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# A BIBLIOMETRIC ANALYSIS OF DESALINATION RESEARCH DURING 1997-2012

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**ABSTRACT**

This study explores a bibliometric approach to quantitatively assessing current research trends on desalination, by using the related literature published between 1997 and 2012 in journals of all the subject categories of the Science Citation Index (SCI). The articles acquired from such literature were concentrated on the general analysis by publication type and language, characteristics of articles outputs, country, subject categories and journals, and the frequency of title-words and keywords used. Over the past 16 years, there had been a significant increase trend in publication outputs, along with more participation of countries/territories. The seven major industrialized countries (G7) published the majority of the world articles, while their article share was being replacing by other countries represented by BRIC countries. An analysis of the title-words and author keywords showed that seawater desalination and membrane technologies were the hottest topics in desalination research. In addition, forward osmosis and capacitive deionization have attracted great attention in the list since 2005. The findings of this study can help relevant researchers understand the performance of desalination research in the world, and suggest directions for further research by a bibliometric method.

**KEYWORDS**

Desalination, Bibliometric, SCI, Membrane, Reverse osmosis.

## 1. INTRODUCTION

Many countries in the world suffer from a shortage of natural fresh water. Worldwide drought and desertification are expected to sharpen the problem [1]. Today, some countries depend on desalination technologies for the purpose of meeting their fresh water requirements. Water desalination on an industrial scale was initiated during the early part of the 20th century [2]. Desalination technologies usually include multi-stage flash (MSF) and multiple effect distillation (MED), membrane reverse osmosis (RO), nanofiltration, etc. With the increasing water demand and the scarcity of renewable natural water resources, the dependence on desalination will continue to grow and consequently its energy consumption and impact on environment will increase without bounds [3]. Overall, it is estimated that over 75 million people worldwide obtain fresh water by desalinating seawater or brackish water.

So far, there have been a number of published papers which have reviewed the economics, cost, process control, solar energy application, renewable energies for desalination technologies [1-6]. Despite the importance of water desalination, there have been few attempts to gather data about the worldwide scientific production of desalination research. Bibliometric studies provided an accurate and presumably objective method to measure the contribution of a paper to the advancement of knowledge [7]. And the *Science Citation Index* (SCI) from the Web of Science databases is the most widely accepted and frequently used database for analysis of scientific publications [8]. Bibliometric indicators including publication countries, research fields, journals, title-words, author keywords and keywords plus have been frequently used to analyze the trends and performance [9,10]. Tanaka and Ho evaluated the global scientific output of desalination research to assess the characteristics of the research tendencies and the research performances during 1991-2008 [11]. However, a large number of articles about desalination technologies have been published since 2009. Therefore, a new bibliometric study is needed to assess the characteristics of the research tendencies and the research performances.

The objective of this study is to analyze the status and trends of desalination research during 1997-2012 in order to help researchers understand the panorama of global desalination research, and predict the dynamic directions of research.

## 2. MATERIALS AND METHODS

One common method of bibliometric research is to trace publications using the SCI of the Institute for Scientific Information (ISI). The data used in this study were based on the database of the SCI published by Thomson Reuters Web of Science, Philadelphia, PA, USA. The topic search can trace the related information in the title, abstract, and key-words at one time [12]. "Desalination", "desalinat*", "desaliniz*" "desalt*" were used as the search phrases to search topics in SCI for the period from 1997 to 2012. The records were then downloaded to a compact disc. The data collected has been examined to assure their identity. Subsequently, the data were analyzed by Microsoft Excel 2010. Articles originating from England, Scotland, North Ireland, and Wales were grouped under the UK heading. Articles from Hong Kong, Macao, and Taiwan were not included in Mainland China.

The study was conducted to determine the trends and performance that including the type and language of publications, characteristics of article output, publication outputs of country, distribution of outputs in subject categories and journals, and frequency of title-words, author keywords, and keywords plus from 1997 to 2012.

## 3. RESULTS AND DISCUSSION

### 3.1 Type of publications and languages of publications

There were 6483 papers related to desalination research in the database, including 10 document types. Journal articles (6064) comprised 93.62% of the total production, followed distantly by proceedings papers (1478; 22.82%), reviews (181; 2.80%), news item (91; 1.41%) and editorial materials (72; 1.41%). The others with less significance were, meeting abstracts (41), letters (17), corrections (9), book chapter (4), and reprints (2). English was the most used language, making up 98.19 % of all the published articles. Obviously, English was by far the dominant language in the journals listed in SCI.

