Erciyes Üniversitesi
Fen Bilimleri Enstitüsü Dergisi
Cilt 36, Sayı 3 , 2020

Erciyes University
Journal of Institue Of Science and Technology
Volume 36, Issue 3, 2020

Life Cycle Assessment of the Neutralization Process in a Textile WWTP

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(Alınış / Received: 29.01.2020, Kabul / Accepted: 05.12.2020, Online Yayınlanma / Published Online: 31.12.2020)

Keywords
Life Cycle Assessment,
Neutralization,
Sustainability,
Textile Industry,
Wastewater treatment,

Abstract: Although industrial wastewater treatment plants (WWTP) have become an important part of textile facilities in reducing environmental pollution problems, they also produce sludge and various emissions such as high chemical oxygen demand, color and conductivity which have serious negative impacts on the environment. One of the processes with enormous chemical consumption in industrial WWTP of textile facilities is the neutralization process, which aims to adjust the pH of the wastewater. Neutralization processes needed to be optimized in order to determine its overall environmental impacts and then identify the most environmentally appropriate options. The aim of this study is to compare the environmental impacts of carbon dioxide and sulfuric acid, which are two alternative chemicals used in the neutralization process of textile facilities, using Life Cycle Assessment (LCA) approach. The environmental impacts resulting from the use of these two chemicals proposed according to the Reference document on Best Available Techniques (BREF) Document for Textile Industry were revealed by the CML-IA method and the gate-to-gate method. According to the results, using carbon dioxide instead of sulfuric acid, the best improvement was in the abiotic depletion category with 92%, while the least improvement was in the eutrophication potential with 39%. No improvement was observed in the global warming potential and human toxicity impacts.

Tekstil Atıksu Arıtma Tesisinde Nötralizasyon Prosesinin Yaşam Döngüsü Değerlendirmesi

Anahtar Kelimeler
Yaşam döngü analizi,
Nötralizasyon,
Sürdürülebilirlik,
Tekstil endüstrisi,
Atık su arıtma,

Öz: Endüstriyel atık su arıtma tesisleri, çevre kirliliği sorunlarının azaltılmasında tekstil tesislerinin önemli bir parçası haline gelmesine rağmen, çevreye ciddi olumsuz etkileri olan çamur ve yüksek kimyasal oksijen talebi (COD), renk ve iletkenlik gibi çeşitli emisyonlar da üretirler. Tekstil tesislerinin endüstriyel atık su arıtma tesislerinde muazzam kimyasal tüketimi olan süreçlerden biri de atık suyun pH'ını ayarlamayı amaçlayan nötralizasyon işlemidir. Bu durumda, genel çevresel etkilerini ortaya koymak ve ardından çevreye en uygun seçenekleri belirlemek için nötralizasyon sürecinin optimize edilmesi gerekiyordu. Bu çalışmanın amacı, tekstil tesislerinin nötralizasyon sürecinde kullanılan iki alternatif kimyasal olan karbondioksit ve sülfürik asidin çevresel etkilerini Yaşam Döngüsü Değerlendirmesi (YDA) yaklaşımı ile karşılaştırmaktır. Atık Arıtımı için Mevcut En İyi Teknikler Referansı (BREF) Belgesine göre önerilen bu iki kimyasalın kullanımından kaynaklanan çevresel etkiler, CML-IA metodu ve kapıdan kapıya yöntemiyle ortaya konulmuştur. Elde edilen sonuçlara göre, sülfürik asit yerine karbondioksit kullanıldığında en iyi gelişme %92 ile abiyotik tükenme kategorisinde olurken, en az gelişme %39 ile ötrofikasyon potansiyelinde oldu. Küresel ısınma potansiyeli ve insan toksisite etkilerinde herhangi bir gelişme gözlenmemiştir.

