Chinese Journal of Chemical Engineering, **20**(3) 478—488 (2012)

Top-cited Articles in Chemical Engineering in Science Citation Index Expanded: A Bibliometric Analysis

Yuh-Shan Ho*
Trend Research Centre, Asia University, No. 500, Lioufeng Road, Wufeng, Taichung County 41354, Taiwan, China

Abstract This study aimed to identify and to analyze characteristics of top-cited articles published in the Web of Science chemical engineering subject category from 1899 to 2011. Articles that have been cited more than 100 times were assessed regarding publication outputs, and distribution of outputs in journals. Five bibliometric indicators were used to evaluate source countries, institution and authors. A new indicator, Y-index, was created to assess quantity and quality of contribution to articles. Results showed that 3828 articles, published between 1931 and 2010, had been cited at least 100 times. Among them 54% published before 1991, and 49% top-cited articles originated from US. The top eight productive institutions were all located in US. The top journals were *Journal of Catalysis*, *AIChE Journal*, *Chemical Engineering Science* and *Journal of Membrane Science*. Y-index was successfully applied to evaluate publication character of authors, institutions, and countries/regions.
Keywords bibliometric, Web of Science, highly cited, Y-index, publication character

1 INTRODUCTION

Top-cited articles can provide insights into how research fields have evolved over time, and identify those researchers who have made high impact in a research field. Although citation rate is not a direct measure of the impact or importance of a particular scholarly work, it does provide a marker of its recognition within the scientific community [1]. Frequently, the best manuscript can be considered the one most cited in peer-reviewed journals [2].

The analysis of citation characteristics has been accepted as a popular method for measuring the impact of an article [3], a researcher [4], a country/region [5], or a year [6]. A number of studies have investigated top-cited articles in the *Journal Citation Reports* (JCR), particularly in medicine, such as in anesthesia [7], ophthalmology [8], urology [9], obstetrics and gynecology [10], rehabilitation [1], and orthopedics [11]. The "citation classics" of several science and engineering related journals have also been described, including *Analytical Chemistry* [12], *Indoor Air* [13], and *IEEE Software* [14].

In recent years, the number of total citations was widely applied to evaluate top-cited articles, such as in comparing universities' scientific performance [15] and high-impact papers presented in the subject category of water resources [16]. In addition, citation history has been used to describe impact character and to project future influence of articles. It has been reported for journals, such as in *American Journal of Roentgenology* [17], *Cardiovascular Research* [18], and *Ophthalmology Journals* [8], and for articles, such as in Patent Ductus Arteriosus research [19], homeopathy research [20], tsunami research [21], and in global climate change research in recent year [22].

In addition to citation analysis, authorship analysis, as well, can help to identify leaders among individual researchers, institutions, or countries. At the individual level, a non-alphabetical name order sends a clear signal to the market that the author who is listed first has actually contributed more [23]. It has been accepted convention among the experimental sciences is that the most important positions are the first and the last, whom very often is the corresponding author [24, 25]. The first author is that person who contributed most to the work, including conducting research and writing of the manuscript [26–28]. The corresponding author is perceived as the author contributing significantly to the article independently of the author position [29]. The corresponding author supervised the planning and execution of the study and the writing of the paper [30]. At the country/region or institutional level, the country/region or institution of the corresponding author might be a home base of a study, or origin of the paper.

In this study, all journal articles and proceeding articles with more than 100 total citations were selected and analyzed with regard to authors, institutions, and countries/regions with citation histories, total citation, and citation in 2011. A new indicator, Y-index, was developed and used to evaluate contributions of individual authors, institutions, and countries/regions.

2 METHODOLOGY

Documents reported in this study were derived from the online version of SCI-Expanded, Thomson Reuters Web of Science database which is the most frequently used source for a broad review of scientific accomplishment in numerous fields [31, 32]. According to Journal Citation Reports (JCR) of 2010, it indexes 8073 journals with citation references across 174 scientific disciplines. Among them, 135 journals were listed in the category of chemical engineering, last indexed in 2010. The Web of Science was updated on

Received 2012-02-06, accepted 2012-04-25.
* To whom correspondence should be addressed. E-mail: ysho@asia.edu.tw

30 December 2011 and data were collected on 03 January 2012. In the category of chemical engineering, 610198 documents, of 22 document types, were published from 1931 to 2010 (Table 1). In this paper, only articles and proceedings papers were considered. A top-cited article is defined as one with at least 100 total citations (TC2011 $\geqslant$100). The annual citation frequencies for each of the top-cited articles were collected. The number of citation of an article in a single year, for example 2011, is referred to as C2011, and the total number of citations since publication to 2011 was referred to as TC2011 [16, 33]. Collaboration type was determined by the addresses of the authors. The term "country/region independent article" was assigned if the researchers' addresses were from the same country/region. The term "internationally collaborative article" was designated to those articles that were coauthored by researchers from multiple countries/regions [20]. The term "institution independent article" was assigned if the researchers' addresses were from the same institution. The term "inter-institutionally collaborative article" was assigned if authors were from different institutions [34]. The impact factor of a journal was determined for each document as reported in the JCR 2010.

Table 1 Distribution of document types

Document types	No. documents	Percentage/%
article	440512	72
news item	54853	9.0
editorial material	36820	6.0
proceedings paper	35867	5.9
note	21219	3.5
letter	19968	3.3
meeting abstract	17848	2.9
review	6131	1.0
book review	3669	0.60
correction addition	2827	0.46
biographical item	2431	0.40
correction	1553	0.26
item about an individual	918	0.15
discussion	601	0.10
abstract of published item	432	0.071
reprint	166	0.027
software review	165	0.027
bibliography	60	0.010
book chapter	22	0.0040
chronology	10	0.0020
hardware review	10	0.0020
database review	5	0.0010

In this study, Y-index (j, θ), is developed. It is related to numbers of first author publications (FP) and corresponding author publications (RP), defined as:

$$j = \sqrt{\mathrm{FP}^2 + \mathrm{RP}^2} \tag{1}$$

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

A country/region with a higher j indicates more papers as first or corresponding authors, and partake leadership role in more papers. θ, a publication character constant, differentiate its nature of leadership role. When θ>0.7854, means published more corresponding author articles and θ<0.7854, means published more first author articles. When θ= 0, j = number of first author articles and $\theta = \infty$, j = number of corresponding author articles.

In SCI-Expanded database, the corresponding author is labeled as reprint author, and is referred to as the corresponding author in this study. In a single author article where authorship is not specified, the author is classified as the first author as well as the corresponding author. Y-index was calculated and was applied to evaluate countries/region, institutions, and authors' publications.

Articles originating from England, Scotland, Northern Ireland, and Wales were reclassified as being from the United Kingdom (UK). Federal Republic of Germany (Fed Rep Ger), German Democratic Republic (Ger Dem Rep), West Germany, Bundes Republik, and Germany were reclassified as being from Germany. Similarly, USSR and Russia were also reclassified as being from Russia. Articles from Hong Kong published after 1997 were not included in the China category, but as a separate region for consistency.