### 3.2 Characteristics of article outputs

**Table 1:** Characteristics of article outputs during 1997-2012

| Year | A | PG | PG/A | NR | NR/A | AU | AU/A | J | A/J |
|---|---|---|---|---|---|---|---|---|---|
| 1997 | 169 | 1687 | 10.0 | 3060 | 18 | 519 | 3.1 | 81 | 2.1 |
| 1998 | 170 | 1563 | 9.2 | 2948 | 17 | 558 | 3.3 | 80 | 2.1 |
| 1999 | 241 | 2210 | 9.2 | 3990 | 17 | 744 | 3.1 | 100 | 2.4 |
| 2000 | 169 | 1582 | 9.4 | 2920 | 17 | 526 | 3.1 | 92 | 1.8 |
| 2001 | 316 | 2843 | 9.0 | 4679 | 15 | 892 | 2.8 | 80 | 4.0 |
| 2002 | 195 | 1850 | 9.5 | 3732 | 19 | 658 | 3.4 | 103 | 1.9 |
| 2003 | 332 | 2995 | 9.0 | 5599 | 17 | 982 | 3.0 | 90 | 3.7 |
| 2004 | 319 | 3053 | 9.6 | 6306 | 20 | 1030 | 3.2 | 124 | 2.6 |
| 2005 | 401 | 3948 | 9.8 | 8614 | 21 | 1252 | 3.1 | 130 | 3.1 |
| 2006 | 317 | 3021 | 9.5 | 7215 | 23 | 1107 | 3.5 | 146 | 2.2 |
| 2007 | 438 | 4191 | 9.6 | 9417 | 22 | 1499 | 3.4 | 162 | 2.7 |
| 2008 | 484 | 4557 | 9.4 | 11416 | 24 | 1626 | 3.4 | 182 | 2.7 |
| 2009 | 646 | 5918 | 9.2 | 15966 | 25 | 2308 | 3.6 | 191 | 3.4 |
| 2010 | 691 | 6151 | 8.9 | 20231 | 29 | 2610 | 3.8 | 210 | 3.3 |
| 2011 | 803 | 7452 | 9.3 | 27413 | 34 | 3116 | 3.9 | 248 | 3.2 |
| 2012 | 792 | 7249 | 9.2 | 27334 | 35 | 3226 | 4.1 | 260 | 3.0 |

A number of articles, PG page count, PG/A the average page count per article, NR cited reference count, NR/A the average cited reference count per article, AU number of authors, AU/A the average authors per article, A/J the average number of articles published per journal.

The publication output of desalination research from 1997 to 2012 is summarized in Table 1. It was observed that the annual amount of articles, cited references, authors per paper and the average number of articles in each journal increased considerably. The number of articles increased to nearly five-fold from 169 in 1997 to 792 in 2012. 18 references were cited per article in 1997, compared to 35 references per article in 2012. The number of authors per article rose from 3.1 to 4.1. In addition, the average number of articles per journal rose steadily from 2.1 per journal in 1997 to 3.0 in 2012. However, the average article length decreased slightly during the study period.

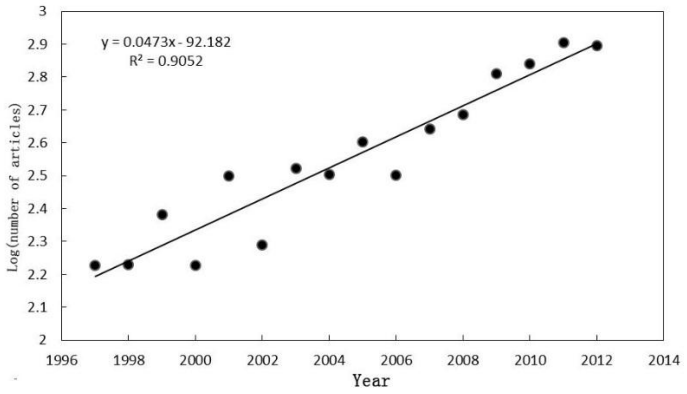


**Figure 1:** Log-transformed number of articles on desalination during 1997-2012

The progression in the number of articles from 1997 to 2012 was further studied and demonstrated in Figure 1. Significant correlations were found between the log-transformed number of articles and the period of 1997-2012. The growth patterns of the progression were simulated by a linear model with coefficient of determination ($R^2$= 0.9052) and increasing rate (0.0473).

