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8TH INTERNATIONAL CONFERENCE ON ENVIRONMENTAL SCIENCE AND TECHNOLOGY

May 18-22, 2022

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WELCOME TO ICOEST 2022

On behalf of the organizing committee, we are pleased to announce that the ***8th*** *International Conference on Environmental Science and Technology* ***(ICOEST-2022)*** *is held in* ***Istanbul, Turkey on May 18-22, 2022*** *(Hybrid Conference). ICOEST 2022 provides an ideal academic platform for researchers to present the latest research findings and describe emerging technologies, and directions in Environmental Science and Technology. The conference seeks to contribute to presenting novel research results in all aspects of Environmental Science and Technology. The conference aims to bring together leading academic scientists, researchers and research scholars to exchange and share their experiences and research results about all aspects of Environmental Science and Technology. It also provides the premier interdisciplinary forum for scientists, engineers, and practitioners to present their latest research results, ideas, developments, and applications in al lareas of Environmental Science and Technology. The conference will bring together leading academic scientists, researchers and scholars in the domain of interest from around the world. ICOEST 2022 is the oncoming event of the successful conference series focusing on Environmental Science and Technology. The scientific program focuses on current advances in th eresearch, production and use of Environmental Engineering and Sciences with particular focus on their role in maintaining academic level in Science and Technology and elevating the science level such as: Water and waste water treatment, sludge handling and management, Solid waste and management, Surface water quality monitoring, Noise pollution and control, Air pollution and control, Ecology and ecosystem management, Environmental data analysis and modeling, Environmental education, Environmental planning, management and policies for cities and regions, Green energy and sustainability, Water resources and river basin management. The conference's goals are to provide a scientific forum for all international prestige scholars around the world and enable the interactive exchange of state-of-the-art knowledge. The conference will focus on evidence-based benefits proven in environmental science and engineering experiments.*

Best regards,

Prof. Dr.Özer ÇINAR

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Optimal Management of Construction Waste

Dino Obradović[1], Marija Šperac[2]*

Abstract

Construction waste is a key issue of modern society. Construction waste is a type of waste generated during the construction of buildings, reconstruction, demolition and maintenance of the existing buildings, and waste generated from excavated materials which cannot be reused for the construction of new buildings without prior recycling or processing. Moreover, construction waste is generated during the production of semi-finished and finished construction products and materials, as well as during the construction and reconstruction of roads. Large quantities of construction waste are generated by earthquakes, floods and destruction caused by war. Construction waste predominantly (95 %) consists of inert waste which means that it is not subject to physical, chemical or biological changes, that it does not dissolve or chemically react, is not flammable, and is not degradable using biodegradable means. Some types of inert construction waste are ceramics, plaster, gypsum, concrete, iron, steel, waste from demolition of buildings, wood, plastics, etc. It may contain hazardous components such as asbestos or asphalt binders, and these components classify it as hazardous waste. Construction waste can generally be divided into three broad categories, such as construction material, demolition waste and hazardous waste. We generate less waste by construction than by demolition. Construction and demolition waste account for the largest percentage of total waste in the European Union – in terms of its volume, it accounts for almost one-third of all waste. For the purpose of achieving the optimal management of construction waste, the following hierarchical approach must be followed: prevention of waste, preparation for reuse, recycling, other treatment procedures, waste disposal. It is necessary to develop a circular economy covering the cycle from construction to demolition to new construction that uses recycled waste materials. Using the available modern technologies, it is possible to reuse most of the construction waste as secondary raw material. The optimal management of construction waste significantly reduces environmental pollution.

Keywords: circular economy, construction waste, optimal management, pollution, recycling

1. INTRODUCTION

1.1. Issues on construction waste

Nowadays, increasing quantities of waste are being generated which create a major problem, as appropriate methods and sites for its disposal need to be found. Moreover, since there is a need to build new buildings and demolish the old, worn-out ones, large quantities of construction waste are also generated. Generally speaking, waste is becoming a key problem of modern civilisation and the inevitable consequence of man's life. The priority should be to reduce environmental pollution and the production of all types of waste, including construction waste. In order to address the problems posed by construction waste, it is necessary to manage it properly. Today, modern technologies allow most waste, including construction waste, to be used as secondary raw material. Proper treatment and management of different types of waste is important. Construction waste is also an important type of waste generated in large quantities.

Construction waste is a type of waste generated during the construction of buildings, reconstruction, demolition and maintenance of the existing buildings, and waste generated from excavated materials which cannot be reused for the construction of new buildings without prior recycling or processing. Moreover, construction waste is generated during the production of semi-finished and finished construction products and materials, as

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well as during the construction and reconstruction of roads. Also, large quantities of construction waste are generated by earthquakes, floods and destruction caused by war.

In terms of quantity, construction and demolition waste constitute the EU's largest waste stream. It represents approximately one-third of the total waste produced. Proper management of construction and demolition waste and waste obtained from recycled materials, including proper handling of hazardous waste, can significantly contribute to sustainability and quality of life. However, the EU construction and recycling industry can also benefit greatly from this as the demand for recycled materials from construction and demolition waste is increasing. However, one of the common obstacles to recycling and reuse of construction and demolition waste in the EU is the lack of confidence in the quality of recycled materials from construction and demolition waste. In addition to this, there is uncertainty as to the potential risk to the health of workers using recycled materials from construction and demolition waste. The lack of trust reduces and limits the demand for recycled materials from construction and demolition waste, thus preventing the development of the infrastructure necessary for the management and recycling of construction and demolition waste in the EU [1].

1.2. Types of construction waste

Some common types of construction waste include:

- Excavation material (soil, stones)
- Insulation and asbestos material
- Concrete and mortar material
- Brick, tiles, ceramics
- Wood materials
- Metallic waste
- Glass, polymers, etc.

Construction and demolition waste grouping are given in Figure 1.

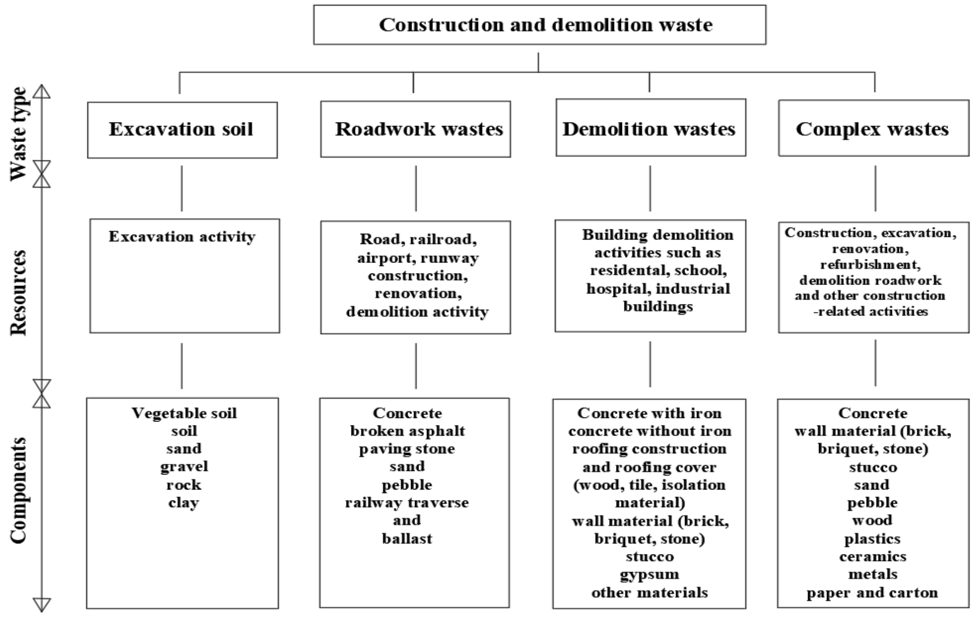

Figure 1. Construction and demolition waste grouping (according to [2])

2. WASTE GENERATION BY ECONOMIC ACTIVITIES AND HOUSEHOLDS

2.1. Waste generation by economic activities and households in EU

In 2018, the total waste generated in the European Union (EU) by all economic activities and households amounted to 2 337 million tonnes [3].

Table 1. shows waste generation by economic activities and households in 2018 in EU. Data are given in % share of total waste.