3 RESULTS AND DISCUSSION

3.1 Effect of time on citation analysis

Citation analysis provides quantitative information about the authors, areas of research and journals. This information is useful to identify classic works and high-impact journals [35]. In this research, articles that have been cited at least 100 times (TC2011 $\geqslant$100) is defined as top-cited articles. A total of 3828 papers, published between 1931 and 2010 in 97 journals, received more than 100 citations since publication. Among them, 27% were published in *Journal of Catalysis* with impact factor 5.415, ranked 4th in 135 journals in chemical engineering field, and 10% were published in *AIChE Journal* ranked 2nd with IF = 2.030 (32/135), and 7.7% were published in *Chemical Engineering Science* ranked 3rd with IF = 2.379 (22/135). Fig. 1 shows geographical distribution of these top-cited articles. North America, West Europe, and Japan were the main production area. Fig. 2 shows that 48% of articles identified were published after 1990s, and 88% after 1970s. It also shows that earlier decades, although published fewer top-cited articles, but have higher citations on average than recent decades. "The drying of porous solids diffusion and surface emission equations" (TC2011 = 247) and "The drying of porous

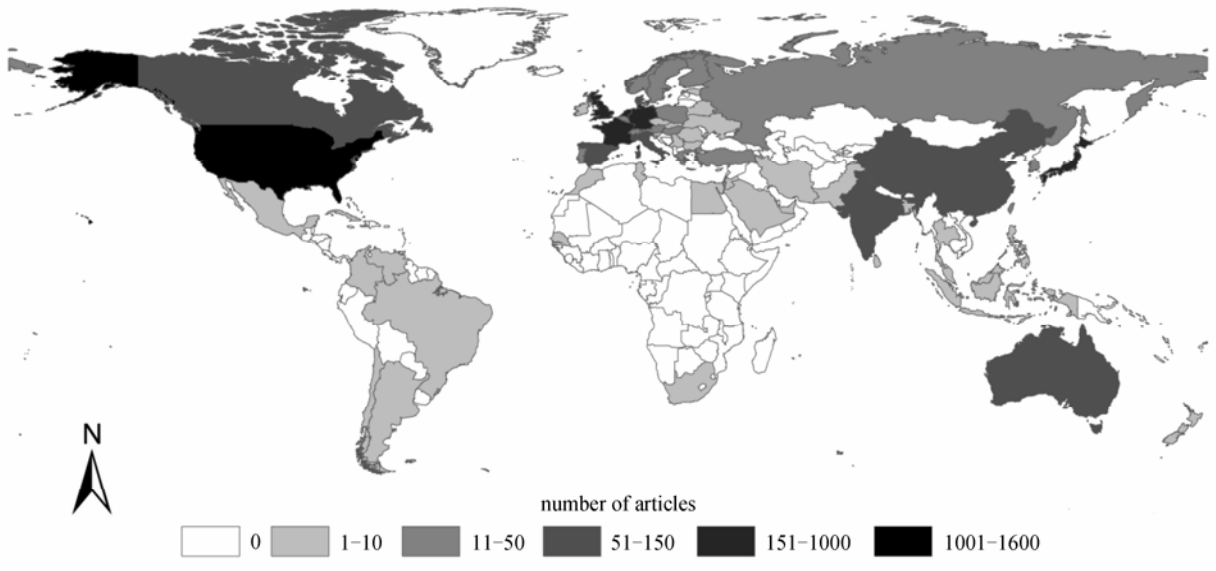

Figure 1 Distribution of top-cited articles in the world

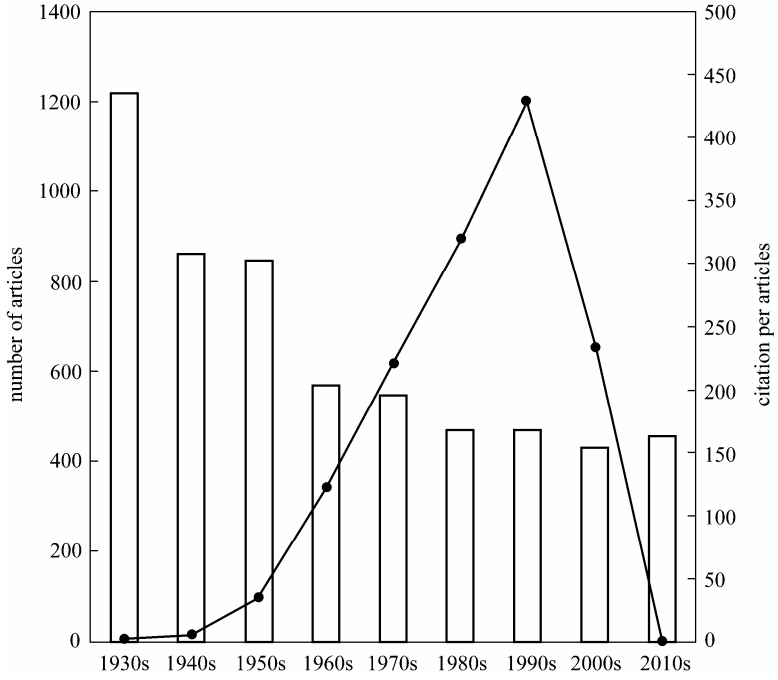

Figure 2 Number of articles on the top-cited article and citation per articles by decade of publication

citation per articles; total articles

solids diffusion calculations" (TC2011 = 226) were the earliest top-cited articles in chemical engineering, published by Newman in 1931 [36, 37]. The latest top-cited article was "Manufacture, integration and demonstration of polymer solar cells in a lamp for the 'Lighting Africa' initiative", published in 2010 (TC2011 = 162).

Table 2 presents articles cited for more than 1000 times. Out of these 24 articles, 11 (46%) were published before 1970, eight (33%) between 1971 and 1990, and five (21%) were published after 1991. The first article cited more than 1000 times was published in 1935 and the latest one was published in 2001. The journals in which these articles published were *Journal of Catalysis* (IF in 2010 = 5.415) with five articles, followed by *AIChE Journal* (IF in 2010 = 2.030), *Chemical Engineering Progress* (IF in 2010 = 0.732), *Chemical Engineering Science* (IF in 2010 = 2.379), and *Catalysis Today* (IF in 2010 = 2.993) with 4, 3, 3, and 2 articles, respectively. Peng and Robinson [38] published the most frequently cited article with TC2011 = 3413. This article was the only one has been cited more than 3000 times in chemical engineering

field. Haruta, M. had 3 articles with TC2011>1000 followed by Kobayashi, T. and Prausnitz, J.M. with two articles (Table 2).

