WASTEWATER TREATMENT PROCESS IN INDUSTRIAL ESTATES BASED ON FUZZY TOPSIS METHOD AS SUPPLY CHAIN SYSTEM

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ABSTRACT

This paper investigates different anaerobic and aerobic wastewater treatment processes operated in Iranian industrial estates. These processes are upflow anaerobic sludge blanket (UASB), upflow anaerobic fix-bed reactor (UAFB), anaerobic baffled reactor (ABR), contact process, and anaerobic lagoon as anaerobic processes and extended aeration, absorption bio-oxidation (A/B), integrated fixed-film activated sludge (IFAS), sequencing batch reactor (SBR) and aerated lagoon as aerobic processes. Then, the most appropriate treatment process is selected by the use of the fuzzy technique for order preference by similarity to ideal solution (FTOPSIS) as a well-known tool in multi-criteria decision making (MCDM). Based on general condition in industrial estate's wastewater treatment plants, technical, economic, environmental, and administrative criteria are weighted and then criteria evaluation and priorities of alternatives has been down by fuzzy TOPSIS method by use of triangular fuzzy numbers. Finally, five anaerobic and aerobic processes are ranked 1 to 5 in order of UAFB, ABR, Contact Process, UASB and Anaerobic Lagoon as anaerobic and IFAS, extended aeration, SBR, aerated lagoon and A/B as aerobic processes, respectively.

KEYWORDS
Wastewater, Treatment, Industrial Estates

INTRODUCTION

Appropriate treatment process selection is one of the most important issues before design and implementation of each wastewater treatment plant (WWTP). According to quantity diversity of industrial wastewater and local condition of effluent sources, it is impossible to use general criteria in treatment process selection. But some points are available in process selection which is applied for almost all kinds of industrial wastewater to achieve the prior treatment process. Designers should consider both quantitative and qualitative criteria very well (Balkema *et al*. 2002, Gratziou 2003, Metcalf & Eddy 2003). Therefore, multi criteria decision methods (MCDM) will be useful particularly. Some multi criteria decision methods such as analysis hierarchical process (AHP), TOPSIS method, fuzzy analysis hierarchical process and fuzzy TOPSIS method have presented yet.

The fuzzy TOPSIS is the fuzzy extension of TOPSIS to efficiently handle the fuzziness of the data involved in the decision making. It is easy to understand and it can effectively handle both qualitative and quantitative data in the multi attribute decision making (MADM) problems. Fuzzy TOPSIS method has been used in this paper due to ambiguity of data.

There are many applications of fuzzy TOPSIS in the literature. For instance, Chu presented a fuzzy TOPSIS method under group decisions for solving the facility location selection problem (Chu, 2002). Chen et al. presented a fuzzy TOPSIS approach to deal with the supplier selection problem in supply chain system (Chen, 2006). Yang and Hung proposed to use TOPSIS and fuzzy TOPSIS methods for plant layout design problem (Yang, 2007).

MATERIALS AND METHODS

In order to anaerobic treatment processes introduction and considering of processes efficiency in industrial estates, field study has carried out. Data analysis and related questionnaires used for processes efficiency determination. Process selection criteria have been issued on the basis of objectivity in industrial estates and fuzzy TOPSIS method specified for processes assessment.

Anaerobic and Aerobic Treatment Alternatives

In this paper, five anaerobic and five aerobic treatment processes which are operating in Iran's industrial estates have been considered as bellow: upflow anaerobic sludge blanket method (UASB), upflow anaerobic fixed bed reactor (UAFB), anaerobic baffled reactors (ABR), contact anaerobic process and anaerobic lagoons as anaerobic processes and extended aeration, absorption bio-oxidation (A/B), integrated fixed-film activated sludge (IFAS), sequencing batch reactor (SBR) and aerated lagoon as aerobic process.

Comparison Criteria

The main comparison criteria of anaerobic and aerobic wastewater treatments alternatives have introduced in this section. Selection criteria contain of: investment costs, operation and maintenance, energy consumption amount, professional labor requirement, required land amount, inflow wastewater quality and quantity, quantitative and qualitative variation of inflow wastewater, shock allow ability, required treatment level, climate conditions, local conditions, applicability, reliability, effectively, amount of produced sludge, reuse and legal and safety commitments (Metcalf, 2003 & Ecology, 1998).

Fuzzy TOPSIS Method

The TOPSIS method was firstly proposed by Hwang and Yoon (Hwang, 1981) .The basic concept of this method is that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from negative ideal solution. Positive ideal solution is a solution that maximizes the benefit criteria and minimizes cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria (Wang, 2006).

