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Developing a multi-criteria decision support system based on fuzzy analytical hierarchical process (AHP) method for selection of appropriate high-strength wastewater treatment plant

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ABSTRACT

The selection of an optimum treatment process for high-strength wastewater is complicated. Familiarity with wastewater treatment methods is not enough to design a plant and requires a multidisciplinary knowledge base. In this research, five alternative wastewater treatment methods for high-strength wastewater were investigated and ranked based on the analytic hierarchy process (AHP) fuzzy method: upflow anaerobic sludge blanket (UASB) + membrane bioreactor (MBR), UASB + extended aeration (EA), anaerobic baffled reactor (ABR), anaerobic lagoon (ANL) + aerated lagoon (AL), and sequencing batch reactor (SBR) + ABR. These treatment methods were ranked based on five criteria, namely energy consumption, effluent total suspended solids (TSS), effluent chemical oxygen demand (COD), cost, and level of technology. The different options of the wastewater treatment plant were rated by expert decision-makers in this field. The results show that for typical high-strength wastewater, the use of an UASB reactor followed by a MBR is the most appropriate alternative for treating the wastewater.

1. Introduction

Nowadays, procuring water resources for different use is a controversial issue around the world. So, reusing treated wastewater and selecting applicable treatment methods are extremely noteworthy. Further, since there are stringent environmental regulations in place, the selection of a treatment system capable of removing and managing high strength wastewater, especially industrial wastewater, is of interest. One of the industries with highly polluted wastewater is the food production and processing industry. Hazrati and Shayegan (2011) suggested installing an up-flow anaerobic sludge blanket (UASB) reactor before the aeration basin to upgrade the activated sludge plants that received extra high-strength wastewater. Most of these activated sludge systems worked at low efficiencies. Further, the high production of excess sludge and unacceptable effluent qualities were the major problems encountered [1]. Hedayati and Sargolzaei (2012) reviewed several methods applied in treating starchy wastewater as high-strength wastewater. They reported that a broad range of methods from activated sludge to modern novel systems, such as membrane technologies, were used to treat this type of wastewater [2]. In another work, they investigated the treatability of starchy wastewater using a sequencing batch reactor (SBR) modified by adding a fixed and moving bed in a novel structure [3]. Wastewater originating from the fish processing industry is another example of high-strength wastewater. Chowdhury et al. (2010) investigated aerobic and anaerobic biological methods applied to treat this type of wastewater [4]. Salminen and Rintala (2002) reported the ability of anaerobic biological digestion in treating the organic solids of slaughterhouse waste [5]. Anaerobic and combined aerobic-anaerobic methods were reported as useful treatments of dairy wastewater [6-8]. Further, there are works that assessed the treatment of dairy wastewater with novel methods such as microbial fuel cells [9]. Liu et al. (2018) applied a CeO_2/Co_3O_4 coated mesh for the treatment

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of food wastewater [10]. It is clear that anaerobic-aerobic combination systems are appropriate for high strength wastewater. Process engineers usually select one of these methods or a combination of them for the treatment of wastewater according to the defined restrictions. Generally, environmental decision making is complex due to the multiple criteria involved in [11]. The selection of an optimized wastewater treatment process is complex. Familiarity with wastewater treatment methods is not enough to design a plant. In other words, the selection, design, construction, and operation of a wastewater treatment plant require a multidisciplinary knowledge base. Different parameters influence the selection of the wastewater treatment process: quality and quantity of wastewater, developing plans, environmental protection indexes, usage of treated wastewater, amount of needed ground surface, level of technology in the region, availability of labor work, weather conditions, etc. For example, designing and constructing a wastewater treatment plant in a city with a high technology level is different from an outland region. As another example, the selection of a lagoon as the location for the treatment process in a humid region is of interest due to the low evaporation rate, but it is unsuitable for a city in the desert with a water shortage and annual evaporation of more than 4 meters. Therefore, developing an algorithm that introduces an optimized selection that considers the effective parameters on the selection of the correct process and its effect on each one is necessary. Different parameters influence the alternative selection: cost, level of technology, etc. Each of these indexes has different weights, or their effective coefficients are not the same for different conditions. So, the weight of each index should first be determined. Then, a plant with optimum performance can be designed via decision-making algorithms. The fuzzy set theory, combined with the analytic hierarchy process (AHP), can be applied to select the optimum wastewater treatment process.

