Bibliometric Analysis of Lead-acid batteries Publications: Trends and Characteristics

Iskra Arsenova

Institute of electrochemistry and energy systems, Bulgarian Academy of Sciences, Sofia, Bulgaria

ABSTRACT

The scientific productivity of *lead-acid batteries* - related research among researchers, countries, institutions, journals, and subject area's was investigated by a bibliometric analysis of *lead-acid batteries* research from 1980 to 2014. The search includes the Web of Knowledge and SCOPUS databases with the word *lead-acid batteries* in the title. From Web of Knowledge 2102 documents were obtained, whereas a total of 4685 documents were obtained from SCOPUS. More than 58 % of the documents are research articles, mostly (more than 92%) written in English, about 20 % produced in the United States and 20% produced by Chinese researchers. The study reveals the most productive institutions and authors. Most prolific author is Detchko Pavlov from Bulgarian Academy of Sciences, who account for 1 % of the published articles. *Journal of Power Sources* is the main journal most used for *lead-acid batteries* research publications (more than 32% in WoS and more than 20% in SCOPUS). According to this results it can be concluded that there is an important gap identified between developed and developing countries in the volume of scientific papers. About the 30% of the papers have been published by the 10 most developed countries excluded Taiwan.

Key-words: lead-acid batteries, bibliometrics, bibliometric indicators, scientific production.

INTRODUCTION

Lead-acid batteries research is an important scientific area. These batteries have applications in energy storage, emergency power, and electric and hybrid vehicles (including off-road vehicles), in telephone systems, power tools, communication devices, emergency lighting systems, and as the power source for mining and material-handling equipment.[1,2] The wide use of the lead-acid battery in many designs, sizes, and system voltages is accounted for by the low price and the ease of manufacture on a local geographic basis of this battery system. The lead-acid battery is almost always the least expensive storage battery for any application, while still providing good performance and life characteristics.[3]

The main objective of this paper is to apply the bibliometric analysis to the Lead-acid batteries papers published in scientific journals with the aim of identifying tendencies, gaps and characteristics in comparing scientific production of some developed countries. These results are expected to be a contribution towards the support of new developments in this area.

The scientific literature was analyzed with emphasis on: papers- temporal trends, document type, language, most frequent subject areas, and most relevant papers from citation indicators; researchers: most productive and most frequent institutions of residence and countries; journals: core journals, and impact factors.

Evaluative bibliometrics, as a subfield of quantitative science and technology studies, can be used to:

- Identify the infrastructure (authors, journals, institutions) of a technical domain;
- Identify experts for innovation-enhancing technical workshops and review panels;

***Address for correspondence:**

Iskra Arsenova, acad. G. Bonchev Str., Bl. 10, 1113 Sofia, Bulgaria

E-mail: isarsenova@gmail.com

Phone number : 00359899394953

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Website: www.jscires.org

DOI: 10.5530/jscires.5.2.5

- Develop site visitation strategies for assessment of prolific organizations globally;
- Identify impacts (literature citations) of individuals, research units, organizations, and countries.[4,5]

Research Objectives

To achieve the aim the following objectives must be fulfilled:

- To find out the year-wise distribution.
- To analyze the authorship pattern.
- To analyze the country productivity.
- To categorize document types.
- To examine subject areas.
- To verify Bradford distribution.

Methodology and Sources

The bibliographic search covered papers published during 1980-2014. The search was performed using the two Data bases (DB) - SCI, (Thomson Reuters) and the SCOPUS. SCI was started by the Institute for Scientific Information (ISI) in 1963. It is now owned by Thomson Reuters and is available online through the Web of Science database (WoS). SCOPUS was started as a commercial endeavor in 2004 by Elsevier Science Publishing Company. These databases include many journals, provide a citation index, and the results of the queries are comparative concerning mainstream papers in scientific research.

We accessed the WoS and SCOPUS until 2014, in order to find out where research in *lead-acid batteries* has been done. We accessed data on documents with the word *lead-acid batteries* in the title and in the abstract of the papers. All records were retrieved for each database and were systematized; then the data sets were validated and normalized, and a quantitative analysis for each category was done: document, author, affiliation (institution), country, journal, subject area.

The 10 most cited papers from two data bases were identified. Impact Factors (IF) were obtained from Journal Citation Report 2014, and core journals were identified with Bradford`s method[6,7]

A total of 5947 records were retrieved up to August 30, 2015.

