Laundry Wastewater Treatment for Its Reuse in Washing Processes

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Abstract

The laundry industrial processes are great water consumers and generate high volumes of aggressive wastewaters to the environment. This work presents a laboratory scale evaluation of a combination of coagulation-flocculation, sedimentation, filtration, and ozonation process stages for laundry wastewater treatment in order to reuse the treated water in the original productive process. The wastewaters were obtained from two industrial laundries with a washing capacity of 1–3 ton/day. The coagulation-flocculation processes were evaluated for two coagulants (aluminum sulfate and aluminum polychloride), both in doses between 25 and 150 mg/L, and pH values between 5 and 10. In the filtration stage, sand, anthracite, both combined in a multistage filtration, and filtration through activate carbon were evaluated at different filtration rates. For ozonation stage two ozone concentrations (30 and 60 mg/L) and two gas flows (30 and 60 L/h) were used. Different parameters such as pH, turbidity, chemical oxygen demand, absorbance at 254 nm, detergent content and total mesophyles were measured. Firstly the study of each process was carried out separately, and later in continuous for all the combined treatment stages. According to physico-chemical parameters, pollutant removals values between 79 and 98% were achieved in all the cases under the conditions studied. Microbiological inactivation higher than 99.999% was also obtained. From a preliminary study, the operation cost for one cubic meter of treated water (0.37 USD/m^3), was lower than the one for one cubic meter of tap water for this industry. This technological scheme, developed at lab scale, is capable to be applied to highly contaminated wastewater, obtaining treated waters with good physico–chemical and microbiological characteristics, at very low operation costs. Taking into account the figures involved, and the great wastewater volumes generated by this industry, the inversion cost will be rapidly recovered.

Key Words

Wastewater treatment; laundry; water reuse; ozonation.

Introduction

Wastewaters from industrial laundries besides a high microbiological load and pollutants (fats, oils, suspended solids) removed from dirty clothes, contain several chemicals (detergents among them) used in the washing operations, which are very difficult to remove by conventional processes and constitute an environmental pollution problem [www.hydroxyl.com., www.laundrytoday.com]. Laundry industries are great tape water consumers in their washing processes; therefore it would be very beneficial to the industry and to the environment to have new suitable technologies for treatment, reclaiming and reuse of these wastewaters in their own productive processes. In the international literature, there are only few studies on laundry wastewaters for their reuse.

Water and wastewater ozonation has become a very attractive treatment method due to the high oxidant and bactericide power of ozone [Finch 1994, Roustan 1991, Victor 1978, Masschelein 1982, Mork 2002]. Several papers have reported on the increased beneficial effects obtained when ozonation is combined with other treatment processes, such as coagulation-flocculation [Durán 2001, Mathonnet 1985, Orta de Velásquez 1998]. Therefore the combination of several treatment stages, involving coagulation-flocculation, sedimentation and filtration processes, followed by ozonation, could significantly enlarge the elimination of organic, inorganic and microbiological loads from wastewaters, allowing their reuse in the original washing processes or in other uses which require great water volumes.

The aim of the present paper was to evaluate at lab scale, the coagulation-flocculation, filtration and ozonation processes in laundry wastewater treatment for its possible reuse.

Experimental

Experimental conditions

The wastewaters were obtained from two industrial laundries in Havana's hotels with a washing capacity of 1–3 ton/day of every sort of clothing. Samples were taken at washing machine discharge water outlets once a week along a period of two months.

Treatment scheme consisted of a combination of coagulation-flocculation, filtration and ozonation processes. Firstly, the study was carried out on each separate operation and afterwards all combined treatment stages were performed in continuous.

Coagulation-flocculation process

It was carried out in a jar testing equipment (Janke&Kunkel). pHmeter Hanna was employed for pH values measurements. Two coagulants were studied: aluminum sulfate $Al_2(SO_4)_3.16\ H_2O$ (Analar) and commercial Aluminum polychloride (PAC) from Prosifloc. Applied doses for both coagulants were between 25 and 150 mg/L. To study the effect of pH on efficiency of coagulation-flocculation process pH values were set between 5 and 9, adjusted with sulfuric acid or sodium hydroxide solutions. Following economic criteria and to establish the required coagulant doses, turbidity removal of 80% was chosen as minimum accepted value.

Coagulation-flocculation process was performed in a 30 L tank adding the best coagulant dose obtained. Water was decanted into another tank from which it was pumped by a peristaltic pump to the filtration stage.

