

Desalination in nuclear plants: a bibliometric study of research activity in scientific literature indexed by SCOPUS base

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Abstract— *With the scarcity of fresh water, desalination is an important instrument to be considered for the production of non-salinized water through waste heat in the dual use of nuclear reactors. The gap that this study seeks to fill is related to the use of bibliometric method, based on information structure, about the scientific studies indexed on the evolution of the topic desalination in nuclear power plants. The objective of this work is to map the themes in the scientific literature between 1966 and the first semester of 2017. Data were collected from the research activities indexed by the SCOPUS database and analyzed with the support of bibliometric software VOSviewer. Among others, the results of the research led to the following conclusions: (1) the articles published in indexed journals represent the largest percentage of the type of instrument used for scientific dissemination, representing 64% of the documents; (2) it is estimated that between the years 2016 and 2025 the indexed research activities involving nuclear desalination continued to grow sharply.*

Keywords— *bibliometric study, desalination, nuclear power plants, scientific literature.*

I. INTRODUCTION

Deep transformations occurred, in the last decades, in society, public, private and third sector's organizations' perception of fresh water use, understood as the water destined to industrial and agricultural use and to human consumption as exhaustible and essential to life and human activities (SHARP, 2017; THISSEN, ET AL., 2017; MANJU e SAGAR, 2017).

Considering that the larger water volume in the planet is brackish, today, to a greater or lesser degree, and seasonally, scarcity of fresh water was observed in several countries, which has motivated the debate on the alternatives to its sustainable use and increment its obtention based on purification processes and salt extraction. (VICTORINO, 2007; JAEGERMEYR, 2017; FANE, 2017).

In this sense, Hirata (2000) defends that potable water supply to all is the big challenge of humankind in the next years, considering that good quality water can reduce death rate and increase population's life span (WORLD HEALTH ORGANIZATION, 2004).

The following facts contribute to the challenge indicated by Hirata (2000): population growth, poor geographical distribution of water resources, rainfall rates instability (ADETAYO, ET AL., 2008; YANO, 2016, AMARASINGHE, ET AL., 2017). These phenomena have pressed and motivated governments, non-governmental organizations and the scientific community to seek alternatives to increment water production and sustainability in its use (SULLIVAN, ET AL., 2017; HASSANLI e EBRAHIMIAN, 2017).

Thus, in this environment with fresh water scarcity and abundance of brackish water, desalination becomes an important means to be considered to obtain non salinized water (BASKI, 2017; JOO e KWAK, 2017; YANG, ET AL., 2017).

To desalinate water it is necessary to warm it, which requires a heat generating source like: hydraulic, natural gas, oil, coal, biomass, wind, solar, geothermal, biogas and nuclear (GAID e COEYTAUX, 2015; LOVEDAY, 2014; BECKER, LAVEE e TAVOR, 2012).

According to the International Atomic Energy Agency (IAEA), 449 nuclear reactors spread across 30 countries produce approximately 11% of the total electric energy generated by man. In this operation, for producing a considerable level of residual heat, thermonuclear plants are potential means to desalinate water, based on the dual use of nuclear reactors, the binomial – electric energy generation / obtention of fresh water (ALJOHANI, ABDUL-FATTAH e ALMARSHAD, 2005; ELASKARY, 2013; JAIN e JAIN, 2007; PETERSON-RETIRED SR, 2008).

In this context, one can observe that, since the 1960s, there has been a deep advance in indexed researches on desalination in nuclear plants. The theme is increasingly

becoming more important, chiefly since Siegel, Golan and Falcon (1966) studies' publishing, which examined the specific types of nuclear plants in combination with desalination plants to establish the economic potential of several sources of heat for application in large scale, with double purpose.

Furthermore, Akash, Al-Jayyousi and Mohsen (1997) work on non conventional energy technologies for water desalination in Jordan through multi-criteria analysis, one of the most cited studies by other researchers, demonstrates the corporification of research activities on the subject in indexed scientific literature and the growing amount of investigations that have contributed to the development of desalination models.

Based on the premise of the need of scientific researches indexation, an important range of authors defends that the use of a set of bibliometric indicators represents one of the most important requirements for mapping, and measuring the progress and evolution of science and technology (BORNMANN AND LEYDESDORFF, 2013; RADICCHI AND CASTELLANO, 2013). By using these indicators, one can notice that there is an issue not considered in previous investigations that constitutes the gap that the present study seeks to fill, namely: the use of the bibliometric method, consubstantiated in informational structure, around the indexed scientific studies on the evolution of the theme desalination in nuclear plants.

Thus, by examining this initial context, the central question of this work was delimited, which is: How, along 51 years of evolution, has the theme desalination in nuclear plants been presented in the scientific literature indexed by SCOPUS base? The objective of this paper, on the other hand, is to map the theme desalination in nuclear plants considering the period from 1966 to the first semester 2017, using the bibliometric methodology. Moreover, in the ambit of this qualitative study, starting from its central objective, thematic areas were identified that provided a conceptual frame, enabling the exploration of data from researches published in scientific literature indexed by SCOPUS base, determined by a set of filters prepared using Boolean architecture and analyzed, with regard to its clusterization, using VOSviewer software.

