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Investigation of Environmental-friendly Technology for a Paint Industry Wastewater Plant in Turkey

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Paint wastewater,
Electrocoagulation,
Fenton process,
Membrane distillation

Abstract: Paint manufacturing process has several unfavorable aspects to the environment in Turkey. One of these impacts is wastewater treatment. Paint wastewater contains huge amounts of toxic chemical substances, bio refractory compounds, pigments and microorganisms. So, advanced treatment requirement is available to dispose of colour, microorganisms and chemical oxygen demand (COD). The high organic content of wastewater causes serious environmental challenges and contamination for the living organisms and the ecosystem in the receiver media unless it is treated adequately. In this context, the treatment process to be implemented should be preferred in such a way as to give the least damage to the environment. In this study, three treatment scenarios that contain electrocoagulation (Scenario-1), Fenton process (Scenario-2) and membrane distillation (Scenario-3) have been created for wastewater treatment facility of a paint industry in Turkey. For three scenarios, environmental impact assessment has been carried out with Fine-Kinney method. It is aimed to choose best environmental technology before investment. The evaluation results revealed that Scenario-2 has the less environmental impacts that total impact value is 556. Scenario-1 has the highest total impact value as 756, relatively. Total impact value related to Scenario-3 is 637. According to the evaluation results, Fenton process is the best environmental-friendly treatment technology for wastewater treatment of a paint industry in Turkey.

Türkiye'de Bir Boya Endüstrisi Atıksu Arıtma Tesisi için Çevre Dostu Teknolojinin Araştırılması

Anahtar Kelimeler
Çevresel etki,
Boya endüstrisi atıksuyu,
Elektrokoagülasyon,
Fenton prosesi,
Membran distilasyonu

Özet: Boya üretim prosesi; Türkiye'de birçok olumsuz çevresel etkiye sahiptir. Bu etkilerden birisi atıksu arıtımıdır. Boya endüstrisi atıksuyu, yüksek miktarda zehirli kimyasal maddeleri, biyolojik olarak parçalanmayan bileşikleri, pigment ve mikroorganizmaları içerir. Sonuç olarak atıksudan; renk, mikroorganizma ve organik madde (KOI) giderimi için ileri bir arıtma prosesine ihtiyaç duyulmaktadır. Atıksuyun yüksek organik madde içeriği, yeterli arıtılmaması durumunda; alıcı ortamda yaşayan organizmalar ve ekosistem için ciddi çevre sorunlarına ve kirliliğe neden olur. Bu kapsamda, uygulanacak arıtma prosesi, çevreye en az zarar verecek şekilde seçilmelidir. Bu çalışmada, Türkiye'deki bir boya endüstrisi atıksu arıtma tesisi için; elektrokoagülasyon (Senaryo-1), Fenton prosesi (Senaryo- 2) ve membran distilasyonu (Senaryo-3) içeren üç adet arıtım senaryosu oluşturulmuştur. Üç senaryo için, Fine-Kinney yöntemiyle çevresel etki değerlendirme gerçekleştirilmiştir. Yatırım yapılmadan önce, en çevre dostu teknolojinin seçilmesi amaçlanmıştır. Değerlendirme sonuçları, Senaryo- 2'nin, 556 toplam etki puanıyla en düşük çevresel etkiye sahip olduğunu göstermektedir. Senaryo- 1 en yüksek toplam etki puanına sahiptir (756). Senaryo 3'e ait toplam etki puanı 637'dir. Değerlendirme sonuçlarına göre, Fenton Prosesi, Türkiye'deki bir boya endüstrisi atıksu arıtma tesisi için en çevre dostu arıtma teknolojisidir.

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1. Introduction

The paint factory is a type of industry that has negative environmental impacts. Turkey is one of the regions that have significant numbers of these type facilities. Paint processing has many unfavourable environmental impacts. Wastewater is the major environmental impact of paint industries.

The paint industry is defined as huge water consumer and owner of huge discharge volumes of colourful wastewater with supernal chemical oxygen demand (COD) and nonorganic loading, establishing it one of the major supplies of serious contamination around the world [1]. The conventional methods for treating paint wastewater, biochemical processes have been implemented [1,2]. Even though more than 90% of contaminants could be removed from the wastewater by these traditional methods, considerable quantities in COD and total dissolved solids (TDS) remain at effluents after the biochemical treatment methods [3,4]. There are many treatment methods such as biochemical and chemical and advanced treatment processes for paint industry.

