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Selection of the best leachate treatment method for the waste of leek fields using Analytic Hierarchy Process (AHP)

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ABSTRACT

A large amount of fruit and vegetable waste is generated every day in big cities. The efficient disposal of such biodegradable waste can be considered a challenge. Leachate contains large amounts of pollutants, and treating it is very complex, expensive, and requires a variety of hybrid processes. This study used the Analytic Hierarchy Process (AHP) to analyze suitable treatment methods for the leachate from fruit and leek fields. Quantitative and qualitative parameters or a combination of these parameters were used as defined in Expert Choice software. The criteria used for this purpose included chemical oxygen demand (COD), biochemical oxygen demand (BOD), COD/BOD, temperature, TOC, pH, total dissolved solids (TDS), total suspended solids (TSS), and time. These criteria, which are important for leachate classification, were identified and extracted by experts; their importance was ranked by AHP software. The research process was divided into two parts to ascertain a faster method: the significance of the parameter time and the insignificance of the parameter time. Biological treatment methods outperformed the other methods where the parameter time was insignificant. In the cases where the parameter time was significant, chemical methods and, in particular, two methods with ozone compounds (Ozone + GAC, Ozone + H_2O_2) outperformed the other methods.

1. Introduction

Leachate can be defined as aqueous effluent from the infiltration of rainwater into waste, the biochemical process in the waste cell, and the content of effluent from the waste itself [1]. During the process of infiltration into waste and leachate, leachate can carry organic matter, minerals, heavy materials, pathogens, and other pollutants. Therefore, leachate is of great environmental importance due to its potential for polluting [2]. Industrialization and improper waste management lead to the accumulation of large amounts of kitchen waste and foods. According to the Food and Agriculture Organization (FAO), most of the food produced, harvested, and used in almost all types of food shown in Figure 1 are disposed of as waste [3]. Large quantities of fruit and vegetable waste are generated daily in major cities around the world; the effective disposal of such highly biodegradable waste is considered a challenge [4].

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With the rapid economic development and structural reform of agriculture around the world, the fruit and vegetable industry has expanded rapidly, and many countries now face the major problem of disposing of large amounts of fruit and vegetable waste. This waste is mainly obtained from the production, transportation, storage, distribution and consumption of fruits and vegetables [5]. The sums of such waste per day are as follows: 90 tons in Mercabarna, near Barcelona, Spain; 6 tons in Tunis, Tunisia; and 15,000 tons in India [6]. In Central de Abasto, the world's second-biggest food and vegetable market located in Mexico City, 895 tons of waste is created every day [7]. Large amounts of organic matter, inorganic salts, ammoniac nitrogen, and metal ions are present in the leachate [8].

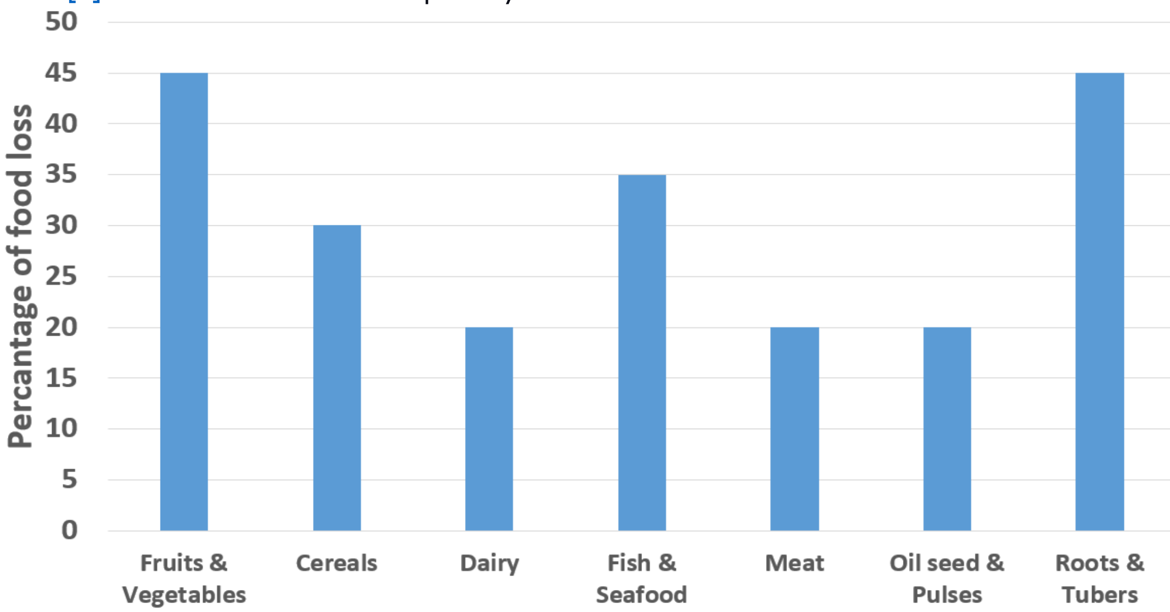

Fig. 1. Food percentage lost in multiple food categories after production, harvest, and utilization due to reports of FAO (http://www.fao.org/save-food/resources/keyfindings/en/) [3].

However, these troublesome leachate pollutants (organic matter and nitrogen) can be recycled as valuable resources [9]. Biodegradable organic matter can be changed into many types of bioenergy [10], involving methane [11], hydrogen [12], and electricity [13]. Humic substances (HS) can be recuperated as fertilizer [14]. Ammoniacal nitrogen can be recouped as nutrient fertilizer [15]. In Iran, about 60 tons of solid waste is produced daily, more than 70% of which is converted into organic fertilizer [52]. There are different methods for disposing of organic waste, including landfilling, incineration, composting, and thermal decomposition [16]. The municipal solid waste leachate is very strong wastewater containing large amounts of priority pollutants, photogenic organisms, stable organic compounds, and heavy metals [17,18,19]. Therefore, special attention should be paid to controlling, collecting, treating, and disposing of this pollutant. Otherwise, the absence of a suitable method for treatment, collection, and disposal of leachate will cause severe soil, groundwater, and surface water pollution with stable and toxic organic compounds, nitrogenous, aromatic, and phenolic compounds. In addition, such a shortcoming will threaten human and aquatic life [20]. Leachate contains large amounts of pollutants that are very complex and expensive to treat and usually require a variety of processes. Therefore, leachate treatment and disposal should be done carefully. Proper leachate treatment is also a major problem in different countries. Various physical, chemical, and biological methods are commonly used to treat leachate [21]. Among the various methods of leachate treatment, biological processes are preferred due to their lower cost, easy operation, and environmental friendliness [22,23]. The removal and treatment using direct biological treatment of municipal leachate are usually low due to its high COD content (6000-15,000 mg/l), ammonium ions (500-3000 mg/l), and high COD /

BOD ratio [24]. The advanced methods for treating landfill leachate can generally be classified into physical, chemical, and biological methods, which are usually combined to improve treatment efficiency. Many studies have been conducted on the leachate of organic compounds using various methods. AOPs such as Fenton, ozonation, cavitation, etc. can be used for the pre-treatment of industrial wastewater to improve its biodegradability index (BOD_5: COD ratio), thus enhancing the probability of degradation [25]. Cavitation is one of the emerging AOPs capable of reducing toxicity and enhancing the mineralization of wastewater [26]. It is the phenomena of formation and growth of the millions of micro cavities under controlled conditions and their subsequent violent collapse due to the pressure variations created [27]. Although cavitation can be induced in many ways, hydrodynamic cavitation has been reported to be the most cost-effective and efficient way of inducing cavitation [28]. As mentioned earlier, selecting the best method for leachate treatment is considered one of the most important and difficult stages of leachate treatment. Notably, a large number of different methods can be used to treat the leachate of fruit and vegetable fields, each with many advantages and disadvantages. Therefore, the best method with the shortest time and the lowest cost should be selected. For this purpose, this paper used the AHP method and Expert Choice software to select the most suitable methods; it has been attempted to rank these methods by considering the important parameters for leachate treatment.

