Citations in chemical engineering research: factors and their assessment

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The study explores citation pattern of the 4112 articles in the field of chemical engineering published from 1974 to 2018 and indexed in Web of Science. Apart from good quality research, a number of other factors may be responsible for citing and not citing an article. The study has also tried to explore such factors. Only the top 500 articles with the most number of citations have been analysed in-depth. The countries like United States of America (USA), China, Germany, United Kingdom (UK), France, Canada, India, Japan, Spain, Russia and Brazil have the highest number of articles. The investigators calculated Pearson correlation between the number of keywords, pages, references and citations and it showed that there is no relationship between the number of keywords and number of citations. The number of pages and the number of references in a publication have a significant and positive impact on the number of citations.

Keywords: Citation analysis; Chemical engineering; Scientometrics; Bibliometrics

Introduction

It is a well-known fact that the quality research is the back bone of any nation and improves the wellbeing and the welfare of the society. There are many factors that affect the quality and impact of a research. The number of citations received is said to be an important parameter for the assessment of the research quality and impact. The study of number of papers and citations may be useful indicators for assessing the level of research, policymaking and as effective tools for evaluating the research activities[1]. In addition to the quality of the research, there are many factors which are responsible for the citations and have generally been assumed to have considerable influences. Such investigations may be an important and necessary task for strengthening the influence of journals and researchers[2]. The evaluation of the quality of papers is a complex task. The number of citations is the most frequently used indicator in assessing the quality of papers, researchers, research centers and universities and some consider the impact factor of the journal, as an indicator for the paper's quality[3]. The conventions of publishing the scientific work in open-access journals with a high impact factor, author h-index and other factors along with the examination of the extent to which it influences the number of citations has also been the perceptions of the authors regarding the impact of any research[4].

The number of citations received is considered as an index of quality and impact but there are other bibliographic elements which are responsible for the citations and the impact of the research work. Falagas, Zarkali, Karageorgopoulos, Bardakas, & Mavros[5] found that the 'article length and journal impact factor are independently associated with the number of citations received by each article. Specifically, they found an increase by an average of 0.079 in the logarithm of citations per article for each additional page, 0.008 for every unit of increase in the journal impact factor. The longer article could reflect increased greater scientific complexity and higher methodological quality of a study and in addition to that, the lengthier articles are expected to contain more information, thus increasing the possibilities to be cited by other researchers'. Subject connection and visibility are factors affecting the citability in this regard[6]. Essentially, the use of citations as an indicator of quality is perceived in such a way that the author of a citing paper has studied the cited paper properly and found it worthy for citation. The reality, however, can be different from this ideal[7]. Sometimes it has been found that the best research is appearing more in international journals than national presuming better citation counts and impact[8]. Some authors indeed have a lack of responsibility in citing papers, whereas some others cite them with good intent. Thus, considering citations as an indicator of a paper's quality is unfair and other measures should be taken into account for identifying the citation influencing factors. The present investigation will try to find such factors which can be primarily liable for the number of citations and the good quality research.

Review of literature

Many studies have been conducted to investigate the factors which are influencing the citation rates and have explored different perspectives of citations and their patterns based on various constructs of research. A study which aimed to examine the factors associated with the number of citations of published articles based on the article length found that the article length and journal impact factor are independently associated with the number of citations received by each article. Specifically, they found an increase by an average of 0.079 in the logarithm of citations per article for each additional page, 0.008 for every unit of increase in the journal impact factor[5]. There are some conventions like publishing the scientific work in open-access journals with a high impact factor and the examination of the extent to which it influences the number of citations.

Vanclay[9] examined the influence that the Thomson Reuters impact factor (TRIF), author h-index and other factors have on citation rates of journal articles in the environmental sciences. Didegah and Thelwall[10] investigated a range of factors which may be associated with the citation counts of social science papers. The authors found that journal and cited references of articles are associated with the citations in the field of social sciences along with the research collaboration. In addition, the paper length, abstract length and abstract readability are also significant determinants of citation counts. Onodera and Yoshikane[11] in their study examined whether there are some general trends across subject fields regarding the factors affecting the number of citations of articles, focusing especially on those factors that are not directly related to the quality or content of articles. The price index was the strongest predictor of citations followed by the number of references while as the number of authors and their achievements were having less effect on citations.

