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Exergy use review of wastewater study in Latin America

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Abstract
Exergy is the maximum useful work that can be obtained from a system in a specific state and environment. Exergy research has focused on energy fuels, although wastewater systems have not been studied in depth. This review explores the study and exergy use for wastewater systems in Latin America over the last 20 years. Chronological production, authors, citations, geographic origin, topic and purpose of publishing were examined through a documentary and bibliometric analysis. Exergy has started its development in Latin America, and it is led by a single school, there is evidence of a single author with 30% of citations and 25% of publications. Brazil, Colombia and Mexico produced 81% of publications, their main purpose is evaluating processes and by-products. The review concluded an incipient exergy development in wastewater systems in the region and exposed the need to stimulate research as a strategy to achieve the SDGs.

Keywords: availability of energy; exergetic efficiency; effluent; sustainability; mathematical method.

Revisión del uso de exergía del estudio de aguas residuales en América Latina

Resumen
La exergía es el trabajo útil máximo que se puede obtener de un sistema en un estado y un ambiente específico. La investigación en exergía se ha centrado en los combustibles energéticos y ha sido poco estudiada en los sistemas de aguas residuales. Esta revisión explora el estudio y uso de la exergía en sistemas de aguas residuales para América Latina en los últimos 20 años. La producción cronológica, los autores, las citas, el origen geográfico, el tema y el propósito de la publicación se examinaron mediante un análisis documental y bibliométrico. La exergía ha iniciado su desarrollo en América Latina y está liderado por una única escuela, puesto que se evidencio un único autor con el 30% de las citaciones y el 25% de las publicaciones. Brasil, Colombia y México produjeron el 81% de las publicaciones, con el propósito principal de evaluar procesos y subproductos. La revisión concluyó un incipiente desarrollo de la exergía en los sistemas de aguas residuales de la región y expuso la necesidad de estimular la investigación como estrategia para lograr de los ODS.

Palabras clave: disponibilidad de energía; eficiencia exergética; efluente; sostenibilidad; método matemático.

1. Introduction

Water resource management is made up of the collection, treatment, distribution and use of water, second collection, treatment and discharge of wastewater into the environment [1]. Wastewater treatment is critic for pollutants reduction and water quality improvement, due to socioeconomic, agricultural and industry development, population growth and low social and political attention generate an increment on pollution load and volume of wastewater [2-5].

Wastewater is composed of water (99,9%) and solids (0,01%) that generate physical, chemical and microbiology pollution, causing damage to the environment and public health [6-8]. Wastewater is considered a mixture of one or many effluents such as industrial, hospital, domestic (black and gray water), commercial, institutional, horticultural, aquacultural wastewater, agricultural runoff, rainwater and other urban runoff [9]. The industrial effluent is responsible for producing 60% of biochemical oxygen demand (BOD), 60% of suspended solids, 90% of toxic waste in water and 75% of organic waste [10].

Worldwide, more than 80% of wastewater is discharged into the environment without adequate treatment [8]. In LatAm, 70% to 80% urban sewerage system water is discharged into the environment without adequate treatment,

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the treatment of the remaining wastewater is carried out through technologies such as stabilization ponds, activated sludge and upflow anaerobic sludge blanket reactors [11-13].

Driven by environmental regulations, the focus of wastewater treatment has traditionally been the quality of the effluent and not necessarily energy or resource efficiency [14]. Nevertheless, the process energy efficiency and potential recovery of by-products such as energy, nutrients, organic matter, metals, among others promote wastewater system sustainability [8].

Calculating exergy allows to determine wastewater system sustainability, which means, knowing the maximum useful work that can be obtained from the system in a specific state and environment, this work could be converted into energy used for wastewater systems and other processes [15-18].

Exergy concept is based on the first law of thermodynamics that corresponds to the conservation principle of energy which states that nothing disappears because energy cannot be created or destroyed [19,20] and the second law of thermodynamics is related to the quality of energy, which specifically deals with the degradation of energy during a process [21].