2. Methodology

2.1. Data collection and classification

The leachate treatment process was studied from different aspects according to previous investigations to select the most appropriate and best possible method for treatment. Hence, each method was evaluated by parameters that are important in leachate treatment compared with other methods. Based on performed research, several important parameters in leachate segregation and treatment were separated to find a relationship for comparing different treatment methods. These parameters, including COD, BOD, COD/BOD, TDS, TSS, time, temperature, TOC, and pH, were selected as a measurement tool to compare the different methods and select the proper leachate treatment. The major criterion for selecting these parameters is their importance in creating a proper leachate treatment. Separating these parameters allows for comparing different methods. A proper comparison can be made by measuring each method to respond to the parameters' needs. Therefore, the performance of any method playing a better role in refining each parameter can be a more suitable one for leachate treatment.

2.2. AHP and expert choice

AHP has been broadly utilized and examined in several areas since its introduction by Thomas L. Saaty in the 1970s [29]. AHP is one of the most comprehensive systems for multi-criteria decision-making. It is a tool for combining quantitative and qualitative factors for process selection and preference determination in an unpredictable problem. The main advantage of this method is its ability to solve problems with complex structures based on pairwise comparisons that conventional mathematical methods cannot solve. By selecting Expert Choice software, in addition to the option of saving time and cost, the opinions of experts are included and increase the details and accuracy of the work. Changing the weight of the criteria based on the experts' opinions is a key feature of this method. For complex multi-criteria analysis task, several Multi-Criteria Decision Analysis (MCDA) models have been described in the literature: Order of Preference by Similarity to Ideal Solution (TOPSIS), Elimination and Choice Translating Reality (ELECTRE), Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), and Analytic Hierarchy Process (AHP) [30]. Bick and Oron [31] presented the MBR treatment process coupled with management modeling [Analytical Hierarchical Process (AHP)] analysis. This management method is based on the assumption that the user can easily define comparative terms instead of absolute values. Akintorinwa and Okoro [32] applied the integration of remote sensing, geophysical data, and the AHP model to classify the Ode-Idanre region, Nigeria, into different landfill suitability zones. The geophysical surveys of Saatsaz et al. [33] were first carried out to delineate the subsurface layers and determine their geological parameters incorporated into the AHP model. Expert Choice software is a powerful tool for multi-criteria decision-making in AHP. AHP facilitates the decision-making process by organizing and evaluating the significance of different criteria and preferences. In this study, various treatment and screening methods were studied using the AHP method and Expert Choice software. This software uses different weighing parameters to select appropriate and desired methods. First, benchmark parameters for weighing were introduced to the software. The software compared the parameters in pairs, and weighing was done by experts. In this process, the significance of COD, BOD/COD, BOD, pH, and TDS was considered higher than other parameters regarding their significance in the leachate and its purification. The other parameters had lower ranks due to their lower importance. Therefore, our benchmark parameters were categorized and classified, and the parameters were separated by experts based on their weights. It is necessary to investigate the variables (alternatives) or different methods to define them for the software to compare and weigh them. Before this step, extensive research was conducted to collect information in the range used in each method for benchmark parameters. Thus, the obtained range used for each parameter in different leachate treatment methods of organic matter and leek fields was a tool that could be used to make pairwise comparisons in expert choice software. To this end, numerical intervals were obtained for each method. Each benchmark parameter was separately examined, and different treatment methods were compared in pairs. It was possible to perform pairwise comparisons between two methods by extensive research on calculating numerical intervals for benchmark parameters and using the obtained information. The superiority of one method over the others is attributed to the options available in the software. Moreover, this issue was generalized to all benchmark parameters. All treatment methods or alternatives were compared in pairs. Afterward, the methods were ranked in each relative parameter due to weighing. Eventually, the software compared these methods based on the weighing and ranking of relative benchmark parameters. In this way, the most appropriate and desirable method for leachate treatment was obtained.

3. Results and discussion

The AHP method was used for comparing the methods used in this study. Especially for multi-criteria decision-making (MCDM) problems, this process broke the decision into a hierarchy of relevant criteria, which were the most influential factors [53]. For this purpose, six experts with experience in leachate treatment created citation criteria in this software. They established the basis for comparing the methods by ranking the benchmark parameters based on the average weight obtained. Then, based on the alternatives proposed by the user, these methods were compared to find the most desirable methods. Another challenge for the assessment team was finding a method that responded more quickly and did the refinement because the sponsoring company needed faster leachate treatment. Hence, the team had to consider time limits as well. After introducing the information into the software, it used the treatment methods in two overall and pairwise forms. salari (2018) used the Expert Choice software to select the best catalysts for the degradation of ciprofloxacin antibiotic by homogeneous Fenton oxidation in wastewater treatment [54]. In another study, AHP software was used to develop a modified water quality index (WQI) other than the standard WQI [55]. Khan (2015) used AHP to estimate the weights of the relative importance of the factors guiding landfill siting using pairwise comparisons [56].

3.1. Choosing the appropriate method due to each parameter

Figure 2 shows an overall comparison among different treatment methods and their performance in each benchmark parameter. In this figure, the significance of our benchmark parameters evaluated and weighed by experts are specified as bar charts; their percentages can be observed on the vertical axis. The studied treatment methods are ranked in the right part of the figure. The performance of each method is also categorized and separated on bar charts in a specific benchmark parameter.