### 3.3 Publication distribution by countries

**Table 2:** Top 20 most productive countries of articles during 1997-2012

| Countries / Territories | 97-12 TA | 97-12 (%) | 97-00 R (%) | 01-04 R (%) | 05-08 R (%) | 09-12 R (%) | 97-12 Change |
|---|---|---|---|---|---|---|---|
| USA | 1126 | 17.4 | 1(16.3) | 1(14.9) | 1(16.6) | 1(19.0) | |
| Mainland China | 642 | 9.9 | 15(2.3) | 6(4.7) | 2(10.6) | 2(13.5) | +++ |
| Spain | 408 | 6.3 | 7(4.5) | 3(6.3) | 3(6.2) | 4(6.8) | |
| Germany | 345 | 5.3 | 2(8.5) | 2(6.5) | 4(5.6) | 10(3.9) | |
| South Korea | 313 | 4.8 | 31(0.7) | 19(2.0) | 11(2.9) | 3(8.1) | +++ |
| UK | 301 | 4.6 | 5(6.4) | 5(5.3) | 5(4.4) | 7(4.1) | - |
| Japan | 263 | 4.1 | 3(8.1) | 4(5.3) | 10(3.0) | 13(3.1) | --- |
| Israel | 259 | 4.0 | 12(3.2) | 8(4.1) | 7(4.0) | 6(4.1) | |
| Australia | 254 | 3.9 | 19(1.5) | 18(2.0) | 15(2.4) | 5(6.2) | ++ |
| France | 235 | 3.6 | 8(4.1) | 9(3.8) | 6(4.3) | 14(3.0) | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Saudi Arabia | 220 | 3.4 | 6(5.9) | 12(2.8) | 23(1.6) | 8(4.0) | |
| India | 208 | 3.2 | 14(2.5) | 13(2.4) | 8(3.2) | 11(3.7) | + |
| Kuwait | 174 | 2.7 | 4(6.8) | 10(3.6) | 13(2.4) | 22(1.4) | --- |
| Italy | 165 | 2.5 | 10(3.3) | 15(2.2) | 9(3.2) | 16(2.1) | |
| Singapore | 159 | 2.5 | 46(0.4) | 30(1.3) | 22(1.6) | 9(3.9) | +++ |
| Egypt | 152 | 2.3 | 20(1.5) | 7(4.4) | 21(1.9) | 19(2.0) | |
| Netherlands | 147 | 2.3 | 13(2.7) | 22(1.8) | 17(2.2) | 15(2.4) | |
| Canada | 146 | 2.3 | 16(2.1) | 17(2.1) | 12(2.8) | 18(2.0) | |
| Russia | 137 | 2.1 | 9(3.5) | 11(3.3) | 16(2.3) | 26(1.2) | -- |
| Iran | 132 | 2.0 | NF(0.0) | 42(0.5) | 27(1.3) | 12(3.6) | ++ |

TA total published articles in the 15 years, % percentage of all articles published in the years, Change the increasing change (+, ++, +++) or the decreasing change (-, --, ---) of percentage of published articles in the 15 years (no symbol means little changes in percentage)