The modern development of exergy analysis was presented by Bosnjakovic in Europe and Keenan in United States [22]. Then in 1950s and 1960s Rant, Grassmann, Brodyansky, Bruges, Keenan, Tribes, Obert, Gaggioli, Evans, Baehr, and Fratzscher made fundamental contributions to the concept of exergy and the publication of research on energy engineering journals continues [23-25].

The historical focus of multiple investigations on exergy is shown in articles by Rezac and Metgalchi in 2004 and Sciubba and Wall 2007; nevertheless, those articles do not include wastewater systems [9,22]. It resulted in the research question: What are the studies and uses of exergy for wastewater systems in LatAm? The development of this review article seeks to make a bibliometric analysis on the study and use of exergy in wastewater systems in LatAm from 2000 to June 2020.

2. Materials and methods

2.1 Documental review

Documentary review was made from exergetic research, carried out in wastewater systems in LatAm. Secondary information search was done with search engines and electronic repositories of the twenty best universities of the region, shown in Table 1 [26].To identify the greatest number of publications, the following keywords were used: exergy, energy availability, exergy analysis, exergetic analysis, exergetic diagnosis, wastewater, treatment plant, Latin America, Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, the Dominican Republic, Uruguay and Venezuela; their combinations in Spanish, Portuguese and English equivalents.

Table 1
Information source

Source type	Tools name
Search engine	Google Academic, Scielo, Springer Link, ScienceDirect, Scopus, Researchgate
Electronic repository	University of Buenos Aires, National Autonomous University of Mexico, University of São Paulo, Pontifical Catholic University of Chile, Monterrey Institute of Technology, University of Chile, University of Campinas, University of the Andes, National University of Colombia, Federal University of Rio de Janeiro, University Estadual Paulista, University of Concepción, University of Santiago, University of Antioquia, Pontifical Catholic University of Rio de Janeiro, Pontifical Javeriana University, Federal University of Minas Gerais, Pontifical Catholic University of Peru, University of Costa Rica, Federal University of Rio Grande do Sul

Source: The Author.

The inclusion criteria for the documentary review is the research on the study and use of exergy in wastewater systems in LatAm.

Systematization and filling of the documents found were effectuated through the bibliographic manager Mendeley® Desktop version 1.19.4, where duplication was eliminated and chronological production, authors and citations from publications were identified. Also, the organization of the publications was complemented by using Microsoft Excel® software spreadsheet.

2.2 Bibliometric analysis

For the bibliometric analysis the type of publication, geographic location, thematic category and purpose of the study were taken into account.

2.2.1 Type of publication:

This document includes the research and it is categorized in: 1) Article: short and specific document, with unique electronic identification using the digital object indicator - DOI or International Standard Publication Number Serials - ISSN. 2) Book: a unitary long publication in one or several volumes and registered with the International Standard Book Number - ISBN. 3) Thesis: written research work to apply for a professional undergraduate or graduate degree.

2.2.2 Geographic location

Territorial location of the country in which the document was published and the case study of the publication.

2.2.3 Thematic categories

Topics where the exergy concept is used: 1) Exergy analysis: detailed examination of maximum useful work that can be obtained from total system exergy (physical, chemical, kinetic, and potential) [27]. 2) Exergetic efficiency: quantitative evaluation of the perfection degree or irreversibility of a process, equipment or installation [28]. 3) Environmental exergy efficiency: relationship between the final product exergy and the total exergy consumed by human and natural resources, including all the exergy inputs [29]. 4) Exergetic renewability: exergy associated to useful products of a given energy conversion process, destroyed exergy, exergy associated to the fossil fuels required, exergy needed to deactivate the waste, and by-products and non-treated waste exergy [30]. 5). Environmental remediation cost: exergy resources consumed in effluent treatment, to bring it to a state of balance with the environment before being discharged into the environment [31]. 6) Specific environmental remediation cost: exergy resources consumed for the removal of BOD5 [15]. 7) Exergetic production cost: total minimum (optimal) operating costs of the process [32].

