 1) is a milestone in VOC studies. A updated model, namely Model of Emissions of Gases and Aerosols from Nature (MEGAN) [43] were developed and widely in recent decade, which might result in the decreased citations of Guenther et al. in 2014. The second most cited article (ranked 2nd in both *TC*2014 and *C*2014) entitled "Complex and oriented ZnO nanostructures" by Tian et al. (Table 1) showed a dramatic increase in the first three years and then plateaued at around 95 citations until 2014. This article was published in *Nature Materials* (*IF*2014 = 36.503), which was influential in the physical chemistry and materials science. A low-temperature, environmentally benign, solution-based approach was reported for the preparation of complex and oriented ZnO nanostructures, which had large advantage of photocatalytic decompositions of VOCs. The high citations of this work were also attributed to the wide applications of novel ZnO nanostructures in sensing, catalysis, optical emission, piezoelectric transduction, and actuations. The article entitled "Fully coupled online chemistry within the WRF model" by Grell et al. (Table 1) also showed an increasing trend of annual citations, reaching 87 citations in 2012 and then leveled off in recent two years.This work successfully coupled online chemistry within Weather Research and Forecasting(WRF) model, resulting a novel model WRF/Chem.

Table 1

The 20 most frequently cited articles in VOCs field in 2014

Rank (*C*2014)	Rank (*TC*2014)	Article title	Authors	Publication Information
1 (118)	1 (2030)	A global-model of natural volatile organic-compound emissions	Guenther, A., Hewitt, C.N., Erickson, D., et al.	Journal of Geophysical Research: Atmospheres (1984–2012), Vol. 100 (D5), 1995, 8873-8892.
2 (102)	2 (892)	Complex and oriented ZnO nanostructures	Tian, Z.R., Voigt, J.A., Liu, J., et al.	Nature materials, Vol. 2 (12), 2003, 821-826.
3 (87)	7 (450)	Fully coupled online chemistry within the WRF model	Grell, G.A., Peckham, S.E., Schmitz, R., et al.	Atmospheric Environment, Vol. 39 (37), 2005, 6957-6975.
4 (71)	81 (169)	Secondary organic aerosol formation in cloud droplets and aqueous particles (aqSOA): a review of laboratory, field and model studies	Ervens, B., Turpin, B.J. and Weber, R.J.	Atmospheric Chemistry and Physics, Vol. 11 (21), 2011, 11069-11102.
5 (69)	42 (231)	Human health effects of air pollution	Kampa and Castanas	Environmental Pollution, Vol. 151 (2), 2008, 362-367.
6 (68)	31 (246)	Diagnosing lung cancer in exhaled breath using gold nanoparticles	Peng, G., Tisch, U., Adams, O., et al.	Nature nanotechnology, Vol. 4 (10), 2009, 669-673.
7 (64)	4 (487)	PAH source fingerprints for coke ovens, diesel and gasoline-engines, highway tunnels, and wood combustion emissions	] Khalili, N.R., Scheff, P.A. and Holsen, T.M.	Atmospheric environment, Vol. 29 (4), 1995, 533-542.
8 (58)	6 (468)	Measurement of emissions from air pollution sources. 3. C-1-C-29 organic compounds from fireplace combustion of wood	Schauer, J.J., Kleeman, M.J., Cass, G.R., et al.	Environmental Science & Technology, Vol. 35 (9), 2001, 1716-1728.
9 (57)	10 (401)	Protocol for the development of the Master Chemical Mechanism, MCM v3 (Part A): tropospheric degradation of non-aromatic volatile organic compounds	Saunders, S.M., Jenkin, M.E., Derwent, R.G., et al.	Atmospheric Chemistry and Physics, Vol. 3 (1), 2003, 161-180.

Contd...

10 (53)	74 (178)	An amorphous solid state of biogenic secondary organic aerosol particles	Virtanen, A., Joutsensaari, J., Koop, T., et al.	Nature, Vol. 467 (7317), 2010, 824-827.
11 (52)	8 (430)	Measurement of emissions from air pollution sources. 5. C-1-C-32 organic compounds from gasoline-powered motor vehicles	Schauer, J.J., Kleeman, M.J., Cass, G.R., et al.	Environmental Science & Technology, Vol. 36 (6), 2002, 1169-1180.
12 (47)	9 (421)	Secondary organic aerosol formation from anthropogenic air pollution: Rapid and higher than expected	Volkamer, R., Jimenez, J. L., San Martini, F., et al.	Geophysical Research Letters, Vol. 33 (17), 2006, L17811
13 (46)	21 (301)	Bacterial volatiles promote growth in Arabidopsis	Ryu, C.M., Farag, M.A., Hu, C.H., et al.	Proceedings of the National Academy of Sciences, Vol. 100 (8), 2003, 4927-4932.
13 (46)	127 (142)	Detection of lung, breast, colorectal, and prostate cancers from exhaled breath using a single array of nanosensors	Peng, G., Hakim, M., Broza, Y.Y., et al.	British Journal of Cancer, Vol. 103 (4), 2010, 542-551.
15 (44)	16 (334)	Volatile organic compounds in breath as markers of lung cancer: a cross-sectional study	Phillips, M., Gleeson, K., Hughes, J.M.B., et al.	Lancet, Vol. 353 (9168), 1999, 1930-1933.
16 (42)	12 (381)	Photocatalytic oxidation for indoor air purification: a literature review	Zhao and Yang	Building and Environment, Vol. 38 (5), 2003, 645-654.
17 (41)	18 (311)	Atmospheric oxidation capacity sustained by a tropical forest	Lelieveld, J., Butler, T.M., Crowley, J.N., et al.	Nature, Vol. 452 (7188), 2008, 737-740.
17 (41)	247 (105)	Superhydrophobic nanoporous polymers as efficient adsorbents for organic compounds	Zhang, Y., Wei, S., Liu, F., et al.	Nano Today, Vol. 4 (2), 2009, 135-142.
19 (39)	32 (244)	Bacterial volatiles induce systemic resistance in Arabidopsis	Ryu, C.M., Farag, M.A., Hu, C.H., et al.	Plant Physiology, Vol. 134 (3), 2004, 1017-1026.
20 (38)	11 (396)	The tropospheric degradation of volatile organic compounds: A protocol for mechanism development	Jenkin, M.E., Saunders, S.M. and Pilling, M.J.	Atmospheric Environment, Vol. 31 (1), 1997, 81-104.