In this paper, the fuzzy TOPSIS method is considered which was proposed by Chen and Chen *et al.* (Chen, 2000; Chen *et al.*, 2006). Linguistic variables and related triangular fuzzy numbers which are used in this paper to assessment of criterions weight importance and alternatives grading have presented in Tables 1 and 2 respectively.

TABLE 1
LINGUISTIC VARIABLES FOR IMPORTANCE WEIGHT OF EACH CRITERION

Linguistic variables	Triangular fuzzy numbers
Very low (VL)	(0, 0, 0.2)
Low (L)	(0.1, 0.2, 0.3)
Medium low (ML)	(0.2, 0.35, 0.5)
Medium (M)	(0.4, 0.5 ,0.6)
Medium high (MH)	(0.5, 0.65, 0.8)
High (H)	(0.7, 0.8, 0.9)
Very high (VH)	(0.8, 1,1)

TABLE 2
LINGUISTIC VARIABLES FOR RATINGS

Linguistic variables	Triangular fuzzy numbers
Very poor (VP)	(0, 0, 2)
Poor (P)	(1, 2, 3)
Medium poor (MP)	(2, 3.5, 5)
Fair (F)	(4, 5, 6)
Medium good (MG)	(5, 6.5, 8)
Good (G)	(7, 8, 9)
Very good (VG)	(8, 10, 10)

RESULTS AND DISCUSSION

Combined anaerobic– aerobic processes have more attended due to industrial unit and related wastewater diversity and quantitative and qualitative variation of effluents. According to object of this paper, different method of operating anaerobic process in wastewater treatment plants of Iran industrial estates have been surveyed. This process which are contain UASB, UAFB, ABR, contact process and anaerobic lagoons have investigated and fuzzy TOPSIS method as a assessment tool has been used to effective treatment process selection. Importance weight of criterions has been evaluated by using of linguistic variables from Table 1 and their related sub criterions. Results and related triangular fuzzy numbers have presented in Table 3.

TABLE 3
IMPORTANCE WEIGHT OF CRITERIA FROM THREE DECISION-MAKERS

Criteria	Linguistic variables			Triangular fuzzy numbers
	DM 1	DM 2	DM 3	
Technical	VH	H	VH	(0.7, 0.93,1)
Economical	H	MH	MH	(0.5, 0.7, 0.9)
Environmental	H	VH	VH	(0.7, 0.93,1)
Administrative	MH	H	H	(0.5, 0.75, 0.9)

Linguistic variables which are presented in Table 2 have been used for rating of alternatives assessment regarding to each criterion. Regarding to mentioned baselines, grade of 5 alternatives have been issued according to 4 criterions which are presented in Table 4.

TABLE 4
RATINGS OF ALTERNATIVES BY DECISION-MAKERS UNDER FOUR CRITERIA IN ANAEROBIC AND AEROBIC PROCESSES

	Criteria	Alternatives	Linguistic variables			Triangular fuzzy numbers
			DM1	DM2	DM3	
Anaerobic Processes	*Technical*	UASB	MG	MG	MG	(5, 6.5, 8)
		UAFB	G	G	G	(7, 8, 9)
		ABR	MG	G	G	(5, 7.5, 9)
		Contact Process	G	MG	MG	(5, 7, 9)
		Anaerobic Lagoon	G	G	G	(7, 8, 9)
	Economical	UASB	G	G	G	(7, 8, 9)
		UAFB	G	G	G	(7, 8, 9)
		ABR	VG	VG	VG	(8, 10, 10)
		Contact Process	MG	MG	MG	(5, 6.5, 8)
		Anaerobic Lagoon	F	F	F	(4, 5, 6)
	Environmental	UASB	G	MG	MG	(5, 7, 9)
		UAFB	G	G	G	(7, 8, 9)
		ABR	MG	MG	G	(5, 7, 9)