Table 1. Waste generation by economic activities and households in EU in year 2018 [3] (% share of total waste)

Country	Types of economic activity					
	Mining and quarring	Manufacturing	Energy	Construction and demolition	Other economic activities	Households
EU	26,6	10,6	3,4	35,9	15,4	8,2
Belgium	0,1	24,9	1,2	33,5	33,1	7,2
Bulgaria	82,4	2,0	10,0	0,1	3,1	2,4
Czechia	0,2	14,6	1,5	41,7	26,7	15,3
Denmark	0,0	4,7	5,1	56,0	17,8	16,4
Germany	2,2	13,9	2,3	55,5	16,8	9,2
Estonia	29,5	18,8	32,3	9,5	7,6	2,4
Ireland	14,2	24,7	1,1	13,6	35,1	11,4
Greece	56,4	11,8	7,6	5,0	9,2	10,1
Spain	17,1	9,9	2,4	27,6	26,5	16,5
France	0,4	6,6	0,4	70,2	13,7	8,7
Croatia	12,0	8,9	1,3	22,7	31,7	23,3
Italy	0,8	16,5	1,3	35,3	28,7	17,5
Cyprus	6,6	16,3	0,1	45,8	14,5	16,8
Latvia	0,1	21,7	2,5	17,5	25,7	32,6
Lithuania	1,6	37,2	2,1	8,8	30,3	20,0
Luxembourg	0,0	6,9	0,1	81,2	9,7	2,1
Hungary	1,0	14,3	11,2	33,2	25,4	14,9
Malta	1,6	1,0	0,0	78,8	11,2	7,4
Netherlands	0,0	9,6	1,1	70,0	13,3	6,0
Austria	0,1	8,7	0,8	74,4	9,3	6,7
Poland	36,7	17,0	10,7	9,7	20,6	5,3
Portugal	0,2	19,0	1,1	8,8	38,1	32,8

Romania	88,0	3,9	3,4	0,3	2,4	2,1
Slovenia	0,2	20,2	11,8	8,1	51,9	7,8
Slovakia	2,2	27,5	7,9	4,4	39,8	18,2
Finland	74,9	6,7	1,0	12,3	3,5	1,6
Sweden	74,7	3,7	1,4	8,9	8,0	3,2
Iceland	0,0	24,4	0,0	3,9	31,5	40,2
Liechtenstein	1,6	1,5	0,0	88,6	1,6	6,7
Norway	1,2	12,8	1,5	40,0	27,4	17,1
United Kingdom	5,2	4,0	0,2	48,8	32,4	9,4
Montenegro	27,4	3,7	27,6	11,3	8,6	21,4
North Macedonia	14,2	46,6	0,5	3,1	35,6	0,0
Serbia	75,6	2,9	14,7	1,1	2,1	3,6
Turkey	17,9	:	26,1	0,0	7,1	28,9
Bosnia and Herzegovina	8,2	28,1	48,1	1,8	0,2	13,6
Kosovo	93,5	2,0	3,4	0,1	0,0	1,0

As can be seen in Table 1, construction and demolition account for the largest share of total waste in about half of the total number of countries presented. From the data obtained, it can be concluded that the construction and demolition sector generate large quantities of waste which needs to be properly disposed of.

The share of different economic activities and of households in total waste generation in 2018 is presented in Figure 2. Data are given in % share of total waste.

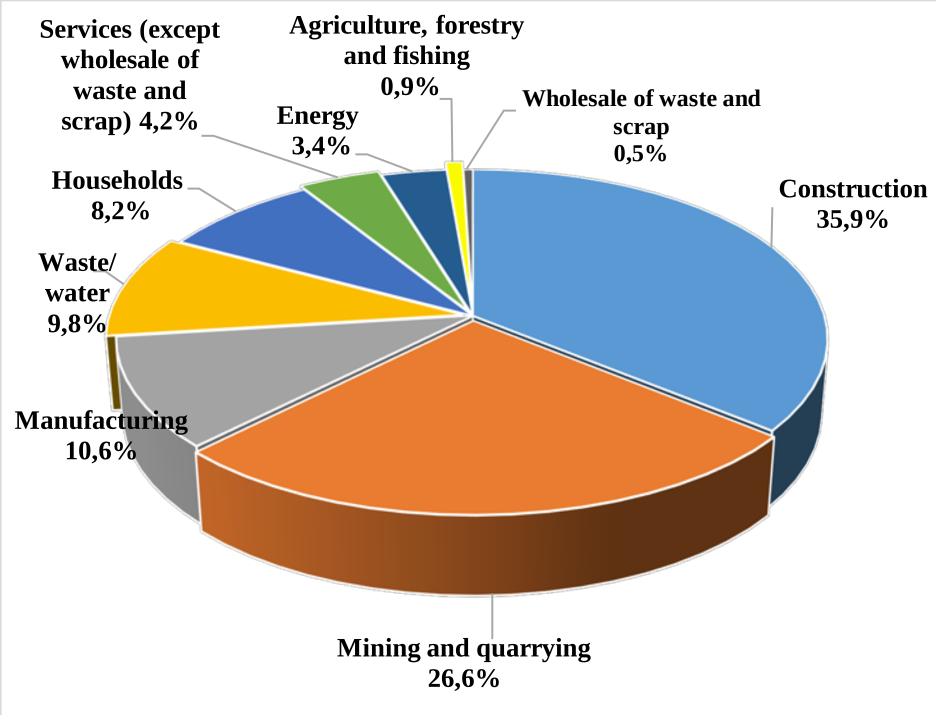

Figure 2. Waste generation by economic activities and households in EU, year 2018 (according to [3])

Presented data on Figure 2 are given in % share of total waste. In the EU, construction contributed 35.9 % of the total in 2018 and was followed by mining and quarrying (26.6 %), manufacturing (10.6 %), waste and water services (9.8 %) and households (8.2 %). The remaining 9.1 % was waste generated from other economic activities, mainly services (4.2 %) and energy (3.4 %) [3]. In overall terms, according to Figure 2, it is the construction sector that generates the largest quantities of waste in the EU, accounting for 35.9 % of the total amount of waste in the EU.

Table 2 shows the development of EU waste generation excluding major mineral waste analysed by economic activity. In 2018, the highest levels of waste generation were recorded for waste and water services (208 million tonnes), for households (186 million tonnes) and for manufacturing activities (180 million tonnes) [3].

As shown in Table 2 for the period from 2004 to 2008, the movement of total waste has taken an ascending trend, as confirmed in Figure 3.

Table 2. Waste generation, excluding major mineral waste in EU from 2004 to 2018 [3] (in million tonnes)

Economic activity	Year							
	2004	2006	2008	2010	2012	2014	2016	2018
Total	**779,5**	**789,9**	**760,5**	**758,7**	**758,0**	**769,0**	**784,7**	**812,0**
Agriculture, forestry and fishing	**62,3**	**56,7**	**45,5**	**20,2**	**20,4**	**17,7**	**19,7**	**19,5**
Mining and quarrying	**10,4**	**7,1**	**10,0**	**7,9**	**7,5**	**7,7**	**6,9**	**8,1**

Manufacturing	**239,9**	**225,8**	**216,8**	**190,5**	**176,4**	**175,9**	**178,9**	**180,1**
Energy	**85,4**	**93,3**	**84,1**	**78,6**	**88,8**	**87,4**	**74,7**	**75,7**
Waste/water	**75,2**	**83,3**	**98,9**	**129,9**	**155,0**	**180,7**	**196,9**	**207,6**
Construction	**34,4**	**33,4**	**34,8**	**42,5**	**39,8**	**38,6**	**37,8**	**41,3**
Other sectors	**97,7**	**111,2**	**88,8**	**102,3**	**88,9**	**85,1**	**88,5**	**94,0**
Households	**174,1**	**179,2**	**181,6**	**186,0**	**180,7**	**175,9**	**181,4**	**185,7**

Figure 3 shows the movement of the total amount of waste in the EU from 2004 to 2018. The trend of increasing the total amount of waste has been observed.

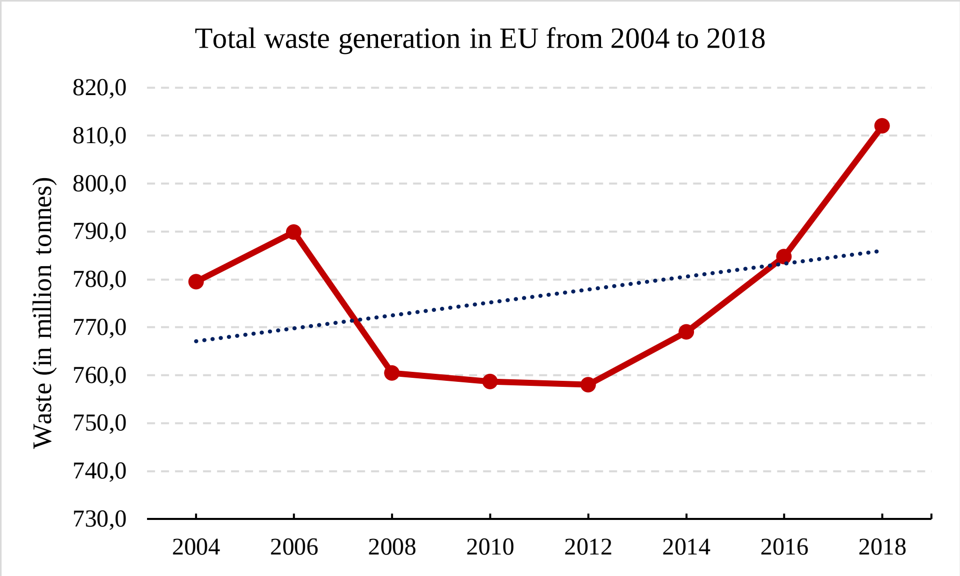

Figure 3. Total waste generation in EU from 2004 to 2018 (author's work according to [3])

2.2. Waste generation by construction sector in EU

The amount of waste generated by the EU construction sector from 2004 to 2018 is on the rise. As shown in Figure 4, an increase in the amount of waste from the construction sector can be observed.

