Patent Bibliometric Analysis of Lithium Air Battery Industry

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ABSTRACT

Lithium air battery is a new kind of green high-energy batteries with the advantages of high energy density, light weight, good security, environment friendly and others. This study examines the inventive activities in lithium air battery industry using the patent information as published by the Innography patent platform. Statistics data are analyzed based on the view of technological development trend, geographical distribution, and innovative organizations. It is observed that although the lithium air battery technology is a newly emerging technology, patent counts have been increasing fast in recent years. Through source jurisdiction and inventor address analysis, it is found that China, Japan, U.S. and Korea are main technological application countries, and important inventors also belong to these countries except for the different rank. The major innovative organizations include Samsung Electronics, Toyota Motor, Solvay S.A., Polypoal Co., Robert Bosch GmbH, etc. According to text clustering analysis of patent contents, it is found that lithium air battery technology is centralized in six main technology fields: Air Electrode, Preparation Methods, Lithium Ion, Carbon Material and Secondary Battery. Finally, core patents are found through patent strength analysis.

INTRODUCTION

Patent is one of the most important components of intellectual property, which provides a unique detailed source of information on inventive activity of technology. The track of technological development can also be reflected by patent data. Patent statistics are frequently viewed as an indicator of technology innovation output. In a former study, Franco analyzes technological entry, exit and survival through patent data (European Patent Office) for 49 technological classes in six countries over the period 1978-1991[1]. The study by Qin and Zhao uses domestic and foreign patents of speech recognition technology in smart TV to analyze technology development trends, technical outputs countries geographic distributions, key technology fields, patent applicants and key inventors and so on[2]. Similarly, in another study, the trends and directions of thin film technology are explored through analysis of US patents. The authors use a classification system for all the patents under technological sector(s) and subsector(s) to determine the major application areas and forecast the future trend in
this technology field [3]. Yet patent count is a rather imprecise measure as it fails to take into account of the contents of patent. For example, the key technology fields which are calculated by patent technology classification numbers such as IPC, USPC, CPC and ECLA etc. are difficult to understand, and then need to find other method to discover key technologies. James et al. use patent titles representing the innovation activity at one company (SAP) and perform a bibliometric analysis using an expert system framework that utilizes text and data mining procedures for analyzing innovation through textual patent data [4].

In recent years, rechargeable nonaqueous lithium air battery has attracted wide attention due to its very high theoretical energy density. Lithium air battery, based on the reaction of lithium with oxygen from air, have very high theoretical specific capacity of 3828 mAh/g and have important potential applications for electric vehicles[5]. Almost all the organizations in the world which are engaged in lithium battery research now focus on lithium air battery. As a result, academic and industrial sectors have devoted large efforts to lithium air battery related research and technology development, thereby increasing the numbers of patents in this discipline. However, there are few studies which analyze lithium air battery field based on bibliometric analysis, especially for using patent data to do analysis. We only find a study which study the technology development trend of lithium air battery in China based on Chinese patent data searched from the SIPO [6]. In light of the lack of studies in this area, this study attempts to explore the inventive activities in lithium air battery industry using the global patent data as published by the Innography platform. The technological development trend, area distribution, innovative organizations and main inventors are studied based on patent data. The key technology fields are explored by text mining of patent content. Furthermore, core patents are found by an indicator of patent strength.

DATA AND METHODOLOGY

Data collection

The patent data are retrieved from the patent database provided by the Innography platform. Innography is an intellectual property website which set up by Dialog company in 2007, and contains more than 80 million patents published by over ninety countries and regions. Moreover, Innography also provide some powerful analysis functions, so the present situation and tendency of special fields can be explored fully and visually.

The search queries are made by key works and IPC (International Patent Classification) numbers. After several search tests, the search query of this field is make sure. The formula is @abstract,pclaims,title) "lithium air" or lithium*air or Li-air or Li/02 or "lithium oxygen" AND @meta IPC_H01M @*. H01M is an IPC number which refers to “Processes or means, e.g. batteries, for the direct conversion of chemical energy into electrical energy”. The patent data are searched in March 2016, to get 1,381 patents.

Considering the limitation of data range, theses patents then make family expansion, and then we get 1,919 patents which are published all over the world. The next step is to pick out patent applications in order to avoid repeated calculation to the same patent which may be published more than once. We get patent applications by
restricting patent kind code, and the limiting condition is kind_code_A or kind_code_A1 or kind_code_A2 or kind_code_Y or kind_code_U. After restrictions filtered to 1,919 patents, we finally get 1,486 patents in lithium air battery industry.

