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Bibliometric Analysis of Wastewater Biological Nitrogen Removal Externally Added Carbon Sources Based on Web of Science and CNKI Databases

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ABSTRACT

To investigate the research hotspots and development status of wastewater biological denitrification with externally added carbon sources, based on the Web of Science Core Collection database and CNKI Resource Library, we used the visualization software CiteSpace to visualize and analyze the authors, countries, institutions and keywords of the articles published in the field of wastewater biological denitrification with externally added carbon sources in the period of 2000-2022, and then analyze their distribution and research hotspots. The results show that the mainstream journals in the field of water environment at home and abroad have paid great attention to the carbon neutrality of wastewater treatment, and the nitrogen and carbon source of wastewater has become a research hotspot in the field of water environment. This study summarizes the current categories of new carbon sources and predicts the feasibility of using waste from the brewing industry as an additional carbon source. It provides a theoretical basis for promoting the resource utilization of waste in the brewing industry.

KEYWORDS

Waste water treatment, nitrogen removal, carbon source, bibliometrics.

1. INTRODUCTION

With the development of industrial and agricultural production, water environment protection has faced enormous pressure, among which the problem of eutrophication of water bodies caused by nitrogen-containing nutrients is particularly prominent. Therefore, higher requirements have been put forward for sewage denitrification treatment. Among numerous sewage treatment methods, biological denitrification technology is an important technology in the field of environmental protection. Its main function is to remove nitrogen pollutants from wastewater. Traditional biological denitrification technology usually includes three stages: anaerobic, anoxic, and aerobic. Under the combined action of microorganisms, organic nitrogen and ammonia nitrogen in wastewater are subjected to ammonification, nitrification, and denitrification reactions, and finally converted into harmless nitrogen gas. However, this traditional technology has some problems, such as low denitrification efficiency, high energy consumption, and high cost, which need further improvement and development. Among them, the problem of insufficient carbon source in denitrification has become the main factor restricting this process[1]。External carbon source technology is a technique that promotes denitrification by denitrifying bacteria by adding a certain amount of organic carbon source to a bioreactor. The advantage of this technology is that it can significantly improve denitrification efficiency and reduce energy consumption, while also reducing the generation of secondary pollution. To address this situation, it is currently common to add external carbon sources to low carbon to nitrogen ratio wastewater to ensure denitrification and denitrification. However, different carbon

sources have different impacts on denitrification. Seeking efficient, inexpensive, and environmentally friendly external carbon sources has become an urgent issue to be addressed.

In recent years, some scholars have attempted to characterize and present the research progress of denitrification with added carbon sources through summarizing a large number of literatures. Among them, a review on denitrification with additional carbon sources, such as Ahmed et al [2] After conducting in-depth literature review and exclusion criteria, it was found that carbon sources are the main contributor and the booster of denitrification. Additionally, adding external carbon sources to biological denitrification is cost-effective and the best choice for nitrogen reduction. Gao Xindong [3] The research progress on the types and influencing factors of external carbon sources in water treatment process was studied, and the research and application of common external carbon sources were summarized. The problems of external carbon sources in practical application were found, and it was also proposed to use certain waste as external carbon sources to solve the problem of insufficient denitrification carbon sources; Xiong[4] exploring the research progress of external carbon sources in wastewater denitrification and denitrification processes, and addressing the need for additional carbon sources in low C/N wastewater, combined with the research results of external carbon sources in denitrification, this paper summarizes the research status, problems, and challenges of traditional and new carbon sources, and puts forward some suggestions for the treatment of urban wastewater; Zhang[5] Based on the current situation of low-carbon source sewage treatment, this paper analyzes the characteristics of low-carbon source sewage treatment, compares the characteristics of low-carbon source sewage treatment schemes such as adding carbon sources and changing the process inlet method, summarizes and analyzes the principles and characteristics of biological denitrification technology and new denitrification processes based on reducing carbon source consumption and improving denitrification efficiency, and proposes prospects for new biological denitrification processes in combination with the development of sewage treatment。Wang et al. [6] This article summarizes the emerging technologies for obtaining internal organic carbon resources from sewage sludge and their applications in improving the denitrification of low-carbon/nitrogen-containing wastewater in sewage treatment plants, while addressing the issues of carbon deficiency and surplus sludge crisis. Although extensive literature reading can provide readers with a deeper understanding of the research field, it is relatively difficult to comprehensively sort out the research hotspots or topics. Moreover, from the perspective of content, there are few scholars who pay attention to the differences between domestic and foreign research on biological denitrification of wastewater and carbon sources, lacking systematic comparative analysis. In terms of methods, there are more subjective methods to analyze the content, and less scientific econometric tools to analyze it. Moreover, quantitative research based on knowledge graphs can more objectively reflect the research hotspots and trends in a certain field [5]。

