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BIBLIOMETRIC STUDY ON ELECTROCHEMICAL RESEARCH BASED ON PAPERS PUBLISHED IN CORE JOURNALS

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ABSTRACT

Describes a bibliometric study on electrochemistry based on publication counts in core electrochemical journals. The journals covered are ***Journal of the Electrochemical Society*** *(USA),* ***Journal of Electrochemistry*** *(Switzerland),* ***Electrochimica Acta*** *(UK),* ***Journal of Applied Electrochemistry*** *(UK) and* ***Journal of Power Sources*** *(Switzerland). The CD-ROM editions 1991 and 1992 of* ***Chemistry Citation Index*** *(CCI) were analysed. A total of 4,020 published items (articles, notes, letters, etc) were retrieved. The top productive countries in the field of chemistry are identified and the standing of these countries in the field of electrochemistry are compared. All countries that have contributed at least one item in any of these core journals are listed along with the number of papers published and the ranks they hold.; international co-authorship matrix among the top productive countries is provided; individual institutions all over the world which contribute significantly during this period are listed; the authorship pattern, types of published items, and distribution range of cited references and related records are studied.*

KEYWORDS: Publication productivity; Electrochemistry; Co-authorship matrix; Cooperation index; Affinity index; Citation analysis.

INTRODUCTION

Electrochemistry is an interdisciplinary subject which deals with the inter-con-version of electrical and chemical ener-gies. The foundations of electrochemistry were laid in the late 18th century by Gal-vani and Volta. Later, electrochemical techniques and theories developed quite rapidly, especially in the hands of Ostwald and his associates. Towards the end of the 19th century, continued progress in these areas was accompanied by developments towards applications, both in the labo-ratory and industry. The 20th century witnessed increasing theoretical and tech-nical advancements in electrochemical science which ultimately led to the for-mation of the Electrochemical Society in the USA in 1902. A monthly journal, *Electrochemical Industry* was started in the same year as a publication of the Electrochemical Publishing Company. In the first half of the 20th century there were only one or two core electrochemical journals and much of electrochemical findings were reported in journals devoted to physical chemistry, general chemistry, metallurgy and

industrial chemistry. The second half of this century witnessed the birth of some core electrochemical journals.

Scientometric studies on specific sub-fields are of recent origin. A notable one is on materials science in India (Aruna-chalam, 1996). Beaven and Rosen (1979) carried out a study on co-authorship and research productivity. Arunachalam (1994) has also given extensive data on co-authorship for a number of countries including the G7, OECD and Asian giants. This paper attempts to study co-author-ship pattern and top ranking institutions in the field of electrochemical research based on the publications which appeared in five core journals. Currently, electrochemical literature is widely scattered in journals of different disciplines.

DEFINITION

Core journals – If all or most of the papers published in a journal belong to a particular discipline, that journal is con-sidered as a core journal of that discipline.

METHODOLOGY

Chemistry Citation Index (CCI) of the Institute for Scientific Information (ISI) is the first comprehensive citation database (with bibliographic details) of the most recently published research findings in the field of chemistry with abstracts in CD-ROM. *CCI* covers every substantive item which include articles, reviews and letters published in all major international jour-nals in the field of chemistry. This is also supplemented with items selected from over 7,000 other journals. Each year about 140,000 items are covered. In this study, we consider all the published items which appeared in five core electroche-mical journals, viz. *Journal of the Electrochemical Society (JES)* from USA; *Journal of Electroanalytical Chemistry, Interfacial Electrochemistry (JEI)* and *Journal of Power Sources (JPS)* from Switzerland; *Electrochinica Acta (ECA*) and *Jounal of Applied Electrochemistry (JAE)* from the UK.

All the 4,020 items, (hereafter the terms 'records' or 'papers' will also be used instead of the term 'item' in the text) that have been published in these journals and covered in the CD-ROM database of *CCI* of 1991 and 1992 are downloaded and put into Foxpro as a master datafile. A few additional data elements are also included in each record. These records (otherwise known as source items) are subjected to analysis using an in-house software, resul-ting in a number of intermediary datafiles which are ultimately used for examining the data from different viewpoints.