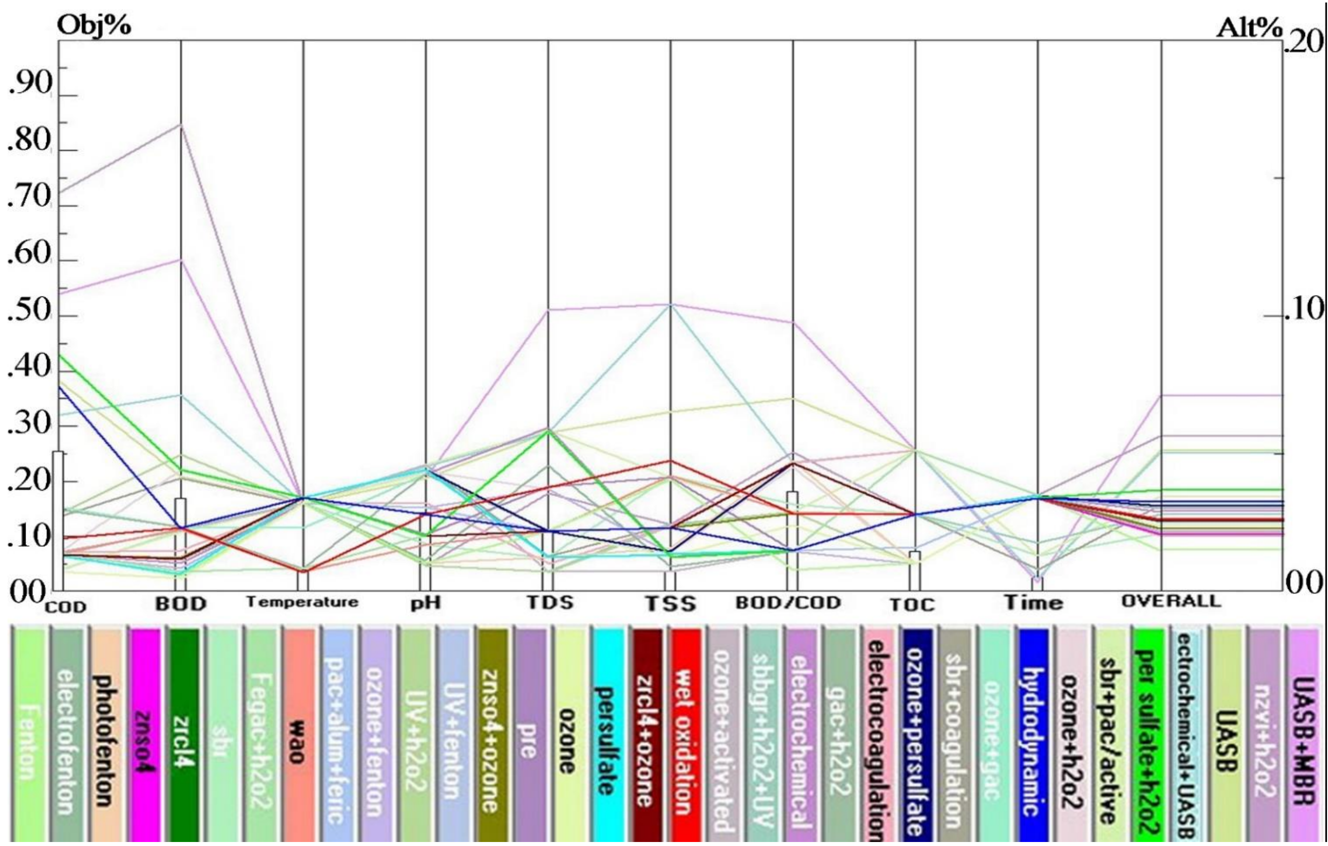

Fig. 2. A general comparison among different treatment methods and their efficiency in each benchmark parameter.

In Figure 2, on each bar chart specific to a benchmark parameter, different treatment methods are packaged due to their performance in a particular parameter. This chart can be used to rank treatment methods due to the benchmark parameter if one of the specific benchmark parameters is more important than the others. At last, in the overall section, the software categorized different leachate treatment methods due to weighing in the performance section. According to the diagram, UASB + MBR, nZVI + H_2O_2, and UASB methods generally outperform the other methods. Most of the methods at the top of this ranking are biological methods that should take a long time to perform. In this regard, gradient graphs were preferred to examine each benchmark parameter separately and determine how each method worked in each section. These diagrams allowed finding the best method in each benchmark parameter with a more desirable and better result. The advantage of this diagram model is that if some benchmark parameters in leachate treatment are more important to the leachate treatment team, they can find the appropriate method based on this diagram model. Figure 3 shows the ranking of methods in the COD benchmark. The vertical line of the graph represents the importance percentage calculated by experts, which is the benchmark to consider the best methods after this line. Lee et al. [57] utilized the AHP model to evaluate the prioritization of key technologies by the silicon photovoltaic industry. Neshat et al. [58] used AHP with Geographic Information System (GIS) to evaluate the susceptibility of decayed areas. Biglarijoo et al. [59] displayed AHP to present $FeCl_2$ as an appropriate catalyst during the Fenton reaction to treat landfill leachates. Martin-Utrillas et al. showed a comparison between the AHP method and Delphi method with an analysis by the method of VIKOR to choose the optimal leachate process treatment in waste treatment [60]. In Figure 3, the UASB + MBR, nZVI + H_2O_2, and persulfate + H_2O_2 methods show better performance in COD removal. According to this figure, oxidation methods, especially in combination with biological methods, can be more effective and useful in removing COD, which can be very profitable. Since the COD parameter is one of the most important parameters in leachate treatment, the chosen method has a high COD removal ability. Also, the selected leachate type is effective in choosing the method because weaker leachates with lower COD can be treated by methods that are in lower ranks; another important parameter in leachate treatment is the cost. Hence, this category should also be considered. Figures 1 and 2 in the Supplementary Materials file show the ranking of the most suitable leachate treatment methods in the benchmark parameter of pH and BOD, respectively. The superior methods in the BOD parameter are nZVI + H_2O_2, electrochemical + UASB, and UASB + MBR, while the SBR + coagulation, SBR + PAC, and SBBGR + UV + H_2O_2 methods showed better performance for the pH parameter. According to Figure 1, biological methods have a higher performance in removing BOD because it is a biological parameter. Also, Figure 2 investigates the significance of pH. According to the figure, the appropriate range for this parameter ranges from six to nine. Because the pH of most leachates is in this range, there is no need to reset the pH for purification, leading to a substantial saving of time and money. Besides, heavy metals are in the form of sediment in this pH range. Therefore, heavy metals can be easily separated when they are soluble in lower and acidic pH ranges. The process of isolating these metals is difficult, time-consuming, and not economically viable during this period. COD decomposition is easier regarding the presence of formed complexes. In contrast, these compounds are not formed at lower pH values, and COD decomposition is more difficult. Hence, this interval seems appropriate for the pH parameter.