This investigation was structured in four parts: (1) introduction; (2) methodology – bibliometric study structure; (3) results and discussions, and (4) conclusions.

II. METHODOLOGY – BIBLIOMETRIC STUDY STRUCTURE

2.1 – Bibliometric method

To concretize the type of methodological perspective it is necessary that the research purpose is precisely prepared, so that results are connected, in the conclusion of the

study, with the investigation central question (RAFFAGHELLI, CUCCHIARA E PERSICO, 2015; SMITH, 2015).

Considering this study objective, the bibliometric method was regarded as the most relevant. This methodology, as investigation form, has cooperated to the understanding of information, chiefly in by clearing bibliographic events and phenomena, evidencing concrete results for the scientific investigation (ZUCCALA, 2004; KOSTOFF, 2005).

The bibliometric method can be depicted as a line of knowledge that converges to the analysis of the quantitative measurement of bibliographic data (FEDOROWICZ, 1982; LOTKA, 1926 e BRADFORD, 1934). The following are considered the most important laws of bibliometry: (1) Zipf-Booth's Law of Word Frequency (FEDOROWICZ, 1982); (2) Inverse Square Law (LOTKA, 1926); and (3) Dispersion Law or Law of Periodicals Productivity (BRADFORD, 1934).

The preliminary Law of Word Frequency, presented by Zipf (FEDOROWICZ, 1982) understands that in a wide writing the catalogue of words' periodicity can be observed, where the terms with higher regularity is the first in the sequence's hierarchy, the expression with the second higher repetition is the second in the structure order, and so on, where the product of the series sequence (R) of a sentence multiplied by the occurrence frequency (F) is more or less constant (C).

Lotka (1926) determined the Inverse Square Law' columns assuming that the amount of authors that perform "N" cooperation in a singular segment of science is around $1/N^2$ of those who perform only one collaboration and that the portion of those who co-participate only once is approximately sixty percent (60%).

As reference, the fraction of highly remarkable researchers in a specialized sector of science shows high production and less remarkable scholars show low production.

The Dispersion Law of Law of Periodicals' Productivity, presented by Bradford (1934), is grounded on the hypothesis that the most productive periodicals on a certain theme appear due to the establishment of a core of magazines resulting from the continuous progress and relevance of a peculiar content.

The most hodiernal bibliometric works have reinforced the laws conceived by Zipf, Lotka and Bradford, where diagnosis is used to build a wide conceptual reference, based on informational data, with the purpose of seeking national and international periodicals, authors with more highlight, conceptual terms and key words to provide information to appraise the research process (GATO ET AL.; GUEDES, 2012).

In this sens, recent scientific investigations, from different fields of knowledge, published in high impact periodicals, have associated the application of bibliometric laws to the use of Boolean operators and guides for the information recovery process (BLANCO-MESA, MERIGÓ, GIL-LAFUENTE, 2017; YE, ET AL., 2017; LAHUERTA, ET AL., 2017; GONZALEZ ALEU, ET AL., 2017; HAUSER-DAVIS, ET AL., 2017).

2.2 – Confirmation of the research gap through bibliometry

In the ambit of this qualitative study, starting from the research preliminary, the context and the preliminary hiatus of the investigation was established. Then the central question of the study was defined, which seeks to understand the scientific interest and unrest through causal relations with the context, in order to justify and explain it (TREINTA ET AL., 2014).

The work objective was defined. Next, due to the objective, the method made possible the delimitation of thematic areas associated to the study central question, aiming at the guidance of operators’ application using the Boolean architecture to extract bibliometric data from the SCOPUS base.

In order to confirm the research preliminary hiatus, in the first round of filters’ application, and using Boolean architecture, it was possible to identify a set of national and international works collected in data banks indexed by SCOPUS, using key words associated to the thematic areas: bibliometric, desalination, and nuclear plant.

First, Boolean operators “OR”; “AND” and “AND”, “AND” were used with the code ALL”, which return documents as long as the word researched appears in one of the following variables: in the paper title, in the source title, idiom, author, editor, affiliation, abstract, key words, references, DOI, ISBN, ISSN, CODEN, subjects, volume fields, publishing year, sequence bank, number of sequence bank, number, chemical name, number of CAS registration, manufacturer, editor or conferences.

In the following rounds, the use of operators “OR”; “AND” and “AND”, “AND” was kept, combined with more specific search codes, namely, TITLE-ABS-KEY, which returns documents as long as the word searched appears in variables: abstract, paper title or key word.

During the search in the base, using Boolean architecture, it was observed that, as the uses of operators with codes form more specific search scripts, as is the case of the code TITLE-ABS-KEY, the amount of documents’ return decreases and reaches zero, as demonstrated in table 1.