More importantly, before deciding the treatment process to be conducted is to determine the damage and impacts to be given to the environment and to decide accordingly. Environmental impact assessment is a methodology that assists to detect the levels of impacts and to categorize the hazard levels. With this methodology, the damage to environment can be identified and be decreased the impact with prevention methods.

In this study, it is aimed to determine the best available treatment process for a paint wastewater treatment plant in Turkey by means of environmental impact assessment methodology. The assessment revealed with fulfilling Fine-Kinney method.

2. Material and Method

2.1. Wastewater treatment methods for painting processing

There are some various methods to dispose of organic substances and colour from painting wastewater such adsorption, membrane processes, advanced oxidation processes and chemical treatment [5,6,7].

2.2. Description of the paint industry

The paint industry is located in an organized industrial zone in Turkey. Main products are furniture paint, decorative paint, industrial paint and ink. All products are water-based paints. The main painting process scheme is shown in Figure 1.

Generally, paint wastewater is characterized by a deep colour, dominant pH, advanced chemical oxygen demand, and low biodegradability [8,9]. Main wastewater contaminants of the industrial plants are suspended solids that could be decreased by the impressive implementation of conventional treatment techniques in the facility. Heavy metals form at least traces amounts in pigments, occur in the industrial wastewater. Oil and grease (O&G) are the other major contaminant indicator for paint industry. The wastewater characteristics of this paint industry are given in Table 1. The wastewater analysis results have been achieved conducting Standard Methods [10].

Figure 1. Paint industry process flow scheme

Table 1. Wastewater characterization of the paint industry

Parameter	Value
COD (mg/l)	5970
Colour (Pt/Co)	28
TSS (mg/l)	1463
Oil and Grease (mg/l)	421
pH	7.69

Figure 2 indicates the available wastewater treatment process flow scheme in the plant. Chemical treatment method is implemented as coagulation and flocculation process and activated carbon adsorption to remove, colour, organic and suspended materials from wastewater. In DAF (dissolved air flotation) tank, oil and grease and other organic material removal have been obtained. Disinfection is fulfilled for pathogens and microorganisms removal from effluent. Activated carbon adsorption is implemented for colour removal from wastewater. The wastewater is discharged to the Organised Industrial Zone Central Wastewater Treatment Plant. Because of high environmental impacts such as toxicity of wastewater, inefficient and inadequate wastewater treatment and sludge production of available treatment system, it is decided to elect new innovative and environmental friendly wastewater treatment process in the paint industry.

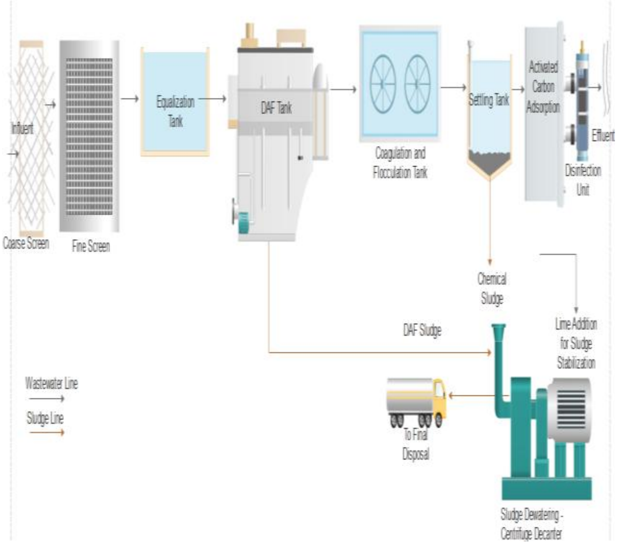

Figure 2. Available wastewater treatment process flow diagram

Also Figure 2 described the sludge treatment unit flow diagram in the wastewater treatment plant. Firstly, chemical treatment sludge is sent to centrifuge decanter for dewatering and thickening. And then, lime addition is implemented for sludge stabilization and finally it is sent to the final disposal firm by way of municipality. The other sludge type is chemical sludge that generated from DAF tank because of chemical addition to increase oil removal efficiency. DAF sludge is treated together with treatment sludge.