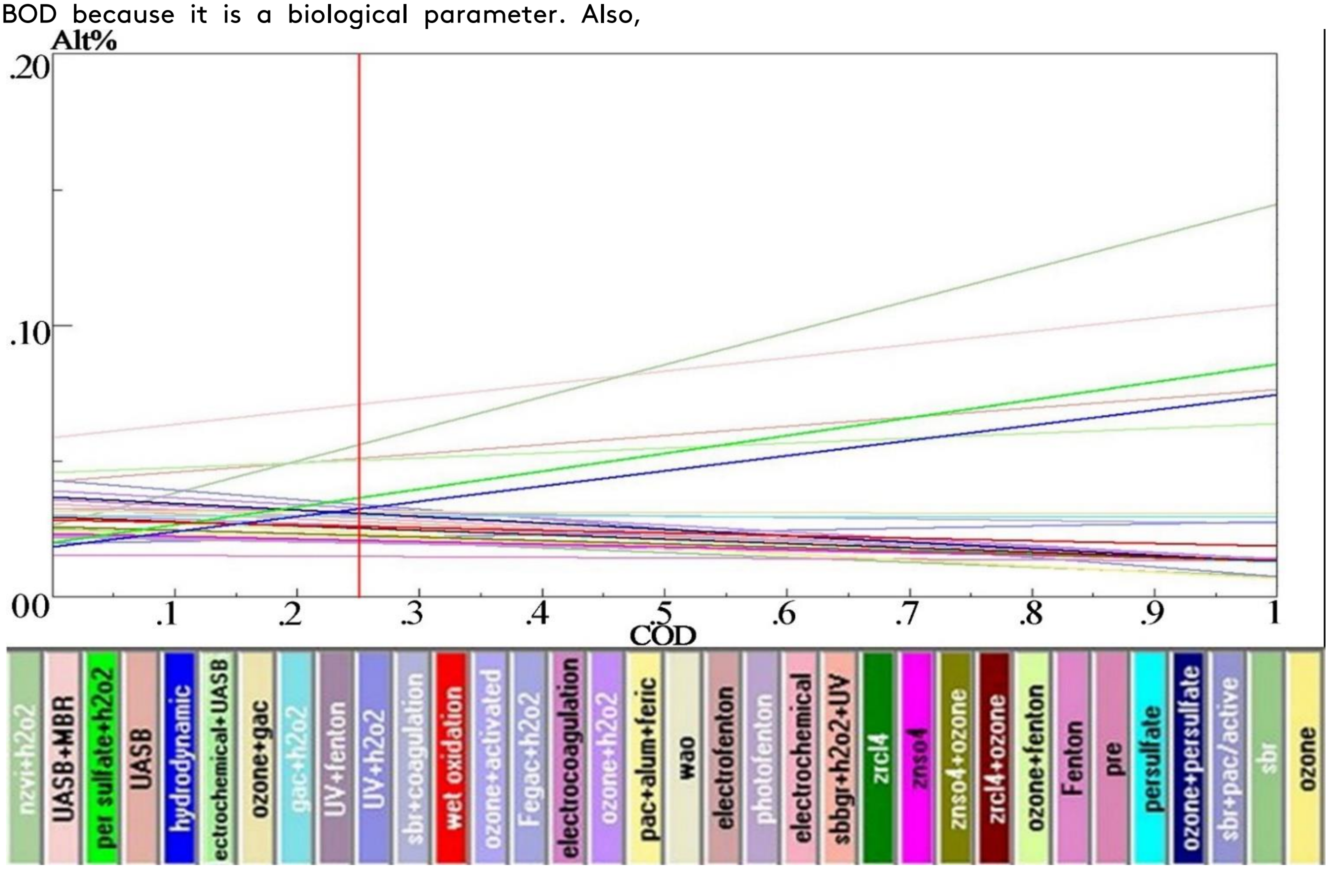

Fig. 3. Ranking of methods based on COD benchmark parameter.

3.2. Two simultaneous benchmark parameters to select appropriate method

Another approach that can facilitate selecting the appropriate method is considering two simultaneous benchmark parameters to measure the method. Thus, the methods which have better performance simultaneously in two benchmark parameters can be easily identified. Since the COD parameter is one of the most important leachate treatment parameters, other parameters can be measured along with this parameter. Figure 4 shows a comparison of the methods in the presence of two COD and BOD parameters simultaneously. It can be found using this diagram that the methods nZVI + H_2O_2, electrochemical + UASB, and UASB + MBR had better performance than the other methods in the simultaneous presence of these two benchmark parameters. Each method can be placed in the upper right-hand part of the diagram among the four parts in these diagrams. It shows a better performance than the other methods because they cover a higher percentage. The COD parameter is in the horizontal direction and the BOD parameter in the vertical direction. The methods that grew in the horizontal axis have a higher performance in removing COD. The methods on the vertical axis have a higher performance to remove BOD. The methods proceed on the y = x-axis. Any method in the upper right-side zone could be considered as a suitable method to be effective in these two parameters (COD and BOD) simultaneously. Figures 3 and 4 in the Supplementary Materials file show the simultaneous diagrams of the COD parameter along with TDS and TOC parameters. The UASB, electrochemical + UASB, and UASB + MBR methods have a higher performance in TOC, while the UASB + MBR, SBR + PAC, and electrochemical methods have a higher performance in TDS.

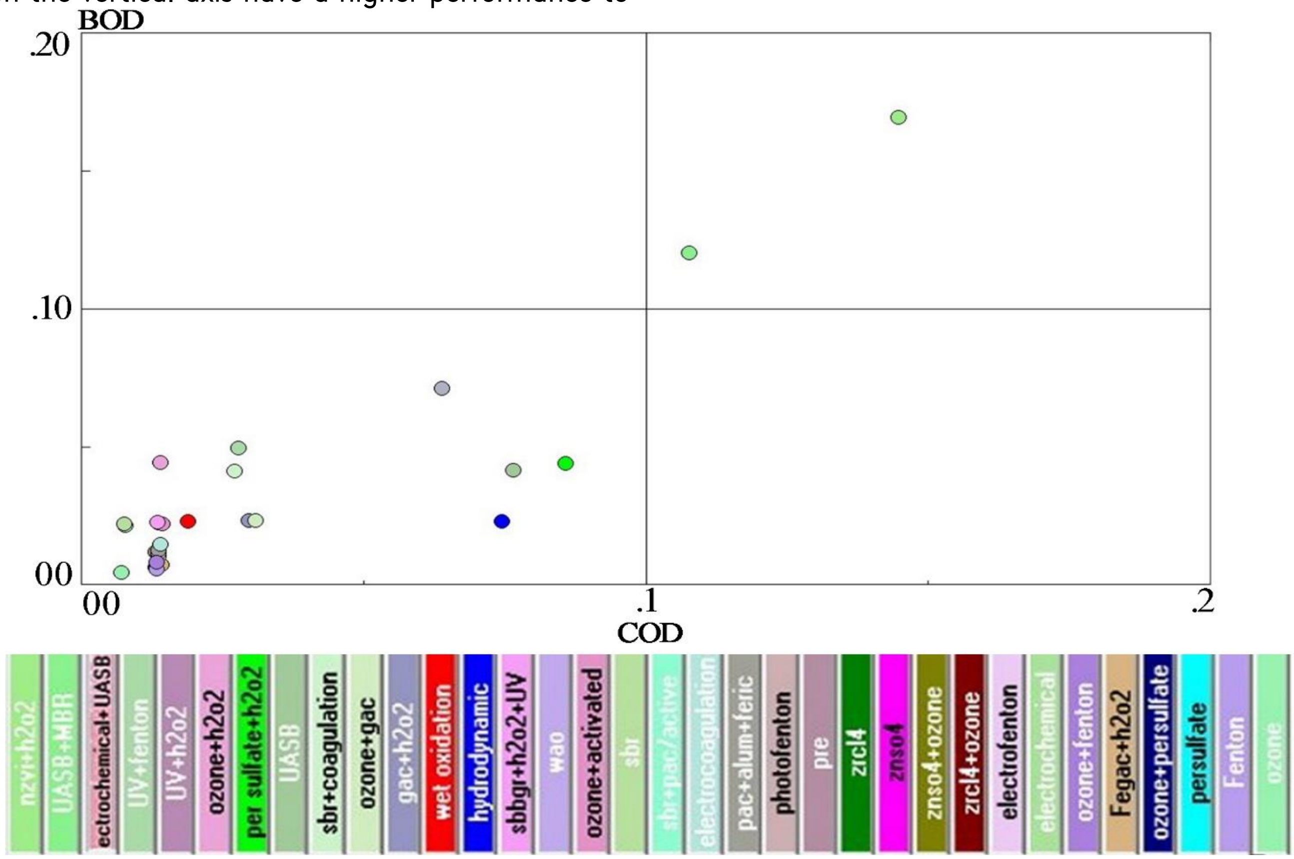

Fig. 4. Simultaneous comparison of methods in the presence of two parameters COD and BOD.

