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Research Trends in Adsorption Technologies for Dye Containing Wastewaters

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Abstract: The main object of this study is to investigate the research trend in removal of dyes from waste water by using adsorption technology for the past 16 years. Data are based on the online version of Science Citation Index (SCI), Web of Science from 1993 to 2008 that covers all the articles published for the past 16 years in SCI journals. Articles referring to dye adsorption were assessed by many aspects including model fitting the trend of publication outputs during 1993-2008, distribution of author keywords and keyword plus analysis. Distribution of articles based on subject categories and journals along with the country wise publications were also studied. From the analysis of words appeared in the title and keywords, it can be concluded that "activated carbon," "biosorption," "kinetics," "Methylene blue," and "isotherms" could be more popular words and the new words like "photocatalytic degradation," "photocatalysis," "titanium dioxide," and "oxidation" appeared to be the new advanced techniques that are going to be adopted more in future studies. This method of bibliometric analysis can help the relevant researchers to realize the panorama of globalized way of dye removal from wastewater and establish the further research direction.

Key words: Adsorption % Dyes % Activated carbon % Biosorption % Isotherm % Kinetics % Scientometrics

INTRODUCTION

Today the population growth increases the environment load irrespective of the rate of economic growth. Since the rapid urbanization has its effects on pollution of river systems and creation of solid wastes [1]. The usage of water is increasing day by day due to the increasing number of the industries. The textile industries are the major water consuming industries and a main source of environmental pollution [2]. In these industries, water is contaminated with different chemicals and auxiliaries, which are used for producing textile goods [3]. Approximately, 10,000 different dyes and pigments are in industrial use, representing the annual consumption of around 7×10^5 tonnes worldwide [4]. These dyestuffs are having highly complicated structures that are not easily bio-degradable [5,6] and their elimination from wastewater is very difficult before releasing into the water bodies. The polluted water is unsafe for fauna and flora due to high temperature, odors, turbidity, colors and toxic chemicals [7,8]. The pollution problems due to the textile industry effluents have increased in the last few decades. From the available literature it can be estimated that approximately 75% of the dyes, discharged by Western European textile processing industries, belong to the following classes: Reactive dye (~36%), acid (~25%) and direct dye (~15%) [9]. The degradation products of textile dyes are often carcinogenic [10-12]. The main aim of this study is to find out the research trend in the removal of dyes from water and wastewater throughout the world.

In this study, we attempted to do the bibliometric and citation analyzes study based on the research articles published for the past 16 years in SCI journals. It is a research method used in library and information sciences. This will provide a quantitative analysis and statistics to describe distribution patterns of articles within a given topic, field, institute and country. Evaluating the performance of each research topic is necessary in order to determine the impact and contribution of authors in their respective fields and also the new researchers to get insight into this most important universal ecological problem.

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MATERIALS AND METHOD

Documents used in this study were based on the online database of the Science Citation Index (SCI) retrieved from the ISI Web of Science, Philadelphia, USA. According to Journal Citation Reports (JCR), it indexes 6,426 major journals with citation references across 172 scientific disciplines in 2007. "Dye and dyes" and "adsorption, sorption and biosorption" were used as the keyword to search titles, abstracts and keywords from 1993 to 2008. As journal articles represented the majority of document types that were also peer-reviewed within this field. Only 4,750 original articles were used in this study. Document information included names of authors, contact address, title, year of publication, keywords, subject categories and names of journals publishing the articles. Articles originating from England, Scotland, Northern Ireland and Wales were reclassified as being from the United Kingdom (UK). Besides, the reported impact factor (IF) of each journal was obtained from the 2007 JCR. Next to number of citations and impact factor of the papers the h-index value also calculated for journals that are published the articles related to dye removal and similarly for the countries and universities that are carrying out the research work in this particular research field. A h-index was defined as the number of papers with citation number greater than or equal to h [13]. More specifically, a scientist has index h if h of his or her Np papers have at least h citations each and the other (Np-h) papers have # h citations each. Hirsch suggests that h-index has a better predictive power than commonly used indexes, such as i) number of publications; ii) total number of citations; iii) average citation number per publication; iv) total number of citations; or v) number of citations of the highly cited publications [14]. To assess the quality of the research work either research group wise or countrywide today the h-index value is consider as most important one. Ranking of the universities and journals were also given based on this h-index value in this bibliometric analysis.

Collaboration type was determined by the addresses of the authors, where the term "single country article" was assigned if the researchers' addresses were from the same country. The term "internationally collaborative article" was designated to those articles that were coauthored by researchers from more than one country. The term "single institute article" was assigned if the researchers' addresses were from the same institute. The term "inter-institutionally collaborative article" was assigned if authors were from different institutes. The records were downloaded into Microsoft Excel software and additional coding was manually performed for the number of authors and origin country of the collaborators. All the articles referring to dye adsorption during the past 16 years, including the last 8 years of 20th century and 8 years of 21st century, were assessed by following aspects characteristics of publication outputs during 1993-2008, distribution of articles in different subject categories, journals, countries, source title, author keyword and keyword plus analysis.

Characteristics of Publication Outputs During 1993-2008: The total number of SCI articles including "dye or dyes" and "adsorption, sorption, or biosorption" in the title only during the last 100 years were analyzed and displayed in Fig. 1 to see the research trend in the last one century. Along with the development of SCI, adsorption of dyes research constantly grew in this long period, started to go up significantly in the year of 1999 and rocketed in the 21st century. Build on many breakthroughs in this study period during 1991 to 2008, especially in the recent decade, adsorption research has become one of the most important topics in water research. Figure 2 shows the cumulative progress of the articles from 1993 to 2008. From 1993 to 1999 there is a constant growth rate of the articles which is shown by the logarithmic model. After that, the exponential model explains the sudden growth of articles throughout the world because of water pollution due to dyes and their health effects [11,15] are increasing day by day. The publication output of adsorption of dyes research during the time span of 1993 through 2008 was summarized in Table 1. The number of articles increased more than eight times i.e. 88 in 1993 to 770 in 2008. The average length of the article has fluctuated from 7.8 to 9.0. Similarly the average number of authors per article also changed from 3.0 to 3.9 and the overall average was 3.6. The cited reference count increased nearly 10 times, from 2,062 to 24,656, during these 16 years of period. In addition, the average cited reference count per article also increased from 23 to 32 that show the importance of the each articles published in this research field.