Articles published earlier were at an advantage to gain more citations, compared to those published at a later time [11]. Nevertheless, the ranking of top-cited papers would still fluctuate over time. Previous research found that since 1988, 94% of the 50 most frequently cited articles published in *American Journal of Roentgenology* have changed their ranking [62]. Although Table 2 shows the articles with high citations, it does not provide any information on its future

Table 2 Ten most frequently cited articles in the field of chemical engineering

TC2011 (rank)	C2011 (rank)	Article information (reference)
3413 (1)	247 (2)	Peng, D. and Robinson, D.B. (1976), New 2-constant equation of state. *Industrial & Engineering Chemistry Fundamentals*, **15** (1), 59−64. [38]
2685 (2)	191 (5)	Renon, H. and Prausnitz, J.M. (1968), Local compositions in thermodynamic excess functions for liquid mixtures. *AIChE J*., **14** (1), 135−144. [39]
2677 (3)	158 (7)	Ergun, S. (1952), Fluid flow through packed columns. *Chem*. *Eng*. *Prog*., **48** (2), 89−94. [40]
2425 (4)	117 (12)	Soave, G. (1972), Equilibrium constants from a modified Redlich-Kwong equation of state. *Chem*. *Eng*. *Sci*., **27** (6), 1197−1203. [41]
2358 (5)	107 (14)	Wilke, C.R. and Chang, P. (1955), Correlation of diffusion coefficients in dilute solutions. *AIChE J*., **1** (2), 264−270. [42]
2217 (6)	194 (4)	Cavani, F., Trifirò, F. and Vaccari, A. (1991), Hydrotalcite-type anionic clays: preparation, properties and applications. *Catal*. *Today*, **11** (2), 173−301. [43]
2211 (7)	131 (9)	Abrams, D.S. and Prausnitz, J.M. (1975), Statistical thermodynamics of liquid-mixtures: New expression for excess Gibbs energy of partly or completely miscible systems. *AIChE J*., **21** (1), 116−128. [44]
1917 (8)	209 (3)	Haruta, M. (1997), Size- and support-dependency in the catalysis of gold. *Catal*. *Today*, **36** (1), 153−166. [45]
1602 (9)	366 (1)	Ho, Y.S. and McKay, G. (1999), Pseudo-second order model for sorption processes. *Process Biochemistry*, **34** (5), 451−465. [46]
1486 (10)	49 (83)	Danckwerts, P.V. (1953), Continuous flow systems: Distribution of residence times. *Chem*. *Eng*. *Sci*., **2** (1), 1−13. [47]
1454 (11)	65 (40)	Fredenslund, A., Jones, R.L. and Prausnitz, J.M. (1975), Group-contribution estimation of activity coefficients in nonideal liquid mixtures. *AIChE J*., **21** (6), 1086−1099. [48]
1409 (12)	62 (48)	Ranz, W.E. and Marshall, Jr., W.R. (1952), Evaporation from drops. Part I. *Chem*. *Eng*. *Prog*., **48** (3), 141−146. [49]
1374 (13)	172 (6)	Haruta, M., Yamada, N., Kobayashi, T. and Iijima, S. (1989), Gold catalysts prepared by coprecipitation for low-temperature oxidation of hydrogen and of carbon-monoxide. *J. Catal*., **115** (2), 301−309. [50]
1186 (14)	58 (62)	Lippens, B.C. and de Boer, J.H. (1965), Studies on pore systems in catalysts: V. The *t* method. *J. Catal*., **4** (3), 319−323. [51]
1179 (15)	67 (34)	Geldart, D. (1973), Types of gas fluidization. *Powder Technology*, **7** (5), 285−292. [52]
1160 (16)	34 (177)	Parry, E.P. (1963), An infrared study of pyridine adsorbed on acidic solids characterization of surface acidity. *J. Catal*., **2** (5), 371−379. [53]
1138 (17)	55 (71)	Lockhart, R.W. and Martinelli, R.C. (1949), Proposed correlation of data for isothermal two-phase, two-component flow in pipes. *Chem*. *Eng*. *Prog*., **45** (1), 39−48. [54]
1128 (18)	107 (14)	Haruta, M., Tsubota, S., Kobayashi, T., Kageyama, H., Genet, M.J. and Delmon, B. (1993), Low-temperature oxidation of Co over gold supported on TiO_2, α-Fe_2O_3, and Co_3O_4. *J. Catal*., **144** (1), 175−192. [55]
1123 (19)	149 (8)	Kreuer, K.D. (2001), On the development of proton conducting polymer membranes for hydrogen and methanol fuel cells. *J. Membr*. *Sci*., **185** (1), 29−39. [56]
1103 (20)	53 (75)	Brinkman, H.C. (1947), A calculation of the viscous force exerted by a flowing fluid on a dense swarm of particles. *Applied Scientific Research Section A—Mechanics Heat Chemical Engineering Mathematical Methods*, **1** (1), 27−34. [57]
1098 (21)	30 (230)	Higbie, R. (1935), The rate of absorption of a pure gas into a still liquid during short periods of exposure. *Transactions of the American Institute of Chemical Engineers*, **31**, 365−389. [58]
1093 (22)	29 (245)	van Deemter, J.J., Zuiderweg, F.J. and Klinkenberg, A. (1956), Longitudinal diffusion and resistance to mass transfer as causes of nonideality in chromatography. *Chem*. *Eng*. *Sci*., **5** (6), 271−289. [59]
1040 (23)	66 (36)	Turchi, C.S. and Ollis, D.F. (1990), Photocatalytic degradation of organic-water contaminants: Mechanisms involving hydroxyl radical attack. *J. Catal*., **122** (1), 178−192. [60]
1010 (24)	34 (177)	Hayden, J.G. and Oconnell, J.P. (1975), Generalized method for predicting 2nd virial-coefficients. *Industrial & Engineering Chemistry Process Design and Development*, **14** (3), 209−216. [61]

Note: TC2011—number of citations till 2011; C2011—number of citations in 2011.

trend in citations frequency.

To examine this aspect, the time trend for the six articles with highest C2011 was demonstrated in Fig. 3. "New 2-constant equation of state" published by Peng and Robinson [38] had highest TC2011, as well as highest annual citations in earlier years, until 2004. This article continue to receive high citations, ranked second in 2011 with C2011 = 247. As seen in Fig. 3, "pseudo-second order model for sorption processes" [46] was the article with highest annual citations from 2008 to 2011, as well as, the only one with annual citations more than 300 times. This adsorption order model has been accepted and applied in adsorption studies.

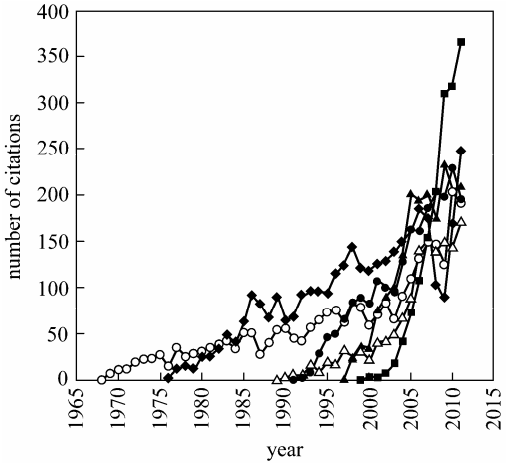

Figure 3 The life of the ten most frequently top-cited articles in 2011 in chemical engineering field

