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Chemical treatment and reuse applications for latex paint industry wastewater

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ABSTRACT

Latex paint industries in Peru produce high volumes of wastewater discharges. This wastewater shows high concentration of suspended solids (>5,000 ppm), COD > 1,000 ppm and bacterial content (>100,000 CFU/mL). This study describes a suitable treatment technology for latex paint industry wastewater that allows treated water reuse in latex paint production. Treatment of these effluents consisted on a physicochemical treatment, using aluminium polychloride (PAC) as coagulant and anionic polyacrylamide (PAM) as flocculant. Process worked with 3 m^3/h treatment flow in following doses: 1,200 ppm PAC and 2 ppm PAM, and hydraulic retention time of 5 h. Clarified water, after disinfection treatment with sodium hypochlorite (10 ppm and 1 h of contact), met the following standards: TSS = 12 ppm, TDS = 680 ppm, free chlorine = 0.6 ppm, pH = 7.3 and bacterial content lower than 1,000 CFU/mL. Three types of acrylic latex paintings with treated water, and quality standards such as pH, viscosity, and density fell within the quality limits, were produced. Up to 56 % of raw wastewater production was obtained and wastewater recycling is a profitable activity due to the economic savings.

Keywords: Wastewater treatment; Wastewater reuse; Latex paint industry; Acrylic paint; Disinfection treatment; Chemical treatment

1. Introduction

Water is an increasingly scarce resource, so its rational use is necessary, which implies sustainable water management. Reused wastewater could be regarded as a new water resource, mainly when it is used in regions where freshwater is scarce [1]. Latex paint industries in Peru generate significant discharges of industrial wastewater, which are approximately 100 m^3 a day per production plant. For this reason, this study aims to check the feasibility of reuse application.

Latex paint manufacturing wastewater emitted from washing operations of production equipment (Fig. 1) has some coloration, suspended solids and organic material contents above the wastewater discharges concentration limits [2]. Likewise, bacterial content is high, because some organic components of latex paints formulation – such as cellulosic thickener, polyphosphate humectant, and amine bases – are nutrients for bacteria [3], making wastewater unsuitable for its discharge into water bodies or for its direct use as process water in latex paints production. For these reasons, effluents treatment is necessary to recover water with determined specifications [2,4].

The most common treatments for these effluents are microfiltration [5], coagulation-flocculation [6–9] and oxidation [4,9], which allow meeting the quality requirements for wastewater discharge into natural water bodies. In the same way, among the variety of coagulants used for the treatment of these effluents, PAC, alum, $FeSO_4$, and $FeCl_3$ are the best options because they efficiently remove COD, suspended solids and color [8]. The right selection of the coagulant depends on its treatment efficiency and sludge generation [8,9].

Extensive research is available on wastewater reuse applications in different industries, such as petrochemical, textile, cement and fish canning. For textile industry, the

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effluent is treated using nanofiltration or ultrafiltration to obtain treated wastewater for its reuse in the textile production process [10]. In addition, research related to reusing fish canning industry wastewater, whose treatment based on coagulation-flocculation, filtration, disinfection, and biological processes, is well known. These technologies allow reuse application in the processes and reduce freshwater consumption [11].

For reuse purposes, the quality of the treated water must be similar to the quality of the process water used for production of latex paints. One of the most critical aspects is bacteria presence in the water, which must be the minimum to avoid bacteria proliferation in manufactured coatings. For this reason, treated water must contain a certain amount of biocide remaining to prevent the spread of bacteria and adverse effects on paint properties, such as pH and viscosity. In addition to treated water analysis, it is essential to evaluate the parameters or critical properties of paints produced with treated water, in order to determine if they meet the quality standards [4]. It is necessary to take into account that these evaluations must be carried out from time to time to verify that the manufactured paints are stable over time and that their useful life is unaffected [3].

This study describes the chemical treatment of latex paint manufacturing wastewater by using coagulation-flocculation and disinfection process. Likewise, this paper explains and discusses a proposal to reuse the treated water in the production of latex paints, based on parameters obtained from water analysis – such as TDS, TSS, COD, and bacterial concentration – and quality parameters of the paints produced with treated water. It also explains the economic feasibility that justifies the recovery of the investment made in the wastewater treatment, recovery/recirculation system and operating costs.