RESULTS AND DISCUSSION

Descriptive analysis of lead acid batteries papers by year of publication

The total number of lead-acid batteries publications was 2102 in the WoS.

The trend analysis from 1980 to 2014 indicates a clear increase of the number of lead-acid batteries papers published: from 8 papers in 1980 to 114 in 2014 (14 times increase) (Figure 1). Nevertheless, when comparing this trend with the total articles in the database it is clear a slight relative increase, that is, from 1.56 in 1991 to 2.51 in 2014.

The SCOPUS database is also analyzed by identifying the number of publications under the subheading lead-acid batteries (see Figure 1). In the 30-year period, there are a total of 4685 publications. We observe an increase of 13 times of the number of publications from 1980 till 2014.

From these data we can infer a first conclusion indicating that, there is increase in the total number of articles per year over the 30 years in the two data bases.

The increase in the period 2000-2014 is obvious. For this reason we analyzed in detail only the data from this 15 years period.

Author frequency results

More than 500 author names in each DB were found. Table 1 shows the 26 most prolific authors, each with more than 9 published articles in WoS and more 11 published articles in SCOPUS and jointly accounting for 20% of all the papers.

In WoS 9 of each 18 authors are from Europe, 8 from Asia and 1 from North America. On the contrary, in the SCOPUS database, the authors from Asia and from Europe are equal number - 9. In two DB the most prolific author is Dechko Pavlov from Bulgaria.

This is another strong indication of the priority given to lead-acid batteries activities in the countries from Europe and Asia.

Countries producing most lead-acid batteries papers

The 10 countries with the highest number of publications are shown in Table2. It is reasonable that the USA is the country most represented in WoS (11.5%). After

USA the most productive country with 9.3 % of publications is People Republic of China. Countries with more or less each one with about 3% of the total were Taiwan, Spain, France and England. Jointly, India, Japan and Iran account for 10 % of the publications.

The analysis of the number of articles by country in Scopus indicates that the most productive country is People Republic of China with 20,5% of all publications. People Republic of China is followed by USA with15.8% of all publications. Germany and Japan have about 300 publications.

The concentration of publications in few developed countries is even more evident in two databases where only two countries (USA and People Republic of China) are leaders. This is a clear hint, in our opinion, not only of the different cultural and economic situations that influence the production of scientific knowledge but also of the different interests, incentives and opportunities that authors encounter when producing and publishing lead-acid papers.

Institutions producing most lead-acid batteries papers

There are more than 500 different institutions, such as universities, research Institutes and corporations. The 23 most highly represented are shown in Table 3. The most productive institution according DB WoS is the Bulgarian Academy of Sciences (31 papers). The Harbin Institute of Technology with 60 total number of papers, and Tsinghai University from PR of China with 46 publications are leaders according DB SCOPUS. Taking together all the institutions by country the Asian institutions account about 50% of all published papers.

Journals containing most lead-acid batteries papers

16 of the journals in WoS published 31 % of the articles about lead-acid batteries (Table 4). Sixteen of the journals have 42,5% of the published articles in SCOPUS. *Journal of Power Sources* is the leader among the journals with the highest number of publications (20% of the total in DB WoS and 13% of the total publications in DB SCOPUS).

Journal of Power Sources and *Journal of Electrochemical Society* have the highest impact (respectively 6.217 and 3.266).

The journal article is the single most common form of publication. Our sample for 2001 to 2014 includes 2102 articles in WoS. Of these, 410 articles have been published in 1 source title. Three zones constitute the most specific subdivisions of these data for which the Bradford hypothesis is not valid. The nucleus of journals (zone 1) consists of 1 journal in Wos, followed by 66 titles (zones 2), 217 titles (zone 3). The ratio of source title number among these 3 zones in WoS is 1:64:279 which isn't quite close to $1:a:a^2$. This may be due to the widespread nature of lead-acid batteries articles in a vast number of source titles.

Hawkins[8] suggests that the droop might be due to the dispersion of the literature on the subject under study. This finding corresponds to the large number of journals in zone 3. Table 5 also lists the cumulative number of articles and the percentage of each zone. The 67 journals in the 1st and 2nd zones cover 74% of literature, and the 1 journal in the 1st zone cover 32.5 % of the literature. This finding implies that, while 32 % of the literature is concentrated in only the one journal, the remaining 68 % is scattered in 283 journals, showing remarkable scattering of lead-acid batteries literature. The final droop portion reveals that the lead-acid batteries literature has been extensively spread to many different journals. The scattering of information poses a problem in the complete retrieval of relevant information.