		Contact Process	MG	MG	MG	(5, 6.5, 8)
		Anaerobic Lagoon	F	F	F	(4, 5, 6)
	Administrative	UASB	F	F	F	(4, 5, 6)
		UAFB	MG	MG	MG	(5, 6.5, 8)
		ABR	MG	G	G	(5, 7.5, 9)
		Contact Process	G	G	G	(7, 8, 9)
		Anaerobic Lagoon	G	MG	G	(5, 7.5, 9)
Aerobic Processes	*Technical*	Extended Aeration	G	G	G	(7, 8, 9)
		A/B	MG	MG	G	(5, 7, 9)
		IFAS	VG	G	G	(7, 8.7, 10)
		SBR	G	G	MG	(5, 7.5, 9)
		Aerated Lagoon	MG	F	MG	(4, 6, 8)
	Economical	Extended Aeration	G	MG	G	(5, 7.5, 9)
		A/B	MG	MG	F	(4, 6, 8)
		IFAS	G	G	MG	(5, 7.5, 9)
		SBR	G	G	G	(7, 8, 9)
		Aerated Lagoon	G	MG	MG	(5, 7, 9)
	Environmental	Extended Aeration	VG	G	G	(7, 8.7, 10)
		A/B	MG	MG	F	(4, 6, 8)
		IFAS	VG	G	G	(7, 8.7, 10)
		SBR	G	G	MG	(5, 7.5, 9)
		Aerated Lagoon	MG	MG	MG	(5, 6.5, 8)
	Administrative	Extended Aeration	G	MG	MG	(5, 7, 9)
		A/B	G	MG	F	(4, 6.5, 9)
		IFAS	G	G	MG	(5, 7.5, 9)
		SBR	G	G	MG	(5, 7.5, 9)
		Aerated Lagoon	VG	G	G	(7, 8.7, 10)

Then the fuzzy decision matrix formed on the basis of triangular fuzzy numbers which are related to criterions and alternatives. Finally, fuzzy weight of alternatives determined. Table 5 shows the result of mentioned functions.

TABLE 5
FUZZY DECISION MATRIX AND FUZZY WEIGHTS OF ALTERNATIVES

	Criteria	Technical	Economical	Environmental	Administrative
	Weight	(0.7, 0.93,1)	(0.5, 0.7, 0.9)	(0.7, 0.93,1)	(0.5, 0.75, 0.9)
Anaerobic Processes	UASB	(5, 6.5, 8)	(7, 8, 9)	(5, 7, 9)	(4, 5, 6)
	UAFB	(7, 8, 9)	(7, 8, 9)	(7, 8, 9)	(5, 6.5, 8)
	ABR	(5, 7.5, 9)	(8, 10, 10)	(5, 7, 9)	(5, 7.5, 9)
	Contact Process	(5, 7, 9)	(5, 6.5, 8)	(5, 6.5, 8)	(7, 8, 9)
	Anaerobic Lagoon	(7, 8, 9)	(4, 5, 6)	(4, 5, 6)	(5, 7.5, 9)
Aerobic Processes	Extended Aeration	(7, 8, 9)	(5, 7.5, 9)	(7, 8.7, 10)	(5, 7, 9)
	A/B	(5, 7, 9)	(4, 6, 8)	(4, 6, 8)	(4, 6.5, 9)
	IFAS	(7, 8.7, 10)	(5, 7.5, 9)	(7, 8.7, 10)	(5, 7.5, 9)
	SBR	(5, 7.5, 9)	(7, 8, 9)	(5, 7.5, 9)	(5, 7.5, 9)
	Aerated Lagoon	(4, 6, 8)	(5, 7, 9)	(5, 6.5, 8)	(7, 8.7, 10)

Then the normalized fuzzy decision matrix is formed as in Table 6.

TABLE 6
NORMALIZED FUZZY DECISION MATRIX

	Criteria	Technical	Economical	Environmental	Administrative
Anaerobic Processes	UASB	(0.5, 0.65, 0.8)	(0.7, 0.8, 0.9)	(0.5, 0.7, 0.9)	(0.4, 0.5, 0.6)
	UAFB	(0.7, 0.8, 0.9)	(0.7, 0.8, 0.9)	(0.7, 0.8, 0.9)	(0.5, 0.65, 0.8)
	ABR	(0.5, 0.75, 0.9)	(0.8, 1, 1)	(0.5, 0.7, 0.9)	(0.5, 0.75, 0.9)
	Contact Process	(0.5, 0.7, 0.9)	(0.5, 0.65, 0.8)	(0.5, 0.65, 0.8)	(0.7, 0.8, 0.9)
	Anaerobic Lagoon	(0.7, 0.8, 0.9)	(0.4, 0.5, 0.6)	(0.4, 0.5, 0.6)	(0.5, 0.75, 0.9)
Aerobic Processes	Extended Aeration	(0.7, 0.8, 0.9)	(0.5, 0.75, 0.9)	(0.7, 0.87, 1)	(0.5, 0.7, 0.9)
	A/B	(0.5, 0.7, 0.9)	(0.4, 0.6, 0.8)	(0.4, 0.6, 0.8)	(0.4, 0.65, 0.9)
	IFAS	(0.7, 0.87, 1)	(0.5, 0.75, 0.9)	(0.7, 0.87, 1)	(0.5, 0.75, 0.9)
	SBR	(0.5, 0.75, 0.9)	(0.7, 0.8, 0.9)	(0.5, 0.75, 0.9)	(0.5, 0.75, 0.9)
	Aerated Lagoon	(0.4, 0.6, 0.8)	(0.5, 0.7, 0.9)	(0.5, 0.65, 0.8)	(0.7, 0.87, 1)

Then weighted normalized fuzzy decision matrix formed on the basis of Table 6 and results have presented in Table 7.

