Evaluation of a wastewater treatment technology for water reuse.

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Abstract

This paper presents the evaluation of a lab scale wastewater treatment technology that can be used to obtain physicochemical and microbiological good quality water for reuse. This technology mainly consists in the combination of coagulation – flocculation, sedimentation and filtration stages and a final water ozonation. It was evaluated for different kinds of wastewaters : domestic (inlet of municipal wastewater treatment plant), industrial laundry, and fish processing plant. Different parameters such as pH, turbidity, total suspended soil, color, chemistry oxygen demand, Absorbance at 254 nm, dissolved oxygen, detergent content were evaluated. Finally, microbiological tests (Total Mesophyles and Total coliforms) were carried out. Aluminum sulfate (doses between 10 and 300 mg/L) was used as coagulant, a cationic polyme(doses between 0 and 1 mg/L) was used as flocculant, and applied ozone doses were between 4 and 300 mg/L. All of these doses varied according to the different kinds of wastewater studied. A pressurized sand rapid filtration was used. Under the conditions studied, this technology was capable of eliminating high concentrations of water pollutants in all cases, independent of the inlet water characteristics. Reductions for physicochemical and microbiological parameters were between 73 and 99 % and higher than 99.99 % respectively. This technology can be used to give a local solution for wastewater treatment for reuse in diverse applications, or in the same industries that generated the wastewater, in which their productive process are high water consumers.

Introduction

Due to the increasing water world scarcity, the international scientific community dedicates great efforts to the solutions find that they allow the wastewater treatment from different origins to be

reuse in diverse uses [1-4]. For that reason, the Ozone Research Center of Cuba is working in the development of technologies that include the water ozonization process inside other wastewater treatment scheme for reuse, fundamentally in the laundry wastewater treatment for reuse in its own processes [5]. Besides with the collaboration of specialists of the Sinaloa Autonomous University, Mexico in the municipal wastewater treatment for reuse in agricultural irrigation. These wastewaters without any treatment have been used for more than 200 years in many countries for irrigation in agricultural, increasing the harvest productivity due to the high contents of agronomic interest compounds. But also the gastrointestinal illnesses have been increased due to the presence of pathogen microorganisms in these wastewaters, producing true problems of public health, especially in the childrens [6] .

In the case of industrial laundry wastewaters, besides the pollutants of the clothes dirt, a great microorganisms quantity, dissolved detergents and other chemical products are presented. These are difficult compounds to remove through a conventional treatment and represent a great problem to the environment [7-9]. At the same time, the industrial laundry processes are great water consumers, so it is very beneficial for them to have appropriate technologies that allow water reuse in their productive processes.

Water ozonization has become a very attractive method in many fields, for the ozone high oxidizer and germicide power [10-13]. Ozone application to enhanced other treatment processes have been reported, for example for the coagulation–flocculation [14, 15, 16]. The combination of the ozonization with other treatment stages increases organic, inorganic and microbiological pollution elimination of these wastewater, facilitating their reuse.

The objective of the present work is the evaluation at lab scale of the combination of coagulation-flocculation, sedimentation, filtration and ozonization processes in wastewater treatment from diverse origins (domestic, industrial laundry, and fish processing plant), for reuse. Which can be in the same industry that generates the wastewater, or in any other activity that requires high water consumptions in its productive processes. Sanitary regulations established should be fulfill for each case.

Materials and Methods

The industrial laundry wastewater were studied in the Ozone Research Center of Cuba, and the domestic and fish processing plant wastewaters were studied in Sinaloa Autonomous University, Mexico.

Wastewater samples:

- Industrial laundry wastewater**:**
They were obtained of an industrial laundry witch has a washing capacity between 1–3 ton / day. The taking sample were carry out one time per week, during two months. Wastewater samples collected at discharge of all washing machine.

- Domestic wastewater:
Samples were obtained from at Culiacán City Wastewater Treatment Plant, Sinaloa State, Mexico, in the plant inlet, one time per week during two months, collecting 30 liters of water in a plastic tank each time.

- Fish processing plant wastewater**:**
Samples were obtained at from Fish Processing Plant, Mazatlán City, Sinaloa State, Mexico at plant inlet in 5 liters plastic tanks of capacity. They were refrigerated and transfered toward the lab.

Conditions:

- **Industrial laundries wastewater:**

Firstly the study of each process was separately carried out, and later in continuous for all the combined treatment stages.