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1. Introduction

The textile industry is one of the sectors that uses the most water, with approximately 200 liters of water to produce 1 kg of textile products [1]. Water used in wet processes such as brushing, desizing, mercerizing, bleaching, dyeing, and finishing turns into wastewater (WW) containing large amounts of pollutants that are very harmful to the environment [2, 3]. The worldwide United Nations Environment Program is estimated that the industry is responsible for dumping 300-500 million tons of heavy metals, solvents, toxic sludge and other waste into water each year [4]. Textile WW is considered to be the dirtiest of all industrial sectors due to both the volume produced and the composition of the chemicals [5]. WWs discharged from textile WWTP includes dyes, metals, salts and other pollutants. Therefore, it has high in color, pH, salt, fats, oil, phosphorus, temperature, suspended solids, chemical oxygen demand (COD), biochemical oxygen demand (BOD) and metals [6-9]. This leads to rapid depletion of oxygen due to the high dissolved BOD value and contaminated surface waters and contaminated aquifers, i.e. water-containing soil or rock layers [10]. WW with high BOD and COD values are highly toxic to biological life. In addition, since most of the dyes and chemicals used in the textile industry are synthetic, they cannot be easily biodegradable[11, 12]. Moreover, low pH in WW causes corrosion of the water transport system and dissolution of metal in water, while high pH water causes scaling in sewage systems. Also, large pH fluctuations are detrimental to the flora and fauna of the receiving bodies [13].

As it is stated above, WWTPs are necessary for the textile industry process with high chemical pollution load to comply with the discharge limits determined by law [14] by reducing their environmental impact. There are mainly three type treatments of textile industry WW: biological treatment, chemical treatment and combinations of these two [15]. These WWTPs include various processes to adjust the characterization of textile WW to discharge. Neutralization is a chemical process by which the pH of the incoming raw WW is adjusted to the neutral pH level by the addition of chemicals so as to make it biologically treatable in the further treatment process [16]. Neutralization is a necessity, especially in industrial treatment systems with biological treatment steps. For most natural water it is in the range of 6.5 to 8.5 pH levels, and this neutral pH is essential for the survival of aquatic organisms [17]. Therefore, WWTP uses a neutralization process to ensure that pH values are within an acceptable range before discharging the WW. Textile WW can be acidic or alkaline depending on the content of the processes. Therefore, the chemicals to be used for neutralization vary according to the characterization of the WW. Chemicals such as Caustic (NaOH) and Calcium Hydroxide ($CaOH_2$) can be used for acidic WW, while chemicals such as Sulfuric Acid (H_2SO_4) and Carbon Dioxide (CO_2) can be used for alkaline WWs [18] . The most known and used chemical for neutralization of alkali textile WWs are sulfuric acid or carbon dioxide and also mentioned in the BREF document for Textile Industry [16]. The European Integrated Pollution Prevention and Control (IPPC) Bureau produces sectoral Best Available Technic reference documents called BREFs to identify best practices and explain techniques. These produced reference documents ensure that the control of emissions is carried out in a consistent manner. Sulfuric acid is strongest, cheapest and most common chemical choice for neutralization process in generally. However, sulfuric acid is defined corrosive for human and dangerous for the environment [19]. Sulfuric acid has a risk for the environment and human beings. Carbon dioxide, which is in liquid form under pressure with negative temperatures, is used in a closed system in the neutralization process. Carbon dioxide is a good alternative to sulfuric acid due to the amount required for the process and its environmental impacts.

Regardless of the chemical used in the neutralization process, it is one of the hazardous processes for the environment with the huge chemical consumption in the WWTP. Although the neutralization process has to be applied to comply with environmental standards, it also has an environmental impact. Therefore, the neutralization process and the chemical alternatives used in it should be evaluated in terms of their environmental impacts. LCA is one of the best methods to evaluation of potential environmental impacts of a product, service or process throughout its life cycle [20] according to ISO 14040 and ISO 14044 [21, 22]. Although LCA has been implemented in many disciplines since 1960, it has been used for the implementation of WW treatment in the 1990s. Since then, many studies were published on the LCA of WWTPs in the literature [23]. In the WWTP area, LCA has been applied to many different fields such as evaluation of conventional technologies and non-conventional technologies [24, 25], operation [26], construction [26], dismantling, water cycle [27, 28], energy use [29, 30] and characterization factor [31]. However, although there is such a huge literature, there is no study focusing on the neutralization process and chemicals used in this process. It is clear that LCA is a valuable tool to investigate environmentally sustainable WWT methods and to assess their environmental impact [32].

In this study, the environmental impacts of the neutralization process in an alkaline textile WWTP are investigated with the LCA approach. The substitution of sulfuric acid with carbon dioxide in the neutralization process was examined in terms of environmental impacts. To our knowledge, there is no study in the literature that examines the environmental impacts of chemicals used in the neutralization process with the LCA approach. Therefore, this study will provide both industry experts and researchers with a perspective for more sustainable chemical selection in neutralization proses from a sustainability point of view.