2.3. Environmental impact assessment methods

Environmental Impact Assessment (EIA) is a method that enables the evaluation for the aspects in the ecosystems. The protection of the fauna and flora means to ensure a sustainable environment and this methodology is an easy way to realize this process [11-12-13-14-15]. The paradigms of EIA have been improved to describe and estimate value variances related to a factor. Evaluation should facilitate description of impacts on water supplies, land, air, ecosystem and natural resources. Lately, there are many different methods used for assessing environmental dimensions. The most frequently used method, which has the simplest calculation method of mathematical methods and question list based methods is L type 5x5 matrix method. Main environmental impact assessment methods are 5x5 matrix, uncertainty analysis, multi-criteria assessment, Delphi method, 3x3 matrixes and Fine-Kinney method [15]. However, it is frequently used in commercial software especially in environmental dimension evaluation studies. The Life Cycle Assessment (LCA) is one of them. Gabi and Simapro are the main software. In this study, environmental dimension evaluation activities were carried out by Fine-Kinney method. The reason why the Fine-Kinney is preferred is to utilize multiple variables and real values.

2.3.1. Fine-Kinney method

Fine-Kinney method improved by G.F. Kinney and A.D Wiruth is a simple and prevalent methodology to evaluate impacts values [16]. This method is frequently implemented in building and cement facilities and it is defined as one of the most ordinary methodologies for minor measured facilities. This method often utilizes statistical assays of previous input. [17].

In this evaluation tool, possibility, frequency and severity variables and range schedules of each indicators are comprised. Impact value is calculated with severity, probability and frequency multiplication. It is shown in Eq. (1).

$$Impact\ (I) = Probability\ (P)\ x\ Frequency\ (F)\ x\ Severity\ (S) \quad (1)$$

In improving the range schedules, reference points have been detected in calculating and with regard to the reference points, alternate marks have been detected based on experimentation. Possibility, frequency and severity indicator interspaces proposed for usage in Fine-Kinney method have been demonstrated in Table 2, Table 3 and Table 4 in turn [16].

Table 2. Possibility scale of Fine-Kinney method [16]

Possibility	Mark
Certainly probable	10
Well probable	6
Rare probable	3
May be	1
Eventual	0.5
Physically impossible	0.2
All but impossible	0.1

Table 3. Rate scale of Fine-Kinney method [16]

Frequency	Mark
Nonstop	10
Everyday	6
Hebdomadal	3
Once a month	2
Several times	1
Annually	0.5

Table 4 . Severity scale of Fine-Kinney method [16]

Severity	Value
Environmental disaster, or damage	100
Disaster	40
Environmental block	15
Significant environmental damage	7
Environmental damage	3
Small or no environmental damage	1

Kinney and Wiruth investigated ‘Certainly probable’ with a scale frequently and described it like an environmental accident which has formed before, has a probability of forming recurrently and would form in the fortune [16]. To decide which possibility scale to elect, for example, if chemical substance leakage occurred in the past, you should select "10". If an accident did not occur in the near past, considering the available precautions, you can choose "0.2" etc. Kinney and Wiruth created a scale schedule for frequency merits as well. Reference merits are the range of 0.5 and 10. To determine frequency value, routine activities implemented in the plant or facility should be considered and how many times repeated in a day or a year. For example, if sewage sludge is sent to disposal plant for a week, you should select "3" as frequency value. For UASB reactor, anaerobic sludge is picked up once a year, you can choose "0.5". In the assessment schedule, the values are detected by thinking cost and amount. First of all, these values should be detected by considering industrial and operational conditions. Then if they are multiplied with each other, you can ensure the risk score where defined as in Table 5.

Table 5. Assessment results of Fine-Kinney method [16]

Range	Mark
I<20	May be acceptable
20<I<70	Probable impact
70<I<200	Considerable impact
200<I<400	High impact
I>400	Severe impact

Based on the detected impact, possibility, frequency and severity marks are ensured from the table and three elements have been multiplied, and the impact value is detected. The ensured impact values are categorized according to Table 5.