- Coagulation-flocculation process:

The study for this process was carried out in separate jars, using a JANKE&KUNKEL digital agitator, RW20DZM model. With a HANNA pHmeter, pH it was controlled. Two coagulants, aluminum sulfate and a commercial coagulant (PROSI-PVS CHEMICALS, S.A DE C.V) denominated Prosifloc – PAC (aluminum polychloride) was studied. Several doses for both coagulants between 25 and 150 mg/L were employed.

Agitation speed gradient used:
- Quick agitation: 250 rpm for 1 minute.
- Slow agitation: 50 rpm for 5 minutes.
  30 rpm for 5 minutes.
- Repose: 30 minutes.

- Filtration process:

In this case a 30 liters recipient of capacity was used, in which the coagulation-flocculation process with the coagulant best doses according to the previous study was carried out. Clarified water by decantation was passed to another recipient, from which it was pumped toward the filter by peristaltic bomb.

Using a lab pressure filter, filtration speeds were studied between 2.5 and 10 m/h, calculated according to the filter traverse area (43.56 cm^2). Silica sand with an effective size of 0.43 mm and a uniformity coefficient of 1.23 was used as filter media.

- Ozonization process (semibatch)

A five liter column was used. Once filled the column with filtrated water and reached in the spectrophotometer the necessary gas ozone concentration, then the gas flow was derived toward the column and the ozonization began. Water samples were taken every five minutes of treatment. Using a gas flow of 60 L/h, three gas ozone concentrations were studied: 30, 45, 60 mg/L. A lab OZOCENIC ozonator was used, and gas ozone concentration was directly measure with a Pharmacia Ultrospec III spectrophotometer**,** at 256 nm. In the outlet gas, a foam collector is connected, before the residual ozone destruction system.

- Combined treatment process in continuous.

With all the work parameters and reagents dose separately established for each stage, continuous experiments were carried out for the combined process stages. Water samples were taken at the inlet and outlet of each process. The diagram used is shown in the figure1.

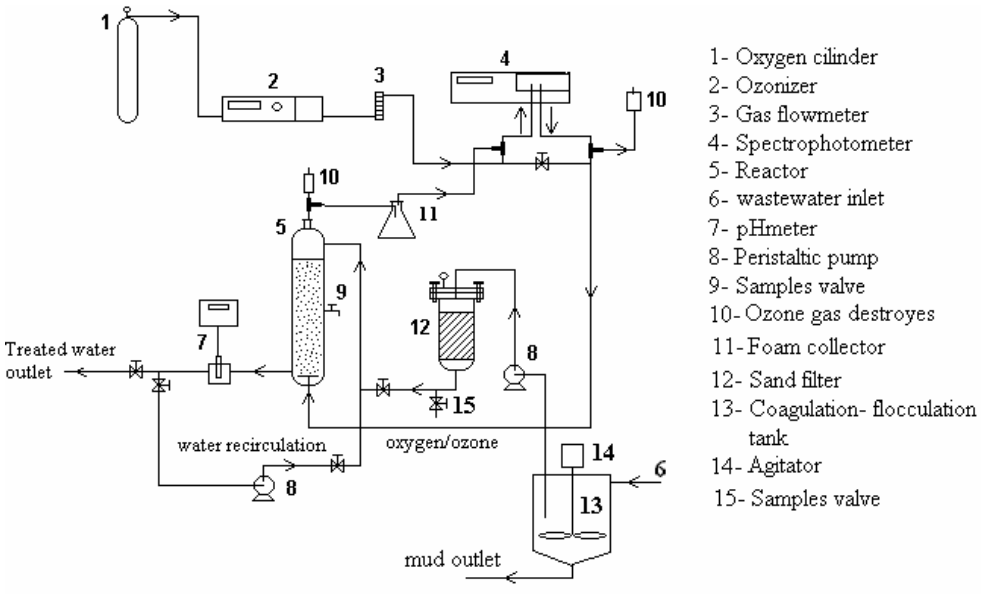


Figure 1. Flow diagram of laboratory setup.

- **Domestic and fish processing plant wastewaters:**

- Coagulation-flocculation process:
These process a jars equipment was carried out, using aluminum sulfate in variable doses between 2 and 100 mg/L and a commercial polymer (Prosifloc C-24124) as flocculants in two doses (0.5 and 1 mg/L). The agitation speed gradient used was the same at the laundry waste.