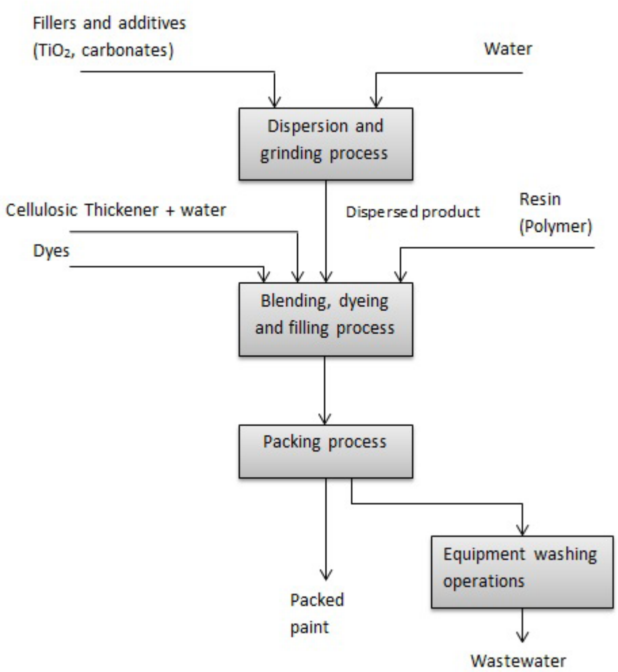

Fig. 1. Production process scheme of latex paint.

2. Methods and materials

The wastewater was directly collected from the wastewater reservoir of a production plant (paint company). Effluents were pink and chemical analysis results are shown in Table 1, as well as for filtrate obtained through 0.45 µm membrane filter. This filtrate simulates the efficiency of coagulation process, TSS removal and gives the values of soluble parameters. For example, it shows that soluble COD, nitrogen and phosphate contents are significant and contribute to the high bacterial concentration.

Coagulation-flocculation is one of the most important and widely used treatment processes of raw water [12] and industrial wastewater [13], due to its simplicity and effectiveness. The coagulation and flocculation tests were performed by jar tests. The coagulant used for the tests was aluminium polychloride (PAC), and anionic polyacrylamide (PAM) as flocculant. In this study, PAC was coagulant selected due to its high performance in TSS and COD removal in paint industry wastewater [8]. Besides, PAC helps to remove TDS because hydrolyzed products are formed [14].

Due to clarified water was bacterial polluted; sodium hypochlorite (NaClO) assays were performed in order to reduce bacterial levels [15]. Optimum sodium hypochlorite dose was determined by measuring free chlorine and bacterial levels in the treated water. Once optimal doses in ppm of PAC, PAM and sodium hypochlorite are determined at laboratory level, the tests were replicated at plant level with 3 m^3/h treatment flow. The treatment equipment consisted on an online system of coagulant and flocculant dosage, a sedimentation tank, and a chlorination tank.

By means of tests performed at the plant level, the following parameters were analysed in the treated water: pH, turbidity, bacterial concentration, TDS, oil and grease, COD, total suspended solids (TSS) and aluminium. Oil and grease, COD, BOD, TDS, TSS, aluminium, chloride, nitrogen, and phosphate were measured according to the standard methods [16]. Turbidity was measured by a portable Hach turbidimeter Model 2100 Q. A Hanna pH-meter HI 2221-01 was used for pH measurements. Likewise, free chlorine was measured by a colorimetric test kit Hanna HI

Table 1
Acrylic latex paint raw wastewater and filtrate results

Parameter	Raw wastewater	Filtrate (0.45 µm)
Oil and grease (mg/L)	89	31
BOD (mg/L)	1750	885
COD (mg/L)	10 241	1972
TSS (mg/L)	16 817	1.1
TDS (mg/L)	1943	1907
Chloride (mg/L)	21	19
Aluminium (mg/L)	117.5	0.94
pH	7.4	7.5
Turbidity (NTU)	>1000	7
Bacterial concentration (CFU/mL)	10^5	10^4
Nitrogen (mg/L)	31.5	30.1
Phosphate (mg/L)	77.7	46.9

3875. Finally, a Troy microbiological test kit was used for bacterial concentration measurements. This method compares colonies density on bacterial indicator to a microbial comparison chart [17].

At the plant level, flow measurements were carried out using a Global Water FP 211 flow meter. These measurements made possible to compare the raw wastewater flow entering the treatment system against treated water flow and estimate wastewater recirculation percentage both in the production process.

For assessing technical feasibility of treated wastewater reuse in the latex paint production process, three types of latex paints were prepared with the treated water: acrylic, styrene acrylic, and vinyl acrylic latexes. Most critical properties were measured: pH, density (kg/gallon) and viscosity (Krebs Units), and compared to the quality standards. In addition, stability tests were performed to ascertain the existence of any alterations in coatings during the storage period, at temperatures of 20°C and 40°C. Resins, fillers, pigments, plain process water and treated water were used to prepare latex paints. To measure the properties of coatings, viscometer (Brookfield, KU-2), pycnometer and potentiometer (HANNA, HI 2221-01) were measured.

