Supplementary Information

Biodiesel Wastewater Treatment by Coagulation-Flocculation: Evaluation and Optimization of Operational Parameters

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Table S1. Fractional factorial design and experimental results for the turbidity removal using Al^{3+} as coagulant agent

Experiment	Range evaluated (codified value)					Turbidity removal / %
	Al^{3+} / (mg L^{-1})	pH	time / min	Stirring	Aeration	
1	54(–1)	5.0(–1)	30(–1)	+1	+1	53.7 ± 6.2
2	540(+1)	5.0(–1)	30(–1)	–1	–1	29.3 ± 3.1
3	54(–1)	9.7(+1)	30(–1)	–1	+1	62.6 ± 3.5
4	540(+1)	9.7(+1)	30(–1)	+1	–1	97.9 ± 0.5
5	54(–1)	5.0(–1)	120(+1)	+1	–1	78.4 ± 4.2
6	540(+1)	5.0(–1)	120(+1)	–1	+1	82.1 ± 0.6
7	54(–1)	9.7(+1)	120(+1)	–1	–1	20.7 ± 7.7
8	540(+1)	9.7(+1)	120(+1)	+1	+1	91.2 ± 3.5

Stirring and aeration: +1.0 (presence) and –1.0 (absence).

Table S2. Fractional factorial design and experimental results for the turbidity removal using Fe^{3+} as coagulant agent

Experiment	Range evaluated (codified value)					Turbidity removal / %
	Fe^{3+} / (mg L^{-1})	pH	time / min	Stirring	Aeration	
1	56(–1)	5.0(–1)	30(–1)	+1	+1	49.8 ± 3.5
2	560(+1)	5.0(–1)	30(–1)	–1	–1	–121.1 ± 9.9
3	56(–1)	9.7(+1)	30(–1)	–1	+1	–50.7 ± 1.0
4	560(+1)	9.7(+1)	30(–1)	+1	–1	2.8 ± 0.7
5	56(–1)	5.0(–1)	120(+1)	+1	–1	95.0 ± 1.9
6	560(+1)	5.0(–1)	120(+1)	–1	+1	–60.1 ± 13.3
7	56(–1)	9.7(+1)	120(+1)	–1	–1	–14.0 ± 8.7
8	560(+1)	9.7(+1)	120(+1)	+1	+1	31.3 ± 6.8

Stirring and aeration: +1.0 (presence) and –1.0 (absence).

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Table S3. Results obtained by the application of the ANOVA test using fractional factorial design (2^{5-2}), for the turbidity removal in the treatment of biodiesel wastewater, using Al^{3+} as coagulant agent

Factor	SoS	df	MS	F	*p*
(1)Al^{3+}	2712.47	1	2712.47	286.98	0.000000
(2)pH	312.86	1	312.86	33.10	0.000030
(3)time	313.97	1	313.97	33.22	0.000029
(4)stirring	5988.77	1	5988.77	633.62	0.000000
(5)aeration	1507.83	1	1507.83	159.53	0.000000
2 by 3	5961.76	1	5961.76	630.76	0.000000
2 by 5	18.47	1	18.47	1.95	0.181242
Error	151.23	16	9.45		
Total SS	16967.35	23			

SoS: sum of squares; df: degree of freedom; MS: mean square; SS: suspended solids.

Table S4. Results obtained by the application of the ANOVA test using fractional factorial design (2^{5-2}), for the turbidity removal in the treatment of biodiesel wastewater, using Fe^{3+} as coagulant agent

Factor	SoS	df	MS	F	*p*
(1)Fe^{3+}	12590.8	1	12590.83	458.62	0.000000
(2)pH	542.4	1	542.38	19.76	0.000408
(3)time	6087.9	1	6087.91	221.75	0.000000
(4)stirring	82373.4	1	82373.38	3000.43	0.000000
(5)aeration	995.5	1	995.52	36.26	0.000018
2 by 3	2695.2	1	2695.20	98.17	0.000000
2 by 5	148.2	1	148.21	5.40	0.033655
Error	439.3	16	27.45		
Total SS	105872.7	23			

SoS: sum of squares; df: degree of freedom; MS: mean square; SS: suspended solids.