Table 1: Boolean architecture to verify the research gap

Round	Operators	Architecture with codes	Number of documents returned
1 ^a	OR, AND	(ALL (desalination)) OR (ALL ("nuclear plant")) AND (ALL (bibliometric))	151
2 ^a	AND, AND	(ALL (desalination)) AND (ALL ("nuclear plant")) AND (ALL (bibliometric))	2
2 ^a	OR, AND	(TITLE-ABS-KEY (desalination)) OR (TITLE-ABS-KEY ("nuclear plant")) AND (TITLE-ABS-KEY) bibliometric)	13
4 ^a	AND, AND	(TITLE-ABS-KEY (desalination)) AND (TITLE-ABS-KEY ("nuclear plant")) AND (TITLE-ABS-KEY (bibliometric))	0

So, based on the systematized analysis of documents returned, observing the study delimitation, the understanding that there is a research gap was corroborated, which is the absence of works that sought to map the development of “trends of investigation on desalination in nuclear plants” in the scientific literature, considering the period from 1996 to the first semester 2017, using bibliometric methodology, and based on data from researches published and indexed by SCOPUS base.

2.3 – Mapping of the development of researches indexed in SCOPUS base

After the research gap confirmation, in the second phase of application of filters using Boolean architecture, 225 national and international works could be identified collected from the data banks indexed by SCOPUS. The details of the Boolean research application and the collection product are presented in table 2.

Table 2: Boolean architecture linked to the study’s central subject matter

Architecture with Boolean operators	Amount of documents
(ALL (desalination)) AND (ALL ("nuclear plant")) AND (LIMIT-TO (LANGUAGE , "English") OR LIMIT-TO (LANGUAGE , "Chinese") OR LIMIT-TO (LANGUAGE , "French") OR LIMIT-TO (LANGUAGE , "Croatian") OR LIMIT-TO (LANGUAGE , "German") OR LIMIT-TO (LANGUAGE , "Japanese") OR LIMIT-TO (LANGUAGE , "Korean") OR LIMIT-TO (LANGUAGE , "Undefined"))	255

For data analysis and presentation of results referring to the frequency of: (1) publications per decades; (2) documents per countries and field of knowledge; and (3) types of documents, Excel software was used.

For data analysis and presentation of clusters: (1) counting of terms; (2) bibliographic coupling; and (3) co-citation, the data collected were entered in the data base of software VOSviewer for treatment of bibliometric data, available on www.vosviewer.com.

The program identifies the examination subject matter in documents in a low dimension space so that the space between any two elements mirrors the equivalence or affinity of items with the best possible precision. For each pair of items *i* and *j*, the VOSviewer requires as

entry a similar ij ($S_{ij} \geq 0$). It treats S_{ij} similarities as measurement in a ratio scale. Thus, the device minimizes a weighted sum of square distances among all pairs of items. The square of the distance between a pair of papers is calculated by the similarity among items. To avoid trivial solutions where all elements have the same position, the restriction imposed is that the average distance between two items must be equal to 1 (VAN ECK AND WALTMAN, 2010).

Considering the central objective of this study, for each of the 255 documents exported from SCOPUS base, in CSV (Excel) format, to VOSviewer analysis base, fields, types of data and counting methods presented in table 3 were considered.

Table 3: Types of fields and counting methods for bibliometric analysis

Data and fields from SCOPUS base for migration to VOSviewer software	
Data	Types of field
Citation information	Authors, document title, year, source title, volume, pages, citation counting, source and types of documents, DOI
Bibliographic information	Affiliations, Editor, idiom of the original document, corresponding address, abbreviated source title
Abstract and key words	Abstract, author key words, key words index
Other information	Information and conference, references
Counting methods used in VOSviewer software.	
Type	Consolidated description
Full	Only the presence or absence of a term in a document is considered.
Fragmented	The weight of a connection is fragmented, so that each reference, citation, or document makes the same global contribution.

Table 4 presents a consolidated description of the types of analysis used in this phase of research and criteria used in the software parameterization, including the counting of terms, the bibliographic coupling and co-citation, the

respective analysis units present in the database and number of analysis units selected for calculation of the total strength of links for preparation of clusterizations maps.

Table 4: Types of analysis and parameterization used in VOSviewer software.

Types of analysis used in VOSviewer software.			
Type	Consolidated description		
Counting of terms	Frequency of terms occurrences in the document body (title and abstract)		
Bibliographic coupling	The list of items is determined based on the number of references that they share.		
Co-citation	The list of items is determined based on the number of times that they are cited together.		
Criteria used in software VOSviewer parameterization.			
Type of analysis	Unit of analysis	Minimum number of analysis units' occurrences in the data base	Number of analysis units selected for calculation of the total strength of links
Counting of terms	Terms	10	37302
Co-citation	Sources	1	10431
Co-citation	Authors	1	35349
Bibliographic coupling	Sources	1	133

Specifically for the creation of maps based on the title body and the abstract body of documents the score of terms was created based on the field publication year, using the binary counting method, where the number of occurrence of the term was equal to 10, at least. The

number of units analyzed selected for the calculation of the total form of links was 37,302 terms. After the treatment of data through Microsoft Excel and VOSviewer software, the results' analysis phase was initiated.