■ Ho and Mckay (1999), TC2011 = 1602, rank 9; ◆ Peng and Robinson (1976), TC2011 = 3413, rank 1; ▲ Haruta (1997), TC2011 = 1917, rank 8; ● Cavani *et al*. (1991), TC2011 = 2217, rank 6; ○ Renon and Prausnit (1968), TC2011 = 2685, rank 2; △ Haruta *et al*. (1989), TC2011 = 1374, rank 13

3.2 Publication performances: countries/regions, institutions, and authors

In recent years, indicators of performance of first authors [34], institutions [63], and countries/regions [64] were reported to compare research performances. Among the top-cited articles, 611 did not have information on author address. Of all the articles with author's addresses, 2899 (90%) articles were country/region independent articles from 53 countries/regions and 318 (10%) articles were internationally collaborative articles from 59 countries/regions. Table 3 shows the top 20 countries/regions, ranked according to the number of total top-cited articles published, in terms of number total articles, country/region independent articles, internationally collaborative articles, first author articles, and corresponding author's articles. Moreover the percentage of independent articles in total articles for each country/region (SP) was also presented. United States

Table 3 Top 20 countries/regions of top-cited articles

Country/region	TP	TPR/%	SPR/%	CPR/%	FPR/%	RPR/%	SP/%
USA	1565	1 (49)	1 (49)	1 (44)	1 (47)	1 (40)	91
Japan	224	2 (7.0)	2 (6.7)	6 (9.1)	2 (6.3)	2 (7.1)	87
UK	207	3 (6.4)	3 (5.6)	4 (14)	3 (5.7)	4 (5.5)	79
Germany	190	4 (5.9)	4 (4.5)	2 (19)	4 (4.9)	3 (5.7)	69
France	169	5 (5.3)	6 (3.9)	3 (18)	5 (4.5)	5 (5.1)	73
Netherlands	152	6 (4.7)	5 (4.2)	6 (9.1)	6 (4.3)	6 (4.2)	74
Canada	131	7 (4.1)	7 (3.7)	9 (7.2)	7 (3.7)	8 (3)	82
Italy	112	8 (3.5)	8 (2.9)	6 (9.1)	8 (3.2)	7 (3.3)	74
Spain	98	9 (3.0)	9 (2.2)	5 (11)	9 (2.4)	9 (2.8)	65
Australia	73	10 (2.3)	10 (2.1)	13 (4.1)	10 (2.0)	10 (2.4)	82
India	61	11 (1.9)	11 (1.9)	20 (2.2)	11 (1.8)	11 (2.2)	89
Denmark	59	12 (1.8)	12 (1.4)	11 (5.3)	12 (1.6)	12 (2.0)	71
China	55	13 (1.7)	13 (1.1)	9 (7.2)	13 (1.3)	13 (1.7)	58
Switzerland	39	14 (1.2)	14 (1.0)	15 (3.5)	14 (1.1)	14 (1.2)	72
Belgium	34	15 (1.1)	16 (0.66)	12 (4.7)	15 (0.9)	19 (0.81)	76
South Korea	32	16 (1.0)	16 (0.66)	13 (4.1)	18 (0.71)	17 (0.85)	59
Greece	29	17 (0.90)	16 (0.66)	16 (3.1)	17 (0.75)	19 (0.81)	66
Turkey	28	18 (0.87)	15 (0.90)	36 (0.63)	16 (0.84)	15 (1.2)	68
Hong Kong, China	25	19 (0.78)	19 (0.59)	18 (2.5)	19 (0.68)	16 (1.0)	68
Sweden	22	20 (0.68)	21 (0.52)	20 (2.2)	21 (0.59)	17 (0.85)	77
Taiwan, China	22	20 (0.68)	19 (0.59)	25 (1.6)	20 (0.62)	21 (0.72)	68

Note: TP—total number of articles; TPR, SPR, CPR, FPR, and RPR—the rank and percentage of total articles, country/region independent articles, internationally collaborative articles, first author articles, corresponding author articles in their total articles; SP—the percentage of country/region independent articles in total articles for each country/region.

Table 4 Top 10 most productive institutions

Institution	TP	TPR/%	SPR/%	CPR/%	FPR/%	RPR/%	SP/%
University of California, Berkeley, USA	85	1 (2.6)	4 (1.7)	1 (5.1)	2 (2.0)	3 (1.3)	71
Massachusetts Institute of Technology, USA	79	2 (2.5)	1 (2.5)	4 (2.2)	1 (2.3)	2 (1.4)	59
University of Texas, USA	62	3 (1.9)	2 (2.0)	7 (1.8)	3 (1.7)	7 (1.1)	73
Exxon Research and Engineering Company, USA	59	4 (1.8)	3 (1.9)	11 (1.6)	4 (1.5)	1 (1.5)	69
University of Minnesota, USA	48	5 (1.5)	5 (1.5)	16 (1.4)	5 (1.4)	8 (1.0)	75
Pennsylvania State University, USA	44	6 (1.4)	6 (1.5)	24 (1.1)	7 (1.1)	4 (1.2)	80
University of Delaware, USA	42	7 (1.3)	8 (1.3)	16 (1.4)	6 (1.2)	22 (0.58)	74
University of Wisconsin, USA	40	8 (1.2)	7 (1.3)	24 (1.1)	8 (1.1)	47 (0.40)	75
Delft University of Technology, Netherlands	40	8 (1.2)	12 (1.0)	6 (1.9)	11 (1.0)	5 (1.1)	75
Carnegie Mellon University, USA	36	10 (1.1)	8 (1.3)	46 (0.70)	9 (1.0)	33 (0.49)	78
University of Tokyo, Japan	36	10 (1.1)	10 (1.2)	28 (0.94)	11 (1.0)	10 (0.81)	72

Note: TP—total number of articles; TPR, SPR, CPR, FPR, and RPR—the rank and percentage of total articles, institution independent articles, inter-institutionally collaborative articles, first author articles, corresponding author articles in their total articles; SP—the percentage of institution independent articles in total articles for each institution.

(USA) was the most productive country in five indicators. The percentage of independent articles represented 91% of the total articles from the USA, which was higher than any other countries/regions, while China had the lowest percentage of independent articles (SP = 58%). The 7 major industrial countries (G7: USA, Japan, the UK, Germany, France, Canada, and Italy) were among the top 8 productive countries. Domination in articles from the mainstream countries was not surprising since this pattern occurs in other scientific fields [65, 66].

Most of the top-cited articles in chemical engineering field were from single institutions. Of all articles with author addresses, 2362 (73%) were institution independent articles and 855 (27%) were inter-institutionally collaborative articles. Table 4 shows the top 11 institutions, ranked according to the total number of top-cited articles. Among the top 11 institutes, 9 (82%) were in USA. University of California, Berkeley ranked first with 85 articles, followed by Massachusetts Institute of Technology (79), and University of Texas (62). Exxon Research and Engineering Company, the only one non-university institution, ranked 4th in total articles. The two non-US institutions were Delft University of Technology in Netherlands and University of Tokyo in Japan, ranked in 9th and 10th, respectively. University of California, Berkeley was also contributing the most inter-institutionally collaborative articles, which meant the university was the most-frequent partners. MIT published the most institution independent articles and first author article, not surprisingly since it was the first to introduce a chemical engineering curriculum in 1888 [67], and was rated the most productive department of chemical engineering in the USA [68]. Exxon Research and Engineering Company produced the most corresponding author articles. Pennsylvania State University had the highest percentage of institution independent articles among its total articles.

