International Journal for Innovation Education and Research ISSN 2411-2933 01-07-2022
DOI: https://doi.org/10.31686/ijier.vol10.iss7.3793

Title: Notes on the development of water treatment technologies: an analysis of patent applications between 2000 and 2020

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Abstract

This paper aims to analyze the research efforts carried out to develop new technological applications in the field of water and sanitation services. We use the Derwent Innovations platform to perform a search for global patent applications made between 2000 and 2020 that received the D15 technological classification ("treating water, industrial waste and sewage"). The survey identified 31,278 patent families, including 2,938 applications that were extended to Brazil. Our results suggest that General Electric (GE) owns the most technologically important water treatment patents. The company also stands out as the main holder of Brazilian patents, being closely followed by other multinationals such as Veolia and 3M. We conclude that large international companies are interested in spreading the main water treatment technologies to Brazil. Due to its large rivers and aquifers, Brazil poses as an attractive place for the development of new water treatment solutions. On the other hand, despite this favorable scenario, Brazilian organizations are staying out of the global race for patents in the field of water-related technologies.

Keywords: research and development, water resources management, sanitation services.

1. Introduction

Currently 768 million people rely on unsafe sources of drinking water while another 2.5 billion individuals do not have access to reliable sewage facilities. These two related problems create serious obstacles to nutrition and social development (HLPE, 2015). In addition, several studies predict the outbreak of new water crises in the coming decades, as consequence of climate changes that will affect the availability of water and due to the increasing conflicts around this essential natural resource (World Bank, 2008; World Economic Forum, 2020).

The universalization of access to water and sanitation services is an urgent priority of the United Nations (UN). In this sense, the sixth Sustainable Development Goal (SDGs) of the 2030 Agenda is "ensuring the availability and sustainable management of water and sanitation for all". Furthermore, SDG No 13 – "taking urgent measures to combat climate change and its impacts" (United Nations, 2015) – can be considered a prerequisite for the conservation of water resources.

Technological innovations have proved to be a key condition for the construction of a socially fairer and, at the same time, more environmentally friendly world. For these reasons, the study of technological challenges for global water security has attracted the interest of several policy makers and academics (HLPE, 2015). Among these challenges, it is recognized that the research of new technologies capable of making water supply and wastewater treatment processes more sustainable represents a crucial element to improve the management of water resources (Environmental Protection Agency, 2014).

However, some research gaps remain to be covered, since, so far, no study has answered two key questions: which organizations have led the development of new technological applications in the field of water supply and sanitation services? Are the holders of these technologies are committed to bringing them to Brazil? The present study seeks to fill these gaps; to this end, we use the Derwent Innovations platform to perform a search for global patent applications that received the D15 technological classification ("treating water, industrial waste and sewage"). These patent searches allowed us to characterize the research and development (R&D) efforts carried out to provide new solutions for water supply management.

This study was organized as follows: Section 2 deepens the themes addressed in this introduction concerning water resources and technological innovations; Section 3 presents the methodology, i.e., the procedures we perform to build the patent databank and to compute technological indicators. Section 4 analyzes the ownership of these patents as well as the technologies they claim, while Section 5 concludes the study.

2. Technological innovations for water resources.

The U.S. Environmental Protection Agency of the U.S. Federal Government has listed ten technological challenges that will need to be addressed in the coming years to ensure the sustainability of global water resources. Three of these challenges are associated with agricultural and industrial activities: i) reduce energy consumption associated with irrigation, extraction, and water treatment activities; ii) recover watersheds and springs contaminated by nutrients from the application of fertilizers (e.g., nitrogen, and phosphorus); iii) develop technologies aimed at the conservation and reuse of water resources in industrial and agricultural activities (Environmental Protection Agency, 2014).

The other critical factors for global water safety encompass energy, water supply and sanitation sectors. There is a need to: iv) make water and sewage distribution infrastructure more sustainable; v) reduce costs and improve techniques for monitoring drinking water sources; (vi) improve the efficiency of watersheds; vii) develop new energy sources less dependent on water resources; viii) increase the resilience of water supply infrastructure in relation to extreme climatic events; ix) improve the world's basic sanitation conditions; x) increase the amount and quality of drinking water sources available to populations living in areas vulnerable to water stress situations (Environmental Protection Agency, 2014).