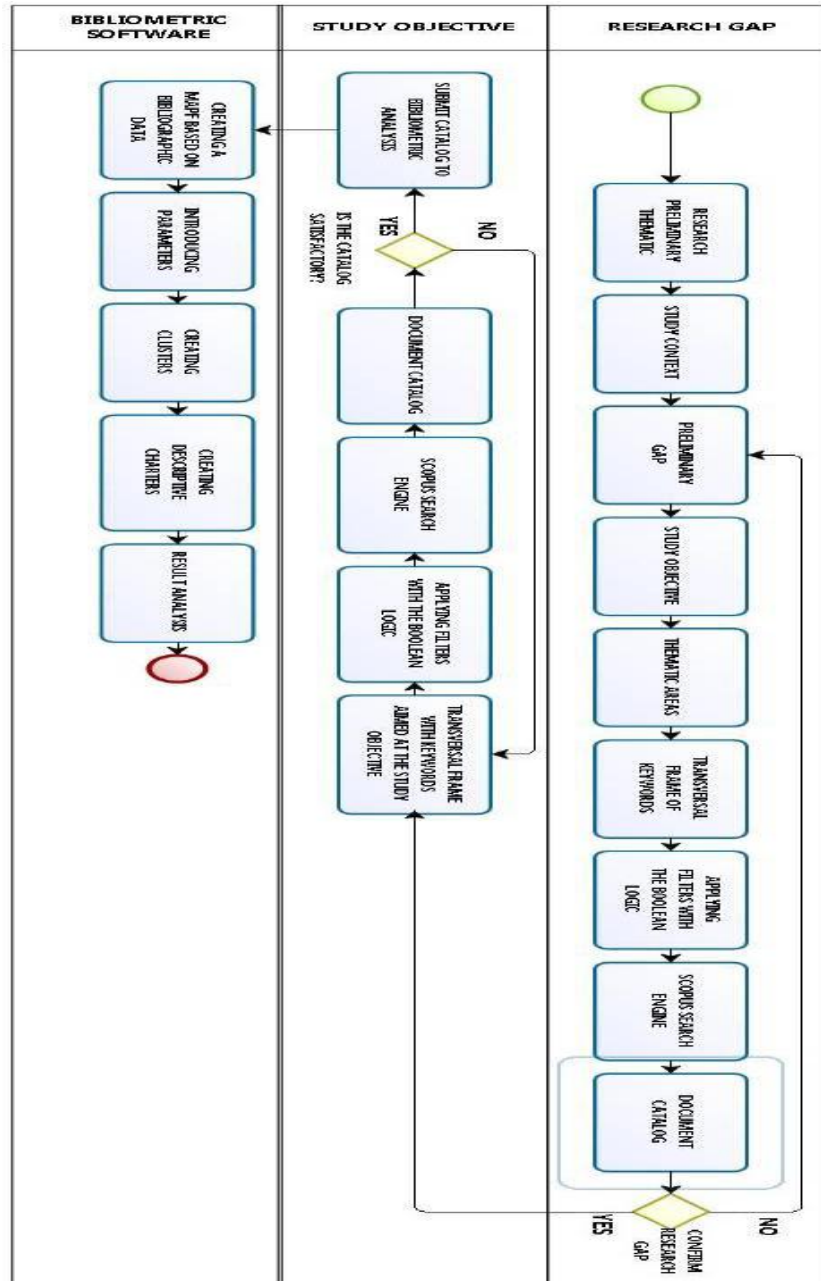


Fig.1: Summary consolidated in the methodological process (Source: developed by the Authors)

III. RESULTS AND DISCUSSIONS

3.1 – Types of documents analyzed and first publications
 On SCOPUS base, grounded on parameters established in the research methodology, it is obtained, as time interval

October 1966 thru July 2017, within which 255 (two hundred and fifty five) documents indexed in the base are found and analyzed, according to percent of documental typologies presented in Figure 2.