TC_{2014}: number of citations till 2014; C_{2014}: number of citations in 2014.

Compared with the MM5/Chem model [44], the new model was statistically skilled and hadbetter performance in forecasting O3. This model was regarded as the cornerstone for a next generation air quality prediction system, which attracted wide attentions from the modelers. The articles of Khalili et al., Schauer et al. and Saunders et al. (Table 1) exhibited similar patterns of citation lifecycles, with a slow increasing trend of annual citations and reaching the peak of around 60 citations in 2014. They ranked 7th, 8th, and 9th in *C*2014, and 4th, 6th,and 10th in *TC*2014, respectively. Khalili et al. [48] studied the source fingerprint of PAH while Schauer et al. [49] measured the source profiles of VOCs. Both studies can provide basic information for further studies such as source apportionment [45,46] and secondary aerosol formations [47,48], and thus was frequently cited by these studies. Saunders et al. (Table 1) presented a protocol for the development of the Master Chemical Mechanism (MCM v3), which was frequently cited by the chemical transport model research.

3.3. *Field of Highly cited articles: Journal and Web of Science Subject Category*

The highly cited articles were published in 107 journals in 55 Web of Science categories. There were 71 journals (66%) publishing only one highly cited article and 15 (14%) journals two articles. Table 2 lists the top 10 journals with more than five highly cited articles.

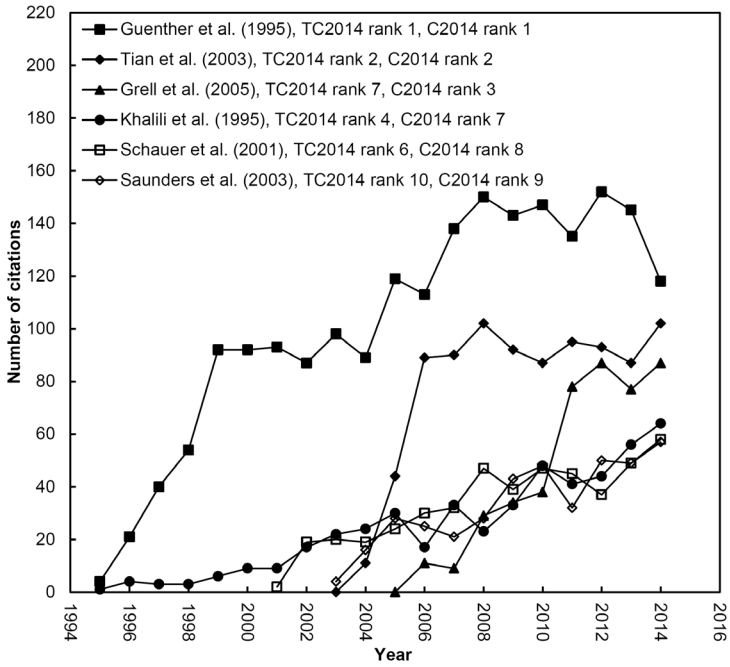

Figure 2

The six articles ranked in both top ten TC2014 and C2014.

Atmospheric Environment published the most articles, contributing 14% (41 articles) of total articles, followed by *Environmental Science & Technology* (9.5%, 28 articles), J*ournal of Geophysical Research-Atmospheres* (7.5%, 22 articles), *Applied Catalysis B-Environmental* (6.1%, 18 articles), and *Atmospheric Chemistry and Physics* (3.7%, 11 articles). Among the above productive journals, the impact factors of *Environmental Science & Technology* (IF2014 = 5.330), *Applied Catalysis B-Environmental* (*IF*2014 =7.435), and *Atmospheric Chemistry and Physics* (IF2014 =5.053) ranked 10th of 47 journals in environmental science, 1st of 47 journals in environmental engineering, and 3rd of 77 journals in meteorology and atmospheric sciences, respectively. Moreover, *Nature* (*IF*2014 = 41.456) with impact factor ranking 1st of 56 journals in multidisciplinary sciences published seven highly cited articles. The journals were top 5% journals in their own Web of Science category. This suggests that the highly cited articles related to VOCs research tended to be published in the high impact journals. However, highly cited articles were also published in journals with low impact factors, for example *Chemical Engineering Progress* (*IF*2014 = 0.333), *J. of Electrostatics* (*IF*2014 = 0.863), and *Ground Water Monitoring and Remediation* (IF2014 = 0.944).