Language of publications

It is also important to note the language of publications. Table 6 shows the number of publications in different languages. English was found to be the predominant language and out of a total of records,. 1233 articles (97.7%) in WoS and 4310 (92%) articles in SCOPUS are in English. Since WoS is a US based database, some bias for English language may have inadvertently crept in the records. Also, since English is the official scientific language in many countries; it leads to its wide usage in dissemination of scientific data and proceedings. This observation matches with other scientific publications where information is available largely in English. Moreover, English is the official language for most international conferences.

Only 8 % of the articles in SCOPUS are not in English. The most common non-English language is Chinese, which constitutes 6 % of the total.

Publication type

For convenience, all documents have been placed in five categories in WoS i.e. journal articles, proceedings papers, reviews, editorial materials and meeting abstracts. In SCOPUS all documents are distributed in seven categories - journal articles, proceedings papers, reviews,

Table 1: The 20 most prolific researchers lead-acid batteries

Wos			SCOPUS		
Authors	**Country**	**Number**	**Authors**	**Country**	**Number**
Pavlov,D.	Bulgaria	40	Pavlov, D.	Bulgaria	36
Karami, H	Iran	27	Sauer, D.U 7101632749	Germany	30
Sauer,DU	Germany	27	Hirai, N.	Japan	21
Guo, YL	Peoples R China	19	Karden, E	Germany	20
Karden,E	Germany	17	Guo, Y. 7406309674	Peoples R China	18
Chen, HY	Peoples R China	16	Cooper,A.	Germany	18
Perrin, M	Germany	14	Hurley,W.G.	Ireland	16
Valenciano, J	Spain	13	Perrin, M. 7102098509	Germany	16
Shukla, AK	India	13	Karami, H. 6603140104	Iran	15
Trinidad, F	Spain	12	Garcia, R.	USA	15
Edwards, DB	USA	12	Masmoudi, A.	Tunisia	15
Kirchev, A	Bulgaria	12	Valenciano, J	Spain	14
Hariprakash, B	India	11	Trinidad, F.	Spain	14
Martha, SK	India	11	Shiota, M. 12767256900	Japan	14
Gaffoor,SA	India	10	Nakayama, Y.	Japan	12
Mattera, F	France	10	Hariprakash, B 7402057483	India	12
Garchel,J	Germany	9	Mattera, F.	France	11
Hsien, YC	Taiwan	9	Chen, H.Y.	Peoples R China	11
			Moseley, P.T. 16425232700	USA	11
			Gaffoor, S.A 7006496688	India	11
			Martha, S.K.	India	11

Table 2: The 10 most prolific countries in lead-acid batteries

WoS			SCOPUS		
Country	**Articles**		**Country**	**Articles**	
	Number	**%**		**Number**	**%**
USA	241	11.5	PR China	961	20.5
PR China	196	9.3	USA	739	15.8
Germany	91	4.3	Germany	295	6.3
Taiwan	64	3.1	Japan	278	6.1
Spain	63	3.0	England	230	4.9
France	61	3.0	France	221	4.8
England	57	2.7	India	175	3.8
India	53	2.5	Taiwan	169	3.6
Japan	53	2.5	Spain	153	3.5
Iran	52	2.5	Italy	148	3.2

Table 3: The most prolific institutions in lead-acid batteries

Institutions	Rang	Country	WoS	SCOPUS	Rang
Bulgarian Academy of Sciences	I	Bulgaria	31	40	IV
Rheinisch-Westfälische Technische Hochschule Aachen	II	Germany	22	39	V
South China Normal University	III	People R of China	17	26	XV
Harbin Institute of Technology	IV	People R of China	12	60	I
Indian Institute of Science	V	USA	16		
IEEE	VI	USA	16	25	XVI
University of Idaho	VII	USA	15		
Cent S Univ	VIII	Peoples R China	15		
Fuzhou University	IX	People R of China	14		
CSIRO Energy Technology	X	Australia	14		
Central Electrochemical Research Institute India	XI	India	13	27	XII
Tsinghua University	XII	People R of China	11	46	II
Shandong Univ	XIII	People R of China	11		
Univ Vigo	XIV	Spain	11		
Xi'an Jiaotong University	XV	People R of China	9	39	VI
Beijing Institute of Technology		People R of China		41	III
Shanghai Jiaotong University		People R of China		36	VII
Huazhong Univ.of Science and Technology		People R of China		34	IX
Tianjin University		People R of China		29	X
University of Sheffield		England		28	XI
University of Sfax		Tunisia		27	XIII
General Motors		USA		26	XIV