Finally, economic assessment of treated water reuse in the process was made. Operational costs (such as chemicals for water treatment, workforce, and energy cost and sludge disposal) were estimated, as well as investment costs (pump, storage tank and piping for the recirculation system of the treated water). Finally, the cost reduction in consumption of freshwater and fine avoided due to compliance with regulations on wastewater discharges reduction was also calculated. These economic parameters quantified the economic savings by reusing the treated water [18]. All costs and estimated savings were calculated through quotations, regular prices, and fine amount related to regulatory standards in Peru for wastewater discharges.

3. Results and discussion

For setting up the PAC optimum dose (in ppm) for the physicochemical treatment, tests using different doses to obtain clarified water with the lowest turbidity were carried out. The results are shown in Table 2.

Addition of PAC to the wastewater removes TSS, TDS, COD, and greatly reduces turbidity. As shown in Table 2, the optimum dose of PAC is 1200 ppm. If a higher dose is applied, turbidity, TDS, and COD values increase due to excess products of hydrolyzed PAC in dissolved and particulate forms in the treated water.

The sedimentation rate has been improved by adding flocculant, so PAM dosification was set at 2 ppm. With a higher dose, the suspended solids start to float up, whereas with a lower dose the sedimentation rate turns lower.

In addition to the tests performed with PAC, tests with $FeSO_4$, $FeCl_3$, and Alum were performed as well. Figs. 2 and 3 show TSS and COD removal efficiencies for these coagulants. In comparison with the other coagulants, PAC was the coagulant giving the highest TSS and COD removal efficiencies.

Besides the coagulant, the optimal dose of sodium hypochlorite (NaClO) was tested by using different doses

Table 2
Turbidity, TDS, pH, and COD values with different doses of PAC

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
PAC dose (ppm)	800	900	1000	1100	1200	1300
PAM dose (ppm)	2	2	2	2	2	2
Turbidity (NTU)	80	50	30	20	10	40
TDS (mg/L)	1134	1013	876	768	635	697
pH	7.4	7.4	7.5	7.5	7.5	7.5
COD (mg/L)	3228	2984	2546	2031	1892	1957

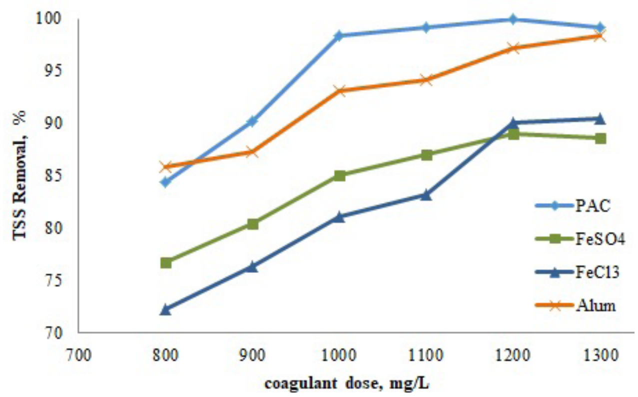

Fig. 2. TSS removal efficiencies with the addition of different doses of coagulants.

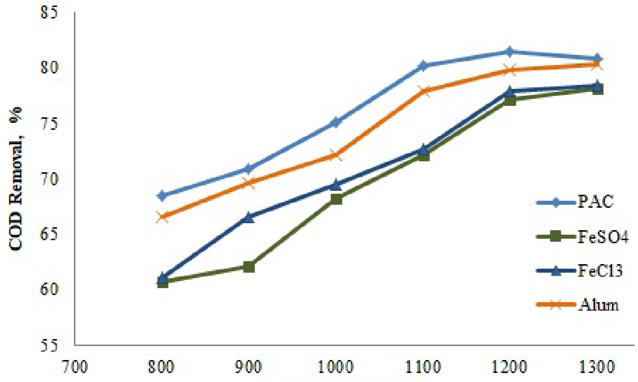

Fig. 3. COD removal efficiencies with the addition of different doses of coagulants.

in order to obtain treated water without bacterial contamination and with a significant concentration of free chlorine. The results show in Table 3.