The construction sector in the EU is the highest producer of waste when compared with other economic sectors, accounting for 35 % of the total waste generation. This equates to two and four times more than the total household waste produced in US and Europe respectively [3], [4], [5].

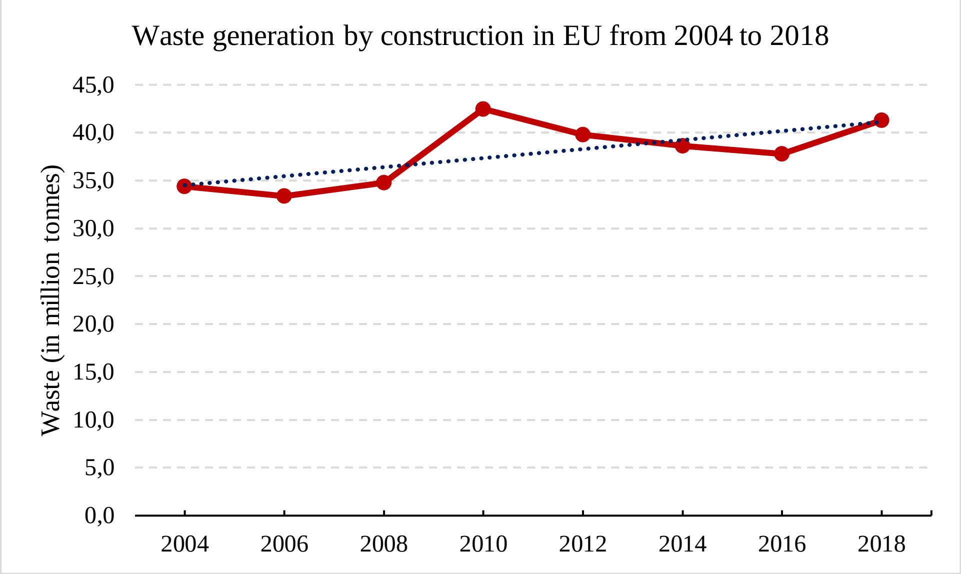

Figure 4. Waste generation by construction activities in EU from 2004 to 2018 (author's work according to [3])

3. CONSTRUCTION WASTE MANAGEMENT

Construction and demolition (C&D) materials (Figure 5) are generated when new building and civil-engineering structures are built and when existing buildings and civil-engineering structures (highways, bridges, utility plants, dams, etc.) are renovated or demolished, including deconstruction activities [6]. A significant amount of industrial waste is created by the construction industry which is generally categorized as construction and demolition waste which has become a concern of governments and consequently, of construction companies [7], [8]. Construction and demolition waste treatment has become an increasingly pressing economic, social, and environmental concern across the world [9]. Construction and demolition wastes threaten many countries because they make up the largest portion of the solid waste stream [10], [11] and construction waste poses a great danger to the environment [12]. Waste management is a crucial part in construction industry [13].

Figure 5. Construction and demolition waste

3.1. Hierarchical approach and circular economy

The construction sector is the biggest driver of resource consumption and waste generation in Europe. The European Union is making efforts to move from its traditional linear resource and waste management system in the construction sector to a level of high circularity [14]. The most recent effort of the European Union resulted in the Circular Economy Action Plan. The first Action Plan that was published in 2015 revolved around the transition from linear to circular economy business models [15], [16].

Circular economy is a strategy used for the transition from the existing linear economy to the circular economy. This is an economic model that provides a sustainable resource management, a longer product lifespan with the aim of reducing waste and an increased use of renewable energy sources. Unlike the linear economy, this is a concept in which the flows of resources and energy are maintained within the closed loop model, aiming to make the products circulate as long as possible within the circular cycle (Figure 6). The emphasis is on the production and design of products that can be easily disassembled, which contain no hazardous substances, have a long lifespan and can be easily repaired [17]. Circular economy is contrary to the concept guided by the principle of, say, “manufacture, consume and discard.” The circular economy model implies a change in the paradigm of the existing management of resources in an efficient and smart way. Such concept is based on eco-innovation, eco-design, advanced technologies, energy efficiency and the use of renewable energy sources. The method of production applied in the linear economy is unsustainable and creates large quantities of waste the disposal of which is based on the mistaken belief that resources are inexhaustible and that the space for waste disposal is unlimited [17].

The 3R approach (Recycle, Reduce and Reuse) is shown in Figure 6 [18].

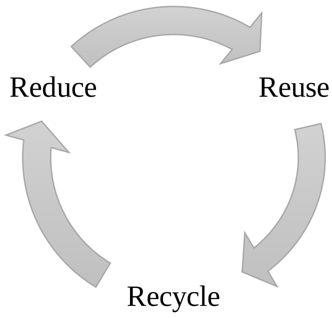

Figure 6. The 3R approach: Recycle, reduce and reuse (according to [18])

The Waste Framework Directive 2008/98/EC [19] lays down some basic waste management principles (Figure 7).

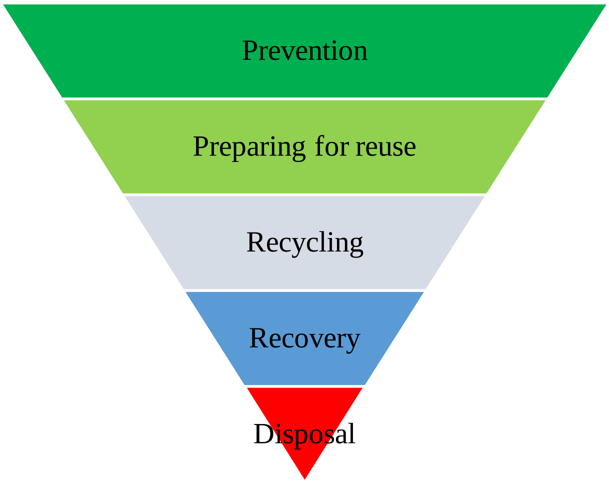

Figure 7. EU waste hierarchy (author's work according to [20])

As presented in Figure 7, which shows the Waste Framework Directive 2008/98/EC, prevention is the most desirable practice, i.e. generation of waste is reduced as much as possible. It is followed by a preparing for reuse, then recycling and recovery. At the very bottom of the hierarchy, there is disposal which is the least desirable way to manage waste.

3.2. Construction waste management after natural disasters

Natural disasters can generate large quantities of waste that may directly threaten public health (e.g. direct human contact with hazardous waste such as asbestos), impede reconstruction (e.g. block access to affected populations and areas) and impact the environment. In particular, damage to infrastructure and buildings generate a significant amount of construction waste such as bricks, concrete and concrete rubble [21]. This occurs in two phases:

1) when the actual natural disaster occurs and
2) later during the response and recovery activities [21].

Large amounts of waste debris occur in urbanised areas when heavy rain on local geology generates flooding and landslides [22]. The pre-disaster construction and demolition waste management phase consists of measures to control disaster waste generation such as building regulations and codes. The post disaster construction and demolition waste management phase includes collecting, transporting, processing and disposing of waste generated by disasters, partial demolitions and reconstruction during relief, rehabilitation and reconstruction phase of disaster waste management cycle [23], [24].

Ruined buildings and infrastructure generates a tremendous quantity of debris including rubble, concrete, bricks, steel and timber that places an additional burden on a community. Thus, in rebuilding, the process should encourage incorporation of building waste reduction, reusing and recycling strategies [25].

3.3. Construction waste management after war destruction

The destruction of property and buildings is an inevitable part of military operations. The accumulation of debris in the streets often impedes the processes of rescue, distribution of aid and services, and other forms of city life as well. Also, the amount of effort and energy needed to remove those residual materials to their final dumping sites divert a lot of urgently needed resources [26].

Some of many benefits of construction and demolition debris management are conservation of natural resources, environmental and economic sustainability, the economical utilization of landfills, the reduction of illegal and unauthorized dumping, reduced energy usage, cost recovery and financial incentives and compliance with policies, laws and regulations [25], [27].