2.4. Description of the case study

Water-based paint wastewater that is occurred along the coating stage with different belching processes contains resins, pigments and agents [18]. There are three treatment scenarios that have been formed to evaluate the environmental dimensions and impacts conducting Fine-Kinney method. In the case study, the main aim is to determine which wastewater treatment method has the less damage and impact to the environment. Before investment, under favour of environmental impact assessment, best environmental-friendly wastewater treatment method has been chosen. The Scenario-1 is electrocoagulation. The Scenario-2 is to implement Fenton process and the Scenario-3 is wastewater treatment with membrane distillation.

2.4.1. Scenario-1

Electrocoagulation process has been attracted a great importance for the wastewater treatment related to the industries that olive mill, chemical mechanical polishing, meat industry, pulp and paper mill, metal cutting and textile wastewaters because of the versatility and the environmental compatibility [5]. Electrocoagulation technology is environmentally friendly so that it does not form corrosion or any pollutants. This technology has some advantages if benchmarked to traditional methods as bare installation, simple to manage, fewer retention time, decrease or disappearance of inserting chemical substances, quick sedimentation of the electro-generated flocs and fewer sludge generation [5,19,20]. This technology utilizes sacrificial metal electrodes dipped in contaminated water implementing electric flow [21].

There are several studies about this technology to remove colour from wastewater. Akyol conducted a study by applying this method [5]. According the study, the most disposal yields for COD and TOC in wastewater were ensured with 93% and 88% for Fe and 94% and 89% for Al electrodes at the optimum terms [5]. The specific dyes such as Acid Black 1, Acid Blue 19, Acid Red 2, Acid Yellow 23, Basic Violet 3, Basic Blue 9, Direct Brown 2, Disperse Blue 3, Reactive Black 5 removal from painting wastewater has been conducted by Daneshvar et al., Vidal et al., Kobya et al. and Aoudj by implementing electrocoagulation in different times [21, 22, 23, 24]. Also, Fajordo et al. fulfilled this technology. They achieved 76% and 97% of colour removal process after 45 and 120 minutes of operation, with an energy consumption of 5 and 14 kWh/ m^3, respectively [25].

The Scenario-1 is electrocoagulation process implementation for paint processing wastewater treatment. For the investment of wastewater treatment plant and to detect environmental-friendly technology, for this technology, environmental impact assessment has been revealed. The Scenario-1 is based on the wastewater treatment flow diagram demonstrated in Figure 3.

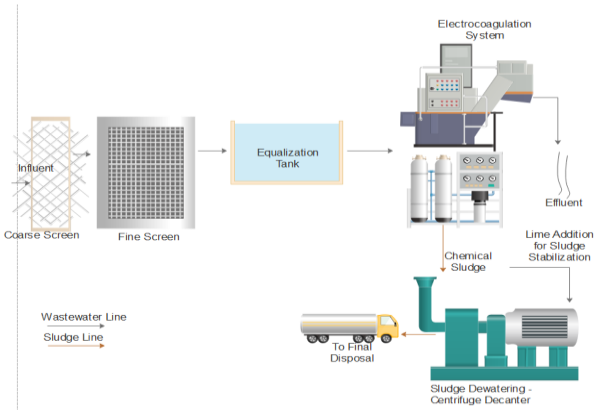

Figure 3. Scenario-1

2.4.2. Scenario-2

Advanced wastewater treatment technologies have been gained attendance and popularity recently. One of them is advanced oxidation process (AOP). There are many advanced oxidation processes such as ozonation, UV+H_2O_2 process, UV+O_3 process, vacuum-ultraviolet (VUV) process, Fenton process, photo-Fenton process and their combinations [26]. Fenton is the most favorable among them. Hydroxyl radicals (*OH) are the most impressive oxidants among the available oxidants [27]. These radicals are generated by homolytic cleavage of hydrogen peroxide catalyzed by Fe^{2+} ions and the reaction is named as Fenton's process [28].

