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Patent activity on water pollution and treatment in China—a scientometric perspective

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Abstract This research intends to investigate the patent activity on water pollution and treatment in China (1985–2007), and then compares the results with patents data about Triadic patents, South Korea, Brazil and India over the same periods, patents data were collected from Derwent World Patents Index between 1985 and May 2008. For this study, 169,312 patents were chosen and examined. Total volume of patents, technology focus, assignee sector, priority date and the comparison with other countries are analyzed. It is found that patents on water pollution and treatment filed at China have experienced a remarkable increase and the increase rate of patents filed at China change simultaneous with the percentage of domestic applications. However, the number of high quality Triadic patents with priority country as China remains small. Furthermore, in addition to individual patent assignees, both Chinese universities and enterprises also play important roles in patent activity of water pollution and treatment. In addition, the pattern of South Korea's development can provide short-term implications for China and the regularity in Triadic patents' development can provide some guidance to China's long-term development. In contrast, the development pattern of Brazil and India is less influential to China's development. Furthermore, China's technology focuses on water pollution and treatment seem to parallel global and triadic patent trends. This research provides a comprehensive picture of China's innovation capability in the area of water pollution and treatment. It will help China's local governments to improve their regional S&T capability and will provide support the National Water Pollution Control and Treatment Project in China.

Keywords Scientometrics · DWPI database · Patent analysis · Water Pollution and Treatment in China

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Introduction

The amount of freshwater on Earth is limited, surging population growth, climate change, reckless irrigation and chronic waste are placing the world's water supplies at threat, a landmark U.N. report said (WWAP 2003). According to U.N. research, 20% of the world's population—1.1 billion people—cannot drink clean water by 2050 at least 2 billion people in 48 countries, and at most 7 billion people in 60 countries, will have serious trouble obtaining enough water. Properly managing water resources is an essential component of growth, social and economic development, poverty reduction and equity, and sustainable environmental services (WWAP 2009). Water pollution and treatment became one of the most important problems we have to face.

Water usage in China has quintupled since 1949. With the economic and social development in China, population increase and climate change and other reasons are pushing the country toward a water crisis. According to the report "National Water Environment Quality in 2007" (MEP 2009) published by the Ministry of Environmental Protection of the People's Republic of China in 2009, 26.5% of water in China's seven biggest river systems had been found to be unable to support animal life, 23.6% was dangerous even to bathe in. World Bank and government researchers recently estimated that 60,000 people in China are dying prematurely each year because of poor quality water, mainly in rural areas (Mure 2007). Water pollution has become one of the most important factors restricting the development of China's economy and society. Thus, it has drawn great attention from national and local governments. In June 2006, the Chinese government started to carry out the National Water Pollution Control and Treatment Project, which aims to improve the comprehensive S&T capability in water pollution control and treatment in China. However, water pollution control and water treatment is a long-term, arduous and complicated systematic project. At present, the key technology in this area has not been identified and serious loss of the situation has not changed. It is necessary to investigate and study the technology status and development trend in this area to support the National Water Pollution Control and Treatment Project.

The research adopts the scientometric methods to analyze the patent information on water treatment. Patent scientometrics is a well-established approach to assess the development status of different research communities and technology fields (Narin 1994). Most of the studies used the patent scientometrics methods mainly deal with four issues: patent counting, citation counting (Acosta et al. 2007), patent coupling (Lo 2008), and mapping (Igami 2008; Kettenring 2007; Porter et al. 2005; Chen et al. 1990). By counting the number of patents filed/granted each year, the growth of the research productivity could be drawn. The method was applied to analyze the productivity on countries (Fu et al. 2009; Tseng 2009; Sternitzke 2009; Sharma et al. 2008; OECD 2000; Zhou et al. 2008; Lo 2007; Chen et al. 2005; Bhattacharya 2004; Barroso et al. 2003; Trajtenberg 1968; Narin et al. 1987, 1988), assignees, inventors (Narin 1994; Azagra-Caro et al. 2007; Banerjee et al. 2000) and technology levels (Yu et al. 2009; Lee et al. 2009; Sakata et al. 2009; Breitzman et al. 2002; Grupp et al. 1999; Garg et al. 1998; Courtial et al. 1995). Many researchers have applied patent analysis at national level to show the technology innovation and trend, in this study, not only patent counting on countries and on assignees but also patent counting on technology field and on timeline are used for in-depth analysis of patent information.

