Industrial Wastewater Treatment in Latin America and Europe: Methods and Applications. Systematic Review of Literature

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Abstract

This research seeks to disseminate the different methods for wastewater treatment in different industries in Latin America and Europe, as well as the most used ones. According to the literature reviewed, a large percentage of industrial wastewater is not treated, especially in Latin America, causing a negative impact on the ecosystem. There are different methods for the treatment of industrial wastewater; however, most of the research on industrial wastewater treatment focuses on the study of a single treatment method. The methodology used was the systematic literature review, 5 categories and 10 subcategories of study were formed to analyze 30 articles published between 2015 and 2020. As the main result, it was obtained that green technologies, such as the wetlands method and use of microalgae, were the most studied in the last five years. The main limitation of this study was the lack of information regarding industrial sectors other than textile and food, so it is suggested to do future research focusing on sectors not yet studied, such as automotive, metalworking, agroindustrial, among others.

Keywords
Wastewater, methods, industrial sector, treatment and Systematic Literature Review.

Introduction
Currently, freshwater sources receive everything from large amounts of garbage to invisible chemicals, which can be harmful to human and wildlife health (National Geographic 2023).
Likewise, more than 70% of wastewater is not treated, causing difficulty in completing the water cycle and although this problem affects Latin American countries to a greater degree, because they do not have a sufficient supply of drinking water (Larios - Meoño et al. 2015), this is not alien to the reality of European countries, as is the case of Spain, which is the European nation with the largest water deficit (Rodríguez Fernández Alba et al. n.d., p. 6).
The lack of controls makes it difficult to know whether the companies actually treat their waste or simply discharge it into the water without formalization or a discharge authorization (Zela Esteban and Olivas Aranda. 2022, p.132).
Similarly, it is estimated that industry acoyunta for 20% of global water consumption and its mismanagement is its main problem, since most of the water used is polluted without being purified or made potable again (Nuevas Normas ISO 2019). Consequently, according to the described problematic, this paper poses the following research question: What research about industrial wastewater treatment has been carried out in Latin America and Europe, between 2015 and 2020?

1.1. Objectives
The purpose of this research is to make known the different methods for wastewater treatment, as well as the most used, efficient and sustainable in the industrial sector in Latin America and Europe. In this way, knowledge will be provided so that the industrial sector can apply it in their processes, contributing to the reduction of water pollution and the continuous improvement of this sector.

2. Literature Review

Wastewater is water contaminated by liquid and solid wastes from homes, institutions, and the industrial and commercial sectors, which may be mixed with rainwater (Vázquez Rossainz 2003, p. 10). These are produced by man's daily activities and are collected by networks of subway pipes that transport the water, either by unitary networks that form a single conduit to collect domestic, industrial and rainwater wastewater, or by separate networks that are composed of two independent pipes for both wastewater and rainwater (Wastewater collection system 2021, para. 3). It should be emphasized that the composition of wastewater has a highly variable chemical composition and concentration due to the different factors that affect it (Rojas 2002). This type of water is composed of approximately 99.9% water and 0.1% solid materials, either dissolved or suspended (they can be sedimentable or colloidal) (Composición de las Aguas Residuales 2000).

It is also important to mention that the main pollutants contained in wastewater can be grouped into: biodegradable organic matter, phosphorus and nitrogen compounds, microorganisms composed of saprophytic organisms and pathogens such as viruses, bacteria, among others; these give the water pestilential, toxic, infective and aesthetic properties (Rojas 2002).

It should be noted that most of the articles reviewed focus on the study of a single method for wastewater treatment, such is the case of Sandoval et al. (2020) who proposed the use of microalgae for the removal of emerging contaminants in wastewater. In this study, it was concluded that the proposed treatment is easy to install in open systems and low cost compared to conventional technologies; in addition, it was revealed that further research is needed on the factors to be controlled to improve the removal process of mixtures of pollutants present in wastewater (pp. 127-137).

Likewise, Jaimes Urbina and Vera Solano (2020) propose a treatment through ozonation to eliminate emerging pollutants from wastewater from the pharmaceutical industry (pp. 249-262). At the end of the study, the results showed that ozonation can provide environmental, sanitary and economic advantages for the elimination of pollution in the aquatic environment. In addition, it was determined that with the use of advanced tertiary treatments it is possible to extract emerging compounds, especially pharmacological substances that today have a viable risk of threatening the quality of drinking water (Jaimes Urbina & Vera Solano 2020).