Distribution of Articles in Different Subject Categories and Journals: In 2007, Journal Citation Report (JCR) of the ISI contains 6,426 major journals with citation references across 172 scientific disciplines in the Science Citation Index (SCI). Based on the classification of subject

Table 1: Characteristics of adsorption of dyes articles from 1993 to 2008

Year	TP	AU	AU/TP	PG	PG/TP	NR	NR/TP
1993	88	268	3.0	726	8.3	2,062	23
1994	84	263	3.1	709	8.4	1,946	23
1995	102	311	3.0	809	7.9	2,490	24
1996	123	370	3.0	979	8.0	2,770	23
1997	147	525	3.6	1,237	8.4	3,711	25
1998	151	494	3.3	1,243	8.2	4,029	27
1999	166	555	3.3	1,416	8.5	4,015	24
2000	231	797	3.5	1,906	8.3	6,414	28
2001	219	780	3.6	1,829	8.4	5,714	26
2002	283	985	3.5	2,542	9.0	7,912	28
2003	363	1,300	3.6	3,017	8.3	10,260	28
2004	389	1,402	3.6	3,227	8.3	11,189	29
2005	453	1,634	3.6	3,541	7.8	12,784	28
2006	546	1,986	3.6	4,377	8.0	16,479	30
2007	635	2,398	3.8	5,081	8.0	20,284	32
2008	770	2,990	3.9	6,207	8.1	24,656	32
Total	4,750	17,058		38,846		136,715	
Average			3.6		8.2		29

TP, number of articles; AU, number of authors; PG, page count; NR, cited reference count; AU/TP, the average number of author per article; PG/TP, the average page count per article; NR/TP, the average cited reference count per article

Table 2: The 13 core journals with the number of articles and impact factor of journals

Journal Title	IF	TP (%)	h index	Category	Position
Journal of Hazardous Materials	2.337	304 (6.4)	26	Environmental Engineering	5/37
				Civil Engineering	1/89
				Environmental Sciences	32/160
Journal of Colloid and Interface Science	2.309	189 (4.0)	31	Physical Chemistry	38/111
Langmuir	4.009	180 (3.8)	31	Physical Chemistry	1/111
Dyes and Pigments	2.796	160 (3.4)	24	Applied Chemistry	4/62
				Chemical Engineering	4/114
				Textiles Materials Science	1/15
Journal of Applied Polymer Science	1.008	129 (2.7)	17	Polymer Science	39/74
Journal of Physical Chemistry B	4.086	113 (2.4)	33	Physical Chemistry	19/111
Colloids and Surfaces A-Physicochemical and Engineering Aspects	1.601	98 (2.1)	16	Physical Chemistry	58/111
Bioresource Technology	3.103	93 (2.0)	22	Agricultural Engineering	1/9
				Biotechnology and Applied Microbiology	34/138
				Energy and Fuels	4/64
Chemical Engineering Journal	1.707	80 (1.7)	17	Chemical Engineering	22/114
Water Research	3.427	69 (1.5)	28	Environmental Engineering	3/37
				Environmental Sciences	12/160
				Water Resources	1/59
Industrial and Engineering Chemistry Research	1.749	65 (1.4)	17	Chemical Engineering	18/114
Adsorption Science and Technology	0.333	64 (1.3)	9	Applied Chemistry	51/62
				Physical Chemistry	110/111
				Chemical Engineering	91/114
Journal of Photochemistry and Photobiology A-Chemistry	1.911	64 (1.3)	21	Physical Chemistry	51/111

IF, impact factor; TP, number of articles

Table 3: Top 20 most productive countries of articles during 1993 to 2008

Country	TP	TP R (%)	SP R (%)	CP R (%)	FA R (%)	RP R (%)	h index
China	588	1 (12)	1 (12)	6 (13)	1 (11)	1 (12)	33
USA	509	2 (11)	4 (9.2)	1 (20)	4 (9.0)	4 (8.5)	49
India	500	3 (11)	2 (11)	7 (8.0)	2 (10)	2 (10)	44
Turkey	457	4 (10)	3 (11)	16 (3.4)	3 (10)	3 (10)	34
Japan	456	5 (10)	5 (8.5)	2 (16)	5 (8.4)	5 (8.2)	37
Germany	238	6 (5.0)	7 (3.2)	3 (16)	8 (3.7)	7 (3.7)	33
Taiwan	219	7 (4.6)	6 (4.9)	22 (2.7)	6 (4.5)	6 (4.7)	33
UK	219	7 (4.6)	7 (3.2)	5 (13)	7 (3.8)	8 (3.7)	33
France	160	9 (3.4)	14 (1.6)	4 (14)	12 (2.3)	12 (2.3)	25
South Korea	156	10 (3.3)	9 (2.6)	8 (7.4)	9 (2.9)	9 (3.0)	22
Spain	145	11 (3.1)	11 (2.5)	9 (6.5)	10 (2.5)	10 (2.5)	20
Egypt	125	12 (2.6)	11 (2.5)	14 (3.5)	13 (2.3)	13 (2.3)	14
Brazil	121	13 (2.6)	10 (2.6)	23 (2.5)	11 (2.4)	11 (2.4)	17
Russia	97	14 (2.0)	13 (2.1)	26 (1.9)	14 (1.9)	14 (1.6)	9
Canada	86	15 (1.8)	18 (1.3)	11 (5.2)	17 (1.3)	17 (1.3)	23
Hong Kong	81	16 (1.7)	16 (1.4)	16 (3.4)	15 (1.5)	16 (1.4)	23
Switzerland	75	17 (1.6)	21 (0.91)	10 (5.6)	19 (1.2)	19 (1.1)	27
Malaysia	74	18 (1.6)	15 (1.5)	26 (1.9)	15 (1.5)	15 (1.6)	16
Poland	69	19 (1.5)	17 (1.4)	26 (1.9)	18 (1.2)	18 (1.3)	11
Australia	65	20 (1.4)	19 (1.1)	19 (3.1)	20 (1.2)	19 (1.1)	16

TP, total articles; SP, single country articles; CP, internationally collaborative articles; FA, first author articles; RP, articles with reprint author (corresponding author); R, Rank; %, share in articles.