This paper applies scientometric methods to analyze patents filed at China in the field of water pollution and water treatment since 1985, when China stipulated the Patent Law. The quantitative characteristics, distribution in specific technology areas and comparison with

some representative countries have been explored. It aims to draw a full picture about the current status and development trend of water treatment technologies in China, thereby leading to the further discussion of the issues and challenges that China are facing in the area.

In this case, this paper employs the three types of representative countries for comparison. The first type indicates developed countries, here we use Triadic patents which is defined by OECD (2000) as a set of patents taken at the European Patent office, the Japan Patent office and US Patent and Trademark office that protect the same invention as a representative, this is a frequently used indicator to assess the technological strengths of nations and the value of patents. The second type is a country that we can borrow ideas from, South Korea's per capita is 1,488 m^3 of water in the world among 153 countries in the first 130, China's per capita is only 2,400 m^3 of water, the world's average is 10,800 m^3 (Yang 2009), so South Korea and China are both countries seriously short of water resource, but South Korea has made great achievements in the field of water treatment, for example, the restoration and reconstruction work of Cheonggyecheon is an important construction practice towards improving Seoul city ecosystem environment (Leng et al. 2007), therefore South Korea is used for comparison. The third type includes two countries similar to China, which are Brazil and India. These three major players in the developing world are all facing critical water pollution.

Data and methods

Patents on water pollution and treatment from China, South Korea, Brazil and India as well as Triadic patents were analyzed. These data are referred to hereafter as the five groups. The data sources of patent documents are from Derwent World Patents Index® (DWPI) on Delphion platform provided by Thomson Reuters. DWPI covers patents from 41 countries and regions, the DWPI patent family is a collection of documents related to the same invention published in different countries and in various languages, which separates out significant departures from original filing of the invention. DWPI provides unique DWPI manual codes, and rewrites the original patent titles and abstracts into more descriptive language. Each DWPI manual code represents a unique concept, which normalizes all the different expressions of the same concept.

The water pollution and treatment is a complex field, which involves many disciplines. In order to retrieve data comprehensively and accurately, we used both the DWPI manual codes and important keywords in search. In addition, the search strategy was revised and validated by technology experts. The search was conducted in May 2008. The final version of the search strategy is as follows.

((((((A12-W11J OR D04* OR F05-A02C OR05-L02 OR H06-C02 OR N07-L01B OR Q24-B10 OR Q24-P06 OR X25-H03) < in > MANUALCODES) OR (("waste water" OR "water pollut*'' OR "water treat*'' OR "water contr*'' OR "water purif*'' OR "water refin*'' OR "water moni*'' OR "water detec*'' OR "wastewater" OR "water filtr*'')) < in > TEXT) NOT (U11* < in > MANUALCODES)) OR (((U11-C15Q OR U11-C15B3) < in > MANUALCODES) and (("wastewater" OR "waste water") < in > TEXT))) AND(PD > = 1985-01-01))) NOT (A12-W11L < in > MANUALCODES)

The search results with the above search strategy were further refined to patents filed at the State Intellectual Property of office of the People's Republic of China (SIPO), Korean

Intellectual Property of office (KIPO), India Controller General of Patents Designs & Trade Marks (CGPDTM) and Brazilian Patent of office (INPI) and Triadic patents respectively.