4. CONCLUSION

Construction waste is generated during construction of buildings, reconstruction and maintenance of buildings, demolition and removal, and excavation of the building material. Construction waste is one of the major problems of modern times since it is generated in large quantities from the increased construction activities, i.e. urbanization. Moreover, large quantities of construction waste are caused by natural disasters, such as earthquakes, floods, as well as war destruction. Some types of construction waste include: concrete, roof tiles, metal, gypsum, floor tiles, wood, plastics, etc. When looking at the structure of waste in the European Union, it has been observed that construction waste accounts for one-third of the total amount of waste. During the construction of buildings, it is necessary to keep in mind the ways of waste management. The European Union applies the waste prevention and management policy based on the specific waste hierarchy which includes: prevention, preparation for reuse, recycling, and other recovery procedures, such as energy recovery and disposal. A lot of material obtained from construction waste such as concrete, bricks and metal is suitable for recycling and reuse. It is important that waste is separated at the site of its formation which prevents contamination by other substances and thus increases its value. It is also important to develop a circular economy model in which the flow of resources and energy is maintained in the closed loop model, where the products circulate as long as possible within the circular cycle. In the circular economy model, eco-design, advanced technologies, energy efficiency and the use of renewable energy sources stand out, which are applicable in the field of construction. Environmental pollution can be reduced if construction waste is optimally managed.

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Using Alkali-Modified Fly Ash/Fe_3O_4/CuO Nano-Composite for Heterogeneous Fenton Treatment of Denim Industry Wastewater

Dilara Ozturk[1]*, Ayse Ozguven[1]

Abstract

This study aims to use Alkali-Modified Fly Ash/Fe_3O_4/CuO nano-composite for COD removal from denim industry wastewater with Heterogeneous Fenton oxidation. The characterization of the catalyst was made before and after the Heterogeneous Fenton process with Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM). The synthesized catalyst has a weight ratio for Fe and Cu of % 39.32 and 16.39 %. According to the FTIR results, Fe_3O_4 and CuO nanoparticles were successfully doped to the alkali-modified fly ash. The operational parameters such as initial wastewater pH (2.5-8.5), H_2O_2 dosage (0.5-2 g/L), and catalyst dosage (0.5-2 g-L) were investigated in a batch system. The optimum conditions were determined for pH, H_2O_2 and catalyst dosage as 2.5, 2 g/L, and 2 g/L. Under optimum conditions, COD removal efficiency was calculated as 78.85%. The catalyst's performance was investigated for adsorption, H_2O_2, and the Heterogeneous Fenton process. The dominant process was the Heterogeneous Fenton process, while adsorption was a less effective process. The catalyst can be evaluated as a promising catalyst for the pretreatment of denim industry wastewater with the heterogeneous Fenton process. It can be developed to achieve more effective COD removal.

Keywords: Advanced oxidation process, catalyst, COD removal, Denim industry wastewater

1. INTRODUCTION

Textile wastewater is one of the pollutants of the receiving environment, which is becoming increasingly important to treat. This type of wastewater has negative effects such as reduced light transmittance and reduced oxygen levels in the receiving environment [1]. Such wastewater must be treated before being discharged into the receiving environment. There are many treatment processes with proven effectiveness for textile industries, such as adsorption[2], coagulation/floculation[3], electrooxidation[4], and Fenton processes[5]. Fenton processes are mainly based on the formation of hydroxyl radicals in the presence of iron ions and H_2O_2[6–8]. Hydroxyl radicals attack organic substances, degrading them into smaller structures or converting them into end products such as H_2O, CO_2, etc. Some advantages of Fenton processes include; easy accessibility of iron and H_2O_2, being resistant to high organic loads, satisfactory pollutant removal performances, and easy operation. Fenton processes can be classified as homogeneous and heterogeneous systems. In homogeneous Fenton processes, soluble salts of Fe^{2+} are used, and there is higher sludge formation comparing heterogeneous fenton processes.

On the other hand, homogeneous Fenton processes are more applicable for acidic conditions, while heterogeneous processes can be applied in a wider pH operating range. Catalysts are used as iron sources in heterogeneous Fenton processes. These catalysts may contain Fe^{2+}, Fe^{3+} and or Fe (ZVI). In addition, catalysts can be enriched with metals such as Cu, Mn, Zn etc., with catalytic activity. In this way, it is ensured that oxidizing radicals are formed not only with Fe ions but also with other metals that can trigger the formation of radicals[9]. In addition, the reusability of catalysts brings an environmentally friendly approach to the Heterogeneous Fenton process. Many materials can be used as catalysts. Among these, utilizing wastes or ores that are abundant in nature for catalyst synthesis is a very environmentally friendly approach[8]. In this study,

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Alkali-Modified Fly Ash/Fe_3O_4/CuO nanoparticles were synthesized as a heterogeneous Fenton catalyst to remove COD from denim industry wastewater. FTIR and SEM analyzes were performed for Alkali-Modified Fly Ash/Fe_3O_4/CuO nanoparticles before and after the reaction to clarify the Heterogeneous Fenton mechanism. The operational parameters such as initial wastewater pH (2.5-8.5), H_2O_2 dosage (0.5-2 g/L) and catalyst dosage (0.5-2 g/L) were investigated in a batch system. Also, the performance of the catalyst was investigated for adsorption, H_2O_2 oxidation and Heterogeneous Fenton processes.

2. MATERIAL AND METHODS

2.1. Chemicals, analysis and calculation methods

NaOH, $FeCl_3.6H_2O$, $FeCl_2.4H_2O$, H_2SO_4, NH_4OH (25%), H_2O_2 (30%), KHP, KI, $(NH_4)6Mo_7O_{24}\cdot 4H_2O$ were all purchased commercially from Sigma (USA). Fly ash was supplied from the ISKEN Sugozu thermal power plant (Adana/TURKEY). Denim industry wastewater was taken from a denim industry in Malatya in Turkey. COD was analyzed according to the closed reflux colorimetric method (Eaton, 1995). The remained H_2O_2 concentration in the solution after the reaction was read according to the method developed by Talinli and Anderson [10]and Benatti et al. [11]. pH readings were made by a multimeter (wtw multi340i). COD removal efficiencies were calculated according to Eq.1 Alkali-Modified Fly Ash/Fe_3O_4/CuO nanoparticles were characterized with FTIR (Thermo scientific Nicolet 6700) and SEM (P Zeiss Sigma 300, EDAX-Metek) techniques before and after the heterogenous Fenton process.

$$Removal\ efficiency\ (\%) = \frac{COD_i - COD_t}{COD_i} \quad (1)$$

2.2. Preparation of Alkali-Modified Fly Ash/Fe_3O_4/CuO nanoparticles

20 grams of fly ash were mixed with 160 ml of 3.5 M NaOH solution and stirred under reflux at 90–100 °C for 24 hours, then filtered and washed with distilled water to ensure the solution pH was 7. The resulting material was dried at 120 °C for 12 hours [12].

5 grams of Alkali-Modified fly ash were dispersed in 250 mL of distilled water, and 0.8M $FeCl_3.6H_2O$ was added to this mixture and mixed for 12 hours. Then, 0.4 M $FeCl_2.4H_2O$ was added to this mixture, and the temperature was increased to 80 °C in the meantime. This solution was mixed for 2 hours. Then, NH_4OH (25%) was slowly added to this mixture drop by drop over 30 minutes until the pH reached the range of 8-9. The pH-adjusted mixture was stirred at 800 rpm for 4 hours at 80 °C. After 4 hours, it was washed several times with ethanol and distilled water to ensure the solution pH was 7, centrifuged at 8000 rpm, and dried at 60 °C for 12 hours.

4 grams of Alkali-Modified fly ash@Fe_3O_4 composite were taken into a 500 mL beaker, and 200 ml of distilled water was added and mixed at 800 rpm for 20 minutes. A certain amount of $Cu(SO_4).5H_2O$ (0.2 M) was dissolved in 50 mL of distilled water in a separate beaker. Then this dissolved liquid was added to the solution, and the temperature was increased to 80 °C and stirred for 2 hours. Then, 0.4 grams of NaOH is dissolved in 25 mL of distilled water in a separate beaker. Then the NaOH mixture was slowly added to the solution dropwise and stirred for 4 hours. After 4 hours, it was washed several times with ethanol and distilled water to ensure the solution pH was 7, centrifuged at 8000 rpm, and dried at 60 °C for 12 hours (Figure1).

Figure 1. The Dried Alkali-Modified Fly Ash/Fe_3O_4/CuO catalyst

2.3. Experimental procedure

All experiments were conducted in a batch system at constant room temperature at 20 °C and 170 rpm agitation speed. Firstly, 50 mL wastewater samples, whose pH value and catalyst dosage were adjusted, were taken into a 100 mL beaker. The adsorption/desorption equilibrium was achieved at 170 rpm agitation speed for 30 minutes. Then, the desired amount of H_2O_2 was added to the beakers, and the heterogeneous Fenton reaction was started. 5 mL volume of samples for COD readings were taken at 10, 30, and 60 minutes. The samples were quickly filtered with 0.45 µm syringe-type filters, and the interference of H_2O_2 for COD was determined. Then, H_2O_2 interference correction was made for COD analysis [13].