In view of this, a comprehensive grasp and comparative analysis of the research hotspots and development trends of biological denitrification of wastewater with added carbon sources is of great significance for promoting theoretical research and practical innovation in China. This article uses CiteSpace, a widely recognized bibliometric software in academia, as a research tool to visually compare and analyze the research results of denitrification with external carbon sources at home and abroad since the 21st century (2000-2022), aiming to objectively present the similarities and differences between domestic and foreign research fields, in order to provide new ideas and directions for domestic research, and to provide reference and inspiration for the research of biological denitrification with external carbon sources in low C/N ratio wastewater in China.

2. DATA AND METHODS

2.1. Data sources and processing

This article summarizes and analyzes from the year 2000, with literature data sourced from the China National Knowledge Infrastructure database and the Web of Science core collection database from 2000 to 2022.

The literature search on China National Knowledge Infrastructure (CNKI) focused on "carbon sources" and "denitrification", with "environmental science and resource utilization" as the search criteria. A

total of 7099 Chinese literature were obtained, including 3386 academic journals, 3527 thesis papers, 112 conference papers, 1 newspaper, and 71 achievements. Excluding some articles, dissertations, advertisements, and literature that are unrelated to the topic, without authors or abstracts, as well as some literature that does not match the year, we carefully screened and deduplicated the data, resulting in 2219 Chinese literature. WOS data is based on the themes of "Carbon Source" and "Nitrogen Removal", with refining conditions mainly in the Web of Science category ("Environmental Science" and "Engineering Environmental" and "Water Resources"). After screening, 2681 articles were obtained, and after careful screening and data deduplication, 2544 English articles were finally obtained.

2.2. Research Methods

2.2.1. Bibliometric analysis method

Bibliometric analysis is a method of studying the external characteristics of scientific and technological literature, using mathematical and statistical methods to analyze the quantitative relationship, distribution structure, and change patterns of scientific and technological literature, evaluate the research status and internal laws of scientific and technological literature, and predict the future evolution trend [6].

2.2.2. Knowledge Graph Analysis Method

Knowledge graph analysis is an analytical method in econometrics that uses visualization techniques to describe knowledge resources and their carriers, excavate, analyze, construct, draw, and display knowledge and its interrelationships. It displays the development process and structural relationships of related research as intuitive graphics, which can be used to understand and predict the forefront and dynamics of the discipline. This article uses a knowledge graph that depicts sustainable development research, mainly including a collaborative network graph of research institutions and a keyword co-occurrence graph [7]。When different institutions and keywords appear in the same literature, it is considered that there is a cooperative or co-occurrence relationship between them. By establishing a graph of cooperative and co-occurrence networks, the cooperation density between individuals is analyzed, and the importance of individuals in the network is measured. The larger the number of publications or the more frequent the occurrence of keywords by Chinese countries or institutions in the graph, the larger the nodes [8]。

2.2.3. Summary and analysis of literature reading

Due to the lack of recognized standards and methods in bibliometric analysis of literature, as well as limitations in selecting literature samples, bibliometric analysis methods can only reflect the basic situation of sustainable development research [9]. Therefore, this article combines the intensive reading and supplementary search of relevant classic literature and high citation frequency literature to summarize and summarize the hotspots of sustainable development research.