In this study, we identify total applications, patent assignee distribution, the top 20 fields of patents applications as well as the priority date for analysis. The priority date (first date of filing of a patent application to protect an invention) is the earliest and therefore closest to the invention date. Thomson Data Analyzer was applied to clean and analyze patent data on water pollution and water treatment, including the data fields of patent assignee, DWPI manual code, priority country, etc. The analysis focuses on China and the comparison with China, particular triadic patent families, South Korea, India and Brazil.

Results and discussion

Overview on patents of water pollution and treatment in China

Overall, the search strategy identified 169,312 patent inventions worldwide on water pollution and treatment over 1985–2007 period. Table 1 presents the trend of patents in water pollution and treatment at SIPO & DWPI between 1985 and 2007. The number of inventions in the area at DWPI had kept increasing from 1985 and peaked by 2000 and

Table 1 Trend of patents in water pollution and treatment at SIPO & DWPI over the period 1985–2007

Year	DWPI	SIPO	Domestic	Foreign	Domestic/SIPO
1985	4,221	137	74	63	0.54
1986	4,150	149	70	79	0.47
1987	4,112	138	71	67	0.51
1988	4,099	189	103	86	0.54
1989	4,418	175	110	65	0.63
1990	4,690	178	129	49	0.72
1991	4,748	208	137	71	0.66
1992	6,025	317	192	125	0.61
1993	5,318	409	198	211	0.48
1994	6,324	471	202	269	0.43
1995	7,123	514	184	330	0.36
1996	7,188	637	242	395	0.38
1997	8,144	666	251	415	0.38
1998	8,735	747	306	441	0.41
1999	9,146	787	351	436	0.45
2000	9,347	975	459	516	0.47
2001	9,909	1,096	552	544	0.50
2002	9,680	1,282	696	586	0.54
2003	9,985	1,645	956	689	0.58
2004	9,937	1,911	1,191	720	0.62
2005	10,621	1,920	1,579	341	0.82
2006	10,702	2,726	2,594	132	0.95
2007	10,690	1,001	956	45	0.96

then the annual inventions have stabilized. The patent applicants came from 86 different countries, demonstrating that the applied research of water pollution and treatment has drawn great attention all over the world. In terms of the total number of patents, Japan demonstrated its dominant position; USA and Germany ranked second and third; while China ranked 6th with a total of 18,278 patent applications.

As shown in Table 1, patent inventions in the field of water pollution and treatment filed at SIPO have demonstrated a stable and strong growing trend. From the increase rate of patents filed at SIPO and the percentage of domestic applications, we can find that the change of increase rate and the change of the percentage happen at the same time, so the growth pattern can be divided into four periods. The first period is from 1985 to 1990, in this period, the number of applications increased slowly, in 1985, the number of applications is 137 and in 1990 the number is 178, but the percentage of domestic applications increased greatly, from 54% in 1985 to 72% in 1990. The second period is from 1991 to 1996, the number of applications increased more quickly, from 208 in 1991 to 637 in 1996, with 306% increase, but the percentage of domestic applications decreased dramatically, from 66% in 1991 to 38% in 1996, implying that other countries attach importance to Chinese water treatment market increasingly. The third period is from 1997 to 2004, both the number and the percentage of domestic applications increased greatly, the number is 1,911 and the percentage of domestic applications is 62% in 2004. The fourth period is 2005–2006, both the number and the percentage of domestic applications increased dramatically, with 2,726 patents filed at China and 95% of domestic applications in 2006.

Table 1 shows that the Chinese government has strengthened environmental protection and raised corresponding financial support to science and technology in this area since 1997. It is worth mentioning that the number of foreign applications decreased greatly in 2005. Nevertheless, in the same year, there are still many countries and regions such as USA, Japan, Australia, EU who filed patents actively in China, indicating the importance of the China market to those countries. In 2006, USA was still the leading country in terms of patent applications in China on water pollution and treatment. (The number of patents in 2007 is comparatively low because it takes 18 months to publicize the patent applications).