TABLE 7
WEIGHTED NORMALIZED FUZZY DECISION MATRIX

	Criteria	Technical	Economical	Environmental	Administrative
Anaerobic Processes	UASB	(0.35,0.6,0.8)	(0.35,0.56,0.81)	(0.35,0.65,0.9)	(0.2,0.38,0.54)
	UAFB	(0.49,0.74,0.9)	(0.35,0.56,0.81)	(0.49,0.74,0.9)	(0.25,0.49,0.72)
	ABR	(0.35,0.7,0.9)	(0.4,0.7,0.9)	(0.35,0.65,0.9)	(0.25,0.56,0.81)
	Contact Process	(0.35,0.65,0.9)	(0.25,0.45,0.72)	(0.35,0.6,0.8)	(0.35,0.6,0.81)
	Anaerobic Lagoon	(0.49,0.74,0.9)	(0.2,0.35,0.54)	(0.28,0.46,0.6)	(0.25,0.56,0.81)
Aerobic Processes	Extended Aeration	(0.49, 0.74, 0.9)	(0.25, 0.52, 0.81)	(0.49, 0.81, 1)	(0.25, 0.52, 0.81)
	A/B	(0.35, 0.65, 0.9)	(0.2, 0.42, 0.72)	(0.28, 0.56, 0.8)	(0.2, 0.49, 0.81)
	IFAS	(0.49, 0.81, 1)	(0.25, 0.52, 0.81)	(0.49, 0.81, 1)	(0.25, 0.56, 0.81)
	SBR	(0.35, 0.70, 0.9)	(0.35, 0.56, 0.81)	(0.35, 0.70, 0.9)	(0.25, 0.56, 0.81)
	Aerated Lagoon	(0.28, 0.56, 0.8)	(0.25, 0.49, 0.81)	(0.35, 0.60, 0.8)	(0.35, 0.65, 0.9)

After the weighted normalized fuzzy decision matrix is formed, fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) for selection of anaerobic processes are determined as in the following:

$A^*_{anaerobic}$ = [(0.9, 0.9, 0.9), (0.9, 0.9, 0.9), (0.9, 0.9, 0.9), (0.81, 0.81, 0.81)]
$A^-_{anaerobic}$ = [(0.35, 0.35, 0.35), (0.2, 0.2, 0.2), (0.28, 0.28, 0.28), (0.2, 0.2, 0.2)]
$A^*_{aerobic}$ = [(1, 1, 1), (0.81, 0.81, 0.81), (1, 1, 1), (0.9, 0.9, 0.9)]
$A^-_{aerobic}$ = [(0.28, 0.28, 0.28), (0.2, 0.2, 0.2), (0.28, 0.28, 0.28), (0.2, 0.2, 0.2)]

Then the distance of each alternative from FPIS and FNIS with respect to each criterion are calculated by using vertex method as:

$$d(A_1, A^*)_{anaerobic} = \sqrt{\frac{1}{3}\left[(0.9-0.35)^2 + (0.9-0.6)^2 + (0.9-0.8)^2\right]} = 0.37$$

$$d(A_1, A^-)_{anaerobic} = \sqrt{\frac{1}{3}\left[(0.35-0.35)^2 + (0.35-0.6)^2 + (0.35-0.8)^2\right]} = 0.30$$

$$d(A_1, A^*)_{aerobic} = \sqrt{\frac{1}{3}\left[(1-0.49)^2 + (1-0.74)^2 + (1-0.6)^2\right]} = 0.33$$

$$d(A_1, A^-)_{aerobic} = \sqrt{\frac{1}{3}\left[(0.28-0.35)^2 + (0.35-0.6)^2 + (0.35-0.8)^2\right]} = 0.46$$

Here only the calculation of the distance of the first alternative to FPIS and FNIS for the first criterion is shown, as the calculations are similar in all steps. The results of all alternatives' distances from FPIS and FNIS are shown in Tables 8 and 9.