3. RESULT ANALYSIS

3.1. Posting trend analysis

Statistics on the publication time of all retrieved literature can to some extent reflect the level of scientific research activity and predict future development trends. Firstly, the visualization analysis of the CNKI database was applied. Firstly, the publication trend of the CNKI database was analyzed based on the unfiltered data. From Figure 1, it can be seen that the publication trend of the CNKI database is mainly divided into three stages: during the budding period (1984-1991), 9 articles were published in 8 years. In an article excerpted by Chinese scholar Astronomy [10] in 1984, it was mentioned that glucose or sodium bicarbonate or a mixture of the two were used as external carbon sources for the treatment of nitrogen fertilizer wastewater by active algae, which is the earliest

research in China to mention external carbon sources; During the slow development period (1992-1999), a total of 38 articles were published. According to relevant literature, research during this period in China focused on the removal of pollutants such as nitrogen and phosphorus from wastewater; During the rapid growth period (2000-2022), 3244 papers were published. During this period, due to China's emphasis on "carbon neutrality" and "low-carbon emissions", research on biological wastewater treatment in China has become increasingly important, mostly focusing on process optimization, energy conservation and emission reduction.

The WOS core collection is analyzed based on citation reports. Firstly, the publication trend of the WOS database is analyzed based on unfiltered data. From Figure 2, it can be seen that the publication trend of the WOS database has always been exponential, with a relatively flat development trend from 1991 to 2003. After 2004, the publication volume has been increasing exponentially year by year. The earliest relevant article retrieved so far is Carley's [11], which mentioned the impact of four carbon sources: methanol, acetate, glucose, and brewery yeast waste on the nitrification denitrification and denitrification efficiency. However, as early as 1962, Ludzack and Ettinger first proposed a pre denitrification process using biodegradable organic matter in water as a carbon source, solving the problem of insufficient carbon source. The rapid growth in research on carbon sources in the later stage may be due to the increasing amount of wastewater required for treatment, the increase in low C/N ratio wastewater, and the increasing emphasis on eutrophication of water bodies. The requirements for nitrogen and phosphorus removal in water bodies are becoming higher and higher, resulting in an increasing demand for external carbon sources to promote denitrification. In recent years, the problem of water eutrophication caused by nitrogen-containing nutrients has become increasingly serious, which has put forward higher requirements for sewage denitrification treatment. Among many municipal sewage treatment methods, the synergistic effect of microbial nitrification and denitrification is used to treat nitrogen-containing substances in water at a low cost and high efficiency. However, there are many drawbacks in the denitrification process, such as small C/N, insufficient carbon source, and high cost. Therefore, there is an increasing amount of research on the addition of carbon source in the denitrification process.

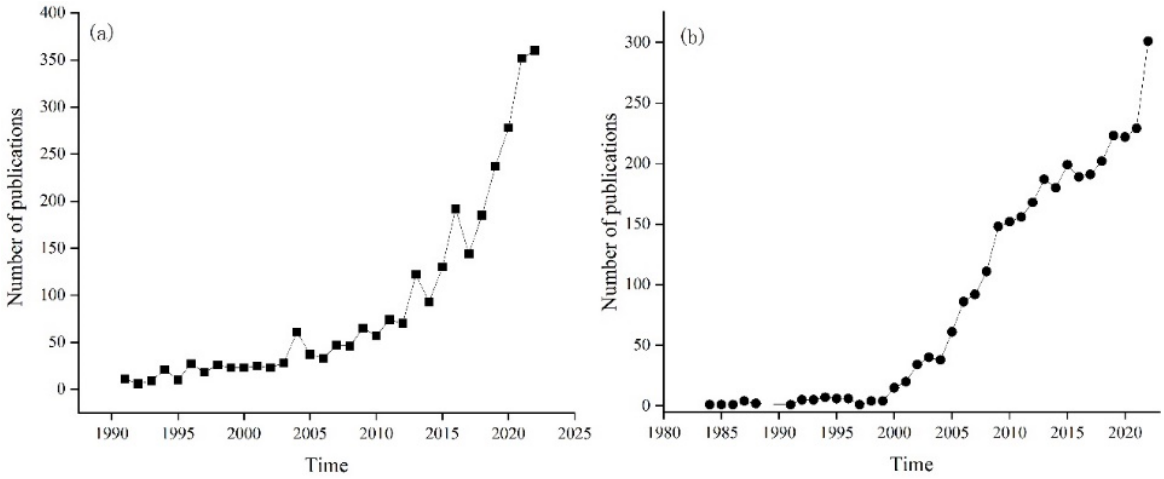

Figure 1. Development trend of carbon sources. (a) CNKI database; (b) WOS database;