2. Materials and Methods

In this study, the environmental impacts of carbon dioxide and sulfuric acid, which are two alternative chemicals used in the neutralization process of textile facilities, were investigated using LCA approach. There are four phases for an

LCA study: goal and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA), and interpretation. The following stages were organized according to LCA phases.

2.1. Goal and Scope

The goal of this study was to evaluate the potential environmental impacts of carbon dioxide and sulfuric acid, which are two alternative chemicals used in the neutralization process of textile facilities using a life cycle approach. These two chemical alternatives have been proposed in the BREF document for Textile Industry [16] for the neutralization process and are widely used in WWTPs. In this study, the LCA methodology ISO 14040 and ISO 14044 [21, 22] were used to assess the environmental impact of two different methods for the neutralization chemicals, which is the sub-process of biological WWTPs. This work was carried out in a denim textile factory using cotton as the main raw material. It has own biological treatment plant with annually 700.000 m^3 capacity and discharges its WW to the municipality sewage system after treatment. The neutralization process has the same capacity as WWTP since all the WWs need to be decreased to pH. Figure 1 shows the flowchart of the WWTP.

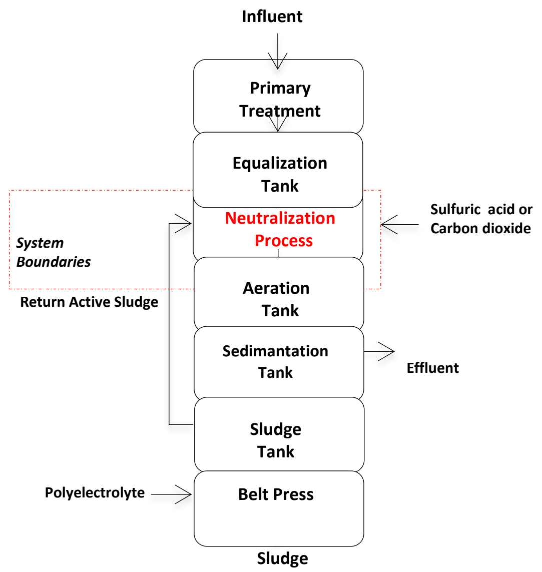

Figure 1. Flowchart of the WWTP.

The process mainly consists of primary, secondary, and tertiary treatment processes. In primary treatment floating and suspended solids are removed by mechanical devices. It includes screening, neutralization, equalization, coagulation, and sedimentation processes. Secondary treatment consists of involving the biological degradation of organic material by microorganisms under controlled conditions. In this process, biological oxidation of the organic material occurs under aerobic conditions in which the WW is aerated to supply oxygen for the micro-organisms. Biological WWTPs consist of a primary tank, neutralization tank, aeration tank, and sedimentation tank. However, since the scope of this study mainly focuses on the neutralization process, all remaining sub-processes were excluded because the remaining sub-processes and the electricity consumption in the neutralization process were the same for both chemical options. The functional unit was chosen 1 m^3 influent and the system boundary was gate-to-gate.

2.2. Life Cycle Inventory

In this study, life cycle inventory (LCI) was prepared by using primary and secondary data. Process specific primary data for chemical consumptions were collected from a textile plant in Turkey for the year 2018. Secondary, LCI data were collected from the Ecoinvent V3.0 database [33]. Table 1 shows that all primary and secondary data used for LCI and chemical consumption values are given for 1 m^3 of WW.

Table 1. Chemical consumption for neutralization of 1 m^3 of WW

Chemicals	Sulfuric acid	Carbon dioxide
Consumptions	1.04 kg	0.44 kg

2.3. Life Cycle Impact Assessment

Comparison of two different neutralization chemicals with LCA was implemented using gate to gate approach with SimaPro 8.4. PhD version software [34]. The LCA was conducted according to ISO 14040 and ISO 14044 standards. The CML-IA was selected as the LCA life cycle assessment method and a total of 11 environmental impacts categories were evaluated [35]. These categories are abiotic depletion (ADP), global warming potential (GWP), ozone layer depletion (ODP), human toxicity potential (HTP), fresh aquatic ecotoxicity potential (FAETP), marine aquatic ecotoxicity potential (MAETP), terrestrial ecotoxicity potential (TETP), photochemical oxidation potential (PCOP), acidification potential (AP), and eutrophication potential (EP).

3. Results

In this study, the environmental impacts of two chemical alternatives in the neutralization process were compared with the LCA method. The results obtained for LCIA were given in Table 2.

