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Creating a critical snapshot of the bioleaching sector by using patent databank analysis

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ABSTRACT

This work defines the profile of the bio-hydrometallurgy sector by presenting a statistical analysis of the patent databank that covers the bioleaching field. The use of prior technology to take a snapshot helped provide a good panorama of the major players in the extractive metallurgy operation. Using an international classification code, 1226 patent families were retrieved. This code was chosen for microorganisms used in extracting nonferrous metals from ores or concentrates via wet processes. After a careful analysis that excluded (i) patent families without applicant information, (ii) those belonging to applicants with just a few families, (ii) those with indexing misconceptions, or (iv) duplicated families, only 312 patent families presented real interest and provided valuable information to facilitate a full analysis. Of the four largest companies producing patents in this area, BHP Billiton led the bioleaching of sulfide ores, followed by Beijing Nonferrous Central South University, which led the strain cultivation methods and inoculum generation, and Nippon Steel which led the wastewater treatment operations. This work also revealed that a classification of technical areas, although very important in classifying some technologies, should be used very carefully, because some mistakes were detected during indexing, and false results were sometimes retrieved while searching the patent databases. The evolution of patent production is closely related to the fluctuations in global metal prices. It is also affected by the strategic decision of a company CEO, especially when the time required to study a specific technology and develop an operation is very long, expensive, and requires specialized and committed technicians. Some challenges which remains to be overcome are: (i) bioleaching of low-grade chalcopyrite ores (ii) improving bacterial tolerance to chloride; (iii) industrial bioleaching of nickel laterites and (iv) bioleaching of rare earths.

1. Introduction

The search for alternative processes for the treatment of sulfide ores, concentrates, or ores with complex mineralogy as well as industrial wastes generated during mining operations has become increasingly important due to the rapid depletion of mineral reserves and the emergence of various environmental issues. Bioleaching is an alternative process of extracting metals from ores, and occupies an important and representative position in the field of innovative mining processes. According to a past study (Gilbertson 2000), bioleaching highly fulfills current mining requirements with regards to capital and operational expenditures, facility of operation and maintenance, and environmental concerns. Considering the extraction of copper and nickel, for instance, conventional routes, such as pyrometallurgy, are highly capital-intensive and are only cost-effective when concentrates are treated, implying that low-grade ores cannot be economically processed by this route. In this context, bioleaching appears as an alternative for processing such sulfide-bearing materials.

The industry of the 21st century, the so-called "Industry 4.0," is smarter and more digitally connected than the previous one, which runs at large steps. Industry 4.0 aims at achieving a top global economic position, uses green technologies, is sustainable, and is more efficient compared with its predecessor. Based on this scenario, innovation is considered a fundamental factor of competitiveness, which increases added value to products and services, increase incomes, generates employment and revenue, strengthens their marks, and helps companies penetrate new markets (Lage et al. 2013). Defining the real concept of innovation and where an innovative concept arises in the productive chain is very important. Several information regarding innovation and its features can be found in the Organization for Economic Co-operation and Development. Its website (www.oecd.org) provides numerous publications related to this field. In comparison, the mining sector tends

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to take a very conservative stance when it comes to innovation. According to a critical opinion (Shook 2015), innovation in the mining sector is slow and more indirectly pronounced with respect to the development of new equipment and processes as well as biotechnological improvements in the mining process.

One of the many methods to measure aspects of innovation is the patent documents analysis. When the company does not use trade secret as a protection of its technological developments, the same company may apply a patent document. In this document, a large amount of important information can be found and correlated to its economic health using statistical treatments.

The use of patent prior art searching as a useful tool to study technological landscapes has not been fully explored in the literature, although some methods to accomplish this have been reported (Abbas et al. 2014). Studies throughout the world often go in depth regarding their technical proficiencies when the subject is literature search. In rare cases, researchers and scientists in the academia know how to use technological information found only in patent databases. Patent agents estimate that 10% of human knowledge is protected by patents and can be found in patent databases, such as United States Patent Office (USPTO), European Patent Office (EPO), Japan Paten Office (JPO), Institut National de la Propriété Industrielle (INPI), and Latin American Patent and Trademark Offices (LATIPAT) (Cohausz, 1998 *apud* Köster, M., et al. (Fabry et al. 2006)).

Searching patent applications or granted patents can reveal several important information. Although patent application cannot be used as an innovation indicator in itself, innovative countries—frequently recognized as global potencies—have a very expressive number of patent applications. The number of patent filings is very often used in the Global Innovation Index (Dutta 2012) and in the Human Development Index (HDI).

A patent document provides legal information status whether this document is an application or a granted patent; where the document has been filled and the entire family of this patent. This second aspect indicates territoriality, because the monopoly of rights is valid only where the patent has been filed. Beyond the legal aspects, another type of important technical information can be found inside the text. When interpreted by a technician, such information is the key to using the content as technological information (Lage et al. 2013). Beyond this, prior art analysis has been considered intrinsically important in achieving the following goals: a) determining novelty in patents, b) analyzing patent trends, c) forecasting technological developments in a particular domain, d) strategic technology planning, e) extracting information from patents for identifying infringements, f) determining patent quality for R&D tasks, g) identifying promising technologies, h) technological road-map building, i) identifying technological vacuums and hotspots, and j) identifying technological competitors (Abbas et al. 2014).