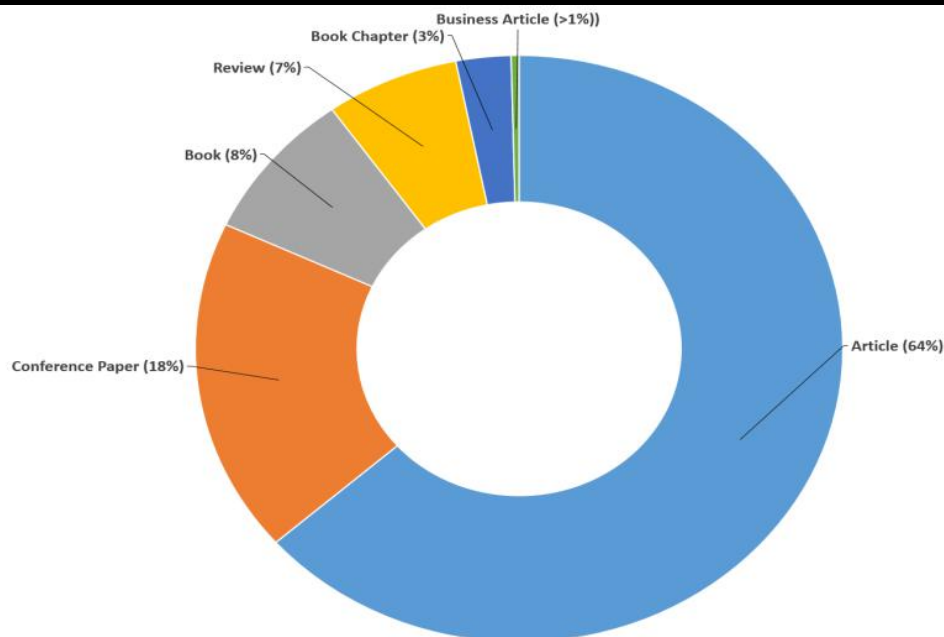


Fig.2: Percent of types of documents analyzed

It is observed that 64% (sixty four percent) of documents analyzed are papers published in periodicals.

During the analytical process, it was identified as initial mark of investigation on the use of desalination in nuclear plants two papers, both published in periodical Nuclear Engineering and Design in 1966. The first, titled Application of nuclear energy to large-scale power and desalting plants, by Siegel, S., Golan, S., and Falcon, J.A., examines the utilization of some types of nuclear plants combined with desalination plants to establish the economic potential of different heat sources for application in large scale and with double purpose – electric energy and fresh water.

The second article, named Feasibility of offshore dual-purpose nuclear power and desalination plants, by Arnold, H.G., Gall, W.R., and Morris, G., discusses the feasibility of offshore dual-purpose nuclear power and desalination facilities as an attractive solution to the issue of localization of nuclear plants. Studies of conceptual design for a large scale nuclear power and desalination plant, using alternatively an island trunk, a deepwater trunk and a moored floating platform are described by the authors.

One can observe that the first work has citation equal to zero and the second study has only three citations. Likewise, no mention of these initial investigations on nuclear desalination in alternative sources like social networks was found.

It was also observed that Akash, Al-Jayyousi and Mohsen (1997) investigation on non conventional energy technologies for water desalination in Jordan by multi-criteria analysis is one of the studies most quoted by other researchers, demonstrating the corporification of research

activities on the subject in scientific literature indexed and the growing amount of investigations that have contributed to the development of desalination models.

3.2 – Publications per decades and estimate of theme growth

Continuing the examination of data, it is verified that, while partitioning the amount of publications per decade, we can observe a clear tendency of thematic growth as of the mid 1990s, which is consolidated in the following years, chiefly from 2006 to 2015.

When we consider the period from January 1st 2016 until the date when we consulted SCOPUS base, July 27m 2017, we obtain an average of 28 publications/year which, in linear bases, indicated an estimated production of 280 publication for the 2016 – 2025 decade, suggesting the maintenance of the growth trend of the number of publications that fit in the arguments of this research. This effect is illustrated in figure 3.

The growth trend of researches addressing the association of different desalination systems through nuclear plants is explained by the researchers and scientific institutions' efforts to provide solution that seek to assure, simultaneously and in a sustainable way, food, water and energetic safety (BASKI, 2017; JOO and KWAK, 2017; YANG, ET AL., 2017).

Based on the results presented and the researches' growth trend, it is possible to presume that in the following decades, nuclear power will exercise a growing function in electric energy generation and water desalination, in order to reduce the impact of scarcity of potable water (VICTORINO, 2007; JAEGERMEYR, 2017; FANE, 2017).

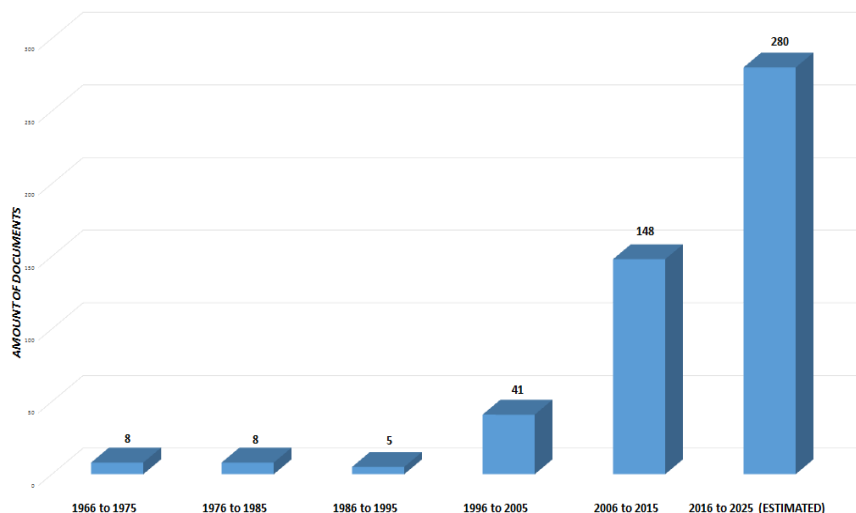


Fig.3: Publications per decades with estimated

3.3 – Publications per country and per field of knowledge

Following with the investigation fruits, it was observed that SCOPUS base provides different views of the bibliographic production behavior per: year, source, author, entity affiliated to the base, type of document, and