3. RESULTS AND DISCUSSION

3.1. Performance of Alkali-Modified Fly Ash/Fe_3O_4/CuO nanoparticles

To exhibit the performance of the Alkali-Modified Fly Ash/Fe_3O_4/CuO catalyst, different processes such as adsorption, H_2O_2 oxidation, and the Heterogeneous Fenton processes were investigated based on COD removal. The experiments were conducted under these conditions: pH, H_2O_2 dosage, and catalyst dosage as 3, 1.5 g/L, and 1.5 g/L, respectively, for 60 minutes. Agitation speed and temperature were kept constant at 170 rpm and 20 °C. The results are shown in Figure 2. As seen in Figure 2, the lowest COD removal efficiency was observed for the adsorption process (10.68 %), while the highest removal efficiency was observed for the heterogeneous Fenton process. The lowest removal efficiency observed in the adsorption process may be due to the dopped surface of fly ash, which can be a potential adsorbent, is full of metal oxides. The similar result have been reported in the literature [9]. For the H_2O_2 oxidation process, it can be said that the oxidation capacity of H_2O_2 may be insufficient; in other words, low COD removal efficiency (35.40 %) may be observed due to the low dosage of H_2O_2. The maximum COD removal efficiency was observed in heterogeneous Fenton processes (63.48 %). This mechanism can be explained with Eqs.2-7 [9,14].

$$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + \bullet OOH + H^+ \quad (2)$$

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + \bullet OH + OH^- \quad (3)$$

$$Cu^{2+} + H_2O_2 \rightarrow Cu^{3+} + \bullet OH + OH^- \quad (4)$$

$$Cu^{3+} + H_2O_2 \rightarrow Cu^{2+} + \bullet OOH + H^+ \quad (5)$$

$$\bullet OOH + Organic\ pollutants \rightarrow degraded\ products \quad (6)$$

$$\bullet OH + Organic\ pollutants \rightarrow degraded\ products \quad (7)$$

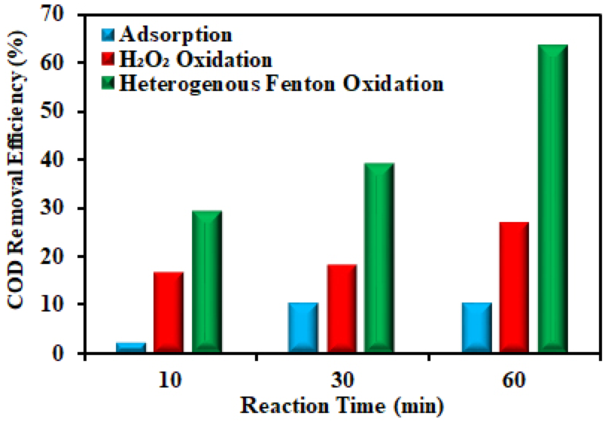

Figure 2. Catalytic performance of Alkali-Modified Fly Ash/Fe_3O_4/CuO

3.2. Effect of wastewater pH

The efficiency of pH value was investigated at 2.5, 3.5, 5.11 (natural pH of wastewater), and 8.5, constant agitation speed of 170 rpm, the temperature of 20 °C, H_2O_2 dosage of 1.5 g/L, and catalyst dosage of 2 g/L, the reaction time of 60 minutes (Figure 3). As seen in Figure 3, maximum (69%) and minimum (44%) COD removal efficiencies were observed at pH of 2.5 and 8.5, respectively. The decreasing trend in COD removal observed above pH 5 can be related to the decomposition of H_2O_2 instead of producing active species[15]. The maximum removal efficiency observed at pH 2.5 may be the more leached Fe and Cu ions from the catalyst to the reaction medium, triggering the formation of more OH. Also in acidic conditions, the Fe and Cu metals on the catalyst surface react with H_2O_2 to produce OH radicals that will oxidize the organic pollutants (Eq.8)[9,16]. The optimum pH value was selected as 2.5.

$$\equiv (Fe, Cu)^{II} + H_2O_2 + H^+ \rightarrow \ \equiv (Fe, Cu)^{III} + H_2O + \bullet OH \qquad (8)$$

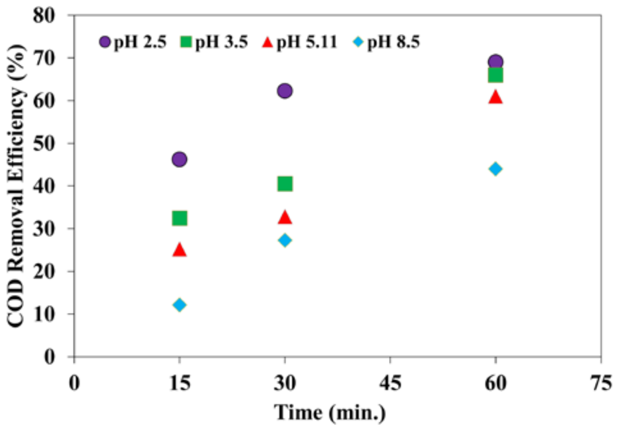

Figure 3. Effect of pH on COD removal

3.3. Effect of Alkali-Modified Fly Ash/Fe_3O_4/CuO dosage

The catalyst dosage (g/L) effect was investigated at 0.5,1, 1.5, and 2, constant agitation speed of 170 rpm, the temperature of 20 °C, H_2O_2 dosage of 1.5 g/L, and pH of 2.5, and the reaction time of 60 minutes. The COD removal efficiencies (%) were calculated as 45.23, 54, 66.36 and 69 for the catalyst dosages (g/L) of 0.5, 1, 1.5 and 2, respectively. With the increase of the catalyst dosage, there was an increase in the amount of Fe and Cu metals on the surface of the catalysts or leaching into the solution environment, resulting in more oxidation of organic pollutants with the production of more OH and HO_2 radicals, leading to an increase in the efficiency of COD removal (Eqs.9 and 10) [9]. The optimum catalyst dosage was selected as 2 g/L.

$$\equiv (Fe, Cu)^{II}{}_{(s)} + H_2O_2 \rightarrow \equiv (Fe, Cu)^{III}{}_{(s)} + OH^- + \bullet OH_{(s)} \qquad (9)$$

$$\equiv (Fe, Cu)^{III}{}_{(s)} + {}_{(s)}H_2O_2 \rightarrow \equiv (Fe, Cu)^{II}{}_{(s)} \bullet HO_2 + H^+ \qquad (10)$$

3.4. Effect of H_2O_2 dosage

The H_2O_2 dosage (g/L) effect was investigated at 0.5,1, 1.5, and 2, constant agitation speed of 170 rpm, the temperature of 20 °C, catalyst dosage of 2 g/L, and pH of 2.5, and the reaction time of 60 minutes. The COD removal efficiencies (%) were calculated as 45.50, 56, 69 and 78.85 for the H_2O_2 dosages (g/L) of 0.5, 1, 1.5, and 2, respectively. The increased COD removal efficiency with increasing H_2O_2 dosage can be attributed to more produced OH radicals. OH radicals produced at higher concentrations result in the oxidation of higher amounts of organic pollutants. In most Fenton processes, high concentrations of H_2O_2 above a certain limit value result in the depletion of OH radicals by H_2O_2, which is defined as the scavenging effect (Eqs. 11 and 12)[8,17]. This is reflected in low pollutant removal. However, since the optimum H_2O_2 dosage was not exceeded in this study, no decrease was observed in COD removal for high H_2O_2 dosages. 2 g/L was taken as the optimum H_2O_2 dosage.

$$H_2O_2 + OH\bullet \rightarrow H_2O + OOH\bullet \tag{11}$$

$$OOH\bullet + HO\bullet \rightarrow H_2O + O_2 \tag{12}$$

3.5. Characteristics of Alkali-Modified Fly Ash/Fe_3O_4/CuO

Figure 4 shows SEM images of Alkali-Modified Fly Ash/Fe_3O_4/CuO before and after the heterogeneous Fenton process. While the smooth sphere structure in Figure 4(a) indicates the characteristic structure of fly ash[18], the spherical nanoparticles indicate dopped Fe_3O_4 and CuO nanoparticles. In general, it can be said that Fe_3O_4 and CuO nanoparticles are well dispersed on Alkali-Modified fly ash. As shown in Figure 4 (b), the structure of nanoparticles on the catalyst surface deteriorated after the heterogeneous Fenton process. This situation can be attributed to oxidation on the catalyst surface due to the reactions in Eqs 9-10. In addition, it is noteworthy that the nanoparticles on the catalyst surface decreased after the heterogeneous Fenton process. This may be related to the leaching of Fe and Cu from the catalyst surface to the wastewater environment under acidic pH conditions [9]. On the other hand, different structures apart from Fe_3O_4 and CuO nanoparticles on the catalyst surface draw attention. This situation may be related to the adsorption of pollutants to the adsorption sites opened on the fly ash surface due to the leaching of Fe and Cu metals from the catalyst surface to the wastewater environment[9].