On the other hand, Alfonso Moreno et al. (2015), apply a wastewater treatment system in a textile industry located in Bogota - Colombia. Making known the O3/H2O2/UV process as the optimum for the treatment of complex synthetic dyes used in the textile industry studied, with results of high effectiveness in the degradation of dyes and efficiency of 99 % (pp. 54-62).

For his part, Cisterna (2017), studies the operation of a biological treatment system using activated sludge fed by an influent with sunflower oil and sucrose, in which the biodegraded material is estimated through a mass balance and operational and design parameters, obtaining that such process is more efficient when a high initial biomass concentration (7500 mg/L) is applied (p. 69).

From an environmental point of view, this research aims to present different methodologies that adopt sustainable technologies and procedures for the reuse of industrial wastewater, as well as their respective applications, contributing to the care of water resources. From an economic perspective, the article will analyze which methods are more efficient for the reuse of wastewater in the industrial sector in Latin America and Europe, in such a way that they represent an economic saving for the companies that use them. From a practical perspective, this research will be very useful for the industrial sector and anyone interested in implementing or developing wastewater reuse systems, based on the different methods and applications that can be carried out for this purpose, as well as their environmental impact. Finally, from a practical perspective, this research will be very useful for the industrial sector and anyone interested in implementing or developing wastewater reuse systems, based on the different methods and applications that can be carried out for this purpose, as well as their environmental impact.

3. Methods

The research conducted in this study is of a basic type, also called theoretical or conceptual. This is characterized because it remains within the theoretical framework in which it originated and aims to seek and obtain more knowledge from the scientific community, but without contrasting it with the practical environment (Muntané Relat, 2010, pp.

221-227). In addition, the present research will have a qualitative approach, which recognizes that subjective meanings and understanding of the context where the phenomenon occurs should be considered in addition to social variables (Vega-Malagón et al. 2014). Likewise, the systematic review method is very useful for the development of the study, since it is a form of research that compiles summarized information on a specific topic based on the research question posed (Aguilera Eguía 2014).

On the other hand, for the development of this study, the efficiency of the methods used for the treatment of industrial wastewater was determined as a dependent variable and the technologies and processes applied for the treatment of industrial wastewater as an independent variable. From this, some of the dimensions were defined, such as the removal efficiency of COD (Chemical Oxygen Demand) and true color parameters, metal removal efficiency, among others. In addition, the respective indicators were defined, such as the percentage of TSS (Total Suspended Solids), BOD (Biological Oxygen Demand), COD (Chemical Oxygen Demand), TP (Total Phosphorus Concentration), BOD5 (Biological Oxygen Demand) and TS (Total Solids) removal, percentage of metals removal, turbidity removal, among others.

In a first exploration, methods and applications for industrial wastewater treatment were analyzed by reviewing articles published in Latin America and Europe during the years 2015 and 2020. The questions that guided the present research are posed as follows: what methods were used in the industrial sector in Latin America and Europe for the treatment of wastewater between the years 2015 and 2020, what are the applications given to treated wastewater in the industrial sector, in Latin America and Europe between the years 2015 and 2020, what are the applications of treated wastewater in the industrial sector, in Latin America and Europe between the years 2015 and 2020?How many literature reviews have been conducted on the reuse of industrial wastewater in Latin America and Europe between 2015 and 2020, which industries generate the most pollution in the water they use for the development of their operations between 2015 and 2020, and which industries are the ones that generate the most pollution in the water they use for the development of their operations between 2015 and 2020.