Yaminfirooz and Ardali[12] studied the factors influencing the citability of published papers in the field of medicine. The study found that the factors like journal IF, journal rank, journal subject quartile, the first/corresponding author's h-index, the number of documents produced by the first/corresponding author, SJR and SNIP had significantly positive correlation with paper citability while the paper age, paper type, the number of references, the number of authors, indexing institute and journal kind have no relationship with paper citability.

So et al[13] in their study examined the number of citations of journal articles with the bibliographic factors that have an effect on citations and to understand the degree of measurable variables that affect impact factor through the scale analysis and correlation analysis between the factors, and to ensure that moderating variables work on increasing impact factor as a moderating effect. Prathap, Mini and Nishy[14] found that in each journal there is a very highly skewed distribution of articles according to citation rates and also there is a little correlation between journal impact factor and actual citation rate of articles from individual scientists or research groups which implies that the journal impact factor does not successfully predict high citations rates in future.

Manriquez, Cataldo and Harz[15] tried to determine which features of dermatological scientific research are associated with systematic review dissemination using citation rates as an indicator. The study found that the journal impact factor, number of authors, and total references cited were positively associated with the number of citations. They concluded that citation number to systematic reviews may be improving by increasing the number of authors, especially collaborative authors, and the number of cited references.

Bornmann and Leydesdorff[16] used percentile shares to analyze the so-called "factors influencing citation impact" (FICs) across year and disciplines. The comparison of the effects of the different FICs (the number of cited references, number of authors, number of pages, and JIF) on citation impact shows that JIF has indeed the strongest correlations with the citation scores. Yu, Yu, Li and Wang[17] used stepwise regression to produce a model which can predict citation counts in the field of library and information science. The authors included a range of possible FICs and concluded that they can predict with relative good accuracy, citation impact using a citation window of five years.

Methodology

The source of the data of the present study was Science Citation Index Expanded (SCI-Expanded) of '*Web of Science Core Collection*'. The phrase search '*Chemical Engineering*' was used to search the data from the year 1974 to 2018 as a topic (Updated on 11-06-2019). The search yielded 5559 publications. The investigators refined the search strategy to document types that include articles only and the rest of the document types were excluded and this resulted into 4112 publications in the field.

Investigators downloaded the overall data into plain text, and then cumulated all those plain text data files into one file using BibExcel software. The software was also used for analyzing the different parameters of the study. The citation records of articles (4112) were downloaded into MS-Excel 2016 for further analysis. The investigators specifically designed the measurement of the number of citations received by each article in the sample. For that TC2018 (total number of citations since the article was first published to 2018, as reflected in Web of Science Core Collection) was used[18-20]. After adding citations of all articles on this index, an average number of citations per year for each article was calculated. Then, based on this index, each article in the sample (of 4112 articles) was ranked to identify top 500 articles with the highest index of citations. This sub-sample of 500 articles was used for in-depth analysis and for general analysis, the whole sample of 4112 articles were used.

Analysis

The data for the present study was extracted on 13th June 2019 and it was found that in chemical engineering research area, there were 5559 publications belonging to 19 document types published during 1974 to 2018. The most-frequently used document type was article (4112) comprising 73.97% of the total productions, followed by editorial materials (523; 9.41%), proceeding papers (409; 7.36%), reviews (375; 6.75 %) and meeting abstracts (252; 4.53%). Others showing less significance were Letters (84), News Items (57), Notes (52), Book

Chapters (27), Bibliographies (22), Reprints (21), Book Reviews (19), Biographical Items (16), Corrections & additions (13), Corrections (8), Items about an Individual (2) and one each for Discussion, Retraction and Software Review respectively. In the study, the general analysis was undertaken on articles only and not all document types while the more specific and detailed analysis was undertaken to the highly cited articles.

Year-wise and country-wise distribution of articles

Figure 1 shows that the number of publications increased from 1991. Table 1 reflects the top countries with total publications $\geq$ 100 (overall sample of 4112) and their contribution and percentage ratio of 500 highly cited articles. It is apparent from the table that countries such as United States of

Table 1 — Chemical engineering publications and most cited studies published from various countries