Table 4: Top 20 Institutes (worldwide) based on corresponding authors published papers related to dye removal from the period 1993 to 2008

Institute	TP	TP R (%)	SP R (%)	CP R (%)	FA R (%)	RP R(%)	h-index
Chinese Academy of Sciences, China	141	1 (3.0)	1 (2.4)	1 (3.9)	1 (2.3)	1 (2.4)	24
Hacettepe University, Turkey	100	2 (2.1)	3 (1.6)	2 (2.9)	3 (1.8)	3 (1.3)	21
Indian Institute of Technology, India	99	3 (2.1)	1 (2.4)	3 (1.7)	2 (2.0)	2 (2.0)	22
Anna University, India	62	4 (1.3)	5 (1.2)	5 (1.4)	4 (1.2)	4 (1.2)	15
Hong Kong University of Science and Technology, Hong Kong	59	5 (1.2)	4 (1.4)	13 (1.0)	5 (1.0)	5 (0.93)	21
Kirikkale University, Turkey	55	6 (1.2)	7 (0.87)	4 (1.6)	6 (0.80)	6 (0.80)	15
Russian Academy of Sciences, Russia	43	7 (0.91)	11 (0.73)	9 (1.2)	9 (0.67)	14 (0.56)	6
Queen's University of Belfast, UK	41	8 (0.86)	14 (0.63)	7 (1.2)	8 (0.70)	7 (0.76)	18
Bharathiar University, India	40	9 (0.84)	8 (0.84)	20 (0.85)	11 (0.63)	16 (0.53)	16
National Research Centre, Egypt	39	10 (0.82)	6 (1.0)	43 (0.53)	7 (0.74)	8 (0.73)	9
Zhejiang University, China	35	11 (0.74)	11 (0.73)	27 (0.75)	9 (0.67)	9 (0.71)	9
Chonbuk National University, South Korea	35	11 (0.74)	17 (0.52)	12 (1.1)	12 (0.57)	10 (0.6.0)	8
Cumhuriyet University, Turkey	32	13 (0.67)	51 (0.31)	7 (1.2)	23 (0.4.0)	14 (0.56)	13
Anadolu University, Turkey	31	14 (0.65)	21 (0.49)	18 (0.91)	32 (0.36)	27 (0.38)	11
University of Hacettepe, Turkey	30	15 (0.63)	51 (0.31)	11 (1.1)	14 (0.55)	27 (0.38)	11
University of Porto, Portugal	30	15 (0.63)	17 (0.52)	23 (0.80)	17 (0.46)	18 (0.47)	11
CSIC, Spain	30	15 (0.63)	21 (0.49)	20 (0.85)	21 (0.42)	19 (0.45)	12
Yuan Ze University, Taiwan	30	15 (0.63)	213 (0.10)	5 (1.4)	21 (0.42)	21 (0.42)	19
Tianjin University, China	29	19 (0.61)	8 (0.84)	130 (0.27)	12 (0.57)	11 (0.58)	11
National Cheng Kung University, Taiwan	28	20 (0.59)	10 (0.77)	103 (0.32)	14 (0.55)	11 (0.58)	7

TP, total articles; SP, Single institute articles; CP, inter-institutionally collaborative articles; FA, first author articles; RP, articles with reprint author (corresponding author); R, Rank; %, share in articles.

Table 5: Top 30 Frequency of words in title of the articles published in adsorption technology in removal of dyes from wastewater from 1993 to 2008

Word in title	93-08TP	93-08R (%)	93-96R (%)	97-00R (%)	01-04R (%)	05-08R (%)
adsorption	1,326	1 (28)	1 (22)	1 (26)	1 (28)	1 (29)
dye	975	2 (21)	3 (15)	3 (20)	2 (21)	2 (22)
dyes	835	3 (18)	2 (20)	2 (22)	3 (19)	5 (15)
removal	616	4 (13)	12 (5.3)	4 (9.2)	4 (12)	4 (16)
aqueous	574	5 (12)	38 (2.5)	8 (6.3)	5 (8.9)	3 (17)
using	482	6 (10)	5 (6.5)	7 (6.6)	6 (8.8)	6 (12)
acid	374	7 (7.9)	7 (6.3)	6 (7.5)	8 (6.9)	10 (8.7)
blue	354	8 (7.5)	24 (3.5)	12 (5.5)	10 (6.2)	8 (9.3)
activated	353	9 (7.4)	20 (3.8)	14 (5.2)	7 (7.3)	10 (8.7)
solution	341	10 (7.2)	55 (2.0)	19 (3.7)	12 (5.3)	7 (10)
carbon	329	11 (6.9)	24 (3.5)	15 (4.6)	14 (4.9)	9 (9.2)
surface	296	12 (6.2)	7 (6.3)	5 (8.1)	9 (6.5)	18 (5.6)
TiO_2	282	13 (5.9)	126 (1.0)	12 (5.5)	10 (6.2)	13 (6.7)
study	273	14 (5.7)	7 (6.3)	9 (5.9)	13 (5.2)	16 (5.9)
reactive	254	15 (5.3)	78 (1.5)	19 (3.7)	15 (4.7)	12 (6.8)
solutions	252	16 (5.3)	46 (2.3)	17 (4.2)	19 (4.1)	13 (6.7)
sorption	249	17 (5.2)	4 (9.3)	10 (5.8)	18 (4.2)	25 (5.0)
studies	245	18 (5.2)	20 (3.8)	29 (2.7)	21 (3.9)	13 (6.7)
effect	218	19 (4.6)	5 (6.5)	11 (5.6)	24 (3.8)	28 (4.4)
properties	216	20 (4.5)	14 (4.3)	18 (3.9)	20 (4.1)	24 (5.0)
photocatalytic	201	21 (4.2)	263 (0.50)	283 (0.58)	17 (4.4)	17 (5.8)
kinetics	201	21 (4.2)	31 (2.8)	37 (2.4)	31 (3.1)	18 (5.6)
red	184	23 (3.9)	55 (2.0)	41 (2.3)	35 (2.9)	22 (5.2)
degradation	182	24 (3.8)	263 (0.50)	104 (1.3)	21 (3.9)	23 (5.1)
methylene	179	25 (3.8)	55 (2.0)	60 (1.9)	30 (3.3)	26 (4.9)
films	179	25 (3.8)	31 (2.8)	15 (4.6)	15 (4.7)	39 (3.2)
water	172	27 (3.6)	24 (3.5)	22 (3.5)	26 (3.4)	32 (3.8)
basic	170	28 (3.6)	78 (1.5)	52 (2.0)	37 (2.6)	26 (4.9)
kinetic	168	29 (3.5)	263 (0.50)	120 (1.2)	54 (2.1)	20 (5.5)
equilibrium	167	30 (3.5)	126 (1.0)	120 (1.2)	47 (2.3)	21 (5.2)