Further analysis shows that out of total 7,061 Triadic patents, 2,493 were filed at China, indicating that the Chinese market has attracted over 35% of high technologies owners in this field. However, only 62 Triadic patents' priority countries are China. Thus, high value innovations on water pollutions and treatment are still lacking in China.

Moreover, the analysis on patents assignee shows that individual inventers contribute a significantly higher proportion of total patent applications (54%). Universities and enterprises also play important roles (both 19%) while research institutes produced only 8% of patents in water pollution and treatment field.

Further analysis of the top 20 assignees indicates that the Chinese universities (15 out of 20) are the majority, while there are only 3 research institutes and 2 companies (see Table 2). We also investigate the collaboration network of the top assignees but little collaboration among enterprises, universities, and research institutes is found.

Comparison of increase rate in patents of water pollution and treatment among five groups

Let us look at the number of patents from the five groups by annual increase. Figure 1 shows a clear increase of China applications compared to other four groups from 1985 to 2007. The number of inventions in Brazil, India, South Korea and Triadic patents had kept increasing from 1985 and peaked by a certain year, however the number of patent

Table 2 Top 20 assignees in China

Rank	Assignee	Number of patents
1	Research Center for Eco-Environmental Sciences, CAS	184
2	Tsinghua University	157
3	Harbin Institute of Technology	151
4	China Petroleum & Chemical Corporation	149
5	Nanjing University	128
6	Zhejiang University	113
7	Shanghai Jiao Tong University	89
8	South China University of Technology	88
9	Tongji University	84
10	Shanghai Wansen Water treatment Co., Ltd	78
11	Tianjin University	65
12	Dalian University of Technology	43
13	Nankai University	38
14	Dalian Institute of Chemical Physics, CAS	32
15	Shandong University	30
16	The Institute of Applied Ecology, CAS	29
17	Southeast University	29
18	Sun Yat-sen university	27
19	Sichuan university	27
20	University of Science and Technology Beijing	27

inventions on water pollution and treatment filed at SIPO had kept a stable increase. Further investigates the average annual increase rate and the percentage of domestic applications in the five groups, from which some interesting phenomenon was found.

The number of patents at SIPO experienced a growth process very similar to the patents at KIPO, with the annual average increase keeping growing until reaching a peak. The annual average increase in the volume of the patents at KIPO surpasses 100 items since 1992, while the same number of patents at SIPO was reached in 1997, and a dramatic increase of the number of the patents at KIPO was occurred between 2002 and 2004, while the great increase in China was occurred between 2004 and 2006. This phenomenon illustrates that South Korea paid attention to water pollution and treatment earlier than China, and the development of water treatment technology in South Korea might have priority over China. However, with China's gradual emphasis on water pollution issues, the gap in terms of the number of patents and timing of two countries on the water treatment patents was diminishing. Thus, experiences from South Korea on the development of water treatment patents can be used for China in that regard as an important reference for future development.

The patents activities in Brazil and India were largely involved by the United States and Europe. The top 20 foreign institutions of water treatment patents registered in Brazil and India are all come from United States and Europe, and their numbers of patent applications are more than 20% of the total of foreign applications. Further investigation on the percentage of domestic applications in the four counties between 1985 and 2007 shows in Table 3. As shown in Fig. 1 and Table 3, the relationship of the number of patents in