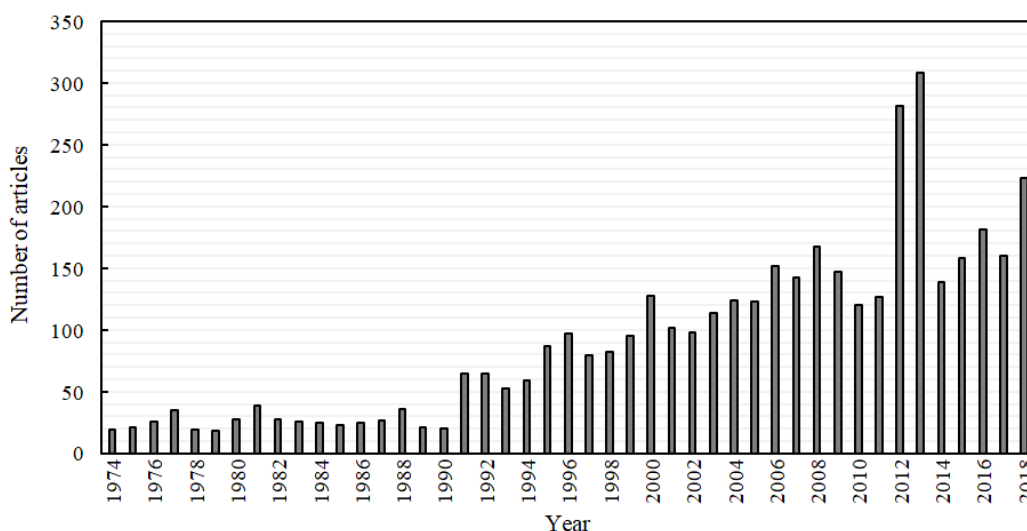| Country	B: TP out of 4112	A:TP out of 500	% ratio A/B
USA	806	120	14.89
Peoples R China	426	80	18.78
Germany	402	52	12.94
UK	301	50	16.61
France	281	41	14.59
Canada	242	27	11.16
India	181	31	17.13
Japan	119	13	10.92
Spain	104	11	10.58
Russia	103	4	3.88
Brazil	101	15	14.85
TP; Total publications			

Fig. 1 — Distribution of chemical engineering publications

America (USA), China, Germany, United Kingdom (UK), France, Canada, India, Japan, Spain, Russia and Brazil have the highest number of articles. It is also evident from the table that Russia contributed only 3.88% of their highly cited publication ratio.

Number of authors and citations

It is seen that 1966 authors contributed to the 500 highly cited articles and among them 1819 were unique authors. It is seen from Fig. 2 that the single author works indicate a decline over time and emergence of collaborative works among CE scholars is increasing.

The number of single author publications per year has decreased over the years and the number of multiple author publications has increased significantly as can be seen from Fig. 3. An ANOVA test was conducted in order to examine the relationship between the number of authors and the citations received by the articles. To perform the ANOVA test, the data was divided into single and multiple author citation groups in order to compare the mean value of the citation index between these two groups. The F-value was 0.01 (p value 0.907) according to the results, since the p value is less than 0.05, it indicates that there is a significant difference between the mean values of the single and multi-authored paper citation index. It can therefore be concluded that multiple author articles are cited more than single author articles. The similar results were also identified by Aksnes[21] who opined that the highly cited articles are typically authored by a large number of scientists, often involving international collaboration, Chen[22] expressed that the number of references cited, the number of coauthors and the number of references can be the good predictors of global citation counts. Peters and Van Raan[23] found that the factors of importance for citations are number of references,
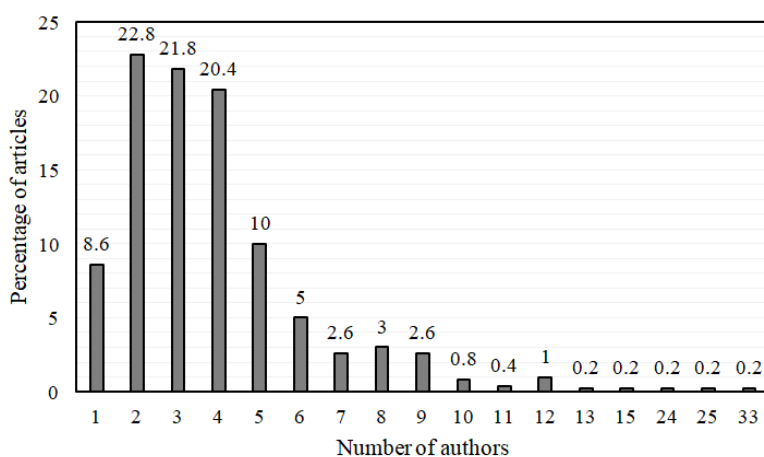

