Scientometric analysis of chemical engineering publications

*Jayant M. Modak and Giridhar Madras**

The objective of this work was to analyse the scientometric parameters for chemical engineering publications. We have compared the number of journal publications and citations by various countries and institutions. The publication record in terms of quantitative aspects of the number of publications from China has increased exponentially over the last decade and has overtaken USA. However, the citation analysis indicates that there is ample scope for improvement. Thus, USA continues to maintain its leadership position with regard to impact in the field. Analysis of the output of selected Indian universities/organizations against that of the top universities in the world, indicated that the records of top institutions from India are not comparable to the best universities in USA, but are comparable to the best in Asia and are significantly better than the best universities in China.

Keywords: Chemical engineering, citations, publications, scientometric analysis.

ACCORDING to the American Chemistry Council, over a quarter of the jobs today in the United States depend in one way or another on chemistry, with over US $400 billion of products that rely on innovations from chemical engineering[1]. The nascent concept of chemical engineering was initially proposed[2] on the concept of 'unit operations' by stating that 'Chemical engineering . . . is not a composite of chemistry and mechanical engineering, but a science of itself, the basis of which is those unit operations which in their proper sequence and co-ordination constitute a chemical process as conducted on the industrial scale'. Chemical engineers have been particularly effective at leading these innovations, because they have been trained to think at a large spectrum of spatial and temporal scales, from the molecular level to the process level. Thus, chemical engineering has continued to provide fresh and creative insights and breakthroughs[3] as technologies have moved from the micro/macroscopic to nanoscales. Chemical engineering graduates are the highest paid engineers in many countries[3] and thus constitute an important facet of the scientific community.

The objectives of this article are to compare the number of journal publications and analysis of the citations to measure the quality of research and its impact, published by various countries and institutions. To achieve these objectives, this study has been divided into four sections. In the first section, we examine the chemical engineering publication record of various countries. In the second section, we compare the output of various international universities and discuss how they have changed over the years. The third section focuses on the quality of publications originating from India, China and USA. The final section compares the output of selected Indian universities/organizations against that of the top universities in the world.

Several other departments like applied chemistry, mechanical engineering, etc. also publish in chemical engineering journals. However, this analysis does not examine which departments publish in chemical engineering journals, but analyses the publications from chemical engineering departments in all journals. The analysis was carried out by searching the ISI Web of Science (which covers the publications and citations from 1945) with the requirement that at least one of the authors has an affiliation 'Chemical Engineering' in the address field (AD = Chem Engn). We considered two five-year periods: 1990–94 and 2000–04 in order to understand the evolving nature of chemical engineering research. Furthermore, the analysis was also done for 2006 to obtain the current trends. Once the data for a particular year or time period are gathered, they are further analysed for different fields provided by the ISI Web of Science.

International publications profile

Table 1 gives the number of journal publications from the top ten countries sorted based on the 1990–94 data. The annual profiles of total publications as well as those of USA, China and India are shown separately in Figure 1.

Jayant M. Modak and Giridhar Madras are in the Department of Chemical Engineering, Indian Institute of Science, Bangalore 560 012, India. *For correspondence. (e-mail: giridhar@chemeng.iisc.ernet.in)

Table 1. Number of publications from various countries

Country	1990–94		2000–04		2006		Ratio[a]
Total	33,835		70,431		19,613		2.08
USA	17,466	51.62%	25,819	36.66%	5188	26.45%	1.48
Japan	3252	9.61%	5381	7.64%	1145	5.84%	1.65
Canada	2620	7.74%	3113	4.42%	934	4.76%	1.19
United Kingdom[b]	1978	5.85%	3779	5.37%	920	4.69%	1.88
Taiwan	1507	4.45%	4326	6.14%	1112	5.67%	2.87
India	1009	2.98%	2000	2.84%	715	3.65%	1.98
Australia	768	2.27%	1893	2.69%	408	2.08%	2.46
South Korea	756	2.23%	6261	8.89%	1469	7.49%	8.28
China	692	2.05%	10,473	14.87%	5923	30.2%	15.13

[a]Ratio of number of publications in 2000–04 and 1990–94.
[b]Includes England, Scotland, Northern Ireland and Wales.

