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Scientometric analysis of transport phenomenon literature, 1900-2007

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ABSTRACT

The present study explores the characteristics of transport phenomenon literature from 1900 to 2007 based on the Science Citation Index Expanded (SCI™ Expanded) database and its implication using two scientometric techniques, namely Bradford-Zipf's law and Lotka's law. The results of this work reveal that the literature on transport phenomenon grows exponentially with an annual growth rate of about 8.67% for the last century. The document type and language distribution, country and institution productivity, core journals, journals with highly cited documents, most highly cited articles and leading authors on transport phenomenon are identified. The present study indicates that the journal literature on transport phenomenon confirms the typical S-shape for the Bradford-Zipf plot. The author productivity distribution however does not confirm with Lotka's law by the Kolmogorov-Smirnov (K-S) goodness of fit test.

Keywords: Bibliometrics; Scientometrics; Citation Analysis; Bradford-Zipf's law; Lotka's law

INTRODUCTION

Transport phenomenon is the transport process of a physical quantity from a high intensity region to a low intensity region. Transport phenomenon is very common in nature as well in industrial processes, and is of fundamental importance for many science and engineering studies. Transport phenomenon usually deals with the transport of energy, momentum and mass. Therefore, heat transfer, fluid mechanics, mass transport, transport of charged or non-charged particles are all important subjects in the broad area of transport phenomenon. For the last decades, the transport phenomenon area has been expanded from the traditional chemical engineering to many other applications, for example in semi-conductor processing,

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such as crystal growth, doping and biomedical engineering.

As a reflection, the transport phenomenon literature must also grow dramatically. The background information reveals in the increasing importance of transport phenomenon and the literature survey by the authors indicates the lack of scientometric study on such area. This study aims to investigate the characteristics of transport phenomenon literature from 1900 to 2007 and its implication using the scientometric techniques, which is a statistical method of bibliography counting to evaluate and quantify the growth and other characteristics of literature for a particular subject or field. Specifically, the objectives of this study are to:

a) to explore the growth of transport phenomenon literature published;
b) determine the core journals that contain a substantial portion of journal literature on transport phenomenon;
c) find the productivity distribution of authors and institutions on this subject;
d) identify major contributing countries that published transport phenomenon articles most; and
e) find the dispersion of kinds of language and document types of the literature on transport phenomenon; and
f) reveal the characteristics of citation for the transport phenomenon literature.

There are lots of works employing scientometric techniques to explore the scientometric characteristics of a particular subject field. However, there has been no scientometric study found dealing with the subject of transport phenomenon. Some selective studies are given in the following brief review of related works.

RELATED WORKS

Retrieving the bibliographic data from the Science Citation Index of the Institute for Scientific Information, Braun, Schubert and Zsindely (1997) measured the frequency of usage of the prefix nano- in the title of journal papers during the 1986-1995. They found that there were 4152 papers having the nano- prefix in their title and the exponential growth is clearly with doubling time of 1.6 years. In addition, nanoscale chemistry, physics, and materials sciences are leading progresses and carbon nanotubes is one of the most active subfield of research in the nanosciences. Using Braun's study as basis, Meyer and Persson (1998) further studied some characteristics of nanotechnology using scientometric data. According to the journal's classification, they found that most nano-papers are published in the major field of natural sciences, then, followed by multidisciplinary sciences, engineering and materials sciences, and

life sciences. USA, Japan and Germany are the three leading countries in nano publications, whereas the Academy of Sciences of the People's Republic of China is the most productive institution. The Massachusetts Institute of Technology (MIT) comes next, followed by University of California at Berkeley and Tohoku University, Japan. In terms of collaboration patterns, it can be seen that some countries (e.g. USA) tend to collaborate with researchers from a variety of countries, while others, e.g., Japan and China, restrict international collaboration. Schummer (2004) conducted a co-author analysis of over 600 papers published in "nano journals" in 2002 and 2003, and investigated if this apparent concurrence is accompanied by new forms and degrees of multi- and inter-disciplinarity as well as of institutional and geographic research collaboration. By analyzing the patterns of research collaboration and comparing with these of classical disciplinarity research, he argued that nanoscale research reveals no particular patterns and degrees of inter-disciplinarity and that its apparent multi-disciplinarity consists of different largely mono-disciplinarity fields which are rather unrelated to each other and which hardly share more than the prefix "nano".

Biswas, Roy and Sen (2007) conducted a study with 358 original contributions published in the journal Economic Botany during 1994 to 2003. The research results reveal that among the citations, books accounted for 59% and articles 41%. The highest number of articles totaling 217 (60.61%) has produced by academic institutions such as universities. Contributions by single author and small teams comprising two or three authors account for about 80% of the papers. The articles originate from 45 countries. The first four countries are responsible for 51.7% and the first ten countries for 67.8% of the articles.

By searching 31 related databases and the online catalogs of two United States national libraries to identify publications, Al-Qallaf (2009) employed bibliometric techniques to identify and analyze the intellectual structure of the Punica Granatum L. (pomegranate) literature. The results show that the literature has grown consistently from 1970 to 2000. Most of the publications are co-authorship (71.8%) and written in the English (70%). Journal articles (75.5%) constitute the largest single type of publication. There are 1,045 unique journal titles containing 2,497 publications. Thirty-eight core journals were identified by the Bradford's law. India and the United States constitute more than 50% of the authors' affiliation. The major subject areas are plant diseases, botanical chemistry, pharmacognosy and plant products

Focusing on books, journal publications, conference proceedings and technical reports, Ackermann (2005) examined the bibliometrics of the controversial scientific literature of Polywater, a new kind of water research. The data were collected from the beginning in 1962

with the first publication of the discovery of polywater and ending in 1974 with the last polywater papers. The sources of publication were drawn from the *Composite Bibliography of Polywater Research Literature, 1962-1974*, compiled by the author, and the citation sources were obtained from the print version of Science Citation Index (SCI) Five and Ten Year Cumulation for 1955-1964, 1965-1969, 1970-1974, and 1975-1979. Ackermann employed four bibliometric indicators, namely publication (P) frequency for measuring publication pattern and output, citation per publication (CPP) for impact, uncited publications (UP) and author self-citations (SC) for their effect on P and CPP. His study showed that journal publications are with the highest publication frequency, books are with the highest citations per publication, and uncited publications and author self-citations are insignificant. Comparing to several non-controversial scientific literature, i.e., normal scientific literature, these findings may demonstrate to be common to other controversial scientific literature.