Kurt et al. conducted a study about this process [27]. They achieved with pH adjustment were about 20% COD removal with this method. With the subscription of Fenton process in both columns and combined reactor surveys, the COD removal was developed by nearly 80% [27]. Degradation of the dye Disperse Red 354 was conducted under four different oxidation conditions (UV+ H_2O_2, O_3, Fenton and Photo-Fenton) by Neamtu et al. (2004) [29]. In another survey, the cumulative yield of removing COD and colour from painting wastewater through the advanced oxidation processes by Kang et al. (1999) [30].

Scenario-2 is based on paint wastewater treatment with advanced oxidation process that contains Fenton process. The schematic diagram of Scenario-2 is given in Figure 4.

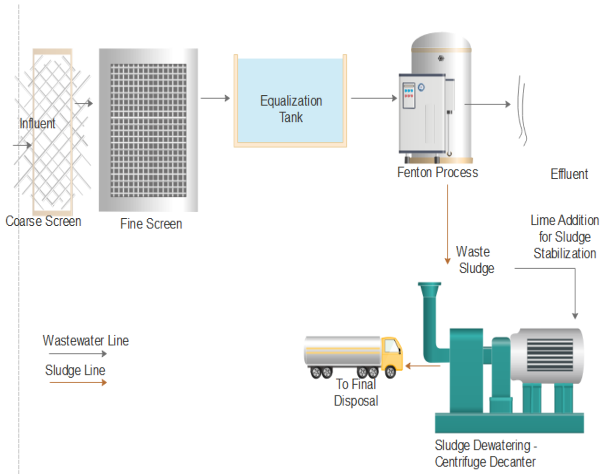

Figure 4. Scenario-2

2.4.3. Scenario-3

Membrane technology is an alternative method for paint wastewater treatment. Reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), and microfiltration (MF) processes enable to eliminate particles, colloids and macromolecules based on the pore size. Membrane is the separation process that is implemented for water and wastewater treatment worldwide. Membrane processes have gained importance due to their natural feasibility, measurable modular design, simple maintenance and excellent rejection rate [31, 32, 33].

Some researchers investigated that colour and toxicity removal from paint wastewater with membrane based processes [34, 35, 36, 37]. Membrane distillation (MD), a new developed membrane-based technology, has produced interest because it can supply a high rejection rate under soft temperatures and nominal atmospheric pressure [31]. The application of membrane distillation for paint wastewater treatment has two particularly main advantages. First, it can use the industrial waste heat already available in paint wastewater without requiring extra heating, as the wastewater discharged from the paint industry is generally above 80 °C. Second, the paint can potentially be recovered from the concentrate [31].

Scenario-3 is composed on paint processing wastewater treatment with membrane distillation process. The schematic diagram of Scenario-3 is given in Figure 5.

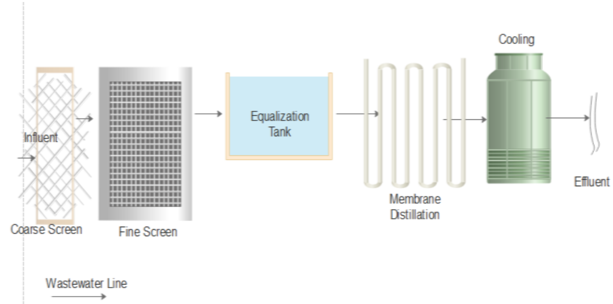

Figure 5. Scenario-3

3. Results

Considering legal requirements for a dye industry operating in Turkey, implementing the Fine Kinney Method, environmental dimensions were determined and environmental impacts were assessed for Scenario-1, Scenario-2 and Scenario-3 that have formed for new plant investment. In this evaluation, the environmental dimensions of each process in the factory were defined; risk assessments were carried out together with the existing measures applied by giving possible environmental aspects. The results of these evaluations have been given in Table 6 related to Scenario-1, Table 7 related to Scenario-2 and Table 8 related to Scenario-3. While assessment, process requirements, by products and end products, operational frequency, preventions to be taken, sludge occurrence, chemical substances use, air emissions, water consumption and energy consumption have been considered for each treatment processes.

3.1. Environmental impact assessment of Scenario-1

Electrocoagulation has some challenges for wastewater treatment besides its advantages. Environmental impact assessment related to electrocoagulation system has been given in Table 6.