Table 2

Top 10 journals with more than five highly cited articles

Journals	*TP* (%)	IF_{2014}	Web of Science category	Position
Atmospheric Environment	41 (14)	3.281	Environmental sciences Meteorology and atmospheric sciences	42/221 15/77
Environmental Science & Technology	28 (9.5)	5.330	Environmental engineering Environmental sciences	3/47 10/221
Journal of Geophysical Research-Atmospheres	22 (7.5)	N/A	Meteorology and atmospheric sciences	NA
Applied Catalysis B-Environmental	18 (6.1)	7.435	Physical chemistry Environmental engineering Chemical engineering	19/139 1/47 4/134
Atmospheric Chemistry and Physics	11 (3.7)	5.053	Meteorology and atmospheric sciences	3/77
Nature	7 (2.4)	41.456	Multidisciplinary sciences	1/56
Geophysical Research Letters	7 (2.4)	4.196	Multidisciplinary geosciences	9/175
Analytical Chemistry	7 (2.4)	5.636	Analytical chemistry	4/74
Journal of the Air & Waste Management Association	6 (2.0)	1.342	Environmental engineering Environmental sciences Meteorology and atmospheric sciences	29/47 137/221 51/77
Journal of Chromatography A	6 (2.0)	4.169	Biochemical research methods Analytical chemistry	15/79 6/74

TP: total number of highly cited articles; TC2014: number of citations till 2014; C2014: number of citations in 2014; N/A: not available in 2014

Environmental sciences with 221 journals published the most articles highly cited articles, contributing 100 articles (34% of total 295 articles). Meteorology and atmospheric sciences with 77 journals and environmental engineering with 47 journals produced 88 and 64 articles, accounting for 30% and 22%, respectively. These Web of Science categories were most productive among the 55 categories which published highly cited articles in VOCs studies. As VOCs are important pollutants existing in atmosphere and have great impact on environmental pollution, such as photochemical smog and haze, they are obtained intensive interest from the subjects related to atmosphere and environment.

3.4. *Publication Distributions: Countries and Institutions*

Among the 295 highly cited VOCs related articles, 239 (81%) articles were single country articles of 26 countries and 56 (19%) articles were internationally collaborative articles from 29 countries. Most articles were produced from the USA, with 150 articles (51%). It was followed by Germany (28 articles), Italy (26), the UK (24), China (20),Canada (16), Japan (10), and Sweden (10).The USA contributed43% of 56 internationally collaborative articles. It was followed by the UK (18; 32%), Germany (17; 30%), Italy (14; 25%),Netherlands (8; 14%), and France (6; 11%). The USA also published the most single country articles, first author articles and corresponding articles, which collectively demonstrated its leading position in VOCs research. Highly cited paper is one indicator of a nation's relative competitiveness in a particular research area [49].The research in USA has the greatest impact in the VOCs field, and far more advanced than other countries.

Table 3 shows the top 15 institutions with more than five highly cited articles, together with the rankings and numbers of six indicators including total number of articles (*TP*) and numbers of first-author (*FP*), corresponding-author (*RP*), single-institution (IP), inter-institutionally collaborative (*CP*), and single-author articles (*SP*) [50]. Ten of the 15most productive institutions were in the USA, two institutions were in China, and one each was from Canada, Germany, and Italy. The University of Colorado with 19 highly cited articles ranked top in *TP, CP, FP*, and *RP*, with a number of 19, 17, 7, and 7, respectively. National Center for Atmospheric Research (NCAR) published the second most highly cited articles, with 17 papers. It also ranked second in *CP* (15), and 6^{th}, 7^{th}, 8^{th} in *FP, RP*, and *IP*, respectively. Both National Oceanic and Atmospheric Administration (NOAA) and United States Environmental Protection Agency (US EPA) ranked 3rd in total number of highly cited articles (*TP* = 13). However, NOAA had only one single institution article (ranking 20^{th}) while US EPA did not have any single institution article. University of California Berkeley and Harvard University published eight highly cited articles while Hong Kong Polytechnic University, Max Planck Institute for Chemistry, and University of Illinois published seven articles. Particularly, Hong Kong Polytechnic University ranked top in *FP* and *RP*, and ranked 2^{nd} in IP, which suggested Hong Kong Polytechnic University was competitive in conducting research independently. All of California Institute of Technology, National Research Council (CNR), Georgia Institute of Technology, Hong Kong University of Science and Technology, Rutgers State University, and University of Waterloo contributed six highly cited articles. University of Waterloo published the most single institution, and

Table 3

Top 15 institutions with more than five highly cited articles (TP> 5)