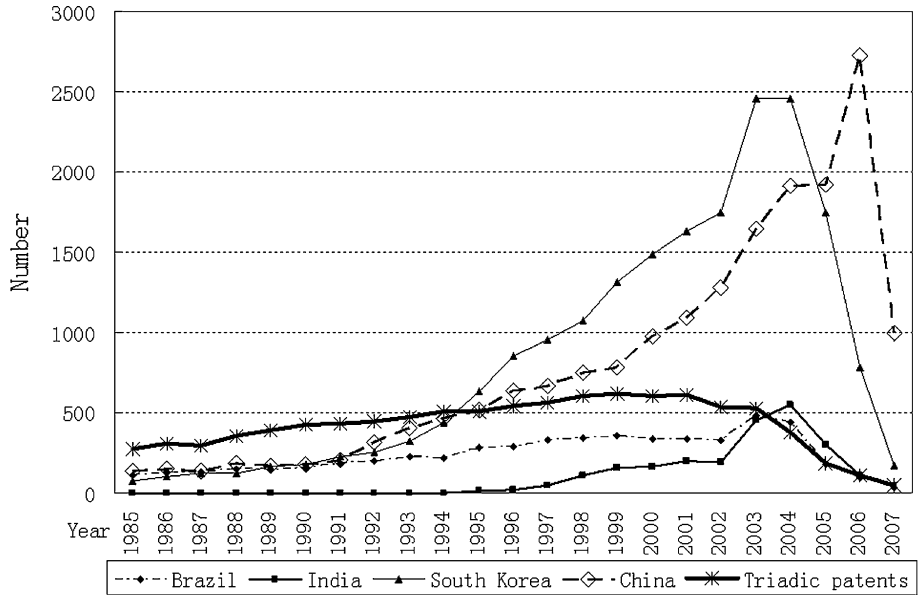

Fig. 1 Patents of water pollution and treatment of the five groups

Table 3 Domestic and foreign patent applications at four countries

	China	South Korea	Brazil	India
Domestic	11,603	13,239	880	435
Foreign	6,675	5,042	3,830	1,514

Brazil, India and Triadic patents validates our speculation. When the number of Triadic patents begins to decline significantly, the numbers of patent applications in Brazil and India dominated by foreign are also started its rapid decline in the ensuing years.

There is some similarity in the patent pattern on water treatment in China, Brazil and India, because the three counties have the similar level of economic development and water pollution, while there also existing some differences among them. Firstly, the numbers of patents in three countries increase gradually and then increase dramatically, but the growth rate of the number of patents in Brazil and India is significantly less than China. Secondly, Table 3 indicates that the percentage of domestic applications in India is 22.3% and the percentage of domestic applications in Brazil is 18.7%, on the contrary, the percentage of domestic applications in China is 63.5%. It also can be seen, China place more emphasis on water treatment technology research and development, so the technical development pattern of water treatment in Brazil and India is not appropriate to China.

Through thorough investigation on Fig. 1, we find that the development process of water treatment in United States, Europe and Japan, which claim the world's most advanced water treatment technology, are very different from China, implying that there is still a wide quality gap between SIPO and Triadic patents.

In summary, we examine the development process of water treatment patents in China and then compare the results with the ones in South Korea, Brazil, India and Triadic

patents. It may be observed that the pattern of South Korea's development can provide short-term reference for China and the regularity in Triadic patents' development can provide some guidance to China's long-term development, however, although Brazil and India has a similar economic conditions and water pollution problems to China, there is a big difference in each indigenous-innovation system, the development pattern of Brazil and India is less influential to China's development. Next, the technology fields of water treatment will be further research focus on China, South Korea and Triadic patents.

Technology focuses of water pollution and treatment patents

The technology focus of a field can be measured through the distribution of its patents over various specific technological areas. In this study, if there are more concentrated patents in certain technological areas, these areas are defined as the technology focus in the field of water pollution and treatment. DWPI manual codes, the unique classification scheme that highlights the application aspect of an invention, are used to analyze technology focus.

Based on the analysis of DWPI manual codes in terms of the number of Chinese patents in each sub-area, the top 20 areas include "Purification of water by other filtration processes", "Water treatment (compositions) scale inhibition", "Purification of water by other method", "Water and sewage treatment", etc. (See Fig. 2).