Table S5. First central composite design and experimental results for the turbidity removal using Al^{3+} as coagulant agent, at the initial pH 9.7, under aeration and stirring

Experiment	Range evaluated (codified value)		Turbidity removal / %
	Al^{3+} / (mg L^{-1})	time / min	
1	300(–1)	30(–1)	99.5 ± 0.4
2	300(–1)	90(+1)	99.2 ± 0.1
3	780(+1)	30(–1)	87.7 ± 3.5
4	780(+1)	90(+1)	83.9 ± 5.6
5	200(–1.4)	60(0)	99.8 ± 0.1
6	879(+1.4)	60(0)	73.5 ± 0.8
7	540(0)	18(–1.4)	89.4 ± 1.7
8	540(0)	102(+1.4)	91.6 ± 4.6
9	540(0)	60(0)	90.7
10	540(0)	60(0)	90.5
11	540(0)	60(0)	93.4
12	540(0)	60(0)	96.4
13	540(0)	60(0)	93.9
	Standard deviation[a]		2.5

[a]Standard deviation of central points (experiments 9 to 13).

Table S6. Second central composite design and experimental results for the turbidity removal using Al^{3+} as coagulant agent, at the initial pH 9.7, under aeration and stirring

Experiment	Range evaluated (codified value)		Turbidity removal / %
	Al^{3+} / (mg L^{-1})	time / min	
1	200(–1)	30(–1)	99.2 ± 0.1
2	200(–1)	70(+1)	99.8 ± 0.0
3	400(+1)	30(–1)	98.2 ± 0.3
4	400(+1)	70(+1)	98.7 ± 0.4
5	159(–1.4)	50(0)	99.3 ± 0.3
6	441(+1.4)	50(0)	97.5 ± 0.2
7	300(0)	22(–1.4)	99.0 ± 0.1
8	300(0)	78(+1.4)	99.5 ± 0.3
9	300(0)	50(0)	99.4
10	300(0)	50(0)	99.6
11	300 (0)	50(0)	99.6
12	300 (0)	50(0)	99.6
13	300 (0)	50(0)	99.6
	Standard deviation[a]		0.1

[a]Standard deviation of central points (experiments 9 to 13).

Table S7. Central composite design and experimental results for the turbidity removal using Fe^{3+} as coagulant agent, under aeration and stirring

Experiment	Range evaluated (codified value)			Turbidity removal / %
	Fe^{3+} / (mg L^{-1})	time / min	pH	
1	46(–1)	80(–1)	3.5(–1)	98.0 ± 1.2
2	46(–1)	80(–1)	6.5(+1)	–75.7 ± 14.7
3	46(–1)	160(+1)	3.5(–1)	99.7 ± 0.1
4	46(–1)	160(+1)	6.5(+1)	–48.8 ± 11.9
5	66(+1)	80(–1)	3.5(–1)	89.6 ± 0.1
6	66(+1)	80(–1)	6.5(+1)	98.9 ± 1.3
7	66(+1)	160(+1)	3.5(–1)	85.9 ± 1.7
8	66(+1)	160(+1)	6.5(+1)	99.6 ± 0.3
9	39(–1.7)	120(0)	5.0(0)	97.1 ± 1.8
10	73(+1.7)	120(0)	5.0(0)	87.7 ± 2.8
11	56(0)	53(–1.7)	5.0(0)	98.6 ± 0.7
12	56(0)	187(+1.7)	5.0(0)	99.6 ± 0.0
13	56(0)	120(0)	2.5(–1.7)	98.5 ± 0.0
14	56(0)	120(0)	7.5(+1.7)	–17.1 ± 6.8
15	56(0)	120(0)	5.0(0)	99.5
16	56(0)	120(0)	5.0(0)	97.8
17	56(0)	120(0)	5.0(0)	99.5
18	56(0)	120(0)	5.0(0)	96.3
19	56(0)	120(0)	5.0(0)	99.6
Standard deviation[a]				1.5

[a]Standard deviation of central points (experiments 15 to 19).

Table S8. Results obtained by the application of the ANOVA test using CCD design for the turbidity removal during the treatment of biodiesel wastewater, using Al^{3+} as coagulant agent

Factor	SoS	df	MS	F	*p*
(1) Al^{3+} (L)	2.84	1	2.84	167.22	0.000004
Al^{3+} (Q)	2.14	1	2.14	126.18	0.00001
(2) Time (L)	0.38	1	0.38	22.72	0.002
Time (Q)	0.10	1	0.10	5.66	0.049
1L by 2L	0.006	1	0.006	0.33	0.583
Error	0.12	7	0.02		
Total SS	5.51	12			

SoS: sum of squares; df: degree of freedom; MS: mean square; SS: suspended solids.