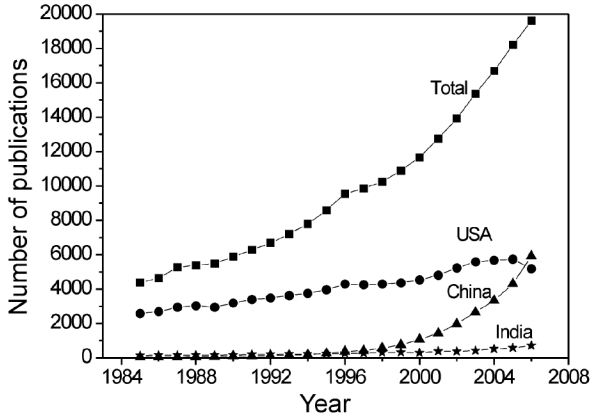

Figure 1. Increase in the number of publications during the period 1987–2006.

It is interesting to note that the top ten country-wise contributors to the chemical engineering field have remained the same during the period 1990–2006, but the order has changed significantly. The number of publications in the field of chemical engineering has increased by a ratio of 2.08 between time periods 1990–94 and 2000–04. During these time periods USA has maintained its top position, but its contribution as a percentage of total publications reduced from 52 to 37. During the same time period, South Korea (8.28) and China (15.13) have significantly increased their number of publications (Table 1). India has nearly doubled its number of publications in line with the overall increase in the number of publications in chemical engineering. The numbers also clearly indicate that in 1990–94, Asian countries (Japan, China, South Korea, Taiwan and India) had less than 25% of the total number of publications, but in 2000–04, Asia contributed the majority (52%) of the total number of publications.

The annual publication profile given in Figure 1 clearly shows that the rate of increase in publications from China is far greater than that of USA, particularly from 1998 onwards, which culminated into China alone publishing more papers than USA in 2006. China alone contributed to nearly 30% of publications in chemical engineering in 2006. The contribution from Asia exceeds 50% of the total number of publications. In quantitative terms alone this is an impressive growth, but in terms of impact of these publications, as we shall see later, there is ample scope for improvement.

Publication profiles of various universities

A complete list of the top 100 universities in the world based on publications in 2006 is given in the Appendix (Table A1). It also provides a comparative performance in the time periods under study. A short summary of the top ten universities is given in Table 2.

Table 2 shows that the top four slots are occupied by the Chinese universities, with Tsing Hua University ranked first in 2006. This has been the most recognized Chinese university worldwide for a long time, and has been consistent in maintaining its publication record. Tianjin University dramatically improved its publication record from 47 papers in 1990–94 to 460 in 2006 alone. The same trend is observed for the other two Chinese universities. The US universities like MIT, Caltech and Texas had increased their publication output by around 20–30% from 1990–94 to 2000–04, but dropped in the rankings due to the meteoric rise of the Chinese universities. For the period 1990–94, the top 20 universities had published 315 or more papers, while in 2000–04 they had published 627 papers or more. However, the top 20 in 1990–94 had only three Asian universities, while this has increased to nine in 2000–04. Thus, nearly 50% of the top universities in the world are Asian, which is consistent with our analysis earlier in the article. For the period 2000–04, no single Indian university appears in the list of the top 75 universities in the world, but Mumbai University Indian Chemical Technology (MUICT, previously known as UDCT;

Table 2. Publication profiles of the top ten universities

University	1990–94		2000–04		2006	
	Publications	Rank	Publications	Rank	Publications	Rank
National Tsing Hua University	425	9	1486	1	495	1
Tianjin University	47	199	860	8	460	2
Chinese Academy of Sciences	20	320	941	6	437	3
Nanjing University	20	320	428	48	332	4
Massachusetts Institute of Technology (MIT)	915	2	1200	3	283	5
University of Texas	603	4	852	9	273	6
Zhejiang University	35	238	524	30	258	7
California Institute of Technology	791	3	1222	2	253	8
University of Minnesota	1141	1	1078	5	245	9
National Taiwan University	235	34	881	7	239	10