TP, total articles; R, ranking

Table 6: Top 25 frequency of author keywords used

Author keywords	93-08TP	93-08R (%)	93-96R (%)	97-00R (%)	01-04R (%)	05-08R (%)
Adsorption	946	1 (29)	1 (15)	1 (21)	1 (29)	1 (32)
kinetics	273	2 (8.5)	4 (4.3)	8 (3.3)	5 (5.3)	2 (11)
activated carbon	180	3 (5.6)	83 (0.62)	5 (4.1)	3 (5.4)	4 (6.3)
methylene blue	168	4 (5.2)	4 (4.3)	13 (1.9)	6 (3.8)	3 (6.5)
dye	150	5 (4.6)	13 (1.9)	2 (5.0)	3 (5.4)	7 (4.5)
biosorption	142	6 (4.4)	N/A	9 (3.0)	15 (2.1)	5 (6.0)
dyes	137	7 (4.2)	4 (4.3)	7 (3.9)	2 (5.8)	9 (3.6)
sorption	120	8 (3.7)	2 (5.6)	3 (4.7)	6 (3.8)	11 (3.3)
isotherms	106	9 (3.3)	28 (1.2)	218 (0.28)	15 (2.1)	6 (4.5)
chitosan	96	10 (3.0)	13 (1.9)	9 (3.0)	10 (3.0)	13 (3.1)
isotherm	91	11 (2.8)	N/A	218 (0.28)	29 (1.5)	8 (4.1)
photocatalysis	90	12 (2.8)	83 (0.62)	218 (0.28)	8 (3.6)	12 (3.1)
adsorption isotherm	89	13 (2.8)	10 (2.5)	45 (0.83)	18 (2.0)	10 (3.5)
reactive dyes	72	14 (2.2)	83 (0.62)	5 (4.1)	9 (3.2)	25 (1.6)
decolorization	70	15 (2.2)	28 (1.2)	45 (0.83)	13 (2.3)	15 (2.4)
TiO_2	69	16 (2.1)	83 (0.62)	14 (1.7)	11 (2.6)	17 (2.2)
adsorption kinetics	65	17 (2.0)	N/A	95 (0.55)	42 (1.0)	14 (2.9)
wastewater	63	18 (2.0)	N/A	14 (1.7)	15 (2.1)	19 (2.1)
reactive dye	57	19 (1.8)	83 (0.62)	45 (0.83)	20 (1.7)	21 (2.1)
dye adsorption	55	20 (1.7)	8 (3.1)	24 (1.1)	26 (1.6)	23 (1.7)
equilibrium	54	21 (1.7)	83 (0.62)	45 (0.83)	63 (0.74)	16 (2.3)
adsorption isotherms	52	22 (1.6)	13 (1.9)	45 (0.83)	20 (1.7)	24 (1.7)
thermodynamics	50	23 (1.5)	83 (0.62)	218 (0.28)	49 (0.86)	17 (2.2)
dye removal	48	24 (1.5)	N/A	24 (1.1)	100 (0.49)	19 (2.1)
titanium dioxide	46	25 (1.4)	N/A	45 (0.83)	20 (1.7)	27 (1.5)

TP, total articles; R, rank; N/A, not applicable

categories in JCR, the publication output data of adsorption of dyes research is distributed in 102 SCI subject categories during the last 16 years. Subject categories containing 400 above articles were separated and statistically analyzed (Fig. 3). The number of scientific articles per category exhibited sustaining growth during the time period covered, which indicates that adsorption of dyes research has been steadily developing in various subject categories. The three most common categories were the physical chemistry, chemical engineering and environmental sciences. There is a vast increase in the number of articles in environmental sciences and environmental engineering categories after 2002. This shows mainly the research trend is focused on adsorption technique mainly to remove the dyes from waste water throughout the world. In total, 4,750 articles were published in a wide range of 676 journals including specialty journals, but also journals of other disciplines. Table 2 shows the 13 core journals with their impact factors, the number of articles, percentage of total articles, subject category, position in the category and h index. *Journal of Hazardous Materials* ranked first with 304 (6.4%) published papers followed by *Journal of Colloid and Interface Science* with 189 papers and *Langmuir* with 180 papers. Moreover, *Science* with one published article and had the highest impact factor (26.372). The other high impact factor journals like *Journal of physical Chemistry* (4.086), *Water Research* (3.427), *Bioresource Technology* (3.103) and *Dyes and Pigment*s (2.796) published 113, 69, 93 and 160 articles respectively. The h index categories show that researchers belong to the following fields like chemistry, chemical engineering and biotechnology are doing more research work in this particular research field.

Distribution of Countrywide Publications: The contribution of different countries/territories was estimated by the location of the affiliation of at least one author of the each published papers. There were 9 articles without any author address information on the ISI Web of Science. Of all the 4,741 articles with author address, 4,063 (86%) were independent publications and 678 (14%) were international collaborative publications. The top 20 countries/territories were ranked by number of publications, including the number and percentage of single country articles, internationally collaborated articles, first author articles, corresponding author articles and h index (Table 3). China alone published 12% of the total articles followed by USA with 11%, India with 11% and Turkey with 10% and Japan with 10%. It is not usual that USA ranked in second in total publications but it still has more collaborative work and published 134 internationally collaborated articles. The analysis shows that India is the most affected country due to dyes from textile industries effluents which is reflected in the percentage of independent publications (11%). Particularly five Asian countries including India, China, Turkey, Taiwan and South Korea were also ranked on top ten. Researchers from these countries were involved more in this particular research field compared to other countries. Next to USA, Japan has more number of collaborative works followed by Germany, France and UK.

Distribution of Institute Publications: From the data given in the Table 4, it is very clear that more numbers of research institutes from Asian countries are concentrating the research work related to dye removal when compared to institutes from other continents. The contribution of different institutes was estimated by the institute of the affiliation of at least one author of the published papers. There were 9 articles without author address information on the download data in ISI Web of Science. Of all the 4,741 articles with author addresses, 2,868 (60%) were single institute publications and 1,873 (40%) were inter-institutionally collaborative publications by more than one institutes. The top 20 institutes were ranked by the number of publications, including the number and percentage of single institute publications and inter-institutionally collaborative publications, as well as first author publications and corresponding author publications with h-index (Table 4). Of the top 20 institutes, 5 were from Turkey, 3 from China, 3 from India, 2 from Taiwan and the others from South Korea, Spain, Egypt, Hong Kong, UK, Portugal and Russia had one institute for each respectively. The ranking of the universities were done on the basis of the reprint authors' total number of publications and first authors' total number of publications. The papers published from Hong Kong, Taiwan and UK universities were having high index value compared to other universities. The result of institutes' output should be interpreted in the context of bias. Chinese Academy of Sciences (CAS), Indian Institute of Technology (IIT) and Russian Academy of Sciences (RAS) had branches in different cities. At present the publications of these two institutes were pooled as one heading and publications divided into branches would result into different rankings.