Fig. 2 — Distribution of highly cited chemical engineering publications based on number of author(s)
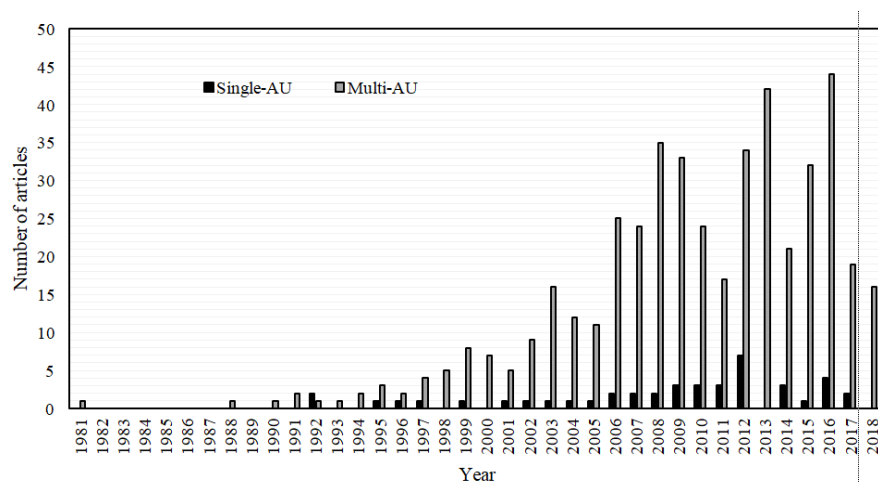

Fig. 3 — The number of single/multi authored chemical engineering publications per year

language, journal category, journal influence weight, and Price Index, which play an important role in the acquisition of citations. In case of chemical engineering research, the number of references per paper shows a larger contribution to the predicted number of citations than the Price Index.

Keywords and number of citations

While performing the author keyword analysis, it was found that there were 120 articles without author keywords. Articles without author keywords were cited 11124 times and 380 articles with author keywords were cited 20139 times. Studies in our sample have used 2045 keywords and among them 1591 were unique keywords. Table 2 shows the most important keywords and their citations. It was found that for the data set of 500 most cited articles, the minimum, maximum, mean value and standard deviation of keywords are 0, 19, 4.090 and 2.755 respectively (Table 5).

With regard to the impact of number of keywords in the study, it is important to examine whether there is a significant relationship between the number of keywords and the number of citations that a study has received. An ANOVA test was conducted to answer this question and we split the sample into different groups according to the number of keywords in articles to compare the mean value of citation index between all those groups. According to the results, the F-value is 1.62 (p value 0.072) which indicates there is no significant difference between the mean values of the citation index of different groups. In addition, we calculated Pearson correlation between the number of keywords and citations. The correlation is 0.027 (p value 0.607) which shows there is no significant relationship between keywords and citations. Taken together, our analysis indicates that there is no relationship between the number of keywords and number of citations that studies in our sample have received. However, earlier studies indicated contrary results regarding number of keywords in an article and number of citations received[13,24]. Similarly Rostami, Mohammadpoorasl and Hajizadeh[25] and Jacques and Sebire[26] suggested that type of the title and articles with keywords different from words included in the title can help to predict the number of citation counts and found that the higher citation rates are associated with having at least two keywords other than the words used in the title which can help increasing the chances of increasing the number of citations.

Number of references and number of citations

So, M. et al. and Akhavan et al.[13,24] in their studies revealed that the relationship between the number of references and the number of citations was positive. This section aims to prove the reliability of their argument in the study. The total number of references used in 500 highly cited articles on Chemical Engineering are 24162, with an average of 48.32 reference per article. The minimum, maximum, mean value and standard deviation of the number of references in the sample are 3, 467, 48.32 and 40.25 respectively (Table 5). Pearson correlation was calculated to examine the relationship between the number of references and the number of citations received by an article, which resulted in the value of 0.191 and p value of 0.000. It shows that there is a significant and positive correlation between the number of references and citations in this case. Similar results were also found by Haslam and Koval[27] who found that the articles with greater length, more references, and more authors were cited relatively often, Yu and Yu[28] found that the highly-cited articles have more references and it seems that the number of references influences the citation impact. They further added that the more literature a researcher reads, more deeply he/she understands the current situation and development trend of his/her research field. This is an effective method to enhance the quality of their research. Peters and Van Raan[23] found that the factors of importance for citations are number of references, language, journal category, journal influence weight, and Price Index, which play an important role in the acquisition of citations.