3.3. The effect of time parameter

The research team was commissioned by the sponsoring company to choose a method with the shortest time, highest performance, and lowest cost. However, biological methods may be more cost-effective than many other methods, but their time parameter is very long. It requires a lot of time, but the research team had limited time. Therefore, the results can be divided due to the importance of time or its non-importance. In contrast, the time parameter has no limit to choosing the appropriate treatment method. The biological methods provided the best results in most parameters and in the performance diagram, which includes UASB + MBR UASB, SBR + coagulation, SBR + PAC, electrochemical + UASB. Obtaining accurate information and detailed comparisons among the methods was achieved by using head-to-head diagrams in pairwise comparisons among the methods. These diagrams helped the research team select the most desirable method. These diagrams show the superiority of one method due to each parameter and finally determine a more desirable method by comparing them. Because biological methods outperformed the other methods, they can be regarded as appropriate and efficient if the time parameter is considered a non-important issue. The best method was chosen by comparing the biological methods because they were better than other methods. Head-to-head diagrams help us make a pairwise comparison among biological treatment methods. By comparing different benchmark parameters between the two methods, the software selects the most appropriate method. Figure 5 shows a comparison among the biological methods. Based on these figures, the UASB + MBR method is significantly superior to the other four methods. Since the sponsoring company wanted to purify the leachate as soon as possible, the research team had to limit the time parameter in the next step. Then, a suitable and desirable method was needed to deal with this issue. Since biological methods are too time-consuming, chemical and physical methods with higher performance were examined. For this purpose, the methods with higher performance and gradient diagrams were separated, and pairwise or head-to-head diagrams were used to compare them to find the most suitable ones. The nZVI + H_2O_2 method showed good performance due to the most benchmark parameters. Figure 6 compares this method with the persulfate + H_2O_2 method. In general, nZVI + H_2O_2 shows better performance. Since the nZVI + H_2O_2 method appears very suitable and in many respects shows a significant advantage over other methods, it can be considered a suitable method. However, this method is only a combination of two oxidation methods, and various physical methods are not seen, and this issue should be considered. Furthermore, since the nZVI + H_2O_2 method was more powerful than other methods in many parameters, comparing this method with other methods had no result other than showing its superiority again. Hence, the research team compared other methods with the persulfate + H_2O_2 method, which was much closer to other methods in many parameters. As a result, this proximity in the parameters helped to better compare the remaining methods among themselves. In contrast, if these methods were compared only with the nZVI + H_2O_2 method, the result would not prove anything except the superiority of this method. In this way, other methods were compared and their value measured to select the best method due to the type of leachate and facilities, as well as the costs and experts' viewpoints.

The costs and use of a suitable combined method to continue the work process were considered to ensure that a suitable method was selected; other comparisons were made among the methods, and the research team considered all aspects. Figure 7 presents a comparison between persulfate + H_2O_2 and ozone + H_2O_2, ozone + GAC, and hydrodynamic cavitation methods. According to the figures, the persulfate + H_2O_2 method has a relatively higher performance than the other methods. However, this difference in the performance of methods is not too large compared to the persulfate + H_2O_2 method. It is possible to discuss the costs and the combined method used. Thus, some methods have lower costs than others, and some combined methods use only one scenario and method for treatment. The persulfate + H_2O_2 method is the same type of method in which only using oxidation is discussed, and it is the combination of two chemical methods. The use of physical and chemical methods is suggested for better performance in leachate treatment. At the same time, cost-effectiveness of the used method is very important. Hence, the persulfate + H_2O_2 method may be suitable, and the combination of physicochemical methods is not considered. Therefore, this method was neglected to make a better comparison among the other methods (ozone + H_2O_2 and ozone + GAC) and hydrodynamic cavitation. A pairwise comparison was performed to find the most appropriate method, both financially and due to combining methods.

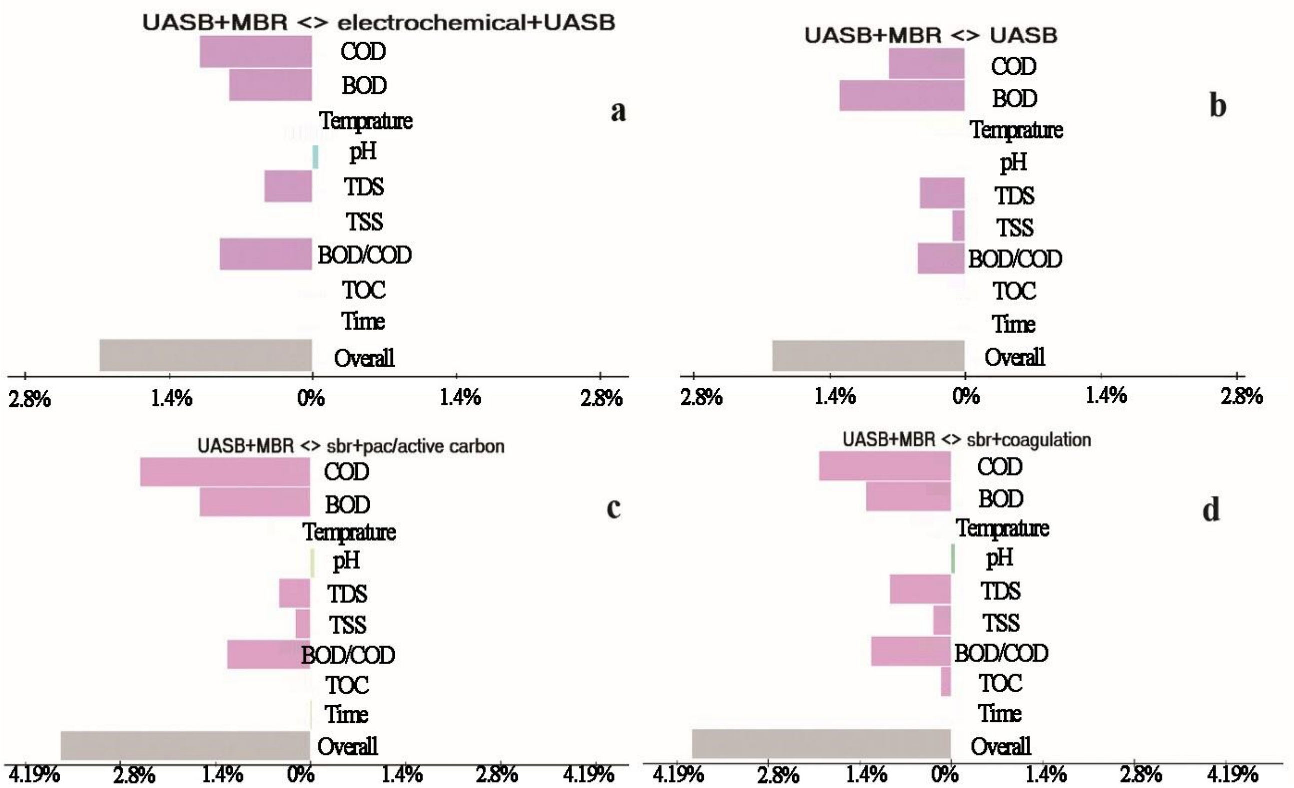

Fig. 5. (a) Comparison between UASB + MBR, electrochemical + UASB methods; although the difference in some parameters is too small, UASB + MBR method shows better results; (b) A pairwise comparison among two biological methods; UASB and UASB + MB are usually more efficient by adding the MBR step; (c) The biological method UASB + MBR was compared with the combined biological method SBR+PAC. Based on the figure, a biological method is superior in many parameters, which is the dominant method; (d) Comparing UASB + MBR method with biological method SBR + coagulation in which a coagulation step was added.