Patent landscape reports present a more secure way to help decision makers avoid possible investment mistakes in a particular area of knowledge. A very straightforward analysis regarding statistics and technical knowledge of a particular sector is the main foundation of a trustworthy conclusion when a patent landscape is built. Several distinct modes can be used to build a technology landscape or create a technological snapshot, e.g., starting from scientific papers and news, interviews with specialists and also using patent information. Recently, the World Intellectual Property Organization (WIPO) published a collection of Guidelines for Preparing Patent Landscape Reports (Trippe 2015).

According to WIPO, approximately 70% of technologies in the world are published only in patent documents. Other data from WIPO show that patent applications worldwide have increased by 7.8% from 2014 to 2015, amounting to 2.888.800 applications worldwide (WIPO 2007, 2016).

A thorough study of prior art can avoid wasting intellectual and financial capital and worktime. Thus, the task of carrying out a comprehensive investigation of a sector's technological production panorama and the impact of inventions produced by companies, universities, and research technology centers is very important (Garcia 2006).

Technological knowledge can be considered as an economic resource of prime importance for enterprises, and is widely considered as a comparative advantage factor that is just as important as financial, physical and human capital (Terra 2000). Good technology management requires an understanding of the evolution of the technology market so that possible trends and emerging needs can be accurately predicted. Prospective studies have a great value to any organization and are particularly important in achieving the R&D and innovation (R&D&I) targets of companies. Prospective studies using quantitative and qualitative methods facilitate the conceptualization of feasible solutions to a problem, which are meant to improve future prospects. From a current overview, forward-looking activities seek to determine plausible perspectives and establish recommendations that could lead to a desired future (Teixeira 2013).

(Kupfer and Tigre 2004) apud Teixeira (2013) classified methods of analysis and prospecting technology techniques into three main groups listed below.

1. Assessment - This consists of monitoring changes in facts, and is normally carried out systematically and continuously.
2. Forecasting - This is the process of establishing projections based on historical information and modeling trends. This method makes a probabilistic prediction of the future development of current technologies through measurements and extrapolations trends.
3. Foresight - This is a qualitative method that anticipates future possibilities based on the perceptions of experts, each supported exclusively by their specialized knowledge and subjective assessments.

(Coelho 2003) apud Teixeira (2013) disclose some methods, techniques, and mapping tools/prospecting most commonly used in studies, which include

- monitoring and intelligence systems: technological competitive intelligence;
- trend analysis: regression analysis, S curves, learning curves;
- expert opinion: Delphi method, panel of experts, critical technologies, surveys, individual assessment, seminars/workshops/committees;
- construction scenarios: SWOT matrix, BCG matrix (Boston Consulting Group), GBN (Global Business Network); and
- computational methods/analytical tools: modeling, simulation, patent analysis, resource analysis expenditure on R&D, multi-criteria analysis, technological maps, content analysis, e.g., data mining, text mining, scientometrics, and bibliometrics.

According to Araújo (1984), (Cabral 1999) apud Antunes and Magalhães (2008), a patent document is the most important source of technological information because of the following reasons:

- it describes the latest technological information regarding the prior art state;
- it enables the identification of key information for innovations in the industry;
- it contains much of the technology disclosed worldwide. In contrast, only a small part of other sources (journals, conferences, seminars, etc.) fully publish the disclosed technology.

Several possibilities concerning the use of patent documents as a source of technological information can be identified as follows:

- newly published patents can act as indicators of the state of the art, presenting the latest information in a given sector of the technique;

- a timely analysis of patents in a given industrial sector coming from one or more countries may indicate trends in the evolution of this sector;
- a time analysis can be performed on a set of patents of a particular industrial sector, revealing its evolution and pointing out new paths of development, for which efforts can be targeted to further modernize the industry;
- it contains information regarding the effective rights of existing patent protection in a country, particularly to avoid patent infringement; and
- in the case of technology transfer negotiations, knowledge of patents enables the identification of both technical alternatives to meet the needs of industry depending on the qualified companies in the sector considered.

According to the Oslo Manual (OECD/Eurostat 2005), patent statistics are increasingly used as indicators of the results of research activities. The number of patents granted to a given company or country may reflect its technological dynamism. Moreover, the growth of patent classes can indicate the direction of technological change in an industry.

Patent applications, such as granted patents, act as an intermediate result of innovation activities and provide information on the innovative capabilities of a company. For instance, a company that applies for a patent is presumably able to develop R&D&I. Data regarding patenting can then provide useful information for innovation surveys (OECD/Eurostat 2005).

The importance of using patents as a source of technological information is also highlighted by the OECD: “Patent-based indicators are extremely useful to compare and monitor production technology trends of different countries” (Dernis and Guellec 2002).

Countries with patenting habits make systematic use of specialized databases for performing patent search; they do so to explore some information fields presented in patent documents, such as international patent classification (IPC), the assignee companies, the inventors involved, the nationality of the inventors, the company nationality, the country of origin of the application document used, the country where the application for protection was first submitted, the date of patent protection application, and the date at which the application was granted, among others (Antunes and Magalhães 2008).

Prior searches of patents correspond to searches for information in specialized sites in the patent literature. Even the official patent offices (national and regional) provide mechanisms for online consultation for the filing of collections and patents granted, *c.f.* the United States Patent and Trademark Office (USPTO), the Japan Patent Office (JPO), the National Institute of Industrial Property (INPI) in Brazil, and so on. Thus, performing patent searches for the most varied purposes is possible.

In addition to the European Patent Office (EPO), examples of official regional patent agencies include the African Regional and Industrial Property (ARIPO), which is formed by English-speaking African nations; the Organization Africaine de la Propriété Intelectuel (OAPI), formed by African nations of the French language; and the Eurasian Patent Organization (EAPO), which is formed by the republics from the collapsed Union of Soviet Socialist Republics (USSR).