- Ozonization process (semibatch).
The same procedure described for the laundry waste was carried out, but in this case they were not filtered after the coagulation-flocculation process, because we had not a lab appropriate filter to simulate the filtration process. Ozonization was performanced with a gas flow of 60 l/h and a gas ozone concentration of 45 mg/L, in a five liter column.

- **Physico-chemical analysis.**
The following analyses were carried out by the techniques described in the Standard Methods (1985) [17]:
- pH
- Chemical oxygen demand (COD): Method (5220 D).
- Detergents: MBAS
- Color: Colorimetric method.
- Turbidity: spectrophotometric method.
- Total suspended solids (TSS).
- Dissolved oxygen.

Absorbance at 254 nm was measured, since at this wavelength absorb the organic compounds that have double bounds and that they are easily oxidade for the ozone, for what the measuring of this parameter allows to follow the water quality obtained.

- **Microbiologic analysis.**
- Total Heterotrophes (CFU/ml): This analysis was used to know the total bacteria number in laundry wastewater and the general disinfection level achieved. It was measured before and after each treatment stage.

- Total Coliforms (MPN/100ml): Water samples were analyzed without treatment, after coagulation-flocculation process with the best doses obtained in the previous study, and later coagulation-flocculation process and 30 minutes of ozonization.

Results and discussion.

- **Laundry wastewater.**

Coagulation-flocculation process:

- pH study:

The coagulation-flocculation process at different pH values of the water was carried out. In the case of Aluminum Sulfate, for the two doses employed (50 and 100 mg/L), the highest removal percents were obtained at pH 6, being for COD between 29.6 and 43.2 %, and for Turbidity between 64.9 and 83.2%. In the PAC case (50 and 100 mg/L) the greatest removal percents were obtained for pH 7, being for DQO between 26.3 and 40.8%, and for Turbidity between 83.1 and 91.5%. At pH 9 the turbidity is increment for two coagulants. This is shown in the figure 2.