Table 2. Chemical consumptions of two different neutralization process (1 m^3 WW)

Impact category	Unit	Neutralization with sulfuric acid	Neutralization with carbon dioxide
ADP	kg Sb eq.	2.76E-05	2.09E-06
ADP-fossil fuels	MJ	6.32E+00	2.84E+00
GWP	kg CO_2 eq.	1.71E-01	3.50E-01
ODP	kg CFC-11 eq.	4.12E-08	2.30E-08
HTP	kg 1,4-DB eq.	3.51E-01	5.25E-01
FAETP	kg 1,4-DB eq.	2.02E-01	1.04E-01
MAETP	kg 1,4-DB eq.	6.54E+02	3.32E+02
TETP	kg 1,4-DB eq.	9.52E-04	5.15E-04
PCOP	kg C_2H_4 eq.	3.05E-04	6.77E-05
AP	kg SO_2 eq.	7.59E-03	8.66E-04
EP	kg PO_4 eq.	8.02E-04	4.86E-04

Thanks to the substitution of sulfuric acid with carbon dioxide, the highest improvement was achieved in the ADP category, with a 92% improvement from 2.76E-05 kg Sb eq. to 2.09E-06 kg Sb eq. The second and third categories with the greatest improvement were AP and PCOP, respectively, with improvements of 89% and 78%. AP of neutralization processes using carbon dioxide is decreased from 7.59E-03 kg SO_2 eq. to 8.66E-04 kg SO_2 eq. (Table 2). Also, 55% improvement was achieved in ADP (fossil fuels) category decreasing from 6.32E+00 to 2.84E+00. Similarly, 49% and 48% of improvements were observed in the FAETP and MAETP categories. TETP category decreased from 9.52E-04 to 5.15E-04, an improvement of 44%, which is still significant. The least improvements occurred in the ODP (44%) and EP (39%) categories, respectively. Figure 1 showed the normalized improvement percent for comparing two neutralization options with the CML-IA method. It is obviously seen that neutralization with carbon dioxide has lower environmental impacts than the sulphuric acid in most environmental impacts considered. The most improvement was obtained in the ADP, AP and PCOP categories, respectively.