Filtration process

Two single inert filter media were used: silica sand and anthracite and the combination of both in a dual media. The filtration through active carbon was also studied. The effective size and the uniformity coefficient were determined, being for silica sand 0.43 mm and 1.32 respectively and for anthracite 0.66 and 2.50 respectively. Dual-media (sand-anthracite) consisted of 70% anthracite in the upper part of the filter and 30% of silica sand in the bottom, as reported in the literature [Maldonado 1992]. For filtration through active carbon, the filter employed had the same geometry as the one used for sand filtration and was located immediately after the sand filter. NORIT-PK active carbon with a particle size of 0.25-1.0 mm was employed.

The effect of filtration rates (5, 10, 15 and 20 m/h) on filtration efficiency was conducted in a laboratory pressure filter. Filtration rates were calculated according to the filter transversal area and the flow rates. Filtration efficiency was determined by turbidity and organic compounds removals, the last one measured as absorbance decrease at 254 nm.

Continuous treatment process

Once the operation parameters and chemical doses were established for each separate unit operation, experiments in continuous were performed using the combined treatment stages as a whole. Physico-chemical and microbiological analysis were performed on water samples taken at the inlet and outlet of each stage of the continuous process. Wastewater treatment scheme is shown in figure 1.

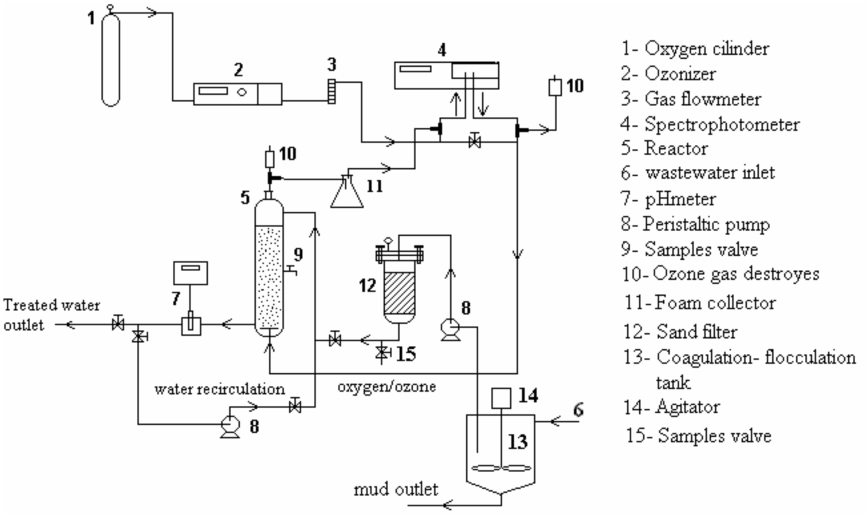

Figure 1. Laboratory experimental installation scheme for laundry wastewater treatment

All along the continuous treatment process special attention was focused on ozonation. Taking into account both the wastewater microbiological quality and economic reasons, two ozone gas concentrations (30 and 60 mg/L) and two gas flow rates (30 and 60 L/h) were tested. Ozone was generated in an AQOZO-LAB ozone generator, designed and constructed by Ozone Research Center (Cuba), which produces 5 g of ozone/h. A 4 L glass bubbling column was employed, provided with a porous borosilicate glass diffuser (porosity 250 microns) and a sample port located approximately at the half of the column height. At the gas outlet a foam collector was installed, followed by a catalytic ozone destructor for residual ozone.

Physico-chemical and microbiological analysis

- Gas ozone concentration: was determined at 256 nm in a spectrophotometer Ultrospec III, Pharmacia (UK).
- Dissolved ozone concentration: was measured in a Dulcometer dissolved ozone monitor (Prominent, Germany), previously calibrated with indigo trisulfonate method.
- pH determinations: A 8520 HANNA pH meter was employed.

- Absorbance at 254 nm: At this wavelength absorbs all the unsaturated compounds that are easily oxidized by ozone.
- Turbidity: A spectrophotometric method was employed, measuring the absorbance at 400 nm. A formazine calibration curve was used.
- Analysis developed following Standard Methods (1985) [Standard Methods 1985]:
  - Chemical oxygen demand (COD): Closed reflux colorimetric method (5220 D).
  - Anionic detergent : Methylene blue test was employed (SAAM)
- Microbiological test employed:
  - Total heterotrophs (UFC/ml) [ISO 6222, 1986]: The counting technique on plaques in agar tryptone - soy broth at 37oC was used.

Results and discussions

Characterization of wastewater.