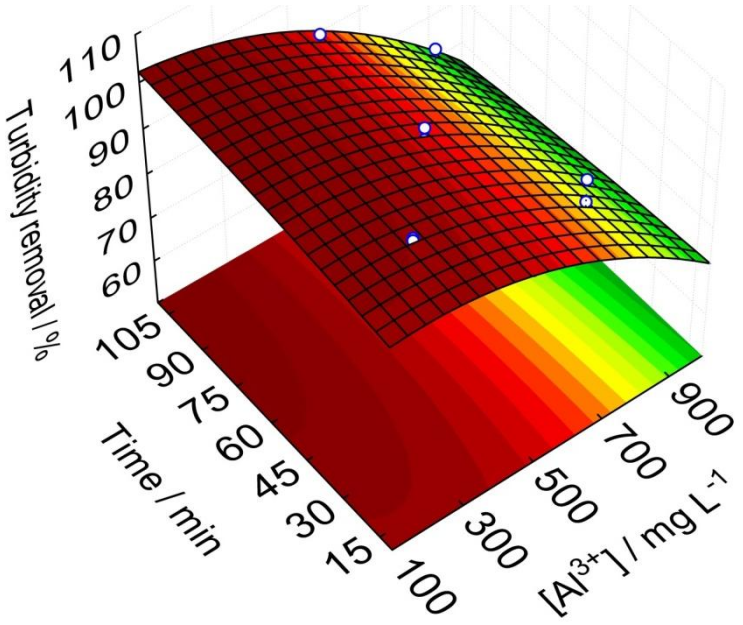

Figure S1. Response surface of quadratic models for turbidity removal obtained by the first CCD during the treatment of biodiesel wastewater using Al^{3+} as coagulant agent, using the initial pH equal to the natural pH of the sample (9.7), under aeration and stirring.

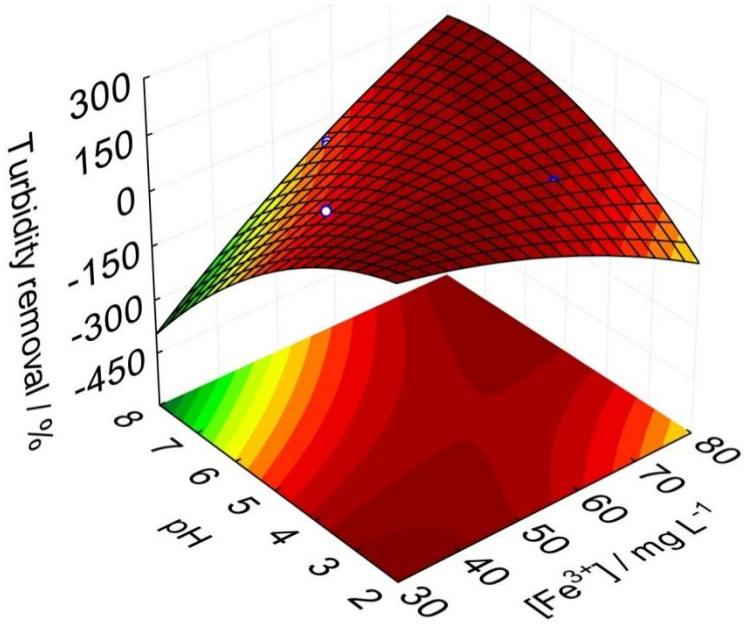

Figure S2. Response surface of quadratic models for turbidity removal during the treatment of biodiesel wastewater using Fe^{3+} as coagulant agent, under aeration and stirring.

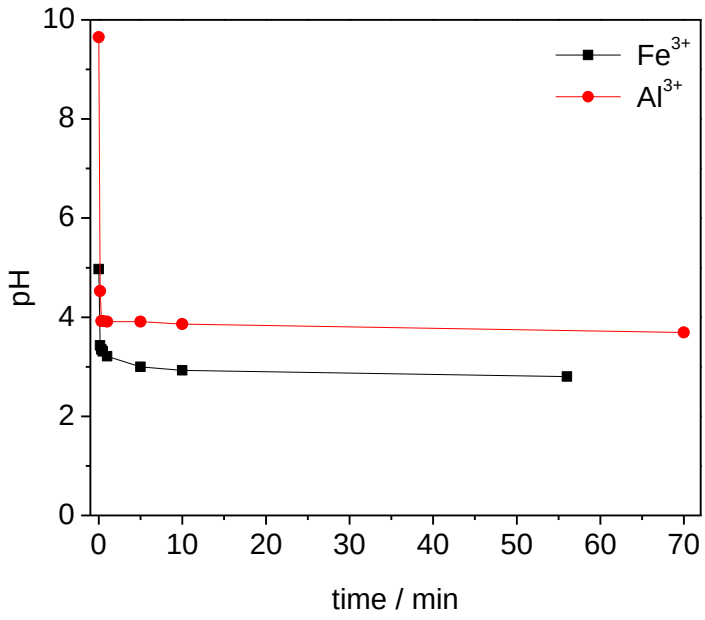

Figure S3. pH evolution during the coagulation-flocculation treatment of biodiesel wastewater under the best and optimized conditions, using, respectively, Fe^{3+} and Al^{3+}.