The benefits of the AHP method over multi-attribute decision algorithms are as follows [12]:

- Considers both qualitative and quantitative information
- Provides an atmosphere to incorporate the subjectivity, experience, and knowledge of the expert
- Computes the weights of each criterion and each alternative

Kalbar et al. (2012) used a scenario-based multiple attribute decision-making (MADM) technique to rank the wastewater treatment plant alternatives. In their works, the common systems of wastewater treatment were ranked in six scenarios. Finally, they select the appropriate alternative for each scenario [13]. Abrishamchi et al. (2005) applied the multi-criteria decision analysis (MCDA) method for the selection of an optimized water distribution system of available and transmitted water in the city of Zahedan, Iran [14]. Karimi et al. (2011) investigated and ranked the anaerobic wastewater treatment systems in the industrial estates of Iran using fuzzy AHP and order preference by similarity to ideal solution (TOPSIS). They ranked the alternatives processes according to the technical, economic, environmental, and administrative criteria [15]. In another study, Karimi et al. (2011) applied this method to select an optimized aerobic wastewater treatment plant [16]. AHP and grey relation analysis (GRA) were used for the optimal selection of full-scale tannery wastewater treatment plants based on economic, technical, and administrative factors in India [17]. In this research, five alternative combined systems for high-strength wastewater treatment were assessed: UASB + membrane bioreactor (MBR), UASB + extended aeration (EA), anaerobic baffled reactor (ABR), anaerobic lagoon (ANL) + aerated lagoon (AL), and sequencing batch reactor (SBR) + ABR). They were ranked according to five criteria (energy consumption, effluent TSS, effluent COD, cost, and level of technology). The method used to assess the applicability of different treatment systems was a fuzzy logic-based AHP. Any hybrid treatment system assessed in these methods leads to a fuzzy set. The result of the analysis should be defuzzified. Finally, the investigated alternative hybrid systems could be ranked in order of the importance of the defined criteria. So, this work aimed to develop a decision support system based on AHP, the assessment of different methods for treating high strength wastewater, and the selection of optimized wastewater treatment process for this type of wastewater.

2. Methodological approach

2.1. Problem description

Process engineers encounter uncertain situations in selecting the appropriate single or combined methods in treating high-strength wastewater. Each method has drawbacks and benefits over the other treatment methods. Further, there are several criteria that must be considered in treating this wastewater. Considering these criteria, as well as the properties of each treating method, creates a vague environment for decision-making. In this situation, the expert's thoughts and subjective perception will be expressed instead of precise data. By using AHP as a decision-making algorithm, the judgment of the individuals will be quantified. So, the process selection will be done according to the statistics and quantitative data.

2.2. Theory

2.2.1. Fuzzy set theory

Fuzzy logic has been applied in different fields of science and technology, but the most important application of this technique is in control systems. Fuzzy logic was approved as a useful method in data clustering. A fuzzy set $\tilde{A}$ is defined as follows:

$\tilde{A}=(l,m,u)$ (1)

2.2.2. Fuzzy AHP

The fuzzy AHP method is comprised of the following steps:
(I) Determination of criteria and alternatives
(II) Determination of linguistic scale (fuzzy number) of the weights of criteria
(III) Pairwise comparison of the criteria and alternatives
According to Chang's method, m extent analysis for each criteria and alternative could be obtained by the following signs [18]:

$$M^1_{\mathrm{Ci\ or\ Ai}}, M^2_{\mathrm{Ci\ or\ Ai}}, \ldots, M^m_{\mathrm{Ci\ or\ Ai}}$$

where C_i and A_i are the ith criteria and alternative, respectively.
(IV) Calculation the synthetic extent and priority of each criteria he fuzzy synthetic extent of ith criteria or ith alternative after pairwise comparison could be determined by the following equation:

$$\mathrm{T}S_i = \sum_{j=1}^{n}\left(M^j_{Ci\ or\ Ai} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M^j_{Ci\ or\ Ai}\right]^{-1}\right) \quad (2)$$

where i = (1,2,…,n), j = (1,2,…,m), M^j_{Ci} is the value of extent analysis of the ith criteria or ith alternative, and n is the number of criteria or alternatives. $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M^j_{\mathrm{Ci\ or\ Ai}}\right]^{-1}$ would be obtained as follows:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M^j_{\mathrm{Ci\ or\ Ai}}\right]^{-1} = \left[\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right] \quad (3)$$