Mean values of the wastewater parameters of the two selected laundries it is shown on Table 1. The high standard deviations and variation coefficients observed are rather high but it is normal in this kind of water, coming from wastewaters which differs from one sample to another, due to different sort of clothing, washing programs and chemical used. This variability determines the need of using an initial collector tank for water homogenization.

Table 1. Characterization of wastewaters from the studied laundries.

Parameters	**Laundry I**			**Laundry II**		
	Media	**S.D**	**V.C**	**Media**	**S.D**	**V.C**
pH	8,28	1,04	12,58	8,11	0,94	11,59
Turbidity (NTU)	84,21	49,65	58,97	170,79	73,78	43,20
COD (mg O_2/L)	334,55	154,83	46,28	331,32	163,34	49,30
Absorbance at 254 nm	0,84	0,38	45,01	1,00	0,29	29,16
Alkalinity (mg $CaCO_3$/L)	232,00	39,60	17,07	316,00	128,17	40,56
SAAM (mg/L)	-	-	-	20,87	6,21	29,74
Total heterotrophes (UFC/ml)	-	-	-	4,7 x 10^7	5,2 x 10^7	111,33

S.D: standard deviation V.C: variation coefficient SAAM : active substances to methylene blue

Coagulation – flocculation stages.

- pH influence:

For both coagulant doses employed, the higher removal percent when aluminum sulphate was added were at pH 6 (64.9 y 83.2 %) and when PAC was employed were at pH 7 (83.1 y 91.5 %).

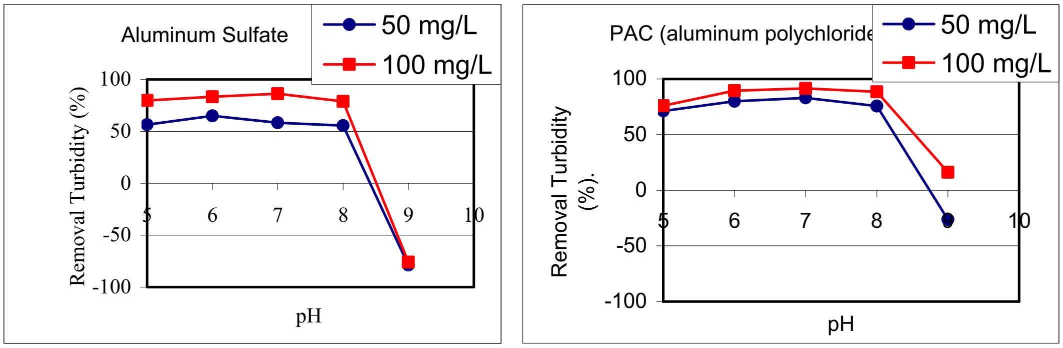

Figure 2. Influence of pH on turbidity removal for both coagulants.

The increment of turbidity at pH 9 for both coagulants studied could be explained by microfloc formation by aluminates ($Al_2O_3{}^{3-}$), that are responsible of the repulsion forces between the particles because of their negative charges. At this pH, PAC showed a lower negative influence as compared with aluminum sulphate.

As pH media of all the studied waters is around 8 (table I) and under this condition adequate turbidity removal are obtained (figure 2), the employment of a pH control system in the industrial application should be discussed.

Coagulant doses determination

At the selected pH values from the preceding study, four coagulant doses were assayed to obtain the best value from the efficiency and economical points of view. Figures 3 show the effect of concentration of both coagulants on turbidity and COD removals.

Best doses resulted 50 mg/L at pH 7 and 100 mg/L at pH 6 for PAC and aluminum sulfate respectively. In general, best results were obtained with PAC. Along this study the PAC/$Al_2(SO_4)_3$ ratio to obtain similar removal effects was 1:2. For those reasons PAC at a dose of 50 mg/L was chosen for the remaining experiments. A two-fold increase of this dose only slightly enlarges the removal effect so it is not economically advisable.