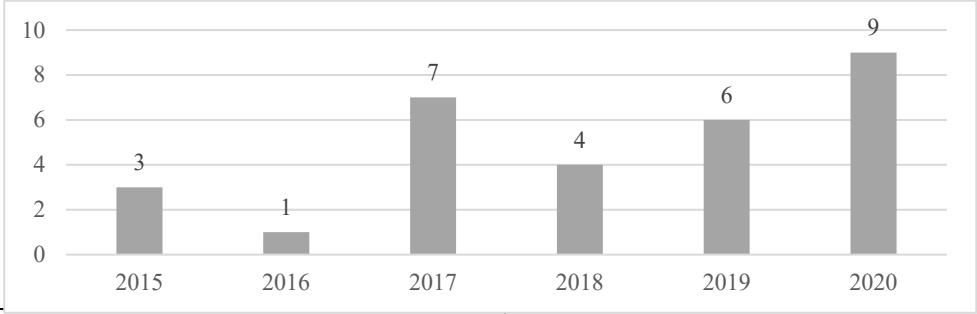
For the selection of the articles, the following inclusion criteria were considered: publications from 2015 to 2020 disseminated in Latin America and Europe, written in English, Spanish or Portuguese, articles from indexed journals belonging to quartile 1 and 2, finally the criterion of academic papers was included. On the other hand, the following exclusion criteria were considered: publications before 2015, articles that were not published in Latin America and Europe, written in languages other than English, Spanish or Portuguese, and articles from indexed journals that do not belong to quartile 1 and 2.

The information searches were conducted in bibliographic databases such as Scopus, Scielo, Proquest, among others; search engines such as Google Scholar, using the following keywords: wastewater, industrial sector, treatment, methods; it should be noted that the Network of Scientific Journals of Europe and Latin America was also searched. In the same way, the temporal space was concentrated covering the years 2015 and 2020. Likewise, the geographical space was delimited, which contained publications from Latin America and the European continent.
Based on the above, a first list of 261 documents was obtained. After applying the inclusion criteria, those articles that did not meet these requirements were discarded. Thus, 30 articles were selected.

For the analysis of these articles, use was made of a matrix supported by pivot tables in MS Excel, allowing a better organization of the information obtained. This was done according to the categories and subcategories designed, which are shown in the following table.

Table 1. Category and subcategories of study

Analysis category	**Subcategories of analysis**
Academic production	1. Number of items produced 2. Types of items produced 3. Academic journals in which studies on wastewater treatment are published
Methods used for wastewater treatment	1. Main methods used 2. Justification of the methods used
Applications for treated wastewater	1. Application of treated water



Context of the study	1. Country/place from which the studies were obtained 2. Years in which the studies were carried out 3. Sector where the wastewater treatment methods were applied
Effects of wastewater treatment methods	1. Contributions and limitations of wastewater treatment methods

Figure 1. Distribución of articles by year of publicación

4. Results and Discussion

During the last few years, studies of wastewater treatment methods in the industrial sector have become more relevant due to the importance it has on the environment. However, most of the articles reviewed focus on the study of a single method for such treatment and the results obtained are not completely efficient.

In the search conducted, a total of 30 articles were found between the years 2015 and 2020. According to the graph, the production of academic articles analyzing the methods and applications of wastewater treatment in the industrial sector have had a significant growth in the years 2019 and 2020, the latter being the year in which more studies have been found regarding the topic.

On the other hand, the publications found appear in 21 academic journals, mainly Colombian, given the higher academic productivity in Colombia compared to other Latin American and European countries. However, the journal in which more articles on the topic of interest were found was Water (Switzerland), which is an international open access journal belonging to quartile one (Q1) that covers aspects of water, such as water science, technology, management and governance (Multidisciplinary Digital Publishing Institute [MDPI], n. d., para. 1).

It should be noted that, like Water magazine, most of the articles are published in specialized science and environmental journals. This shows that there is a tendency to disseminate research in sustainable journals.

During the study, different methods used for wastewater treatment in the industrial sector were found. However, some of them were mentioned several times, since they have been of greater interest to the researchers. The following table shows the number of times that the methods found corresponding to the research topic were studied during the analysis of the articles.

Table 2. Main methods used

Industrial wastewater treatment/methods	Total items	Industrial wastewater treatment/methods	Total items
Adsorption	1	Reverse Osmosis	1
Application of pre-polymerized compound coagulants	1	Ozonization	3
Application of a biosurfactant inwaste oil separation using a prototype DAF	1	ZLD (zero liquid discharge)process	1
Biodegradation of fats, oils andgreases by activated sludge	1	Electrochemical techniques combined with ultravioletirradiation	1
Bioremediation	1	Conventional technologies and advanced oxidation process	1
Coagulation and flocculation	2	Conventional and non- conventional surface treatments	1
Heterogeneous Fenton (Advanced oxidation process)	1	Use of spirulina biomass, primary sedimentation, andchemical precipitation	1
Ceramic membrane filtration	1	Use of activated carbon	1
Dissolved air flotation	1	Use of yeast and bacterial biosurfactants as demulsifiers	1
Wetlands	4	Use of microalgae	2
Activated sludge	1	Use of biochar	1
Nanofiltration	1	**Total**	30