Distribution of Word in Title Analysis: The analysis of words in the title of the research articles gave the exact trend in this research field. The words like "activated carbon" and "Methylene blue" appeared often in the title for the past 16 years (Table 5). This shows the adsorption technique using activated carbon is the easy and economic method for the wastewater treatment in this study period. Adsorption is a process by which solute molecules adhere to a surface with which they come into contact, due to the forces of attraction at the surface of the adsorbents. Next to this method the words like "TiO_2," "reactive," "water," "degradation," and "photocatalytic" in the title show the next buoyant method for the wastewater treatment in this research field is photocatalytic degradation method using TiO_2. Further the analysis shows the efficiency of the activated carbon is determined from the adsorption of Methylene blue dye to get approximately the surface area of the activated carbon.

Distribution of Author Keyword Analysis: The source titles and author keywords supply "reasonably" details of the articles' in this subject. In particular, author keyword analysis could offer the information of research trend that is concerned by researchers throughout the world. Bibliometric method concerning author keyword analysis can be found in recent years [16,17], whereas using the author keyword to analyze the trend of research is much more infrequent. The technique of statistical analysis of keywords might be aimed at discovering directions of science and prove the importance of monitoring the development of science and programs. Examination of author keywords in this study period revealed that 6,896 author keywords were used. Among them, 5,147 (75%) keywords appeared only once and 796 keywords appeared twice. The large number of only-once author keywords probably indicated a lack of continuity in research and a wide disparity in research focuses [18]. Most of the research articles were not considered to be in the mainstream of adsorption of dyes from water research by their authors. Author keywords appeared in the articles refer on adsorption of dyes from 1993 to 2008 were calculated and ranked by total for the past 16-year period in the time intervals of 4 years. Author keywords that ranked top 25^{th} in last 16 years are displayed in Table 6, where the research changes can be roughly found. "Adsorption," "sorption," "kinetics," "isotherms", "biosorption," "dye," and "dyes" are the most frequently used keywords as they were used as searching keywords. The most used adsorbents are "activated carbon," "chitosan," "titanium dioxide," and "montmorillonite" for the last 16 years time. "Methylene blue" and "reactive dyes" are more concerned by researchers. "Kinetics" and "isotherms" are the most frequently used topics in research. The research trend shows that research with "activated carbon," "titanium dioxide," "photocatalysis," "biosorption," and "isotherms" could be the main research topics in the future. In addition, "photocatalytic degradation," and "coagulation" also appeared as new author keywords in later studied years.

Distribution of Keyword plus Analysis: Keywords plus provides search terms extracted from the titles of papers cited in each new article in the database in ISI [19]. In author keywords analysis, we preserve the intact words that the authors want to transmit. Although it makes same single word or phrase appear in different author keywords, we can compare discrimination between author keywords, or sum up the dissimilar keywords with common phrase or single word for further study. The keyword plus analysis as an independent supplement, reveals the articles contents with more details. There are some similar and dissimilar trends between their statistical results in this study periods. The distribution of the keywords plus with its rank and percentage in different periods was revealed in Table 7. Keywords plus as an additional search terms, are usually more concerned about the novel research direction than the mature direction in the field [19]. The following words like "films," "degradation," "surface," "oxidation," and "acid" appeared in top 30 keyword plus but not in author keywords. "Kinetics," "color removal," and "oxidation" appeared an increased trend in this studied years. Moreover "reactive dyes," "azo dye," "acid dyes," "fly ash," and "biosorption" appeared in the later studied years and more popular in keywords plus.

Research Trend of Adsorbents: Carbon, titanium dioxide (TiO_2), chitosan (chitin), montmorillonite, ash, bentonite, sawdust, silica (SiO_2) and clay were the most used adsorbent for removal dyes from water in this study period. The research trend of articles related to activated carbon and other 8 frequently available adsorbents is shown in Fig. 4. Most commonly used adsorbent for wastewater treatment is activated carbon. It is manufactured from carbonaceous materials such as wood,

Table 7: Top 30 frequency of keywords plus used

Keywords plus	93-08TP	93-08R (%)	93-96R (%)	97-00R (%)	01-04R (%)	05-08R (%)
adsorption	1387	1 (31)	1 (23)	1 (26)	1 (29)	1 (34)
removal	765	2 (17)	11 (3.1)	6 (6.7)	2 (13)	2 (24)
sorption	596	3 (13)	5 (4.7)	2 (8.3)	3 (12)	3 (16)
water	517	4 (12)	3 (5.0)	3 (7.5)	4 (11)	5 (14)
waste-water	435	5 (10)	250 (0.31)	27 (2.5)	7 (7.0)	4 (14)
aqueous-solutions	430	6 (10)	11 (3.1)	5 (6.8)	6 (7.9)	7 (12)
dyes 419	7 (9.3)	2 (9.1)	3 (7.5)	5 (8.0)	11 (11)	
activated carbon	384	8 (8.6)	43 (1.6)	15 (3.5)	8 (6.6)	8 (12)
aqueous-solution	375	9 (8.4)	11 (3.1)	27 (2.5)	13 (5.2)	6 (12)
equilibrium	371	10 (8.3)	8 (3.8)	7 (5.9)	10 (5.9)	9 (11)
kinetics	327	11 (7.3)	43 (1.6)	47 (1.7)	14 (5.1)	10 (11)
dye 286	12 (6.4)	16 (2.8)	23 (2.9)	8 (6.6)	13 (7.7)	
methylene-blue	285	13 (6.4)	16 (2.8)	32 (2.4)	20 (3.6)	12 (9.3)
adsorbents	240	14 (5.3)	8 (3.8)	8 (4.1)	11 (5.9)	16 (5.6)
degradation	217	15 (4.8)	32 (1.9)	24 (2.7)	16 (4.6)	14 (5.9)
color removal	212	16 (4.7)	32 (1.9)	10 (3.7)	12 (5.3)	19 (5.1)
films 191	17 (4.3)	59 (1.3)	9 (3.8)	15 (5.0)	22 (4.4)	
oxidation	177	18 (3.9)	32 (1.9)	74 (1.3)	17 (4.3)	21 (4.7)
decolorization	172	19 (3.8)	N/A	74 (1.3)	31 (2.6)	15 (5.7)
reactive dyes	164	20 (3.7)	N/A	150 (0.64)	26 (2.9)	18 (5.3)
acid 163	21 (3.6)	32 (1.9)	17 (3.2)	18 (3.9)	25 (3.8)	
basic-dyes	160	22 (3.6)	250 (0.31)	57 (1.6)	33 (2.4)	19 (5.1)
surface	156	23 (3.5)	7 (4.1)	17 (3.2)	22 (3.4)	26 (3.5)
biosorption	153	24 (3.4)	N/A	201 (0.48)	54 (1.7)	17 (5.5)
fly-ash	152	25 (3.4)	32 (1.9)	27 (2.5)	27 (2.8)	24 (4.1)
spectroscopy	141	26 (3.1)	6 (4.4)	10 (3.7)	22 (3.4)	37 (2.7)
ions 137	27 (3.1)	43 (1.6)	57 (1.6)	46 (1.8)	23 (4.3)	
particles	135	28 (3.0)	22 (2.5)	10 (3.7)	18 (3.9)	43 (2.4)
azo dyes	123	29 (2.7)	32 (1.9)	43 (1.9)	35 (2.3)	29 (3.3)
separation	122	30 (2.7)	22 (2.5)	16 (3.3)	25 (3.1)	46 (2.4)