Table 3. Publications in *Science*, *Nature* and *PNAS* from various countries

	1990–94	2000–04	2006
Science			
Total	62	99	19
USA	59	93	18
China	0	1	0
India	0	0	0
Nature			
Total	40	54	18
USA	33	48	13
China	0	1	0
India	1	0	0
PNAS			
Total	46	129	57
USA	46	125	52
China	0	2	2
India	0	1	1

Table 4. Publications in the top three chemical engineering journals from various countries

	1990–94	2000–04	2006
AIChE Journal			
Total	716 (1067)	764 (1376)	201 (425)
USA	523	465	85
China	4	37	20
India	24	35	14
Chemical Engineering Science			
Total	1182 (2160)	1387 (2665)	295 (726)
USA	483	410	68
China	13	83	17
India	63	91	26
Industrial and Engineering Chemistry Research			
Total*	1155 (2054)	2005 (3971)	475 (1099)
USA	634	909	160
China	9	115	47
India	64	86	49

*Figures in brackets refer to the total number of publications in the journal (all affiliations).

Table A1) appears in the top 100 universities. However, if the intensive parameter, namely the number of publications per faculty per year is used as the criterion for ranking, then two Indian institutes, namely Indian Institute of Science (IISc), Bangalore and MUICT appear in the list of the top 50 universities of the world. The publication profile of top Indian institutions/organizations is given in the Appendix (Table A2).

Quality of publications

The quantitative data presented earlier in the article clearly show that the number of publications from China exceeded that from USA in 2006. Another equally important aspect that needs to be examined is the quality of these publications. We have chosen two different indicators for this: (i) quality of the journals in which the papers are published, and (ii) the number of citations.

The quality of journals in which papers are published is assessed for two broad categories: (a) the publications which are conventionally accepted as top journals for research in any area, namely *Science*, *Nature* and *Proceedings of the National Academy of Sciences, USA* (*PNAS*) and (b) the top three journals that publish general research in chemical engineering, namely, *AIChE Journal*, *Chemical Engineering Science*, and *Industrial and Engineering Chemistry Research* (*I&EC Research*). It should be pointed out that publications with at least one of the authors having 'Chemical Engineering' affiliation are considered for both categories.

Table 3 shows that the number of publications from USA in *Science*, *Nature* and *PNAS* is more than 90% of the total, thereby indicating the dominance of USA in the field. In contrast, contributions from India and China are almost nil.

Table 4 shows that the contribution from USA in *AIChE Journal*, *Chemical Engineering Science* and *I&EC Research* put together has decreased from 53% in 1990–94 to 43% in 2000–04. It further decreased to 32% in

Table 5. List of journals with number of publications (*P*) for the period 2000–04 from USA, China and India and impact factor (IF) of the journals in 2005