As shown in Table 3, the addition of sodium hypochlorite to the clarified water reduces bacterial concentration. The optimal dose of sodium hypochlorite is 10 ppm with a contact time of one hour. Under these conditions, the

Table 3
Bacterial concentration, TDS, pH, and COD levels with different doses of sodium hypochlorite (NaClO)

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
NaClO dose (ppm)	5	6	7	8	9	10
Free chlorine (mg/L)	0.0	0.0	0.2	0.2	0.4	0.6
Bacterial concentration	Heavy	Slight	Slight	Slight	Slight	Very slight
(CFU/mL)	10^5	10^4	10^3	10^3	10^3	$< 10^3$
TDS (mg/L)	641	647	654	662	673	682
pH	7.5	7.4	7.3	7.3	7.2	7.2
COD (mg/L)	1616	1428	1279	1045	1011	951

Table 4
Obtained results of the parameters before and after physicochemical and disinfection treatments

Parameters	Before	After	% Removal
BOD (mg/L)	1750	374	78.6
COD (mg/L)	10241	964	90.6
TSS (mg/L)	16817	12	99.9
TDS (mg/L)	1943	680	65.0
Aluminium (mg/L)	117.5	0.133	99.9
pH	7.4	7.3	–

Table 5
Raw wastewater and treated water flow rates measured at the plant level

Flow measured	Raw wastewater	Treated water
Flow rate 1 (m^3/d)	62.2	32.7
Flow rate 2 (m^3/d)	70.5	40.6
Flow rate 3 (m^3/d)	72.5	42.5

treated water presents minimal microbiological contamination, and the presence of free chlorine ensures its preservation over time. Likewise, the addition of NaClO reduces soluble COD concentration due to its oxidation power and pH value slightly decreases. The TDS content increases due to the sodium dissolved.

After obtaining optimal doses of PAC, PAM and sodium hypochlorite, the parameters of the raw wastewater (before treatment) and treated water (after treatment) are compared. The results are shown in Table 4.

The results presented in Table 4 show that chemical treatments successfully reduced all the parameters evaluated by more than 85% (removal percentage). The application of these technologies removed TSS, aluminium, and COD efficiently. However, it is necessary to verify treatment efficiency after every reuse cycle to set up the number of reuse cycles based on TDS concentration. Process water used in latex paint production has a TDS limit content of 1000 ppm, so it would be recommendable that treated water does not have a TDS concentration over than 1000 ppm.

About COD remaining content in treated water, it meets the regulatory standards in Peru related to wastewater discharges. Nevertheless, its concentration is quite significant, so a complementary treatment technology – such as advanced oxidation or electrochemical methods – would be necessary for removing COD and residual organic matter. However, it was not used since the significance of this study is investigating the reuse of treated water obtained by coagulation-flocculation and disinfection treatments.

As part of the technical feasibility of reusing the treated water in the production process, the flow rates of raw wastewater and treated water were measured at the plant level. These results are shown in Table 5.

As shown in Table 5, the treated water flow rate corresponds to 56% average of the raw wastewater flow rate. The treated water flow corresponds to the water flow for reuse or recirculation. Therefore, 56% of wastewater recirculation is obtained in the production process. The difference between these two flow rates is due to the hydraulic retention time of 5 hours and sludge formation, whose generation rate is 1990 kg/d.

As pointed out, latex paint manufacturing process consumes abundant water and generates large amounts of wastewater. For this reason, from the environmental management approach, the proposal of reusing the treated water seems to be a sustainable alternative. Thus, even if the treated wastewater does not meet the requirements for its disposal, an alternative would be reusing the treated water in the production process. Likewise, the feasibility of reusing the treated wastewater depends on its quality and its performance in latex paint production. To this end, it is necessary to set up specific tests to assess the meeting of quality control requirements.

To verify reuse application, the treated water, with the characteristics indicated in Table 4, was tested as process water in latex paint production. Test paints produced with treated water were evaluated according to the quality control adopted by the paint company. Table 6 shows the results of the properties of the test paint (acrylic) and standard paint (made with conventional process water). In addition, it shows the recommended values for the properties.

According to the results presented in Table 6, the paints properties produced by the treated water meet the recommended quality values required by the company. When comparing the features of the test paint with the standard, both viscosity and density are slightly higher, since the treated water has a higher concentration of suspended sol-

Table 6
Quality results for acrylic latex paints produced

Properties	Test paint	Standard paint	Recommended
Viscosity (KU)	120.1	119.2	110.0–125.0
pH	8.6	8.46	8.0–9.0
Density (kg/gallon)	4.93	4.92	4.9–5.1

Table 7
Stability test results of test paint and standard paint (acrylic)

Stability (viscosity)	Test paint	Standard paint
Initial viscosity (KU)	120.1	119.2
Stability 40°C (accelerated)		
To 7 days	117.9	119.4
To 15 days	121.9	121.3
To 30 days	120.1	120.3
Stability 20°C (room temperature)		
To 15 days	120.1	121.1
To 30 days	119.7	121.3

Table 8
Economic feasibility of reusing treated water

Economic parameter	Monetary value 10^3, US$/year
Total operating cost	32.8
Total investment cost	6.3
Cost reduction by reusing water	8672.2
Total saving	8633.0

ids than process water, resulting in a slight increase in the values of these properties. However, these values do not exceed the recommended values to maintain the quality of the paints. Respect to pH, the results of test paint and regular paint are similar.