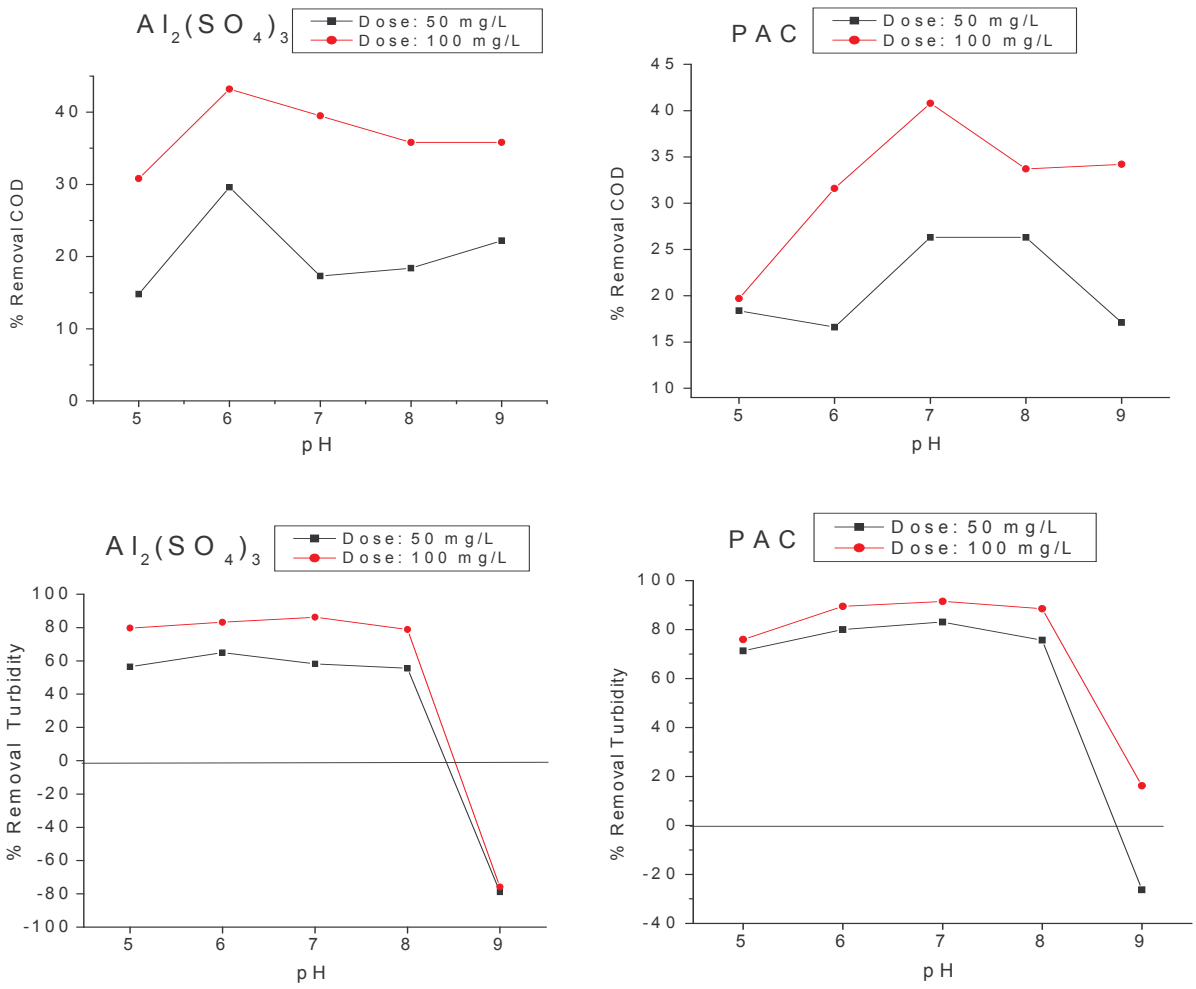
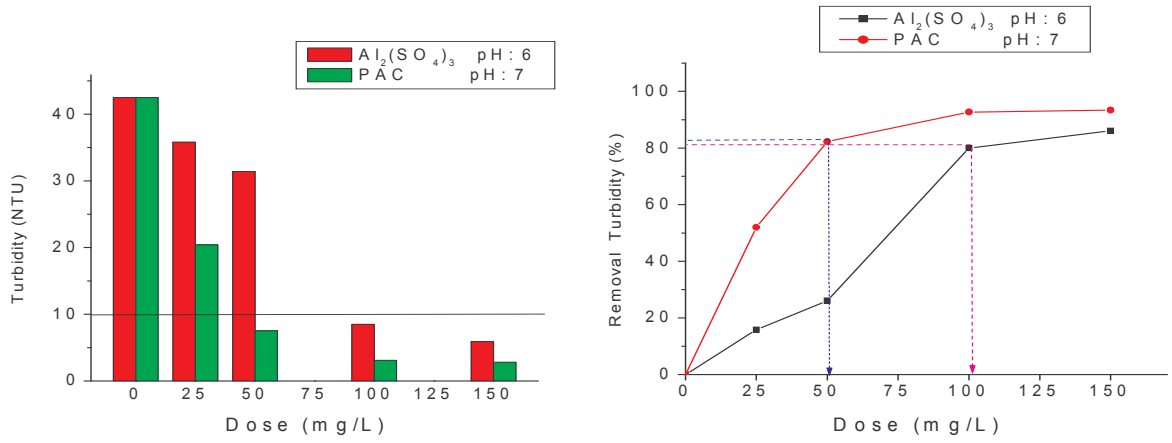


Figure 2, pH study for two doses employed of both coagulants.

- Determination of the best coagulation doses.

Using the chosen pH values from previous study, four doses of both coagulants were studied to obtain the best dose, being for the PAC: 50 mg/l at pH 7 and 100 mg/L for the Aluminum sulfate at pH 6. This is shown in figure 3, for the values and removal percents of Turbidity and COD.