ANALYSIS

The top twelve countries in terms of productivity in the field of chemistry are identified, using the address field search in *CCI* and the ranking of these countries are compared with that of electrochemistry (Table 1). In both subject fields, the USA and Japan occupy the first two positions. The rank of other countries varies from slight to significant. The variations in the productivity of each country is reflected in percentage share rather than rank. The notable variations in the fields of che- mistry and electrochemistry are the former Soviet Union (USSR) with 10.4% and 3.0%, France with 6.9% and 10.5% and Canada

with 3.7% and 6.5% respectively. The poor show of the former Soviet Union in the field of electrochemistry may be attributed to the non-inclusion of papers which appear in *Soviet Electrochemistry*, the Soviet Russia's national core electro-chemical journal. The performance of France and Canada in the field of elec-trochemistry is noteworthy. It is noted that although a large number of India's papers appear in her three national core electro-chemical journals, viz. *Bulletin of Elec-trochemistry*, *Journal of the Electro-chemical Society of India* and *Transac-tions of the SAEST* have not been included in this study, India's share at 3.2% is satis-factory. Two Asian giants, India and China (excluding Japan) jointly account for 7.3% in chemistry and 7.6% in electro-chemistry. One notable point here is that the list (of top twelve productive coun-tries) is the same for both the fields of chemistry and electrochemistry.

Table 2 lists 57 countries which have con-tributed at least one paper to the core journals, with data indicating the total number of papers and international co-authorship links. The figures for total number of papers are based on all-author counts, i.e. if a paper is authored by persons from different countries, each country is credited with one paper. The grand total arrived at is 4,504 as against 4,020 which is the total number of papers analysed in this study. Of the 57 countries, ten have no international co-authorship links/papers. A total of 56 records do not have addresses in the database.

Table 1: Comparison of Performance of the Top Ranking Countries in the Field of Chemistry and Electrochemistry

Chemistry				Electrochemistry		
Country	Rank	Papers	%	Rank	Papers	%
USA	1	75549	34.3	1	1127	32.8
Japan	2	27057	12.3	2	484	14.1
USSR	3	22992	10.4	11	104	3.0
Germany	4	22090	10.0	4	282	8.2
UK	5	15611	7.1	6	222	6.5
France	6	15140	6.9	3	359	10.5
India	7	8298	3.8	10	110	3.2
Canada	8	8194	3.7	5	223	6.5
Italy	9	8134	3.7	8	141	4.1
Spain	10	6738	3.1	7	148	4.3
China	11	5767	2.6	9	137	3.9
Poland	12	4615	2.1	12	97	2.8
		220185	100.0		3434	100.0

Note: The total number of papers from the top 12 countries is considered as 100% for this comparison

Table 2: World Contribution to Electrochemistry

Rank	Country	x	y	Rank	Country	x	y
1	USA	1127	135	30	Denmark	20	4
2	Japan	484	31	30	Finland	20	10
3	France	359	96	32	Norway	19	4
4	Germany	282	77	33	Egypt	17	0
5	Canada	223	44	34	Croatia	12	4
6	UK	222	57	34	Singapore	12	3
7	Spain	148	53	36	South Africa	11	3
8	Italy	141	53	37	Austria	10	5
9	China	137	23	37	Chile	10	0
10	India	110	15	39	Hong Kong	9	3
11	USSR	104	19	39	Mexico	9	4
12	Poland	97	28	41	New Zealand	8	0
13	Australia	76	18	42	Romania	6	4
14	Netherlands	72	15	42	Turkey	6	1
15	Brazil	67	27	44	Algeria	5	3
16	Argentina	57	22	44	Morocco	5	4
17	Bulgaria	56	19	46	Venezuela	4	0
18	Sweden	55	17	47	Malaysia	2	0
19	Greece	53	12	47	Saudi Arabia	2	2
20	Switzerland	50	10	47	Somalia	2	2
21	Taiwan	49	5	50	Albania	1	1
22	Belgium	47	14	50	Bangladesh	1	0
23	Yugoslavia	45	15	50	Indonesia	1	1
24	Czechoslovakia	41	16	50	Iraq	1	0
25	South Korea	35	10	50	Jamaica	1	0
26	Israel	34	9	50	Luxembourg	1	0
27	Hungary	33	9	50	Peru	1	1
28	Ireland	25	6	50	Philippines	1	0
29	Portugal	22	14	--	Blank records(z)	56	--
					TOTAL	4504	928