In the current work, a snapshot of the bioleaching area in terms of the technologies described in patent applications is established. Considering the importance of prior art searching, this snapshot is created to demonstrate the important aspects of bioleaching and identify some of best practices which must be considered when a technological landscape using patent databases is generated.

2. Methodology

Thomson Innovation® was chosen as the patent database through which this work was completed. This is a paid patent search tool that has a user-friendly interface and relies on frequent updating of its database. Thomson Innovation® can access the following patent collections from official patent offices: USPTO, EPO, WIPO, IPAustralia, IPO (United Kingdom), CIPO (Canada), INPI (France), and DPMA (Germany), and can also retrieve bibliographic information from JPO (Japan) and (KIPO) Korea. Some of these offices, such as EPO and WIPO, not only publish European patents and PCT but also patent applications from several different countries, thus covering an extensive area of patent applications filed.

Other public databases, such as Google Patents, Patent lens, and so on, exist. However, information contained in these databases is updated less frequently compared with Thomson Innovation®.

The strategy for the patent search was to use the IPC. This is because it accurately defines the technological field to be searched. The present study used the IPC C22B 3/18 as the code corresponding to the following (in hierarchical level):

C - chemistry, metallurgy;

C22 - metallurgy, ferrous alloys or nonferrous, treatment of alloys or nonferrous metal;

C22B - production or refinement of metals, pretreatment of raw materials; and

C22B 3/18 - extraction of metal compounds from ores or concentrates by wet processes via leaching with the help of microorganisms or enzymes, such as bacteria or algae.

Other IPCs related to biotechnology exist, such as B82Y 5/00 (nanobiotechnology, nanomedicine, such as protein engineering and drug delivery and C12Q 1/68 (measurement processes or trials involving enzymes or microorganisms involving nucleic acids), among others. However, the focus of this paper was to analyze only the keyword “bioleaching,” which is specifically described by IPC C22B 3/18.

On December 20th, 2016, the Thomson Innovation® system was accessed. We searched for patent documents using the IPC C22B 3/18, without other search restrictions and temporal boundaries. This search resulted in a total of 3699 patent filings worldwide, representing 1226 patent families.

All patent documents retrieved in the search were exported to an Excel® spreadsheet. Thomson Innovation® provided 93 different fields of information for each patent document. However, not all fields contained information for every document, i.e., there were empty fields. For this reason, as well as to focus on the analysis of information, the following fields were selected for analysis:

As the patent document owner

- *Assignee-Standardized*
- *Assignee-Original*
- *Assignee-Original with address*
- *Assignee-DWPI*
- *Assignee Code-DWPI*

As the inventor

- *Inventor-Original*
- *Inventor-with address*

As the title, abstract, claims of patent document

- *Title*
- *Title-DWPI*
- *Abstract*
- *Abstract DWPI*
- *Description*
- *Claims*

As the numbers and application date, publication, and priority

- *Application Number*

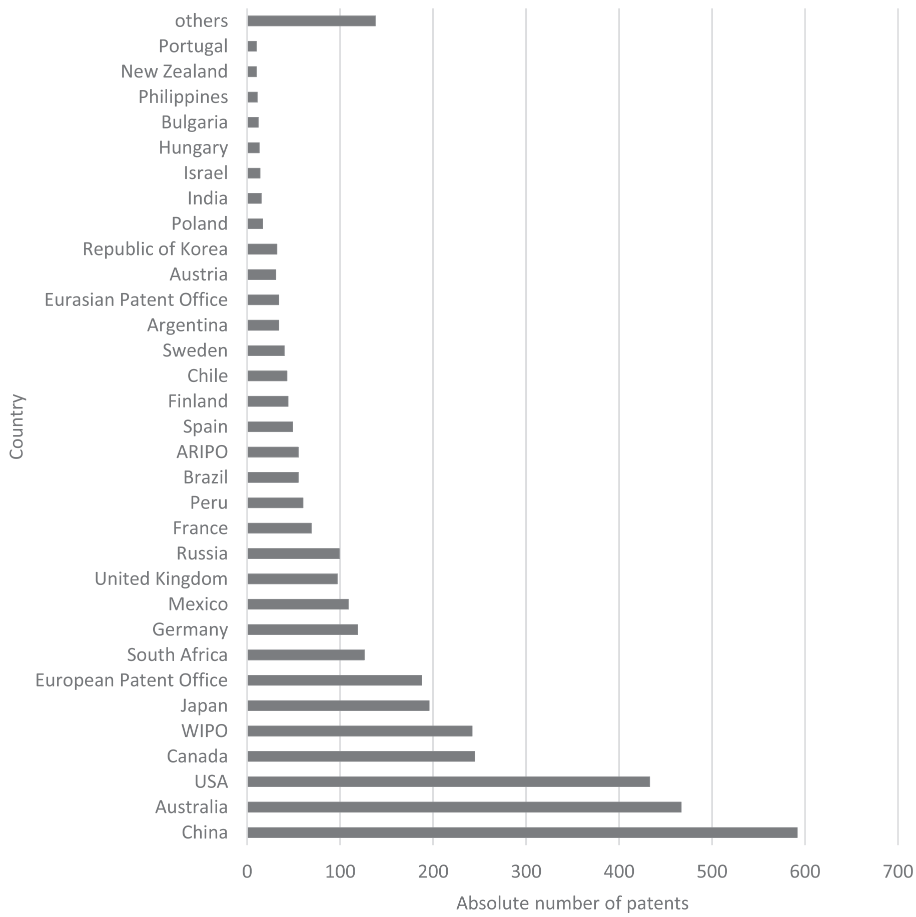

Fig. 1. Main protection markets: absolute number of patent documents.