Furthermore, the comparison between the top 20 DWPI manual codes of patents filed at China and those of Triadic patents demonstrates that 15 out of 20 top manual codes are the same, implying that the technology focuses in water pollution and treatment in China are in line with the ones in developed countries. "Dewatering sludge", "Other filtration process", "Oxidation/aeration with other", "Purification of water [general]", "Removal of inorganic nitrogen compounds from water" are only in the patents filed at SIPO, implying that the technology in China focuses on industrial wastewater treatment. And "Measuring purity of water", "Removal of metals from water", "Removal, effluent treatment—processes, apparatus", "Reverse osmosis; semi-permeable membranes", "Semi-permeable membrane separation processes" only appeared in Triadic patents, implying that the technology in

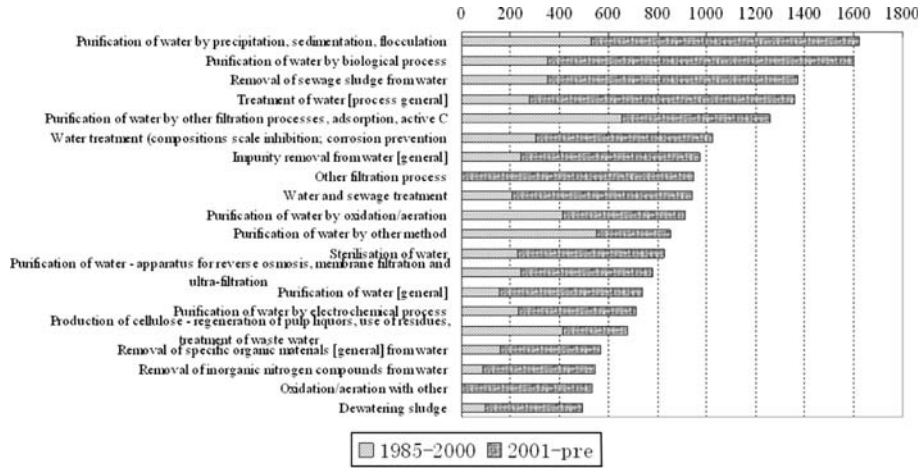

Fig. 2 Time frame of top 20 DWPI manual codes of water pollution and treatment patents filed at SIPO (1985–2000 vs. 2001-present)

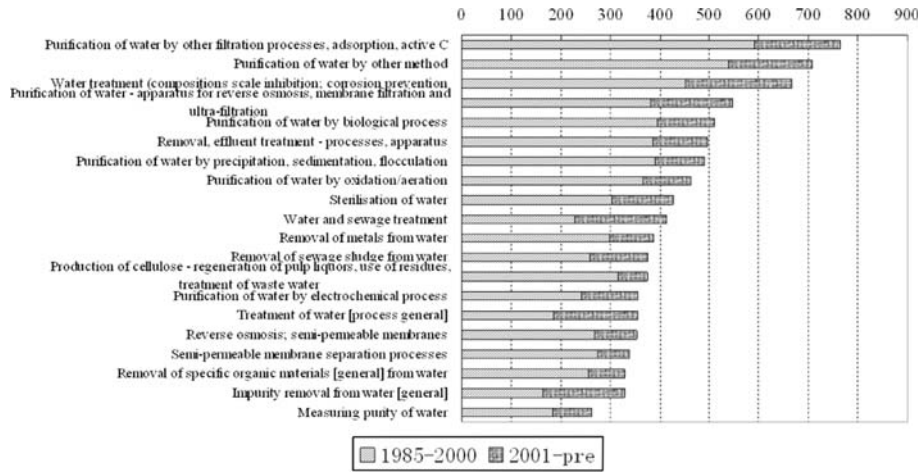

Fig. 3 Time frame of top 20 DWPI manual codes of water pollution and treatment patents filed at Triadic patents (1985–2000 vs. 2001-present)

Triadic patents focuses on removal something from water and purification of water (See Figs. 2, 3).

In addition, the comparison between the top 20 DWPI manual codes of patents filed at China and those of South Korea demonstrates that 18 out of 20 top manual codes are the same, implying that the technology focuses in water pollution and treatment in China are much similar with South Korea (See Figs. 2, 4).