USA			China			India		
Journal	IF	*P*	Journal	IF	*P*	Journal	IF	*P*
Ind Eng Chem Res	1.504	909	*Chem J Chinese U*	0.771	406	*Chem Eng Sci*	1.735	91
Langmuir	3.705	834	*Chinese J Chem Eng*	0.34	295	*Ind Eng Chem Res*	1.504	86
Macromolecules	4.024	745	*J Appl Polym Sci*	1.072	282	*J Appl Polym Sci*	1.072	64
J Phys Chem B	4.033	617	*Acta Chim Sinica*	0.845	251	*Indian J Chem Techn*	0.226	48
J Chem Phys	3.138	564	*Acta Crystallogr E*	0.581	241	*Chem Eng J*	2.034	43
AICHe J	2.036	465	*Chinese J Anal Chem*	0.397	224	*Can J Chem Eng*	0.574	39
Chem Eng Sci	1.735	410	*Chinese J Inorg Chem*	0.697	218	*J Mol Catal A-Chem*	2.348	37
J Am Chem Soc	7.419	392	*Chinese Chem Lett*	0.355	214	*AIChE J*	2.036	35
J Electrochem Soc	2.19	364	*Acta Phys-Chim Sin*	0.427	204	*Langmuir*	3.705	35
Biotechnol Bioeng	2.483	323	*Acta Polym Sin*	0.414	187	*Bioproc Biosyst Eng*	0.807	32
Polymer	2.849	316	*Chinese J Org Chem*	0.81	178	*Appl Catal A-Gen*	2.728	29
J Appl Polym Sci	1.072	310	*Spectrosc Spect Anal*	0.557	178	*Biochem Eng J*	1.781	28
Comput Chem Eng	1.501	294	*Chinese J Catal*	0.665	163	*J Membrane Sci*	2.654	27
J Colloid Interf Sci	2.023	281	*Chinese J Chem*	0.819	140	*Sep Purif Technol*	1.752	26
J Catal	4.78	275	*T Nonferr Metal Soc*	0.302	117	*Chem Eng Commun*	0.397	25
Weighted average IF	3.01			0.62			1.62	
Average IF	2.69			0.60			1.69	

Table 6. Citation analysis of journal publications from USA, China and India

	2000				2002				2004			
	P	*C*	*C/P*	*h*	*P*	*C*	*C/P*	*h*	*P*	*C*	*C/P*	*h*
USA	4527	81642	18.0	103	5231	71860	13.7	92	5674	47656	8.4	69
China	1073	7703	7.2	36	1977	12510	6.3	42	3332	14567	4.4	41
India	287	2825	9.9	26	380	3046	8.0	26	526	2745	5.2	21

P, *C* and *C*/*P* represent the total number of publications, citations for these publications and citation per publication respectively. *h* represents the *h*-index.

2006. In case of China, the percentage contribution in these journals increased from 0.8 in 1990–94 to 5.7 in 2000–04, and further increased to 8.6 in 2006. In the case of India, the percentage contribution was almost the same (5%) in the time periods 1990–94 and 2000–04. It increased to 9.2% in 2006.

A detailed analysis of the top 15 journals in terms of the number of publications from USA, China and India for the period 2000–04 is shown in Table 5. The number of publications in these top 15 journals is approximately one-third of the total for each country. The impact factor (IF) of the journals has been taken from the Journal Citation Report (JCR) published by ISI Web of Science for the year 2005. The low impact factor observed for China is primarily due to the large number of publications in Chinese journals. This is in contrast to India, wherein only one journal in the top 15 is published from India. For India, six journals are common with USA, while only two are common between USA and China.

In order to examine the second quality indicator, namely citations per publication, we chose publications in 2000, 2002 and 2004. A similar analysis for a five-year period was not done because ISI Web of Science does not permit citation analysis for more than 10,000 publications. Table 6 shows the number of publications in a particular year, number of citations for these publications as on 14 November 2007 and the average citations per paper. It can be seen that the average citations per paper published from USA is nearly twice that of China or India for the corresponding years. It is also clear that the publications from India, though smaller in number, have higher number of citations per publication compared to China. However, the *h*-index of China is higher than that of India (Table 6), indicating that though the average quality of papers from China (based on *C*/*P*) is lesser than that of India, the number of highly cited papers (based on *h*-index) is higher than that of India. The quality indicators, namely the number of publications in top journals as well as citation analysis, clearly point to the dominance of USA. In case of China, a significant improvement in quantity is not reflected in the quality indicators.