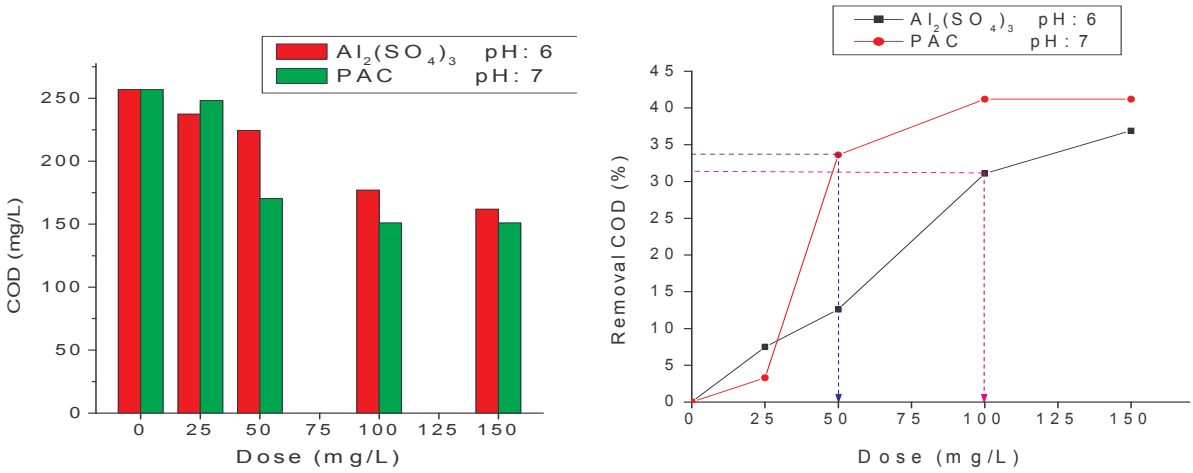


Figure3. Determination of the both coagulants work doses, for the chosen pH of the previous study, for the Turbidity and COD.

Filtration stage study

The main objective of this stage was to remove all suspended particles that had not been decanted after coagulation-flocculation process.

In figure 4 it is shown that if for some operation error a good coagulation-flocculation process were not carried out, the silica sand filtration is capable of to remove particles in suspension and to diminish the water turbidity. Even if the wastewater arrived to the filtration stage with high turbidity values, this stage would be capable of obtaining high removal percents, as shown in the figure 5.

For filtration speeds studied the removal percents obtained are similar, for what is possible to carry out this operation with a pressure rapid filter with filtration speeds between 5 and 10 m/h (120 – 240 m^3/m^2/día).

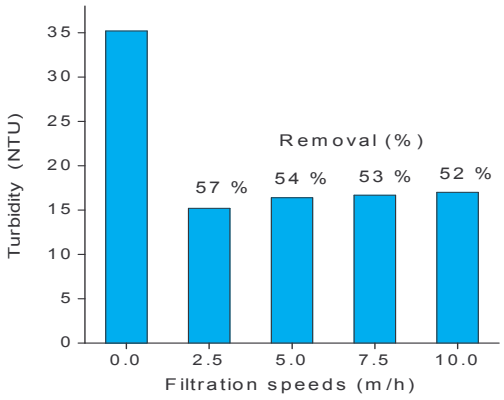


Figure 5. Turbidity high levels removal for several filtration speed.

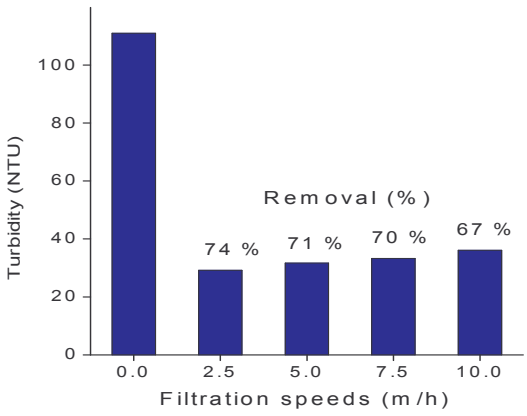


Figure 4. Water turbidity removal for several filtration speeds.

Ozonization stage study:
In figure 6 it is appreciated that the turbidity and the absorbance at 254 nm values of the previously coagulated and filtered waters do not change appreciably for the three gas ozone concentrations studied.