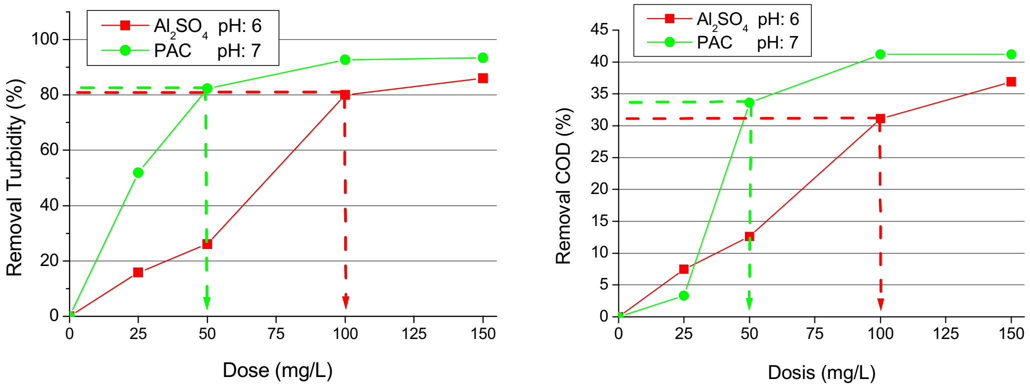

Figure 3. Effect of coagulant doses on turbidity and COD removal

Filtration process

Figure 4 illustrates of the filtration rate for the different filter media employed on the turbidity and absorbance at 254 nm removals. Among the filter media under study, only silica sand showed the adequate performance in turbidity removal at high filtration rate. Having a smaller granulometry, sand retains a greater quantity of particles at high filtration rates.

With respect to 254 nm absorbance removal, it can be observed that the three filter media exhibited the same behavior.

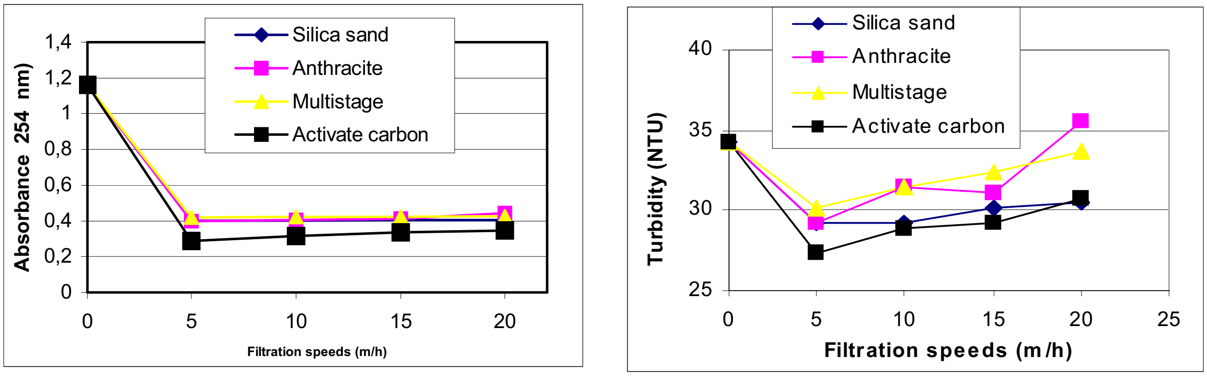

Figure 4. Effect of sand and active carbon filtration rate on the turbidity and absorbance at 254 nm removals

These results suggest that, in this case, silica sand filtration is the most suitable, considering that it is widely used in water treatment because of its low cost, easy operation and cleaning.

Figure 4 shows the turbidity and absorbance at 254 nm removals with the use of active carbon filtration at different filtration rates. The excellent carbon adsorptive properties are evidenced in the good removal values obtained which are independent of the filtration rate employed.

Evaluation of treatment stages in continuous

In figure 5 the turbidity removal in the different treatment stages is shown. It is observed that the highest removal percents are achieved in the stage of coagulation-flocculation. This is a logical behavior, taking into account that the main function of this stage is the elimination of suspended particles that represent the main contribution to the turbidity of water.

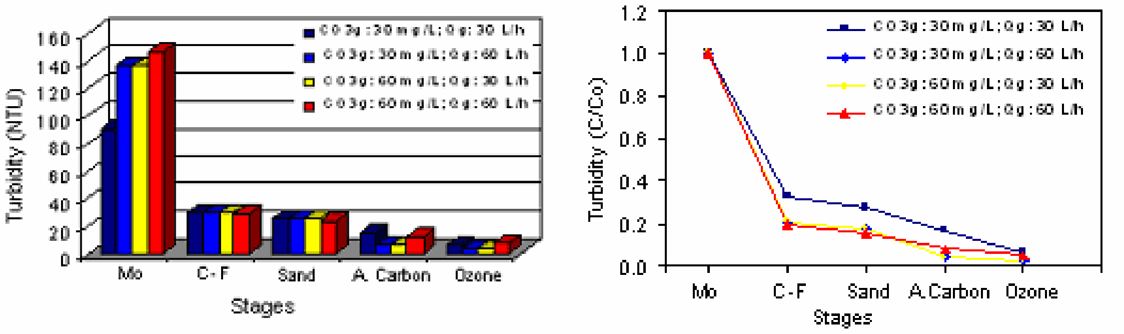

Figure 5. Effect of treatment stages on turbidity removal.