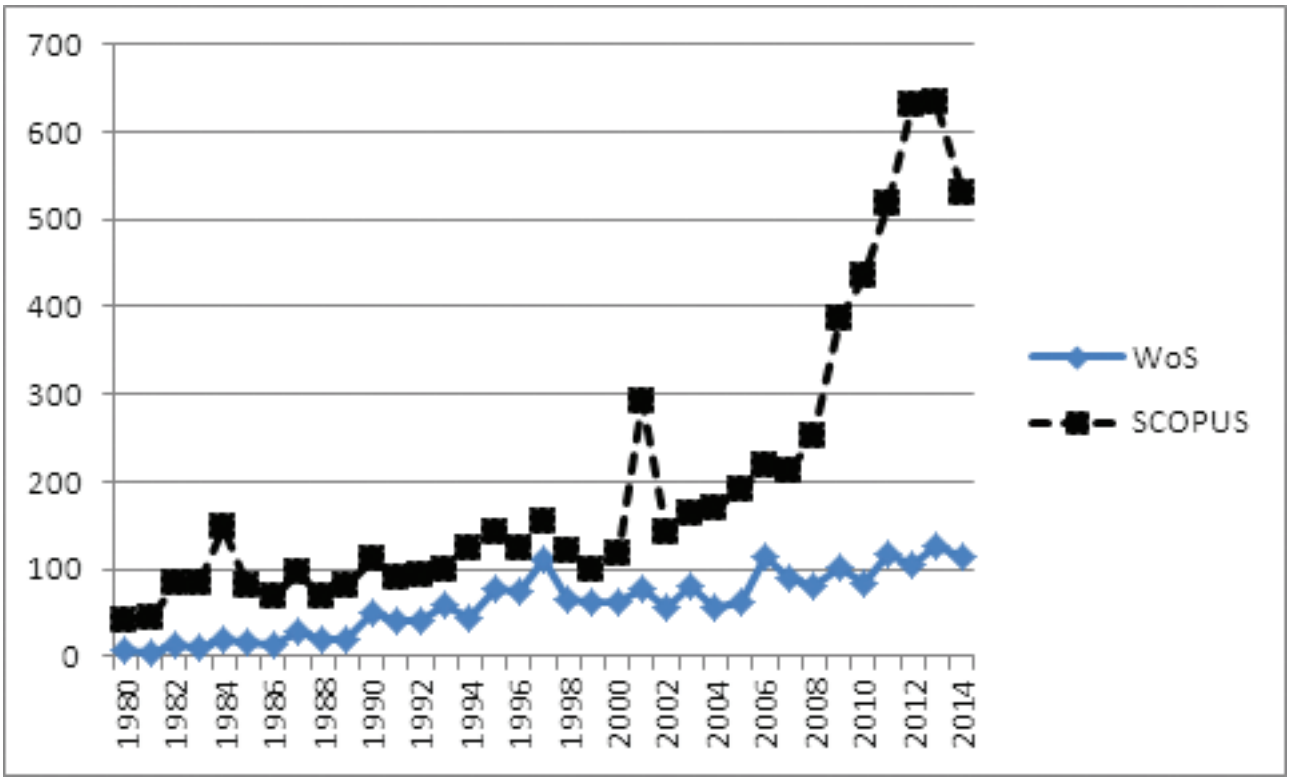

Figure1: Growth of publications in lead-acid batteries during 1980-2010, WoS and SCOPUS DB

Table 4: Journals containing most papers in lead-acid batteries with impact factor (i.f.)