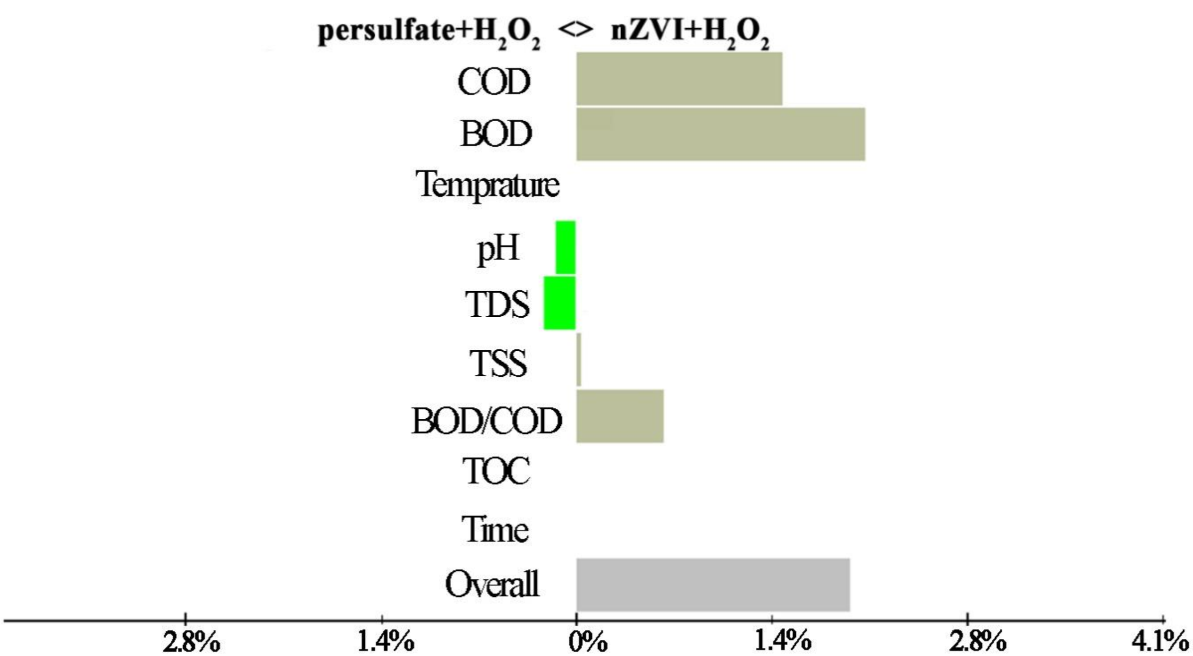

Fig. 6. Comparison between two chemical methods (nZVI + H_2O_2 and persulfate + H_2O_2).

Figure 8 presents a pairwise comparison between H_2O_2 + ozone, ozone + GAC, and hydrodynamic cavitation methods to examine these three methods by considering the financial costs and the combination of methods. As seen in the diagrams, each method is superior to the other in pairwise comparison among the benchmark parameters; these methods generally show identical performance. If one benchmark parameter is of particular importance in the leachate, the appropriate method can be selected using these diagrams. Among these methods, the hydrodynamic cavitation method performs better in removing COD than the other two methods. Hence, we can refer to the diagrams for other parameters. The comparison provided by the software presents almost all three methods for leachate treatment in one place, and the discussion concerning costs and a combination of methods can be considered. Thus, combined ozone methods have low costs and good economic efficiency, while the hydrodynamic cavitation method is relatively expensive compared to the other two methods. Therefore, the H_2O_2 + ozone and ozone + GAC methods can be considered. On the other hand, the H_2O_2 + ozone method is a combination of chemical methods that are only oxidation-based. And the ozone + GAC method creates a combined chemical-physical method by adding the GAC step. Finally, the research team can find the best method with the most desirable condition by considering all the cases.

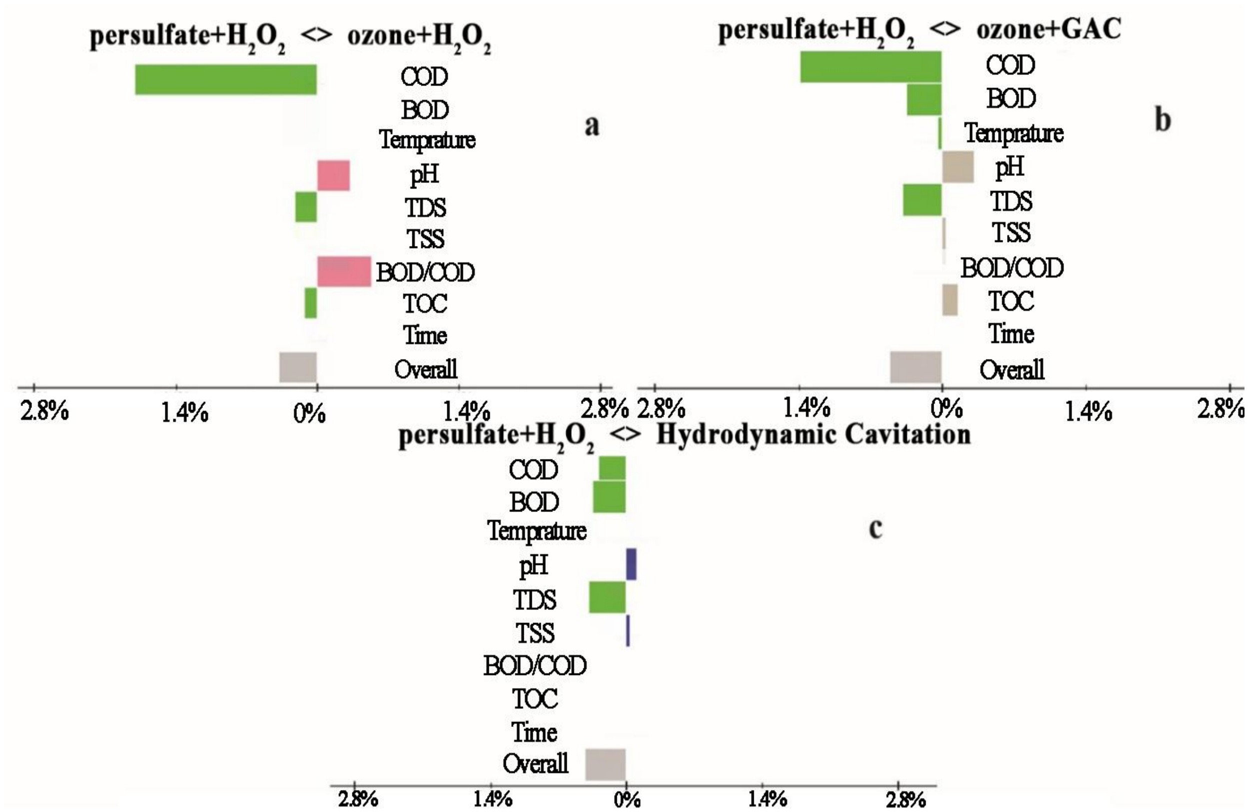

Fig. 7. (a) Comparison between two oxidation methods H_2O_2 + ozone and persulfate + H_2O_2; (b) Comparison between persulfate + H_2O_2 oxidation method and ozone + GAC chemical-physical combined method; and (c) Comparison between methods of hydrodynamic cavitation and persulfate + H_2O_2 .