Figure 2 shows the patent distribution of top 20 DWPI manual codes in China over time. After comparing the patent numbers in those two different time frames 1985–2000 and 2001-present, we found that most applications in those technology focuses those areas after year 2001. In particular, 80% of patents on "Water treatment (compositions)scale

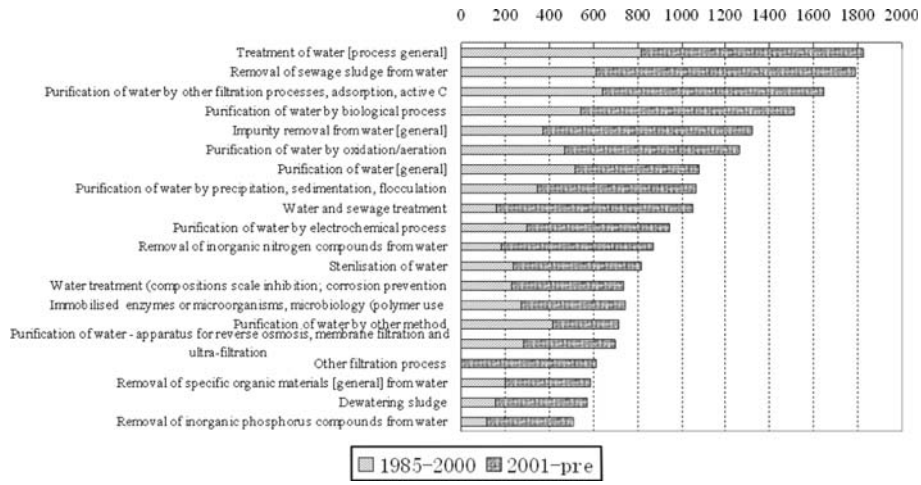

Fig. 4 Time frame of top 20 DWPI manual codes of water pollution and treatment patents filed at KIPO (1985–2000 vs. 2001-present)

Table 4 The distribution of top 20 technology fields of patents filed at SIPO, KIPO and Triadic patents over the period 2001-2007

Technology fields by DWPI manual codes	SIPO	KIPO	Triadic patents
Desalination of brine or sea water	✔		
Dewatering sludge	✔	✔	
Immobilised enzymes or microorganisms, microbiology (polymer) use		✔	
Impurity removal from water [general]	✔	✔	✔
Measuring purity of water			✔
Organic waste, town waste or sludge fermentation	✔		
Other filtration process	✔		
Oxidation/aeration with other	✔		
Purification of water-apparatus for reverse osmosis, membrane filtration and ultra-filtration	✔	✔	✔
Purification of water [general]	✔	✔	
Purification of water by biological process	✔	✔	✔
Purification of water by electrochemical process	✔	✔	✔
Purification of water by ion exchange			✔
Purification of water by other filtration processes, adsorption, active C	✔	✔	✔
Purification of water by other method		✔	✔
Purification of water by oxidation/aeration	✔	✔	✔
Purification of water by precipitation, sedimentation, flocculation	✔	✔	✔
Removal of inorganic nitrogen compounds from water	✔	✔	
Removal of metals from water		✔	✔
Removal of sewage sludge from water	✔	✔	✔
Removal of specific organic materials [general] from water	✔	✔	✔
Removal, effluent treatment-processes, apparatus		✔	✔
Reverse osmosis; semi-permeable membranes			✔
Sterilisation of water	✔	✔	✔
Testing and detection [exc. bacteria, fungi, viruses]			✔
Treatment of water [process general]	✔	✔	✔
Water and sewage treatment	✔	✔	✔
Water treatment (compositionsscale) inhibition; corrosion prevention	✔	✔	✔

inhibition; corrosion prevention", "Water and sewage treatment", "Purification of water by biological process", "Purification of water-apparatus for reverse osmosis, membrane filtration and ultra-filtration", "Removal of sewage sludge from water", "Purification of water by electrochemical process", and "Sterilisation of water" were filed after 2000. Moreover, the same analysis over patents in top 20 technology focus in the same time frame shows same trends (Fig. 4), that is, most South Korean patents were filed after 2000. However, the same analysis over patents in top 20 technology focus of Triadic patents in the same time frame shows opposite trends(Fig. 3), that is, most Triadic patents were filed before 2000, implying the maturity of technologies in USA, Japan and Europe.

