Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2018.21761

101 (2018) 151–156
January

Characterization and treatability of alkyd resin production wastewater

Olcay Tünay*, Deniz Çakır, Işık Kabdaşlı

Environmental Engineering Department, Civil Engineering Faculty, İstanbul Technical University, 34469 Maslak, İstanbul, Turkey, Tel. +90 212 285 65 75; email: tunayol@itu.edu.tr (O. Tünay), Tel. +90 507 213 21 99; email: dennysdc@gmail.com (D. Çakır), Tel. +90 212 285 65 86; email: kabdasli@itu.edu.tr (I. Kabdaşlı)

Received 18 July 2017; Accepted 3 December 2017

ABSTRACT

Wastewaters originating from alkyd resin production are typical examples of strong organic effluents containing toxic compounds. In this study, characterization and pretreatment of alkyd resin production wastewaters were experimentally assessed. The study aimed to remove toxics, reduce the strength of wastewaters to provide safe storage and their acceptability by joint treatment systems. Physical–chemical treatment methods were employed for pretreatment to ensure their applicability at every industrial scale. Wastewaters originating from the production were strong containing 23–40 g/L COD. Air stripping tested as a first stage of treatment proved to be efficient reducing COD up to 40% removing solvent residues and volatile matter and increasing the BOD_5/COD ratio 0.57 of raw wastewater to 0.70. Acid cracking process made use of acid character of wastewater which had been enhanced by $FeCl_3$ addition provided additional 10%–33% COD removal (overall COD removal 60%). Coagulation–flocculation with $FeCl_3$ or alum worked better following aeration and acid cracking and increased COD removal with an additional 25%. Saponification provided limited COD removal. Aeration was the key process in removing toxics and reducing wastewater strength. The tested physical–chemical treatment after aeration worked well with varying efficiencies reaching total COD removals exceeding 60%.

Keywords: Acid cracking; Air stripping; Alkyd resin production wastewater; Coagulation–flocculation; Esterification; Strong wastewater treatment

1. Introduction

Industrial pollution which poses significant adverse effects on the environment requires frequently a case by case evaluation for effective control. This is particularly valid for those industries producing toxic and/or concentrated wastewaters [1]. Such cases often arise for chemical industries which have a great spectrum of products manufactured using a variety of processes from which toxic or otherwise hard to deal waste streams originate [2]. As a consequence, scientific literature is rich in this area. There are a number of studies for the characterization and handling of strong wastewaters of organic nature, originating from organic chemicals industry as well as from a variety of other sources. Polyester manufacturing wastewaters [3] textile printing wastewaters [4], painting wastewaters [5], semiconductor wastewaters [6], oily wastewaters [7], are examples of such studies. Alkyd resin production, on the other hand, is one of the most common processes which also yields highly polluted and toxic wastewaters yet studies for waste control for this industry are rather scarce. Alkyd resin is the main ingredient of solvent-based paints and has several other uses [8,9,10]. Alkyd resin production is realized worldwide on varying scales of plant capacities from small workshops to large integrated chemical plants [11]. The wastewaters originating from the industry are concentrated having 20–40 g/L COD and contain toxic compounds such as solvents [12]. The wastewaters exhibit a significant treatment demand before being discharged into joint treatment systems. On the other hand, the processes planned for the treatment of the industry are needed to be applicable by relatively small enterprises.

This study attempts to evaluate the alkyd resin production processes, to define waste streams, their characterization and to conduct treatability studies in the context of reducing

---

* Corresponding author.

1944-3994/1944-3986

wastewater strength and removing the compounds that may inhibit or interfere with joint treatment systems embodying biological treatment. The process analysis and wastewater characterization are based on an alkyd resin production plant which is housed in an integrated paint production factory located near Istanbul.

2. Material and methods

2.1. Analysis methods

Organic matter was determined using collective parameters namely, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), and total organic carbon (TOC). COD indicates virtually all oxidizable organic matter content of the sample measured by dichromate as an oxidizer. COD was determined by the open reflux titrimetric method according to ISO 6060 [13]. All other analyses were performed as defined in Standard Methods [14]. BOD_5 being a measure of biologically degradable organic matter was determined by a 5-d BOD test. TOC is a rapid method that analyzes for organic carbon and expresses the result as the amount of carbon found. It was monitored on a Tekmar Dorhmann Apollo 9000 model carbon analyzer using combustion at very high temperatures with a reusable platinum catalyst maximizing TOC recovery. Suspended solids were determined by total suspended solids dried at 103°C–105°C. Sulfate was measured by $BaSO_4$ precipitation followed by ignition of residue using gravimetric method. Chloride was determined by mercuric nitrate method. Oil and grease defined as solvent extractible matter was measured by Soxhlet extraction method. pH measurements were made with Orion 720A+ model pH meter.