It was probed that the dose of the chosen coagulant (PAC: 50 mg/L) for this first treatment stage (figure 3), was the appropriate one to achieve around 80% of removal of turbidity, without consuming an excessive quantity of coagulant. The remaining 20% was removed in the later stages.

Note that with the use of activated carbon filtration and ozonation steps, the turbidity of water was less than 10 U.T, as established in the drinking water guidelines [N.C 93-02, 1985].

The use of activated carbon in the filtration stage allows the highest COD removal percents (figure 6). This result confirms that most of the chemical compounds and matter organic present in these water was adsorbed by active carbon. That is why the later ozonation step had not a significant effect on the removal of COD. It seems that the application of ozone mainly acted on the removal of microorganisms.
In the figure 7 the highest removals of compounds that absorb at 254 nm are obtained in the stages of coagulation-flocculation (60%) and filtration through active carbon (70%). In the stage of ozonation only slight removals of this parameter was obtained. This can be explained by the fact that this kind of compounds which could readily react with ozone were removed before.

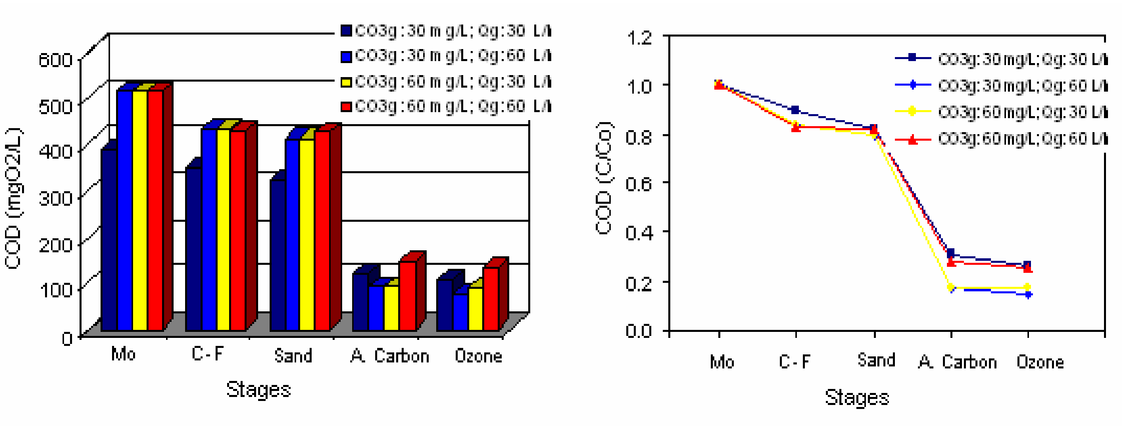

Figure 6. Effect of treatment stages on COD removal.

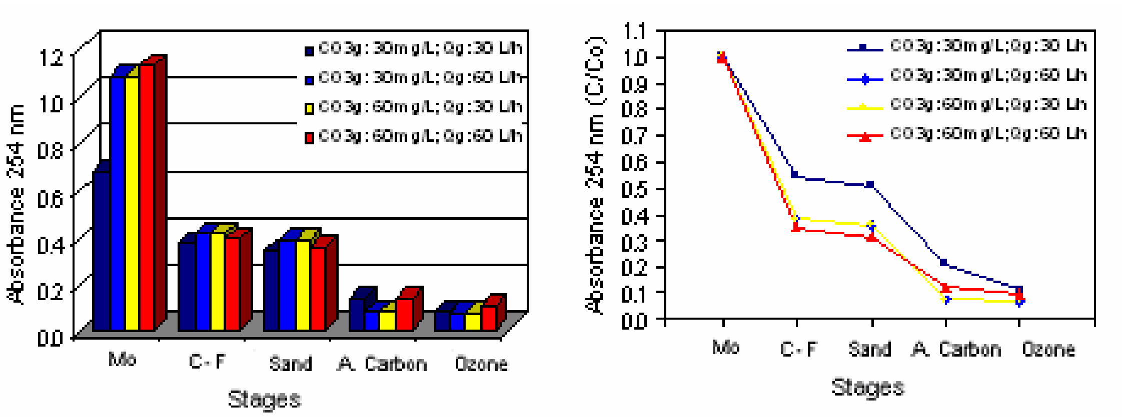

Figure 7. Effect of treatment stages on 254 nm absorbance removal.