In addition, Table 4 illustrates the distribution of top 20 technology fields of patents filed at SIPO, KIPO and Triadic patents between 2001 and 2007. After 2000, the comparison between the top 20 DWPI manual codes of patents filed at SIPO and KIPO shows

that only 12 out of 20 top manual codes are the same, which is lower than the number of matches (18 out of 20) between 1985 and 2007. The technology focuses in water pollution and treatment in China are different from South Korea. This study suggested that the Chinese Government to strengthen the field of "Immobilised enzymes or microorganisms, microbiology (polymer) use", "Purification of water by other method", "Removal of metals from water" and "Removal, effluent treatment-processes, apparatus" etc. in the short-term future.

Moreover, after 2000, the comparison between the top 20 DWPI manual codes of patents filed at SIPO and Triadic patents shows that only 6 out of 20 top manual codes are the same, implying that after 2000, the technology focuses in water pollution and treatment in China are different from the ones in developed countries. This result suggested that the Chinese Government should strengthen the field of "Measuring purity of water", "Purification of water by ion exchange", "Removal of metals from water" and "Reverse osmosis; semi-permeable membranes" etc. in the long-term future.

In general, this result also suggested that the Chinese Government should consider shift its support focus from the following field "Desalination of brine or sea water", "Organic waste, town waste or sludge fermentation", "Other filtration process" and "Oxidation/aeration with other".

Conclusion

This paper intends to study water pollution and treatment patents filed at China since 1985. Total volume of patents, technology focuses, assignee sectors, priority date and the comparison with other countries are analyzed. We found that

(1) Patents on water pollution and treatment filed at China have a stable and remarkable increase, while the numbers of inventions in the area at DWPI have kept increasing from 1985 and peaked by 2000. The increase rate of patents filed at SIPO change simultaneous with the percentage of domestic applications. However, the number of Triadic patents with priority country being China is small.
(2) In addition to individual patent assignees, both Chinese universities and enterprises also play important roles in patent activity of water pollution and treatment.
(3) The pattern of South Korea's development can provide short-term implications for China and the regularity in Triadic patents' development can provide some guidance to China's long-term development. In contrast, the development pattern of Brazil and India is less influential to China's development.
(4) China's technology focuses in water pollution and treatment seem to parallel global and triadic patent trends. Most China and South Korean patents were filed after 2000, and most Triadic patents were filed before 2000 to the contrary, showing fast innovation in water pollution and treatment in China.
(5) The study suggested that the Chinese Government strengthen such fields as "Immobilised enzymes or microorganisms, microbiology (polymer) use", "Purification of water by other method", "Removal of metals from water" and "Removal, effluent treatment-processes, apparatus" etc. in the coming five years and strengthen the field of "Measuring purity of water", "Purification of water by ion exchange", "Removal of metals from water" and "Reverse osmosis; semi-permeable membranes" etc. in the long-term future. We believe that in the future, the Chinese Government could reduce its support for such fields as "Desalination of brine or sea

water", "Organic waste, town waste or sludge fermentation", "Other filtration process" and "Oxidation/aeration with other".

This study describes the trend path and current status of patent activity in water pollution and treatment in China. We hope that the study can provide science policy makers a whole picture about innovation capability in this particular field and help them to make better decisions, especially for the National Water Pollution Control and Treatment Project in China.

The next stage of this study will invite experts in the field to explain the results from the patent analysis. Also, patent citation analysis of China's Triadic patents should be able to help identify key technologies.

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