According to the results of Table 6, water pollution, soil pollution and natural sources consumption are the main environmental impacts for electrocoagulation. Total impact value is 756.

3.2. Environmental impact assessment of Scenario-2

Advanced oxidation process has some advantages such as high colour removal efficiency. Environmental impacts assessment results have been described in Table 7.

According to Table 7, natural sources consumption, soil and water pollution are the major environmental impacts of advanced oxidation for dye wastewater treatment. Total impact value is 556.

3.3. Environmental impact assessment of Scenario-3

Membrane distillation technology has some advantages such as no requirement for disinfection but for cleaning membrane module water is consumed in huge amounts and electricity and heat consumption is available for this process. The results have been defined in Table 8.

In the result of environmental impact assessment for Scenario-3, fundamental environmental impacts are natural sources consumption, greenhouse effect and soil pollution. Total value of environmental impact assessment is 637.

4. Discussion and Conclusion

Environmental impact assessment has been fulfilled by carrying out Fine Kinney method for 3 scenarios. Environmental impact results comparison of Scenario-1, Scenario-2 and Scenario-3 has been demonstrated in Figure 6, 7 and 8, respectively. Environmental impacts values comparison of all scenarios is given in Figure 9.

Table 6. Environmental impact assessment of Scenario-1 (Electrocoagulation)

Environmental Dimension	Environmental Impact	Assessment	Probability	Frequency	Severity	Impact Value	Result
Chemical Usage	Soil and Water Pollution	Wastewater treatment is ensured with chemical usage. Chemical usage is followed	6	6	7	252	High Impact
Sludge Treatment	Soil Pollution	The occurred sludge will be chemical characterization. Sludge treatment will be applied.	6	3	7	126	Considerable Impact
Energy Consumption	Natural Sources Consumption	There is high electricity consumption because of power requirement.	6	6	7	252	High Impact
Wastewater Treatment	Water Pollution	Colour removal is ensured.	3	6	7	126	Considerable Impact

Table 7. Environmental impact assessment of Scenario-2 (Fenton Process)

Environmental Dimension	Environmental Impact	Assessment	Probability	Frequency	Severity	Impact Value	Result
Wastewater Treatment	Water pollution	Colour removal has been obtained. Fe^{+2} and H_2O_2 are not toxic.	1	1	7	7	May be Acceptable
Chemical Usage	Soil and water pollution	Fe^{2+} and H_2O_2 are used. Chemical consumption is followed and leakage chemical collection system will be formed.	6	6	7	252	High Impact
Sludge Treatment	Soil Pollution	Sludge occurrence is available. Sludge treatment is implemented.	1	3	15	45	Probable Impact
Energy Consumption	Natural Sources Consumption	Electricity consumption has high value for reactor operation.	6	6	7	252	High Impact

Table 8. Environmental impact assessment of Scenario-3 (Membrane Distillation)

Environmental Dimension	Environmental Impact	Assessment	Probability	Frequency	Severity	Impact Value	Result
Wastewater Treatment	Greenhouse effect	In membrane distillation, CO_2 emission is occurred. It causes greenhouse effect.	3	6	7	126	Considerable Impact
Water Consumption	Natural Sources Consumption	Water consumption is followed. Back washing is implemented for prevention of fouling.	6	6	7	252	High Impact
Sludge Treatment	Soil Pollution	This system is nearly zero sludge system.	1	1	7	7	May be acceptable
Energy Consumption	Natural Sources Consumption	Electricity and heat consumption has high value for reactor operation. Cooling is implemented.	6	6	7	252	High Impact