Institution	R (*TP*)	R (*IP*)	R (*CP*)	R (*FP*)	R (*RP*)	R (*SP*)
University of Colorado, USA	1 (19)	8 (2)	1 (17)	1 (7)	1 (7)	N/A
National Center for Atmospheric Research, USA	2 (17)	8 (2)	2 (15)	6 (5)	7 (5)	3 (1)
National Oceanic and Atmospheric Administration (NOAA), USA	3 (13)	20 (1)	4 (12)	3 (6)	3 (6)	N/A
United States Environmental Protection Agency (US EPA), USA	3 (13)	N/A	3 (13)	10 (4)	3 (6)	N/A
University of California Berkeley, USA	5 (8)	8 (2)	5 (6)	6 (5)	7 (5)	3 (1)
Harvard University, USA	5 (8)	8 (2)	5 (6)	3 (6)	3 (6)	N/A
Hong Kong Polytechnic University, China	7 (7)	2 (5)	41 (2)	1 (7)	1 (7)	N/A
Max Planck Institute for Chemistry, Germany	7 (7)	20 (1)	5 (6)	11 (3)	10 (4)	N/A
University of Illinois, USA	7 (7)	3 (4)	23 (3)	6 (5)	10 (4)	N/A
California Institute of Technology, USA	10 (6)	N/A	5 (6)	11 (3)	20 (2)	N/A
National Research Council (CNR), Italy	10 (6)	20 (1)	11 (5)	23 (2)	20 (2)	N/A
Georgia Institute of Technology, USA	10 (6)	N/A	5 (6)	23 (2)	12 (3)	N/A
Hong Kong University of Science and Technology, China	10 (6)	4 (3)	23 (3)	11 (3)	12 (3)	N/A
Rutgers State University, USA	10 (6)	N/A	5 (6)	56 (1)	54 (1)	N/A
University of Waterloo, Canada	10 (6)	1 (6)	N/A	3 (6)	3 (6)	N/A

TP: total number of highly cited articles; *IP*: single institution articles; *CP*: inter-institutionally collaborative articles; *FP*: first author articles; *RP*: corresponding author articles; *SP*: single author articles; R: rank; N/A: not available.

ranked 3rd in both FP and RP, indicating its capability of independent research, which was similar to Hong Kong Polytechnic University. Among these productive institutions, single articles were not so many, with NCAR and University of California Berkeley publishing one article each. University of California Riverside and The University of Tokyo published the most single articles (*SP* = 2).

3.5 *Highly Cited Authors*

The average number of authors for these highly cited articles was 5.1, with 43 as the largest number of authors. The average number of authors per article increased from one in both the 1950s and the 1970s to 5.9 in the 2000s and to 8.0 in the 2010s. Of the 295 highly

cited articles, 17 (5.8% of 295 articles) were written by single authors, 45 (15%) by two authors, 51 (17%) by three, 44 (15%) by four, with 40 (14%) by five, 35 (12%) by six, 63 (21%) involving more than six authors.

There were 1,221 authors from 33 countries contributing to the 295 highly cited articles in VOCs related research. Among all the authors, 15% (178 authors) had both first and corresponding author articles, 79% (964) had no first author articles, 79% (970) had no corresponding author articles, 73% (893) had not first author articles or corresponding authors articles. More specifically, from the 178 authors, only seven authors (3.9% of the 178 authors) had $h > 0.7854$, five (2.8%) authors had $0 < h < 0.7854$, and166 (93%) authors had $h = 0.7854$. In addition, 77 (43%) authors published only first author articles ($h = 0$) and 71 (40%) authors published only corresponding author articles ($h = \pi/2$).

The Y-index (j, h) for 30 authors with $j \geq 3$, is presented in Fig. 3. S.C. Lee from Hong Kong Polytechnic University had the highest j of ten, who published seven highly cited articles including three first authored and seven corresponding authored articles with Y-index (10, 1.166). S.C. Lee is a specialist of VOCs measurements in indoor and outdoor environment. He depicted the characteristics of VOCs as well as other air pollutants in different indoor environment (homes, offices, schools, shopping malls and restaurants) [51,52]and roadside [53,54]. As a case study in Hong Kong, these studies provided good examples for VOCs characterization in other areas such as Beijing and Guangzhou in China [55,56], Delhi in India [57], Birmingham in UK [58]. Moreover, Professor Lee is expert in air pollution control, especially photodegradation of air pollutants using TiO_2. His work demonstrated the applications of photocatalytic technology using TiO_2 for removal of air pollutant such as nitrogen oxide (NO) and VOCs, which was novel in the field of VOCs control technology [59,60]. M. Phillips from Menssana Research Inc. in the USA had the same publication potential but different publication characteristics from S.C. Lee. M. Phillips published six highly cited articles including five first authored and corresponding authored articles respectively with Y-index (10, 0.7854). Professor Phillips worked on VOCs in breath and detection of diseases using VOCs as makers [61]. His articles pioneered in disease diagnosis including lung cancer [62], asthma [63], and pulmonary tuberculosis [64] by determination of breath VOCs markers, which caused wide attention across the world.A. Guenther from National Center for Atmospheric Research in the USA had the same publication characteristics from M. Phillips but different publication potential with Y-index (8, 0.7854).Professor Guenther is a celebrated scientist who established the global model for estimating natural VOCs. He also investigated the behaviors of biogenic VOCs and their impacts on air quality [65,66]. His work has been a cornerstone of biogenic VOCs studies. In recent decade, he developed a new model (MEGAN) for estimations of regional and global biogenic emissions, which was again applied by numerous scientists across the world. I.T. Baldwin, G.R. Cass, J. Pawliszyn, G. Guerra, A.C. Lewis, K.S. Suslick, S. Dragonieri, P. Papaefthimiou, G. Peng, and C.H. Ao had the same value of $j = 3$ located in the same curve in Fig. 3 but they had very different publication characteristics. I.T. Baldwin, G.R. Cass, and J. Pawliszyn published only corresponding author articles ($h = \pi/2$); G. Guerra, A.C. Lewis, and K.S. Suslick had more corresponding author articles ($h = 1.107$); S. Dragonieri, P. and Papaefthimiou, G. Peng had more first author articles ($h = 0.436$); and C.H. Aopublished only first author article($h = 0$).