By searching the MEDLINE database for articles indexed under the publication type "Randomized Control Trial (RCT)", Tsay and Yang (2005) investigate the features of RCT literature based on bibliometric methods. Their research results revealed that the literature growth rate, from 1965 to 2001, is steadily rising and follows an exponential model. From 1990 to 2001, a total of 114,850 citations dealing with RCTs were retrieved, among them the multi-center study is extensively used. Forty-two core journals were identified using Bradford's law. Generally, RCTs are found in publications concentrating on cardiovascular disease, cancer, asthma, postoperative condition, health, and anesthetics. Hassan (2005) investigated the evolution of the knowledge structure of the field of fuel cells during the nineties using data on patents and scientific publications. He employed simultaneous mapping approach to examine deeply the cognitive structure of the field of fuel cells at the world level. The results demonstrated the heterogeneity of the field of fuel cells. It also showed that "the fuel cell field was subject to increasing cognitive linkages between science and technology and substantial cognitive interrelations among the knowledge bases of the sub-fields identified."

METHODOLOGY

For the present work, the database of Science Citation Index Expanded™ (SCI™ Expanded), a product of the Thomson Scientific, is employed to retrieve bibliographic data of literature on transport phenomenon from 1900 to 2007. Although other databases such as Applied Science and Technology ABS, Compendex and EngIndex/FS are also available for bibliometric analysis, SCI™ Expanded is used because it is recognized as the leading English-language supplier of services providing access to the published information in the multidiscipline fields of science

and technology. Moreover, it is the only database that offers a comprehensive citation data of the published literature.

The Web of Science SCI™ Expanded is a multidisciplinary index to the journal literature of the sciences. It fully indexes over 6,650 major journals across 150 scientific disciplines and includes all cited references captured from indexed articles from 1900 to date (Thomson Reuters, 2009). For the present study the time span of the SCI™ Expanded available is from 1900 to 2007. Generally, each record in the SCI™ Expanded database contains an English-language title and descriptive abstract together with full bibliographic information. The bibliographic information includes the journal or other publication title, the authors' name and affiliation, document type, and the language of the original document. Documents indexed included books and monographs, conferences, symposia, meetings, journal articles, reports, theses and dissertations.

As SCI™ Expanded is adopted for the present study, the first limitation of this research is the limitation of the selective collection of SCI™ Expanded journal. Those articles published in a journal not indexed by SCI™ Expanded are not retrieved. The second limitation of the present study is caused by the use of search commands. In this study, the search command TS = (transport phenomen* or "heat transfer" or "mass transfer" or "fluid mechanics") is used in the topic field to retrieve most of the papers which embodied these three key words in article title or abstract. The truncation search statement (transport phenomen*) was used to retrieve the single noun and plural noun of phenomenon. Although transport phenomenon, heat transfer, mass transfer or fluid mechanics are quite common and broad, an article in transport phenomenon subject not entitled or abstracted with one these keywords may not be retrieved. However, these two limitations are considered to be minor.

Each relevant record was then downloaded to a compact disc. Care has been exercised to examine the data collected to assure their identity. Subsequently, the data were analyzed by using spreadsheet applications. By employing scientometric techniques, especially literature growth model, Bradford's law, Lotka's law and citation counting, the results of this study are analyzed and discussed.

THE GROWTH OF TRANSPORT PHENOMENON LITERATURE PUBLISHED

For the duration from 1900 to 2007, the SCI™ Expanded contains 96,685 items on transport phenomenon. Table 1 shows the distribution of the number of literature published and the

cumulated number yearly. Before 1960, the number of SCI^{TM} Expanded papers on transport phenomenon published each year was no more than 100. The year of 1961 to 1990 was the period of significant publication on transport phenomenon based on the SCI^{TM} Expanded as the number of articles published on transport phenomenon grew steady about 100 papers every two to four years. The number of article for 1961 was 114 and 1106 for 1990. A rapid growth of the transport phenomenon literature appeared in 1991 with the total number of 3116 articles. It is a surprise considering that there were about 2000 more articles published in 1991 compared to 1990. The reason why this growth happened needs to be studied further. The literature growth became much more rapid with 1000 articles every four to five years after 1991. There were about 3000 to 4000 articles published each year from 1991 to 2000. The production of transport phenomenon literature grew dramatically fast with 1000 articles every three years after 2001. The number reached 6672 in 2005. Indeed, the literature on transport phenomenon grows exponentially for the last half century as demonstrated in Figure 1, which illustrates that the cumulative literature on transport phenomenon may be fitted relatively well by an exponential function as $y = 11.2e^{0.867(x-1902)}$, where y is the cumulative literature on transport phenomenon collected in SCI^{TM} Expanded and x stands for the year. The annual growth rate is around 8.67%. This suggests that transport phenomenon is a subject with a relatively large growth rate even though it has been developed for more than one century.

Table 1: Literature production of the transport phenomenon, 1900-2007

Year	**1902**	**1907**	**1909**	**1910**	**1911**	**1912**	**1914**	**1916**	**1917**	**1918**
Article	1	1	1	3	2	2	3	2	1	1
Cumulate	1	2	3	6	8	10	13	15	16	17
Year	**1921**	**1922**	**1923**	**1924**	**1926**	**1927**	**1928**	**1929**	**1930**	**1931**
Article	4	5	2	7	4	5	12	9	14	13
Cumulate	21	26	28	35	39	44	56	65	79	92
Year	**1932**	**1933**	**1934**	**1935**	**1936**	**1937**	**1938**	**1939**	**1940**	**1941**
Article	7	11	13	13	13	22	12	23	18	13
Cumulate	99	110	123	136	149	171	183	206	224	237
Year	**1942**	**1943**	**1944**	**1945**	**1946**	**1947**	**1948**	**1949**	**1950**	**1951**
Article	10	5	12	3	14	13	27	37	38	47
Cumulate	247	252	264	267	281	294	321	358	396	443
Year	**1952**	**1953**	**1954**	**1955**	**1956**	**1957**	**1958**	**1959**	**1960**	**1961**
Article	43	54	77	52	74	76	100	95	93	114