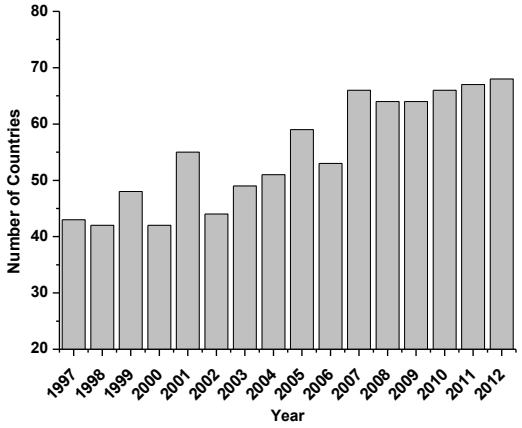


**Figure 2:** Growth trends of number of countries in 1997-2012

There were 132 articles without any author address information on the ISI Web of Science. Remained 6153 publications were from 99 countries/territories. More and more countries participated in study of this field during the past 15 years (Fig.2). The top 20 countries were ranked by the number of articles (Table 2). Two North and Central American countries, seven European countries, nine Asian countries, Egypt and Australia were ranked in the top 20. All of the seven major industrialized nations of the world (G7), USA, Italy, Japan, Germany, UK, Canada and France were in the top 10 countries. The pattern of domination in publication of the G7 has occurred in most scientific fields, reflecting the high economy activity and academic level of these countries [13,14]. In addition, BRIC countries (Brazil, Russia, India and China) have attracted great concern in the list of top 20 countries. Three of BRIC countries, China, India and Russia were in the top 20 countries and had a notable growth while Brazil took the 24th place during 1997-2012. Five Middle Eastern countries (Israel, Saudi Arabia, Kuwait, Egypt and Iran) attracted great attention in the top 20 list. Arid geographical conditions could explain the observations [15]. Besides, Asian countries showed a notable increase trend especially for China, South Korea and Singapore.

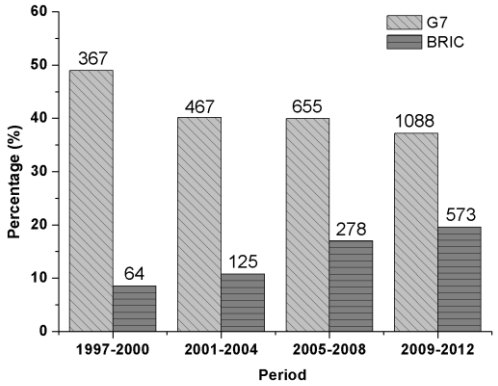


**Figure 3**: Comparison between G7 and BRIC countries on the number and percentage of articles

The comparison between G7 and BRIC countries is demonstrated in Fig.3. Although G7 countries played a predominant role in desalination research and the articles from these countries kept increasing in quantity, their article share kept decreasing during the study period. On the contrary, BRIC countries had a significant growth in both article number and share. Especially for Mainland China (Table 2), the number of SCI publications took the second place in 2005-2012 and the second place in the whole study period. It may be attributed to the rapid growth of its population and national economy in the past decades.

### 3.4 Distribution of output in subject categories and journals

**Table 3:** Top 20 subject categories with the most articles for 4-year periods

| Categories | 97-12 TA | 97-12 (%) | 97-00 R (%) | 01-04 R (%) | 05-08 R (%) | 09-12 R (%) | 97-12 Change |
|---|---|---|---|---|---|---|---|
| Engineering Chemical | 3428 | 52.9 | 1(47.4) | 1(59.1) | 1(52.3) | 1(52.1) | |
| Water Resources | 2881 | 44.4 | 2(42.5) | 2(54.6) | 2(42.3) | 2(42.1) | |
| Energy Fuels | 515 | 7.9 | 4(8.3) | 5(5.7) | 6(6.3) | 4(9.6) | + |
| Environmental Sciences | 474 | 7.3 | 7(5.0) | 8(3.6) | 7(6.2) | 3(10.0) | +++ |
| Chemistry Analytical | 458 | 7.1 | 3(9.7) | 3(7.7) | 3(8.7) | 7(5.2) | -- |
| Polymer Science | 443 | 6.8 | 8(4.8) | 6(4.9) | 5(6.5) | 5(8.3) | ++ |
| Biochemical Research Methods | 320 | 4.9 | 6(6.3) | 4(6.0) | 4(7.2) | 12(2.9) | - |
| Engineering Environmental | 317 | 4.9 | 10(2.9) | 9(2.8) | 9(4.1) | 6(6.7) | +++ |
| Chemistry Multidisciplinary | 214 | 3.3 | 14(2.3) | 11(2.4) | 11(2.9) | 9(4.2) | + |
| Biochemistry Molecular Biology | 211 | 3.3 | 5(7.1) | 7(3.8) | 8(4.1) | 19(1.6) | --- |
| Thermodynamics | 206 | 3.2 | 11(2.8) | 13(2.0) | 12(2.8) | 11(4.0) | |
| Chemistry Physical | 179 | 2.8 | 22(1.2) | 17(1.5) | 20(1.6) | 8(4.3) | + |
| Engineering Civil | 178 | 2.7 | 12(2.4) | 10(2.5) | 10(4.0) | 14(2.2) | |
| Materials Science Multidisciplinary | 169 | 2.6 | 29(0.9) | 27(0.7) | 18(2.0) | 10(4.1) | ++ |
| Biotechnology Applied Microbiology | 146 | 2.3 | 9(3.2) | 14(1.9) | 17(2.1) | 13(2.2) | |
| Food Science Technology | 136 | 2.1 | 15(2.3) | 12(2.1) | 13(2.7) | 18(1.7) | |
| Mechanics | 126 | 1.9 | 17(2.1) | 16(1.7) | 15(2.1) | 16(1.9) | |
| Engineering Mechanical | 125 | 1.9 | 19(1.9) | 18(1.4) | 19(2.0) | 15(2.1) | |
| Spectroscopy | 98 | 1.5 | 18(2.0) | 15(1.9) | 16(2.1) | 26(0.9) | - |
| Chemistry Applied | 93 | 1.4 | 20(1.3) | 20(1.1) | 14(2.1) | 22(1.2) | |