According to the table shown, it can be said that wetlands, ozonation, use of microalgae, coagulation and flocculation (in order of priority) are methods that have been studied more than once. This means that there is interest in studying these methods because, according to Cartagena David (2019), natural processes are economic and ecological technologies that would provide a simple alternative, with low costs, helping to prevent, mitigate and minimize the impacts and consequences on the environment and human health.
All the articles found are aimed at finding the ideal method that meets the needs of your sector, both environmental and economic. Thus, a table will be presented in which the purposes of the methods used will be shown in more detail and individually.

Table 3. Justificación of the methods used

Author(s)	Industrial wastewater treatment/method	Justification
Acuña Samaniego, M. (2020)	Wetlands	It is an ecological and economically viable option, composed of impermeable cells with a specific substrate that promotes the rooting of vegetation, which will be used as a water filter.
Marazzi, F., Bellucci, M., Fantasia, T., Ficara, E., & Mezzanotte, V. (2020).	Use of microalgae	Easy to install treatment in open systems and low cost compared to other technologies, allowing the removal of emerging contaminants.
Jaimes Urbina, J. A., Vera Solano, J. A. (2020)	Ozonization	Its objective is to eliminate residues present in wastewater, resulting in improvements in taste, color, filtration characteristics and biodegradability of the water, as well as inhibiting the growth of fungi and algae, and reducing turbidity.

Meneses Barroso, Y. M., Patiño Mantilla, P. A., Betancur Perez, J. F. (2019).	Use of spirulina biomass	Spirulina biomass is composed of live and dead biomass, which allows the removal of most of the contaminating residues from metals.
Alfonso Moreno, F. L., Choachí, M. Z., Mendoza Urrea, S., Pulido Talero, W. E. (2015).	Advanced oxidation	Technology that generates hydroxyl -OH that react rapidly and can easily degrade pollutants such as complex synthetic dyes, due to their instability and that are highly oxidizing.
Dotto, J., Moreno Palacio, S., Regina Fagundes-Klen, M., & Bergamasco, R. (2019).	Coagulation and flocculation	Low-cost and eco-friendly technologies, where natural coagulants (Moringa oleifera, Jatropha curcas, tannins and corn) are used because they are non-toxic and have a wide range of biodegradable properties.
Jimenez Cercado, M. E., Guilcamaigua Anchatuña, D. X., Quintero Quiñonez, N., Muñoz Naranjo, D. (2019).	Adsorption (use of natural adsorbents)	Treatment using natural adsorbents (orange peel, corn husk and rice husk), which underwent drying, crushing and screening processes to remove oils from the wastewater.

In the following table, some of the applications that can be given after the most studied and applied wastewater treatments in the industrial sector during the last years will be shown.

Table 4. Treated water applications

Industrial wastewater treatment/method	**Application of treated water**
Wetlands	Irrigation systems, providing macronutrients and trace elements to soils for plant development.
Use of microalgae	In the washing of equipment of the same industry, as a means of irrigation,agriculture, livestock, safe discharge into the environment.
Ozonization	Safe discharge into the environment, cleaning of equipment in the pharmaceutical industry or in the tanning process itself.
Use of spirulina biomass	Biodiesel production, safe discharge into the environment.
Advanced oxidation	Reuse in the production process (textile industry), safe disposal in the environment.
Coagulation andflocculation	Application for purification systems, also used for agricultural irrigation or industrial reuse in the refrigeration process. In addition to being suitable for discharge into the environment without having a negative impact on it.
Adsorption (use of natural adsorbents)	It is used as a polishing method after conventional treatments that can be used for cleaning purposes of machinery, vehicles and irrigation. It can also be discharged into the environment.

As can be seen, all industrial waters after being treated are capable of being discharged into the environment without having a negative effect.

In the present study, parameters were defined to delimit the search for articles on the research topic. Regarding the geographical context, it was defined that the publications should be studies developed in Latin America and Europe, and the following graph shows how these studies are distributed.