Cumulate	486	540	617	669	743	819	919	1014	1107	1221
Year	**1962**	**1963**	**1964**	**1965**	**1966**	**1967**	**1968**	**1969**	**1970**	**1971**
Article	153	151	199	405	570	601	598	642	677	625
Cumulate	1374	1525	1724	2129	2699	3300	3898	4540	5217	5842
Year	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**
Article	645	647	558	626	586	714	710	664	767	738
Cumulate	6487	7134	7692	8318	8904	9618	10328	10992	11759	12497
Year	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**
Article	784	851	827	852	821	906	883	852	1106	3116
Cumulate	13281	14132	14959	15811	16632	17538	18421	19273	20379	23495
Year	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
Article	3214	3428	3676	3968	4295	4432	4531	4754	4824	5321
Cumulate	26709	30137	33813	37781	42076	46508	51039	55793	60617	65938
Year	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**				
Article	5491	5832	6289	6672	7141	7491				
Cumulate	71429	77261	83550	90222	97363	104854				

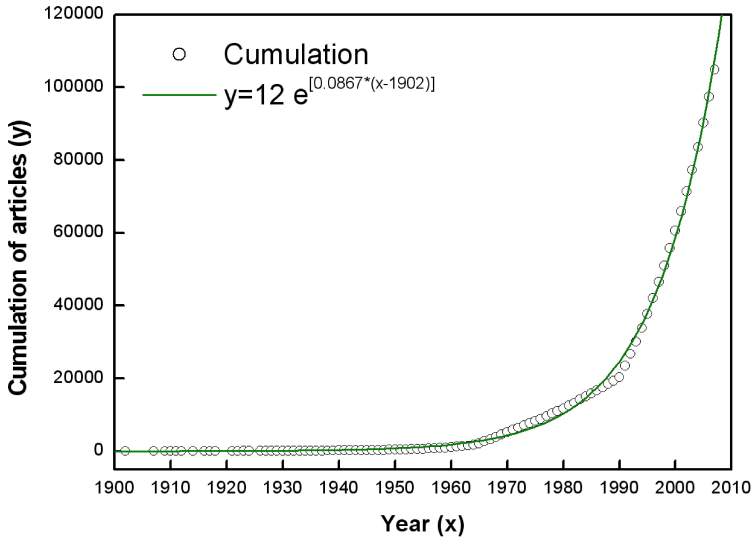

Figure 1: Cumulative growth of the transport phenomenon literature, 1900-2007

Some Bibliometric Characteristics of Transport Phenomenon Literature

Table 2 illustrates the distribution of document type in transport phenomenon literature. As common in many subjects, the single most prevalent form of publication is the research article, which contributes 91.37% of the total literature. The second largest form of transport phenomenon publication is review, which covers 2.57%, significantly lower than that for research articles. Other minor documents are such as notes (2.51%), meeting abstract (1.96%), letter, editorial material and book review. Most of the document type on transport phenomenon collected in the SCI™ Expanded is in the form of journal articles. This reflects the collection policy of the SCI™ Expanded. The major source materials for the SCI™ Expanded database are scientific and technical journals and some conference publications published throughout the world over a wide range of languages.

Table 2: Distribution of document type of the transport phenomenon literature, 1900-2007

Document type	No. of documents	%	Cum. %
Article	95808	91.37	91.37
Review	2692	2.57	93.94
Notes	2630	2.51	96.45
Meeting Abstract	2060	1.96	98.41
Letter	595	0.57	98.98
Editorial Material	459	0.44	99.42
Book Review	244	0.23	99.65
Discussion	86	0.08	99.73
Correction	77	0.07	99.81
Bibliography	52	0.05	99.86
Correction, Addition	43	0.04	99.90
Reprint	35	0.03	99.93
News Item	29	0.03	99.96
Biographical-Item	17	0.02	99.97
Abstract of Published Item	12	0.01	99.99
Item About an Individual	9	0.01	99.99
Software Review	6	0.01	100.00
Total	104854	100.00	

One interesting observation is the growing number of languages in which transport phenomenon literature is being communicated. As one might expect, English is the predominant language of documents on transport phenomenon. As shown in Table 3, English language documents constitute 94.93% of the total. There are only 5.07% non-English language documents. This may be due to the fact that the UK and the USA are the predominant countries of publication and that the SCI™ Expanded is an American-Based database. Moreover, English is the official language for most international conferences. In addition to English, the transport phenomenon literature is also published in 21 different languages, based on the collection in SCI™ Expanded. Among them, German and French are the second and third largest contributing languages.

Table 3: Language distribution of the transport phenomenon literature, 1900-2007

Rank	Language	No. of documents	%	Cum. %
1	English	99539	94.93	94.93
2	German	1695	1.62	96.55
3	French	989	0.94	97.49
4	Russian	894	0.85	98.34
5	Japanese	829	0.79	99.13
6	Polish	223	0.21	99.35
7	Chinese	199	0.19	99.54
8	Spanish	179	0.17	99.71
9	Rumanian	124	0.12	99.83
10	Ukrainian	31	0.03	99.86
11	Hungarian	27	0.03	99.88
12	Czech	24	0.02	99.90
13	Slovene	24	0.02	99.93
14	Italian	18	0.02	99.94
15	Croatian	15	0.01	99.96
16	Serbo-Croatian	13	0.01	99.97
17	Portuguese	13	0.01	99.98
18	Korean	5	0.00	99.99
19	Swedish	5	0.00	99.99

20	Slovak	4	0.00	100.00
21	Dutch	2	0.00	100.00
22	Finnish	1	0.00	100.00
23	Multi-Language	1	0.00	100.00
Total		104854	100.00	

Country and Institution Productivity

Table 4 illustrates the distribution of 30 most productive countries contributing to the transport phenomenon literature, ranked by the number of documents each country contributes. It can be seen that the largest contributor, USA, has 3047 institutions published 32,549 (26.21%) documents. Japan and France are ranked the second and the third respectively, contributing 9,312 (7.50%) and 7,797 (6.28%) SCI^{TM} Expanded documents on transport phenomenon, followed by Germany (4th), England (5th) and China (6th).