**Inventive ability evaluation**

In order to find the main companies and research organizations in lithium air battery industry, the patent numbers of organizations are counted by patent assignee field. But the inventive ability of company and research organization can’t be evaluated only by patent statistic numbers, and then Innography provides patent assignee bubble analysis diagram to discover the inventive ability of company and research organization. The patent applicants bubble analysis diagram can intuitively reflect the technological gap and comprehensive economic strength between patent applicants [8-9]. In the figure, the bubble size represents the number of patent, and the horizontal axis represents the integrative technical indicators which relate to the patent numbers, IPC numbers and citations per patent. The larger the horizontal axis value, the greater the technical ability of patent. The vertical axis represents the economic strength of enterprises which relate to the income of patent assignees, numbers of litigation and countries of inventors. The larger the vertical axis value, the greater the economic strength of assignees.

**Core patent identification**

By patent strength indicator of Innography, core patent can be identified. Patent strength indicator is a new original evaluation indicator of Innography, and it is the latest research result from the University of California, Berkeley, and George Mason University. This indicator can help users to find core patents quickly and efficiently. Patent strength reference more than ten relevant patent value indicators, including: backward citations, forward citations, claim numbers, family numbers, patent age, patent litigation and others.

Each patent will get a value by using patent strength indicator and this value is between 0-100 percent. The patents with strength value of 80%-100% are core patents of technology field; 30%-80% are important patents; 0-30% are general patents.

**RESULTS**

**Technology development trend analysis**

The technology development trends can be reflected by the numbers of publication year, and then the 1,486 patents in lithium air battery industry are grouped yearly.

![Figure 1. The development trend of patents in lithium air battery industry.](image-url)
From Figure 1, it is obvious that there are few patent applications before 2000, and the patent numbers have been upgrading unceasingly since 2000. The patent numbers have increased rapidly in recent five years. The patent numbers in 2015 and 2016 are insufficient and only for reference.

Geographical distribution analysis

1) Technology application country analysis

From patent exclusivity and regional characteristic point of view, the country or IP organization which patent is submitted is the area that the technology will be applied. Therefore, the area distribution status of technology application can be analyzed by the country or IP organization which patent applied.

We can see from Fig.2 that lithium air battery patent applications mainly in East Asia, North America and Europe. The top four countries are China, the United States, Japan and South Korea, the number of patents owned by these four countries accounted for about 72% of the total patents. In addition, patents applied from the World Intellectual Property Office (WIPO) and the European Patent Office (EPO) are 163 and 113, ranking fifth and sixth. Patents in other countries are relatively few.

2) Technology source country analysis

Patent data provide detailed address information of inventor, and we can obtain the country or region from the address which inventor locates. Patent inventors are the creators of innovation, so the inventor’s address represents the location of inventive activity for which the patent is sought [10]. Hence, the main technology source country can be found by inventor country analysis.
Figure 3. Technology source country analysis.

The top 10 technology source countries are shown in Fig.3. We can see from the figure that the United States is the most important technology source country, and 26.7% patents are invented by Americans. Japan, China and South Korea are also important technology source countries. Compared with technology application country, it is obvious that China is the most important application country of lithium air battery technology, but the United States is the technology leader in research.

Innovative organizations analysis

In order to find main innovative enterprises and research institutes in lithium air battery industry, the researchers of this study calculate the patent numbers of assignees. After the cleaning of patent assignee, we get the top 10 enterprises and research institutes in the worldwide as Table 1 shown.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Patent Assignee</th>
<th>Patent Number</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Samsung Electronics Co., Ltd.</td>
<td>98</td>
<td>Korea</td>
</tr>
<tr>
<td>2</td>
<td>Toyota Motor Corp.</td>
<td>89</td>
<td>Japan</td>
</tr>
<tr>
<td>3</td>
<td>Solvay S.A.</td>
<td>51</td>
<td>Belgium</td>
</tr>
<tr>
<td>4</td>
<td>Polyplus Co., Ltd.</td>
<td>47</td>
<td>America</td>
</tr>
<tr>
<td>5</td>
<td>Robert Bosch GmbH</td>
<td>46</td>
<td>Germany</td>
</tr>
<tr>
<td>6</td>
<td>Chinese Academy of Sciences</td>
<td>44</td>
<td>China</td>
</tr>
<tr>
<td>7</td>
<td>Sion Power Cor.</td>
<td>37</td>
<td>America</td>
</tr>
<tr>
<td>8</td>
<td>BASF SE</td>
<td>29</td>
<td>Germany</td>
</tr>
<tr>
<td>9</td>
<td>Uchicago Argonne LLC</td>
<td>27</td>
<td>America</td>
</tr>
<tr>
<td>10</td>
<td>Hi-Ten Limited LLC</td>
<td>26</td>
<td>India</td>
</tr>
</tbody>
</table>