TA total published articles in the 15 years, % percentage of all articles published in the years, Change the increasing change (+, ++, +++) or the decreasing change (-, --, ---) of percentage of published articles in the 15 years (no symbol means little changes in percentage)

There was a great diversity including 142 subject categories related to the research topic of desalination in Journal Citation Reports (JCR) of the ISI. Top 20 subject categories with the most articles were listed in Table 3, containing the rank and the percentage of the article quantities in three periods (every 4 years from 1997 to 2012), and the extent along 16 years. The five most common categories were Engineering Chemical (52.9%), Water Resources (44.4%), Energy Fuels (7.9%), Environmental Sciences (7.3%) and Chemistry Analytical (7.1%) along 16 years. Especially for the field of Engineering Chemical and Water Resources, they both played dominated roles all through the past 16 years. The most rapid growth were "Environmental Sciences'' and "Engineering Environmental", from 5.0% to 10.0 % and 2.9% to 6.7%, respectively. More and more studies about wastewater treatment by using desalination technologies could explain above observation [16-18]. The article percentage in Polymer Science and Materials Science Multidisciplinary showed a significant increase. For high recovery and low energy consideration, material research have become hot study spots in the study period [19,20]. However, significant decrease of percentage was observed in the following categories: Chemistry Analytical and Biochemistry Molecular Biology, which may indicated that more and more concern was focused on environmental application and material research comparing to traditional chemistry or molecular biology field.

**Table 4:** Top 20 journals with the most articles during 1997-2012

| Journals | TA |
|---|---|
| Desalination | 2004 |
| Desalination and Water Treatment | 474 |
| Journal of Membrane Science | 350 |
| Analytical Chemistry | 80 |
| Separation and Purification Technology | 76 |
| Renewable Energy | 73 |
| Water Research | 67 |
| Journal of Chromatography A | 66 |
| Water Science and Technology | 63 |
| Industrial Engineering Chemistry Research | 62 |
| Energy | 58 |
| Environmental Science Technology | 58 |
| Filtration Separation | 48 |
| Solar Energy | 44 |
| Renewable Sustainable Energy Reviews | 41 |
| Analytical Biochemistry | 39 |
| Energy Conversion and Management | 38 |
| Electrophoresis | 37 |
| Applied Thermal Engineering | 34 |
| Journal of Chromatography B Analytical Technologies in The Biomedical and Life Sciences | 34 |

There were 6064 papers published in a wide range of 500 journals. The 20 journals with the largest number of published papers are listed in Table 4. There are 12 journals with more than 50 published articles on desalination research from 1997 to 2012. *Desalination*, *Desalination and Water Treatment*, *Journal of Membrane Science* and *Analytical Chemistry* published most articles in the 16 years. *Desalination* held primacy during the past 15 years. In addition, membrane technology has become the most hot research topics in desalination field. Besides, five journals which focused on energy research have attracted great attention in the list. In fact, current desalination methods require large amounts of energy which is costly both in environmental pollution and in money terms [1]. Energy source acts as one of the most important factors affecting the desalination cost. Therefore energy research for desalination was one of the hot spots in desalination study.