Table 4: Institution productivity distribution of transport phenomenon literature, 1900-2007

Rank	Country	Documents	Institutions
1	USA	32549	3047
2	Japan	9312	1310
3	France	7797	1628
4	Germany	6887	1374
5	England	6576	754
6	China	6260	625
7	Canada	5194	459
8	India	4174	613
9	Korea	3639	451
10	Russia	3608	920
11	Italy	3447	603
12	Taiwan	3071	159
13	Netherlands	2515	336
14	Spain	2320	302
15	Australia	2036	218
16	Brazil	1658	293
17	Poland	1528	264

18	Sweden	1382	205
19	Switzerland	1330	230
20	Turkey	1273	142
21	Belgium	946	160
22	Portugal	946	101
23	Greece	809	112
24	Mexico	806	175
25	Israel	697	139
26	Ukraine	674	183
27	Romania	629	151
28	Finland	619	113
29	Argentina	597	112
30	Austria	424	94

Thirty most productive institutions are listed in Table 5. It should be noted that an institution may be a single institute or may consist of several institutes. Among them, there are 14 institutions contributing more than 500 documents on transport phenomenon all over the world. The Indian Institute of Technology in India is the largest contributor, publishing 1385 SCI™ Expanded papers on the subject. The Russian Academy of Sciences in the Russia is the second contributor publishing 1163 documents. The Chinese Academy of Sciences in the People's Republic of China, the University of Illinois, the Massachusetts Institute of Technology (MIT) and the University of Minnesota, ranked third to sixth, contribute 869, 834, 703, and 669 documents, respectively.

Table 5: The most productive institutions of the transport phenomenon literature, 1900-2007

Rank	Institution	Country	Articles
1	Indian Institute of Technology	India	1385
2	Russian Academy of Sciences	Russia	1163
3	Chinese Academy of Sciences	China	869
4	University of Illinois	USA	834
5	Massachusetts Institute of Technology (MIT)	USA	703
6	University of Minnesota	USA	669
7	Purdue University	USA	644

8	French National Center for Scientific Research (CNRS)	France	635
9	University of Texas	USA	633
10	University of Tokyo	Japan	607
11	Pennsylvania State University	USA	584
12	Tsing hua University	China	579
13	University of California, Berkeley	USA	569
14	Tohoku University	Japan	510
15	Kyushu University	Japan	477
16	NASA	USA	456
17	University of Cambridge	England	449
18	University of Michigan	USA	447
19	National University of Singapore	Singapore	446
20	University of Wisconsin	USA	443
21	Kyoto University	Japan	440
22	Delft University of Technology	Netherlands	422
23	Korea Advanced Institute of Science and Technology (KAIST)	Korea	422
24	Texas A&M University	USA	413
25	Oak Ridge National Laboratory	USA	397
26	University of Waterloo	Canada	392
27	Georgia Institute of Technology	USA	376
28	University of British Columbia	Canada	374
29	National Cheng Kung University	Taiwan	372
30	University of Maryland	USA	370

Bradford Distribution of Journal Literature

As discussed previously, journal article is the single most prevalent form of publication. In total, there are 4390 journals publishing 104,116 transport phenomenon articles. Among them 1291 (29.4%) journals published only one article on the subject from 1900 to 2007. The Bradford's (1953) law has been widely employed to study journal literature distribution. Brookes (1973) created the Bradford-Zipf's S graph and explained the initial concave curve of the Bradford distribution as representation of the higher density of the nuclear zone. Journals in the nuclear zone constitute the core journals. Figure 2 illustrates the Bradford-Zipf plot—the cumulative number of papers for each journal against the logarithm of its ranks—for journal literature of transport phenomenon. Clearly, the figure demonstrates the typical S-shape for the

Bradford-Zipf plot. However, the approximately linear portion appears after the journal ranking of about 36. The top 36 journals located within the initial concave curve portion of the Bradford-Zipf plot may be considered as the core journals in transport phenomenon literature. These 36 core journals contribute 34,965 articles, about 33.6% of the total literature of transport phenomenon. The other literature is dispersing to 4354 journals.

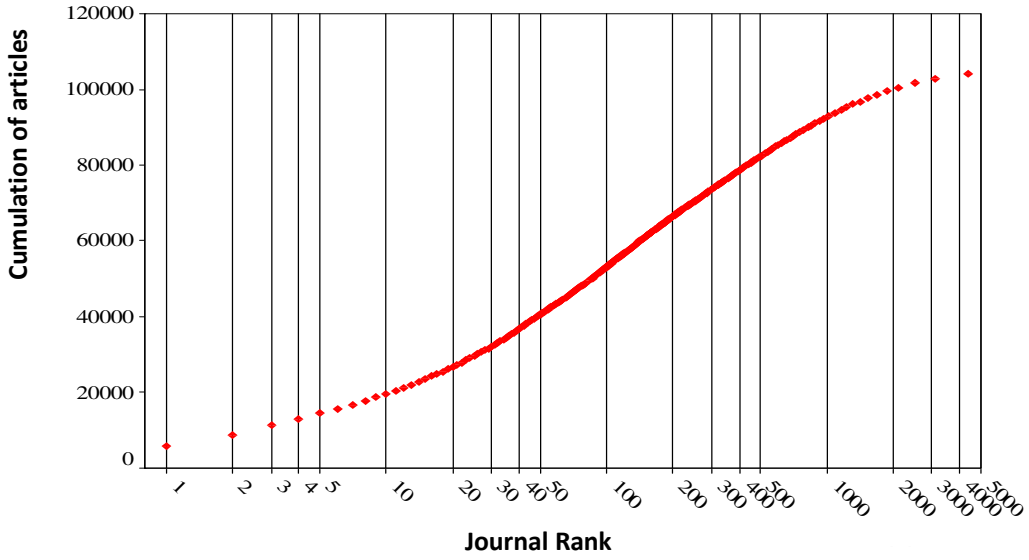

Figure 2: The Bradford-Zipf plot of transport phenomenon journal literature, 1900-2007

Table 6 provides the ranking list of 36 core journals and number of articles published by each journal. In this table, the top 36 journals are ranked in descending order of the number of published articles. The table also lists initial publication date, frequency of publication and subject field, taken from *Journal Citation Reports*, 2005 (science edition) (JCR 2005) and Ulrich's on Disc (Ulrich's Periodical Directory 2005). It should be noted that the comparison of journal productivity on transport phenomenon in the present study disregards the age of a journal. Some journals, such as *Physical Review B*, published in 1893, are quite old, while others, such as *Experimental Thermal and Fluid Science*, published in 1988, are relatively young. The production rate of the 36 core journals is further discussed in the following paragraphs.