field of knowledge. These different views facilitated, in the bibliometric perspective, the refinement of perception with regard to trends of researches on desalination using nuclear reactors per country and field of knowledge, as presented in table 5.

Table.5: Publications per country and field of knowledge

Period	Country with higher number of publications (amount)	Field of knowledge with higher number of publications (amount)
2006 to 2017	United States (59)	Energy (90)
1996 to 2005	China (6) and Saudi Arabia (6)	Energy (19)
1986 to 1995	Saudi Arabia (2)	Environmental Sciences (5)
1976 to 1985	United States (3) and Egypt (2)	Engineering (6)
1966 to 1975	United States (2) Egypt (1)	Engineering (8)

It was expected that Middle East and North Africa countries were present in the list of those that published most on desalination through nuclear plants, considering that surrounding countries like Oman, Bahrain, Kuwait, United Arab Emirates and Saudi Arabia obtain most of their portable water using desalination technology and gathered they generate almost half of the whole desalinated water generated in the world (ALHANAE, SANDERS e MESHKATI, 2017).

With regard to fields of knowledge with higher number of publications, the research results indicated that throughout the last 51 years of evolution, the subject was initially addressed with higher concentration in the engineering segment, however, a transformation occurred in scientific researches with more relevance of the theme for innovation of sustainable technologies, from multidisciplinary perspective, considering that the themes,

as of 1986 started to transit more often in Energy and Environmental Sciences areas.

3.4 – Clusterization of terms

Clusterization of terms is calculated based on the frequency of occurrences of the word in the document body (title and abstract) and the association strength of the word presence in the publication, measured by the amount of times the term appears. Figure 4 shows the research most important words and the clustered connections in the period from 1966 to July 2017. Three large clusters were identified, characterized by different colors, which depict the relationships among words and repetition of terms. The words “concentration”, “paper” “technology” are among the expressions that presented higher frequency of occurrence.

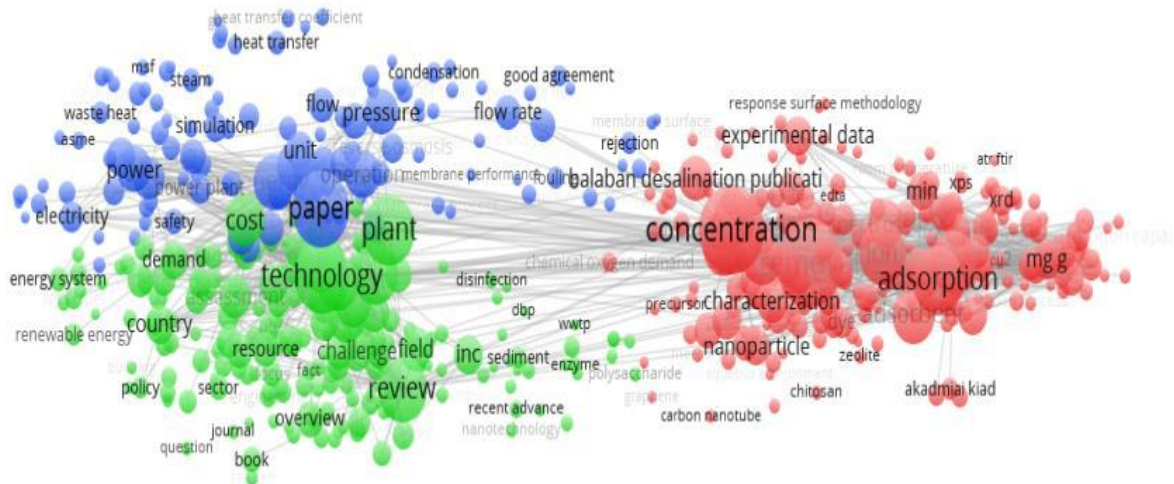


Fig.4: Clusterization of terms in documents' titles and abstracts

The relevance of expressions can be explained by the fact that many works investigate and/or quote studies where these words have higher importance with regard to the nuclear desalination theme.

3.5 – Sources: bibliographic coupling and co-citation

In this section, results regarding bibliographic coupling and co-citation of sources (periodicals) that published on the theme ‘desalination in nuclear plants’ are presented. Figure 5 depicts the periodicals’ relations based on the amount of references they share. Figure 6, on the other hand, explains the periodicals relation based on the number of times they are cited together.