Note:
x denotes total number of papers
y denotes total number of international co-authorship links, if a paper has 3 authors from 3 different countries, each country is credited and hence the number 928 is the total links and not total co-authorship papers.
z records do not have addresses

Table 3 is the international co-authorship matrix among the top twelve countries. The cooperation index (Schubert and Braun, 1990) is used to measure the

cooperation between countries. The formula used for the index is:

Rik = nik / (nink) ½ where;

Rik is the Co-authored index between countries i and k and nik is the number of internationally co-authored papers of countries i and k and ni and nk are the total number of papers by countries i and k respectively. A higher co-authorship index points to higher co-authorship strength between the pair. The USA and Germany have internationally co-authored papers with every other country in the matrix. Japan scores low on the co-authorship index but comparatively higher then China and India, even though it occupies second in rank in terms of productivity. India and China did not indicate a single co-authorship paper. The index indicates that the two Asian giants (being the top two populous countries and geographically adjacent) do not have links among their scientists.

Table 3: International Co-authorship Matrix Among the Top 12 Ranked Countries

	USA	JPN	SUN	DEU	UKD	FRA	IND	CAN	ITA	ESP	PRC	POL
USA	-	6.8	5.8	23.1	12.0	14.2	8.5	27.9	15.1	19.6	5.1	18.1
JPN	6.8	-	4.5	5.4	6.1	4.8	13.0	6.1	0.0	0.0	19.4	0.0
SUN	5.8	4.5	-	11.7	0.0	5.2	0.0	0.0	24.8	0.0	0.0	19.9
DEU	23.1	5.4	11.7	-	8.0	18.9	17.0	11.9	20.1	24.5	5.1	54.4
UKD	12.0	6.1	0.0	8.0	-	21.3	12.8	0.0	16.9	5.5	22.9	0.0
FRA	14.2	4.8	5.2	18.9	21.3	-	10.1	17.7	40.0	69.4	0.0	10.7
IND	8.5	13.0	0.0	17.0	12.8	10.1	-	19.2	8.0	0.0	0.0	0.0
CAN	27.9	6.1	0.0	11.9	0.0	17.7	19.2	-	16.9	0.0	17.2	34.0
ITA	15.1	0.0	24.8	20.1	16.9	40.0	8,0	16.9	-	13.8	14.4	25.7
ESP	19.6	0.0	0.0	24.5	5.5	69.4	0.0	0.0	13.8	-	7.0	8.3
PRC	5.1	19.4	0.0	5.1	22.9	0.0	0.0	17.2	14.4	7.0	-	0.0
POL	18.1	0.0	19.9	54.4	0.0	10.7	0.0	34.0	25.7	8.3	0.0	-

Note: The co-authorship matrix is multiplied by 1000 for easy comparison

USA = United States
JPN = Japan
SUN = USSR
DEU = Germany
UKD = United Kingdom
FRA = France
IND = India
CAN = Canada
ITA = Italy
ESP = Spain
PRC = China
POL = Poland

Figure 1 shows the degree of affinity of one country towards the other in terms of co-authorship. The co-authorship

Figure 1: Affinity Index: Country A Towards Country B

Country A	Country B	Aff.Index
USA ->	CAN	11.5%
CAN ->	USA	46.67%
JPN ->	PRC	19.23%
PRC ->	JPN	27.78%
SUN ->	ITA	18.75%
ITA ->	SUN	6.00%
DEU ->	POL	13.24%
POL ->	DEU	47.37%
UKD ->	PRC	7.55%
PRC ->	UKD	21.05%
FRA ->	ESP	20.00%
ESP ->	FRA	43.24%
IND ->	CAN	25.00%
CAN ->	IND	7.32%
CAN ->	POL	12.82%
POL ->	CAN	21.74%
ITA ->	FRA	20.45%
FRA ->	ITA	10.34%

index indicates only the co-authorship strength between two countries and does not point out which one is the sought after country among the co-authorship pair. The affinity index of one country towards the other and vice versa explicitly points out this. The affinity index of a country (A) towards another (B) is calculated using the formula (Okubo et al, 1992);

$$\frac{\text{No of links between A and B} \times 100}{\text{No. of links between A and the rest of the world}}$$

In this study 'rest of the world' means the remaining eleven countries in the constant set of the top 12 countries. A higher affinity index indicates that the first country seeks the latter's cooperation. While the co-authorship strength between the USA and Canada is strong, it is Canada who seeks the co-authorship. In the case of co-authorship pattern between India and Canada, it is India who seeks Canada. Similarly, the affinity index between Poland and Germany; Spain and France indicate Poland and Spain as the seeking country for co-authorship.