TABLE 8
DISTANCES BETWEEN ALTERNATIVES AND A^* WITH RESPECT TO EACH CRITERION

		Technical	Economical	Environmental	Administrative
Anaerobic Processes	$d(A_1,A^*)_{anaerobic}$	0.37	0.38	0.35	0.46
	$d(A_2,A^*)_{anaerobic}$	0.25	0.38	0.25	0.38
	$d(A_3,A^*)_{anaerobic}$	0.34	0.31	0.35	0.35
	$d(A_4,A^*)_{anaerobic}$	0.35	0.47	0.37	0.29
	$d(A_5,A^*)_{anaerobic}$	0.25	0.55	0.47	0.35
Aerobic Processes	$d(A_1,A^*)_{aerobic}$	0.33	0.36	0.31	0.44
	$d(A_2,A^*)_{aerobic}$	0.43	0.42	0.50	0.47
	$d(A_3,A^*)_{aerobic}$	0.31	0.36	0.31	0.43
	$d(A_4,A^*)_{aerobic}$	0.42	0.30	0.42	0.43
	$d(A_5,A^*)_{aerobic}$	0.50	0.37	0.45	0.35

TABLE 9
DISTANCES BETWEEN ALTERNATIVES AND A^- WITH RESPECT TO EACH CRITERION

		Technical	Economical	Environmental	Administrative
Anaerobic Processes	$d(A_1,A^-)_{anaerobic}$	0.30	0.42	0.42	0.22
	$d(A_2,A^-)_{anaerobic}$	0.40	0.42	0.46	0.34
	$d(A_3,A^-)_{anaerobic}$	0.38	0.51	0.42	0.41
	$d(A_4,A^-)_{anaerobic}$	0.36	0.34	0.36	0.43
	$d(A_5,A^-)_{anaerobic}$	0.40	0.21	0.21	0.41
Aerobic Processes	$d(A_1,A^-)_{aerobic}$	0.46	0.40	0.53	0.40
	$d(A_2,A^-)_{aerobic}$	0.42	0.33	0.34	0.39
	$d(A_3,A^-)_{aerobic}$	0.53	0.40	0.53	0.41
	$d(A_4,A^-)_{aerobic}$	0.43	0.42	0.43	0.41
	$d(A_5,A^-)_{aerobic}$	0.34	0.39	0.36	0.49

Then closeness coefficients of alternatives are calculated by this formula:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, \quad i=1,2,...,m$$

According to the closeness coefficient of alternatives, the ranking order of alternatives is determined. The first alternative is determined as the most appropriate anaerobic process for industrial estates. Value of this parameters and final ranking order of alternatives have been presented in Table 10.

TABLE 10
COMPUTATIONS OF d_i^* , d_i^- AND CC_i AND RATING ORDER OF ALTERNATIVES

		d_i^*	d_i^-	CC_i	Ranking order
Anaerobic Processes	UASB	1.55	1.36	0.4666	UAFB> ABR> Contact process > UASB> Anaerobic lagoon
	UAFB	1.26	1.62	0.5631	
	ABR	1.36	1.72	0.5593	
	Contact Process	1.47	1.48	0.5020	
	Anaerobic Lagoon	1.63	1.24	0.4313	
Aerobic Processes	Extended Aeration	1.45	1.79	0.5533	IFAS> Extended Aeration> SBR > Aerated Lagoon > A/B
	A/B	1.82	1.47	0.4470	
	IFAS	1.42	1.87	0.5689	
	SBR	1.56	1.70	0.5202	
	Aerated Lagoon	1.68	1.58	0.4847	

CONCLUSION

By using fuzzy TOPSIS, uncertainty and vagueness from subjective perception and the experiences of decision-maker can be effectively represented and reached to a more effective decision**.** In this study anaerobic and aerobic process selection with fuzzy TOPSIS method has been proposed. The decision criteria were technical, economical, environmental and administrative criterion and their sub-criterion. These criteria were evaluated to determine the order of anaerobic and aerobic alternatives for selecting the most appropriate one. In fuzzy TOPSIS decision makers used the linguistic variables to assess the importance of the criteria and to evaluate the each alternative with respect to each criterion. These linguistic variables converted into triangular fuzzy numbers and fuzzy decision matrix was formed. Then normalized fuzzy decision matrix and weighted normalized fuzzy decision matrix were formed. After FPIS and FNIS were defined, distance of each alternative to FPIS and FNIS were calculated. Then the closeness coefficient of each alternative was calculated separately. According to the closeness coefficient, the ranking order of anaerobic and aerobic alternatives has been determined as UAFB > ABR > Contact process > UASB > Anaerobic lagoon and IFAS > Extended Aeration > SBR > Aerated Lagoon > A/B respectively.

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