3.2. Periodical distribution

Based on CNKI visualization analysis, a brief analysis was conducted on 3244 literatures related to nitrogen removal and carbon sources from 2000 to 2022. The top 5 journals with the highest publication volume are shown in Table 1. From this, it can be seen that in the CNKI database literature, "Environmental Science" ranks first in terms of article volume, "China Environmental Science" ranks second in terms of article volume, and "Journal of Environmental Science" ranks third in terms of

article volume. In the WOS core collection, Water Resource ranks first in terms of article volume, Water Science and Technology ranks second in terms of article volume, and Science of the Total Environment ranks third in terms of article volume, as shown in Table 1. Among them, "Environmental Science" is a national core environmental journal, and "Water Research" is a top tier journal in the water field. These two journals have given great attention to the research on external carbon sources for wastewater treatment, indicating the global importance of nitrogen removal and external carbon source research in the water research field. This research has gradually become a hot topic of attention.

Table 1. CNKI database and WOS core collection are the top 5 journals in the field of nitrogen removal and carbon sources

	CNKI	Proportion (%)	WOS	Proportion (%)
1	Environmental science	30.15	Water Resarch	7.05
2	China Environmental Science	20.42	Water Science and Technology	6.79
3	Journal of Environmental Science	14.69	Science of the Total Environment	6.38
4	Journal of Beijing University of Technology	8.02	Chemosphere	5.45
5	Journal of Chemical Industry and Engineering	7.63	Chemical Engineering Journal	4.03

3.3. Analysis of research power

3.3.1. National Cooperation Network

To study the characteristics of cooperation among the publishing countries for nitrogen removal and carbon sources, CiteSpace software was used to analyze 2544 research results extracted from WOS. The top 10 countries in terms of publication volume and proportion are shown in the figure, with China ranking first, followed by USA, and South Korea ranking third. The number of publications in China is 1244, which is more than three times the number of publications in the United States, and it is in a leading position. This may be closely related to the Chinese government's introduction of a series of policies and regulations to increase efforts in water pollution control. In addition, countries such as Australia, India, Canada, Spain, Germany, Poland, Japan, Italy, etc. have also published many research results in this field.

Figure 3. National collaborative network analysis

3.3.2. Author Collaboration Network

The more workers conducting a study, the higher the level of attention it receives. Analyze the authors of papers retrieved from the CNKI database and WOS core collection using Citespace software. The top 5 authors in terms of publication volume are shown in the table. In the CNKI database, Peng Yongzhen (Beijing Institute of Technology) has published 90 related papers, ranking first, Wang Shuying (Beijing Institute of Technology) has published 42 related papers, ranking second, and Li Jun (Beijing Institute of Technology) has published 35 related papers, ranking second. The majority of the top 5 are from Beijing University of Technology, and among the core collections of WOS, Peng still ranks first in terms of publication volume, while the top five are all domestic authors. Peng's team published 1719 papers in total, focusing on the fields of shortcut nitrification, SBR, biological nitrogen removal, denitrifying phosphorus removal, etc. [13~16], and its research on carbon sources is mainly about the addition amount of different traditional carbon sources (sodium acetate, glucose, ethanol, etc.), the impact on nitrogen removal efficiency. [17]

Table 2. Auth authors and publications of the top 5 publications on denitrification and carbon source research

	Author (CNKI)	Number of publications	Author (WOS)	Number of publications
1	Peng Yongzhen	90	Peng Yongzhen	46
2	Wang Shuying	42	Chen Yinguang	18
3	Li Jun	25	He ShengBing	12
4	Zhang Jie	22	Wang Shuying	12
5	Li Dong	18	Li Baikun	12