Of the 3828 top-cited articles in chemical engineering field, there were 7194 authors. The percentages of articles with one, two, three, and four authors were 13.6%, 37.1%, 23.8%, and 13.5%, respectively. Further analysis was carried out on the total, first, single, and corresponding author of the top-cited articles that have author information. Of all top-cited articles, 1592 (42%) articles without corresponding author information on the Web of Science were excluded from the analysis. There were 2236 articles published by 1678 corresponding authors who were from 803 institution and 55 countries/regions. 1367 (81%) authors only had one top-cited article as a corresponding author. Corma, A. published the most corresponding author articles with 18 articles followed by McKay, G. with 13; Herrmann, J.M. with 11; Burch, R. with 11; and Iglesia, E. with 10. Overall, top-cited articles (3828) were published by 2973 first authors from 924 institution and 58 countries/regions. Majority authors (2426, 82%) only had one top-cited article as a first author. The top three most productive first authors were Corma, A. published 17 top-cited articles followed by Burch, R. with 12 and Ho, Y.S. with 11. Table 5 shows the top 10 productive authors, ranked by the total number of top-cited articles. Bell, A.T. contributed the most with 36, followed by Prausnitz, J.M. (34).

Of the 3828 articles, 2236 articles had both first author and corresponding author information and were used to calculate a Y-index for countries/regions, institutions, and individual authors. Fig. 4 shows the other top 15 countries/regions with $j>30$ except USA. USA had 904 first author articles and 899 corresponding author articles, and had the highest Y-index of (1275, 0.7826), followed distantly by Japan ($j = 222$), Germany ($j = 182$), the UK ($j = 173$), and France ($j = 163$). Japan, UK, Canada, Australia, Denmark, and Turkey all have a θ greater than 0.7854,

Table 5 Top 10 most productive authors

Institution	Rank (TP)	Rank (FP)	Rank (RP)	Rank (GP)
Bell, A.T.	1 (36)	N/A	17 (5)	N/A
Prausnitz, J.M.	2 (34)	547 (1)	N/A	N/A
Moulijn, J.A.	3 (24)	N/A	N/A	N/A
Boudart, M.	3 (24)	7 (6)	N/A	N/A
Corma, A.	5 (23)	1 (17)	1 (18)	N/A
Iglesia, E.	6 (22)	7 (6)	5 (10)	N/A
Sachtler, W.M.H.	6 (22)	547 (1)	51 (3)	N/A
Vannice, M.A.	8 (21)	4 (9)	6 (9)	2 (5)
Grossmann, I.E.	9 (19)	177 (2)	312 (1)	N/A
Hall, W.K.	9 (19)	69 (3)	N/A	70 (1)

Note: TP—total number of top-cited articles; FP—first author articles; RP—corresponding author articles; GP—single author articles; N/A—not available.

indicating these countries published more corresponding author top-cited articles. A similar distribution pattern for institutions was also found (Fig. 5). MIT had the highest j in Y-index (51.2, 0.6747), followed by University of California, Berkeley (49.4, 0.6273), and Exxon Research and Engineering Company (44.6, 0.8330). The distribution of Y-index was more dispersed among institutions than among countries/regions. Berkeley MIT, and Princeton University all had a θ smaller than 0.7854, an indication that these institutions published more first author articles than corresponding author article.

Figure 6 shows distribution of Y-index of authors. Corma, A. published the most top-cited articles included 15 first author and 18 corresponding author articles with a Y-index of (23.4, 0.8761), followed distantly by Burch, R. with (14.9, 0.8330). McKay, G. published more corresponding author articles with the highest θ (1.344) while Ho, Y.S. published more first author articles with the lowest θ (0.1974). Aksu, Z. and Topsoe, N.Y. had the same numbers of publications (j = 9.22) but Aksu, Z. (θ = 0.8622) published more corresponding author articles than Topsoe, N.Y. (θ = 0.7086). Most authors in Fig. 6 had a θ greater than 0.7854, except for Ho, Y.S., Topsoe, N.Y., and Oh, S.H.

3.3 Impact of top ten articles

Table 6 shows the top 10 articles. Among them, three were published in *AIChE Journal*, and two were published in *Catalysis Today* and *Chemical Engineering Science* respectively. All the top 10 articles were published as institution independent articles. Three of them were published by authors from the USA (University of California, Berkeley), more than any other country/region. An article titled "new 2-constant equation of state", published in *Industrial & Engineering Chemistry Fundamentals* by Peng and Robinson [38] from Department of Chemistry and Engineering in University of Alberta in Canada, received the most

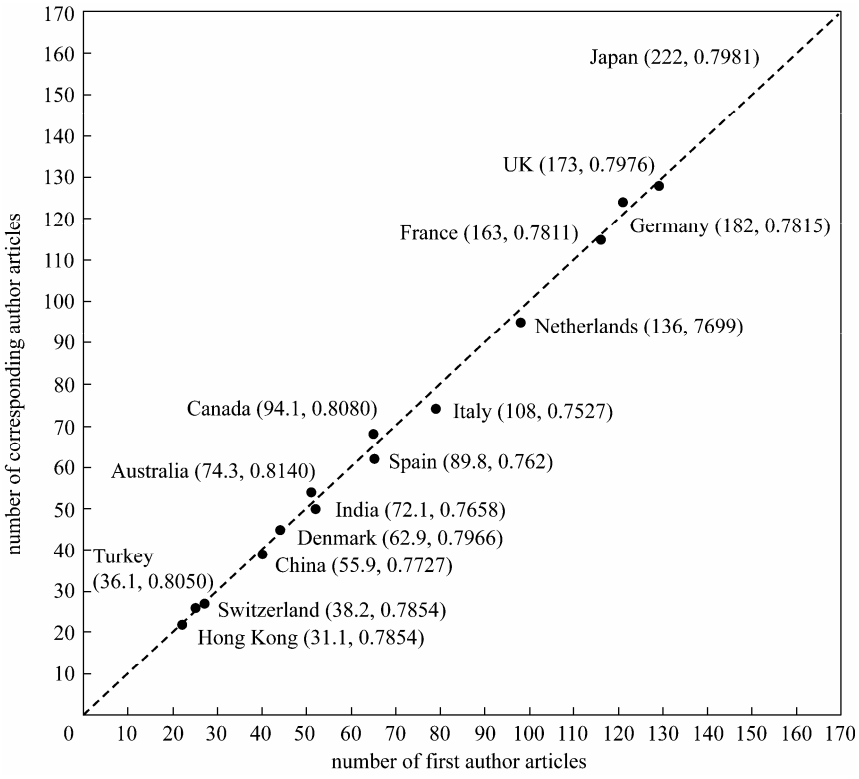

Figure 4 Countries/regions with Y-index (j>30)