2.2. Wastewater production and characterization

Alkyd resins are a sort of synthetic resin which are produced through condensation reaction of polyalcohols and poly-functional organic acids. There are many types of alkyd resins produced from different raw materials, although the production process is the same. The process can be realized by using either fatty acids or fats. If fats are starting material a pre-processing is needed to convert the fats to monoglycerides. This step is accomplished by reacting the fats with a polyalcohol such as glycerol. This reaction is termed alcoholysis. After alcoholysis or if the fatty acids are starting material, a poly-condensation reaction which is basically an esterification process is employed to produce alkyd resins [1,8]. An esterification reaction is combination of a carboxylic acid and alcohol to yield an ester and water. The produced water in this reaction is the main source of wastewater from the process. Solvents are also used in the esterification process to remove water. The amount of wastewater originated from alcoholysis process was quite low and determined to be around 0.3 L/ton of production. This waste stream was concentrated having COD values of 300–400 g/L and was classified as hazardous waste [15]. Therefore, the main wastewater source in the investigated plant was esterification process. Alkyd production is a batch process. At the end of the process the product was extracted while the wastewater was collected in a pit. After the wastewater discharge was completed, its volume was measured and following a vigorous mix, the samples were taken from the pit. The samples were collected for the productions which used raw materials; monoglycerides obtained from soybean oil, phthalic anhydride and xylene as a solvent in the present study. This combination corresponded to the most common process. Although the raw materials remained unchanged, process variables such as degree of polymerization, pH and temperature were changed depending on the required product specifications. These changes were reflected in the wastewater quality.

Our evaluation for a variety of products indicated a range 10–20 L of wastewater per ton of product, however, the amount was frequently closer to the upper end. For the characterization of esterification wastewater samples were taken for productions of different character and results are presented in Table 1.

Other parameters measured but not listed in Table 1 were chloride, sulfate, oil and grease, and suspended solids. Suspended solids concentration ranged between 60 and 80 mg/L with an average value of 70 mg/L. Chloride concentration was measured as 7.0 mg/L. Sulfate concentration was below detection limit (10 mg/L) of gravimetric analysis. Oil and grease concentrations varied between 12 and 18 mg/L with an average of 15 mg/L. Therefore, pH and organic matter were the main parameters characterizing the wastewater in the present study. The BOD_5 of sample II was measured and BOD_5/COD ratio was found as 0.57 which indicated, considering the BOD_5/COD ratio of domestic wastewater is 0.68, a moderately biodegradable wastewater. COD of samples was variable. COD/TOC ratios varied between 3.75 and 4.4 indicating this variability was also affected by structural differences. However, the amount of wastewater produced through the process was another determining factor of wastewater strength [15]. We could reach only two studies to make a comparison of wastewater character. Schwingel de Oliveira et al. [16] have given the wastewater strength of alkyd resin production as 80,750 mg/L COD and 33,600 mg/L TOC. Process definition of the source was not given in their study. The wastewater strength used in their study was greater than that found in our study and COD/TOC ratio was 2.40 which was also different from our study. Kausley et al. [12] reported the wastewater strength of an alkyd resin production facility where phthalic acid was used, as pH 2.3 ± 0.1, TOC: 14,500 ± 100 mg/L, COD: 39,500 ± 100 mg/L, and BOD_5: 19,000 ± 100 mg/L. The ratios COD/TOC and BOD_5/COD were calculated as 2.72 and 0.48, respectively. Their wastewater had a greater similarity to wastewater used in our study in terms of parameter values, although COD/TOC value was still lower than that found in this study.