Table 6 also lists 36 titles which have at least published 459 articles on transport phenomenon.. With no surprise, *International Journal of Heat and Mass Transfer* (5758 articles), is the largest contributor to the journal literature on transport phenomenon and *Journal of Heat*

Transfer—Transactions of the ASME is the third one with 2758 articles, as the key words of their titles include heat transfer and/or mass transfer. Other three most productive journals, namely *Chemical Engineering Science* (2920 articles), *Chemical Engineering Science* (2920 articles) *Industrial & Engineering Chemistry Research* (1632 articles) and *AIChE Journal* (1445 articles) are chemical engineering related. Eleven of the 36 most productive journals are thermodynamics and mechanical engineering oriented and thirteen are chemical engineering journals. Other four journals belong to applied physics, condensed matter physics, crystallography and electrochemisty, and material science.

Table 6: Top 36 journals published more than 459 documents on transport phenomenon, 1900-2007

Rank	Journal Name	No. of Documents	Publication Frequency	Publication Date	JCR Subject Categories
1	International Journal of Heat and Mass Transfer	5758	26/Y	1960	Thermodynamics; Engineering, Mechanical ; Mechanics
2	Chemical Engineering Science	2920	24/Y	1951	Engineering, Chemical
3	Journal of Heat Transfer- Transactions of The ASME	2758	Monthly	1970	Thermodynamics ; Engineering, Mechanical
4	Industrial & Engineering Chemistry Research	1632	24/Y	1987	Engineering, Chemical
5	AIChE Journal	1445	Monthly	1955	Engineering, Chemical
6	Heat and Mass Transfer	1187	Monthly	1968	Thermodynamics ; Mechanics
7	International Communications in Heat and Mass Transfer	1095	10/ Y	1974	Thermodynamics ; Mechanics
8	Numerical Heat Transfer Part A-Applications	1063	20/ Y	1978	Thermodynamics; Mechanics
9	Journal of Membrane Science	951	40/ Y	1977	Engineering, Chemical ; Polymer Science
10	High Temperature	850	Bi-monthly	1963	Physics, Applied
11	Canadian Journal of Chemical Engineering	809	Bi-monthly	1944	Engineering, Chemical
12	Applied Thermal Engineering	794	18/ Y	1980	Thermodynamics ; Energy & Fuels ; Engineering, Mechanical ; Mechanics
13	Physical Review B	790	48/ Y	1893	Physics, Condensed Matter
14	International Journal of Thermal Sciences	753	12/ Y	1962	Thermodynamics ; Engineering, Mechanical
15	Journal of Crystal Growth	732	24/ Y	1967	Crystallography
16	Chemie Ingenieur Technik	720	Monthly	1928	Engineering, Chemical
17	International Journal of Heat and Fluid Flow	678	6/ Y	1971	Thermodynamics; Engineering,

Rank	Journal Name	No. of Documents	Publication Frequency	Publication Date	JCR Subject Categories
					Mechanical ; Mechanics
18	Experimental Thermal and Fluid Science	621	8/ Y	1988	Thermodynamics ; Engineering, Mechanical ; Physics, Fluids & Plasmas
19	Journal of Food Engineering	611	Monthly	1947	Engineering, Chemical Food Science & Technology
20	Journal of The Electrochemical Society	602	Monthly	1947	Electrochemistry Materials Science, Coatings & Films
21	Journal of Chemical Engineering of Japan	584	Bi-monthly	1968	Engineering, Chemical
22	Drying Technology	577	Monthly	1983	Engineering, Chemical Engineering, Mechanical
23	Journal of Applied Physics	555	semi-annually	1931	Physics, Applied
24	Journal of Turbomachinery-Transactions of the ASME	551	Quarterly	1870s	Engineering, Mechanical
25	Chemical Engineering Communications	540	Quarterly	1973	Engineering, Chemical
26	International Journal of Refrigeration-Revue Internationale Du Froid	532	8/ Y	1978	Thermodynamics ; Engineering, Mechanical
27	Chemical Engineering Research & Design	525	8/ Y	1923	Engineering, Chemical
28	Journal of Thermophysics and Heat Transfer	509	Quarterly	1987	Thermodynamics ; Engineering, Mechanical
29	AIAA Journal	507	Monthly	1963	Engineering, Aerospace
30	Nuclear Engineering and Design	488	12/ Y	1965	Nuclear Science & Technology
31	Thermal Engineering	481	Monthly	1954	Engineering, Mechanical
32	Desalination	479	48/Y	1966	Engineering, Chemical Water Resources
33	Kagaku Kogaku Ronbunshu	473	Bi-monthly	1975	Engineering, Chemical
34	Astrophysical Journal	469	36/Y	1895	Astronomy & Astrophysics
35	Mechanical Engineering	467	Monthly	1906	Engineering, Mechanical
36	Physics of Fluids	459	Monthly	1958	Mechanics Physics, Fluids & Plasmas

Journals with Highly Cited Articles

Journals with highly cited articles are also of significant interest. Table 7 shows that, by the year 2007, there are 21 journals with at least seven articles cited more than 100 times each. *AIChE Journal* has 35 articles cited more than 100 times each. *Nature,* comes next with 32 highly-cited articles, and followed by *Chemical Engineering Science* (26), *International Journal of Heat and Mass Transfer* (23), *Astrophysical Journal* (16) and *Physical Review B* (16).