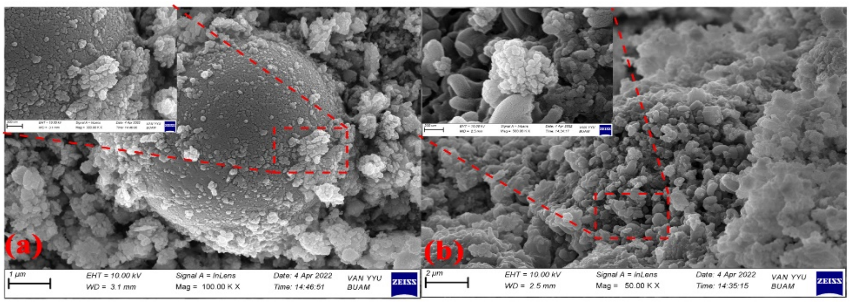

Figure 4. SEM images of Alkali-Modified Fly Ash/Fe_3O_4/CuO (a) before and (b) after the heterogenous Fenton process

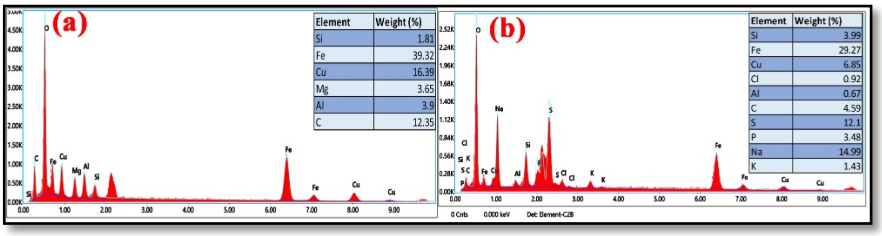

Figure 5. EDX analysis of Alkali-Modified Fly Ash/Fe_3O_4/CuO (a) before and (b) after heterogenous Fenton process

Figure 5 shows the results of EDX analysis of Alkali-Modified Fly Ash/Fe_3O_4/CuO before and after the heterogeneous Fenton process. The weight percentages of Fe in the catalyst are 39.32% and 29.27% before and after the process, respectively. The percentages of weight for before and after the heterogenous Fenton process of Cu are 16.39% and 6.85%. In Figure 5 (a), the weight percentages of 1.81% Si, 3.90% Al, and 3.65% Mg in the catalyst can be attributed to the structure of Fly ash [19]. After the heterogeneous Fenton process, the newly observed peaks of elements such as Cl, and Na, may be attributed to the adsorbed pollutants of the denim industry wastewater on the catalyst surface. The weight percentages of Cu and Fe decreased after the heterogeneous Fenton process. This situation may be due to their reduction due to leaching metals into the solution and may be due to the oxidation reactions occurring on the catalyst's surface. As confirmed from Figure 4 (b), after the heterogeneous Fenton reaction, the structural formations of Fe_3O_4 and CuO nanoparticles on the catalyst surface were disrupted, and the amount of dopped nanoparticles decreased.

Figure 6 shows the FTIR spectrum of Alkali-Modified Fly Ash/Fe_3O_4/CuO before and after the heterogeneous Fenton process. A broad band observed at 3412 cm^{-1} can be attributed to O–H stretching vibration. The peak observed at 1053 $cm^{-1,}$ and 804 cm^{-1} can correspond to the asymmetric stretching of Si-O-Si comes from fly ash[18]. The bands observed at 552 and 553 cm^{-1} may result from Fe-O[20] and the bands observed at 607 cm^{-1} can be attributed to the Cu-O vibrations[21]. The newly observed broad peaks at 1098 cm^{-1} may be attributed to the asymmetric Si–O–Si stretching [22]. This may be due to the opened surface of fly ash as a result of leached metal nanoparticles to the solution from the catalyst surface. A distinctive peak at 614 cm^{-1} may indicate the substituted benzene from aromatic dyes [23] in denim industry wastewater. According to the FTIR, SEM/EDX results, it can be said that the Fe_3O_4 and CuO nanoparticles were successfully dopped on Alkali-Modified fly ash, participated in the Fenton oxidation and showed good performance as a heterogeneous Fenton catalyst.

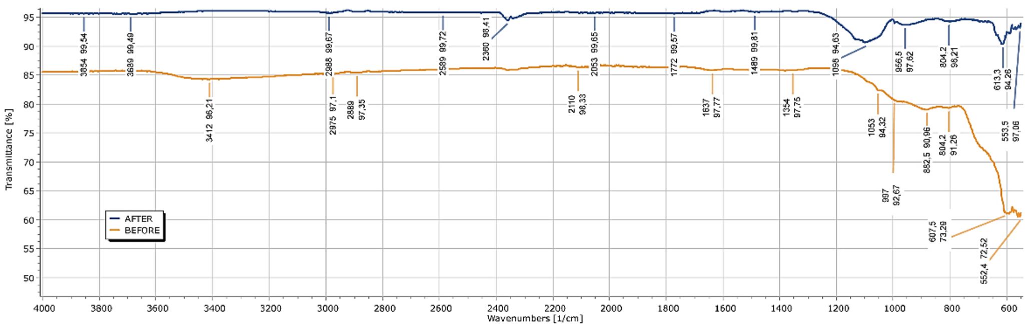

Figure 6. FTIR spectrum of Alkali-Modified Fly Ash/Fe_3O_4/CuO before and after the heterogenous Fenton process

4. CONCLUSIONS

This study investigated the effectiveness of Alkali-Modified Fly Ash/Fe_3O_4/CuO Nano-Composite as a heterogeneous Fenton catalyst for COD removal from denim industry wastewater. In addition to the economic evaluation of fly ash as a waste material, it is aimed to expand the surface area to which metal oxides can be doped by modifying it with NaOH. Then, Fe_3O_4 nanoparticles were doped as an iron source, and CuO nanoparticles were doped on Alkali-Modified Fly Ash, which triggers radical generation in Fenton reactions, allowing the catalyst to be magnetic and easily separated. According to the FTIR analysis, Fe_3O_4 and CuO nanoparticles were successfully dopped on alkali-modified fly ash and participated in the Fenton oxidation. The catalyst's efficiency in the heterogeneous Fenton process has been proven, and its contribution to the COD removal with the adsorption process was very low (10.68%). The optimum conditions were determined for pH, H_2O_2 dosage and catalyst dosage as 2.5, 2 g/L and 2 g/L, with COD removal efficiency of 78.85%. The catalyst can be evaluated as a promising catalyst for the pretreatment of denim industry wastewater with the heterogeneous Fenton process. It may be beneficial to dope a few more active metals and/or modify the surface to increase its catalytic activity.

Biography: Asst. Prof. Dr. Dilara OZTURK is currently working in the Department of Environmental Engineering, Van Yuzuncu Yil University, Van, Turkey. She received her BSc in Environmental engineering in 2009 from Ataturk University, Erzurum, Turkey, and her MSc in Chemistry (physiochemistry) from Yuzuncu Yil University in 2013 and her PhD in Environmental Engineering from Ataturk University, Erzurum, Turkey in 2019. Ozturk is currently working on advanced oxidation processes, nanomaterials and process optimization techniques for wastewater treatment.

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The authors declare they have no financial interests.

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Removal of Phenol from Oil Refinery Phenolic Wastewaster with Photo-Fenton-UVC$_{254}$ Process

Fatih Gulmez[1]*, Ali Oguzhan Narci[2], Deniz Ozturk[3], Esra Can Dogan[4]

Abstract

Oil refinery wastewater with high phenol concentration, causes a high inhibition effect on microbiological activity of biological treatment. Therefore, the phenolic wastewaters are diluted 1/10 with oily wastewater and is given to the activated sludge system.

In this study; the photo-Fenton (UVC) process phenol removal performance from phenolic stripped real refinery wastewater having characteristics of pH: 10.2, phenol: 80.6 mg/L, COD: 1682 mg/L, total cyanide: 6 mg/L, oil-grease: 12.2 mg/L, S^{-2}: 0.172 mg/L and NH_4^+-N: 360 mg/L has been investigated at laboratory scale. Experiments were planned with Taguchi experimental design and process time (60, 90, 120 min), H_2O_2/phenol rate (5, 7.5, 10), H_2O_2/Fe^{+2} rate (5, 10, 15) and light intensity (number of UVC lamps: 2, 3, 4) parameters on phenol removal were evaluated. Phenol removal performance of the photo-Fenton process was evaluated by response surface methodology.