Table 1
Character of wastewaters of esterification process

	Sample I	Sample II	Sample III
COD (g/L)	35–38	23–24	35–40.5
TOC (g/L)	8–9	6–7	8–12
pH	2.0–2.5	2.0–2.5	2.0–2.5

2.3. Planning of treatability study

The wastewaters, although BOD_5 value indicated a moderate biodegradability, were strong and required to be diluted before biological treatment. However, dilution requirement was high and could be facilitated if the wastewater was partially treated. Alkyd resin is produced in either integrated plants or small plants. Wastewater production in integrated plants is limited originating only from water-based paint production. In both types of plants, alkyd resin production capacity varies with time. All wastewaters are combined and treated in a central treatment plant which is generally comprised of chemical and biological units in integrated plants. These plants may handle alkyd resin wastewaters with a careful metering after a dilution so as to comply with the limitation of biological treatment. Small plants either haul or discharge their wastewaters into sewer which may particularly for highly concentrated wastewater place an economical burden. On the other hand, a temporary storage of alkyd resin wastewaters is needed for both types of plants. The storage may pose a hazard to environment due to toxics (mostly solvents) emission. These toxics also inhibit biological treatment. Aeration is considered a simple and effective means of removing solvents which can be captured using activated carbon, oils or any other cheap material to control air pollution.

The treatability study was planned taking into account the above rational and requirements. Therefore, the first step was considered as the removal of volatile fraction using the aeration as the simple expedient. This application was aimed to control toxics for safe storage of the wastewaters as well as to facilitate further treatment, particularly biological process. Aeration was effective in removing volatile materials and proved to be an efficient process in the case of textile printing wastewater treatment [4]. Further treatment steps were also planned as low cost, physical–chemical processes that could be realized even at small facilities. Acid cracking is the main treatment applied to oily wastewater at acidic pH values. Alkyd resin wastewater contains oils and compounds made up of oils and its pH is acidic. Hence, acid cracking was envisaged as the first step of treatment after aeration. The wastewater contains oil emulsion with high negative surface charges which apparently cannot be neutralized by the positive charges of hydrogen ions. Therefore, the application was aimed to provide additional positive charges by adding $FeCl_3$ being soluble at pH 2.0. This addition supplies high amount of positive charges through ferric iron (Fe^{3+}) and hydroxo complexes by which oil particles are neutralized and coalesce to be separated by gravity. $FeCl_3$ was selected as the source of (3+) valence ions since it had the advantages over alum such as ease of solubilization, ease and fastness of precipitation and separation at near neutral pH as well as non-toxic character with respect to alum. Coagulation and flocculation was applied in place of or in addition to acid cracking. The starting point was that the wastewater after acid cracking was highly acidic and needs to be neutralized before handling. Coagulation and flocculation with the addition of a coagulant working at a neutral pH such as alum can be realized through neutralization and simply adding an appropriate coagulant to remove further colloids of any kind as well as adsorbable soluble organics. Saponification is an alkaline hydrolysis of fatty acid esters. Metallic soaps are produced using alkaline earth or heavy metals. Metallic soaps are insoluble in water and have a wide spectrum of usage as lubricants, dryers, sizing of textile material, etc. Considering the existence of fatty acids in various forms in the alkyd resin wastewater saponification process using calcium and barium was also tested. The metals selected for this process were relatively non-toxic and had a potential of reuse.

2.4. Experimental procedure

Aeration was realized in Erlenmeyers into which air was fed through diffusers. The system was operated either open to the atmosphere or connected to scrubbers containing aqueous alkaline solution. Three gas washing bottles connected in series were used for this purpose. Aeration was accomplished both at pH 2.0 (original pH of the samples) and at pH 7.0. Air flow was varied between 1.6 and 6.4 $m^3/L\,h$ where L is the aerated wastewater volume in liters. 1.6 $m^3/L\,h$ air flow is denoted by Q. Acid cracking experiments were run in a jar test with 15 min flash mixing, 15 min slow mixing and 2 h separation sequence. The experiments were conducted at pH 2.0–2.5 and with $FeCl_3$ dosage of 1,000 mg/L at the beginning and 10 mg/L non-ionic polyelectrolyte addition 1–2 min before the slow mixing began. Coagulation–flocculation experiments were carried out again in a jar test with the same sequence and timing that of acid cracking. Alum (1,000 mg/L) or $FeCl_3$ (1,000–1,500 mg/L) and polyelectrolyte (10 mg/L) were used. pH of the solution was adjusted to 6.0–6.5. Saponification was realized using either $CaCl_2$ or $BaCl_2$ addition with flash mixing and settling at pH 10.0.