Technological innovation represents a key element to address the ten technological challenges listed above (Environmental Protection Agency, 2014) and to promote global water security (HPLE,2015). Dosi's seminal paper (Dosi, 1982) emphasizes the emergence of new technological trajectories (TTs) due to scientific development and changing consumption patterns. During the selection of the technologies that will be part of the TTs, each company will define the new applications that will be prioritized among the several existing options for the allocation of the R&D budget. Relative price changes caused by cost shocks generate powerful incentives to implement new projects (Mowery & Rosenberg, 1979). In parallel to these cost changes, the technological choices also depend on the general state of science and the knowledge base accumulated by engineers and researchers (Pavitt & Soete, 1980).

HLPE (2015) states that agricultural irrigation consumes annually about 70% of the world's freshwater. The report projects a drop in this percentage in the face of the future competition with other sectors for water access. Hence, both agriculture and modern industry will need to adapt to a scenario of increasing water costs. According to Crestana and Mori (2015), the water and energy cost shocks will redirect increasing portions of the corporate R&D budgets towards the development of new technologies able to optimize the use of water resources.

3. Methodology

We chose the Derwent Innovation Index for performing our patent search. The platform was accessed through the Capes Portal and the survey covered the period extending from January 2000 to December 2020. We carried out a search for patents that: i) belong to the Derwent Technological Class - Code D15 (treating water, industrial waste, and sewage); ii) display the prefix 'US' in their numbering, i.e., the prefix that indicates the documents issued by the United States Patent and Trademark Office (USPTO). The Derwent Platform allowed us to classify the patents by technological classes and owners. We use the same platform to generate two proxies for measuring the technological relevance of the intellectual property documents identified by our search - the indicators for forward citations and of extension patents.

According to Trajtenberg (1990), the citations that a patent receives from other ones represent a proxy for the technological importance of the inventions disclosed in the first patent that was cited. Similarly, Harhoff, Scherer, & Vopel (2003) found a strong correlation between the size of a patent family and the monetary value attributed to the invention by its holders . According to this reasoning, companies prioritize extending to other countries the technologically most important patents, which also are more likely to generate royalty revenues, due to the additional costs generated by each revalidation request approved abroad (Ferrari et. al., 2020).

4. Results

The survey identified 31,278 patent families, including 2,938 applications that were extended to Brazil. Figure 1 describes the evolution per biennium of patent filings on water treatment technologies. During the period of 2000 to 2007, patent applications remained stable, around 2,500 documents per two-year span. This scenario changed after the 2006-2007 biennium. The year of 2008 marked a turning point; since then, patent applications in the fields of water and sanitation have continuously increased for five straight biennia Thus, the intensification of the R&D efforts in the field of water & sanitation services coincided with the outbreak of the global financial crisis of 2008-2009.

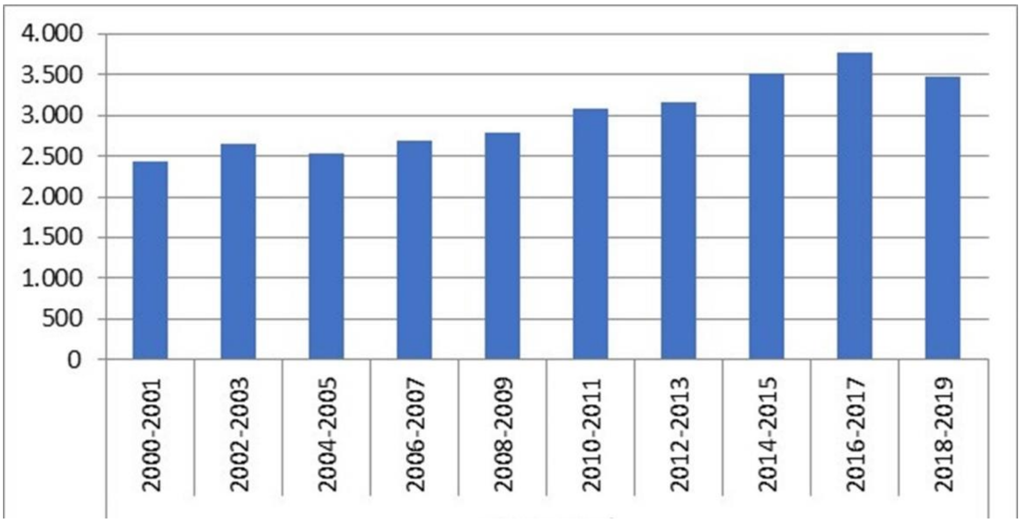

Figure 1. Patent applications per biennium in the field of water & sanitation services (base of 252,061 patent families)
Source: Derwent Innovations Index – DII (Web of Science/Clarivate Analytics)

This coincidence did not go unnoticed. According to Water Research Foundation (2009) and Winpenny et. al. (2009), in many countries, the 2008-2009 financial crisis overlapped with a previous water crisis. These two events contributed to highlight the financial vulnerability and the governance problems of water resources management. In this context, large multinational companies started to increase their R&D investments in water solutions technologies as consequence of growing environmental concerns and of the perception of new economic opportunities related to water and sanitation services.