Assuming $S_i = (l_i,m_i,u_i)$ and $S_j = (l_j,m_j,u_j)$, the degree of possibility of ($S_i \geq S_j$) could be defined as follows:

$$V(Si \geq Sj) = \mathrm{hgt}\,(Sj \cap Si) = \mu_{Si}(d) \quad (4)$$

$$\mu_{S_i}(d) = \begin{cases} 1 & m_i \geq m_j \\ 0 & l_j \geq u_i \\ \dfrac{l_j - u_i}{(m_i - u_i) - (m_j - l_j)} & \text{else} \end{cases} \quad (5)$$

where d is the highest intersection point between these two membership functions (μ_{Si} and μ_{Sj}).
(V) Determination of the final weight of each criteria and consequent normalization.
The weight vector is defined as follows:

$$W' = (d'(C_1), d'(C_2), \ldots, d'(C_k))^T \quad (6)$$

where d is the highest intersection point between these two membership functions (μ_{Si} and μ_{Sj}).
(V) Determination of the final weight of each criteria and consequent normalization
The weight vector is defined as follows:

$$W' = (d'(C_1), d'(C_2), \ldots, d'(C_k))^T \quad (7)$$

where this value must be normalized.
(VI) Pairwise comparison of the alternative.
In this step, similar methods used for criteria comparison would be applied.
(VII) Comparison and rating the alternatives.
Finally, the outranking of alternatives would be computed using global performance (GP). The GP of each alternative would be determined as follows:

$$\mathrm{GP}(A_i) = d'\left(A_{i_{C1}}\right) \times d'(C_1) + d'\left(A_{i_{C2}}\right) \times d'(C_2) + \cdots + d'\left(A_{i_{Cj}}\right) \times d'(C_j) \quad (8)$$

where $d'\left(A_{i_{Cj}}\right)$ is the weight of i^th^ alternative for j^th^ criterion.

2.3. Alternatives

2.3.1. Upflow anaerobic sludge blanket

UASB is an anaerobic bioreactor designed to treat high-strength industrial wastewater. In UASB technology, the balance between the forces from the upflow stream and gravity causes the suspension of granular sludge. Accordingly, only the dense flocculated granules can survive, and light sludge is being washed out. So, preparing the appropriate conditions in the operation period is the critical factor in selecting this reactor.

2.3.2. Anaerobic baffled reactor

ABR can be considered as a series of UASBs without the formation of granular sludge. In this reactor, acidogenisis and methanogenisis phases have been separated, which makes the reactor resistant against the unfavorable conditions and the presence of toxic materials in the inlet wastewater.

2.3.3. Activated sludge

The activated sludge process consists of (I) an aeration reactor to convert organic compounds to simpler ones such as CO_2 and (II) a sedimentation tank in which the biomass is settled and removed. Improper sedimentation leads to effluent with low quality that contains a high concentration of suspended solids. Extended aeration is an activated sludge process with longer hydraulic retention time and less waste sludge.

2.3.4. Membrane bioreactor

A membrane bioreactor (MBR) is a modified activated sludge process. In this treatment system, the sedimentation tank is replaced by a membrane filtration module. Accordingly, the problems related to improper sludge sedimentation will be solved.

2.3.5. Sequencing batch reactor

A sequencing batch reactor (SBR) is another type of activated sludge process in which aeration and sedimentation take place in one reactor.

2.3.6. Aerobic and anaerobic lagoon

Aerated and anaerobic lagoons are treatment ponds in which biological treatment occurs through aerobic and anaerobic microbial activity, respectively.