N=	WoS		SCOPUS	
	Source titles	Number of publications	Source titles	Number of publications
1	J. of Power Sources	410	J. of Power Sources	607
2	J.of the Electrochemical society	28	Inter. Telecommunications energy conf. INELEC	127
	IEEE Transactions on energy conversion	21	Advanced Materials Research	99
	IEEE Transactions on industrial electronics	21	Revet	82
3	Electrochemica Acta	20	SAE Technical Papers	68
4	International telecom-munications energy conf.INTELEC	20	Applied Mechanics and Materials	68
5	J. of applied electrochemistry	19	Electrochimica Acta	50
6	Advanced materials research	15	J.of the Electrochemical Society	45
7	ECS Transactions	13	Ecs Transactions	42
8	Energy conversion and management	13	Renewable Energy	31
9	International J.of electrochemical science	11	Energy Policy	30
10	Lead acid batteries science and technology.A handbook of LAB technology and its influence on the product	11	Renewable and Sustainable Energy Reviews	300
11	Energies	10	Journal of Applied Electrochemistry	27
12	IEEE Industrial electronics society	9	Dianyuan Jishu Chinese Journal of Power Sources	26
13	IEEE Transactions on Vehicular technology	9	2014 9th International Conference on Ecological Vehicles and Renewable Energies Ever 2014	137
14	Sixteenth annual battery conf. On application and advances	9	INTELEC International Telecommunications Energy Conference Proceedings	127
15	Applied energy	8	2012 1st International Conference on Renewable Energies and Vehicular Technology	98
16	Renewable energy	8	IEE Conf.Publication	29

Table 5: Bradford zones of scatter for lead-acid batteries literature, according WoS 2001-2014

Zones	N= of source titles	N= of articles	Cumulative N=, %
I	1	410	410 (32.5%)
II	66	512	932 (73.8%)
III	217	330	1262 (100.0%)
Total	284	1262	

editorial materials, meeting abstracts, Business Articles and Articles in Press.

Some of the publications are included in two categories - journal articles and proceedings papers. Table 7 illustrates the document type in lead-acid batteries, which indicated that the prevalent form of documentation is journals. The major sources are scientific and technical journals and conference proceedings published throughout the world. From 2001 to 2014, the most common document type is journal article, contributing about 72 % of the total in WoS and 58% in SCOPUS (table 7). Conference papers make up the remaining 44%. They are the 2-nd most common document type. Reviews are in the third place.

Subject areas analysis

Analysis by subject areas has disclosed that all original articles in lead-acid batteries researches are published

Table 6: Language used for publication of lead-acid batteries knowledge

Language	WoS		SCOPUS	
	N=	%	N=	%
English	1233	97.7	4310	92.0
Chinese	10	0.8	283	6.0
Japanese	3	0.2	29	0.6
German	4	0.3	24	0.5
Korean	0	0.0	13	0.3
French	0	0.0	11	0.2
Romanian	0	0.0	3	0.06
Polish	5	0.4	6	0.1
Russian	0	0.0	3	0.06

Table 7: Number and type of publications in different document's categories

Document Types	WoS		SCOPUS	
	N=	%	N=	%
Articles	897	71.1	2697	57.6
Proceedings papers	551	43.7	2106	45.0
Book chapter	25	2.0	25	0.5
Reviews	23	1.9	917	19.6
Editorial materials	6	0.5	0	0.0
Meeting abstracts	2	0.4	14	0.3
Business Article	0	0.0	2	0.04
Article in Press	0	0.0	2	0.04

Table 8: The top 10 most cited articles in lead acid batteries research in WoS

N=	Title	Authors	Country	Source title/year	Citations
1	Electrochemical Energy Storage for Green Grid	Yang, Zhenguo; Zhang, Jianlu; Kintner-Meyer, Michael C. W. ; Lu, Xiaochuan; Choi, Daiwon ; Lemmon, John P. Liu, Jun	USA	Chemical Reviews, 2011	489
2	Battery separators	Arora P; Zhang ZM	USA	Chemical Reviews, 2004	361
3	Functional Materials for Rechargeable Batteries	Cheng, Fangyi; Liang, Jing; Tao, Zhanliang; et al.	People R of China	Advanced Materials, 2011	334
4	Vapor-grow carbon (VGCFs)-Basic properties and their battery applications	Endo, M; Kim, YA; Hayashi, T; et al.	Japan, USA	Carbon , 2001	332
5	Accurate electrical battery model capable of predicting, runtime and I-V performance	Chen M; Rincon-Mora GA	USA	IEEE Transactions on energy conversio, 2006	298
6	Methods for state-of-charge determination and their applications	Piller S; Perrin M; Jossen A	Germany	J. of Power Sources, 2001	285
7	Extended Kalman filtering for battery management systems of LiPB-based HEV battery packs - Part 3. State and parameter estimation	Plett GL	USA	J. of Power Sources, 2004	269
8	Energy storage systems for automotive applications	Lukic Srdjan M.; Cao Jian; Bansal Ramesh C.; et al	USA	IEEE Transactions on industrial electronics, 2008	211
9	Energy-management system for a hybrid electric vehicle, using ultracapacitors and neural networks	Moreno J; Ortuzar ME; Dixon JW	Chile	IEEE Transactions on industrial electronics,, 2006	204
10	Energy storage devices for future hybrid electric vehicles	Karden Eckhard; Ploumen Serv; Fricke Birger; et al.	Germany, USA	J. of Power Sources, 2007	141