3. Results and discussion

3.1. Aeration

Aeration experiments were conducted for four different air flows and for two different pH values. The two pH values employed were pH 2.0–2.5 and pH 7.0. The aim was to differentiate the fractions; volatile, non-polar substances that are removable by aeration being practically independent of pH and polar fraction that can be volatilized in unionized (molecular) form at low pH values. The original pH of the sample (2.0–2.5) was selected as low pH application to avoid making an additional pH change. This pH was also low enough to keep practically all organic acids in unionized form. pH 7.0 was selected to avoid pH adjustment at the end of the process. This pH value was also high enough to provide high level of ionization of organic acids. Experiments were carried out in order to determine the aeration duration. The aeration time was extended to 148 h in the experiments. The results indicated that COD removal practically ceased at 32 h. Fig. 1(a) delineates COD abatements obtained for sample I during aeration with an air flow of 1.6 $m^3/L\,h$ (Q).

As seen from Fig. 1, COD abatement was realized at a great extent until 12 h, and only a slight difference existed beyond the aeration time of 12 h for both pH values tested. COD removals at acidic pH value were more rapid than those of pH 7.0 until 12 h, but ultimate COD removals were very close to one another implying that majority of the volatile fraction was of apolar nature. The solution pH which

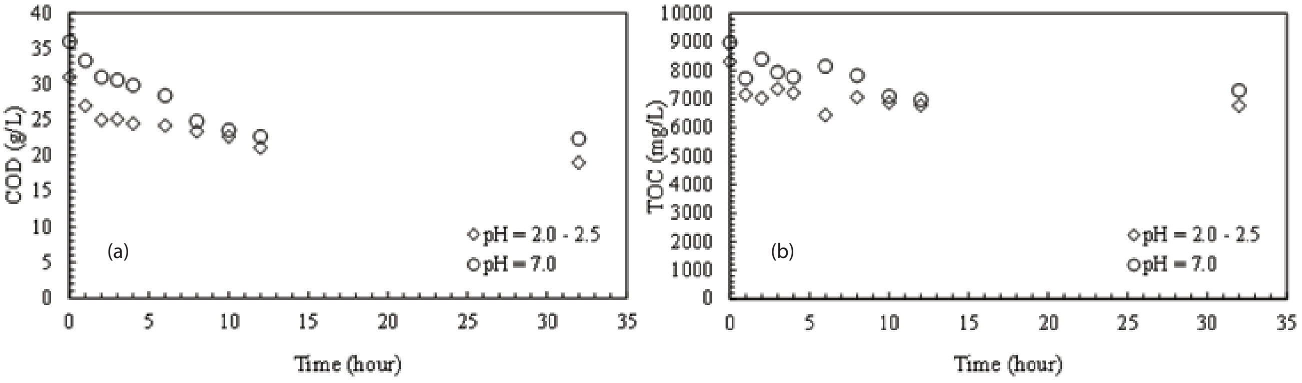

Fig. 1. Results of aeration experiments for sample I.

remained constant during the entire aeration period, further testified this conclusion. COD removal efficiencies at the end of aeration time of 32 h at pH 2 and 7 were measured as 37% and 38%, respectively. COD/TOC ratio may be taken as a measure of compositional homogeneity of the sample, therefore, TOC changes were monitored in parallel with COD during aeration experiments (Fig. 1(b)). COD/TOC ratio was measured at the time zero of aeration as 3.73 and 4.0 for pH 2 and 7, respectively. COD/TOC ratio fluctuated between the range of 3.77 and 3.11 for aeration at pH 2, and 4.3 and 3.16 for aeration at pH 7 within the first 12 h. These ratios further decreased to 2.8 and 3.06 at the end of 32 h for pH 2 and 7, respectively. These significant reductions in COD/TOC ratios can be attributed to changes in the composition of the sample during aeration. The results of aeration experiments obtained for pH 2.0–2.5 and for the end of 32 h are tabulated in Table 2 for varying aeration intensities.

As can be seen from Table 2, process efficiencies depend on character of the wastewater. Aeration intensities did not affect the efficiency for sample I, but significantly affected the process performance for sample 2, also a very low aeration intensity could be effective for the case of sample III. Since both raw materials used in the production and process characteristics vary depending on the product, the wastewater character and the response of wastewaters to aeration will vary. This work helps to define a framework for the process based on the main parameters. Air stripping as a simple aeration or as more efficient tower designs has been used for volatile control. Although wastewater characters are different there are applications to strong organic wastewaters containing volatile organic matter. Kabdaşlı et al. [4] applied aeration to textile printing wastewaters which contained solvents and other volatile material. The initial COD of the wastewater used in their experimental study varied between 47 and 49 g/L. Aeration application to this wastewater provided 38%–40% COD removal. Tünay et al. [17] obtained up to 26% COD removal for latex-based paint wastewaters by aeration.