### 3.5 Analysis of title-words

**Table 5:** Top 30 most frequency of title-words for every 4 year period

| Title-words | 97-12 TA | 97-12 (%) | 97-00 R (%) | 01-04 R (%) | 05-08 R (%) | 09-12 R (%) | 97-12 Change |
|---|---|---|---|---|---|---|---|
| Desalination | 2159 | 16.8 | 1(18.6) | 1(19.7) | 1(16.5) | 1(15.1) | |
| Water | 1329 | 10.3 | 2(10.7) | 2(10.56) | 2(10.2) | 3(10.1) | |
| Membrane | 1249 | 9.7 | 3(7.4) | 4(6.5) | 3(8.3) | 2(11.9) | +++ |
| Reverse | 816 | 6.3 | 4(7.1) | 3(7.9) | 4(5.6) | 4(7.9) | |
| osmosis | 697 | 5.4 | 5(5.0) | 7(4.1) | 5(4.5) | 5(6.3) | |
| Seawater | 591 | 4.6 | 6(4.8) | 5(5.4) | 6(4.4) | 6(4.3) | |
| Solar | 471 | 3.7 | 8(3.4) | 8(3.3) | 8(3.5) | 7(3.9) | + |
| System | 437 | 3.4 | 9(3.3) | 10(3.0) | 9(3.3) | 8(3.5) | |
| Analysis | 412 | 3.2 | 10(3.1) | 9(3.3) | 7(4.0) | 12(2.7) | |
| Plant | 393 | 3.1 | 7(3.8) | 6(4.3) | 11(3.2) | 14(2.3) | - |
| Energy | 340 | 2.6 | 16(2.3) | 12(2.5) | 15(2.4) | 9(2.8) | + |
| Performance | 338 | 2.6 | 15(2.5) | 15(2.2) | 14(2.5) | 10(2.8) | + |
| Process | 333 | 2.6 | 18(1.8) | 16(2.0) | 10(3.2) | 13(2.6) | |
| Heat | 317 | 2.5 | 11(3.1) | 13(2.4) | 13(2.6) | 15(2.2) | - |
| Mass | 296 | 2.3 | 12(3.1) | 11(3.0) | 12(3.2) | 18(1.4) | - |
| Distillation | 287 | 2.2 | 20(1.5) | 20(1.4) | 17(2.1) | 11(2.7) | ++ |
| Electrodialysis | 211 | 1.6 | 13(2.8) | 14(2.3) | 21(1.5) | 25(1.2) | --- |
| spectrometry | 198 | 1.5 | 17(2.0) | 17(2.0) | 16(2.4) | 30(0.8) | - |
| Desalting | 194 | 1.5 | 14(2.7) | 18(1.8) | 18(2.0) | 29(0.9) | - |
| Treatment | 187 | 1.5 | 27(0.9) | 21(1.3) | 22(1.5) | 17(1.6) | + |
| Power | 182 | 1.4 | 19(1.5) | 19(1.7) | 24(1.3) | 20(1.3) | |
| Experimental | 174 | 1.4 | 28(0.7) | 30(0.9) | 25(1.3) | 16(1.7) | + |
| Removal | 171 | 1.3 | 22(1.3) | 26(1.0) | 23(1.5) | 19(1.4) | + |
| Production | 167 | 1.3 | 23(1.2) | 23(1.3) | 19(1.6) | 27(1.1) | |
| Brackish | 165 | 1.3 | 24(1.0) | 22(1.3) | 26(1.3) | 22(1.3) | |
| Application | 157 | 1.2 | 21(1.5) | 24(1.1) | 30(1.1) | 22(1.3) | |
| Characterization | 150 | 1.2 | 25(1.0) | 25(1.1) | 27(1.2) | 26(1.2) | |
| Evaluation | 146 | 1.1 | 26(0.9) | 28(0.9) | 20(1.5) | 28(1.0) | |
| Wastewater | 146 | 1.1 | 29(0.7) | 29(0.9) | 28(1.2) | 24(1.2) | ++ |
| Nanofiltration | 142 | 1.1 | 30(0.5) | 27(0.9) | 29(1.1) | 21(1.3) | ++ |

The article titles present the core information that the authors would like to express. Therefore, all of the single words in the titles of articles were selected and analyzed for development trends of desalination. Title-words with general meanings, such as "by", "on", "with" and "using", were not included from the date analysis. The percentages of top 30 title-words were presented in Table 5. In addition, the title-words ''membrane'' and ''membranes'' were grouped into ''membrane''. Other than the term ''desalination'' used for searching, "water", "membrane", "reverse",

"osmosis" and "seawater" were the most five frequently title-words used in the 16-year research period, which indicated that seawater desalination and membrane technologies were the most hot topics in desalination research.