For example, Siemens AG believed that despite the economic crisis that was hitting the world in 2008, the need for freshwater in an increasingly dry world would always bring economic opportunities for companies dealing with water resources. The company envisioned urbanization and water scarcity as two lasting trends that would require a new set of water treatment innovations (Falson, 2008). This opinion expressed by Siemens AG was also shared by its main competitors. The Public-Private Infrastructure Advisory Facility (PPIAF) observed the widening of interest of the private sector in new R&D projects concerning water resources management (Public-Private Infrastructure Advisory Facility, 2011).

The joint reading of Tables 1 and 2 reinforces these propositions. Table 1 lists the top holders of water treatment patents, considering the period extending from 2000 to 2020. This ranking is led by the American company General Electric (GE). In Table 2, we split this ranking into biennia, with the aim of highlighting at which two-year time spans the GE and the other companies presented in Table 1 were part of the group of the top ten patent holders.

Table 1. Top 20 Water Treatment Patents Holders (base of 31,278 patent families covering January 2000 to December 2020).

Assignee	General Ranking	Patents
GENERAL ELECTRIC	1	382
ECOLAB USA INC	2	213
KURITA WATER IND	3	186
VEOLIA WATER SOLUTIONS TECHNOLOGIES	4	176
UNIV DHAHRAN KING FAHD PETROLEUM MINER	5	160
TORAY IND	6	156
EVOQUA WATER TECHNOLOGIES	7	154
BASF	8	134
DOW GLOBAL TECHNOLOGIES	9	133
UNIV CALIFORNIA	10	132
3M INNOVATIVE PROPERTIES	11	128
SIEMENS WATER TECHNOLOGIES	12	127
NALCO	13	122
SAMSUNG ELECTRONICS	14	114
TOSHIBA	15	112
OTV SA	16	105
MITSUBISHI HEAVY IN	17	100
MASSACHUSETTS INST TECHNOLOGY	18	95
LG ELECTRONICS INC	19	89
COUNCIL SCI IND RES INDIA	20	88

Source: Derwent Innovations Index – DII (Web of Science/Clarivate Analytics)

Table 2 suggests the existence of two different phases. Up until 2005, patent filings per biennium were much lower (Figure1). In the first quinquennium of the 2000s, there was a certain diversity among patent holders, since small specialized companies in water treatment (Kurtia, Nalco, OTV S.A. and Zenon), public institutions and universities were often part of the group of the Top 10 patent holders (Table 2). This scenario changed after the 2006-2007 biennium, since multinational companies like GE, Veolia, BASF and Siemens have become frequently the leaders of the biennial Top-10 rankings of patents holders (Table 2). As result of the R&D projects performed by these international conglomerates, the patents filings on water treatment patents have accelerated since then.

An emblematic case that deserves to be highlighted is that of Zenon, a Canadian company in Oakville that had an extensive patent portfolio, with an emphasis on ultrafiltration technology in water treatment (Zehr, 2006). In 2006, GE Water & Process Technologies acquire Zenon Environmental Inc. in a $760 million operation. According to Water World (2006) this event marked the end of an era, when the main Canadian independent water treatment company became a department within a large global conglomerate. Several savvy experts predicted at the time that the Zenon acquisition would pave the way for GE to take the lead in developing new water treatment technologies (WATER WORLD, 2006). In fact, as shown in Table 2, GE stayed at the Top-2 position of the patent holders' rankings throughout the following decade after Zenon acquisition (2007-2017).