Tables 4a and 4b list the top ranking institutions in terms of the total number of items published and the number of internationally co-authored papers, respectively. CNRS (which represents a group of laboratories) and the University of Paris in France tops this list. Electrochemical research is concentrated in France in these two institutions. Among the developing countries, Central Electrochemical Research Institute in India is the single largest contributing institution, which has 53 papers to its credit. In the USA and Japan, research in electrochemistry is not concentrated in a few institutions. The University of Texas (USA) has 58 papers (rank 3rd) and Central Electrochemical Research Institute (India) has 53 papers (rank 5th). However, both USA and India are not placed on the list of institutions having at least 5 co-authorship papers. The University of Autonoma Madrid (Spain) has 16 co-authorship papers out of a total of 21 and the University of Belgrade, Yugoslavia has 10 co-authorship papers out of a total of 33. The University of Alicente, Spain and the University of Rome, Italy holds the 8th and 9th

ranks respectively in the list of international co-authorship papers eventhough are not placed on the list of top productive institutions, indicating that the two universities mostly publish co-authored papers. Among the private institutions, IBM Corporation (USA) has 48 co-authored papers published (rank 8th).

Table 4a: List of Institutions Arranged by Total Number of Papers

Institutions	Total	Institutions	Total
University of Paris, France	78	University of Barcelona, Spain	29
CNRS, France	75	Kyoto University, Japan	27
University of Texas, USA	58	Lawrence Berkeley Lab, USA	27
Texas A & M University, USA	56	Univ-Rome-La Sapienza, Italy	27
Central Electrochemical Research Institute, India	53	Royal Institute of Technology, Sweden	27
Bulgarian Academy of Sciences	50	USN, USA	27
University of Southampton, UK	49	Czechoslovak Academy of Sciences	25
IBM Corporation, USA	48	University of Sao Paulo, Brazil	24
CNR, Italy	40	University of Sherbrooke, Canada	24
University of Calif., Berkeley,USA	40	Yamaguchi University, Japan	24
University of Ottawa, Canada	38	CSIRO, Australia	23
AT & T Bell Lab, USA	37	General Motors Corporation, USA	23
Tohoku University, Japan	33	Hahn Meitner Inst Kernforsch Berlin Gmbh, Germany	23
University of Belgrade, Yugoslavia	33	University of Oxford, England	23
Hokkaido University, Japan	32	University of Waterloo, Canada	23
North Carolina State University, USA	32	University of Utrecht, Netherlands	22
University of Illinois, USA	32	University of Autonoma Madrid, Spain	21
Case Western Reserve University, USA	31	University of New Castle Upon Tyne, England	21
Tokyo Institute of Technology, Japan	30	Motorola Inc, USA	20
University of Warsaw, Poland	30	Pennsylavania State University, USA	20
Acad Sinica, Peoples Republic of China	29	University of North Carolina, USA	20
		University of Tokyo, Japan	20

Twenty papers is the threshold for inclusion in this list of institutions

Table 4b: List of Institutions arranged by Total Number of Internationally Co-authored Papers

Institutions	Total	Institutions	Total

CNRS, France	40	University of Cordoba, Spain	7
University of Paris, France	19	University of Ottawa, Canada	7
CNR, Italy	18	University Sao Paulo, Brazil	7
Bulgarian Academy of Sciences, Bulgaria	17	Case Western University, USA	6
University of Autonoma Marid, Spain	16	Lawrence Berkeley Lab, USA	6
University of Southampton, England	15	National University of Plata, Argentina	6
University of Alicante, Spain	12	Rudjer Boskovic Institute, Croatia	6
University of Rome, Italy	12	University of Barcelona, Spain	6
University of Belgrade, Yugoslavia	10	University of Karlshruhe, Germany	6
University of Milan, Italy	9	University of Laguna, Spain	6
University of Poitiers, France	9	University of Munster, Germany	6
University of Waterloo, Canada	9	University of New Mexico, USA	6
Aristotelian University of Tehessaloniki, Greece	8	University of Utrecht, Netherlands	6
CSIRO, Australia	8	Cornell University, USA	5
Royal Institute of Technology, Sweden	8	Max Planck Gesell, Germany	5
Texas A & M University System, USA	8	Pusan National University, South Korea	5
University of Warsaw, Poland	8	University of Coimbra, Portugal	5
Czechoslovak Academy of Sciences, Czechoslovakia	7	University of Minnesota, USA	5
Helsinki University of Technology, Finland	7	University of North Carolina, USA	5
North Carolina State University, USA	7	University of ULM, Germany	5