Number of pages and number of citations

This section investigated the relationship between the length of articles and the number of citations in the sample of 500 highly cited articles on Chemical Engineering. It was found that the minimum,

Table 2 — Frequency of the major KW among the 500 most cited publications

KW	No. of times used	TC2018
Chemical Engineering	17	1021
Mass Transfer	14	756
Multiphase Flow	12	548
Discrete Element Method	11	426
Optimization	11	940
Process Intensification	11	564
Modeling	10	551

KW; Keywords *TC2018;* Total no. of citations till 2018

maximum, mean value and standard deviation of number of pages are 2, 46, 12.434 and 6.128 respectively (Table 5). To analyze the relationship between the number of pages and citation, Pearson correlation was calculated. The Pearson's correlation is 0.150 and p value is 0.001, this suggests that the number of pages in a publication has a significant and positive impact on the number of citations that the publication likely to receive. The main reason behind this could be the methodology and findings of lengthier articles are presented and discussed more clearly and in more detail, and thus have a greater impact[5,23].

Research areas and number of citations

Even though the sample of papers share a Chemical Engineering theme, they can be traced back to various research streams. In fact, researchers from diverse credentials have tried to put on Chemical Engineering related concepts in their fields of research. To examine the influence of the diverse nature of the Chemical Engineering articles on their citations, investigators scrutinized the number of citations that studies from diverse research realms have received. To determine whether there is a substantial variance in the number of citations between different streams. Table 3 displays the total number of publications share out of the whole sample (4112) and sub sample of 500 most-cited articles in each area of research. It is evident from Table 3 that the major research areas are Engineering, Chemistry, Computer Science, Material Science, Education & Educational Research and Science & Technology - Other Topics.

The Table 3 also displays the total number of citations and average number of citations per study within each research area. It is also seen from Table 3 that the contribution of highly cited articles with highest average number of citations per study are of "Computer Science" research area. Interestingly, the total publication output of "Engineering" research area is on top with 2774 publications, out of which

326 publications belonged to highly cited articles (sub-sample of 500) with Avg=58.5 which is 4th among the top six research areas. An interesting observation drawn from the table is that there is a significant increase in Chemical Engineering related studies from computer science and Education & Educational Research researchers, which indicates that a new research venue for scholars to pursue in the future. These results are in context of the global phenomena of interdisciplinary and multidisciplinary nature of researches in highly emergent and top areas of which chemical engineering is one of the well pursued and interesting areas among the researchers world over.

The time trend investigation of publications in each specific research area has been displayed by Fig. 4. The data for this investigation has been extracted from the full sample (4112 articles). It also illustrates how the relative number of publications in each research area has changed between 1974 and 2018.

Scholarly outlets and number of citations

In this section, examination of sub-sample of articles was performed to determine whether there is a meaningful relationship between the journals in which an article is published and the number of citations that it has received. Table-4 shows the journals that have published the highest number of the 500 most-cited articles. The "Chemical Engineering Science" Journal is at the top of the list publishing 79 articles.

Fig. 5 shows the pattern of the number of articles published among each journal over time. The figure also shows articles published up to 2015 allowing three years for a stable citation index, because citation statistics produced by data from periods shorter than three years may not be sufficiently stable[29-30]. It is evident from the Fig. 5 that there wasn't any publication among the highly cited publication sample of 500 articles published in 1982-1987, 1989 and 2001.

Table 3 — Share of different research streams from chemical engineering publications

RA	TP out of 4112 (P)	TP out of 500 (P)	TC2018	Avg
Engineering	2774 (67.47)	326 (65.2)	19069	58.5
Chemistry	755 (18.37)	89 (17.8)	6301	70.8
Computer Science	426 (10.36)	68 (13.6)	4838	71.15
Materials Science	191 (4.65)	34 (6.8)	2294	67.48
Education & Educational Research	188 (4.58)	8 (1.6)	314	39.25
Science & Technology - Other Topics	183 (4.46)	37 (7.4)	1728	46.71
Others	1623 (39.47)	235 (47)	14165	