Table 2. Company position in the biennial Top-10 rankings of patents holders

ENTERPRISES	2000-2001	2002-2003	2004-2005	2006-2007	2008-2009	2010-2011	2012-2013	2014-2015	2016-2017	2018-2019	Total Patents
GENERAL ELECTRIC CO				2	2	1	1	1	2		382
ECOLAB USA INC							9	2	1	2	216
KURITA WATER IND LTD		8	8		9	5		9	4	5	188
VEOLIA				8	8	3	4	6	8		176
UNIV DHAHRAN KING FAHD								4	3	1	164
TORAY IND INC						8	2	8	6		156
EVOQUA WATER TECHNOLOGIES LLC							6	10	9	4	154
BASF SE				5	5	9	5				134
DOW								5	5	7	133
UNIV CALIFORNIA	4										132
SIEMENS WATER TECHNOLOGIES CORP				3	1	2	8				127
NALCO CO	7				3	10					122
SAMSUNG							3	3			114
TOSHIBA KK					7	4	10				112
OTV SA		10	2	4	10	6					105
MITSUBISHI HEAVY IND CO LTD								7	7		100
MASSACHUSETTS INST TECHNOLOGY										9	96
LG ELECTRONICS INC										3	92

COUNCIL SCI IND RES INDIA		6		6							88
IND TECHNOLOGY RES INST			6								86
NALCO CO.		4		9	6						80
ZENON	3		4								45

Source: Derwent Innovations Index – DII (Web of Science/Clarivate Analytics)

The indicators for forward citations presented in Appendix 1 provide additional evidence regarding the key role of Zenon acquisition to GE. Appendix 1 points out the 21 patents that have received more than 100 citations from others. The same appendix also presents the family size of each patent[1]. Most of the companies listed in Table 1 do not appear in Appendix 1. GE represents the main exception to this trend. The conglomerate owns 3 highly cited patents (two of them inherited from Zenon and one developed internally) that have been extended to at least 5 countries. Considering the patent value indicators described in Section 3, this evidence suggests that GE hold in its technological portfolio the most important patents in field of water supply and wastewater treatment.

As shown in Table 3, GE is also the main owner of Brazilian water treatment patents. Furthermore, looking closely at Table 3, a first finding that stands out is that the top holders of Brazilian patents are the same companies listed in Table 1. This convergent scenario suggests the interest of global multinationals in extending water treatment technologies to Brazil, a country with huge water resources and immense energy potential. On the one hand, foreign companies increasingly connection with Brazilian water & sanitation sectors is stimulating new solutions for water resources management. On the other hand, the lack of Brazilian organizations in Table 3 raises concerns.

Table 2. Top 20 Brazilian Water Treatment Patents Holders (base of 2,938 patent families covering January 2000 to December 2020).

COMPANIES	**General Ranking**	Patents
GENERAL ELECTRIC CO	**1**	**67**
VEOLIA WATER SOLUTIONS TECHNOLOGIES SU	2	64
ECOLAB USA INC	3	62
3M INNOVATIVE PROPERTIES CO	4	61
DOW GLOBAL TECHNOLOGIES LLC	5	57
NALCO CO	6	50
BASF SE	7	46
DOW GLOBAL TECHNOLOGIES INC	8	42
NALCO CO.	9	40

[1] "The size of a patent family is equivalent to the number of nations in which a specific invention has obtained patent protection" (Ferrari, et. al., 2020).

OTV SA	10	37
VEOLIA WATER SOLUTIONS TECHNOLOGIES	11	33
ROHM HAAS CO	12	31
3M INNOVATIVE PROPERTIES	13	29
KEMIRA PLC	14	29
3M INNOVATIVE PROPERTIES CORP	15	27
BASF AG	16	26
KONINK PHILIPS NV	17	26
SIEMENS IND INC	18	26
DEGREMONT	19	25
PROCTER GAMBLE CO	20	24

Source: Derwent Innovations Index – DII (Web of Science/Clarivate Analytics)

5. Conclusion

This study painted a detailed portrait of the patent applications in the field of water and sanitation services. The results highlight two different phases: during the period of 2000 to 2007, patent applications remained stable, around 2,500 documents per biennium. Furthermore, there was also certain diversity among patent holders since small specialized companies in water and sanitation services (such as Zenon, OTV and Nalco) and universities were part of the group of the Top 10 patent assignees in all the two-year times spans. This scenario changed after the global economic crisis of 2008. In this troubled year, large multinational companies started to increase their R&D investments in water solutions technologies as consequence of growing environmental concerns and of the perception of new economic opportunities related to water resources management. As result of these new R&D projects, the patent applications in the field of water and sanitation services have continuously increased during the 2010s.