TP, total articles; R, rank; N/A, not applicable

Table 8: Most frequently cited articles between 1993 and 2008

Year	Article/Journal	Authors	C	C/Y	Country
1999	Pseudo-second order model for sorption processes	Ho, YS; McKay, G [22]	594	59	Hong Kong
9	Process Biochemistry				
2005	Nanowire dye-sensitized solar cells	Law, M; Greene, LE; Johnson, JC; Saykally, R;	480	120	USA
5	Nature Materials	Yang, PD [23]			
2001	Engineering of efficient panchromatic sensitizers for				
1	nanocrystalline TiO2-based solar cells	Nazeeruddin, MK; Pechy, P; Renouard, T; Zakeeruddin,			
	Journal of the American Chemical Society	SM; Humphry-Baker, R; Comte, P; Liska, P; Cevey, L; Costa,			
		E; Shklover, V; Spiccia, L; Deacon, GB; Bignozzi, CA; Gratzel, M [24]	526	66	Switzerland
1996	Subpicosecond interfacial charge separation in				
6	dye-sensitized nanocrystalline titanium dioxide films	Tachibana, Y; Moser, JE; Gratzel, M; Klug, DR;	376	29	UK, Switzerland
	Journal of Physical Chemistry	Durrant, JR [25]			
1993	Gemini surfactants - a new class of self-assembling molecules	Menger, FM; Littau, CA [26]	352	22	USA
	Journal of the American Chemical Society				
1998	Sorption of dye from aqueous solution by peat	Ho, YS; McKay, G [27]	315	29	Hong Kong
	Chemical Engineering Journal				

C: number of citations from year of publication through 2008; C/Y: number of citations per year

coal and waste agricultural biomass etc. A char is made by burning the material in the absence of air. The char is then oxidized at higher temperatures to create a porous solid mass, which has large surface area per unit mass.

Since activated carbon is having more surface area it removes maximum amount of pollutants from wastewater compared to other adsorbents. This is reflected in the number of articles published using carbon as an adsorbent in this 16 years period. Figure 5 shows the research trend of other easily available adsorbents like titanium dioxide (TiO_2), chitosan (chitin), montmorillonite, ash, bentonite, sawdust, silica (SiO_2) and clay. From the figure, it is clear that next to carbon, titanium dioxide and ash are the most commonly used adsorbents.

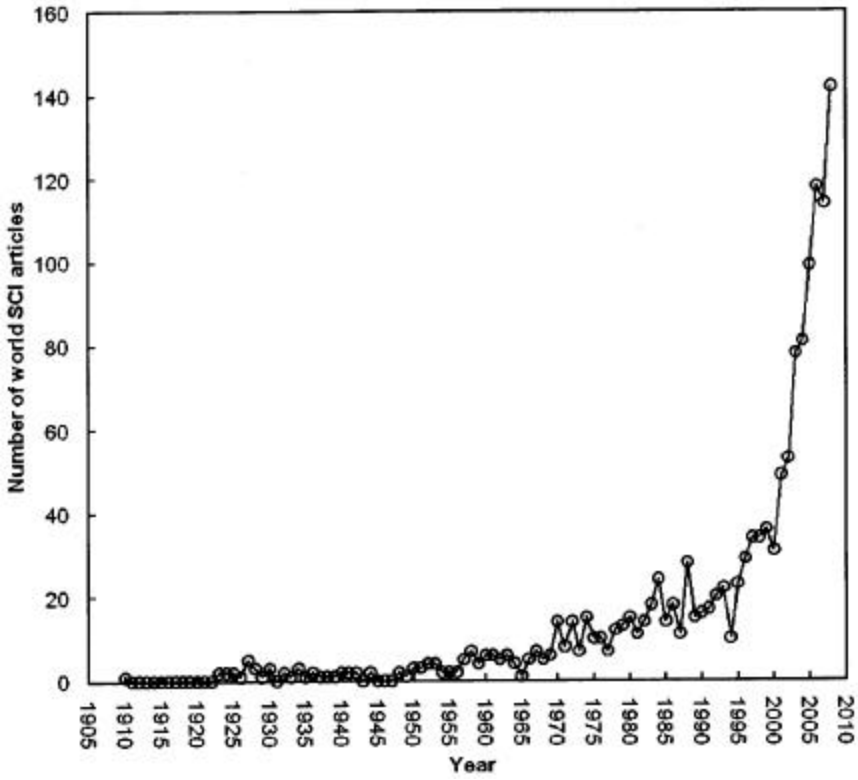

Fig. 1: Number of SCI articles referring to “dye or dyes” and “adsorption, sorption, or biosorption” in the title during the last 100 years