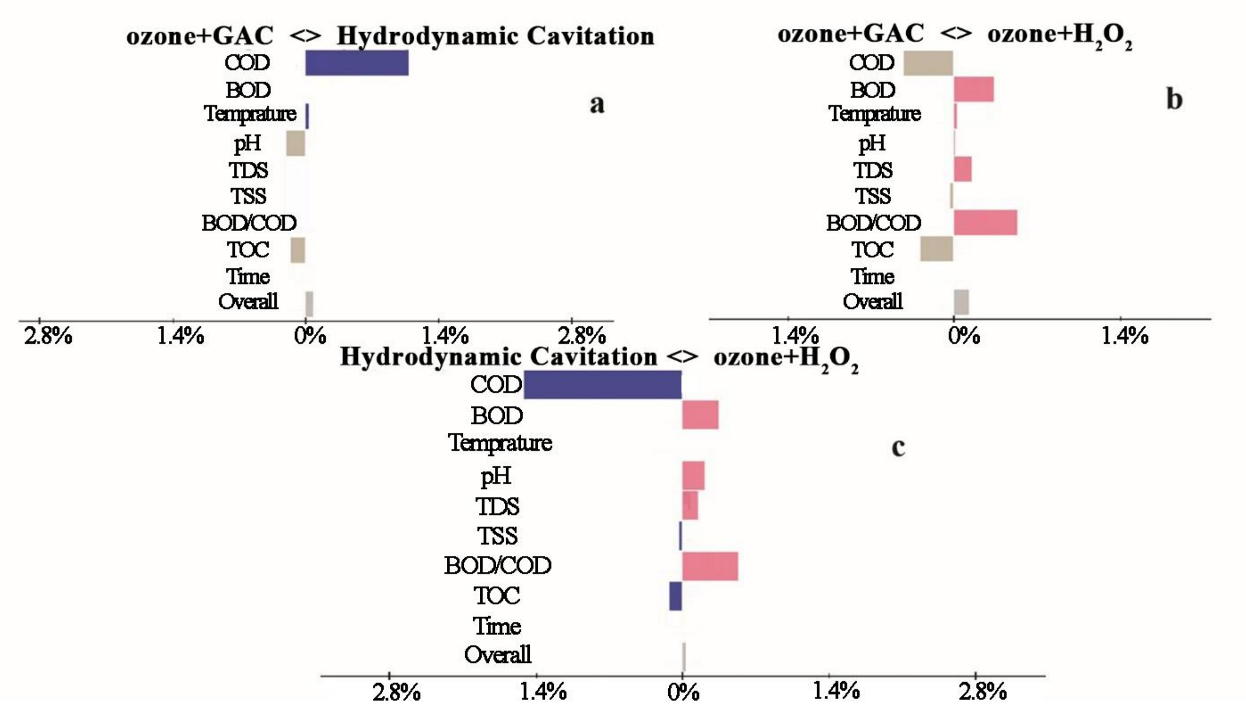

Fig. 8. (a) A pairwise comparison of the combined chemical-physical method of ozone + GAC with the physical and expensive method of hydrodynamic cavitation; the difference is too small, and the financial discussion and combining methods are discussed; (b) Comparing two ozone-based methods that ozone + GAC is chemical-physical, and H_2O_2 + ozone is merely an oxidation-based method; (c) Head-to-head diagram to compare two methods of hydrodynamic cavitation and H_2O_2 + ozone; based on the diagram, the difference between the two methods is very small, the cost becomes substantial.

In Table 1, a comparison between the methods used in AHP indicates the advantages and disadvantages of technologies to show in which situations they can be used for leachate treatment. On the other hand, this comparison table could be another tool to complement the AHP software to select a suitable method for purifying the leachate based on its characteristics. Table 2 shows the boundaries of comparison between the alternatives. It depicts all the methods used in AHP with the boundaries of each alternative (COD, BOD, COD / BOD, temperature, TOC, pH, TDS, TSS, and time), which could help in choosing the appropriate technology according to the leachate parameters.

4. Conclusions

Regarding the importance of leachate in environmental issues, its purification has been among the major challenges for many experts. The organic matter leachate studied in this research is one of the leachates produced in abundance, involving many industries and sectors. Various methods for the treatment of a special type of leachate, namely leachate from fruit and leek fields, were investigated in this research. The AHP method, identified by Expert Choice software, was used to select the best treatment method. First, the benchmark parameters (COD, BOD, COD/BOD), temperature, TOC, pH, TDS, TSS, time) were extracted by experts, and their importance was ranked in the software. Then, by introducing the information of each treatment method previously studied, it was possible to create a way for comparing the treatment methods using benchmark parameters. Since the sponsoring institution requested a faster method, the research team divided the research process into two parts: the significance of the time parameter and its insignificance. The methods can be divided into two groups with the time parameter as a determining factor. Where the time parameter was not important, biological methods showed a better performance than other methods. Since biological methods require a lot of time, the methods that were more prominent in performance and gradient diagrams were examined by pairwise comparison.

And the persulfate + H_2O_2 and nZVI + H_2O_2 methods seemed more appropriate and efficient than other methods. The research team also considered the financial parameters and the combination of methods to select the appropriate method. Thus, the two methods had to be compared to the other three superior methods (H_2O_2 + ozone, ozone + GAC, and hydrodynamic cavitation). The two methods with ozone (ozone + GAC and ozone + H_2O_2) were relatively less expensive than the hydrodynamic cavitation method and the nZVI + H_2O_2, H_2O_2 + ozone, and persulfate + H_2O_2 methods due to a special system, i.e., only chemical oxidations that were not responsive to the combination of physicochemical methods; the ozone + GAC method is responsive to both parameters. Other complement tools besides the AHP software made up a comprehensive package to choose a proper method aligned with the characteristics of the special leachate. Therefore, the ozone+ GAC method was selected due to its higher performance with the range of 7500-8000, 550-700, 90-100, and 8-9 for the parameters of COD, BOD, temperature, and pH, respectively; it is the most aligned method with the studied leachate.

Table 1. Comparison between methods used in AHP.