How to cite this article: Adedayo, A.V. Discouraging Honorific Citation J Scientometric Res. 2016;5(1):43-8. Full text available at http://www.jscires.org/v5/i1

Table 9: The top 10 most cited articles in lead acid batteries research in SCOPUS

N	Title	Authors	Country	Source title,year	Citations
1	Methods for state-of-charge determination and their applications	Piller, S. Perrin, M. Jossen, A.	Germany	J. of Power Sources, 2001	458
2	Energy storage systems-Characteristics and comparisons	Ibrahim, H.;Ilinca,A.]Perron, J.	Canada	Renewable and Sustainable Energy Reviews, 2008	381
3	Vapor-grown carbon fibers (VGCFs) - Basic properties and their battery applications	Endo M; Kim YA; Hayashi T; Matusita, T; Nishimura, K.; Miyashita, K; Dresselhaus, MS.	Japan USA	Carbon, 2001	363
4	Rechargeable lithium batteries with aqueous electrolytes	Li,W. Dahn,J.R.; Wainwright,,D.	Canada	Science, 1994	316
5	Enhancement of long stability of sulphur cathode by encapsulating sulfur into micropores of carbon spheres	Zhang, B.; Qin,X.; Li,G.R. Gao,X.P.	People R of China	Energy&Envirinmental Science, 2010	299
6	A mathematical model for lead acid batteries	Salameh, Ziyad. Cassacca M., Lynch,W.	USA	IEEE Transactions on energy conversio 1992	294
7	A review of impedance measurement fpr determination of the state-of-charge or state-of-health of secondary batteries	Huet, F.	France	J.of Power Sources,1998	241
8	New dynamical models of for lead acid batteries	Ceraolo, M.	Italy	IEEE Transactions on Power Systems,2000	232
9	Direct determination of lead speciation in contaminated soils by EXAFS spectroscopy	Manceau,A. ;Sarret, G.; Cambiet, P.; Prost, R	France	Environmental Science and Technology,1996	226
10	**Electrochemical studies of cobalt hydroxide - an additive for nickel electrodes**	Elumalai, P., Vasan, H.N.	India	J. of Power Sources,2001	162