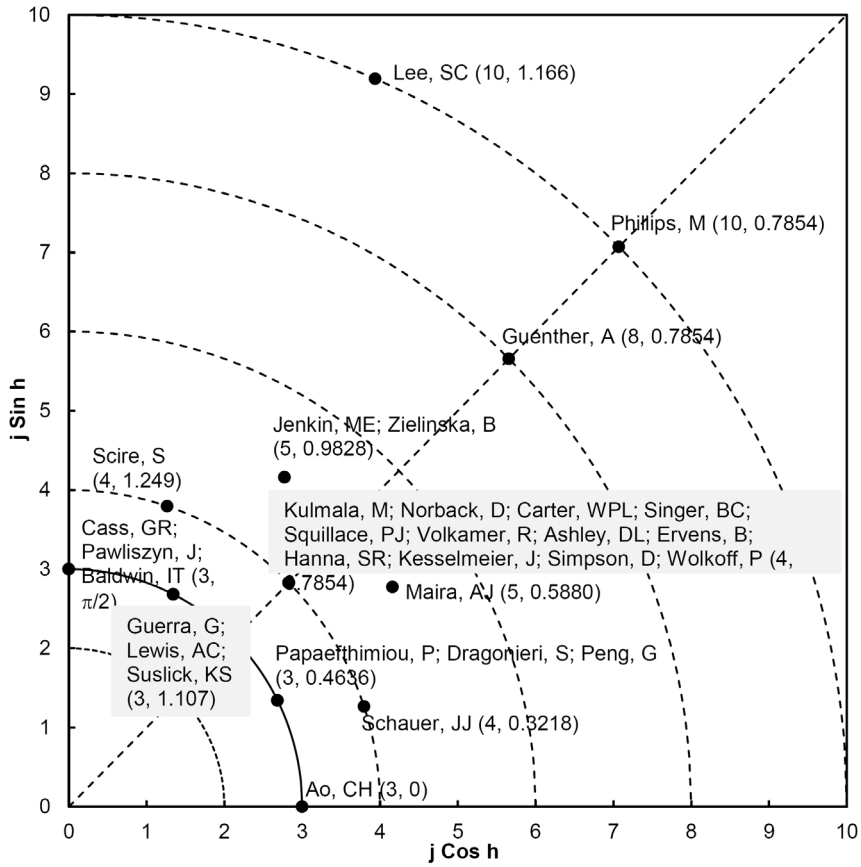

Figure 3

Top 30 authors with Y-index ($j \geq 3$)

4. Conclusions

A bibilometric analysis was conducted on highly cited articles basing on the Science Citation Index Expanded (SCI-EXPANDED) database from 1900 to 2014. The 295highly cited articles (*TC*2014 ≥ 100)were published in 107 journals. *Atmospheric Environment* was the most productive journal, followed by *environmental Science & Technology* and *Journal of Geophysical Research-Atmospheres*.This suggests that VOCs obtained intensive interest from the subjects related to atmosphere and environment.The USA contributed the most highly cited articles, with most prolific institutions such as University of Colorado, NCAR, NOAA, and US EPA. S.C. Lee from Hong Kong Polytechnic University, M. Phillips from Menssana Research Inc., and A. Guenther from NCAR were revealed to be influential scientists by using Y-index analysis. Moreover, citation analysis indicated that "A global model of natural volatile organic compound emissions" was the most classical work written by A. Guenther in VOCs-related field.

References

[1] Atkinson, R. Atmospheric chemistry of VOCs and NOx. Atmospheric environment, Vol. 34 (12), 2000, 2063-2101.

[2] Seinfeld, J.H. and Pandis, S. N. Atmospheric chemistry and physics: from air pollution to climate change, 2nd Edition, John Wiley, New York, 2006.

[3] Arnold, S.R., Spracklen, D.V., Williams, J., Yassaa, N., Sciare, J., Bonsang, B., Gros, V., Peeken, I., Lewis, A.C., Alvain, S., Moulin, C. Evaluation of the global oceanic isoprene source and its impacts on marine organic carbon aerosol. Atmospheric Chemistry and Physics, Vol. 9, 2009, 1253-1262.