2.2.4 Purpose of study

Action to achieve the investigation objective.

3. Results

3.1 Documental review

Search engines and electronic repositories retrieved 5,459 records as a result of multiple combinations of keywords. A total of 62 publications met the inclusion criteria, from which 46 were excluded due to duplication, resulting in 16 publications relevant to bibliometric analysis.

The chronology of publications is represented by an annual average of 0.8 publications, with a maximum of 2 publications per year and for the second decade in study of 21st century, the number of publications per year increased by 167% compared to the first decade (Fig. 1).

The documentary review identified 34 authors who published about exergy study and use for wastewater systems in LatAm, of which 14 are main authors and De Oliviera has the largest participation in publications (18,75%) and publications (6,25%), being the pioneer and with the largest associated participation in publications.

The total number of citations found is 314, the book by De Oliviera (30.2%) and the article by Barrera and collaborators (21.1%) are the most cited publications and the remaining represent 48.7% with values between 0 and 12.9% shown in Table 2.

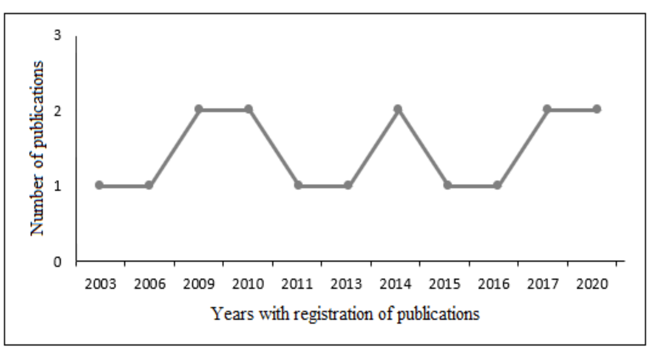

Figure 1. Publications per year between 2000-2020 on study and use of exergy in wastewater systems in Latin America.
Source: The Author.

Table 2
Citations by publication

Publication name	Author	Citation	Citation (%)
Exergy: Production, Cost and Renewability	De Oliveira, 2013	103	30,2
A comparative assessment of anaerobic digestion power plants as alternative to lagoons for vinasse treatment: life cycle assessment and exergy analysis	Barrera et al., 2016	72	21,1
Development of a methodology for cost determination of wastewater treatment based on functional diagram	Lamas et al., 2009	44	12,9
Thermoeconomic analysis applied to an alternative wastewater treatment	Lamas et al., 2010	28	8,2
Life-cycle greenhouse gas emissions assessment and extended exergy accounting of a horizontal-flow constructed wetland for municipal wastewater treatment: A case study in Chile	Casas et al., 2017	25	7,3
On an Exergy Efficiency Definition of a Wastewater Treatment Plant	Gallegos et al., 2003	24	7,0
Environmental exergy analysis of wastewater treatment plants	Mora et al., 2006	21	6,2
Exergetic and economic evaluation of incorporation of hydrogen production in a cassava wastewater plant	Ferreira et al., 2017	12	3,5
Comparative exergy assessment of vinasse disposal alternatives: Concentration, anaerobic digestion and fertirrigation	Nakashima et al., 2020	6	1,8
Exergetic sensibility analysis and environmental evaluation of chitosan production from shrimp exoskeleton in Colombia	Meramo et al., 2020	3	0,9
Exergetic evaluation of water quality for three rivers in Colombia	Bastidas, 2014	2	0,6
Energy and exergy analysis of etanol production process from banana fruit	Velásquez et al., 2010	1	0,3
Exergoecological assessment of sewage treatment processes	Mora, 2009	0	0
Gasification of faecal biomass for biofuel production: Study of thermochemical conversion and exergoecological evaluation	Dalvi, 2015	0	0
Exergetic evaluation of waste water and sludge treatment system with electrical generation of a processed food plant	Aguilar, 2014	0	0
Economic and vigorous analysis of technologies for the energy use of biogas, produced in wastewater treatment plants	López, 2011	0	0

Source: The Author.