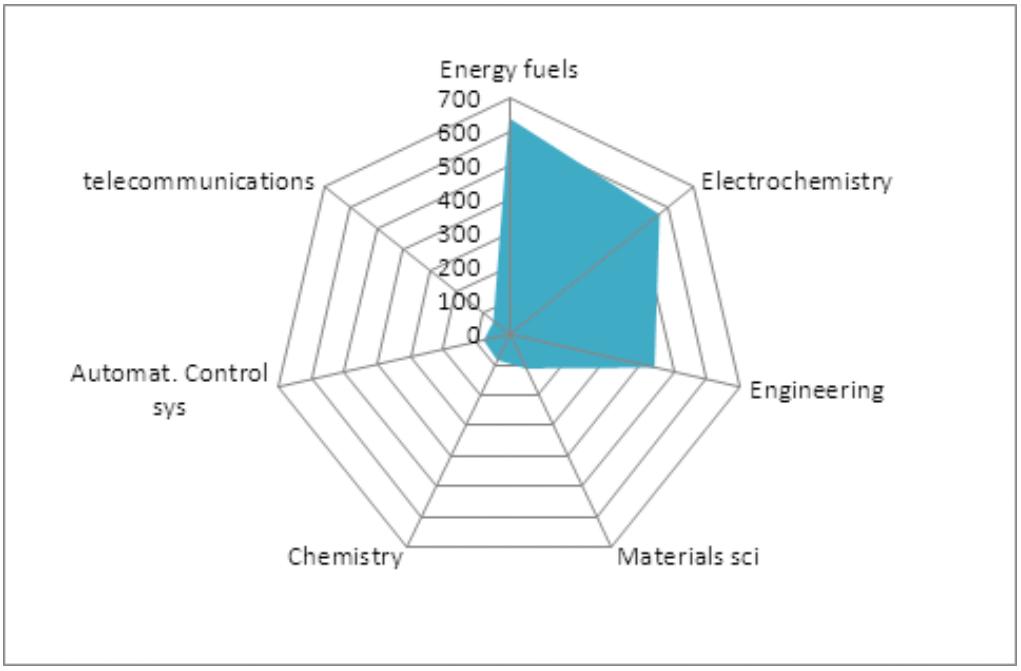

Figure 2: The most used subject areas in lead acid batteries, WoS DB

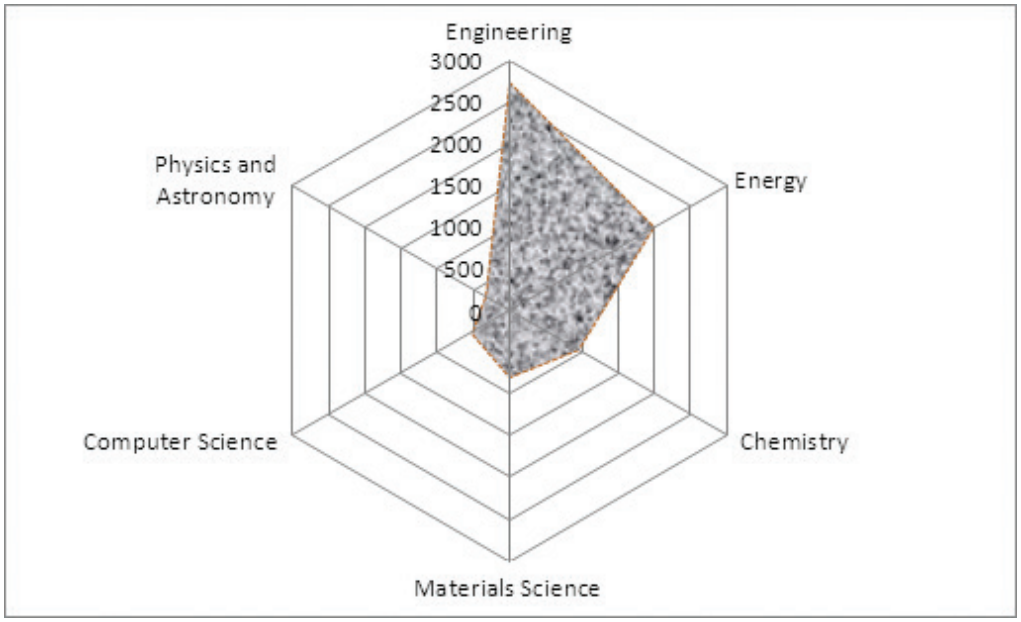

Figure 3: The most used subject areas in lead acid batteries, SCOPUS DB

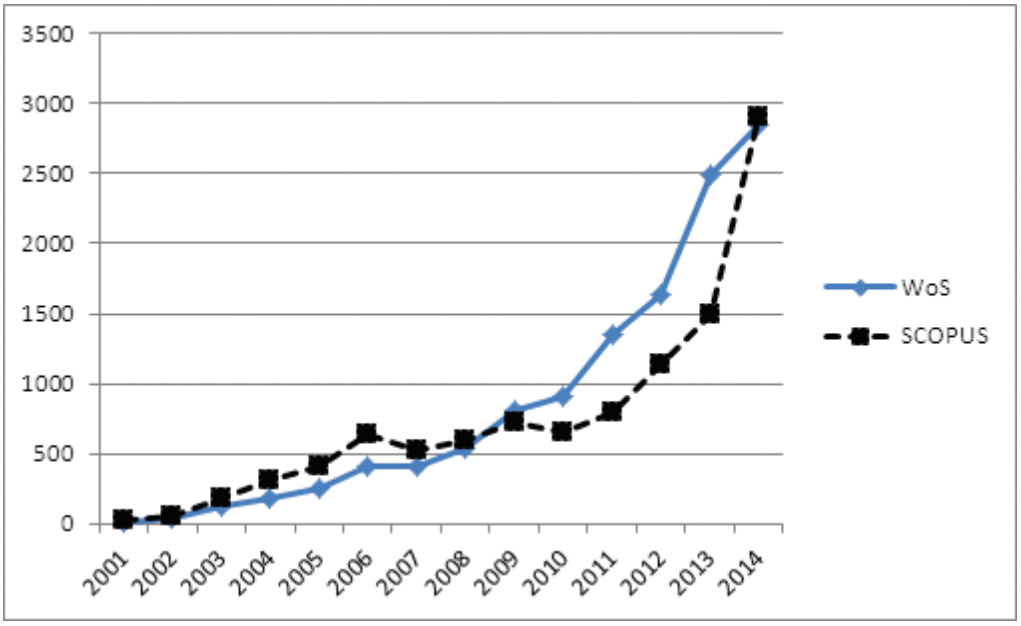

Figure 4: Growth of citations in lead-acid batteries during 1980-2010, WoS and SCOPUS DB