Comparison of Indian universities with international universities

We now assess the performance of Indian universities/ organizations with a few universities across the world

Table 7. Citation analysis for select universities during the period of 2000–04

	P	*C*	*h*-index	*F*	PFY	CFY
India						
IISc	212	1707	21	10	4.24	34.14
IIT-M	121	476	11	21	1.15	4.53
IIT-K	169	1701	20	17	1.99	20.01
IIT-KGP	103	564	13	22	0.94	5.13
IIT-B	159	1329	16	28	1.14	9.49
IIT-D	78	463	11	17	0.92	5.45
NCL*	244	2477	23	–	–	–
IICT*	70	457	12	–	–	–
Jadavpur University	58	361	11	26	0.45	2.78
MUICT	277	2074	20	14	3.96	29.63
Anna University	131	588	11	20	1.31	5.88
USA						
MIT	1200	22734	69	37	6.49	122.89
University of Minnesota	1078	18746	59	42	5.13	89.27
Purdue University	435	6310	37	35	2.49	36.06
Pennsylvania State University	457	5124	34	27	3.39	37.96
Michigan State University	261	2379	24	26	2.01	18.30
Ohio State University	316	2863	24	22	2.87	26.03
Asia						
NUS, Singapore	727	8268	35	43	4.15	47.25
Tsing Hua University, China	1486	10857	37	65	4.57	33.41
Seoul National University, South Korea	1106	12521	44	35	6.32	71.55
National Taiwan University, Taiwan	881	6526	28	37	4.76	35.28
Tianjin University, China	860	3615	20	52	3.31	13.90
Kyushu University	459	2938	24	27	3.39	21.76

*Number of researchers (*F*) in NCL/IICT was not available. *P* and *C* represent total number of publications and citations for these publications. *F* is the number of faculty. PFY denotes publications per faculty per year and CFY represents citations per faculty per year.

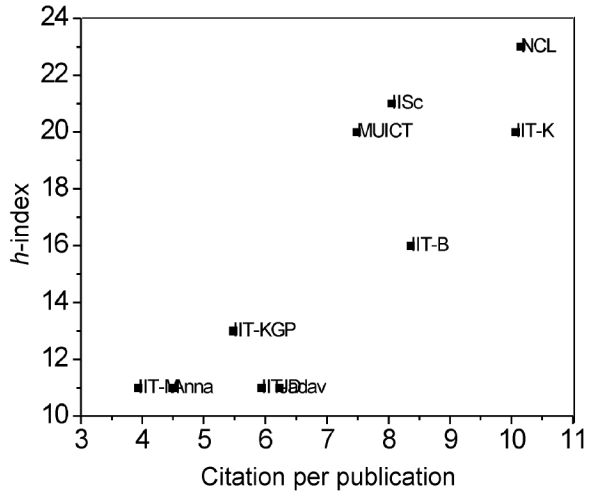

Figure 2. Variation of citations per publication with *h*-index for Indian institutions.

based on the publication record for the period 2000–04. The choice of these universities was based on the number of publications during that period. (i) In the case of India, the top ten universities have been chosen. (ii) For Asia, we have chosen the top two Chinese universities and one top university each from Singapore, South Korea, Taiwan and Japan. (iii) In the case of USA, we have chosen two universities from the top five (MIT and Minnesota), two universities ranked between 40 and 50 (Purdue and Penn State) and two universities ranked between 90 and 100 (Michigan State and Ohio State).

The number of faculty listed in Table 7 has been taken from the world-wide chemical engineering faculty directory[4]. For Chinese universities, the number of faculty has been taken from the websites of the respective organizations. The data in Table 7 show that only three institutions, namely IISc, MUICT, IIT-K, and one organization (NCL) have two or more publications per faculty per year (PFY). In terms of citations, the same four institutions have more than 20 citations per faculty per year (CFY). Among the IITs, the record for Kanpur is the best considering all the parameters. The records of top institutions from India (IISc and MUICT) are poor compared to those of MIT and Minnesota in terms of both PFY and CFY. However, it is better than Purdue and Penn State in terms of PFY and comparable in terms of CFY. Based on the data in Table 7, Figure 2 shows the variation of *h* and *C/P* for Indian institutions.