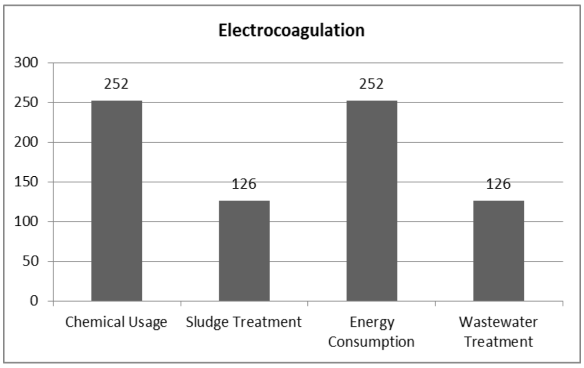

Figure 6. EIA of Scenario-1

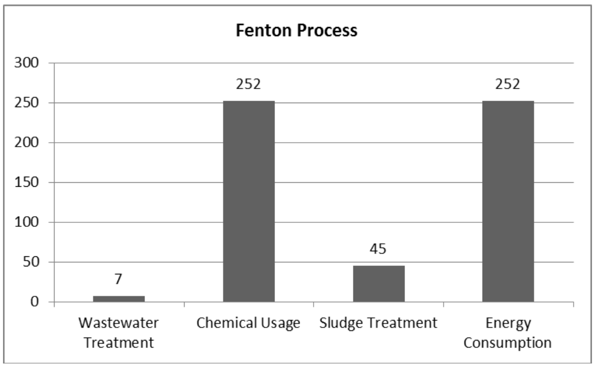

Figure 7. EIA of Scenario-2

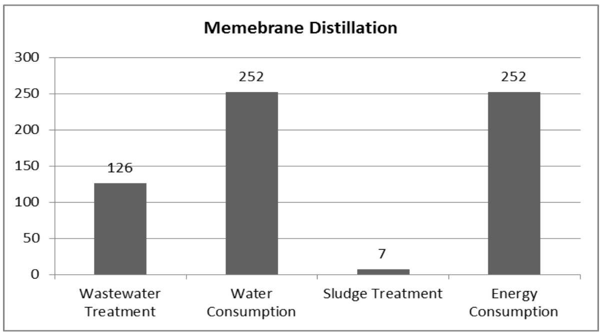

Figure 8. EIA of Scenario-3

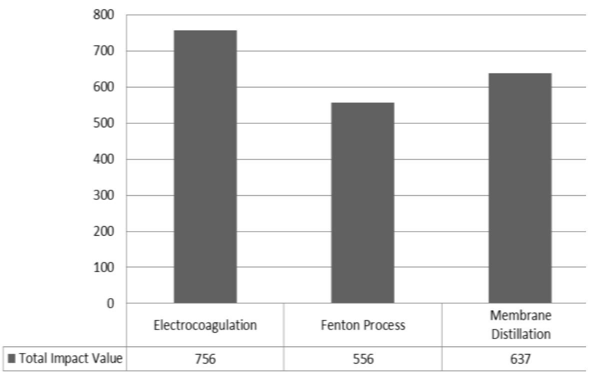

Figure 9. Comparison of 3 scenarios

Environmental impact assessment for a paint processing industry located and operated in Turkey has been implemented by carrying out Fine Kinney Method for Scenario-1, Scenario-2 and Scenario-3 are electrocoagulation, Fenton process and membrane distillation, respectively. Environmental impact assessment is a tool for determining environmental-friendly treatment technology before investment. Fine Kinney method can be preferred as EIA methodology. Use of Fine-Kinney method in Environmental Impact Assessment studies can be considered as a contribution to the literature, unlike other studies.

For Scenario- 1, chemical usage, and energy consumption has the same environmental impact value as 252. Impact value of wastewater treatment and sludge treatment has the same value is 126. Total impact value is 756.

The environmental impact value of wastewater treatment is 7 for Scenario-2. The highest value is 252 related to chemical usage and energy consumption. The impact value of sludge treatment is 45. The main environmental impacts are natural sources consumption and soil and water pollution.

In Scenario-3, water and energy consumption have the highest environmental impact value as 252. Water consumption and electricity consumption are the main environmental dimensions Because of nearly zero-sludge process; the impact value of sludge treatment is only 7. Water consumption is in huge amounts causes to natural sources consumption because of backwashing and cleaning membrane modules. The environmental impact value related to wastewater treatment is 126 with greenhouse effect impact.

For detecting which process will be implemented, total environmental value of this wastewater treatment scenarios have been considered. Total value of electrocoagulation technology is 756 has the highest value. Total environmental impact value related to membrane distillation technology is 637 and the score of Fenton process is 556. According to the environmental impacts assessment results, Fenton process could be proposed for treating the paint processing wastewater.

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