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Publication-based survey for status of scientific research and impact on post-combustion CO_2 capture

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ABSTRACT

Post-combustion CO_2 emissions caused by fossil fuel utilization have become a worldwide issue. To understand the macro-level status of research findings and impacts on post-combustion CO_2 capture, a publication-based survey since 2000 was performed using Web of Science™ Core Collection and Journal Citation Reports® 2014. The number of articles published, citations and important publications were examined to assess the quantity and quality of scientific findings on post-combustion CO_2 capture. Results show that a total of 1025 articles were published during 2000–2013. A remarkable increase in publication numbers was found in 2011 and has remained high in the last three years. The United States and China are the top-two contributors of articles, far surpassing those of all other countries, with an approximate combined of 40% from these two countries. Post-combustion CO_2 capture approaches using absorption, adsorption and membrane techniques were dominant. Times Cited of articles regarding post-combustion CO_2 capture reached to peak in 2010 while the number of citing articles is continuously increasing. The most popular, most-cited and highest impact factor journals were found as *International Journal of Greenhouse Gas Control*, *Industrial and Engineering Chemistry Research* and *Science*, respectively.

1. Introduction

Sustainable development of energy, economy and environment has become an important issue in most countries throughout the world. However, rapid economic development requires increased energy consumption. Growing world energy demand for fossil fuels (e.g., coal, petroleum and natural gas) has played a key role in the upward trend of emissions of CO_2, an important greenhouse gas. Since fossil fuels are dominant in the structure of the world's primary energy consumption, their utilization especially by means of combustion/burning results in massive post-combustion CO_2 emissions (CO_2 emissions from flue gas) (Fig. 1). Statistics show the atmospheric concentration of CO_2 concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel combustion. In particular, atmospheric CO_2 concentrations reached 390.5 ppm in 2011, a rise of 11.7 ppm from 2005 (IPCC, 2013). According to IEA, annual CO_2 emissions from fuel combustion dramatically increased from nearly zero at the start of the Industrial Revolution to over 31 $GtCO_2$ in 2011 (IEA, 2013). Therefore, as an important part of control and reduction of emissions from fossil fuel combustion, post-combustion CO_2 capture has received great attention in the last two decades (Figueroa et al., 2008; Yang et al., 2008; Olajire, 2010).

Owing to the contradiction between fossil fuel combustion and CO_2 emissions goals, efficient, economic, and environment-friendly methods of carbon capture from combustion flue gas are urgently required to achieve CO_2 emission reduction and resource utilization (Aarona and Tsouris, 2005). Many researchers from both the developed and developing countries have conducted a large amount of scientific and technological researches on post-combustion CO_2 capture using different approaches (Rao and Rubin, 2002; White et al., 2003; Yang et al., 2008; Mohamed et al., 2008; Rochelle, 2009; D'Alessandro et al., 2010; Ho et al., 2011). However, the macroscopic status of the quantity and quality of research findings regarding to post-combustion CO_2 capture is unknown.

In this work, a survey based on studies published after 2000 regarding post-combustion CO_2 capture was performed. The purpose of this paper is to understand the development status of research findings and impacts on post-combustion CO_2 capture, considering: the number of research findings, regional distribution of researchers, popular approaches, citations of research findings

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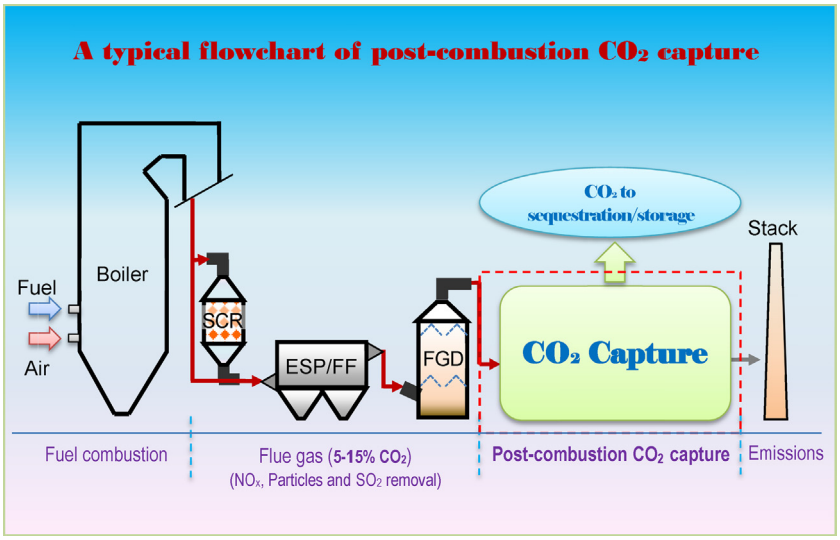