- *Application Date*
- *Publication Number*
- *Publication Date*
- *Earliest Priority Year*
- *Priority Date*
- *Publication Kind Code*

As the Family, IPC classification of patent document (*International Patent Documentation* (INPADOC) is a patent databank produced by the EPO, and contains patent families and weekly actualized status information)

- *INPADOC Family Members*
- *INPADOC Family ID*
- *DWPI Family Members*
- *DWPI Accession Number*
- *IPC-Current*
- *IPC-Current-DWPI*

The first analysis was carried out in countries where the owners filed their patent documents (also considered "protection of markets" of the bioleaching technologies). The identification of the countries was undertaken in accordance with the country code contained in the patent publication number. During the evaluation, the total number of patent documents found in the search was used, because it was not appropriate to use the number of patent families once the protection was deemed territorial.

The second analysis aimed to analyze the actual attractiveness of the main markets in the bioleaching area, i.e., how many patent applications were made by foreigners in every major market/country. This goal was accomplished by considering the total number of applications in each country subtracted from the number of applications made by the country's own residents.

The third analysis assessed the evolution of the application of patent families worldwide. The year of the earliest priority of each patent family was used as the priority date (date of birth of the invention). This is more suitable for this analysis than using the date of publication or filing date.

The subsequent analysis was related to patent owners, and was carried out by analyzing all the information fields related to owner/assignee provided by the Thomson Innovation® database. The field "Code Assignee-DWPI," for instance, consists of a code designated by the Thomson Innovation® system for each applicant company of the patent. This code is very useful in searches because there are groups of companies who apply their patents using different assignee names. One example is BHP Billiton, a large mining company that has patent filings on behalf of several applicants, including BHP Billiton Ltd., BHP Billiton PTY Ltd., BHP Billiton Innovation PTY Ltd., BHP Innovation PTY Ltd., Minera Escondida, and several others. In addition, there were cases in which errors were found in the depositor's name registry, specifically, typo errors like "Biliton" and "Billiton." For this reason, the search code of the applicant (when available) must only be used as complimentary field in performing the search. Using the same example of the BHP Billiton group, the "Assignee Codes-DWPI" were found: BRHI, BILT, Bill, and BHPB. Following such an approach, the leading company/institution applicants of patent documents were identified.

Upon reading each patent document, we found repeated documents, i.e., belonging to the same family in the same unit of the invention. Therefore, we identified gaps in the INPADOC family classification. Meanwhile, the four major institutions/companies in terms of bioleaching patent families were identified, and subsequently, the technology snapshot was taken for each cited owner.

3. Results and discussion

3.1. Protection markets - countries where patent applications are filed

To assess the bioleaching technology protection markets or the countries in which the owners filed their patent documents, 3699 patent documents were used. As mentioned earlier, once such protection is deemed territorial, it would not be appropriate to use the number of families (1226 families). Fig. 1 presents the results obtained using the abovementioned search strategy.

As can be seen, the three main bioleaching technology markets with market protection are China, Australia, and the United States with 592, 467, and 433 patent documents, respectively. Some patent offices are also presented in Fig. 1, along with regional offices, such as the EAPO, EPO, ARIPO, and WIPO.

Australia is known for the technological dynamism of its mineral sector, which is mainly due to the high concentration of mineral reserves. Furthermore, several research institutions can be found in Australia, and these contribute significantly to the generation of patent documents. These institutions include the Universities of Queensland and Western Australia and several Cooperative Research Centers, which carry out research activities in the mining field. Another example is the Mining and Manufacturing division of the Commonwealth Scientific and Industrial Research Organization (CSIRO), in which research related to bioleaching is carried out (CSIRO 2015).

The large number of patent filings in the United States can be explained by the high concentration of biotechnology research institutions in the country. The world's largest biotech hubs are located in down in Boston and San Francisco. In addition, several mining companies are located in the Midwest, such as Colorado, New Mexico, Montana, and Utah.

3.2. Protection markets - applications by residents and foreigners

Fig. 2 was drawn with the purpose of analyzing the actual attractiveness of the main markets in the bioleaching area, i.e., how many patent applications were made by foreigners in every major market/country. This was determined by subtracting the number of applications in each country from the total number of applications made by the country's own residents, according to the country code of the number of priority.

With 592 patent documents, China currently has the largest number of applications. However, only 188 patent documents (32% of the total applications) were filed by foreigners, implying that 404 patent documents (68% of the applications) were held by residents.

Like China, the United States also has a high percentage of applications by residents: 61% or 265 patent documents. Consequently, foreign applications by percentage comprised 39% of the total applications.

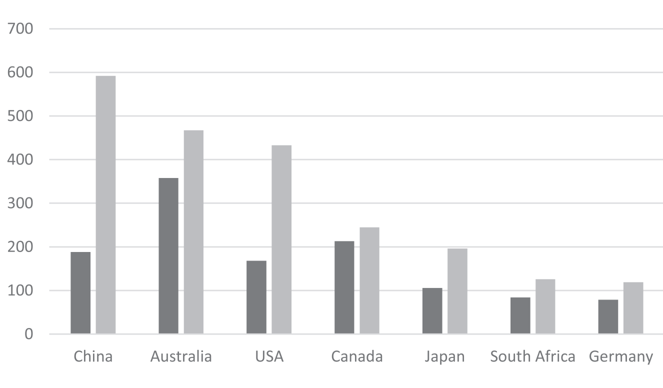

Fig. 2. Main protection markets: absolute number of patent filings by foreigners.