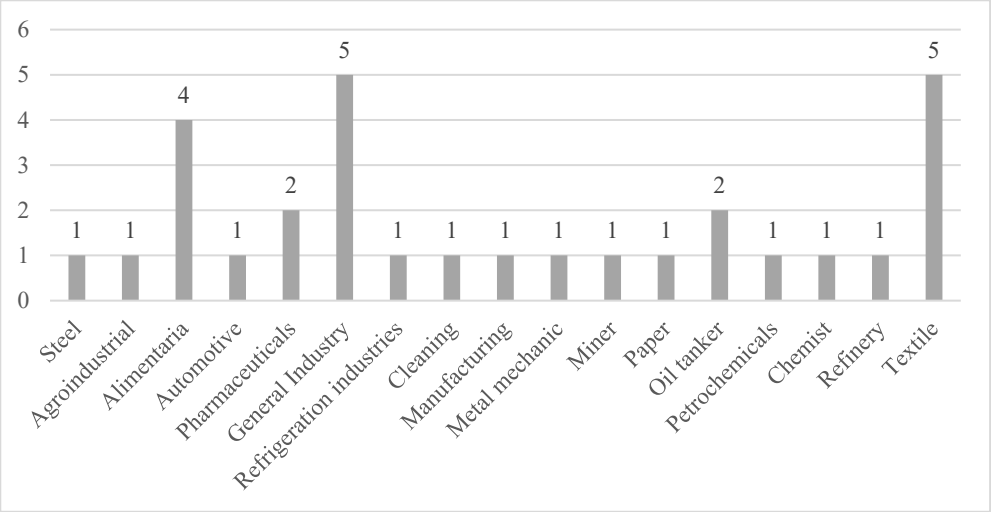


Figure 2. Country/place where the studies were performed

It can be seen that there is a large number of articles studied in Colombia, followed by Brazil and Italy, so it can be said that Latin America is in constant research regarding industrial wastewater treatment and therefore in constant environmental awareness.

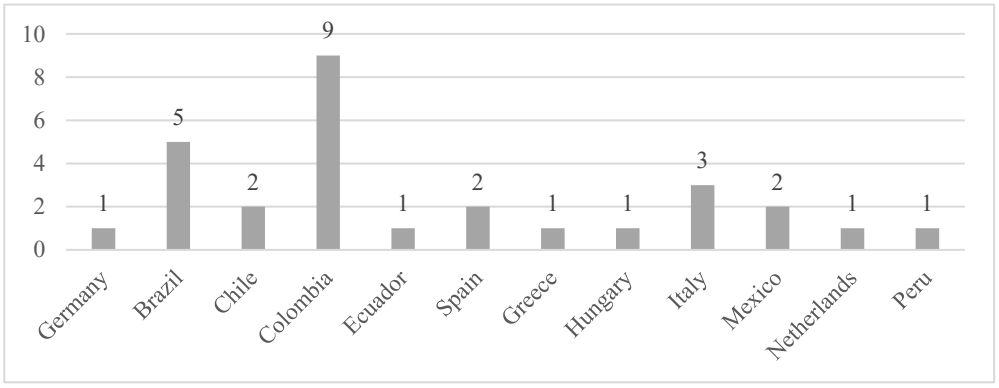


Figure 3. Sectors of application of wastewater treatment methods

On the other hand, in recent years, more articles have been published in different parts of the world, so it can be said that the scientific community has awakened a significant interest in wastewater treatment in the industrial sector and its applications.

The sectors in which the methods found in the articles studied have been applied are diverse. Among them are the textile, steel, food, pharmaceutical and oil industries, among others. However, the textile sector is one in which there are more studies on wastewater treatment. This is due to the fact that, in its processes, the water resource is usually contaminated in large quantities.

The following and last subcategory of study will show the contributions and limitations of the most studied and/or used wastewater treatment methods in recent years.