2.4. Application case

In this study, two expert decision-makers rated the different options of the wastewater treatment plant. Five arrangements of bioreactors as alternatives were determined as follows:

A_1: Upflow anaerobic sludge blanket (UASB) + membrane bioreactor (MBR)

A_2: UASB + extended aeration (EA)

A_3: Anaerobic baffled reactor (ABR)

A_4: Anaerobic lagoon (ANL) + aerated lagoon (AL)

A_5: Sequencing batch reactor (SBR) + ABR

The criteria defined by the expert decision-makers are as follows:

C_1 (Energy consumption): This criterion is related to the amount of energy consumption of the units during the treatment process.

C_2 (Effluent COD): This criterion shows the amount of organic matters in the effluent stream.

C_3 (Effluent TSS): This criterion is an index of the amount of suspended solids in the effluent stream.

C_4 (Cost): This criteria is related to the amount of capital and maintenance cost.

C_5 (Level of Technology): This criteria is an index of the level of technology that is needed to construct the units.

3. Results and discussion

The fuzzy AHP was applied to select the optimized option in this case, as noted below.

The fuzzy triangular numbers that correspond to each linguistic value are shown in Table 1.

Table 1. Fuzzy number assigned to the linguistic expression of weights of criteria and alternatives.

Linguistic expression	Triangular fuzzy number	
Absolutely preferable (AP)	(5,7,9)	(0.11,0.14,0.2)
Extremely preferable (EP)	(3,5,7)	(0.14,0.2,0.33)
Fairly preferable (FP)	(1,3,5)	(0.2,0.33,1)
Slightly preferable (SP)	(1,1,3)	(0.33,1,1)
Equally preferable (EQ)	(1,1,1)	(1,1,1)

In Table 2, the fuzzy evaluation matrix of the pairwise comparison of the criteria constructed by two decision makers is shown.

Table 2. The evaluation matrix of pairwise comparison of criterion.

	C_1 (Energy consumption)	C_2 (Effluent COD)	C_3 (Effluent TSS)	C_4 (Cost)	C_5 (Level of Technology)
DM1					
C_1 (Energy consumption)	(1,1,1)	(0.11,0.14,0.2)	(0.11,0.14,0.2)	(1,3,5)	(1,3,5)
C_2 (Effluent COD)	(5,7,9)	(1,1,1)	(3,5,7)	(5,7,9)	(5,7,9)
C_3 (Effluent TSS)	(5,7,9)	(0.14,0.2,0.33)	(1,1,1)	(3,5,7)	(3,5,7)
C_4 (Cost)	(0.2,0.33,1)	(0.11,0.14,0.2)	(0.14,0.2,0.33)	(1,1,1)	(1,1,3)
C_5 (Level of Technology)	(0.2,0.33,1)	(0.11,0.14,0.2)	(0.14,0.2,0.33)	(0.33,1,1)	(1,1,1)
DM2					
C_1 (Energy consumption)	(1,1,1)	(0.2,0.33,1)	(0.2,0.33,1)	(1,1,1)	(1,3,5)
C_2 (Effluent COD)	(1,3,5)	(1,1,1)	(1,1,3)	(3,5,7)	(5,7,9)
C_3 (Effluent TSS)	(1,3,5)	(0.33,1,1)	(1,1,1)	(3,5,7)	(3,5,7)
C_4 (Cost)	(1,1,1)	(0.14,0.2,0.33)	(0.14,0.2,0.33)	(1,1,1)	(1,1,1)
C_5 (Level of Technology)	(0.2,0.33,1)	(0.11,0.14,0.2)	(0.14,0.2,0.33)	(1,1,1)	(1,1,1)

Table 3. Mean fuzzy number of pairwise comparison of the criterion.

	C_1 (Energy consumption)	C_2 (Effluent COD)	C_3 (Effluent TSS)	C_4 (Cost)	C_5 (Level of Technology)
C_1 (Energy consumption)	(1,1,1)	(0.16,0.24,0.6)	(0.16,0.24,0.6)	(1,2,3)	(1,3,5)
C_2 (Effluent COD)	(3,5,7)	(1,1,1)	(2,3,5)	(4,6,8)	(5,7,9)
C_3 (Effluent TSS)	(3,5,7)	(0.24,0.6,0.67)	(1,1,1)	(3,5,7)	(3,5,7)
C_4 (Cost)	(0.6,0.67,1)	(0.13,0.17,0.27)	(0.14,0.2,0.33)	(1,1,1)	(1,1,2)
C_5 (Level of Technology)	(0.2,0.33,1)	(0.11,0.14,0.2)	(0.14,0.2,0.33)	(0.67,1,1)	(1,1,1)

Table 4. Mean fuzzy number of pairwise comparison of the alternatives for energy consumption (C_1).