The effluent phenol value was reduced to 4.89 mg/L with 95% removal efficiency with photo-Fenton process under optimum operating conditions (process time: 120 minutes; H_2O_2/phenol: 10; H_2O_2/Fe^{+2}:5 and number of lights: 4). Consequencely, it has been determined that the photo-Fenton process is very effective in removing phenol, sulfur, cyanide and oil-grease and the effluent can be directly fed into the activated sludge system without dilution. In addition, with alternative applications such as longer-term photo-Fenton application in the presence of higher iron and H_2O_2 or the use of membrane processes after the oxidation process for COD, TDS and NH_4^+-N removal, the treated water can be sent to the wastewater recovery unit or deep sea discharge.

Keywords: phenolic wastewater, photo-Fenton (UVC), refinery industry, taguchi experimental design, optimization.

1. INTRODUCTION

The increasing world population and the economic growth targets of the countries constantly increase the need for oil and other energy resources. Global energy demand is expected to increase by 37% by 2035 [1]. Oil is expected to account for 32% of the world's energy supply in 2030 [2]. Oil refining industry; for one unit of crude oil refining, between 0.4 and 1.6 units of process water is needed and industrial wastewater is produced at this rate [3]. High amounts of process water are consumed in many processes such as cooling towers, atmospheric and vacuum distillation, crude oil desalination, coking and cracking in the oil refinery industry. Each of these oil refinery wastewater types is transported to industrial wastewater treatment units with separate sewage and pipe systems according to their characterization [4].

Wastewater with high phenol concentration produced in the delayed coking units (DCU) of oil refineries is sent to the phenolic sour water stripping unit, where it is stripped of its pollutants such as sulfur and ammonium

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nitrogen with steam. As a result of the toxicity test studies, it was determined that phenolic stripped waters had a high degree of inhibition on microbiological activity and low biological treatability. In order to treat phenolic stripped water in the activated sludge biological treatment process, an advanced treatment process is needed to reduce the phenol concentration.

Scientific studies have been carried out on the removal of TOC, COD and phenol from many wastewater types containing phenol and especially in petroleum refinery wastewater by Fenton and photo-Fenton advanced oxidation processes and then remarkable phenol removal performances have been obtained.

In this study, phenol removal from real oil refinery phenolic wastewater with photo-Fenton-UVC_{254} process has been investigated. The effects of operating parameters such as reaction time, H_2O_2/phenol ratio, H_2O_2/Fe^{+2} ratio and light intensity on phenol removal efficiency have been examined. Experiment plan will be created using Taguchi experimental design method and response surface method were used for phenol removal efficiency optimization.

2.1. MATERIALS AND METHODS

2.1.Oil Refinery Phenolic Stripped Water (Raw Water) Characterization

In order to conduct laboratory scale experiments regarding phenol removal with the photo-Fenton-UVC_{254} process, 40 liters of instant samples were taken from the oil refinery phenolic stripped water and raw water characterization studies were carried out. As a result, the raw water characterization before the treatment studies was obtained in Table 1.

The process flow diagram of sour water stripping unit, where our raw water that we used in the experiments come from, is shown in Figure 1. In a short summary, sour water stripping unit is composed of a sour water feed drum, a stripper column, a reflux drum, a reboiler, several pumps, heat exchangers and coolers. Sulfhur and ammonium nitrogen contents of phenolic sour water coming from delayed coker unit is stripped by using low pressure steam in this pretreatment process. And the stripped phenolic water is sent to wastewater treatment plant or delayed coker unit back for the reuse.

Table 1: Oil refinery phenolic stripped water (raw water) characterization

Parameter	**Unit**	**Phenolic Stripped Water (Raw Water) Analysis**
Oil and Grease	mg/L	12,2
pH	-	10,2
Conductivity	µS/cm	367
TDS	mg/L	171
S^{-2}	mg/L	0,172
COD	mg/L	1682
BOD	mg/L	28,5
Phenol	mg/L	80,6
NH_4^+-N	mg/L	360
Total Fe	mg/L	0,15
Total CN^-	mg/L	6

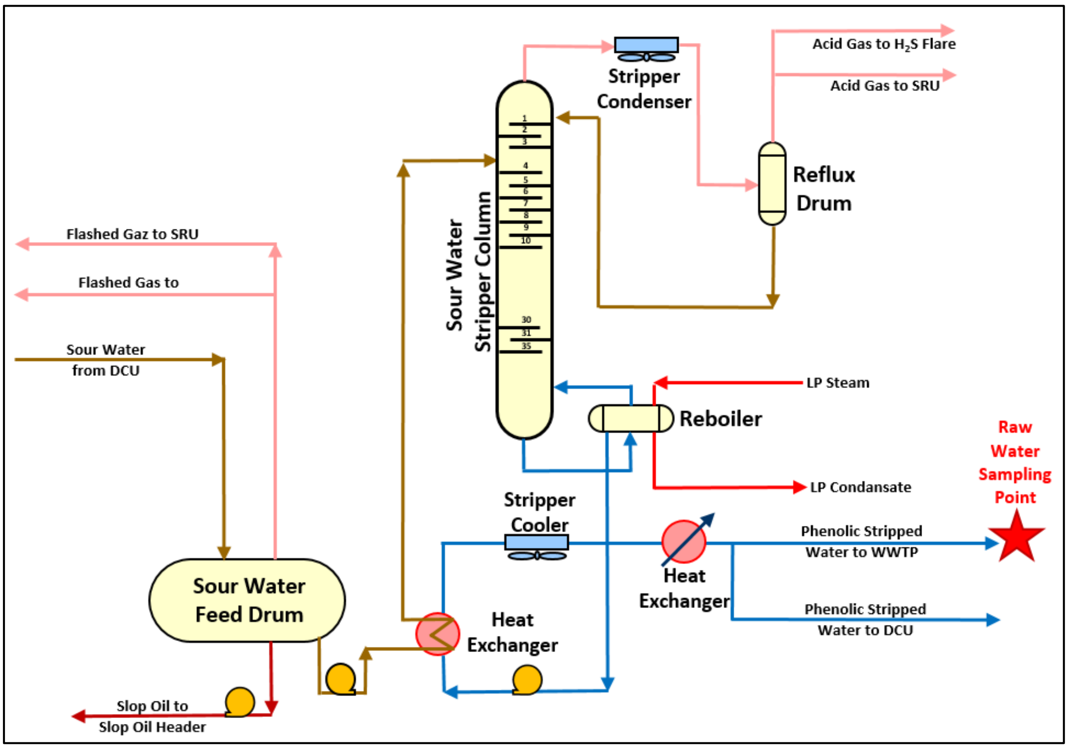

Figure 1: Process flow diagram of sour water stripping (SWS) unit in oil refinery

2.2.Experimental Set-up

Schematic representation of experimental set-up that is composed of electrical power supply (1), electrical cables (2), air supply (3) and air diffuser for mixing (4), quartz glass tubes (5), UVC light lamps (6), 3 liter broxylate glass process reactor (7) and aluminum plate isolation (8) for UVC emission are shown in Figure 2.

2 liters of raw water was poured into the process reactor in each experiment, connections of air source for mixing and connections of energy source for UV lights were completed. After adding ferrous iron and hydrogen peroxide into the process reactor, reaction started under UVC lights. When the reaction time was over, treated water was filtered and ready for the analysis.

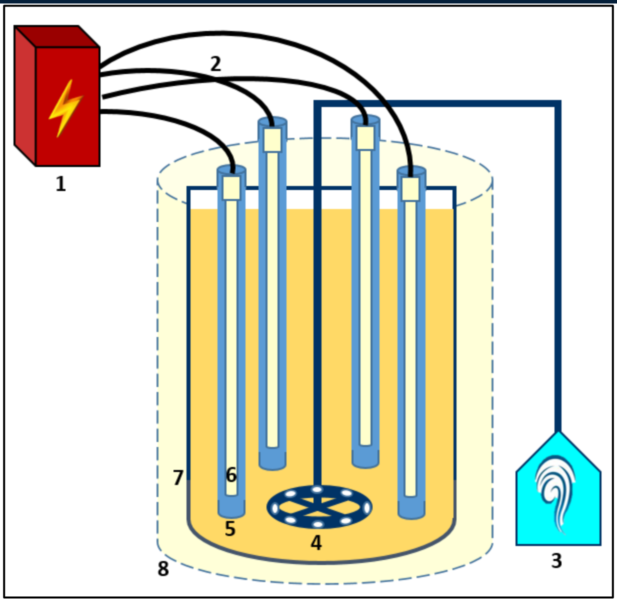

Figure 2: Schematic representation of experimental set-up

2.3.Experimental Design Method

Experimental studies for the treatment of oil refinery phenolic wastewater by the photo-Fenton process were planned with the "Taguchi Experimental Design Method" and the analysis of the experiment results was carried out with the " Response Surface Methodology " using the "Design Expert 10.0.4" software. 4 parameters or controllable factors such as process time, H_2O_2/phenol ratio, H_2O_2/Fe^{2+} ratio and light intensity were determined and 3 different levels were chosen as it is seen in Table 2.