For analysing the paints stability produced with the treated water, the tests were carried out at 20°C and 40°C during 30 days. During the 30-day test at 40°C, the viscosity was checked as a stability indicator. Likewise, the stability tests were performed at room temperature (20°C) to determine if there are significant changes in viscosity with the passage of days. In Table 7 comparison of the stability results of the test paint with the standard coating (acrylic) is shown.

According to the stability results presented in Table 7, the viscosity of the test paint falls within the allowed range, and it is practically stable during the storage period. This stability is explained because of non-significant bacterial concentration, which consumes cellulosic thickener and generates viscosity decrease. During the stability period, the viscosity values of the test paints were very similar to the viscosity values of the regular paint. Therefore, according to these results, acrylic latex paints produced with treated water are stable for storage.

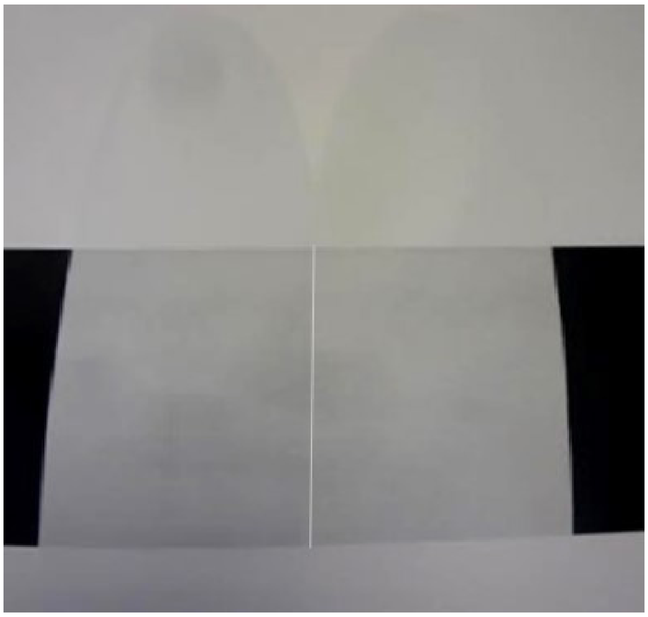

Fig. 4. Comparative color test and hiding power of paint applications.

In addition to evaluation of viscosity, density and pH, the color and hiding power of test paints were also evaluated. For this purpose, painting applications were performed on a black striped surface, comparing the hiding power and the similarity in color. Fig. 4 shows the acrylic latex paint application on a black striped surface to examine the regular paint (left side) and the test paint (right side) applications, and the results show that paint applications are similar. The colors are identical and cover the black stripe equally. For these reasons, there is no significant difference between both paints.

The economic assessment of reusing treated water in the production of latex paints is compiled in Table 8. As shown, the saving is quite significant since reusing the water reduces the costs of freshwater consumption, and avoids the payment of fines. The amount of these penalties is due to the high volumes of wastewater discharge with excessive pollutant load (high concentration of suspended solids, COD and BOD).

Total saving was calculated by the following equation:

$$\text{Total saving} = \text{Cost reduction by reusing water} - (\text{Total operating cost} + \text{Total investment cost})$$

4. Conclusions

The coagulation-flocculation and disinfection processes are efficient to obtain treated water with good quality that can be reused in the production of latex paints. The removals percentage of BOD, COD, TSS, TDS, and aluminium are 78.6, 90.6, 99.9, 65.0 and 99.9%, respectively. Also, considerable volumes of treated water are obtained, being up to 56% average of the volume of production of raw wastewater.

According to the economic feasibility of reusing the treated water, considerable savings are obtained, making it a profitable activity in Peru.

Wastewater treatment and reuse applications, besides the economic benefit, have ecological benefits due to the sustainable water management: reduction of the consumption of water resources and reduction of wastewater discharges into natural water bodies.

It is recommended to treat the sludge generated in the physicochemical treatment, to recover carbonates, fillers, and pigments, which could be used as raw materials for the production of paints. If this occurs, latex paint manufacturing wastewater could be reused up to 100%.

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