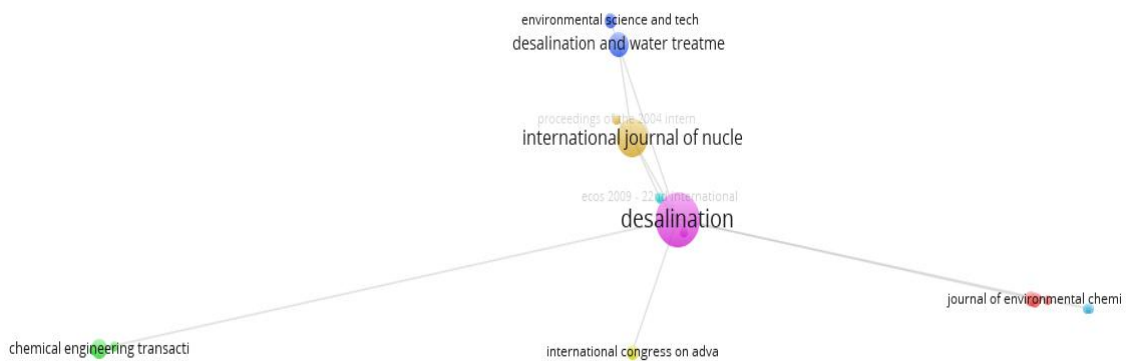


Fig.5: Bibliographic coupling of main periodicals

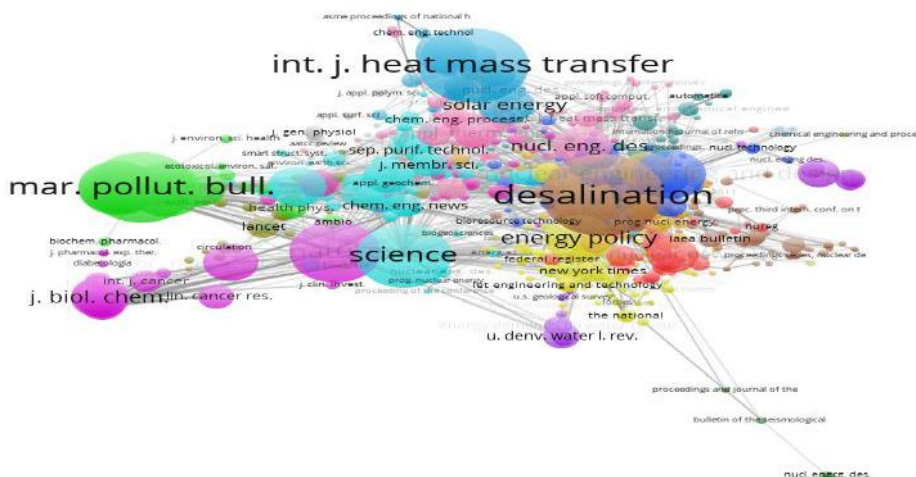


Fig.6: Co-citation of main periodicals

It is thus demonstrated that “Desalination” periodical is the publication source with higher number of reference sharing and the most cited when the naming of indexed works indicate other periodicals likewise.

The results can be explained by the thematic directioning of the source to the desalination subject, and it is possible to apply to this case the Dispersion Law or the Law of Periodicals’ Productivity, presented by Bradford (1934), based on the hypothesis that the most productive periodicals about a certain theme, appear due to the establishment of a group of magazines that arise from the continuous progress and relevance of a peculiar content.

With regard the “Desalination” periodical, the work by Ingersoll, ET AL., (2014) is outstanding among the ten most cited papers on small scale modulat reactors for co-generation of electricity and potable water.

It is an indexed investigation that, though not having the highest number of citation, reached the impact index of weighted citation in the field of 2.96 and citation benchmarking of 95% (Source: SCOPUS Metric).

These indicators demonstrate that it is a significantly cited paper when compared to similar papers. The index attested that the paper was more cited than expected, considering the publication year and the type of document (ERDT, ET AL., 2016).

The citation benchmarking, on the other hand, shows how the citations received by this paper are compared to the average of similar papers. The 95% percent is high and indicates that it is a paper with high global impact regarding the desalination theme (Source: SCOPUS Metric).

Publication date, type of document and the disciplines associated to their origin were considered. The papers were compared within an 18-month window, and was separately calculated for each one of the disciplines of their sources. A minimum set of 2,500 similar papers is required (NUTTALL, ET AL., 2016).

3.6 - Co-citation of Authors

In this section the co-citation of authors is presented, where the relationship among them is determined based on the number of times they are cited together by the works published and indexed. Though the cluster around Ronald Eisler presents the highest frequency of co-citations, the clusterization formed from Ibrahim Dincer works results in higher impact, considering that his studies on the comparative assessment of sodium-cooled fast reactors for nuclear desalination reached weighted citation impact in field of 1.92 and citation benchmarking of 70% (Source: SCOPUS Metric).