Table 7: Transport phenomenon journals with at least seven documents cited more than 100 times, 1900-2007

Rank	Journal Name	No. of documents
1	AiChE Journal	35
2	Nature	32
3	Chemical Engineering Science	26
4	International Journal of Heat and Mass Transfer	23
5	Astrophysical Journal	16
6	Physical Review B	16
7	Environmental Science & Technology	13
8	Physical Review Letters	13
9	Journal of Fluid Mechanics	12
10	Journal of Heat Transfer-Transactions of the ASME	12
11	Journal of the Electrochemical Society	12
12	Physics Reports-Review Section of Physics Letters	10
13	Reviews of Modern Physics	10
14	Water Resources Research	10
15	Journal of Membrane Science	9
16	Proceedings of the National Academy of Sciences of the United States of America	8
17	Geochimica Et Cosmochimica Acta	8
18	Industrial & Engineering Chemistry Process Design and Development	7
19	Science	7
20	Journal of Applied Physics	7
21	Annual Review of Fluid Mechanics	7

Most Highly Cited Documents

Table 8 lists the 30 most highly cited, more than 500 times each, documents with title, author(s) name, journal's name and document type, ranked by cited rate by 2007. It can be seen that the most highly cited article is entitled "*Zener model description of ferromagnetism in zinc-blende magnetic semiconductors"*, authored by Dietl et al. and published in *Science*. The cited times for this particular paper are as high as 2167. The

second most highly cited paper with cited number of 2148 was also published in *Science* entitled "*Nanobelts of semiconducting oxides*" authored by Pan et al. These two papers are on semiconductors. The next two most highly cited papers are physics related. This may suggests that fundamental studies receive more citations. Table 8 illustrates that among the 30 most highly cited articles, 18 are original research articles and 12 are review papers. It is interesting to note that most review papers are written by a single or two authors, while original research articles are usually co-authored work by at least three authors. This suggests the importance of collaboration for original research on transport phenomenon.

Table 8: Most highly cited articles of transport phenomenon, 1900- 2007

No	Title	Author	Journal	Type	Times Cited	Publish Year
1	Zener model description of ferromagnetism in zinc-blende magnetic semiconductors	Dietl, T; Ohno, H; Matsukura, F; Cibert, J; Ferrand, D	Science	Article	2167	2000
2	Nanobelts of semiconducting oxides	Pan, ZW; Dai, ZR; Wang, ZL	Science	Article	2148	2001
3	Metal-insulator transitions	Imada, M; Fujimori, A; Tokura, Y	Reviews of Modern Physics	Review	1435	1998
4	Microbial biofilms	Costerton, JW; Lewandowski, Z; Caldwell, DE; Korber, DR; Lappinscott, HM	Annual review of Microbiology	Review	1229	1995
5	Transport phenomena in a completely ionized gas	Spitzer, L; Harm, R	Physical Review	Article	1104	1953
6	Mixed-valence manganites	Coey, JMD; Viret, M; von Molnar, S	Advances in Physics	Review	1069	1999
7	Longitudinal diffusion and resistance to mass transfer as causes of nonideality in chromatography	Vandeemter, JJ; Zuiderweg, FJ; Klinkenberg, A	Chemical Engineering Science	Article	977	1956
8	Pressure temperature time paths of regional metamorphism .1. heat-transfer during the evolution of regions of thickened continental-crust	England, PC; Thompson, AB	Journal of Petrology	Article	892	1984
9	Lattice bgk models for navier-stokes equation	Qian, YH; Dhumieres, D; Lallemand, P	Europhysics Letters	Article	876	1992
10	The pseudogap in high-temperature superconductors: an experimental survey	Timusk, T; Statt, B	Reports on Progress in Physics	Review	864	1999
11	Particle-imaging techniques for experimental fluid-mechanics	Adrian, RJ	Annual review of Fluid Mechanics	Review	823	1991
12	Kondo effect in a single-electron transistor	Goldhaber-Gordon, D; Shtrikman, H; Mahalu, D; Abusch-Magder, D; Meirav, U; Kastner, MA	Nature	Article	819	1998
13	Random-matrix theory of quantum transport	Beenakker, CWJ	Reviews of Modern Physics	Review	808	1997
14	Atheroma and arterial wall shear - observation, correlation and proposal of a shear dependent mass transfer mechanism for altherogenesis	Caro, CG; Fitzgera.JM; Schroter, RC	Proceedings of the Royal Society of London Series B-Biological Sciences	Article	765	1971

No	Title	Author	Journal	Type	Times Cited	Publish Year
15	Brownian motors: noisy transport far from equilibrium	Reimann, P	Physics Reports-Review Section of Physics letters	Review	734	2002
16	Mr diffusion tensor spectroscopy and imaging	Basser, PJ; Mattiello, J; Lebihan, D	Biophysical journal	Article	732	1994
17	Chemical mass-transfer in magmatic processes .4. a revised and internally consistent thermodynamic model for the interpolation and extrapolation of liquid-solid equilibria in magmatic systems at elevated-temperatures and pressures	Ghiorso, MS; Sack, RO	Contributions to Mineralogy and Petrology	Review	731	1995
18	Stratosphere-troposphere exchange	Holton, JR; Haynes, PH; Mcintyre, ME; Douglass, AR; Rood, RB; Pfister, L	Reviews of Geophysics	Review	723	1995
19	Mass-transfer studies in sorbing porous-media .1. analytical solutions	Vangenuchten, MT; Wierenga, PJ	Soil Science Society of America Journal	Article	668	1976
20	Coulomb blockade and the Kondo effect in single-atom transistors	Park, J; Pasupathy, AN; Goldsmith, JI; Chang, C; Yaish, Y; Petta, JR; Rinkoski, M; Sethna, JP; Abruna, HD; McEuen, PL; Ralph, DC	Nature	Article	662	2002
21	Cytotoxic activity of tumor-necrosis-factor is mediated by early damage of mitochondrial functions - evidence for the involvement of mitochondrial radical generation	Schulzeosthoff, K; Bakker, AC; Vanhaesebroeck, B; Beyaert, R; Jacob, WA; Fiers, W	Journal of Biological Chemistry	Article	617	1992
22	Mechanisms of slow sorption of organic chemicals to natural particles	Pignatello, JJ; Xing, BS	Environmental Science & Technology	Review	608	1996
23	On quantum theory of transport phenomena steady diffusion	Nakajima, S	Progress of Theoretical Physics	Article	582	1958
24	The continuous phase heat and mass-transfer properties of dispersions	Calderbank, PH; Mooyoung, MB	Chemical Engineering Science	Article	580	1961
25	Quantum theory of electrical transport phenomena	Kohn, W; Luttinger, JM	Physical Review	Article	574	1958
26	Electrical conductivity of individual carbon nanotubes	Ebbesen, TW; Lezec, HJ; Hiura, H; Bennett, JW; Ghaemi, HF; Thio, T	Nature	Article	552	1996
27	Light-emitting-diodes with variable colors from polymer blends	Berggren, M; Inganas, O; Gustafsson, G; Rasmusson, J; Andersson, MR; Hjertberg, T; Wennerstrom, O	Nature	Article	541	1994
28	Physiological and environmental-regulation of stomatal conductance, photosynthesis and transpiration - a model that includes a laminar boundary-layer	Collatz, GJ; Ball, JT; Grivet, C; Berry, JA	Agricultural and Forest Meteorology	Article	540	1991
39	Percolation, statistical topography, and transport in random-media	Isichenko, MB	Reviews of Modern Physics	Review	527	1992
30	Contemporary issues in electron transfer research	Barbara, PF; Meyer, TJ; Ratner, MA	Journal of physical chemistry	Review	516	1996