[4] Fred, F., Jack, C., Ray, F., Paul, G., B., G.A., Nicholas, H.C., Brian, L., Shaw, L., Michael, T., Hal, W., Pat, Z., 1992. Emissions of volatile organic compounds from vegetation and the implications for atmospheric chemistry. Global Biogeochem. Cycles 6, 389-430.

[5] Piccot, S.D., Watson, J.J. and Jones, J.W. A global inventory of volatile organic compound emissions from anthropogenic sources. Journal of Geophysical Research: Atmospheres (1984–2012), Vol. 97 (D9), 1992, 9897-9912.

[6] Kansal, A. Sources and reactivity of NMHCs and VOCs in the atmosphere: A review. Journal of Hazardous Materials, Vol. 166, 2009, 17-26.

[7] Feron, V.J., Til, H.P., de Vrijer, F. and Van Bladeren, P.J. Review: toxicology of volatile organic compounds in indoor air and strategy for further research. Indoor and Built Environment, Vol. 1 (2), 1992, 69-81.

[8] Sundell, J. On the history of indoor air quality and health. Indoor Air, Vol. 14, 2004, 51-58.

[9] Huang, R.-J., Zhang, Y., Bozzetti, C., Ho, K.-F., Cao, J.-J., Han, Y., Daellenbach, K.R., Slowik, J.G., Platt, S.M., Canonaco, F., Zotter, P., Wolf, R., Pieber, S.M., Bruns, E.A., Crippa, M., Ciarelli, G., Piazzalunga, A., Schwikowski, M., Abbaszade, G., Schnelle-Kreis, J., Zimmermann, R., An, Z., Szidat, S., Baltensperger, U., Haddad, I.E., Prévôt, A.S.H.. High secondary aerosol contribution to particulate pollution during haze events in China. Nature Vol. 514, 2014, 218-222.

[10] Derwent, R.G., Jenkin, M.E., Passant, N. R. and Pilling, M. J. Reactivity-based strategies for photochemical ozone control in Europe. Environmental Science & Policy, Vol. 10 (5), 2007, 445-453.

[11] Liu, S.C., Trainer, M., Fehsenfeld, F.C., Parrish, D.D., Williams, E.J., Fahey, D.W., Hübler, G., Murphy, P.C. Ozone production in the rural troposphere and the implications for regional and global ozone distributions. Journal of Geophysical Research: Atmospheres, Vol. 92, 1987, 4191-4207.

[12] Poisson, N., Kanakidou, M., Crutzen, P.J. Impact of Non-Methane Hydrocarbons on Tropospheric Chemistry and the Oxidizing Power of the Global Troposphere: 3-Dimensional Modelling Results. Journal of Atmospheric Chemistry, Vol. 36, 2000, 157-230.

[13] Moore, W. and Graham, S.A. Toxicity of volatile organic compounds to insect eggs. Journal of Agricultural Research, Vol. 12 (9), 1918, 579-587.

[14] Read, W.H. The toxicity of the vapours of volatile organic compounds to the "red spider" mite (Tetranychustelabius l.). Annals of Applied Biology, Vol. 19 (3), 1932, 432-438.

[15] Mo, Z., Shao, M., Lu, S., Qu, H., Zhou, M., Sun, J. and Gou, B. Process-specific emission characteristics of volatile organic compounds (VOCs) from petrochemical facilities in the Yangtze River Delta, China. Science of the Total Environment, Vol. 533, 2015, 422-431.

[16] Carter, W.P. Development of the SAPRC-07 chemical mechanism. Atmospheric Environment, Vol. 44 (40), 2010, 5324-5335.

[17] Pasteris, G., Werner, D., Kaufmann, K. and Höhener, P. Vapor phase transport and biodegradation of volatile fuel compounds in the unsaturated zone: a large scale lysimeter experiment. Environmental Science & Technology, Vol. 36 (1), 2002, 30-39.

[18] Ao, C.H., Lee, S.C., Yu, J.Z. and Xu, J.H. Photodegradation of formaldehyde by photocatalyst TiO2: effects on the presences of NO, SO2 and VOCs. Applied Catalysis B Environmental, Vol. 54 (1), 2004, 41-50.

[19] Massolo, L., Rehwagen, M., Porta, A., Ronco, A., Herbarth, O. and Mueller, A. Indoor–outdoor distribution and risk assessment of volatile organic compounds in the atmosphere of industrial and urban areas. Environmental toxicology, Vol. 25 (4), 2010, 339-349.

[20] Zhang, G.F., Xie, S.D. and Ho, Y.S. A bibliometric analysis of world volatile organic compounds research trends. Scientometrics, Vol. 83 (2), 2010, 477-492.

[21] Lefaivre, K.A., Shadgan, B. and O'Brien, P.J. 100 most cited articles in orthopaedic surgery. Clinical Orthopaedics and Related Research, Vol. 469 (5), 2011, 1487-1497.

[22] Patterson, M. and Harris, S. The relationship between reviewers' quality-scores and number of citations for papers published in the journal Physics in Medicine and Biology from 2003–2005. Scientometrics, Vol. 80 (2), 2009, 343-349.

[23] Ho, Y.S. Top-cited articles in chemical engineering in Science Citation Index Expanded: A bibliometric analysis. Chinese Journal of Chemical Engineering, Vol. 20 (3), 2012, 478-488.