Table 5. Contributions and limitations of wastewater treatment methods

Authors	Contributions	Limitations
Acuña Samaniego, M. (2020)	The optimal and most efficient technology for wastewater treatment is artificial wetlands. The effectiveness of this method is characterized by the adsorption of a large amount of pollutants such as metals, nitrogenous species and phosphates. In addition, it improves environmental quality, health and, above all, the low cost of implementation, which makes it an economic advantage.	The difference in COD removal efficiency given by their authors, where Arteaga et al., (2019) concludes that such method has 87% while Jaramillo et al., (2016) 56.9%.
Marazzi, F., Bellucci, M., Fantasia, T., Ficara, E., & Mezzanotte, V. (2020).	The process selected for wastewater treatment was the interaction of microalgae and bacteria in CO2 to evaluate the feasibility of treating whey without any dilution or pretreatment, obtaining an average pollutant removal efficiency of 93% thanks to Scenesdesmus acuminatus and 94% thanks to the mixed population.	Residual concentrations of the most important pollutants observed in the Plexiglas column photobioreactors (PBR) were low which prevented their discharge into wastewater, according to Italian regulations.
Jaimes Urbina, J. A., Vera Solano, J. A. (2020)	Ozone treatment of wastewater from the pharmaceutical industry was the most efficient method for the removal of pharmaceutical compounds with ozone being used in many processes as the homogeneous advanced oxidizer and considered the most powerful oxidant, thusincreasing the biodegradability of the water.	The level of concentration of waste from the pharmaceutical industry depends on the sources where it is generated, and the presence of such waste is a major environmental problem.
Meneses Barroso, Y. M., Patiño Mantilla, P. A., Betancur Perez, J. F. (2019).	The use of spirulina biomass was the most efficient method for chromium removal in the metalworking industry, achieving a removal of up to 96.5% and a sludge generation of less than 10%, allowing the recovery of chromium for further use.	As the contact time increases at 24 hours, there is a decrease in the percentage of removal, and a constant analysis of the amount of chromium in the spirulina biomass must be made.
Alfonso Moreno, F. L., Choachí, M. Z., Mendoza Urrea, S., Pulido Talero, W. E. (2015).	The optimal treatment of complex synthetic dyes used in the textile industry was the combination of conventional treatments with the advanced oxidation process where four stages are carried out in compliance with the regulatory limits of BOD, COD and color parameters that represent water quality. Likewise, the advanced oxidation process is a clean, environmental, and optimal technology, achieving results of 99% effectiveness and dye degradation efficiency.	If the company increases the capacity of its dyeing process, which has the greatest impact on the quality of the discharge, it will increase the pollutant load and therefore fail to comply with two or more parameters.
Dotto, J., Moreno Palacio, S., Regina Fagundes-Klen, M., & Bergamasco, R. (2019).	Natural coagulants were used instead of synthetic coagulants in the removal of apparent color, turbidity, COD, and absorbance for the treatment of wastewater in the textile industry, achieving many advantages in which a low implementation cost technology stands out. It should be noted that the organic coagulant, Moringa seed extracted from KCl, was more efficient than the synthetic coagulant.	Low turbidity effluents cause the formation of scales with low sedimentation capacity, reducingthe coagulation and flocculation performance of the coagulant.

Jimenez Cercado, M. E., Guilcamaigua Anchatuña, D. X., Quintero Quiñonez, N., Muñoz Naranjo, D. (2019).	The method used for the removal of oils and suspended solids in wastewater from washing machines and vehicle lubricants was by bioadsorption and coagulation-flocculation, achieving a final removal of 99.55%.	The rice husk adsorbent applied in the bioadsorption process is not sufficient to remove the maximum amount of turbidity, so the coagulation-flocculation process is subsequently applied.

5. Conclusion

The purpose of this study was to analyze the most commonly used methods for wastewater treatment in different industries in Latin America and Europe. Among the main results of the study, with respect to literary production, it is observed that there were more articles published in the years 2019 and 2020. Also, the main methods used for wastewater treatment in the industrial sector were wetlands, ozonation, use of microalgae, coagulation and flocculation, as they are methods that have been studied more than once.

On the other hand, the main contribution of this research is to provide knowledge about the most efficient and sustainable methods used for wastewater treatment so that companies in any industrial sector can apply them in their processes. This will contribute to the continuous improvement of the industry by reducing costs and pollution of the aquatic environment significantly. Finally, the main limitation of the present study was the limited availability of open access articles and the lack of information on industrial sectors other than the textile and food sectors, for which reason it is suggested that future recommendations be made focusing on factors that have not yet been studied.

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