3.2 Bibliometric analysis

Author prefer to publish articles (63%) followed by undergraduate and postgraduate theses (31%) and finally books (6%).

Brazil, Colombia and Mexico are the countries with the largest number of documents published and according to the case study of the publications (Fig. 2), only Mora's thesis has two studies in Brazil and one in Colombia.

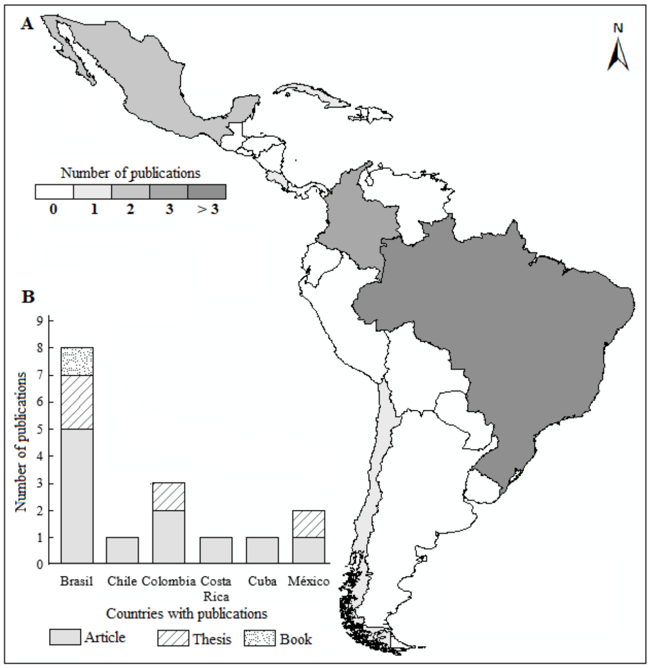

Figure 2. Geographical origin of publications of exergy study and use for wastewater systems in Latin America, 2000-2020. A) Publications by country. B) Number and type of publications by country.
Source: The Author.

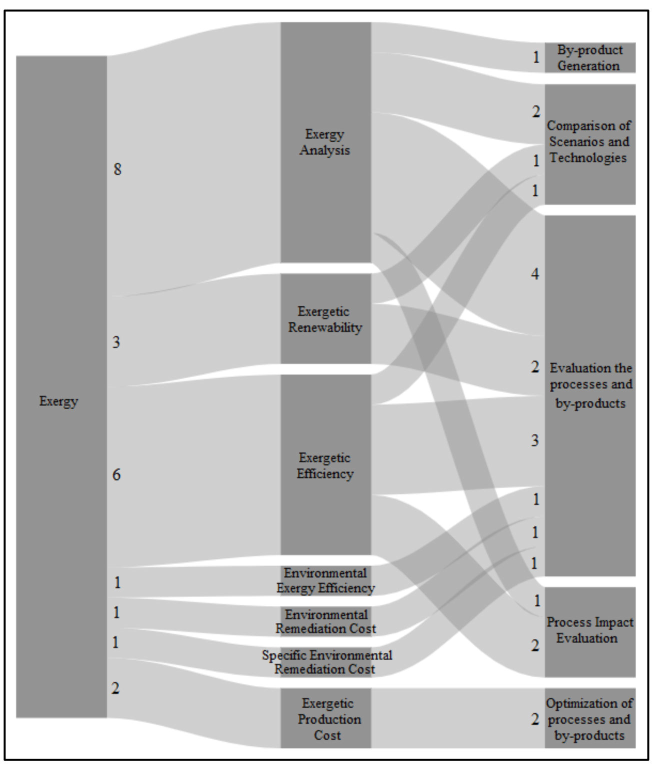

Figure 3. Number of topics and purpose included in the bibliometric review of exergy study and use for wastewater systems in Latin America, 2000-2020.
Source: The Author.