	A_1	**A_2**	**A_3**	**A_4**	**A_5**
A_1	(1,1,1)	(1,1,1)	(0.13,0.17,0.27)	(1,1,2)	(0.33,1,1)
A_2	(1,1,1)	(1,1,1)	(0.14,0.2,0.33)	(1,2,3)	(0.33,1,1)
A_3	(4,6,8)	(3,5,7)	(1,1,1)	(4,6,8)	(3,5,7)
A_4	(0.67,1,1)	(0.6,0.67,1)	(0.13,0.17,0.27)	(1,1,1)	(0.2,0.33,1)
A_5	(1,1,3)	(1,1,3)	(0.14,0.2,0.33)	(1,3,5)	(1,1,1)

Table 5. Mean fuzzy number of pairwise comparison of the alternatives for COD removal (C_2).

	A_1	**A_2**	**A_3**	**A_4**	**A_5**
A_1	(1,1,1)	(3,5,7)	(5,7,9)	(4,6,8)	(3,5,7)
A_2	(0.14,0.2,0.33)	(1,1,1)	(2,4,6)	(1,3,5)	(1,1,1)
A_3	(0.11,0.14,0.2)	(0.17,0.27,0.67)	(1,1,1)	(0.27,0.67,1)	(0.13,0.17,0.27)
A_4	(0.13,0.17,0.27)	(0.2,0.33,1)	(1,2,4)	(1,1,1)	(0.6,0.67,1)
A_5	(0.14,0.2,0.33)	(1,1,1)	(4,6,8)	(1,2,3)	(1,1,1)

Table 6. Mean fuzzy number of pairwise comparison of the alternatives for TSS removal (C3).

	A_1	**A_2**	**A_3**	**A_4**	**A_5**
A_1	(1,1,1)	(3,5,7)	(5,7,9)	(4,6,8)	(2,4,6)
A_2	(0.14,0.2,0.33)	(1,1,1)	(4,6,8)	(1,2,4)	(1,1,1)
A_3	(0.11,0.14,0.2)	(0.13,0.17,0.27)	(1,1,1)	(0.17,0.27,0.67)	(0.13,0.17,0.27)
A_4	(0.13,0.17,0.27)	(0.27,0.67,1)	(2,4,6)	(1,1,1)	(1,1,1)
A_5	(0.17,0.27,0.67)	(1,1,1)	(4,6,8)	(1,1,1)	(1,1,1)

Table 7. Mean fuzzy number of pairwise comparison of the alternatives for cost (C4).

	A_1	**A_2**	**A_3**	**A_4**	**A_5**
A_1	(1,1,1)	(0.14,0.2,0.33)	(0.14,0.2,0.33)	(0.11,0.14,0.2)	(0.14,0.2,0.33)
A_2	(3,5,7)	(1,1,1)	(0.2,0.33,1)	(0.14,0.2,0.33)	(1,1,1)
A_3	(3,5,7)	(1,3,5)	(1,1,1)	(0.57,0.6,0.67)	(3,5,7)
A_4	(5,7,9)	(3,5,7)	(2,3,4)	(1,1,1)	(4,6,8)
A_5	(3,5,7)	(1,1,1)	(0.14,0.2,0.33)	(0.13,0.17,0.27)	(1,1,1)

Table 8. Mean fuzzy number of pairwise comparison of the alternatives for level of technology (C5).

	A_1	**A_2**	**A_3**	**A_4**	**A_5**
A_1	(1,1,1)	(0.14,0.2,0.33)	(0.14,0.2,0.33)	(0.11,0.14,0.2)	(0.17,0.27,0.67)
A_2	(3,5,7)	(1,1,1)	(0.6,0.67,1)	(0.17,0.27,0.67)	(1,1,2)
A_3	(3,5,7)	(1,2,3)	(1,1,1)	(0.14,0.2,0.33)	(2,3,5)
A_4	(5,7,9)	(2,4,6)	(3,5,7)	(1,1,1)	(3,5,7)
A_5	(2,4,6)	(0.67,1,1)	(0.24,0.6,0.67)	(0.14,0.2,0.33)	(1,1,1)

The mean fuzzy values of the two decision-makers are shown in Table 3. Tables 4-9, like the criteria comparison, show the mean fuzzy values of the pairwise comparison of the alternative reactor layouts for each criterion.