The most rapid growth was "membrane" from 7.4% to 11.9 %, which was highly accorded with the prediction that membrane technology had become the most widely technology of water desalination especially for seawater [4]. Meanwhile, "distillation", "wastewater" and "nanofiltration" showed a notable growth. Saline wastewater has become a important source for water desalination and currently represents about 6% of total capacity due to increase in water demand and environmental consideration [3,18]. The growth of "distillation" could be attributed to MED was gaining market share in recent years [3]. Nanofiltration acts as one of the most representative membrane technologies and gained more and more attention [4].

### 3.6 Analysis of author keywords and keywords plus

As author keyword analysis provides effective information about research trends for researchers, it has proved to be extremely significant for monitoring the development of research topics [21]. According to the data, 11351 different author keywords were used from 1997 to 2012. Among them, 76.7% of them (8702) appeared only once, reflecting a lack of continuity in research and a wide difference in research focuses [22]. The top 30 most active author keywords in the 16 years were listed in Table 6.

**Table 6:** Top 30 most frequency of author keywords used for every 4-year period

| Keywords | 97-12 TA | 97-12 () | 97-00 R () | 01-04 R () | 05-08 R () | 09-12 R () | 97-12 Change |
|---|---|---|---|---|---|---|---|
| Desalination | 1545 | 29.0 | 1(27.6) | 1(29.6) | 1(28.7) | 1(29.5) | |
| Reverse osmosis | 768 | 14.4 | 2(17.9) | 2(17.1) | 2(13.2) | 2(13.0) | |
| Seawater | 389 | 7.3 | 3(8.0) | 3(9.2) | 3(7.1) | 3(6.6) | |
| Solar energy | 332 | 6.2 | 4(6.0) | 5(6.0) | 4(5.8) | 4(6.2) | |
| Electrodialysis | 234 | 4.4 | 6(5.3) | 4(6.2) | 5(5.3) | 8(3.1) | - |
| Nanofiltration | 184 | 3.5 | 7(3.1) | 6(2.9) | 6(3.5) | 5(3.9) | + |
| Membranes | 179 | 3.4 | 5(5.7) | 7(2.8) | 8(3.4) | 9(3.1) | |
| Membrane distillation | 150 | 2.8 | 16(1.3) | 21(0.9) | 7(3.4) | 6(3.6) | + |
| Fouling | 108 | 2.0 | 18(1.1) | 10(2.0) | 11(2.1) | 11(2.3) | |
| Ultrafiltration | 107 | 2.0 | 11(1.8) | 8(2.4) | 9(2.3) | 13(1.8) | |
| Optimization | 106 | 2.0 | 12(1.6) | 9(2.2) | 20(1.1) | 10(2.4) | |
| Brackish water | 102 | 1.9 | 9(2.4) | 11(1.8) | 14(1.9) | 12(1.9) | |
| Forward osmosis | 100 | 1.9 | NF(0.0) | NF(0.0) | 16(1.5) | 7(3.2) | +++ |
| Boron | 85 | 1.6 | 24(0.7) | 24(0.9) | 10(2.3) | 15(1.7) | + |
| Renewable energy | 82 | 1.5 | 25(0.5) | 14(1.5) | 15(1.7) | 14(1.7) | + |
| Pretreatment | 78 | 1.5 | 8(2.6) | 13(1.6) | 23(1.0) | 17(1.4) | |
| Modeling | 77 | 1.4 | 15(1.5) | 15(1.2) | 13(2.0) | 19(1.3) | |
| Simulation | 63 | 1.2 | 13(1.6) | 16(1.1) | 21(1.1) | 23(1.1) | - |
| Membrane fouling | 61 | 1.1 | 19(1.1) | 18(1.0) | 22(1.1) | 21(1.2) | |
| Water treatment | 59 | 1.1 | 20(1.1) | 22(0.9) | 24(1.0) | 20(1.2) | |
| MSF | 58 | 1.1 | 10(2.4) | 12(1.8) | 18(1.3) | 30(0.5) | --- |
| Scaling | 57 | 1.1 | 14(1.6) | 25(0.8) | 25(0.9) | 24(1.1) | |
| Mass spectrometry | 56 | 1.1 | 23(0.7) | 26(0.7) | 12(2.1) | 26(0.8) | |
| Salinity | 54 | 1.0 | 26(0.4) | 27(0.6) | 27(0.8) | 18(1.4) | + |
| Concentration Polarization | 53 | 1.0 | 28(0.2) | 19(1.0) | 17(1.4) | 25(1.0) | |
| Evaporation | 50 | 0.9 | 21(1.1) | 17(1.1) | 19(1.2) | 28(0.7) | |
| Capacitive Deionization | 49 | 0.9 | NF(0.0) | NF(0.0) | 30(0.5) | 16(1.7) | ++ |
| Corrosion | 46 | 0.9 | 17(1.3) | 20(1.0) | 28(0.8) | 27(0.7) | - |
| Brine | 45 | 0.8 | 27(0.4) | 28(0.5) | 29(0.6) | 22(1.2) | |
| Energy recovery | 43 | 0.8 | 22(0.9) | 23(0.9) | 26(0.9) | 29(0.7) | |