[24] Khan, M.A. and Ho, Y.S. Top-cited articles in environmental sciences: Merits and demerits of citation analysis. Science of the Total Environment, Vol. 431, 2012, 122-127.

[25] Ho, Y.S. A bibliometric analysis of highly cited articles in materials science. Current Science, Vol. 107 (9), 2014a, 1565-1572.

[26] Ma, J.P., Fu, H.Z. and Ho, Y.S. The top-cited wetland articles in Science Citation Index Expanded: Characteristics and hotspots. Environmental Earth Sciences, Vol. 70 (3), 2013, 1039-1046.

[27] Chen, H.Q. and Ho, Y.S. Highly cited articles in biomass research: A bibliometric analysis. Renewable & Sustainable Energy Reviews, Vol. 49, 2015, 12-20.

[28] Fu, H.Z. and Ho, Y.S. Top cited articles in adsorption research using Y-index. Research Evaluation, Vol. 23 (1), 2014, 12-20.

[29] Cano, V. and Lind, N.C. Citation life cycles of ten citation classics. Scientometrics, Vol. 22 (2), 1991, 297-312.

[30] Bouabid, H. Revisiting citation aging: a model for citation distribution and life-cycle prediction. Scientometrics, Vol. 88 (1), 2011, 199-211.

[31] Ho, Y.S. Classic articles on social work field in Social Science Citation Index: A bibliometric analysis. Scientometrics, Vol. 98 (1), 2014b, 137-155.

[32] Garfield, E. KeyWords Plus: ISI's breakthrough retrieval method. Part 1. Expanding your searching power on Current Contents on Diskette. Current Contents, Vol. 32, 1990, 5-9.

[33] Ho, Y.S., Satoh, H. and Lin, S.Y. Japanese lung cancer research trends and performance in Science Citation Index. Internal Medicine, Vol. 49 (20), 2010, 2219-2228.

[34] Fu, H.Z., Wang, M.H. and Ho, Y.S. The most frequently cited adsorption research articles in the Science Citation Index (Expanded). Journal of Colloid and Interface Science, Vol. 379 (1), 2012, 148-156.

[35] Li, Z. and Ho, Y.S. Use of citation per publication as an indicator to evaluate contingent valuation research. Scientometrics, Vol. 75 (1), 2008, 97-110.

[36] Ho, Y.S. The top-cited research works in the Science Citation Index Expanded. Scientometrics, Vol. 94 (3), 2013, 1297-1312.

[37] Mo, Z., Fu, H.-Z., Ho, Y.-S. Highly cited articles in wind tunnel-related research: a bibliometric analysis. Environmental Science and Pollution Research, Vol. 25, 2018, 15541-15553.

[38] Fu, H.Z. and Ho, Y.S. Top cited articles in thermodynamic research. Journal of Engineering Thermophysics, Vol. 24 (1), 2015, 68-85.

[39] Chuang, K.Y. and Ho, Y.S. A bibliometric analysis on top-cited articles in pain research. Pain Medicine, Vol. 15 (5), 2014, 732-744.

[40] McGlenny, W.A., Pleil, J.D., Evans, G.F., Oliver, K.D., Holdren, M.W. and Winberry, W.T. Canister-based method for monitoring toxic VOCs in ambient air. Journal of the Air & Waste Management Association, Vol. 41 (10), 1991, 1308-1318.

[41] Ray, N.H. Gas chromatography. I. The separation and estimation of volatile organic compounds by gas-liquid partition chromatography. Journal of Applied Chemistry, Vol. 4 (1), 1954, 21-25.

[42] Guenther, A., Geron, C., Pierce, T., Lamb, B., Harley, P. and Fall, R. Natural emissions of non-methane volatile organic compounds, carbon monoxide, and oxides of nitrogen from North America. Atmospheric Environment, Vol. 34 (12), 2000, 2205-2230.

[43] Guenther, A., Karl, T., Harley, P., Wiedinmyer, C., Palmer, P.I. and Geron, C. Estimates of global terrestrial isoprene emissions using MEGAN (Model of Emissions of Gases and Aerosols from Nature). Atmospheric Chemistry and Physics, Vol. 6, 2006, 3181-3210.

[44] Grell, G.A., Emeis, S., Stockwell, W.R., Schoenemeyer, T., Forkel, R., Michalakes, J., Knoche, R. and Seidl W. Application of a multiscale, coupled MM5/chemistry model to the

complex terrain of the VOTALP valley campaign. Atmospheric Environment, Vol. 34, 2000, 1435-1453.

[45] Zheng, M., Salmon, L.G., Schauer, J.J., Zeng, L., Kiang, C.S., Zhang, Y. and Cass, G.R. Seasonal trends in PM2.5 source contributions in Beijing, China. Atmospheric Environment, Vol. 39 (22), 2005, 3967-3976.

[46] Ravindra, K., Sokhi, R. and Van Grieken, R. Atmospheric polycyclic aromatic hydrocarbons: source attribution, emission factors and regulation. Atmospheric Environment, Vol. 42 (13), 2008, 2895-2921.