Five papers is the threshold for inclusion in this list of institutions.

Table 5 is the distribution pattern of published items by type of publications. 'Article' dominates, followed by 'Notes" 'Letters'. Review papers constitute less than 1% (26) of items published. Japan contributed 1 review paper and the USA 15. Table 6 depicts the authorship pattern. The moving average method shows that concentration is on two-authored and three–authored papers (58%). The data for the years 1992 and 1993 were checked separately but this pattern still holds irres-

Table 5: Distribution of Type of Published Items

Type	Items	
	No	%

Article	3479	86.5
Note	307	7.6
Letter	133	3.3
Correction	38	0.9
Review	26	0.7
Editorial	19	0.5
Bibliography	14	0.4
Discussion	4	0.1
Total	4020	100.0

Table 6: Authorship Pattern

No of Authors	Papers No	%
1	411	10.2
2	1269	31.6
3	1119	27.8
4	659	16.4
5	328	8.2
6	131	3.3
7	55	1.4
8	31	0.8
9	7	0.2
10	4	0.1
>10	4	0.1
Total	4020	100.0

Authors per paper is 3.00

pective of the year. The authorship per paper is 3 which is lower than the world standard of 3.26 in the year 1988 (ISI, 1989).

Table 7 gives the distribution range of cited references which showed an average of 22.0 papers. Nearly 48% of the papers have more than 20 references.

Table 8 provides the statistics on 'related records' within the database for the 4020 items covered in this study. This is a new field available from this CCI database (no database offers this 'related records' facility except the citation databases from ISI) create links between related items using cited references. If two papers (known as records in a database) have at least one common cited reference, then these records are assumed to be related records. About 45% of papers have at least 20 related records. This indicates the inter-disciplinary nature of the subject electrochemistry.

CONCLUSION

The world publication distribution in electrochemical research in terms of papers published in journals is more or less similar to that of chemical research. The USA tops the productivity list, followed by Japan. The co-authorship strength of Spain with France and Poland with Germany are significant. Japan, the second largest contributing country, seldom goes for co-authorship or sought-after for co-authorship. Next to the USA, Germany is the most sought-after country for co-

Table 7: Distribution of Cited References

Range of Cited References	Total	%	Cumulative Total	%
0 - < 5	227	5.7	227	5.7
5 - < 10	458	11.4	685	17.1
10 - < 15	691	17.2	1376	34.3

15 - < 20	723	18.0	2099	52.3
20 - < 25	564	14.0	2663	66.3
25 - < 30	448	11.1	3111	77.4
30 - < 35	314	7.8	3425	85.2
35 - < 40	194	4.8	3619	90.0
40 - < 45	115	2.9	3734	92.9
45 - < 50	96	2.4	3830	95.3
50 - < 55	59	1.5	3889	96.8
55 - < 60	42	1.0	3931	97.8
60 - < 65	40	1.0	4020	100.0
Total	4020	100.0		

Table 8: Distribution of Related Records

Range of Related Records	Papers No	%
0 - < 5	576	14.3
5 - < 10	508	12.6
10 - < 15	591	14.7
15 - < 20	541	14.5
>= 20	1804	44.9
Total	4020	100.0

authorship. The strength of co-authorship both for India and China are very poor. The first two top ranking institutions for co-authorship are from France, viz. CNRS and the University of Paris. These two are also the top productive institutions. Next to 'Articles', 'Notes' is the most used type of published item. Nearly 60% of the papers are two-authored and three-authored. The citation average per paper is 22.0. The interdisciplinary nature of electrochemistry is more evident from the fact that more than 45% of the total papers published in 5 core electrochemistry journals have at least 20 related papers as indicated in the *CCI* database.

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