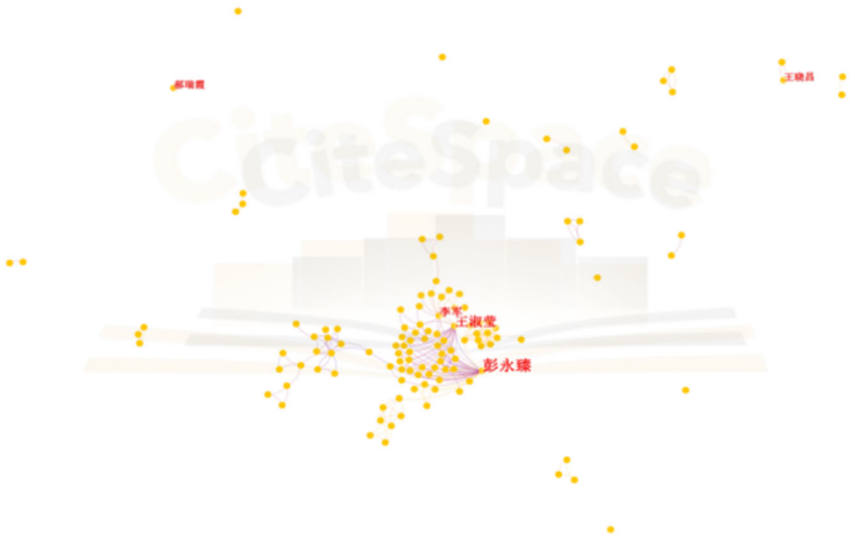

Figure 4. Collaborative network analysis of the CNKI database authors

Figure 5. WOS database authors collaborative network analysis

3.3.3. Research Institution Collaboration Network

Based on the CNKI database and the WOS core collection, the top 5 institutions with published papers were counted separately. According to CNKI database analysis, Xi'an University of Architecture and Technology ranks first with 40 articles published, Shenyang Jianzhu University ranks second with 39 articles published, and Tongji University ranks third with 36 articles published. According to the statistical analysis of WOS core collection data, it is still Chinese institutions that have made significant contributions in this field. The Chinese Academy of Science, ranked first with 128 articles, ranks first, while the other top five institutions are all Chinese institutions. This indicates that Chinese research institutions have made outstanding contributions in the field of denitrification and nitrogen removal with added carbon sources. This is consistent with the research trend in recent years to explore new carbon sources with high environmental safety performance, low prices, and especially the "waste to treat waste" approach. At the same time, it also indicates that Chinese researchers can quickly grasp the research direction and respond to national policy needs in a timely manner.

Table 3. Based on the database of CNKI KI and the collection of WOS core

	Research institutions (CNKI)	Number of publications	Research institutions (WOS)	Number of publications
1	Xi'an University of Architecture and Technology	40	Chinese Academy of Science	128
2	Shenyang Jianzhu University	39	Harbin Institute of Technology	92
3	Tongji University	36	Beijing University of Technology	81
4	Suzhou University of Science and Technology	34	Tongji University	79
5	Beijing University of Technology	32	Tsinghua University	51

Figure 6. CNKI Organization Collaborative Network analysis

Figure 7. WOS Organization Collaboration Network analysis

3.4. Hotspot keyword analysis

In the knowledge graph, the size of keywords is used to represent research heat. The larger the keywords, the more keywords they represent, and the curve represents the co-occurrence relationship between hotspots. In order to further analyze the research hotspots in the field of denitrification with added carbon sources [18], this article statistically analyzed the keywords published in the CNKI database and WOS core collection, as shown in the figure. The keywords that did not meet the conditions, such as artificial wetlands and influencing factors, were removed. The top ranked keywords in the CNKI database include denitrification, denitrification and phosphorus removal, denitrification, carbon source, biological denitrification, sewage treatment, added carbon source, carbon to nitrogen ratio, urban sewage, and low carbon to nitrogen ratio. Combined with relevant paper analysis, the research hotspots in this field include the following aspects: research on biological denitrification, optimization of denitrification chemical technology, and application of denitrification with added carbon sources. From the analysis of domestic research keywords, most scholars have found that when studying the biological denitrification process, it is often due to insufficient carbon sources that the removal rate of denitrification is low, leading to excessive TN in the effluent, which

in turn triggers readers to study carbon sources. Process the WOS core collection data, with the main hot keywords including Waste water, External carbon resource, carbon resource, nitrogen removal, etc. From the analysis of foreign keywords, the main focus is on exploring the selection of suitable denitrification processes and carbon source types. The keywords in the CNKI database and Web of Science core collection are basically the same, both of which focus more on the impact of carbon sources on denitrification processes and the study of new carbon sources. But in China, more emphasis is placed on process optimization and carbon source application, while in foreign countries, more emphasis is placed on performance and carbon source types.