RA; Research Area *TP (P);* Total publications and percentage *TC2018;* Total Citation till 2018 *Avg;* Average Citations Per Study
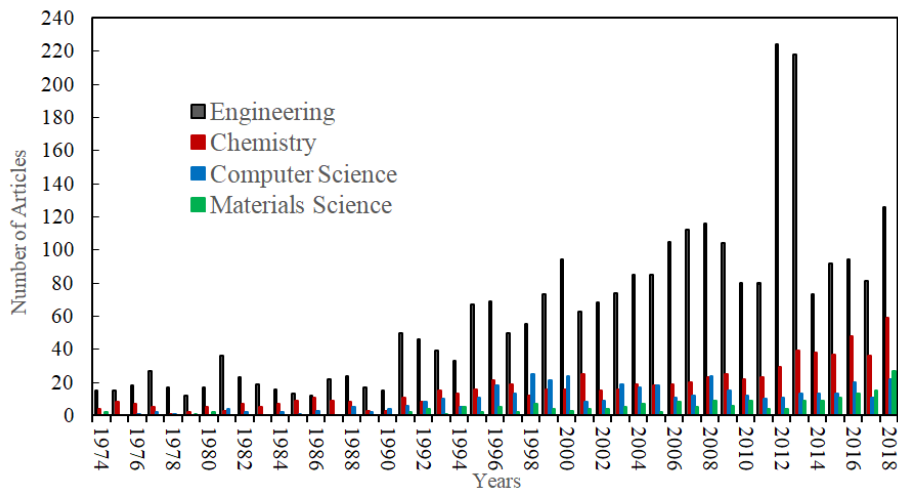
Fig. 4 — Number of chemical engineering studies based on the research areas/year
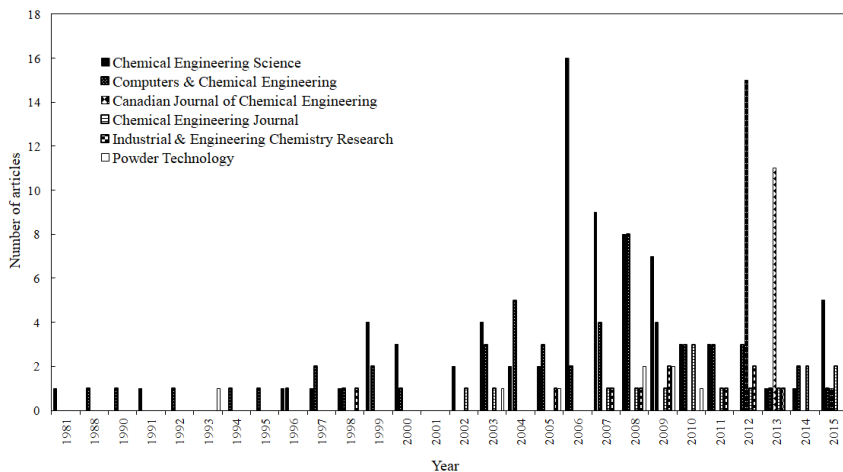

Fig. 5 — Number of chemical engineering studies published by major journals/year

Table 4 — Number of most cited articles in major journals

Journals	TP	TC2018
Chemical Engineering Science	79	5688
Computers & Chemical Engineering	56	4229
Canadian Journal of Chemical Engineering	27	801
Chemical Engineering Journal	21	806
Industrial & Engineering Chemistry Research	12	631
Powder Technology	10	471

TP; Total Publication *TC2018;* Total citations till 2018

Table 5 — Descriptive statistics

Variable	N	Mean	St.Dev	Minimum	Median	Maximum
AU	500	3.932	2.911	1.000	3.000	33.000
KW	500	4.090	2.755	0.000	5.000	19.000
NR	500	48.32	40.25	3.00	40.00	467.00
PG	500	12.434	6.128	2.000	11.000	46.000

StDev; Standard Deviation *AU;* Authors *KW;* Keywords *NR;* Number of References *PG;* Pages

Conclusion

The global ramifications of research growth have impacted every discipline of knowledge with new vistas of emergent techniques and methods for conducting and publishing the research and development activities. It has wider implications on the structure and morphology of different areas of knowledge which is best understood by the metric studies to determine these changes and design models of knowledge growth and trends of research phenomena. The present study conducted a similar investigation in the field of Chemical Engineering which represented some of the known and a few unknown global trends of research process. The subject witnessed the boom in the number of its publications with major contributions as well as citations from USA, China and Germany. A venture of collaboration in research is becoming a norm now in academic disciplines to increase the visibility and readability of the literature and the same were observed along with new research specializations being pursued in the research field. These results are in context of the global phenomena of interdisciplinary and multidisciplinary nature of researches emergent in top areas of knowledge of which chemical engineering is one, which is well pursued and interesting among the researchers worldwide.

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