Australia has the second largest number of patent applications in the bioleaching field worldwide. Out of 467 documents, 358 (77%) were filed by foreigners. This finding suggests that, aside from being an important generator of technologies, Australia is also an important market in this segment because a significant number of companies/foreign institutions choose to protect their inventions there. Furthermore, Australia is the greatest producer of nonferrous metals, which are related to bioleaching technologies. Similarly, Canada can also be considered an important market of bioleaching technologies because it had the fourth largest number of applications, of which 87% were filed by foreigners. Considering the ratio of the total number of applications versus the number of applications by foreigners, Canada appears to be the most sought-after market in this field.

Meanwhile, out of the total patents filed in Japan, South Africa, and Germany, 54%, 67%, and 68% were filed by foreigners, respectively. A very good way to measure the strength of a technology is to consider the patents filed in the three greatest patent offices in the world, namely, USPTO, EPO, and JPO. Although this is a remarkable indicator to measure global interest in a particular technology, in this specific sector of knowledge (mining and bioleaching), the main markets in which to file a patent are directly related to countries where the raw materials can be found and processed (i.e., those with robust mining sectors).

3.3. Temporal evolution of patent applications filed

To assess the evolution of the application of patent documents, we used the earliest priority year of each of the 1226 patent families identified. We selected this criterion due to the fact that the priority date is the closest to the birth of technology development and is more suitable for this analysis than the date of publication or the filing date.

Fig. 3 summarizes the evolution of the applications for bioleaching patents. Two main peaks of patent applications can be seen: those filed in 1999 (66 patent applications) and 2010 (70 patent applications). In contrast, the years 2003 and 2004 showed low numbers of patents filed (26 and 22 applications, respectively). According to Brierley (2010), most of the bio hydrometallurgical innovations become feasible when metal prices are low. This is because, during this time, more companies are willing to implement technologies that have the potential to reduce production costs, despite the risks associated with the development of disruptive innovations in the mining sector.

The last two years shown in the chart (2016 and 2015) do not represent the total number of filed applications in the period due of the mandatory document secrecy period. In addition, there is often an indexing delay of at least two years between the filing of a patent application and the recording of this information in the electronic research databases, which further complicates the analysis of the latest years of applications.

The first patent application related to bioleaching area or for possessing IPC C22B 3/18 found in the database was filed in 1912 under publication number DE279312 ("Verfahren zur Behandlung von Meerespflanzen"). Roughly translated, this means "Process of treatment using marine plants." No additional information in English was found. The text of the patent indicates that this does not represent a kind of bioleaching technology. Therefore, this patent was either classified incorrectly by the DPMA or may be an error in the database.

The second patent application encountered in the database was filed in the United States on October 24th, 1955, by the company named Kennecott Copper Corporation ("Cyclic leaching process employing iron oxidizing bacteria") (Zimmerley et al. 1955). The number of publication request was US 2,829,964, and the patent was granted in 1958. Interestingly, the same process flowsheet claimed by the patent is still used today with only minor changes. According to Olson et al. (2003) this is considered as the first patent in the field and is most likely based on previous scientific investigations focused on the involvement of bacteria in the generation of acid mine drainage (AMD). For instance,

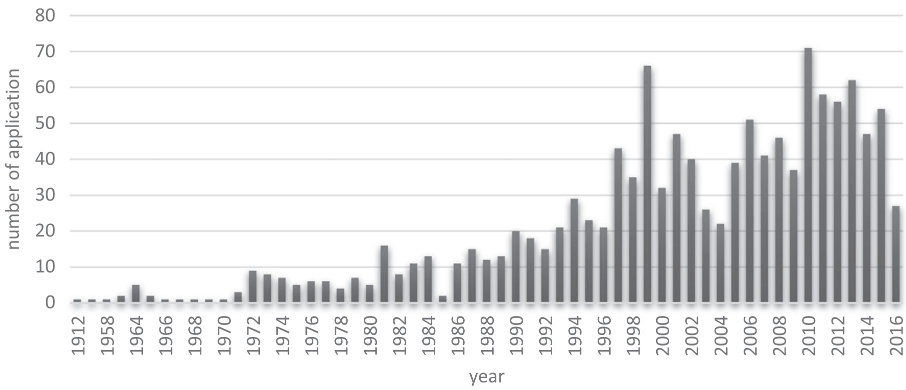

Fig. 3. Temporal evolution of patent documents applications in the world.

Colmer and Hinkle (1947) reported the discovery of a bacteria involved in ferrous iron oxidation. Seven years later, Bryner et al. (1954), published one of the first pieces of evidence proving the contribution of acidophilic microorganism in the leaching of iron and copper sulfides. Therefore, the patent was filed shortly after bioleaching was scientifically demonstrated (Ehrlich 2004). One important milestone was the commissioning of the LoAguirre plant in Chile, the first commercial heap bioleaching operation in the world (Gentina and Acevedo 2016).

3.4. Countries where technologies were originated

The process of identifying the patent families was initiated by identifying that 43 patent families that did not have any indication of which company/institution would be the assignee. The assessment continued with the initial focus on assignees who had the largest number of patent documents. After identifying the 735 patent documents from the largest patent applicants (companies/institutions), we found that the other applicants only had one or two patents, which corresponded to a total of 448 documents. Therefore, we decided to proceed with a more detailed evaluation of 735 patent documents of the largest company/institution patent assignees, as these accounted for 60% of the total population evaluated, as shown in Table 1.