NF means no found.

Except for the searching word "desalination", the five most frequently used keywords were "reverse osmosis", "seawater", "solar energy", "electrodialysis" and "nanofiltration", which was highly accorded with the research trends as we know. "Reverse osmosis", "electrodialysis" and "nanofiltration" are all representative membrane technologies and the observation proved the dominated role for membrane technologies in desalination research during 1997-2012. Membrane methods are less energy intensive than thermal methods and since energy consumption directly affects the cost-effectiveness and feasibility of using desalination technologies membrane methods such as reverse osmosis (RO) and electrodialysis (ED), are attracted great attention lately. It was reported that of the global desalted water, 63.7% of the total capacity is produced by membrane processes and 34.2% by thermal processes [4]. "Seawater" ranked the 3rd place because seawater acted as the most important desalination source. The desalination source water is split with about 58.9% from seawater, and 21.2% from brackish groundwater sources, and the remaining percentage from surface water and saline wastewater [23]. In addition, "solar energy" were widely used in desalination process both for thermal and non-thermal desalination technologies [24,25]. Besides, forward osmosis and capacitive deionization have attracted great attention in the list since 2005. Forward osmosis has a potential role in desalination and water reclamation, therefore it has drawn much attention from researchers [26, 27]. Meanwhile, capacitive deionization acted as an alternative to the more conventional membrane desalination technologies like reverse osmosis and electrodialysis, and became a hot study area in recent years [28]. On the contrary, MSF showed a significant decrease in the share of desalination research. Though MSF has proven to be the most reliable thermal desalination technology as it has dominated the thermal desalination market during the 1980s and 1990s, with the improvements in rival technologies as RO, the installation of MSF plants is on a downward trend and with present 25% worldwide capacity share.

## 4. CONCLUSION

In this study, some significant findings have been obtained on the research trends throughout the period from 1997-2012. The number of articles

about desalination increased significantly in the last 16 years. In total, there are 6064 articles in 500 journals listed in 142 SCI subject categories. The research on the fields of desalination focused on engineering chemical, water resources, energy fuels, environmental sciences and chemistry analytical. Meanwhile, more and more attention was paid to environmental sciences and engineering environmental in the last 16 years. In addition, *Desalination* published the most articles.

G7 countries played a predominant role in desalination research and published a large number of articles. All of the seven major industrialized nations of the world (G7) were in the top 10 most productive countries. However, the article share of G7 showed a notable decline trend in the past 16 year. Otherwise, BRIC countries had a rapid growth in both article number and share. It indicated that national concentration in the academic world is not so obvious as before.

According the analysis of title-words, "water", "membrane", "osmosis", "reverse" and "seawater" were the most frequently used title-words in the 16 years, which indicated that seawater desalination and membrane technologies were the hottest topics in desalination research. From the distribution of author keywords, "reverse osmosis" headed the most frequently used author keywords through the 16 years. "seawater", "solar energy", "electrodialysis" and "nanofiltration" were recent major topics of desalination research. "Reverse osmosis", "electrodialysis" and "nanofiltration" are all representative membrane technologies and the observation proved the dominated role for membrane technologies in desalination research during 1997-2012. In addition, "forward osmosis" and "capacitive deionization" have attracted great attention in the list since 2005. The findings of this study can help relevant researchers understand the performance of desalination research in the world, and suggest directions for further research by a bibliometric method.

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