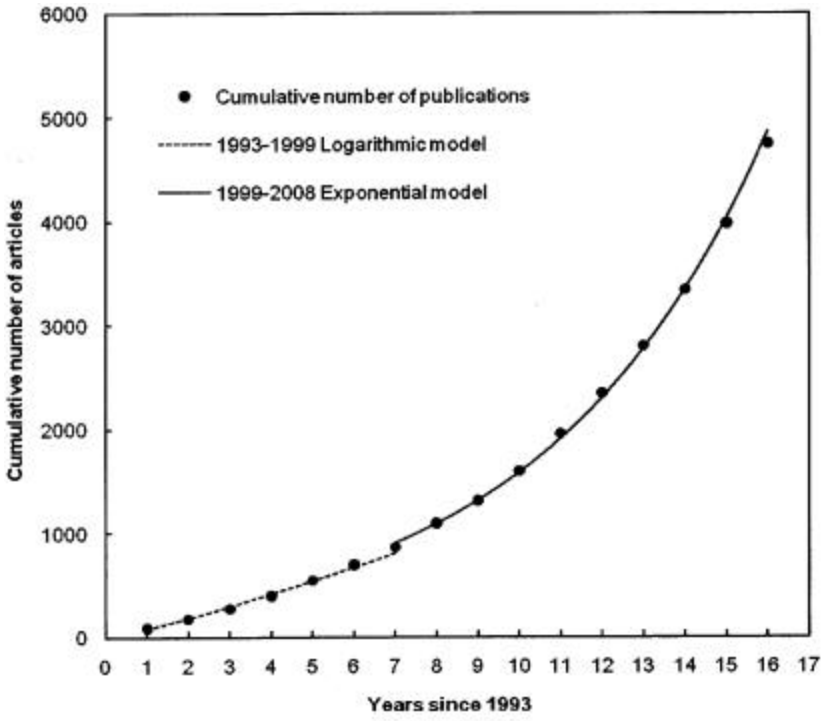

Fig. 2: Cumulative number of publications by year from 1993 to 2008

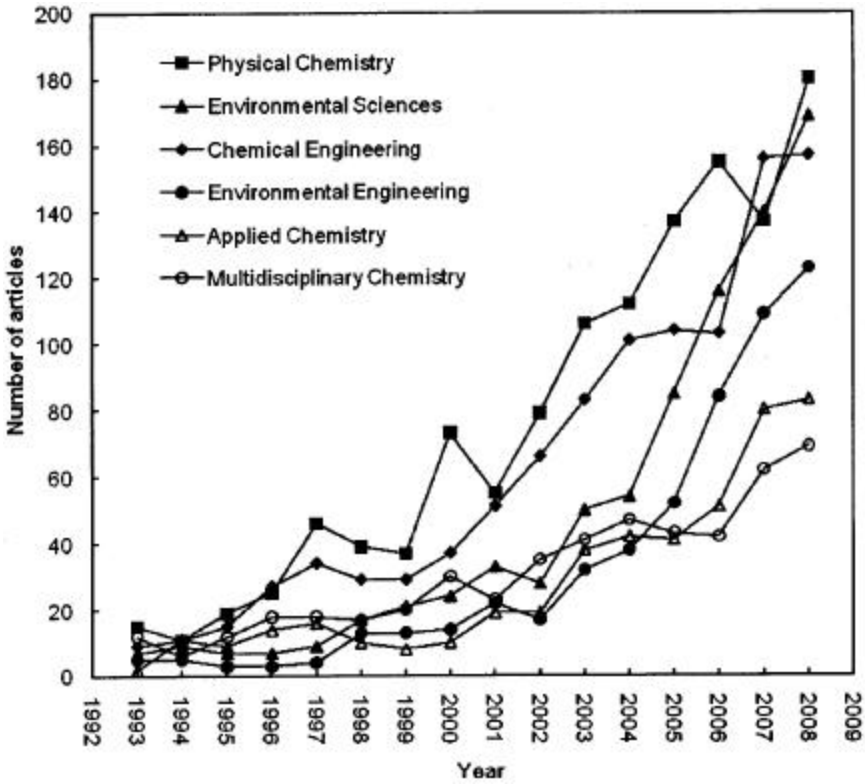

Fig. 3: Comparison between the growth trends of subject categories containing 400 above adsorption dyes related articles during the last 16 years

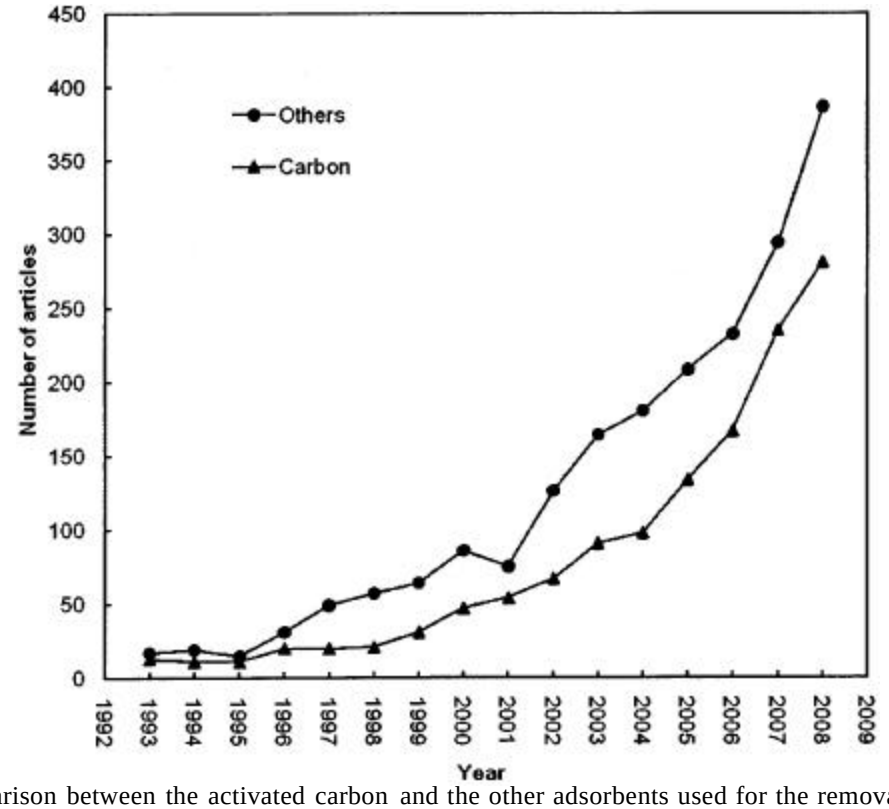

Fig. 4: Comparison between the activated carbon and the other adsorbents used for the removal of dyes related articles during the last 16 years