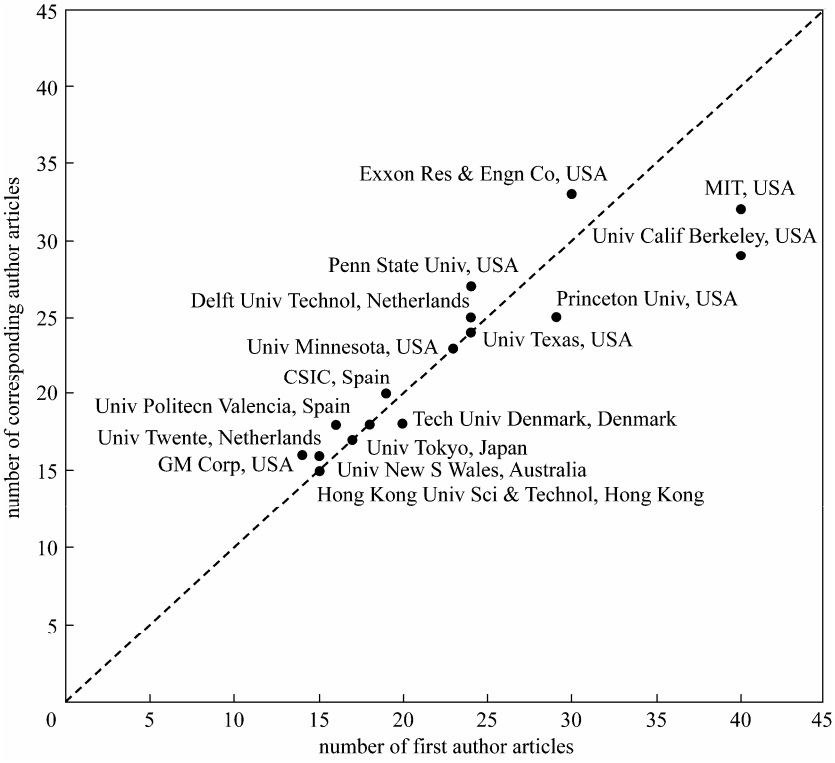

Figure 5 Top 16 institutions with Y-index (j>20)

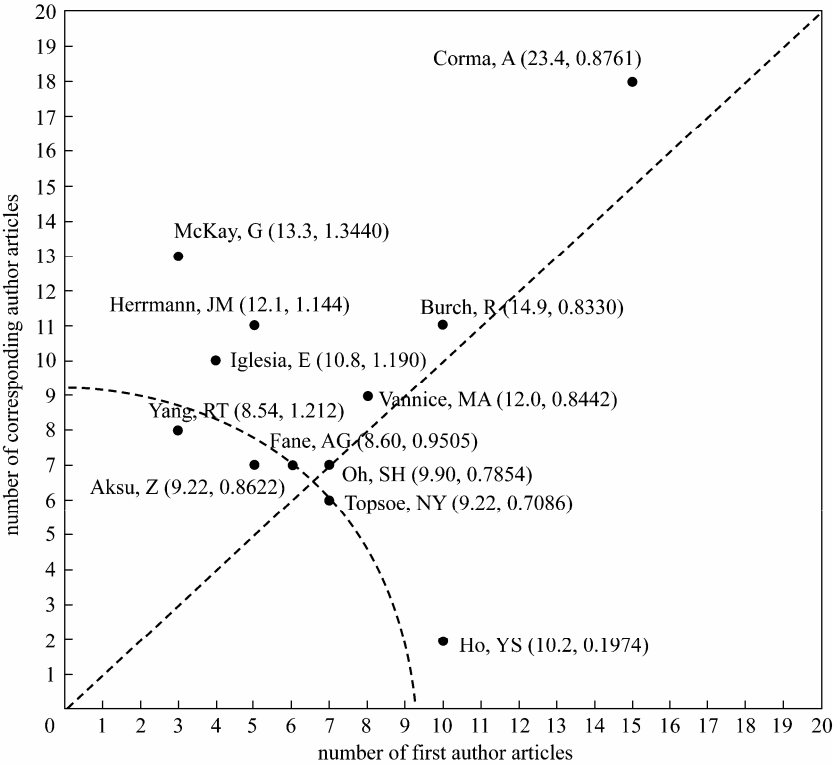

Figure 6 Top 12 authors with Y-index (j>8.5)

citations (TC2011 = 3413). The article has been cited by 4722 authors, from 1362 institutions, in 75 countries/regions. It was cited in 40 subject areas, and was cited on an average of 98 times per year. Three other articles that had higher citations per year were published by authors from Osaka National Research Institute in

Table 6 Top 10 articles with highest total citation since publication to 2011

Article (reference)	AU	IN	CT	SA	C/Y	Journal (IF2010)	Country	TC2011	C2011
Peng and Robinson (1976) [38]	4722	1362	75	40	98	**Industrial & Engineering Chemistry Fundamentals*	Canada	3413	247
Renon and Prausnitz (1968) [39]	3467	1015	70	34	62	*AIChE Journal* (2.03)	USA	2685	191
Ergun (1952) [40]	4887	1387	77	58	45	*Chemical Engineering Progress* (0.732)	USA	2677	158
Soave (1972) [41]	3335	1067	70	37	62	*Chemical Engineering Science* (2.379)	Italy	2425	117
Wilke and Chang (1955) [42]	4816	1154	74	57	42	*AIChE Journal* (2.03)	USA	2358	107
Cavani *et al*. (1991) [43]	3914	955	65	38	111	*Catalysis Today* (2.993)	Italy	2217	194
Abrams and Prausnitz (1975) [44]	2960	861	65	34	61	*AIChE Journal* (2.03)	USA	2211	131
Haruta (1997) [45]	4596	1043	67	34	137	*Catalysis Today* (2.993)	Japan	1917	209
Ho and McKay (1999) [46]	3577	950	74	42	134	*Process Biochemistry* (2.648)	China	1602	366
Danckwerts (1953) [47]	2657	764	68	55	26	*Chemical Engineering Science* (2.379)	UK	1486	49

Note: AU—numbers of authors cited; IN—numbers of institutions cited; CT—numbers of countries\regions cited; SA—numbers of subject areas cited; C/Y—citations/year; TC2011—total number of times cited since the paper was published to 2011; C2011—total number of times cited in 2011; IF2010—impact factor in 2010 JCR; *—*Industrial & Engineering Chemistry Fundamentals* was not listed in JCR after 1986.

Japan (137), the Hong Kong University of Science & Technology in Hong Kong (134), and University of Bologna in Italy (111), respectively. In addition, two articles "manufacture, integration and demonstration of polymer solar cells in a lamp for the 'Lighting Africa' initiative" [69] and "on the development of proton conducting polymer membranes for hydrogen and methanol fuel cells" [56] also had high citations per year of 162 and 112, respectively, but were not included in Table 6.