The values of the fuzzy synthetic extent for the criteria are as follows:

$$S_{C_1} = \left((1,1,1) \oplus (0.16,0.24,0.6) \oplus (0.16,0.24,0.6) \oplus (1,2,3) \oplus (1,3,5)\right) \otimes \begin{bmatrix} \left((1,1,1) \oplus (0.16,0.24,0.6) \oplus (0.16,0.24,0.6) \oplus (1,2,3) \oplus (1,3,5)\right) \oplus \\ ((3,5,7) \oplus (1,1,1) \oplus (2,3,5) \oplus (4,6,8) \oplus (5,7,9)) \oplus \\ \left((3,5,7) \oplus (0.24,0.6,0.67) \oplus (1,1,1) \oplus (3,5,7) \oplus (3,5,7)\right) \oplus \\ \left((0.6,0.67,1) \oplus (0.13,0.17,0.27) \oplus (0.14,0.2,0.33) \oplus (1,1,1) \oplus (1,1,2)\right) \oplus \\ ((0.2,0.33,1) \oplus (0.11,0.14,0.2) \oplus (0.14,0.2,0.33) \oplus (0.67,1,1) \oplus (1,1,1)) \end{bmatrix}$$

$$S_{C_1} = (0.0468,0.1276,0.3040)$$
$$S_{C_2} = (0.2113,0.4332,0.8942)$$
$$S_{C_3} = (0.1442,0.3268,0.6757)$$
$$S_{C_4} = (0.0404,0.0599,0.1371)$$
$$S_{C_5} = (0.0299,0.0526,0.1052)$$

According to Equation 1, the degree of possibility will be calculated as follows:

$$V(S_{C_1} \geq S_{C_2}) = 0.2329$$
$$V(S_{C_2} \geq S_{C_1}) = 1$$
$$V(S_{C_1} \geq S_{C_3}) = 0.4451$$
$$V(S_{C_3} \geq S_{C_1}) = 1$$
$$V(S_{C_1} \geq S_{C_4}) = 1$$
$$V(S_{C_4} \geq S_{C_1}) = 0.5715$$
$$V(S_{C_1} \geq S_{C_5}) = 1$$
$$V(S_{C_5} \geq S_{C_1}) = 0.43$$
$$V(S_{C_2} \geq S_{C_3}) = 1$$
$$V(S_{C_3} \geq S_{C_2}) = 0.83$$
$$V(S_{C_2} \geq S_{C_4}) = 1$$
$$V(S_{C_4} \geq S_{C_2}) = 0$$
$$V(S_{C_2} \geq S_{C_5}) = 1$$

$\mathrm{V}(\mathrm{S}_{\mathrm{C}_5} \geq \mathrm{S}_{\mathrm{C}_2}) = 0$
$\mathrm{V}(\mathrm{S}_{\mathrm{C}_3} \geq \mathrm{S}_{\mathrm{C}_4}) = 1$
$\mathrm{V}(\mathrm{S}_{\mathrm{C}_4} \geq \mathrm{S}_{\mathrm{C}_3}) = 0$
$\mathrm{V}(\mathrm{S}_{\mathrm{C}_3} \geq \mathrm{S}_{\mathrm{C}_5}) = 1$
$\mathrm{V}(\mathrm{S}_{\mathrm{C}_5} \geq \mathrm{S}_{\mathrm{C}_3}) = 0$
$\mathrm{V}(\mathrm{S}_{\mathrm{C}_4} \geq \mathrm{S}_{\mathrm{C}_5}) = 1$
$\mathrm{V}(\mathrm{S}_{\mathrm{C}_5} \geq \mathrm{S}_{\mathrm{C}_4}) = 0.88$