Author Productivity and Lotka's Law

Table 9 illustrates the distribution of author productivity on transport phenomena. The table indicates that, based on the database of this study and during the study period, 134268 authors have authored or co-authored 104854 articles. On average, each author published 0.78 articles. Table 9 also illustrates that most of authors (or co-authors), i.e., 66.08% of the authors published only one article on transport phenomena. It is probably like the Lotka's (1926) law that about 60% authors contribute only one paper. The authors who published two articles on the subject area under study contribute 15.47%. There are 16 authors who published more than 100 papers and within them only one author published more than 200 articles on transport phenomena.

Table 9: Author Productivity

Articles	Authors	%	Cumulate %
1	88730	66.08	66.08
2	20775	15.47	81.55
3	8864	6.60	88.15
4	4663	3.47	91.62
5	2757	2.05	93.67
6-25	7878	5.87	99.54
26-50	483	0.36	99.90
51-75	80	0.06	99.96
76-100	22	0.02	99.98
101-125	10	0.01	99.99
126-150	3	0.002	99.992
151-175	2	0.001	99.993
189	Unknown	0.001	99.994
>201	1	0.001	99.995
Total	134268		100

In this study a procedure which conforms closely to Lotka's original formulation in the test of conformity of the author data was explored. Lotka's law was used to measure the productivity of authors. The general form of Lotka's law can be stated as:

$y = c/x^n$

where y = percentage of authors

x = number of articles published by an author

c = constant

-n = slope of the log-log plot of the above equation.

Employing a least square power curve fitting against the data of author productivity results in n=-2.11 and c=66.1 percent. The data of author productivity and the fitted curve are shown in Figure 3.

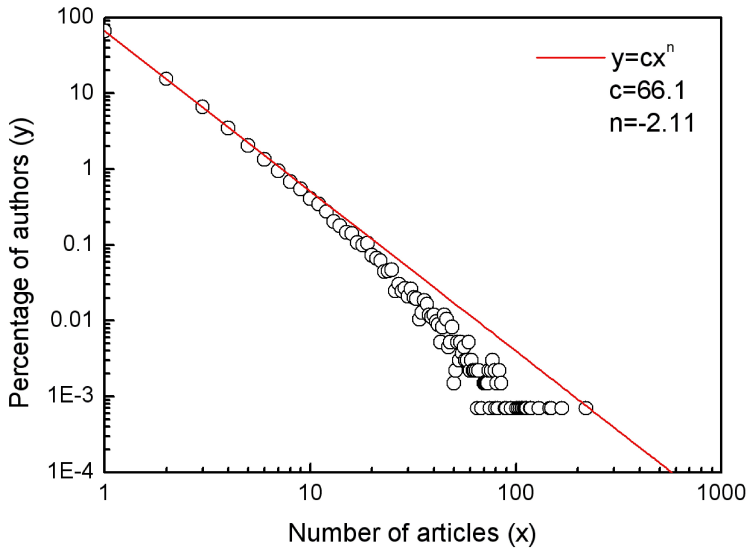

Figure 3: Productivity of authors of transport phenomenon

In order to test the goodness of fit, the Kolmogorov-Smirnov (K-S) statistic test was used for this type of data. The (K-S) test determines the maximum deviation (Dmax) between the theoretical (for this case, the fitted) and observed cumulative distribution functions. Dmax = Max $S_N(X)$-$F_O(X)$ is the theoretical cumulative distribution function of a sample of N observations. At a 0.01 level of significance, the K-S statistic is equal to $\frac{1.63}{\sqrt{n}}$. If Dmax is less than the K-S statistic, then the observed distribution fits the theoretical distribution. The K-S statistic was used in this study to test the goodness of fit to the observed author productivity. Table 10 illustrates the number of authors corresponding with number of articles equal to or less than 10 published.

As shown in Table 10, Dmax is 0.088, and the K-S statistic is $\frac{1.63}{\sqrt{134269}}$ =0.00445. The value of Dmax is more and therefore the observed data does not apply to the general form of Lotka's law.

Table 10: Productivity of authors

No. of articles	No. of authors	Observed y(%)	$S_N(x)$	Fitted y(%)	$F_o(x)$	$\lvert F_o(x)-S_N(x) \rvert$
1	88730	0.6608	0.6608	0.7488	0.7488	0.0880
2	20775	0.1547	0.8156	0.1311	0.8799	0.0643
3	8864	0.0660	0.8816	0.0473	0.9272	0.0456
4	4663	0.0347	0.9163	0.0229	0.9501	0.0338
5	2757	0.0205	0.9368	0.0131	0.9632	0.0264
6	1806	0.0135	0.9503	0.0083	0.9715	0.0212
7	1275	0.0095	0.9598	0.0056	0.9771	0.0173
8	914	0.0068	0.9666	0.0040	0.9811	0.0145
9	732	0.0055	0.9720	0.0030	0.9841	0.0121
10	547	0.0041	0.9761	0.0023	0.9864	0.0103

Dmax=0.088

At 0.01 level of significance, K-S statistic= $\frac{1.63}{\sqrt{134269}}$ =0.00445

Dmax= 0.0880 > 0.00445. Therefore, data does not fit the general form of Lotka's law.