Table A1. List of the top 100 universities in terms of research publications in 2006 and their position in 1990–94 and 2000–04

University	1990–94		2000–04		2006	
	Publications	Rank	Publications	Rank	Publications	Rank
Natl Tsing Hua Univ	425	9	1486	1	495	1
Tianjin Univ	47	199	860	8	460	2
Chinese Acad Sci	20	320	941	6	437	3
Nanjing Univ	20	320	428	48	332	4
Indian Inst Technol (all 7 IITS put together)	465	7	652	17	303	5
MIT	915	2	1200	3	283	6
Univ Texas	603	4	852	9	273	7
Zhejiang Univ	35	238	524	30	258	8
Caltech	791	3	1222	2	253	9
Univ Minnesota	1141	1	1078	5	245	10
Natl Taiwan Univ	235	34	881	7	239	11
Kyushu Univ	186	57	459	41	205	12
Natl Cheng Kung Univ	279	28	735	11	202	13
Hunan Univ	104	116	496	34	201	14
Lund Univ	39	218	627	20	194	15
Univ Calif Berkeley	501	6	806	10	188	16
Shandong Univ	#N/A	#N/A	362	60	187	17
Hanyang Univ	17	357	642	18	182	18
Suzhou Univ	#N/A	#N/A	350	64	176	19
Lanzhou Univ	#N/A	#N/A	328	69	173	20
Univ Calif Davis	225	37	704	14	169	21
Univ Michigan	325	18	628	19	169	22
Xiamen Univ	#N/A	#N/A	160	167	169	22
Sun Yat Sen Univ	#N/A	#N/A	212	119	165	22
Univ Toronto	436	8	473	40	162	25
Natl Tech Univ Athens	210	47	718	13	158	26
Dalian Univ Technol	36	232	335	66	156	27
Univ London Imperial Coll Sci Technol & Med	160	71	671	16	155	28
Pohang Univ Sci & Technol	69	151	511	31	152	29
Seoul Natl Univ	79	141	1106	3	147	30
Princeton Univ	341	17	581	24	137	31
Univ Manchester	169	66	104	235	133	32
Carnegie Mellon Univ	260	31	549	28	131	33
Texas A&M Univ	41	211	365	57	128	34
Univ Florida	183	59	507	32	127	35
Shanghai Jiao Tong Univ	#N/A	#N/A	237	102	126	36
Univ Calif Santa Barbara	156	77	616	21	125	37
Univ Delaware	551	5	694	15	124	39
Univ Patras	209	48	476	39	123	40
Univ Cambridge	198	52	437	44	120	41
Sichuan Univ	#N/A	#N/A	216	114	118	42
Tech Univ Denmark	143	82	420	50	115	43
Univ Waterloo	358	13	431	46	114	45
Zhejiang Univ Technol	#N/A	#N/A	136	193	114	45
Stanford Univ	343	16	562	27	113	47
Penn State Univ	309	22	457	42	110	48
Purdue Univ	376	11	435	45	107	49
Univ Washington	299	23	488	35	106	50
Eindhoven Univ Technol	82	136	266	88	105	51
Yonsei Univ	15	378	356	61	103	52
Cent S Univ Technol, China	#N/A	#N/A	188	142	103	52
Korea Univ	20	320	261	90	102	54
Univ Queensland	182	60	429	47	99	55
Hong Kong Univ Sci & Technol	#N/A	#N/A	488	35	97	56
Chungnam Natl Univ	25	282	223	111	97	56
E China Univ Sci & Technol	#N/A	#N/A	118	218	97	56
Natl Univ Singapore	216	41	727	12	93	60
Natl Taiwan Univ Sci & Technol	107	111	441	43	93	60
Univ New S Wales	214	43	427	49	93	60
INHA Univ	14	393	326	70	92	63

(*Contd*)

Table A1. (*Contd*)