We can see from the table that there are two research institutes and eight enterprises in the top 10 assignees. It shows that enterprise is the main technology strength in lithium air battery industry. Among the top 10 assignees, three belong to America, and two belong to Germany, and other innovative organizations are located in different countries. Samsung Electronics Corporation has the largest patent numbers in lithium air battery industry.
To further study the integrative innovation ability of main organizations, patent assignee bubble analysis diagram are drawn. It can be seen from Fig. 4 that Samsung Electronics Co. has the biggest bubble, indicating the largest number of patent, and it is the rightmost bubble, followed by Toyota Motor Corp with the highest height, indicating that the two companies have the strongest integrative technology and economic strength in lithium air battery field. Polyplus Company and Sion Power Company are located in the lower right axis, indicating that although the integrative economic strength is weak of the two companies, the technical comprehensive strength is better. The patent number of Chinese Academy of Sciences (CAS) is more, but the integrative technology and economic strength are not prominent, as the distribution area in the lower left axis.

Main technologies analysis

Main technologies can be found based on text clustering, and Innography provide this function. Before text clustering, patents need to do family reduction in order to avoid repeated calculation of the same invention which can be applied or published more than once. We get 726 patents after family reduction in lithium air battery field, and then main technologies are analyzed with these patents using text clustering method.
It can be seen from Fig. 5 that the lithium-air battery technology research focused on six technical fields: Air Electrode (248 patents), Preparation Methods (187 patents), Lithium Ion (190 patents), Carbon Material (131 patents), Active Material (128 patents), Secondary Battery (99 patents), and the hot sub-technologies of each technical field in the figures are also shown. These technologies are key problems which need to be solved in lithium air battery research, and also the core of patent protection.

**Core patent analysis**

In order to find core patents, 726 patents are analyzed by patent strength indicator, and the distribution are shown in Fig. 6. We can see from the figure that there are 17 core patents with patent strength value greater than 80%, accounting for 2.34% to total patents. 165 patents with patent strength value greater than 30% and less than 80% are important patent, accounting for 22.73%. 544 patents with patent strength value less than 30% are general patents, accounting for 74.93%.

![Figure 6. Patent strength distribution of lithium air battery industry.](image)

Next, 17 core patents are studied to explore the powerful technology countries and companies. According to the patent assignee analysis, Polyplus Company has two core patents, Electorvaya Inc. has two core patents, BASF Company has two core patents, and other core patents are in different companies. According to the inventor’s country analysis, we find that the most of core patents belong to the United States, with 12 (70%) core patents. Canada has three core patents, ranked in the second. Japan and Singapore has a core patent respectively. According to the source jurisdiction analysis, it is found that major application country is the United States, and there are 16 patents are filed in the United States, and the other one is in Japan. It can be seen that the most important market of lithium air battery technology is the U.S., that is, important companies have focused on the American market of lithium air battery industry.

**CONCLUSIONS**

In this paper, we use patent analysis method to research global lithium air battery industry. Patent data are collected from Innography platform, and relative methods, such as technology cycle time (TCT), inventive ability evaluation, and core patent identification are introduced. The results show that the patent numbers in lithium air battery industry have increased rapidly in recent five years. Main enterprises and
research institutes are selected by the patent numbers, and we find enterprises are the main technology strength of lithium air battery industry. The major innovative organizations include Samsung Electronics, Toyota Motor, Solvay S.A., Polyplus Co., Robert Bosch GmbH, etc. To further study the integrative innovation ability of main organizations, patent assignee bubble analysis diagram are drawn, and we find Samsung Electronics and Toyota Motor have the have the strongest integrative technology and economic strength. According to patent text clustering, it is found that the lithium air battery technology research focused on six technical fields: Air Electrode, Preparation Methods, Lithium Ion, Carbon Material, Active Material, and Secondary Battery. Finally, core patents are explored using patent strength indicator, and the powerful technology countries and companies are also discovered.

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REFERENCES