Leading Authors

Table 11 lists the 16 most productive authors who published more than one hundred papers on transport phenomena and the number of papers are cited more than 10 times each. Sparrow, E.M., a professor at the Department of Mechanical Engineering at the University of Minnesota, with 219 papers published, is the most productive author in the subject of transport phenomena. Sparrow is also the only author who publishes more than 200 papers. His most cited paper entitled "*Fully developed flow and heat-transfer in ducts having streamwise-periodic variations of cross-sectional area*" has been cited 214 times. He has three more papers cited more than 100 times each. The second most productive author is Viskanta, R., a professor emeritus of School of Mechanical Engineering at Purdue University, who has published 168 papers. Two of Viskanta's papers, each cited 170 times, are "*Heat-transfer to*

impinging isothermal gas and flame jets" and "*Radiation heat-transfer in combustion systems*". Pop, I. who is affiliated with College of Mechanical Engineering, University of Cluj, Romania, is ranked number three with 167 papers. His most cited paper, which was cited 20 times, is "*The effect of variable viscosity on flow and heat-transfer to a continuous moving flat-plate*". He has published 20 articles with 10 cited times.

Table 11: The Most Productive Authors

Ranks	Authors	Articles	cited more than 10 times
1	Sparrow, EM	219	71
2	Viskanta, R	168	60
3	Pop, I	167	20
4	Bejan, A	149	57
5	Mujumdar, AS	146	31
6	Han, JC	130	49
7	Guiochon, G	119	62
8	Vafai, K	118	37
9	Nath, G	113	6
10	Wu, C	112	54
11	Sedahmed, GH	110	17
12	Gorla, RSR	108	9
13	Chen, JC	107	35
14	Krishna, R	105	49
15	Tao, WQ	103	10
16	Chen, CK	101	17

CONCLUSIONS AND SUMMARY

The present work explores the characteristics of transport phenomenon literature from 1900 to 2007 based on the database of SCI™ Expanded and its implication using the scientometric techniques. The study reveals that the literature on transport phenomenon grows

exponentially with an annual growth rate of 8.67% for the last century. This reflects the extensive worldwide study on transport phenomenon. The study also reveals that, as for other subjects, most of document type is in the form of research articles constituting 91.4% of the total literature and English is the predominant language (94.9%). USA, Japan and France are the three biggest contributing countries on transport phenomenon literature. The Indian Institute of Technology in the India is the largest single institution publishing 1385 papers on transport phenomenon.

The present study also indicates that the journal literature on transport phenomenon confirms the typical S-shape for the Bradford-Zipf plot. The top five of the 36 core journals identified are *International Journal of Heat and Mass Transfer*, *Chemical Engineering Science*, *Journal of Heat Transfer—Transactions of the ASME*, *Industrial & Engineering Chemistry Research* and *AIChE Journal*. Among them, *AIChE Journal*, which has 35 articles cited more than 100 times each, is the journal contributing most to the most highly cited papers. On the other hand, the most highly cited article entitled "*Zener model description of ferromagnetism in zinc-blende magnetic semiconductors*", authored by Dietl et al. and published in *Science* had been cited 2167 times by the year of 2007.

Most of authors or co-authors (66.08%) published only one article on transport phenomena. It is probably confirms the Lotka's law that about 60% authors contribute only one paper in any given field. The observed author productivity does not apply to the general form of Lotka's law by the K-S goodness of fit test. The five most productive authors corresponding with the number of their papers are Sparrow, E.M. (219), Viskanta, R. (168), Pop, I (167), Bejan, A. (149) and Mujumdar, A.S. (146).

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REFERENCES

Ackermann, E. 2005. Bibliometrics of a controversial scientific literature: polywater research, 1962-1974, *Scientometrics*, Vol. 63, no. 2: 189-208.

Al-Qallaf, C.L. 2009. A bibliometric analysis of the Punica Grantum L. literature, *Malaysian*

Journal of Library & Information Science, Vol.14, no.1: 83-103.

Biswas, B.C., Roy, A. Sen B.K. 2007. Economic botany: A bibliometric study, *Malaysian Journal of Library & Information Science*, Vol.12, no.1: 23-33

Bradford, S.C. 1953. *Documentation.* 2nd ed. London: Crosby Luckwood

Braun, T., Schubert, A. and Zsindely, S. 1997. Nanoscience and nanotechnology on the balance. *Scientometrics*, Vol. 38, no. 2: 321-325.

Brookes, B.C. 1973. Numerical methods of bibliographic analysis. *Library Trends*, Vol. 22, no. 1: 18-43.

Hassan, Emmanuel. 2005. The evolution of the knowledge structure of fuel cells. *Scientometrics*, Vol. 62, no. 2: 233-238.

Journal Citation Reports. 2005. Available at: http://thomsonreuters.com/products_services/science/science_products/a-z/journal_citation_reports

Lotka, A.J. 1926. The frequency distribution of scientific productivity. *Journal of the Washington Academy of Sciences*, Vol. 16, no: 12: 317-323.

Meyer, M. and Persson, O. 1998. Nanotechnology-interdisciplinarity, patterns of collaboration and differences in application. *Scientometrics*, Vol. 42, no. 2: 195-205.

Schummer, J. 2004. Multidisciplinarity, interdisciplinarity, and patterns of research collaboration in Nano Science and Nano Technology. *Scientometrics*, Vol. 59, no. 3: 425-465.

Thomson Reuters. 2009. *Web of Science Databases*. Available at: http://images.isiknowledge.com/WOK46/help/WOS/h_database.html

Tsay, M.Y. and Yang, Y.H. 2005. Bibliometric analysis of the literature of randomized controlled trials. *Journal of the Medical Library Association*, Vol. 93, no. 4: 450-458.

Ulrich's Periodicals Directory 2005. Available at: http://www.ulrichsweb.com/ulrichsweb/