Fig. 1. A typical flowchart of post-combustion CO_2 capture.

and important publications. The goal of this work is to provide a positive reference for future scientific studies in the field of post-combustion CO_2 capture.

2. Methods

2.1. Search method

The Thomson Reuters Web of Science™ Core Collection (Web of Science Core Collection, 2014), the world's leading database and research platform in the sciences, social sciences, arts, and humanities, was used to search for high-quality scientific publications from 2000 to 2013. First, we used the database to search the articles closely related post-combustion CO_2 capture. The search strategy used in this work was [CO_2 (Title) AND capture (Title) AND post combustion (Theme)] OR [carbon dioxide (Title) AND capture (Title) AND post combustion (Theme)] OR [CO_2 (Title) AND capture (Title) AND flue gas (Theme)] OR [carbon dioxide (Title) AND capture (Title) AND flue gas (Theme)]. Once the articles published were identified, they were subsequently classified according to their characteristics, and the mathematical statistics were then performed for comparison and assessment.

2.2. Statistical parameters

To compare the scientific findings on post-combustion CO_2 capture, bibliometric and citation analyses were used in this work (De Bellis, 2009; Rosas et al., 2011). Specifically, the number of scientific articles published was determined and sorted based on source region and capture approaches. The citations analysis including times cited and number of article cited was conducted using their citation reports. Moreover, we determined the most important publications based on article number, times cited and impact factor from Journal Citation Reports® (JCR) 2014 (Journal Citation Reports, 2014).

3. Results

3.1. Number of articles

3.1.1. Total numbers

A total of 1025 of 23,630,555 articles published in 199 journals were found worldwide to be related to post-combustion CO_2 capture from 2000 to 2013. The distribution of total number of published articles throughout the years is illustrated in Fig. 2. It can be observed that the annual total number of articles as a whole increased gradually during this period. In particular, before 2006 the annual number displayed as slowly increasing rate with the exception of 2003. During 2007–2010 it entered into a faster growth phase. Remarkably, since 2011 there has been a substantial increase in the number of articles published and the rate remained stubbornly high during the last three years. Further statistics based on a cumulative curve show that the median year of article number is about 2011, which means that approximately the same number of articles on the subject have been published in the last two years (2012–2013) as in the eleven years prior (2000–2011).

3.1.2. Regional distribution of researches

Fig. 3 shows the top-10 distribution of source region. Authors or investigators from the United States were the most prolific (241 of 1,025 total articles, 24%), followed by China (164 articles, 16%), Canada (90 articles, 9%), Australia (78 articles), Norway (64), UK (61), Spain (55), Korea (51), Germany (47) and France (46). It can be seen that article publication numbers from the United States and China are much higher than other regions as they account for 40% of the all total number of article published. Moreover, the top

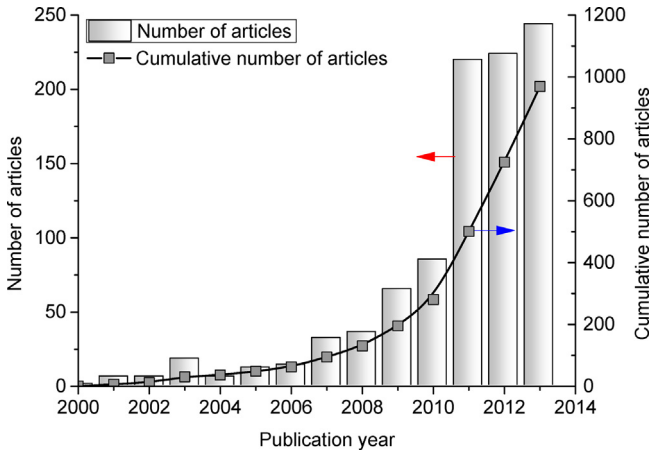

Fig. 2. Number of article published on post-combustion capture from 2000 to 2013.