University	1990–94		2000–04		2006	
	Publications	Rank	Publications	Rank	Publications	Rank
McGill Univ	263	29	310	75	91	65
Kyoto Univ	262	30	389	54	90	66
Chonbuk Natl Univ	#N/A	#N/A	197	132	89	67
Aristotle Univ Thessaloniki	#N/A	#N/A	159	170	88	69
Sungkyunkwan Univ	#N/A	#N/A	263	89	86	70
Osaka Univ	186	57	329	68	85	71
Chulalongkorn Univ	#N/A	#N/A	197	132	82	74
Chonnam Natl Univ	14	393	184	147	81	75
Univ Wisconsin	391	9	597	22	80	76
Univ S Carolina	41	211	352	62	80	76
McMaster Univ	212	46	272	85	80	76
Univ Massachusetts	216	41	410	53	79	77
Muict, India	218	40	277	84	78	79
Beijing Univ Chem Technol	#N/A	#N/A	177	153	76	83
Technion Israel Inst Technol	204	49	370	55	74	84
Michigan State Univ	118	99	261	90	74	84
S China Univ Technol	14	393	142	186	74	84
Argonne Natl Lab	35	238	139	188	74	84
IIT Kanpur	141	83	169	165	74	84
Monash Univ	81	137	211	122	73	88
Tokyo Inst Technol	315	20	366	56	72	89
Univ Zagreb	83	135	212	119	72	89
Univ Illinois	384	10	484	38	71	92
Queens Univ	136	84	202	126	71	92
Chung Yuan Christian Univ	75	145	154	177	71	92
Univ Connecticut	222	40	364	59	68	98
Univ Laval	108	110	291	82	68	98
Ecole Polytech	134	87	200	127	68	98

#N/A, Not applicable; was not ranked for that period.

Table A2. List of top Indian universities based on the number of publications

University	1990–94		2000–04		2006	
	Publications	Rank	Publications	Rank	Publications	Rank
MUICT	218	1	277	1	78	1
IIT Kanpur	141	3	169	4	74	2
IIT Kharagpur	49	7	103	8	67	3
IIT Bombay	115	5	159	5	66	4
Anna Univ	38	9	131	6	57	5
Natl Chem Lab	214	2	244	2	54	6
IIT Madras	118	4	121	7	49	7
Indian Inst Sci	61	6	212	3	44	8
IIT Delhi	46	8	78	9	34	9
Indian Inst Chem Technol	27	10	70	10	28	10
Jadavpur Univ	22	13	58	11	18	11
IIT Roorkee		#N/A	18	19	17	12
Panjab Univ	23	12	15	20	15	13
Bhabha Atom Res Ctr	6	17	41	12	13	14
Natl Inst Technol*	25	11	29	14	13	14
Andhra Univ	7	16	29	14	11	16
Alagappa Univ		#N/A	38	13	10	17
Birla Inst Technol & Sci		#N/A		#N/A	10	17
Cent Leather Res Inst		#N/A	29	14	10	17
Univ Calcutta	11	15	28	17	9	20
Banaras Hindu Univ	14	14	27	18	5	21

*All NITs put together. Previously NITs were called Regional Engineering Colleges.

Among the Asian universities, the record of Seoul National University stands out both in terms of number of publications and CFY. In fact, it is comparable to the top US universities like MIT and Minnesota. The records of the top institutions from India (IISc and MUICT), China (Tsing Hua University), Singapore (NUS) and Taiwan (National Taiwan University) are comparable in terms of PFY and CFY.

1. Chemistry is essential to living; http://www.americanchemistry.com, accessed on 1 November 2007.
2. Perkins, J. D., Chemical engineering – The first 100 years. In *Chemical Engineering: Visions of the World* (eds Dalton, R. C., Price, R. G. H. and Woods, D. G.), Elsevier Science, 2003.
3. International benchmarking of US chemical engineering research competitiveness, NAE Report, USA. *Chem. Eng.*, 2007; http://books.nap.edu/openbook.php?record_id=11867&page=224
4. World wide chemical engineering faculty directory; http://www.che.utexas.edu/che-faculty/index.html, accessed on 1 November 2007.

ACKNOWLEDGMENTS. Financial assistance provided by the Department of Biotechnology, New Delhi, for the Science Observatory project is gratefully acknowledged.

Received 27 November 2007; revised accepted 4 April 2008