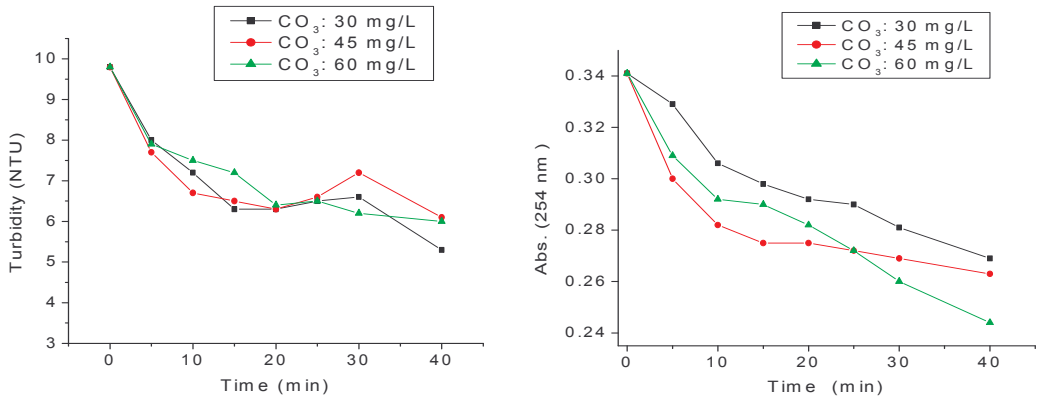


Figure 6. Comparison of three ozone concentrations for turbidity and absorbance at 254 nm removal.

In the COD case (figure 7), from 20 minutes of ozonization and 60 mg/L of gas ozone concentrations, it is that a greatest removal is appreciated in comparison with the other two ozone concentrations. Keeping in mind the above-mentioned, is that was decided to choose as work gas ozone concentration, the corresponding to 60 mg/l.

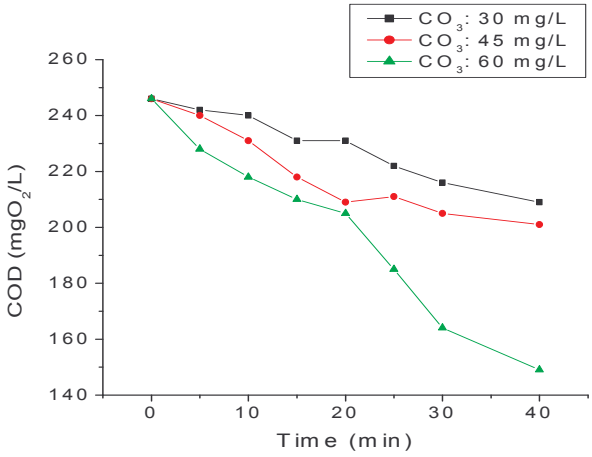


Figure 7. Comparison of three ozone concentrations for COD removal.

Combined treatment:

In table I a summary of removal for studied parameters and contribution to remove of each stage respect to the water inlet and overall removal is shown. It is observed that the greatest removals of turbidity, absorbance at 254 nm, COD and color, are obtained in the coagulation-flocculation stage, at the first treatment stage that is carried out, but not for detergents and microorganisms that are mainly removed in the later ozonization stage.

Table I. Measured parameter values, and partial removal percents for each stage and total removal percent for the whole treatment.

Analysis	Initial sample	STAGES (% partial removal)						%R Total
		Coag. - Flocul.	% R *	Filtrat.	% R *	Ozone	% R *	
pH	7.8	7.51	-	7.51	-	7.48	-	-
Turbidity (NTU)	295	12	96	5	58	4	20	**99**
254 nm abs.	1.855	0.389	79	0.341	12	0.271	21	**85**
COD (mg O_2 /L)	658	246	63	244	0.8	179	27	**73**

MBSA (mg/L)	5.93	4.80	19	-	-	0.63	87	**89**
Color (U Co-Pt)	> 60	-		-	-	0	100	**100**
Alkalinity (mg $CaCO_3$/L)	300	218	27	220	-	200	9	**33**
Total Heterotrophes (CFU/ml)	3.7 x 10^6	3.3 x 10^6	11	-	-	12	99.999	**99.999**

*% R *: % partial removal of the stage.*

- **Domestic wastewater.**

- Coagulation-flocculation process:
In table II obtained values and removal percents in the jar tests are shown, this test carried out with aluminum sulfate doses between 6 and 100 mg/L, using 0.5 mg/L of cationic polymer. It should be pointed out that with only 6 mg/L of coagulant high removals of the parameters under study are obtained.

Table II. Parameters values, and removal percents for the different doses of the coagulant employed.

Coag. doses (mg/L)	pH	NTU	% R	TSS mg/L	% R	Color (U Pt-Co)	% R	Abs. 254 nm	% R
A.C	7.75	330	-	324	-	1550	-	0.878	-
6	7.86	10	97	15	95	129	92	0.326	63
12	7.83	9	97	15	95	128	92	0.318	64
24	7.73	7	98	13	96	116	93	0.298	66
48	7.71	4	99	9	97	89	94	0.263	70
100	7.47	3	99	5	98	63	96	0.229	74

A.C: wastewater inlet

- Ozonization after coagulation-flocculation process.
In table III the measured parameter values and removal percents are shown for the process water inlet (A.C), after the coagulation-flocculation process (C-F: aluminum sulfate: 12 mg/L + polymer: 0.5 mg/L) and later ozonization with contact times from 5 up to 30 minutes.