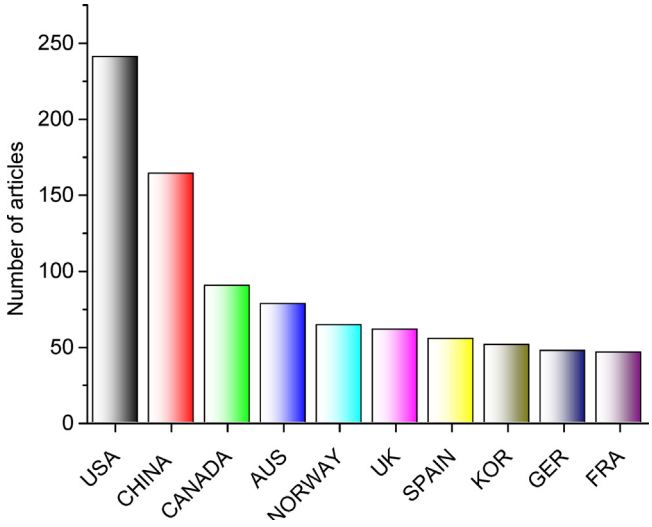

Fig. 3. Source region of article published on post-combustion capture from 2000 to 2013.

3 source regions including the United States, China and Canada had approximately half of the total contribution (49%).

3.1.3. Capture approaches

Articles regarding post-combustion CO_2 capture were found to involve 29 subjects in the Web of Science Core Collection. Subjects with more than 50 articles include Engineering, Energy Fuels, Chemistry, Environmental Science Ecology and Materials Science. Essentially, regardless of discipline, post-combustion capture approaches can be categorized by their principle and approach. According to Fig. 4, post-combustion CO_2 capture using absorption, adsorption and membrane-based approaches were most dominant, making up about 80% of the investigated techniques, followed by biological fixation, electrochemical separation and ionic liquid method.

3.2. Citations

Citations include the times cited for articles found and citing number of articles found. According to Fig. 5, the total times cited value during 2000–2013 was 16469 and correspondingly, the average citations value per article was 16.07. The H-index indicates that at least 65 articles were cited by 65 times. Specifically, from 2007 the annual times cited value was found to increase exponentially over publication years, reaching a maximum in 2010. However, it tended to decrease from 2011. On the other hand, the total citing article value of 33,560 was more than twice as much as the times cited value. On the whole, times cited values reached a peak

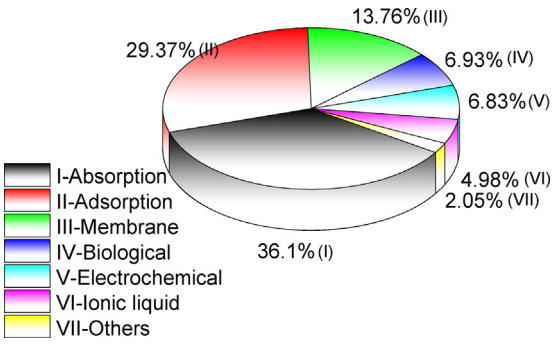

Fig. 4. Approaches of post-combustion capture from 2000 to 2013.