4 CONCLUSIONS

A total of 3828 top-cited articles published in 97 journals in chemical engineering field were identified. Interesting, the 1990s published more top-cited article than any other decades, and the *Journal of Catalysis*, which ranked 4th in 135 journals in chemical engineering field in 2010, published more top-cited articles than any other journals. The effect of time and journal ranking on citations was less than expected. USA ranked first in all indicators, but the article with most citations was published by Peng and Robinson from the University of Alberta, Canada. Corma published the greatest number of articles. McKay had the most corresponding author articles, while Ho had the most first author articles. All the top 10 articles were published as institution independent articles. It raised the question of why inter-institutional collaboration did not produce anyone of the top 10 articles. Further research can focus on whether collaboration is conducive in producing best quality papers, or just good papers. In this study, Y-index was successfully applied to evaluate publication character of authors, institution, and countries/regions. It is an attempt to assess both the publication quantity and character of contribution with a single index. The numbers of first and corresponding author articles were similar for institutions and countries/regions, but varied significantly among individuals. University of California, Berkeley was the most productive institution while Massachusetts Institute of Technology had highest publication performance of first and corresponding author articles, as indicated by Y-index. Both first author and corresponding author are major contributors to a published research work, but the quality of their contribution do differ significantly. The use of Y-index can assist researchers to look behind merely total publication, but also at the amount of contribution, as well as the character of contribution. In assessing performance of individual, institutions, or countries/regions, Y-index should be used to complement existing indicators.

REFERENCES

1 Shadgan, B., Roig, M., HajGhanbari, B., Reid, W.D., "Top-cited articles in rehabilitation", *Arch. Phys. Med. Rehabil*., **91**, 806−815 (2010).

2 Robinson, J.K., Callen, J.P., "The best of the best: A new section led by Henry W. Lim, MD", *Arch. Dermatol*., **146**, 554 (2010).

3 Bloch, S., "And the winners are: the top articles of 2001", *Aust. N. Z. J. Psych*., **36**,157 (2002).

4 Stern, R.S., Arndt, K.A., "Top cited authors in dermatology—A citation study from 24 journals: 1982−1996", *Arch. Dermatol*., **135**, 299−302 (1999).

5 Madhan, M., Chandrasekar, G., Arunachalam, S., "Highly cited papers from India and China", *Curr. Sci*., **99**,738−749 (2010).

6 Falkai, P., "What was new, interesting and frequently cited in 2009?", *Eur. Arch. Psych. Clin. Neurosci*., **260**, 87−89 (2010).

7 Baltussen, A., Kindler, C.H., "Citation classics in anesthetic journals", *Anesth*. Analg., **98**, 443−451 (2004).

8 Ohba, N., Nakao, K., Isashiki, Y., Ohba, A., "The 100 most frequently cited articles in ophthalmology journals", *Arch. Ophthalmol.*, **125**, 952−960 (2007).
9 Hennessey, K., Afshar, K., MacNeily, A.E., "The top 100 cited articles in urology", *CUAJ*, **3**, 293−302 (2009).
10 Brandt, J.S., Downing, A.C., Howard, D.L., Kofinas, J.D., Chasen, S.T., "Citation classics in obstetrics and gynecology: The 100 most frequently cited journal articles in the last 50 years", *Am. J. Obstet. Gynecol.*, **203**, 355.e1−355.e7 (2010).
11 Lefaivre, K.A., Shadgan, B., O'Brien, P.J., "100 most cited articles in orthopaedic surgery", *Clin. Orthop. Rel. Res.*, **469**, 1487−1497 (2011).
12 Riordon, J., Zubritsky, E., Newman, A., "Top 10 articles—Analytical chemistry looks at 10 seminal papers", *Anal. Chem.*, **72**, 324A−329A (2000).
13 Sundell, J., Nazaroff, W.W., "The most cited articles in Indoor Air, through 18 years", *Indoor Air*, **19**, 91−92 (2009).
14 O'Leary, D.E., "The most cited IEEE Software articles", *IEEE Softw.*, **26**, 12−14 (2009).
15 Wang, M.H., Fu, H.Z., Ho, Y.S., "Comparison of universities' scientific performance using bibliometric indicators", *Malays. J. Libr. Sci.*, **16**, 1−19 (2011).
16 Chuang, K.Y., Wang, M.H., Ho, Y.S., "High-impact papers presented in the subject category of water resources in the Essential Science Indicators database of the institute for scientific information", *Scientometrics*, **87**, 551−562 (2011).
17 Chew, F.S., "AJR: the 50 most frequently cited papers in the past 50 years", *Am. J. Roentgenol.*, **150**, 227−233 (1988).
18 Opthof, T., Coronel, R., "The most frequently cited papers of Cardiovascular Research (1967-1998): 'The Millennium Minutes'", *Cardiovasc. Res.*, **45**, 3−5 (2000).
19 Hsieh, W.H., Chiu, W.T., Lee, Y.S., Ho, Y.S., "Bibliometric analysis of patent ductus arteriosus treatments", *Scientometrics*, **60**, 205−215 (2004).
20 Chiu, W.T., Ho, Y.S., "Bibliometric analysis of homeopathy research during the period of 1991 to 2003", *Scientometrics*, **63**, 3−23 (2005).
21 Chiu, W.T., Ho, Y.S., "Bibliometric analysis of tsunami research", *Scientometrics*, **73**, 3−17 (2007).
22 Li, J.F., Wang, M.H., Ho, Y.S., "Trends in research on global climate change: A Science Citation Index Expanded-based analysis", *Glob. Planet. Change*, **77**, 13−20 (2011).
23 Engers, M., Gans, J.S., Grant, S., King, S.P., "First-author conditions", *J. Polit. Econ.*, **107**, 859−883 (1999).
24 Zuckerman, H.A., "Patterns of name ordering among authors of scientific papers: A study of social symbolism and its ambiguity", *American Journal of Sociology*, **74**, 276−291 (1968).
25 Costas, R., Bordons, M., "Do age and professional rank influence the order of authorship in scientific publications? Some evidence from a micro-level perspective", *Scientometrics*, **88**,145−161 (2011).
26 Riesenberg, D., Lundberg, G.D., "The order of authorship—Who's on first", *JAMA-J. Am. Med. Assoc.*, **264**, 1857 (1990).
27 Herbertz, H., Müller-Hill, B., "Quality and efficiency of basic research in molecular biology: A bibliometric analysis of thirteen excellent research institutes", *Res. Policy*, **24**, 959−979 (1995).
28 Kempers, R.D., "Ethical issues in biomedical publications", *Fertil. Steril.*, **77**, 883−888 (2002).
29 Mattsson, P., Sundberg, C.J., Laget, P., "Is correspondence reflected in the author position? A bibliometric study of the relation between corresponding author and byline position", *Scientometrics*, **87**, 99−105 (2011).
30 Burman, K.D., "Hanging from the masthead—Reflections on authorship", *Ann. Intern. Med.*, **97**, 602−605 (1982).
31 Allik, J., "Quality of Estonian science estimated through bibliometric indicators (1997-2007)", *P. Est. Acad. Sci.*, **57**, 255−264 (2008).
32 Bornmann, L., Daniel, H.D., "Selecting manuscripts for a high-impact journal through peer review: A citation analysis of communications that were accepted by Angewandte Chemie International Edition, or rejected but published elsewhere", *J. Am. Soc. Inf. Sci. Technol.*, **59**, 1841−1852 (2008).
33 Wang, M.H., Li, J.F., Ho, Y.S., "Research articles published in water resources journals: A bibliometric analysis", *Desalin. Water Treat.*, **28**, 353−365 (2011).
34 Li, Z., Ho, Y.S., "Use of citation per publication as an indicator to evaluate contingent valuation research", *Scientometrics*, **75**, 97−110 (2008).
35 Dubin, D., Häfner, A.W., Arndt, K.A., "Citation-classics in clinical dermatological journals: Citation analysis, biomedical journals, and landmark articles, 1945−1990", *Arch. Dermatol.*, **129**, 1121−1129 (1993).
36 Newman, A.B., "The drying of porous solids diffusion and surface emission equations", *Trans. Am. Inst. Chem. Eng.*, **27**, 203−220 (1931).
37 Newman, A.B., "The drying of porous solids diffusion calculations", *Trans. Am. Inst. Chem. Eng.*, **27**, 310−333 (1931).
38 Peng, D., Robinson, D.B., "New 2-constant equation of state", *Ind. Eng. Chem. Fund.*, **15**, 59−64 (1976).
39 Renon, H., Prausnitz, J.M., "Local compositions in thermodynamic excess functions for liquid mixtures", *AIChE J.*, **14**, 135−144 (1968).
40 Ergun, S., "Fluid flow through packed columns", *Chem. Eng. Prog.*, **48**, 89−94 (1952).
41 Soave, G., "Equilibrium constants from a modified Redlich-Kwong equation of state", *Chem. Eng. Sci.*, **27**, 1197−1203 (1972).
42 Wilke, C.R., Chang, P., "Correlation of diffusion coefficients in dilute solutions", *AIChE J.*, **1**, 264−270 (1955).
43 Cavani, F., Trifirò, F., Vaccari, A., "Hydrotalcite-type anionic clays: preparation, properties and applications", *Catal. Today*, **11**,173−301 (1991).
44 Abrams, D.S., Prausnitz, J.M., "Statistical thermodynamics of liquid-mixtures: New expression for excess Gibbs energy of partly or completely miscible systems", *AIChE J.*, **21**,116−128 (1975).
45 Haruta, M., "Size- and support-dependency in the catalysis of gold", *Catal. Today*, **36**, 153−166 (1997).
46 Ho, Y.S., McKay, G., "Pseudo-second order model for sorption processes", *Process Biochem.*, **34**, 451−465 (1999).
47 Danckwerts, P.V., "Continuous flow systems: Distribution of residence times", *Chem. Eng. Sci.*, **2**, 1−13 (1953).
48 Fredenslund, A., Jones, R.L., Prausnitz, J.M., "Group-contribution estimation of activity coefficients in nonideal liquid mixtures", *AIChE J.*, **21**, 1086−1099 (1975).
49 Ranz, W.E., Marshall, Jr., W.R., "Evaporation from drops. Part I", *Chem. Eng. Prog.*, **48**, 141−146 (1952).
50 Haruta, M., Yamada, N., Kobayashi, T., Iijima, S., "Gold catalysts prepared by coprecipitation for low-temperature oxidation of hydrogen and of carbon-monoxide", *J. Catal.*, **115**, 301−309 (1989).
51 Lippens, B.C., de Boer, J.H., "Studies on pore systems in catalysts: V. The t method", *J. Catal.*, **4**, 319−323 (1965).
52 Geldart, D., "Types of gas fluidization", *Powder Technol.*, **7**, 285−292 (1973).
53 Parry, E.P., "An infrared study of pyridine adsorbed on acidic solids characterization of surface acidity", *J. Catal.*, **2**, 371−379 (1963).
54 Lockhart, R.W., Martinelli, R.C., "Proposed correlation of data for isothermal two-phase, two-component flow in pipes", *Chem. Eng. Prog.*, **45**, 39−48 (1949).
55 Haruta, M., Tsubota, S., Kobayashi, T., Kageyama, H., Genet, M.J., Delmon, B., "Low-temperature oxidation of Co over gold supported on TiO_2, α-Fe_2O_3, and Co_3O_4", *J. Catal.*, **144**, 175−192 (1993).
56 Kreuer, K.D., "On the development of proton conducting polymer membranes for hydrogen and methanol fuel cells", *J. Membr. Sci.*, **185**, 29−39 (2001).
57 Brinkman, H.C., "A calculation of the viscous force exerted by a flowing fluid on a dense swarm of particles", *Appl. Sci. Res. A*, **1**, 27−34 (1947).
58 Higbie, R., "The rate of absorption of a pure gas into a still liquid during short periods of exposure", *Trans. Am. Inst. Chem. Eng.*, **31**, 365−389 (1935).