The subsequent procedure identified the country of origin of each patent document among the 735 total documents, after which we built a graph showing these countries. The criteria used to identify the country of origin was the geographic location of the assignee identified through the addresses registered during the filing of the patent.

After identifying the country of origin of each of the 735 patent families, we present the results in Fig. 4. The three major countries that generated patents related to bioleaching were as follows: (i) China, containing 189 families of patents (30%); (ii) Australia, containing 126 patent families (20%); and (iii) United States, containing 55 families of patents (9%).

Table 1
Total assessed patent families.

Description	Absolute number of patent families	Percentage amount
Number of Family patents found in the search	1226	100%
Total patent families belonging to the owners with the largest number of patents families	735	60%
Total patent families filled by assignees that have only 1 or 2 patent family	448	36%
Total patent families that have no indication of which company/institution would be the assignee	43	4%

3.5. Main patent document owners

The analysis of the patent families' owners began by identifying those who had less than 1% of patent families (in relation to total 735 families evaluated); in other words, owners that had 6 or fewer patent families. We then eliminated 276 families from the minority owners. Thus, the subsequent analysis was based on a population of 459 families of bioleaching patents, representing the 27 leading companies/institutions identified earlier.

The main applicant company of patent documents was BHP Billiton with 74 patent applications. This is followed by Beijing Nonferrous Metal-Central South University, Geobiotics (Chile), and Nippon Mining (Japan), as shown in Table 2.

While performing a detailed review of each of these 459 families of patents, we found that there were repeated documents, i.e., those belonging to the same family because they were the same unit of the invention. The number then fell from 459 to 312 families, as shown in Table 2. This finding indicated gaps in the INPADOC family classification and/or in the Thomson Innovation® database. This misleading data probably arose from failures, which may be due to the fact that the EPO, responsible for the INPADOC classification, depended on the information given by offices of each country. We found that the countries with the highest number of repeated documents were Mexico, South Korea, Australia, and the Philippines.

As described by the EPO, a database named "Worldwide Legal Status Database (INPADOC)" can be considered an EPO product that provides weekly descriptions of changes in the legal status, formats, and layouts of applied patent documents, records data, lists of attributes, and explanations of legal events marks. Information can be acquired in the bulletins for patents or registrations in various patent authorities, including the EPO itself. The data were collected by the EPO in Vienna (Austria) and inserted into the master database. The EPO waives any responsibility for the accuracy of the data and information from authorities other than the EPO itself. In particular, the EPO does not guarantee that the data are complete, updated, or adjusted for specific purposes (EPO 2013).

Meanwhile, Thomson Innovation® provides an information field called "DWPI Accession Number," which consists of a reclassification of patent families by DWPI. Examples include the documents KR2002070281A and KR727719B1 owned by BHP Billiton, which are considered by the INPADOC system as two distinct families, despite the fact that both deal with the same kind of invention. Meanwhile, the DWPI classification considers both patents as belonging to the same patent family, thus granting them the same "DWPI Accession Number." However, we observed that numerous patent documents in this field were empty and had no information. Thus, the solution was to manually sort and evaluate each patent document.

In accordance with the flowchart used, represented schematically by Fig. 5, we found that the error rate when using the INPADOC family, in this case provided by Thomson Innovation system, was 32%. This is

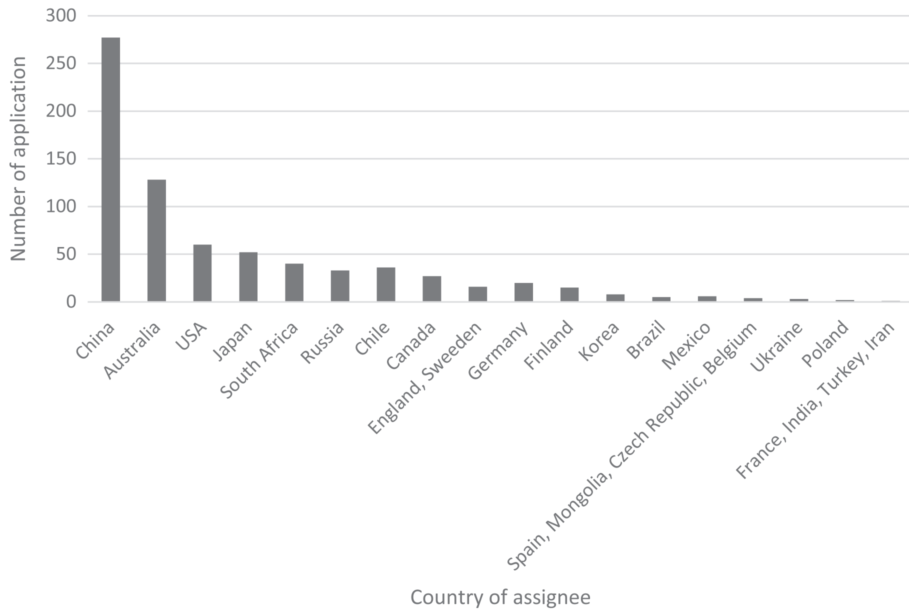

Fig. 4. Main countries of origin: absolute number of patent families.

Table 2
Key patent holders after reading the documents.