Table 2
Results of aeration experiments conducted on varying air flows ($Q = 1.6\ m^3/L\ h$)

Sample	Aeration intensity	COD		
		Initial (mg/L)	Final (g/L)	Removal (%)
I	*Q*	31,000	19,000	39
I	4*Q*	31,000	19,000	39
II	*Q*	23,000	19,570	15
II	2*Q*	23,000	16,050	30
III	*Q*/8	40,310	31,370	21

BOD_5 measurements on sample II undergone aeration for 32 h at pH 2.0 and an aeration intensity of 2*Q* resulted in a BOD_5/COD ratio of 0.70. Considering the BOD_5/COD ratio of 0.57 for the raw sample II, aeration application could be evaluated as a process of removing the solvents, other toxic or otherwise hard to treat components yielding a relatively diluted wastewater which is more amenable to biological treatment. However, aeration process requires a well-worked optimization for the best results. The main disadvantage of aeration is the stripping of solvents and other materials directly off the air which causes air pollution. Therefore, a test was planned to evaluate if a part of volatile off gases could be captured by using an alkaline aqueous solution. The experiment was conducted using sample I at pH 2.0 and with an air flow of *Q*. COD removal from sample I at the end of 32 h was found as 32%. Result of the experiment was evaluated on the mass of COD basis, and captured COD in scrubbers was determined as 6.6% removed COD. This amount can be interpreted as non-solvent volatile components removed from the sample. Solvent removal from off-gases may be carried out using special solutions, oils or special absorbers to control air pollution.

3.2. Acid cracking with $FeCl_3$

Acid cracking experiments were run on both raw and aerated samples. Results of experiments are summarized in Table 3. As seen from the table, COD removals were between 10% and 21%. These figures were lower than those of aeration pretreatment. Even lower efficiencies were obtained for aerated samples except for sample I. For the aerated sample I, overall (aeration + acid cracking (33%)) roughly 60% COD removal was reached. For sample I, COD/TOC ratios were found for aerated and acid cracking of aerated samples as 2.8 and 2.2, respectively. These figures again indicated a structural change in the wastewater. Biodegradability, however, remained at the same level as indicated by BOD_5/COD ratio of 0.72 for sample II. Acid cracking process was effective in several cases as oily and paint production wastewaters. Kabdaşlı et al. [18] obtained up to 95% COD removal by acid cracking for wastewaters originating from water-based paint production with latex binder with initial COD values up to 16 g/L.

3.3. Coagulation and flocculation

Coagulation and flocculation experiments were performed on sample III using either $FeCl_3$ or alum with dosages varying between 1,000 and 1,500 mg/L. Results of the experiments are outlined in Table 4. Coagulation and flocculation of acid cracking effluent of the raw sample yielded up to 15% COD removals. Acid cracking effluent of aerated sample provided better results and 25% and 26% COD removals obtained by coagulation and flocculation with 1,000 mg/L $FeCl_3$ and alum, respectively. These COD removals were typical for coagulation and flocculation application. This process increased the total dilution of highly concentrated sample III nearly 50% together with aeration and acid cracking. The increase in COD removal by coagulation and flocculation in the aerated sample could be related to enrichment of the aerated effluent in terms of polar, adsorbable substances.

3.4. Saponification

Saponification was tested as an alternative process and as a means of recovery using calcium and barium salts at pH 10 on aerated sample II. As seen in Table 5, COD of aerated sample II could be reduced 5% and 7% using barium and calcium salts, respectively. The separated solid phase is likely fatty acids combined as metal soaps. The amount separated material is considerable from the standpoint of recovery and may be increased by enrichment of free fatty acid content of wastewaters. Other metals, particularly heavy metals, may also have potential for the recovery of metallic soaps.