59 van Deemter, J.J., Zuiderweg, F.J., Klinkenberg, A., "Longitudinal diffusion and resistance to mass transfer as causes of nonideality in chromatography", *Chem. Eng. Sci.*, **5**, 271−289 (1956).
60 Turchi, C.S., Ollis, D.F., "Photocatalytic degradation of organic-water contaminants: Mechanisms involving hydroxyl radical attack", *J. Catal.*, **122**, 178−192 (1990).
61 Hayden, J.G., Oconnell, J.P., "Generalized method for predicting 2nd virial-coefficients", *Ind. Eng. Chem. Fund.*, **14**, 209−216 (1975).
62 Bui-Mansfield, L.T., "Whatever happened to the 50 most frequently cited articles published in *AJR*?", *Am. J. Roentgenol.*, **185**, 597−601 (2005).
63 Ho, Y.S., Satoh, H., Lin, S.Y., "Japanese lung cancer research trends and performance in Science Citation Index", *Intern. Med.*, **49**, 2219−2228 (2010).
64 Wang, M.H., Yu, T.C., Ho, Y.S., "A bibliometric analysis of the performance of Water Research", *Scientometrics*, **84**, 813−820 (2010).
65 Li, L.L., Ding, G.H., Feng, N., Wang, M.H., Ho, Y.S., "Global stem cell research trend: Bibliometric analysis as a tool for mapping of trends from 1991 to 2006", *Scientometrics*, **80**, 39−58 (2009).
66 Suk, F.M., Lien, G.S., Yu, T.C., Ho, Y.S., "Global trends in Helicobacter pylori research from 1991 to 2008 analyzed with the Science Citation Index Expanded", *Eur. J. Gastroenterol. Hepatol.*, **23**, 295−301 (2011).
67 Kim, I., "Chemical engineering: A rich and diverse history", *Chem. Eng. Prog.*, **98**, 2S−9S (2002).
68 Zhu, Y.Q., Wang, M.H., Ho, Y.S., "An analysis of research activity in department of chemical engineering in USA", *Arch. Environ. Sci.*, **5**, 62−70 (2011).
69 Krebs, F.C., Nielsen, T.D., Fyenbo, J., Wadstrøm, M., Pedersen, M.S., "Manufacture, integration and demonstration of polymer solar cells in a lamp for the 'Lighting Africa' initiative", *Energy Environ. Sci.*, **3**, 512−525 (2010).