Our results similarly suggest that General Electric (GE) owns the most technologically important water treatment patents. The company also stands out as the main holder of Brazilian patents, being closely followed by other multinationals such as Veolia and 3M. We conclude that large international conglomerates are interested in spreading the main water treatment technologies to Brazil. Due to its large rivers and aquifers, Brazil poses as an attractive place for the development of new water and sanitation solutions. On the other hand, despite this favorable scenario, Brazilian organizations are staying out of the global race for patents in the field of water-related technologies.

6. Acknowledgement

We are grateful to XXXX for its support to this research and to XXXX for granting a XXX fellowship to XXX. Note: we will fill these gap (“XXX”) after the manuscript approval.

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Appendix

Appendix 1. Data on water treatment patents that received more than 100 forward citations and have been extended to other countries

Title	Citations	Extension patents	Company part of Table 1
Microchip releasing molecules into e.g., bloodstream, includes reservoirs from which they are released under control into carrier fluid	480	8	No
Fluid treatment system comprises inductively coupled ballast circuit for non-contact power transfer to electromagnetic radiation emitting device	465	12	No
Composite particles made of resin and filler material are useful in subterranean formation and in water filtration	322	12	No
Aeration system for aerating tank water in tank containing immersed membrane modules in reactor has aerators such as conduit aerators that admit tank water when air is supplied at lower flow rate	**210**	**13**	**ZENON ENVIRONMENTAL INC**
Assay device for determination of analytes in biological, environmental or industrial fluid samples, provides controlled movement of reagents without use of membranes	195	2	No
Monitoring system used to determine well fluid properties comprises a well module having probe and sensor(s), data collection center, monitoring site, and communication link	**194**	**2**	**GENERAL ELECTRIC CO (GENE-C)**

Changing molecular structure of biomass feedstock to produce fuel involves preparing biomass feedstock by reducing dimension of each piece of biomass; and pretreating feedstock using pretreatment method e.g., pyrolysis followed by processing	185	17	No
Anaerobic digester system for converting waste material into e.g., methane, includes single anaerobic digester with pressurized headspace	174	2	No
Test device used for detection of samples such as anticoagulant, has sample receiving chamber engaging to test platform containing test strip, detachably	171	2	No
Waste containment system characteristic indication, e.g., for chemical waste, involves performing electrical time domain reflectometry using electrically conductive element provided along specific length of casing string	165	2	No
Membrane process for treating and purifying industrial effluent wastewater, ground water and surface water, involves utilizing cationic inorganic and/or polymeric flocculants	157	2	No
Electrochemical method for deionizing fluid, involves passing fluid through open channel(s) formed between battery electrodes, contacting electrodes with regenerant and deionizing fluid by passing through battery	156	2	UNIV CALIFORNIA (REGC-C)
Nanostructured material use in purification of fluids, e.g., petroleum, biological fluids, foodstuffs, or beverages, comprises defective carbon nanotubes from impregnated, functionalized, doped, charged, coated, and/or irradiated nanotubes	149	2	No
Production of steam from feedwater comprising oilfield produced water, for downhole use in heavy oil recovery operations, involves evaporation step followed by removal of hardness from distillate	148	2	IONICS INC
Filter medium for removing microbiological contaminants, e.g., virus from fluid, includes	144	2	No

microporous structure, and microbiological interception enhancing agent comprising cationic material and biologically active metal			
Membrane separator for solid-liquid separation comprises membrane separator unit with membrane modules each having separating membrane and membrane fixing members, gas diffuser and enclosure wall	143	8	MITSUBISHI HEAVY IND CO LTD
Continuous conversion of solid lignocellulosic biomass to ethanol by subjecting biomass slurry to high temperature and/or oxygen enriched atmosphere, hydrolyzing, fermenting, separating ethanol, and treating wastewater	139	7	No
Preparation of ordered mesoporous sorbent by mixing imprint coating precursor and ordered mesoporous substrate, treating coated mesoporous substrate with acid solution, and evaporating then titrating coated mesoporous substrate	137	1	No
Electrolysis cell of open configuration used for treating contaminated aqueous solutions comprises closely spaced electrodes and units for supplying electrolytic solution and regulating residence time of solution	136	18	No
Contaminated water treatment apparatus for treating storm water contains filter medium comprising mulch layer over soil mixture containing non-organic matrix material and organic material, in treatment chamber	131	1	No
Filtering of water containing solid impurities involves introducing water of volume equal to withdrawn amount of retentate with high concentration of solids from tank, with membranes in tank immersed in water	**129**	**6**	**ZENON ENVIRONMENTAL INC**

Source: Derwent Innovations Index.