Assignee	Assignee origin country	Number of family patents according to INPADOC classification	Number of family patents after a manual sorting
Bactech	Australia	18	12
Beckmann Alexander	Germany	13	3
Beijing Nonferrous	China	46	45
BHP Billiton	Australia	74	39
Bioheap	Australia	22	12
Biomin Technologies	South Africa	7	3
Biosigma	Chile	21	10
Biotecnologias Del Aqua	Chile	8	5
Boliden	Sweden	13	8
Changchun Gold Res. Inst.	China	18	12
Gen. Mining Union Corp.	South Africa	9	5
Geobiotics	USA	24	11
Inst. Process Eng. Cas.	China	7	7
Korea Inst. Geoscience	Korea	8	8
Mintek	South Africa	19	7
Moscow Steel Alloys Inst.	Russia	11	10
Nippon	Japan	23	21
Outotec	Finland	9	3
Teck. Cominco	Canada	11	4
Teck. Resources Pty.	Australia	8	3
Central South Univ.	China	41	40
Univ. Maryland	USA	7	4
Univ. Nanhua	China	8	8
Univ. Northeastern	China	11	11
Univ. Osaka Prefecture	Japan	9	7
Univ. Shandong	China	7	7
Zijin Mining Group Co. Ltd.	China	7	7
Total		459	312

because the number of patent families was reduced from 459 to 312 after the individual assessment of each document.

According to Table 2, we also observed that only four companies/institutions reached a total of 145 patent families, representing 46% of the 312 rated families. These companies/institutions included BHP Billiton, with 39 patent families; Beijing Nonferrous Metals, with 45 families; Central South University, with 40 patent families, and Nippon Mining with 21 patent families. Thus, professionals interested in studying technologies related to bioleaching should pay close attention to these four companies, which seemed to have generated the greatest amount of technical knowledge, as shown by their patents.

Fig. 6 shows the evolution of the applications of patent families of these companies/institutions. We used the earliest priority year of each family in creating the chart.

The families of BHP Billiton patents were concentrated in the early years, as shown in the graph; moreover, application peaks occurred in 1999 and 2001. However, after 2010, we could not find any clear order of occurrences of company patent applications, and the reason for this remains unclear. The other companies began to file applications in 2002 and continued throughout the years. The Central South University is the owner of the most recent patent families, based on the fact that it has only filed applications from 2013 to 2016.

Table 3 presents a grouping of the main fields of technology protected by patent families of the four aforementioned major companies/institutions.

As depicted in Table 3 any company considering projects on leaching of sulfide ores, particularly those of copper should also consider bioleaching as a viable and cost effective option. When heap leaching is the most promising alternative, conditions should be created for bacterial growth inside the heaps, even if when no bioleaching parameter will be monitored during the heap operation. Heap aeration is one such example because it improves bacterial activity and then metal dissolution. Furthermore, despite not being shown during the analysis of the patent applications the bio-oxidation of sulfide ores should also be one of the technological options to be applied during the metallurgical test work for gold ores.

4. Conclusion

This work has revealed several statistical information concerning patent applications in bioleaching. As it can be seen, the production of such biotechnology through patent application is ruled by four major

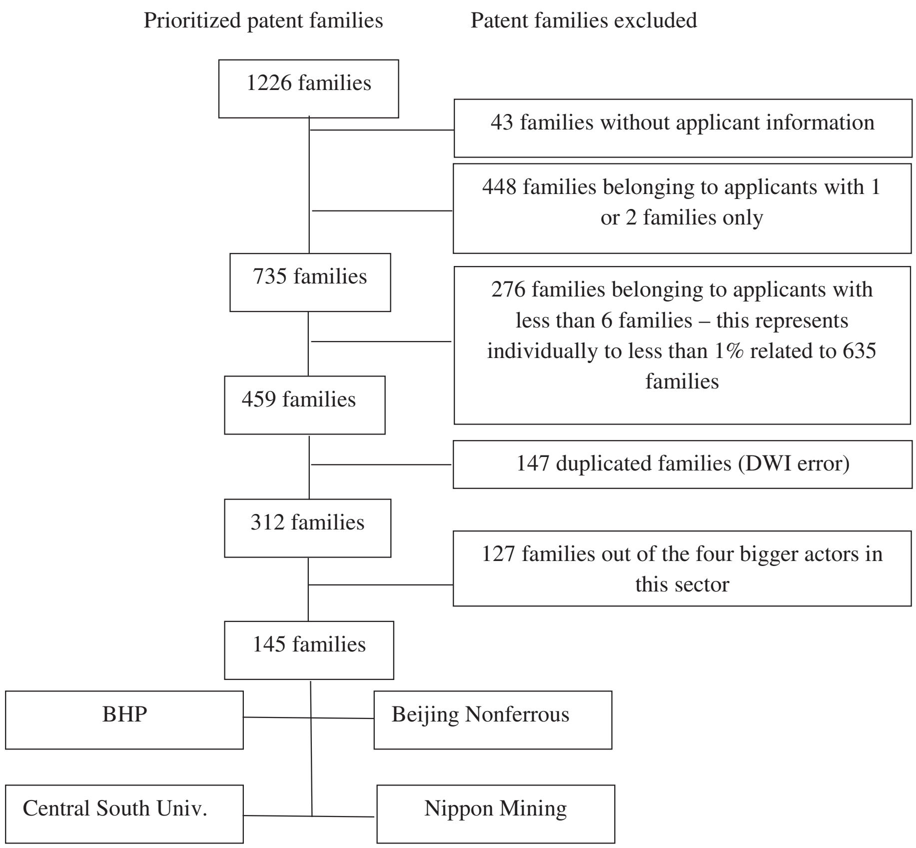

Fig. 5. Schematic representation of the filters in the sample population.

players: BHP Billinton, Beijing Nonferrous, and Nippon Mining (representing multinational companies), as well as Central South University (representing academia). Therefore, the leading producers of bioleaching patents are located mainly in Asia and Oceania. Moreover, technologies developed by the four major players also indicate the trends and specializations of each company, namely, BHP Billiton leads the bioleaching of sulfide ores, Beijing Nonferrous protects the strain cultivation methods and generation of inoculum, followed by Central South University in the same area, whereas Nippon Steel leads the wastewater treatment operations.