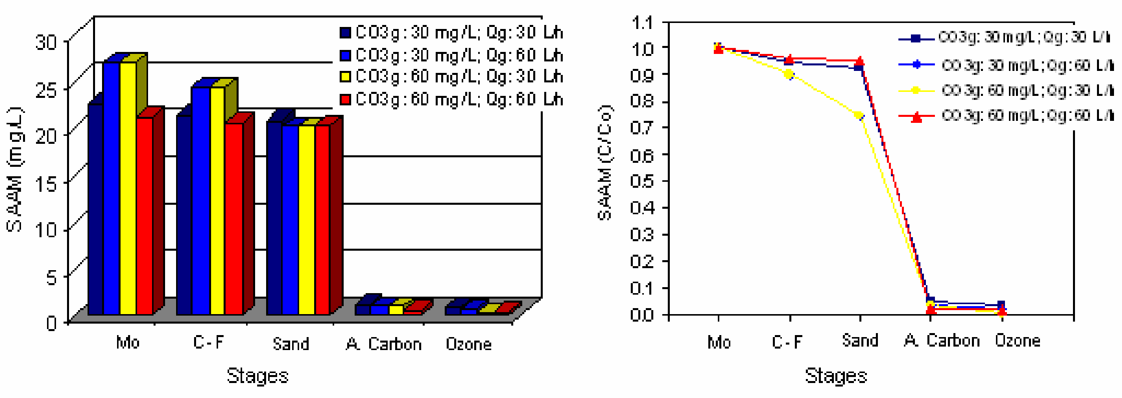

Figure 8. Effect of treatment stages on detergents removal.

In the case of the detergents (figure 8) it is evident that the active carbon filtration has a high efficiency in the removal of this parameter (96%). The others steps of treatment did not cause a good elimination of these compounds. As for other contaminants the ozonation step could not remove in a considerable way the low concentrations of detergents that remain after the previous stages.

Microbiological analysis

In Table 2 high contamination of microorganisms in wastewaters tested is shown. These high concentrations are due to the contribution of towels and bed clothes.

Table 2. Elimination of microorganisms after each treatment stage.

Samples	Total Heterotrophs (UFC / ml)	% Removal
Initial sample	$4,7 \times 10^{7}$	-
Coagulation-Flocculation	$7,2 \times 10^{6}$	**84,68**
Sand filtration	$7,0 \times 10^{6}$	**2,78**
Activated carbon	$2,5 \times 10^{6}$	**64,28**
Ozonation	$1,63 \times 10^{2}$	**99,99**

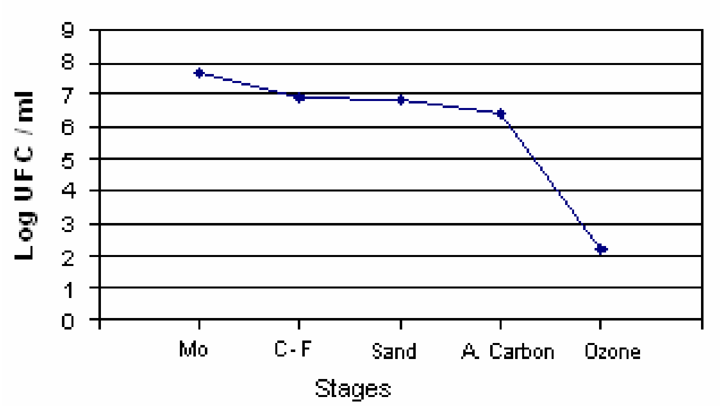

Figure 9. Influence of the treatment stages in the microorganism removal

In the ozonation stage significant results for the microorganisms removal are achieved (higher than 99,99%), fulfilling the Cuban drinking water guidelines(< 2×10^{2} CFU/ml of Total Heterotrophs). In the previous treatment stages the necessary removals to match guidelines were not reached.

Figure 9 shows that with the combination of all treatment stages a reduction of 5 logarithms of total heterotrophs were obtained, being the ozonation stage the responsible for the reduction of four logarithms.

Ozonation process evaluated in continuous.

In Table 3 is observed that the values of global transfer efficiency did not surpass the 53 %, for the applied and consumed ozone doses, and diminishes as the gas flow increases. Other authors [Bataller 2000] have reported that for a fixed gas ozone concentration, an increase of the gas flow rate implies, within certain levels, a transfer efficiency increase. The observed effect could be due to an excessive gas flow that implied a higher bubble ascent speed in the liquid and therefore smaller contact times and gas-liquid transfer. It could also be influenced by the presence of chemical products and detergents that are used in the laundry processes and that could be refractory to the ozone action.