Table 3
Results of acid cracking experiments

Sample		COD		
		Initial (mg/L)	Final (mg/L)	Removal (%)
I	Raw	31,000	24,480	21
I	Aerated (4*Q*)	19,000	12,800	33(59)*
II	Raw	23,000	19,350	16
II	Aerated (*Q*)	19,570	17,330	12(25)*
II	Aerated (2*Q*)	16,050	13,960	13(40)*
III	Raw	40,310	33,750	16
III	Aerated (*Q*/8)	31,730	28,590	10(29)*

*Overall COD removal.

Table 4
Results of coagulation and flocculation experiments

Coagulant	Dose (mg/L)	Initial COD (mg/L)	Effluent COD (mg/L)	Removal (%)
Acid cracking effluent of raw sample III				
$FeCl_3$	1,000	33,750	30,950	8
$FeCl_3$	1,500	33,750	31,320	7
Alum	1,000	35,500	30,190	15
Acid cracking effluent of aerated sample III				
$FeCl_3$	1,000	28,590	21,530	25
$FeCl_3$	1,500	28,590	21,975	23
Alum	1,000	28,590	21,170	26

3.5. Discussion

The planned treatment applications for alkyd resin production wastewaters worked well despite the three samples taken had different strength and character. The performance of treatment applications, although varied were generally in the expected range and in the same magnitude with those of literature values that belonged to wastewaters of similar strengths. Aeration proved to suit targeted functions and modified the characteristics of wastewaters. On aerated samples, acid cracking process performance decreased slightly while coagulation and flocculation performance increased with respect to raw wastewater samples. For some samples, aeration as a single-step treatment provided significant dilution. Table 6 displays the COD removals obtained by combination of treatment alternatives.

Sample III was the most concentrated sample. Efficiencies of the treatment steps applied were lower than those of other samples, in spite of this fact nearly 50% dilution was provided with the combination of treatment systems. However, two-step treatment as coagulation and flocculation and acid cracking yielded 25% COD removal and, if we consider aeration as an essential step, COD removal of aeration and acid cracking was approximately 30%. Recent research on oily wastewaters has shown that coagulation and flocculation efficiency can be increased by use of novel coagulants. Sun et al. [19] reported that newly developed materials such as polymeric aluminum ferric silicate prepared for high oil containing wastewaters may help to improve the coagulation and flocculation performance.

Saponification removed about 1 g/L COD which may amount to several kilograms metallic soap per cubic meter

Table 5
Results of saponification experiments

Metal	Dose (g/L)	Initial COD (mg/L)	Effluent COD (mg/L)	Removal (%)
$CaCl_2$	3.4	19,590	18,200	7
$BaCl_2$	6.7	19,590	18,560	5

Table 6
COD removal performances for treatment alternatives for sample III

Treatment method	COD removal (%)
Aeration	22
Acid cracking	16
Aeration + acid cracking	29
Coagulation flocculation + acid cracking	25
Aeration + acid cracking + coagulation and flocculation	47

of wastewater. This level of recovery seems to deserve further study. Use of new methods such as developed by Vávra et al. [20], which is based on separation of fatty acid from ester mixture, may help to further increase the level of recovery.

4. Conclusions

This study attempted to analyze the production processes and wastewater production of alkyd resin manufacturing. The main wastewater source is esterification process with wastewater flow ranging between 10 and 20 L/ton product. The wastewater is strong containing 23–40 g/L COD. The strength depends on raw materials and products as well as wastewater production. Wastewater character is also variable as reflected by COD/TOC ratio which changes in the interval 3.75–4.4. The wastewater is moderately biodegradable as indicated by BOD_5/COD ratio of 0.57. Relatively easy to use physical–chemical pretreatment alternatives were tested to remove toxicity, increase the biodegradability, provide safe storage and dilute the wastewater. Aeration as a first-step treatment proved to be useful, removing solvents and other volatiles increasing biodegradability and providing a significant dilution by reducing the COD up to 40%. Removal efficiencies depend on wastewater character, composition as well as on aeration intensity. The drawback of the process is the need of capturing volatile fraction. The alkaline scrubbing application could retain 6% of volatilized COD. Acid cracking performance was found variable on raw and aerated samples. Aerated sample responses were between additional 10% and 33% COD removal and at the highest removal, aeration plus acid cracking, COD removal efficiency reached 60%. Coagulation and flocculation worked better on samples pretreated with aeration and acid cracking with a COD removal around 25%. Precipitation with calcium and barium salts of wastewater, although COD removal is limited, may provide recovery of fatty acids.

References

[1] N.L. Nemerow, J.F. Agardy, Strategies of Industrial and Hazardous Waste Management, Van Nostrand Reinhold, New York, 1998.