Another contribution of the current work concerns the critical assessment of technological information obtained through patent databases. Thus, it is uppermost to highlight various aspects when carrying out a patent landscape:

1) Previous treatment of raw data when addressing large numbers of patent documents. Some misconceptions, misspelled names or indexing errors, IPC misclassifications, duplicity of information regarding applications or granted documents, different definitions of patent families or even late update of databases could also be found in automated analysis and this kind of result mislead the decision maker. In such case, we found an error of 32% in the original 459 patent families retrieved, which means147 duplicated families (DWPI). Thus, conducting a very careful analysis of every information field in a patent document is very important in order to avoid misconception and false technological landscapes;
2) Patent landscapes by themselves may not identify significant technological progress in a particular area of knowledge. Although many patent applications could be retrieved, regarding these and other

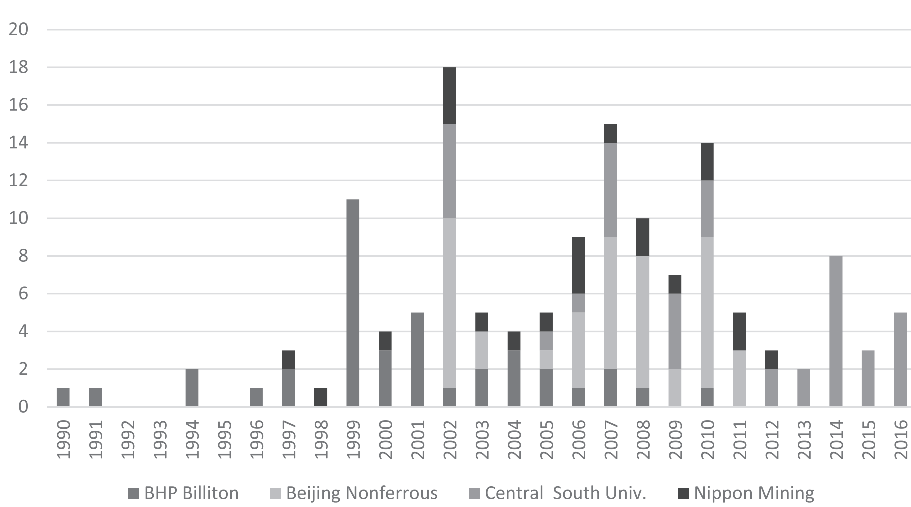

Fig. 6. Temporal evolution of the deposits made by leading companies/institutions.

Table 3
Stratification of patent families of the four largest companies/institutions applicants according to the main protected technological fields.

Technology related to	BHP billiton	Beijing nonferrous	Central south univ.	Nippon steel
Bioleaching of sulfide ores (Ni, Cu and others)	14	6	6	4
Bioleaching of lateritic ore	4	3	0	0
Bioleaching of chalcopyrite	4	4	3	6
Precious metals bioleaching	4	2	2	0
Bioleaching of low grade ores	0	9	4	0
strains cultivation method and generation of inoculum	2	18	12	1
Treatment of wastewater or waste containing metal	0	1	0	8
Others	11	2	12	2
Total	39	45	24	21

players, only a few technological improvements in the bioleaching sector have been observed through the years. Brierley (2010) reports that the path from laboratory research to commercial application of biohydrometallurgical technologies has faced many obstacles and challenges, including the following: (i) timing to convert lab process into pilot plant, (ii) site specificity of machinery, (iii) competitiveness concerning similar industrial processes, (iv) risks involving technological failures, (v) high amount of capital investments, (vi) intellectual property issues, (vii) process guarantees, and (viii)availability of skilled engineers and scientists.

Some interesting information regarding patents applications filed in China by either foreigners or nationals calls for analysis, considering not only the domestic production of technology but also the local innovation polices defined by the Chinese government.

Overall the patent landscape presented herein unveils an overview of developments in bioleaching. Most patents focus on the use of saline and its impact on copper extractions as well as bacterial growth because of the chloride toxicity. This is because of the use of saline waters solutions in both Chile and Australia. In addition, the use of high temperatures improves copper extraction from chalcopyrite (the most difficult copper mineral to be leached) and another cluster of patents mostly from BHP Billiton covers this subject. New strains which can grow at high temperatures as well as optimized methods for the production of inoculum were also patented by Chinese Universities. Furthermore, patents protecting the use of high temperature in bioleaching also include the design of new bioreactors in which oxygen transfer is improved. Usually the bioleaching patents described herein disclaim new processes integrating different research fields such as biotechnology (strain cultivation and inoculum production) and process engineering such as heap leaching and solvent extraction.

Some challenges which remains to be overcome are: (i) chalcopyrite bioleaching, particularly from low-grade ores and mining tailings, for which heap leaching operations are among the few cost-effective solutions available; (ii) the development of bioleaching process in the presence of high saline waters i.e., improving bacterial tolerance to the anion; (iii) the use of biologically-produced organic acids to leach nickel laterites. In addition, the absence of biotechnological routes to leach rare earth ores is also worth citing.

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