On the other hand the small removal levels obtained for some of the parameters could also be due to the high pH value and the hydrogen peroxide content of the wastewaters. During ozonation at basic pH values free radicals are formed, which exhibit high oxidation potentials and reaction rates, but they could react with the hydrogen peroxide instead of existing pollutants. This behavior has been reported by other authors [Kuo 2000].

Table 3. Ozone doses, transfer global efficiency and removal percents obtained.

Exp.	$CO_{3\,g}$ e (mg/L)	$CO_{3\,g}$ s (mg/L)	Qg (l/h)	D.A (mg/L)	D.C (mg/L)	E.T (%)	% Removal				
							U.T	Abs. 254 nm	COD	SAA M	Totals Heter.
1	30	14	30	56	30	53	58.3	45.3	12.6	36.4	99.97
2	30	20	60	113	39	35	33.3	11.1	16.7	41.3	99.68
3	60	31	30	113	55	49	41.6	39.6	13.4	88.0	99.88
4	60	33	60	226	100	44	35.3	21.2	8.9	100.0	99.99

Legend:
CO3 g e: Inlet gas ozone concentration.
CO3 g s: Oulet gas ozone concentration.
Qg: Gas flow in the column.
D.A: Applied ozone dose.
D.C: Consumed ozone dose.
E.T: Transfer gas - liquid global efficiency.

The statistical analysis of data demonstrated that there were not significant differences in the four ozonation variants studied. As Cuban drinking water guidelines are fulfilled in all cases, but with the variant 1 higher transfer efficiency is achieved, the chosen ozonation condition is the corresponding to that of smallest ozone concentration (30 mg/L) and gas flow (30 L/h).

Summary of the combined treatment.

The Table 4 summarizes the averages values of experiments in continuous. It is observed that in the coagulation-flocculation stage the highest removal percents of turbidity and absorbance at 254 nm are achieved, while the highest removal percents of COD and detergents are achieved in the active carbon filtration stage. The highest microorganisms removal percents was obtained in the ozonation stage.

Tabla 4. Mean values obtained on each stage and partial and total removal percent.

Samples	Initial sample	**ETAPAS** (% remoción parcial *)				**% R. Total**
		Coagulation-Flocculation	Sand filtration	Activated carbon	Ozone	
pH	7,94	7,74	7,73	7,67	7,97	-
Turbidity (NTU)	127,0	28,9 (77 %)	24,3 (16 %)	9,52 (61 %)	5,3 (44 %)	**96,00**
COD (mg O_2/L)	483,0	409,1 (15 %)	391,2 (4 %)	112,1 (71 %)	100,0 (11 %)	**79,00**
Absorbance 254 nm	0,991	0,397 (60 %)	0,367 (8 %)	0,109 (70 %)	0,082 (25 %)	**92,00**
SAAM (mg/L)	24,4	22,5 (8 %)	20,3 (10 %)	0,86 (96 %)	0,41 (52 %)	**98,00**
Total Heterotrophs (CFU/ml)	4,7 x 107	7,2 x 10 ^{6} (84,68 %)	7,0 x 10 ^{6} (2,78 %)	2,5 x 10^{6} (64,28 %)	1,63 x 10^{2} (99,99 %)	**99,99**

% partial removal *: removal percent related to the previous stage.
% R. total: Total removal percent of the last treatment stage with related to the initial sample.

Taking into account the physico-chemical and microbiological results obtained, the waters obtained after the treatments could be used in the laundry processes, or for other purposes, for example: for watering of golf courts or gardens, car and floor washing, or other activities near to the laundries, always fulfilling in each case the guidelines according to the proposed use [EPA 1992, WHO 1989, Bontoux 1998].

Preliminary economic analysis.

- Annual operating cost

For a laundry with capacity of 10 tons clothes/day, with a water consumption up to 270 m^3 / day, working in continuous during 16 hours, on the basis of the equipment, chemicals and electricity costs for all treatment stages, and 85 % of water to recover, that would imply a water volume to treat of approximately 83 768 m3/year, the expected annual operating cost would be of approximately 31 099 USD / year.

- Cost / m^3 of treated water:

Annual operating cost / m^3 treated water = 0,37 USD / m^3

- Annual savings for 85% of the waste waters recovery.