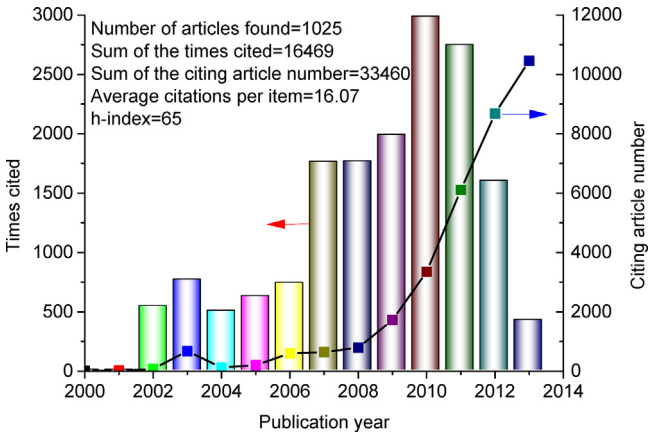

Fig. 5. Citations of articles published on post-combustion capture from 2000 to 2013.

in 2010 while citing numbers values increased as publication year displaying a sharp increase beginning in 2008.

3.3. Important publications

To further compare the qualities of scientific researches on post-combustion capture, the top-10 important publications were determined based on total article number, total times cited and impact factor as seen in Table 1. More than half of the articles (50.8%) related to post-combustion CO_2 capture were published in the article number-based top ten journals. 56.4% of total times cited was found among the top-10 journals based on times cited. All top-10 journals publishing articles related to post-combustion CO_2 capture had 5yr-impact factors greater than 3 (according to JCR 2014).

Among these journals, *International Journal of Greenhouse gas Control*, *Industrial and Engineering and Chemistry Research* and *Science* were considered as the most important publications based on article number, times cited and impact factor since they published more impactful research findings on post-combustion CO_2 capture.

4. Discussion

The scientific research on post-combustion CO_2 capture is closely associated with globalization dealing with climate change. The United Nations Framework Convention on Climate Change was opened for signature in 1992 to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Afterwards, signatures of the Kyoto Protocol in 1997, the Bali Action Plan in 2007, the Copenhagen Accord in 2009 and the Durban Platform for Enhanced Action in 2011 made rigorous and specific requirements on greenhouse gas emissions and control. Under this background, the scientific research on CO_2 capture from combustion sources underwent a rapid development, which was indirectly reflected by a continuous increase in the number of scientific findings in the form of published articles. Investigations on the number of articles published revealed that in the most recent 5 years (2008–2013), the concern of environmental issues caused by post-combustion CO_2 emissions has received great attention. Also, it indicates that scientific researches on effective control of post-combustion CO_2 emissions have been done extensively all over the world.

As excepted, high degree of industrialization, advanced scientific consciousness and good research environment (including hardware and software) has supported the publishing of a large number of research findings including achievements in post-combustion CO_2 capture. According to the results, the top-10

Table 1
Important top-10 journals published the articles regarding post-combustion CO_2 capture.

Ranking	Article number-based		Cited times-based		Impact factor-based	
	Publication name	Number published	Publication name	Times cited	Publication name	5 yr-Impact factor[a]
1	Int. J. Greenhouse Gas Control	131	Ind. Eng. Chem. Res.	1868	Science	34.463
2	Ind. Eng. Chem. Res.	85	Int. J. Greenhouse Gas Control	1671	Energy Environ. Sci.	15.263
3	10th Int. Conf. Greenhouse. Gas Control Technol	78	Energy Fuel	990	ChemSusChem	7.497
4	Energy Fuel	54	Environ. Sci. Technol.	962	Chem. Commun.	6.485
5	Abstr. Paper Am. Chem. Soc.	47	Angew. Chem. Int. Ed.	824	Environ. Sci. Technol.	6.277
6	Environ. Sci. Technol.	28	Energy	752	Appl. Energy	5.597
7	Chem. Eng. J.	27	Energy Conver. Manag.	646	Int. J. Greenhouse Gas Control	5.207
8	Energy	26	J. Membrane Sci.	583	J. Membrane Sci.	5.094
9	Fuel	24	Fuel	552	Energy	4.465
10	Chem. Eng. Res. Des.	21	Energy Environ. Sci.	442	Int. J. Hydrogen Energy	3.448

[a] According to JCR (2014).