It is observed that with the combination of both treatment stages the total removal percents obtained (Total %R) are in all the cases higher than 90%, being total almost for the total coliforms at 30 minutes of ozonization (99.999 %). This high microorganism elimination indicates that with ozonization is possible to fulfill international standards for agricultural irrigation reuse with and without restrictions (< 1000 MPN/100 ml of total coliforms) [18-23].

At the same time were proven that the dissolved oxygen levels were increased between 15 and 20 times in comparison with the levels of the water without treatment, being this very favorable if the reuses it is for agricultural irrigation.

Table III. Measured parameter values, and partial removal percents for each stage and total removal percent for the whole treatment.

Stage	pH	NTU	% R	SST mg/L	% R	Color Pt-Co	% R	Abs 254 nm	% R	COD mg/L	% R	Colif. Total NMP/100 ML	% R

A.C	7.8	330	-	324	-	1550	-	0.878	-	178	-	22.4 x 106	-
C-F	7.7	9	97	17	95	144	91	0.33	62	44	75	9.2 x 106	59
O_3													
5 min	7.6	5	44	7	59	48	67	0.143	57	36	18	-	-
10min	7.5	5	44	7	59	40	72	0.107	68	-	-	-	-
20 min	7.6	4	56	7	59	34	76	0.091	72	-	-	-	-
30 min	7.6	4	56	7	59	30	79	0.09	73	15	66	20	99.99
Total %R	**-**	**-**	**99**	**-**	**98**	**-**	**90**	**-**	**90**	**-**	**92**	**-**	**99.999**

A.C: wastewater inlet, C-F: Coagulation-flocculation, O_3: Ozone

- **Fish processing plant wastewater.**

- Coagulation-flocculation process.

This wastewater presents very particular characteristics because of its organics compounds high content, bleed, animal fat, etc, as well as high color levels and strong and characteristic smell fishy. Due to the above-mentioned in the jars tests the best results were obtained for aluminum sulfate dose of 30 mg/L and it was necessary a polymer dosage of 20 mg/L, being formed a floccules mixture where a part of them deposited to the glass bottom, and another considerable part ascended to the surface for flotation because containing fatty and oil compounds.

In table IV the measured values and removal percents are shown for wastewater inlet (A.C), treated water after the coagulation-flocculation process (C-F), and after 30 minutes of ozonization.

Table IV. Parameter values and partial removal percents for each stage and overall for the whole treatment.

Stage	pH	NTU	% R	SST mg/L	% R	Color Pt-Co	% R	Abs 254 nm	% R	COD mg/L	% R
A.C	7.8	1232	-	1230	-	7850	-	6.242	-	278	-
C-F	7.7	102	92	140	89	1750	78	2.827	55	119	57
O3 30 min	7.8	9	91	17	88	155	91	1.414	50	31	74
Total %R	**-**	**-**	**99.3**	**-**	**98.6**	**-**	**98**	**-**	**77.3**	**-**	**88.8**

A.C: wastewater inlet, C-F: Coagulation-flocculation, O_3: Ozone

It is to highlight the pollutants removal high efficiencies obtained, keeping in mind the great wastewater contamination, overalls of organic compound, color and turbidity. At the same time the ozonization totally eliminated the strong smell of this water.
The dissolved oxygen levels increased from 0.48 mg/L in the water inlet up to 15.69 mg/l after the ozonization process, representing an increment of 30 times. These dissolved oxygen concentrations guarantee a greater biodegradability of these water.

Conclusions

- With the combination of the coagulation-flocculation, sedimentation, filtration, and ozonization processes, physico-chemical pollutants removals between 72 and 99% are achieved in all the cases, and microbiologic inactivation superior to 99.999 % are obtained.

- These technological scheme, at lab scale study, is capable to be applied to different types of highly contaminated wastewater, obtaining treated waters with good physico–chemical and microbiological characteristics. These treated waters can be reused in the same industry that generates the wastewater, or in any other activity that consumes high volumes of water.

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