Method	Advantages	Disadvantages
UASB+MBR	Provides high removal efficiency even at high OLR and low temperature and therefore requires smaller reactor volume [36,37]	A considerable portion of biogas produced may be dissolved in the effluent whose recovery is needed [38,39].
H_2O_2+nZVI	Ability to prevent producing a large amount of sludge in the treatment process [43]	High concentrations of H_2O_2 to achieve acceptable performance are required [43].
UASB	Simple construction and low operation and maintenance cost due to local availability of construction material and other parts [34].	Long startup time is required due to the slow growth rate of microorganisms in case activated sludge is not amply available [35].
UASB+ electrochemical	Ability to withstand organic shock loads [36,40]	In cold regions temperature needs to be maintained within (15–35°C) to achieve steady state performance [41].
H_2O_2+ persulfate	This method does not produce residues or sludge [44]	High amount of persulfate is required that is not financially affordable [44].
SBR+ PAC	Less land requirements due to compact tank construction [44]	Low pathogen removal [45]
H_2O_2+ ozone	-Generation of ozone on-site (no storage-associated dangers) - [46]	Short half-life (ozone) [46]
Hydrodynamic cavitation	Capable of reducing the toxicity and enhancing the mineralization of the wastewater [24]	Low rates of degradation or mineralization when applied individually for the treatment of complex wastewater [49].
GAC+ ozone	Good elimination of color and odor (ozone) Efficient treatment for cyanide and sulfide removal [46]	A few dyes are more resistant to treatment and necessitate high ozone doses [46].
SBR+ Coagulation	Possibility of producing electric energy from biogas [45].	Dependence on some foreign spare parts almost inevitable [45].
Persulfate+ ozone	-Initiates and accelerates azo bond cleavage (hypochlorite treatment) -Increases biodegradability of the product -High throughput -No sludge production -Disinfection (bacteria and viruses) [47]	Pre-treatment indispensable [47]
Electrocoagulation	Adaptation to different pollutant loads and different flow rates (E) [48]	Anode passivation and sludge deposition on the electrodes that can inhibit the electrolytic process in continuous operation [48].
GAC+ H_2O_2	Quality of the outflow (effective destruction of the pollutants and efficient reduction in color) [46]	Efficiency is strongly influenced by the type of oxidant [46]
Method	Advantages	Disadvantages
UV+ Fenton	Highly effective against most viruses, bacteria, spores, and cysts [50]	Ineffective if TSS is too high [50]
UV+ H_2O_2	-Requires shorter contact time than other tertiary wastewater treatment methods - Compact footprint for its disinfection capability [50]	-Low doses can be ineffective against some viruses, spores, and cysts -Photo-Reactivation possible [50].
Wet oxidation	ability to convert the present organic substances to low-molecular, biologically degradable substances [42]	Works at increased temperatures and pressure, which requires high energy input [42].
Ozone+ activated carbon	-Low-cost and easy maintenance -Excellent for removing the color and odor [46]	Short service life [46]
WAO	Ability to improve the degradation capability [42]	Temperature needs to be maintained over 200°C to achieve acceptable performance [42].
Electro-Fenton	-Easy operation -Established technology [51]	Sludge formation [54]
Photo-Fenton	Biodegradability improvement [54]	-Operation in acidic conditions -Requires neutralization of pH [54]

Table 2. Boundaries of comparison between the alternatives.

Method	**COD (mg/l)**	**BOD (mg/l)**	**Temperature (C)**	**pH**	**TDS (mg/l)**	**TSS (mg/l)**	**BOD/COD**	**TOC (mg/l)**	**Time (min)**
Hydrodynamic Cavitation	6000-18000	270_2200	25-40	6.7-7.6	108500	106 na	0.07- 0.13	1600-1700	120-150
Wet Oxidation	1200-6500	100-2400	90-210	5-7.5	751	18	0.08-0.2	225-2484	100-500
Persulfate+H_2O_2 oxidation	19180-20448	830-1821	28	11	25296	120-140	0.043-0.09	-	60_120
$ZrCl_4$+ozone	3125	274	29.2	6	6483	-	0.07-0.34	-	90
$ZnSO_4$+ozone	3200	250-270	28-30	6	6480-6600	-	0.08-0.2	-	
$ZnSO_4$	3200	250-270	28-30	6	6480-6600	-	0.08-0.1	-	60
$ZrCl_4$	3125	274	29.2	6	6483	-	0.07-0.11	-	30
Persulfate	2480	90-100	28	8.5	-	-	0.04-0.12	860	240
O_3+Persulfate	1800-2500	90-100	28	9-10	8150	200-220	0.04-.3	650-1010	210-240
FeGAC+ H_2O_2	1800-4200	95-250	90-100	6_	-	80-1750	0.006-0.09	1050-4000	80-100
GAC+ H_2O_2	7500-8000	500-650	90-100	9-	-	-	0.07-0.08	2200-2600	60
Coagulation+ H_2O_2	1700-2600	-	20-25	4_7	-	180-210	-	-	30
O_3+GAC	7500-8000	550-700	90-100	8_9	-	-	0.07-0.09	2300-2600	30_40
O_3	250-850	10_20	20-22	8_11	-	-	0.05-0.15	280_300	30-60
Electrochemical Oxidation	1600-3000	90-300	60-80	6_9	-	120-200	0.04-0.09	1150_1500	120_360
Fenton	700-2000	40-70	20-25	2.5-3	-	-	0.02-0.05	284-750	120-150
Photo Fenton	1500-3500	200-400	20-25	2.5-3	3900-6800	130-400	0.18-0.3	250-650	60-160
Electro Fenton	1500-3000	150-250	27-31	2.4-4	18910	132	0.1	1347	45-60
WAO	2500-3500	400-500	160-220	4-7	-	-	0.13-0.15	1450	120-150
PAC+ Alum	1500-3500	200-500	25-31	5-7.5	4500-9600	80-380	0.08-0.1	635-831	120-210
O_3+Fenton	1700-2200	70-100	20-21	5-7	-	190-200	0.02-0.12	280-290	90-120
O_3+ H_2O_2	1100-4000	500-2000	22	8-8.7	-	90-100	0.1-0.3	-	30-90
Electrocoagulation	2000-4000	200-500	21-31	6_8	2255	290	0.2-0.3	2200-2600	30-60
UV+ H_2O_2	7700	1300	25	2-4	-	1023	-	-	100-110
UV Fenton	7700	1300	25	2-4	-	1023	0.17-0.2	-	100-110
O_3+Activated Carbon	3000-5200	500-600	20-23	7.5-9	-	-	0.1	-	40
SBBGR+ H_2O_2+UV	2300-2500	400-600	20-25	8-8.5	-	300-350	0.2-0.25	-	360
Method	COD (mg/l)	BOD (mg/l)	Temperature (C)	pH	TDS (mg/l)	TSS (mg/l)	BOD/COD	TOC (mg/l)	Time (min)
SBR + PAC	1655	373	33.6	6-9	-	689	0.218	-	120-1000
SBR+ Coagulation	3530-6420	830-1100	25-26	7-8.5	-	115-220	0.17-0.24	-	1000-1200
nZVI+ H_2O_2	85000	20000	18-19	2.5-6.5			0.34	-	120
SBR	800-1600	250-600	28-29	7		700-900	0.09-0.2	340-800	120-1000
Elechemical oxidation + UASB	4750-15700	2270-2500	37	7.9-8.9	-	-	-	-	360+20days
UASB	4000-17000	500-2000	23-30	6.5-8	-	350-620	0.3-0.45	4600-4800	5-20 days
UASB+ MBR	10000-40000	4000-27000	30	6.5-8	-	685-3440	0.42-0.52	-	30-200 days

GAC: Granular Activated Carbon
WAO: Wet air oxidation
PAC: Powdered Activated Carbon
SBR: Sequencing batch reactor
SBBGR: Sequencing Batch Bio-filter Granular Reactor
nZVI: Nano zero-valent iron
UASB: Upflow anaerobic sludge blanket
MBR: Membrane bioreactor

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