The weight factor will be defined according to Equation 3 as follows:

$$\mathrm{d}'(\mathrm{C}_1) = \mathrm{V}(\mathrm{S}_{\mathrm{C}_1} \geq \mathrm{S}_{\mathrm{C}_2}, \mathrm{S}_{\mathrm{C}_1} \geq \mathrm{S}_{\mathrm{C}_3}, \mathrm{S}_{\mathrm{C}_1} \geq \mathrm{S}_{\mathrm{C}_4}, \mathrm{S}_{\mathrm{C}_1} \geq \mathrm{S}_{\mathrm{C}_5}) = \min(0.23, 0.44, 1, 1) = 0.23$$

$$\mathrm{d}'(\mathrm{C}_2) = \min(1,1,1,1) = 1$$
$$\mathrm{d}'(\mathrm{C}_3) = \min(1,0.83,1,1) = 0.83$$
$$\mathrm{d}'(\mathrm{C}_4) = \min(0.56,0,0,1) = 0$$
$$\mathrm{d}'(\mathrm{C}_5) = \min(0.43,0,0,0.88) = 0$$
$$\mathrm{w}' = (0.23,1,0.83,0,0)$$

The normalized weight factor of the criteria (w) is as follows:

$$w = (0.11,0.49,0.40,0,0)$$

So, the effluent TSS (C3) is the most important criterion in selecting the wastewater treatment method.

Table 9. Weight factors of alternatives.

	A_1	A_2	A_3	A_4	A_5
C_1	0	0	1	0	0.3051
C_2	1	0.3689	0	0	0.3853
C_3	1	0.4287	0	0.1235	0.2953
C_4	0	0.2281	0.7269	1	0.1789
C_5	0	0.3579	0.5808	1	0.1979

Similar to the method used for the determination of the criteria weight factor, the normalized weight factors of the alternatives for each criterion were calculated and are shown in Eq. 7.

Table 10. Normalized weight factors of alternatives.

	A_1	A_2	A_3	A_4	A_5
C_1	0	0	0.7662	0	0.2338
C_2	0.5701	0.2103	0	0	0.2197
C_3	0.5413	0.2321	0	0.0668	0.1598
C_4	0	0.1069	0.3406	0.4686	0.0839
C_5	0	0.1675	0.2718	0.4680	0.0926

For each alternative, the global performance (GP) has been computed by Eq. 7.

Figure 1 shows the outranking of alternatives according to the weights of all the criteria. There are two types of outranking. In series 1, the weights of all the criteria were assumed to be equal. Accordingly, the outranking of alternatives is $A_2>A_5>A_1>A_4>A_3$. But in series 2, the outranking of criteria was considered and the resulted outranking is $A_1>A_2>A_5>A_3>A_4$.

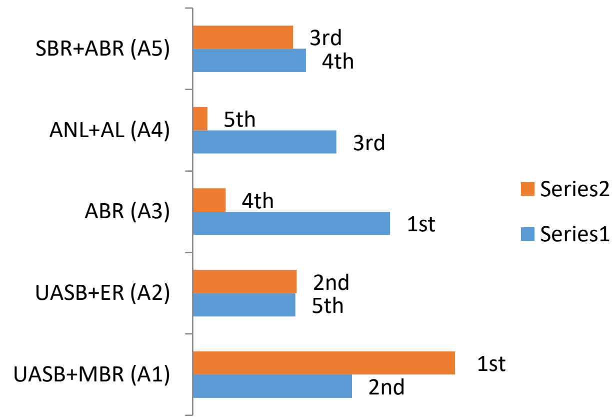

Fig. 1. Outranking of alternatives.

Accordingly, it is clear that using an UASB followed by a MBR is the best alternative to treating high load wastewater.

4. Conclusions

In this research, five alternative methods for high strength wastewater were investigated: upflow anaerobic sludge blanket (UASB) + membrane bioreactor (MBR), UASB + extended aeration (EA), anaerobic baffled reactor (ABR), anaerobic lagoon (ANL) + aerated lagoon (AL), and sequencing batch reactor (SBR) + ABR). They were ranked based on the analytic hierarchy process (AHP) fuzzy method. These alternative methods were investigated based on five criteria, namely energy consumption, effluent TSS, effluent COD, cost, and level of technology. The results showed that using an UASB followed by a MBR is the most appropriate process for treating high-strength wastewater.

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