in more than 25 subject areas. This indicates that these researches have covered a broad range of subject areas.

Figures 2 and 3 illustrate the focus on original subject areas of the articles in lead-acid batteries research, which are defined as that each of these subject areas has included at least 5 % original articles. It is seen that the top 6 subject areas according WeS are: Energy fuels, Electrochemistry, Engineering, Materials sciences, Automatic Control systems and Telecommunications, which have published most original articles. In SCOPUS the most developed subject areas are: Engineering, Energy, Chemistry, Materials sciences, Computer Science and Physics &Astronomy. This indicates that lead-acid batteries research is very much focused in these non only chemistry subject areas.

Citation analysis

Some of the many possible uses of citations are bookmarks, intellectual heritage, impact tracker and self-serving

purposes. The main function of the applicability of citation analysis is to show the impact or quality measure.[9]

By the time of this study, there have been 12033 total number of citations in WoS and 10436 total number of citations in SCOPUS published during 2001-2014.

Citations through the years have been shown in Figure 4. It is clearly seen that there has been almost continuous growth in the number of citations through the years, with the rapid growth started from 2003.

The continuous growth in citations numbers through the years is partly because citations accumulate by years, and within each year, citations include not only current articles but also previous ones which may date back to a few years or even many more years ago. However, the continuous and rapid growth in citations since 2003 is also partly attributed to the continuous and rapid growth of the original articles from 2000. The delay of years is because citations are always one or two years behind the original publications. On the other hand, the continuously increasing number of citations also indicates that the general impact of the original articles in lead-acid batteries research has been increasing gradually.

Table 8 and 9 show the most cited articles in WoS and SCOPUS DB. Only five of the top cited articles in two DB are the same. Not surprisingly, the highest ranked journals also have the most cited article is J.of Power Sources. Tables show that the most cited country among the top 10 articles is USA.

It is interesting to note that some of the most cited articles treat more general questions. For example the articles N= 1 and N= 6 from table 9 treat mathematical models. Article N= 4 from table 9 is dedicated to rechargeable lithium batteries. As well the number of the most cited articles, examined the structure of active materials is small.

CONCLUSION

One of the main conclusions of the empirical analysis of lead acid batteries publications is the important gap identified between developed and developing countries in the volume of scientific papers. About the 33% of the papers have been published by the 10 most developed countries excluded Spain and Taiwan.

The results are summarized as follows:

1. The lead-acid batteries literature from 1980 to 2014 grew practically exponentially.
2. The single most common form of publication covered in two data bases is the journal article, which contributes more than 58 % of the total literature.
3. The United States of America is the predominant publishing country in WoS in the lead-acid batteries literature (about 12 % of papers). People Republic of China is the most prolific country in SCOPUS with 20.5% of all papers. English is the most common language. English articles constitute more than 92 % of the total.
4. The subject areas are diverse. The areas that look into lead acid batteries are energy, engineering, chemistry, material sciences, energy fuels.
5. The analysis of the core journals indicates that the more productive is Journal of Power Sources.
6. According Bradford law of information distribution we established that only 1 journal consist the 1st zone and cover 30% of the literature. The remaining 70% of articles is scattered in 284 journals.

This report represents the effort to explore the global scientific production employing *Lead acid batteries*. It provides quantitative information about the growth of *Lead acid batteries* research and qualifiers, a ranking of the most successful authors, institutions, countries, journals, topics and temporal trends.

ACKNOWLEDGEMENT

I would like to gratefully and sincerely thank academician Dechko Pavlov for his guidance, understanding, patience, and most importantly, his encouraging.

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How to cite this article: Arsenova I. Bibliometric Analysis of Lead-acid batteries Publications: Trends and Characteristics J Scientometric Res. 2016;5(2):148-58. Full text available at http://www.jscires.org/v5/i2