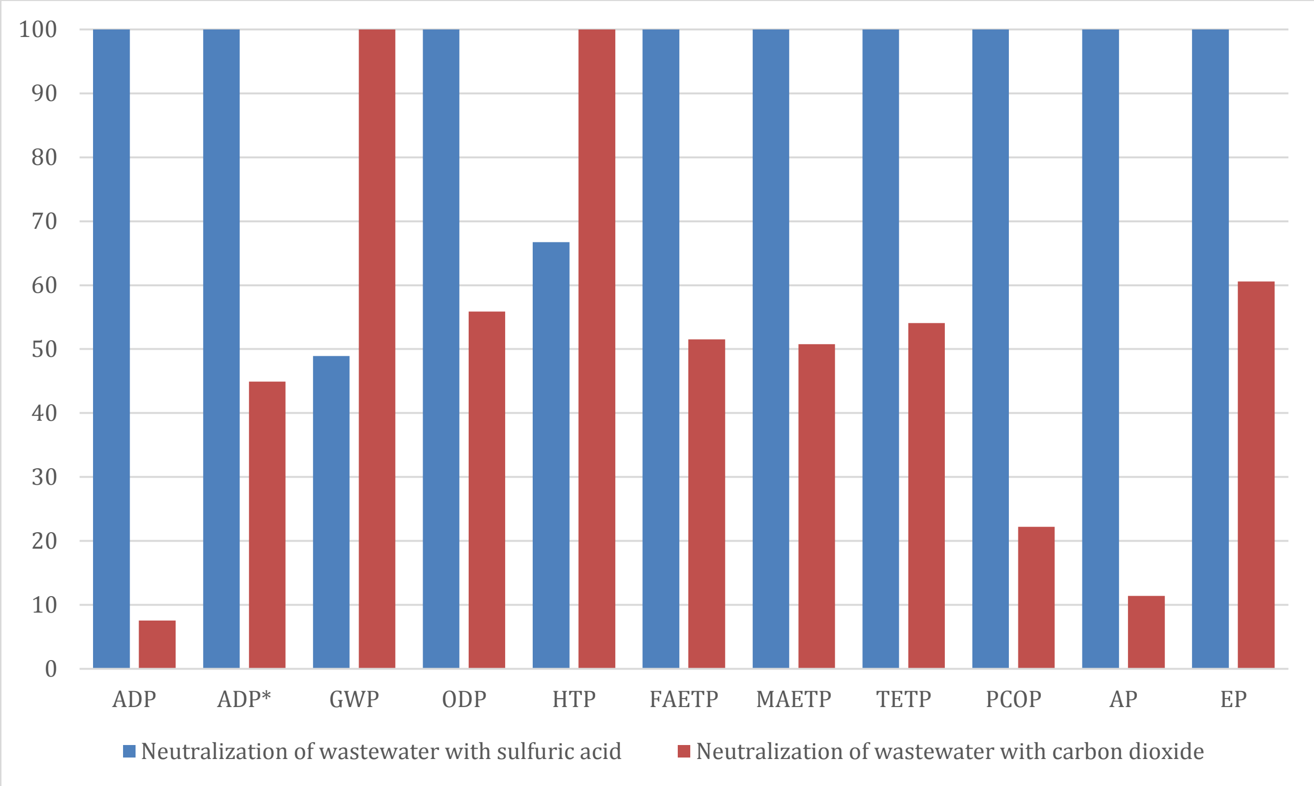

Figure 1. Result of LCIA for comparing two neutralization options with CML-IA method (*fossil fuels)

In contrary to the aforementioned environmental impact categories, the neutralization process with carbon dioxide has a deterioration of 104 % and 50 % in GWP and HTP categories, respectively. The GWP value for sulfuric acid is 1.71E-01 kg CO_2 eq. In the literature, environmental impact of industrial sulfuric acid production system was evaluate using LCA [19]. The study found that for the functional unit of this study, sulfuric acid emitted 9.28E-02 kg of CO_2 equivalent. The results of this study are similar to the results we obtained in this study. Eco-friendly green chemistry options to ensure sustainable development have become more popular among a number of alternatives in the literature. For example, green chemistry and engineering for wastewater treatment were examined and the use of supercritical carbon dioxide has emerged as an environmental friendly alternative to organic solvents and that the combination of ionic fluids, especially supercritical CO_2, is important [36]. In another study proposed a new and effective catalysis system by using in situ carbonic acid from carbon dioxide as a green acid in the presence of Chromium chloride [37]. According to the results, in situ carbonic acid can be used as a low-cost and less environmental impact acid to replace mineral acids such as sulfuric acid. According to IPCC (2013), carbon dioxide has 25 times less greenhouse effect than methane and 310 times less than nitrogen dioxide [38]. According to this study, carbon dioxide has a less environmental impact in many categories such as AP, EP etc. The results of this study were realized in parallel with the studies in the literature examining carbon dioxide from an environmental perspective. As a result, it is clear that the neutralization process with carbon dioxide yields better results in many environmental impacts and carbon dioxide is more sustainable as also suggested in the BREF document for Textile Industry published in 2018.

4. Discussion and Conclusion

The purpose of this study was to evaluate the potential environmental impacts of the two chemical alternatives applied in the neutralization process using the LCA in a WWTP of a textile factory in Turkey. With this approach, sulfuric acid is substituted carbon dioxide following the BREF document for Textile Industry [16], aiming to adjust pH in the neutralization process. CML-IA method is chosen for the assessment of environmental impacts.

The results showed that the neutralization process with carbon dioxide is better in nine of the eleven environmental impacts examined, while the neutralization process with sulfuric acid is better in the two environmental impact categories as GWP and HTP. Significant improvements in the range of 89-92% were achieved especially in ADP, PCOP, and EP impact categories. Thus, using carbon dioxide in the neutralization process will have important contributions in reducing the emission of phosphorus in water, depletion of non-living resources, and secondary air pollution. However, with the use of carbon dioxide in the process, GWP category value doubled. Similarly, there was a 50% increase in the HTP category. Since the most important environmental impact of the textile industry is water pollution, the fact that carbon dioxide has a less environmental impact than sulfuric acid in the categories of ADP, ODP, FAETP, MAETP, TETP, PCOP, AP, and EP will reduce this pollution. Carbon dioxide, one of the two chemicals proposed to be used for neutralization in the BREF document for Textile Industry, is a more sustainable alternative to sulfuric acid for alkali WWs according to the LCA results.

The findings of this study will provide insight for scientists, policy-makers, and experts to improve the sustainability of WW treatment plants. These results showed that the neutralization process environmental impacts could be reduced by substitution of the chemicals with green alternatives according to LCIA methods. In further studies, LCA can be conducted including the whole process of WWTPs to have a holistic approach. Moreover, other chemicals used for alkali WW neutralization process can be added to the comparison.

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