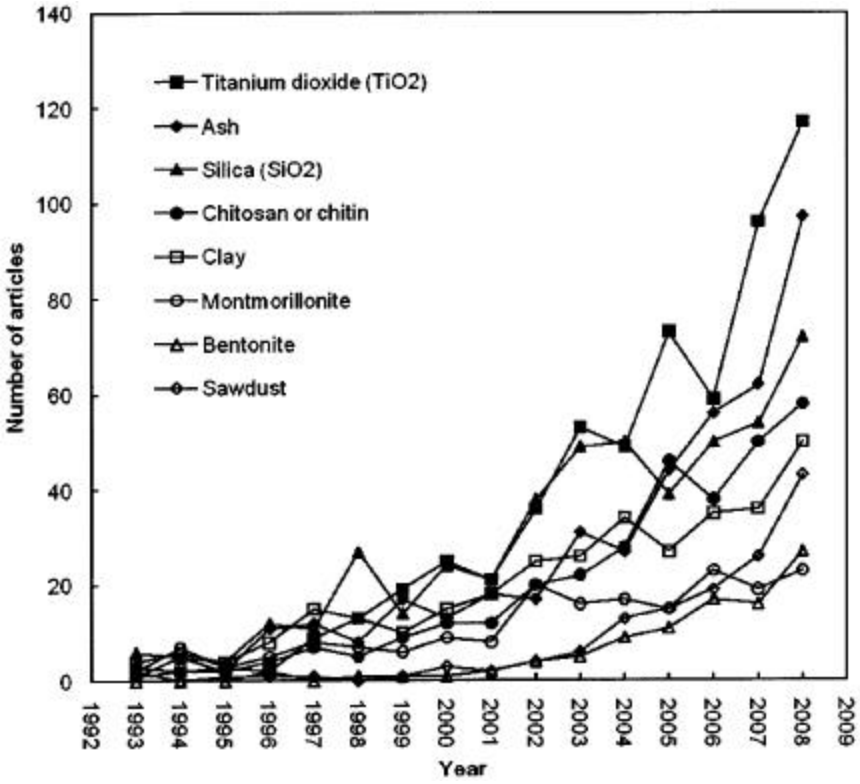

Fig. 5: Comparison between the 8 adsorbents used frequently for the removal of dyes from water related articles during the last 16 years

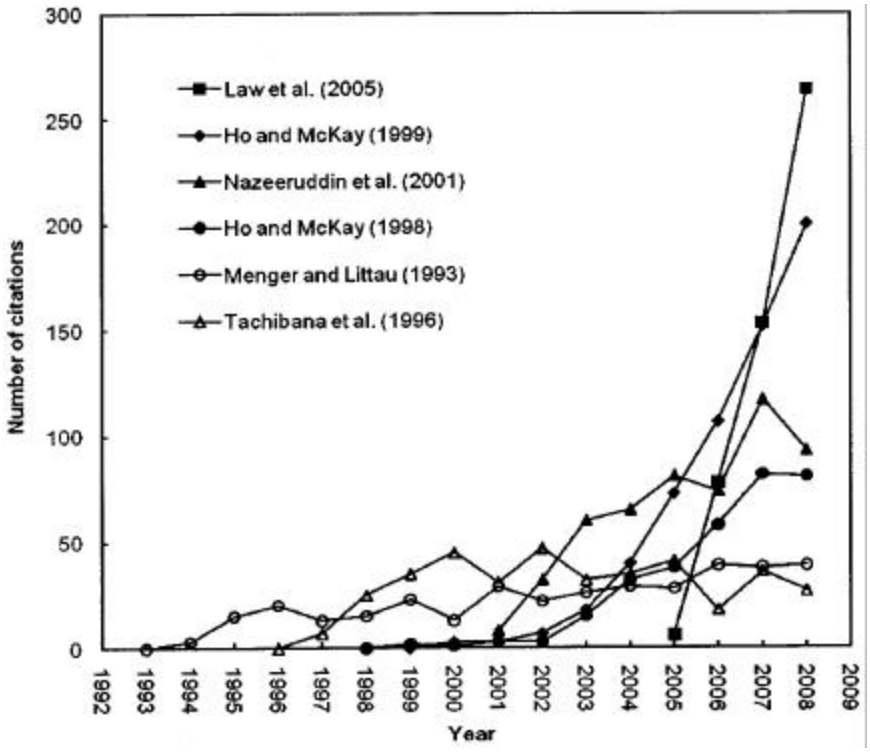

Fig. 6: Most frequently cited articles between the years1993 and 2008

The easily available saw dust is also used as one of the adsorbent now for wastewater treatment and it shows a steady increase in the number of articles published in the 16 years of time. Most frequently cited papers in this research field during the past 16 years. The impact of an article is mainly reflected from its citations per year since the time of its publication. The time dependence for a single article is called its history. Calculating the citation times versus time as article's citation history has been reported [16]. Similarly, the most-frequently cited articles in Patent Ductus Arteriosus research, homeopathy research [20], tsunami research [16] and biosorption technology in water treatment research [21] were also presented in recent years. Among papers related to adsorption technology in removal of dyes from water in the period of 1993 to 2008, the most frequently cited article was pseudo-second order model for sorption processes." The impact of this article is still keep on increasing in recent years (Fig. 6). This paper, in 1999 by Ho and McKay from Hong Kong, was published in the *Process Biochemistry* journal and has been cited for 603 times in 2008 since the time of its publishing. *Process Biochemistry* belongs to the categories of biochemistry and molecular biology, biotechnology and applied microbiology and chemical engineering. The most frequently cited articles that have been cited for more than 300 times since its publishing to 2008 were listed in Table 8. Five of the most frequently cited articles were published in chemistry related journals. *Chemical Engineering Journal* is the only one journal belongs to the category of chemical engineering. The most frequently cited articles were originated from Hong Kong (2), United States (2), Switzerland (2) and one in UK. The papers that are having more than 300 times of citation were shown in Fig. 6. The article that is having highest number of visibility was "nanowire dye-sensitized solar cells." This paper, in 2005 by Law *et al*. from the USA, was published in the *Nature Materials* and has highest number of citations per year. *Nature Materials* belongs to the categories of physical chemistry, multidisciplinary materials science, applied physics and condensed matter physics.

CONCLUSIONS

In this study on research trend in removal of dyes from wastewater papers dealing with SCI, we obtained some significant points on the research performance throughout the period from 1993 to 2008. The mathematic model fitting showed that yearly publications had a distinct growth with a high rate during the last decade. In total 3,857 journal articles were published in 676 journals listed in the 102 subject categories. Maximum number of articles in adsorption of dyes was published by the *Journal of Hazardous Materials*. Almost 14% of all journals were listed in the physical chemistry field. China, USA and India published the maximum number of papers but USA published more internationally collaborative papers compared to other countries. Carbon is the evergreen adsorbent in this research field. In addition, analysis of distribution of author keywords and keywords plus in different periods could be a method to obtain research trends and recent hotspots in this wastewater treatment field. The new trend of the research work is reflected in terms of its citations from the time of its publication and the life of an article along with the h-index value. This has been clearly explained in this research field for the benefit of the new researchers. The result analysis by this bibliometric method can help relevant researchers to understand the panorama of global research and establish the further research direction.

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