countries with respect to published article numbers were found to be developed countries with the exception of China, the world's largest developing country. Specifically, the greatest contributor was the United States, but China has made significant progress with respect to scientific researches on this subject, with its total number of articles published ranked as No. 2 in this work. Actually, the scientific research on post-combustion CO_2 capture is interrelated to the situation of CO_2 emissions besides the level of development. According to IEA, nearly two-thirds of global CO_2 emissions for 2011 originated from just ten countries, with the top-2 shares of China (25.4%) and the United States (16.9%) far surpassing those of all others. Combined, these two countries alone produced 13.2 $GtCO_2$ (IEA, 2013). Therefore, it is necessary and urgent to require strengthening of scientific research on CO_2 capture in these countries. This result also suggests that both developed and developing countries have made great efforts to propel scientific researches on CO_2 emission reduction from combustion sources, although there are some differences in research level and conditions, which may cause the difference in number of research articles published.

With the development of fundamental theory and new technology, there has been a trend of diversification in scientific research on post-combustion CO_2 capture. Relatively mature approaches, e.g., absorption, adsorption and membrane-based approaches, account for approximate 80% share of all CO_2 capture techniques investigated. However, it should be noted that most of these approaches are actually not purely traditional approaches, but include novel or improved technologies such as the use of regenerated solution (ammonia and amine) as absorbents (Wang et al., 2011), modified materials as adsorbents and advanced nanomaterials as membranes (Zhao et al., 2012; Yazaydin et al., 2009; Abanades et al., 2004; Powell and Qiao, 2006). Compared with traditional approaches, renewable and sustainable approaches (e.g., biological, electrochemical and ionic liquid-based) account for less share but usually display superior economical performance or are more environment-friendly (Ho et al., 2011; Li and Chen, 2005). Overall, scientific research on post-combustion CO_2 capture approaches have been developed with regard to high performance, low cost, and environmental friendliness.

Citations are considered as one of critical parameters to assess the originality or novelty of scientific work. The result demonstrates that during 2007–2012 the recognized degree of fundamental researches regarding post-combustion CO_2 capture entered the golden age. In addition, the continuous increase in the amount of references implies that the scientific researchers are paying more attention to the accumulation, inheritance and development of existing scientific findings.

Besides the citations, the journal itself is also an important criterion for scientific work. In the field of post-combustion CO_2 capture, the most popular, most-cited and highest impact factor journals were found as *International Journal of Greenhouse Gas Control*, *Industrial and Engineering and Chemistry Research* and *Science*. The journals strongly related to the theme of greenhouse gas emission reduction and process science & engineering are still preferred to publish the articles regarding post-combustion CO_2 capture. However, there are few articles published in the highest-impact journals, e.g., only one article was found to be published in *Science*, suggesting that fundamental and advanced research related to post-combustion CO_2 capture needs to be further strengthened. Additionally, compared with old brand journals (e.g., *Industrial and Engineering and Chemistry Research* launched in 1962 and *Science* founded as long ago as 1883), some journals established for not a long time (e.g., *International Journal of Greenhouse Gas Control* has been launched in 2007) made great progress in both the quantity and quality of articles published. It is indirectly demonstrated that they have enormous potential for the publication of high-level scientific findings on post-combustion CO_2 capture.

It should be noted that this work investigated the status of scientific research on post-combustion CO_2 capture using the data from Web of Science Core Collection and JCR, which are both resources from Thomson Reuters. Although the database used for article search and journal assessment is comprehensive, the results may not be completely accurate due to limitation of search strategy, which may cause some highly-related articles to have not been included in the present work. However, the articles and journals included in this survey are the major contributors in the area of post-combustion CO_2 capture.

5. Conclusions

The number of articles published on post-combustion CO_2 capture generally increased with publication year during 2000–2013 with the most remarkable increase occurring in 2011 and high rate maintained since. The United States and China were the top-2 contributors for the articles together with approximately 40% share. Post-combustion CO_2 capture approaches using absorption and absorption were dominant in the literature but renewable and sustainable approaches, including biological, electrochemical and ionic liquids, also had a certain share. Cited number of articles regarding post-combustion CO_2 capture reached a peak in 2010 while the number of citing articles has continuously increased. The most popular, most-cited and highest impact factor journals were

found as *International Journal of Greenhouse Gas Control*, *Industrial and Engineering and Chemistry Research*, and *Science*.

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