[47] Griffin, R.J., Nguyen, K., Dabdub, D. and Seinfeld, J.H. A coupled hydrophobic-hydrophilic model for predicting secondary organic aerosol formation. Journal of Atmospheric Chemistry, Vol. 44 (2), 2003, 171-190.

[48] Grieshop, A.P., Logue, J.M., Donahue, N.M. and Robinson, A.L. Laboratory investigation of photochemical oxidation of organic aerosol from wood fires 1: measurement and simulation of organic aerosol evolution. Atmospheric Chemistry and Physics, Vol. 9 (4), 2009, 1263-1277.

[49] King, D.A. The scientific impact of nations. Nature, Vol. 430, 2004, 311-316.

[50] Ho, Y.S. and Kahn, M. A bibliometric study of highly cited reviews in the Science Citation Index Expanded™. Journal of the Association for Information Science and Technology, Vol. 65 (2), 2014, 372-385.

[51] Lee, S.C., Li, W.M. and Ao, C.H. Investigation of indoor air quality at residential homes in Hong Kong—case study. Atmospheric Environment, Vol. 36 (2), 2002a, 225-237.

[52] Lee, S.C., Guo, H., Li, W.M. and Chan, L.Y. Inter-comparison of air pollutant concentrations in different indoor environments in Hong Kong. Atmospheric Environment, Vol. 36 (12), 2002b, 1929-1940.

[53] Lee, S.C., Chiu, M.Y., Ho, K.F., Zou, S.C. and Wang, X. Volatile organic compounds (VOCs) in urban atmosphere of Hong Kong. Chemosphere, Vol. 48 (3), 2002c, 375-382.

[54] Ho, K.F., Lee, S.C. and Chiu, G.M. Characterization of selected volatile organic compounds, polycyclic aromatic hydrocarbons and carbonyl compounds at a roadside monitoring station. Atmospheric Environment, Vol. 36 (1), 2002, 57-65.

[55] Liu, Y., Shao, M., Zhang, J., Fu, L. and Lu, S. Distributions and source apportionment of ambient volatile organic compounds in Beijing city, China. Journal of Environmental Science and Health, Vol. 40 (10), 2005, 1843-1860.

[56] Liu, Y., Shao, M., Lu, S., Chang, C.C., Wang, J.L. and Chen, G. Volatile organic compound (VOC) measurements in the Pearl River Delta (PRD) region, China. Atmospheric Chemistry and Physics, Vol. 8 (6), 2008, 1531-1545.

[57] Hoque, R.R., Khillare, P.S., Agarwal, T., Shridhar, V. and Balachandran, S. Spatial and temporal variation of BTEX in the urban atmosphere of Delhi, India. Science of the Total Environment, Vol. 392 (1), 2008, 30-40.

[58] Vardoulakis, S., Solazzo, E. and Lumbreras, J. Intra-urban and street scale variability of BTEX, NO2 and O3 in Birmingham, UK: implications for exposure assessment. Atmospheric Environment, Vol. 45 (29), 2011, 5069-5078.

[59] Ao, C.H., Lee, S.C., Mak, C.L. and Chan, L.Y. Photodegradation of volatile organic compounds (VOCs) and NO for indoor air purification using TiO2: promotion versus inhibition effect of NO. Applied Catalysis B: Environmental, Vol. 42 (2), 2003a, 119-129.

[60] Ao, C.H. and Lee, S.C. Enhancement effect of TiO2 immobilized on activated carbon filter for the photodegradation of pollutants at typical indoor air level. Applied Catalysis B: Environmental, Vol. 44 (3), 2003b, 191-205.

[61] Phillips, M. Method for the collection and assay of volatile organic compounds in breath. Analytical biochemistry, Vol. 247 (2), 1997, 272-278.

[62] Phillips, M., Cataneo, R.N., Cummin, A.R., Gagliardi, A.J., Gleeson, K., Greenberg, J., Maxfield, R.A. and Rom, W.N. Detection of lung cancer with volatile markers in the breath. Chest Journal, Vol. 123 (6), 2003, 2115-2123.

[63] Rumchev, K., Spickett, J., Bulsara, M., Phillips, M. and Stick, S. Association of domestic exposure to volatile organic compounds with asthma in young children. Thorax, Vol. 59 (9), 2004, 746-751.

[64] Phillips, M., Cataneo, R.N., Condos, R., Erickson, G.A.R., Greenberg, J., La Bombardi, V., Munawar, M.I. and Tietje, O. Volatile biomarkers of pulmonary tuberculosis in the breath. Tuberculosis, Vol. 87 (1), 2007, 44-52.

[65] Pierce, T., Geron, C., Bender, L., Dennis, R., Tonnesen, G. and Guenther, A. Influence of increased isoprene emissions on regional ozone modeling. Journal of Geophysical Research: Atmospheres (1984–2012), Vol. 103 (D19), 1998, 25611-25629.

[66] Karl, T., Potosnak, M., Guenther, A., Clark, D., Walker, J., Herrick, J.D. and Geron, C. Exchange processes of volatile organic compounds above a tropical rain forest: Implications for modeling tropospheric chemistry above dense vegetation. Journal of Geophysical Research: Atmospheres (1984–2012), Vol. 109 (D18)), 2004,D18306.