[2] USEPA, Final Development Document for Effluent Limitations Guidelines and Standards for the Organic Chemicals Plastics and Synthetic Fibers Point Source Category, Washington, D.C., 1987.

[3] S. Meriç, N.I. Kabdaşlı, O. Tünay, D. Orhon, Treatability of strong wastewaters from polyester manufacturing industry, Wat. Sci. Technol., 39 (1999) 1–7.

[4] N.I. Kabdaşlı, M. Gürel, O. Tünay, Characterization and treatment of textile printing wastewaters, Environ. Technol., 21 (2000) 1147–1155.

[5] B.R. Kim, M. Zinbo, J.A. Adams, W.C. Young, Nonbiodegradable organic compounds found in automotive spray booth scrubber water, Wat. Environ. Res., 73 (2000) 405–412.

[6] H.S. Ling, K.D. Chang, Combined physical, chemical, biological treatments of wastewater containing organics from a semiconductor plant, J. Hazard. Mater., 97 (2003) 159–171.

[7] G. Libralato, A.V. Ghirardini, F. Avezzu, Evaporation and air stripping to assess and reduce ethanolamines toxicity in oily wastewater, J. Hazard. Mater., 153 (2008) 928–936.

[8] E.F. Assanvo, P. Gogoi, S.K. Dolui, S.D. Baruah, Synthesis, characterization, and performance characteristics of alkyd resins based on *Ricinodendron heudelotii* oil and their blending with epoxy resins, Ind. Crops Prod., 65 (2015) 293–302.

[9] X.C. Yin, H.D. Duan, X.J. Wang, L. Sun, W.J. Sun, H.M. Qi, L.N. Ma, An investigation on synthesis of alkyd resin with sorbitol, Prog. Org. Coat., 77 (2014) 674–678.

[10] M.R. Islam, M.D.H. Beg, S.S. Jamari, Development of vegetable-oil-based polymers, J. Appl. Polym. Sci., 131 (2014) 40787. Doi: 10.1002/app.40787.

[11] R.C. William, In: C.D. Craver, C.E. Carraher, Eds., Advances in Alkyd Resins, Chapter 5, Applied Polymer Science: 21st Century, Elsevier Science Limited, Amsterdam, 2000.

[12] S.B. Kausley, K.S. Desai, S. Shrivastava, P.R. Shah, B.R. Patil, A.B. Pandit, Mineralization of alkyd resin wastewater: feasibility of different advanced oxidation processes, J. Environ. Chem. Eng., https://doi.org/10.1016/j.jece.2017.04.001.

[13] International Standard ISO 6060, Water Quality – Determination of the Chemical Oxygen Demand, ISO, Geneva, 1986.

[14] Standard Methods for the Examination of Water and Wastewater, 20th ed., American Public Health Association/American Water Works Association/Water Environment Federation, Washington, D.C., 1998.

[15] D. Çakır, Characterization and Treatability of Alkyd Resin Production Wastewater, MSc Thesis, Environmental Engineering Department, İstanbul Technical University, Turkey (in Turkish), 2009.

[16] I. Schwingel de Oliveira, L. Viana, C. Verona, V.L.V. Fallavena, C.M. Azevedo, M. Pires, Alkydic resin wastewater treatment by Fenton and Foto-Fenton processes, J. Hazard. Mater., 146 (2007) 564–568.

[17] O. Tünay, E. Kocabaş, T. Ölmez-Hancı, I. Kabdaşlı, Characterization and treatability of latex and PVA based paint production wastewaters, Fresenius Environ. Bull., 19 (2010) 1884–1888.

[18] I. Kabdaşlı, O. Tünay, K. Konuk, G. Etçioğlu, E. Kocabaş, Treatability of wastewaters originating from water-based paint production with latex binder, Fresenius Environ. Bull., 21 (2012) 3122–3126.

[19] Y. Sun, C. Zhu, H. Zheng, W. Sun, Y. Xu, X. Xiao, Z. You, C. Liu, Characterization and coagulation behavior of polymeric aluminum ferric silicate for high-concentration oily wastewater treatment, Chem. Eng. Res. Des., 119 (2017) 23–32.

[20] A. Vávra, M. Hájek, F. Skopal, The removal of fatty acids from methyl esters, Renewable Energy, 103 (2017) 695–700.