The exergy analysis (36%), exergetic efficiency (27%) and exergetic renewability (14%) have been the main topics of study in LatAm and 23% represents environmental exergy efficiency and the cost of environmental remediation, specific environmental remediation and exergetic production (Fig. 3). The objective of these topics was evaluating the processes and by-products as well as comparing scenarios and technologies.

4. Discussion

Besides, the low number of researchers and institutions evidenced a low publishing number compared to exergy studies by Rezac and Metgalchi in 2004 and Sciubba and Pared in 2007. The chronological production began in 2003 and the first worldwide exergy studies were published in 1870 and from the 1970s his research has been in progress [9,33]. Tai et al. (1986) first research publication on exergy estimation in a wastewater system.

From 2000 to 2020, the documents published had an annual average of 0.8 publications, highlighting the second decade of study with an increase of 167% of publications per year for LatAm. However, Sciubba and Wal, 2007 defined the application of exergy as exponential growth until 2004, while Seabra and Caldeira, 2020 determined an annual average of 78.38 publications until 2000 and an annual average of 918.28 before 2019. Thus, LatAm research is 17 years behind the world (Table 2).

In LatAm, exergy research is funded by government institutions that have limited resources, without support and participation from the private industry [34]. This study evidenced that 81% of the publications were made in public university research centers, mainly in Brazil, Colombia and Mexico. Unlike the world context, the oil crisis in 1973 forced the government institutions and private companies to invest in solutions for saving energy and increasing the energy efficiency of processes [22]. It is clear that this model has not been visible in LatAm even when efficient use of energy is compulsory.

To comply with international energy treaties and conventions, global energy efficiency policies and the Sustainable Development Goals – SDGs [35], LatAm requires forming alliances and strategies to address exergy studies in wastewater systems because exergy or useful work could be converted into energy used for wastewater systems and other processes. Based on the above information, to study and implement exergy applications in wastewater systems, it is necessary to promote training and formation for professional researchers in this field, public-private articulation to develop Exergy studies applied to local industries, the creation of schools of thought and long-term work groups along with innovation in technologies to minimize negative impacts from the concept of exergy.

In general, exergy research is oriented to exergy analysis for energy fuels, making wastewater systems remain overlooked and with fewer resources [36-38]. Nonetheless, exergy analysis is the most examined research topic in LatAm and worldwide, that even the standard way in which exergy analysis is used has been established [39].

Achieving the sustainable development objective called clean water and sanitation is possible if exergy studies are approached. Provision of clean water and sanitation services are priorities for developing countries. These countries disregard the negative impacts of wastewater management and pollution because they are not aware of their importance and how they affect human health and the environment [40]. Nevertheless, the applicability of exergy in wastewater systems would allow nutrient recovery and by-products performance improvement. it could also be used to reduce polluting loads and maximize the exergetic efficiency of wastewater treatment systems. Lastly, exegetical indices and indicators could be formulated as a control strategy that allows a comparative evaluation of the system performance and optimization.

5. Conclusions

The results showed an incipient exergy research development in wastewater systems for LatAm in last two decades.

LatAm research is 17 years behind the world and it is not ongoing due to the few research schools and the low interest in the study of exergy in wastewater systems.

To study and implement exergy applications in wastewater systems, it requires promoting training and formation for professional researchers in this field, and public-private articulation to develop exergy studies applied to local industries.

Achieving the sustainable development objective called clean water and sanitation is possible if exergy studies are approached, and the positive impact of exergy applicability on wastewater systems would help achieve the following sustainable development goals: affordable and clean energy, climate action, underwater life, and terrestrial ecosystem life.

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