Cost of tape water: 1,20 USD / m^3
Savings per m3 water = 0,83 USD / m^3
Annual savings = 0,83 USD / m^3 x 83 768 m^3 / year = 69 527 USD / year

From the estimated investment for this technological scheme at industrial scale (approximately 34 000 USD), for a laundry of washing capacity up to 10 tons/day, the investment recovery time would be smaller than one year.

Conclusions

- The aluminum polychloride (PAC) was the best coagulant, in dose of 50 mg/L.
- The activated carbon resulted to be very efficient in the removal of detergents (96%) and COD (71%).
- Based on quality and economic considerations, the most suitable ozonation conditions for laundry wastewater treatment were: gas ozone concentration of 30 mg/L and gas flow of 30 L/h, This treatment stage is very efficient in the disinfection, with microorganisms removals higher than 99,99%.
- With the proposed treatment scheme, waters with appropriate physico-chemical and microbiological characteristics are obtained, which could be reused in the laundry processes and other uses.

References

1. APHA, AWWA, WPCE, Standard Methods for the Examination of Water and Wastewater, 16 th Ed. USA, 1985.

2. Bataller. M. Caracterización de columna de burbujeo para el tratamiento de agua con ozono. Tesis doctoral. CNIC. 2000.

3. Bontoux. L. The regulatory status of wastewater reuse in the European Union. In: Asano. T, ed. Wastewater reclamation and reuse. Lancaster, PA, Technomic Publishing, 1998: 1463-1476.

4. Conteo Total de Microorganismos. International Standard, ISO 6222 : 88, 1986.

5. Comité Estatal de Normalización: N. C. 93-02 / 1985. Agua Potable, Requisitos Sanitarios y Muestreo. Cuba.

6. Durán. A, Gonzalez. E, Ramírez Rosa María. Comparación de dos procesos fisicoquímicos para el tratamiento de aguas residuales. Tecnol.Ciencia Ed. (IMIQ), 16 (1): 28-41, 2001.

7. Finch G.R, Black E.K. and Gyüreck L. Ozone disinfection of *Giardia* and *Cryptosporidium.* American Water Works Association Research Foundation, American Water Works Association, Denver, 1994.

8. Gurol M.D. y Nekouinaini S. Effect of organic substances on mass transfer in bubble aeration. J. Water Pollut. Control Fed. 57, 235, 1985.

9. Kuo,C.H, Zappi, M. E, Chen, S.M. Peroxone oxidation of toluene and 2, 4, 6 trinitrotoluene. Ozone Science & Engineering, 22, 519, 2000.

10. Masschelein WJ. Ozonization Manual for Water and Wastewater Treatment. Ed John Wiley and Sons, New York. 1982. Cap.28: 137.

11. Mathonnet. S, Casellas. C, Bablon. G, Bontoux. J. Impact of preozonation on the granulometric distribution of materials in suspensión. Ozone Science & Engineering, Vol. 7, pp 107-120, 1985.

12. Mork D., Tecnología en la generación de ozono. Pasado, presente y futuro. Conferencia regional, IOA, Ciudad México, 4, 2002.

13. Orta de Velásquez. M.T, Altamirano. J.M, Monje. I, Manero. O. Improvement of wastewater coagulation using ozone. Ozone Science & Engineering, Vol. 20, pp 151-162, 1998.

14. Maldonado. V. Manual de tratamiento de agua. Capítulo 9, Filtración. pp 83-152. CEPIS/OPS. Lima, Perú.

15. Roustan M., Stambolieva Z., Duguet J.P., Wable O. and Mallevialle J. Research note: Influence of hydrodynamics on *Giardia* cyst inactivation by ozone. Study by kinetics and by "CT" approach. Ozone Science & Engineering, Vol. 13, pp 451, 1991.

16. US Enviromental Protection Agency / US Agency for International Development. Guidelines for water reuse. Washington, DC, Environmental Protection Agency, Office of Wastewater Enforcement and Compliance, 1992 (technical report no. EPA/625/R-92/004).

17. Víctor J. E, Scott. C, McGinnis. K. T. Ozonation in a wastewater reuse system: examination of products formed. Journal WPCF. July 1978. pp 1727-1732.

18. WHO, Health guidelines for the use of wastewater in agriculture and aquaculture, World Health Organization. Tech. Rep. Series 778, WHO, Geneva, Switzerland, 1989.

19. www.hydroxyl.com / CLEANSEA. Laundry Water Re-use.

20. www.laundrytoday.com / Understanding Ozone-The natural way to purify air & water.