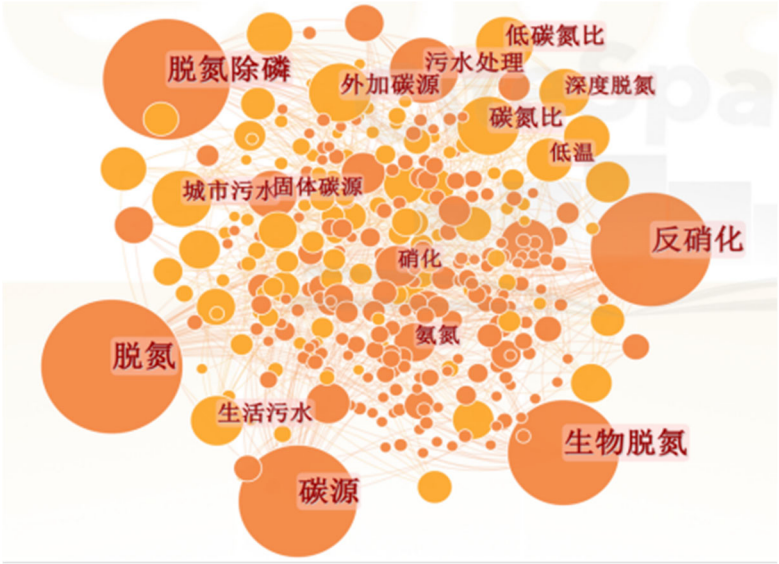

Figure 8. The visualization of co-occurrence network visualization

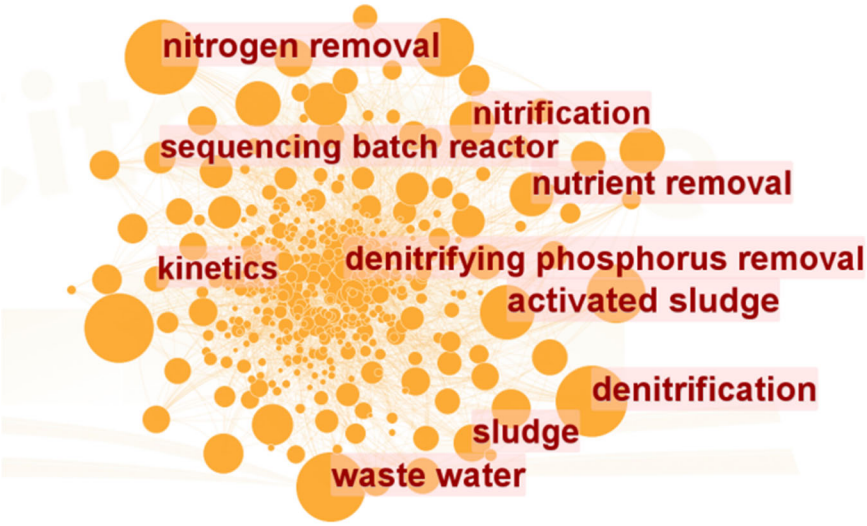

Figure 9. WOS database research domain co-occurrence network visualization

Table 4. Based on the CNKI database and WOS core collection, the top 10 high-frequency research hotspots in the field of nitrogen and carbon sources

	CNKI		WOS	
	High-frequency words	frequency	High-frequency words	frequency
1	Denitrification	370	nitrogen removal" nitrogen and removal"	1274
2	Denitrification and phosphorus removal	292	carbon resource and carbon	505
3	heterotrophic denitrification	268	denitrification	472
4	carbon resource	250	waste water	443
5	Biological denitrification	226	performance	340
6	sewage disposal	86	activated sludge	272
7	influence factor	69	nitrification	189
8	Additional carbon source	68	waste water treatment	185
9	Carbon to nitrogen ratio	67	nutrient removal	176
10	urban sewage	62	microbial community	172

4. CONCLUSION

The research on carbon sources for denitrification is reviewed by bibliometric analysis. During the statistical period, China ranked first in terms of the number of publications; in terms of research institutions, the Chinese Academy of Sciences published the largest number of articles; and the top-ranked research scholars were also Chinese. This indicates that our research on carbon sources for nitrogen removal from wastewater treatment is at the forefront. Based on the citespace software to denitrification externally carbon source of the key words to analyze, the results show that domestic and foreign have focused on the economy, process, environmental protection, sources of interaction between each other, the relationship between the study. Also, it is committed to the use of waste as a carbon source to promote the process of denitrification, in order to achieve high efficiency and " to treat waste with waste ".

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