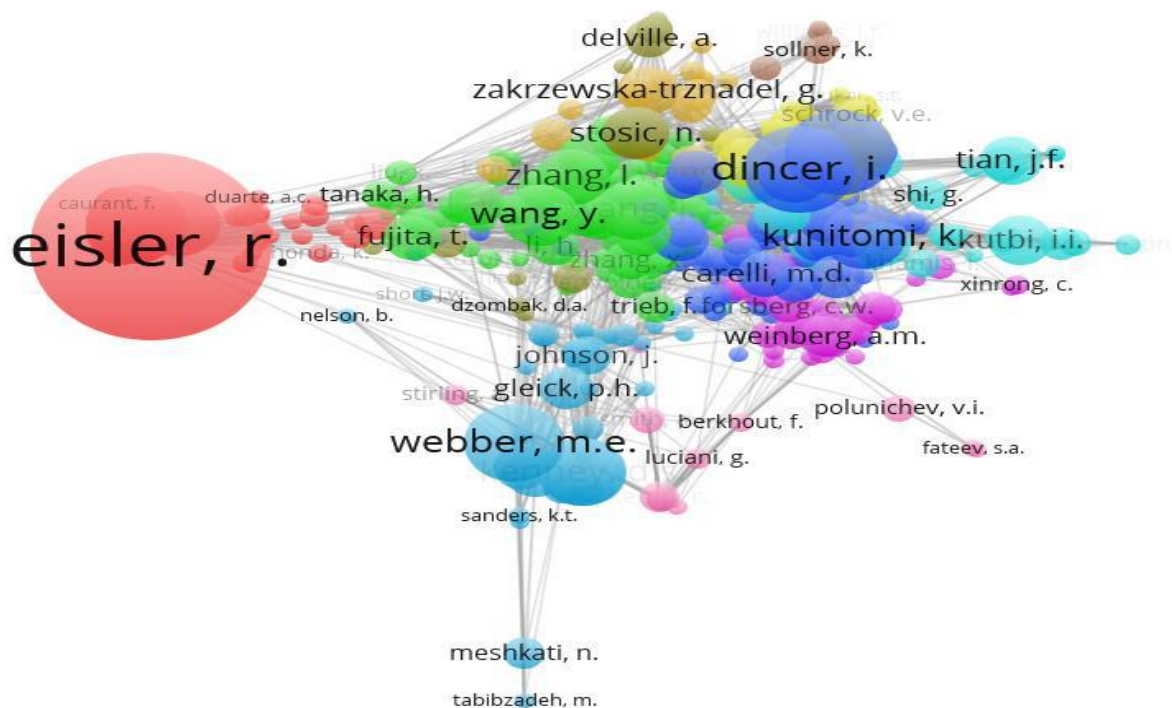


Fig.7: Clusterization of co-citations of authors

The co-citation of authors’ results can be explained by Lotka’s inverse square law, where the reference is that the fraction of researchers more outstanding in a specialized sector of science presents high production and less

outstanding researchers show low production. However, due to the new forms of scientific expression, it is necessary to consider the impact based on alternative sources as well (ERDT, ET AL.,2016).

IV. CONCLUSION

The gap this study sought to fill relates to the use of the bibliometric method, consubstantiated in informational structure, about indexed scientific studies on the evolution of the theme desalination in nuclear plants.

The objective of this work was to map the themes in scientific literature between 1966 and the first semester 2017. Data were collected from research activities indexed by SCOPUS base and analyzed with the support of VOSviewer software.

So, considering the research objectives and delimitation, we can summarize the conclusions of the work as follows: (1) papers published in indexed magazine represent the highest percent of the type of instrument used for scientific divulgation, representing 64% of documents; (2) it was estimated that between years 2016 and 2025 the desalination theme will keep on presenting a sharp growth in indexed publications; (3) in the last 10 years the United States of America is the country that presented the higher number of publications; (4) since 1996 the scientific knowledge segment that attracts more publications is the energy field; (5) the words that presented higher frequency of occurrence in titles and abstracts of indexed works are concentration, paper and technology; (6) the Clusterization of sources per bibliographic coupling and per co-citation demonstrated that Desalination periodical is the one with highest sharing and joint citation among the documents analyzed; and (7) Clusterization of authors per co-citation evidenced that Ronald Eisler and Ibrahim Dincer the authors showing highest frequency based on the number of times they are cited jointly with other authors by published and indexed works.

Moreover, we recommend that future works investigate, on the theme desalination in nuclear plants, based on bibliometric methodology: (1) the bibliographic coupling, considering documents, authors and organizations as analysis units; (2) co-citations of cited references; and (3) co-authorships, observing authors and organizations units. Finally, the research results also led us to conclude that, along the last 51 years of evolution, the subject nuclear desalination was initially addressed with higher concentration in engineering segment, however, a transformation occurred in scientific researches indexed in SCOPUS base, with more relevance of the theme for innovation of sustainable technologies, from a multidisciplinary perspective.

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