Table 2: Taguchi L9 (34) Experimental Design Factors and Levels

Code	Symbol	Factors	Unit	Experimental Factor Level		
				Low (1)	Medium (2)	High (3)
A	t	Time	Min.	60	90	120
B	H_2O_2/Phenol	H_2O_2/Phenol Ratio	g/g	5	7,5	10
C	H_2O_2/Fe^{+2}	H_2O_2/Fe^{+2} Ratio	g/g	5	10	15
D	L_i	Light Intensity-UVC_{254}	.Lamp Number	2	3	4

The most critical parameters found in the literature studies for the removal of TOC, COD and phenol from oil refinery phenolic wastewater with the photo-Fenton process are reaction time, H_2O_2/phenol ratio, H_2O_2/Fe^{+2} ratio and light intensity. For this reason, in many studies it was determined that the optimum pH value for TOC, COD and phenol removal with photo-Fenton was 3.0, and the pH parameter was not included in the process variables [5], [6].

For photo-Fenton-UVC254 process, using Taguchi design method, 3 different levels were used in 4 different parameters and an experimental set of 9 experiments was created. Table 3 shows the Taguchi experimental design table prepared for laboratory studies of phenol removal with Photo-Fenton-UVC254 process from oil refinery phenolic wastewater. A combination table of 4 different parameters and 3 different levels generated by Taguchi method determined our experimental road map.

Tablo 3: Taguchi L9 (3^4) Experimental Design Parameters and Levels for Photo-Fenton Process

Experiment No	Experiment Factors			
	A t	B H_2O_2/Phenol	C H_2O_2/Fe^{+2}	D Light Intensity
	Min.	g/g	g/g	Lamp Number
1	90	7,5	15	2
2	60	10	15	4
3	90	5	10	4
4	120	5	15	3
5	120	10	10	2
6	120	7,5	5	4
7	60	5	5	2
8	90	10	5	3
9	60	7,5	10	3

3. RESULTS AND DISCUSSION

3.1.Experiments and Analysis Results

The phenol values in the effluent of the experiments carried out with photo-Fenton-UVC_{254} process according to the Taguchi experimental design plan are shown in Table 4 below.

Table 4: Phenol values of treated water with photo-Fenton process

Experiment Number	Experiment Factors				Treated Water Phenol Values
	A t	B H_2O_2/Phenol	C H_2O_2/Fe^{+2}	D Light Intensity	
	min.	g/g	g/g	Lamp number	mg/L
1	90	7,5	15	2	19,3
2	60	10	15	4	12,4
3	90	5	10	4	19,9
4	120	5	15	3	21,2
5	120	10	10	2	11,9
6	120	7,5	5	4	12,1
7	60	5	5	2	18,7
8	90	10	5	3	9,9
9	60	7,5	10	3	16,3

Characterization of raw water and treated water and removal efficiencies of all parameters obtained from the laboratory experiments performed with the photo-Fenton-UVC_{254} process are shown in Table 5 below. In each of the 9 experiments, an increase in the electrical conductivity and TDS parameters of the treated water was observed due to the sulfuric acid solution dosage to reduce the pH of the raw water to 3.0 before the experiment started, and the removal efficiencies were calculated as negative. For this reason, the removal efficiencies of pH, electrical conductivity and TDS parameters are not shown in the table. Sulfur removal efficiency could not be shown in Table 5, as the purified water sulfur parameter value was below the analysis kit measurement range (<0.1 mg/L).

Table 5: Removal efficiencies of different parameters with photo-Fenton-UVC_{254} process

Parameter	Unit	Phenolic Stripped Water (Raw Water)	Photo-Fenton-UVC_{254} Effluent Water (Treated Water)	Removal Efficiency
Oil and Grease	mg/L	12,2	1	%91,8
pH	-	10,2	3,03	-
Conductivity	µS/cm	367	4200	-
TDS	mg/L	171	2121	-
S^{-2}	mg/L	0,172	< 0,1	-
COD	mg/L	1682	1166	%30,7
BOD	mg/L	28,5	22	%22,8
Phenol	mg/L	80,6	4,89	%93,9
NH_4^+-N	mg/L	360	386,8	-
Total Fe	mg/L	0,15	-	-
Total CN^-	mg/L	6	2,05	%65,8

Parameters other than phenol such as TDS, conductivity, sulfur and COD were also analyzed however a significant model could not be obtained as a result of ANOVA analysis. Therefore, phenol was the only parameter used for optimization of photo-Fenton process.

The result values of ANOVA (Analysis of Variance) method performed on the output phenol values for the optimization of the phenol removal with photo-Fenton-UVC process are given in Table 6. When ANOVA results are evaluated; It was determined that the variables of H_2O_2/phenol ratio, H_2O_2/Fe^{2+} ratio and light intensity had a significant effect on the phenol removal performance of the Photo-Fenton process.

Table 6: ANOVA results of effluent phenol values of the experiments

Phenol Removal	Sum of Squares	Degree of Freedom	Average of Squares	F Values	P-Values Prob>F	Effect
Model	140.63	4	35,16	65,58	0,0007	Important
A: Time	0.89	1	0,89	1,66	0,2669	-
B: H_2O_2/Phenol	109.92	1	109,92	205,02	0,0001	Important
C: H_2O_2/Fe^{+2}	24.97	1	24,97	46,57	0,0024	Important
D: Light Intensity	4.86	1	4,86	9,06	0,0396	Important

As a result of ANOVA, a significant model was obtained on phenol removal. The model equation is below.

Effluent Fenol (mg/L) = 28,34824 – (0,012844*Time) – (1,71208*H_2O_2/Phenol) + (0,40798*H_2O_2/Fe) – (0,89959*Intensity of Light) (1)

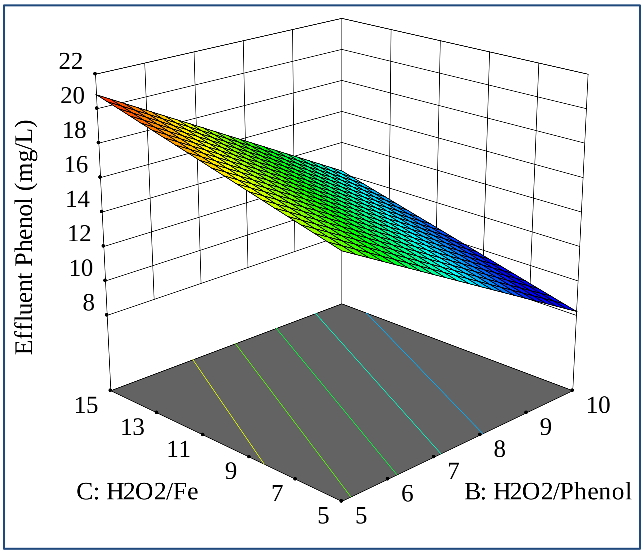

Figure 3: Effect of inlet parameters on phenol removal with photo-Fenton-UVC_{254} process

Figure 3 shows the graph regarding the effect of H_2O_2/phenol ratio and H_2O_2/Fe^{2+} ratio, which were found to have a significant effect on the phenol value of treated water, on the output phenol value. It can also be seen that if H_2O_2/phenol ratio increases, the effluent phenol value decreases while if H_2O_2/Fe^{2+} ratio decreases, the effluent phenol value decreases. According to Figure 4, high correlation coefficient was found between model results and experimental results, showing reliability of the results.

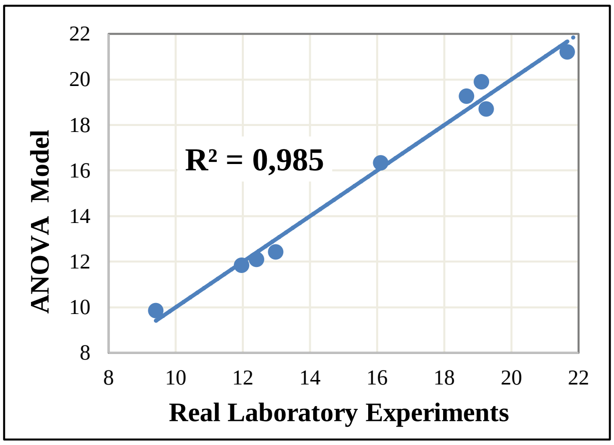

Figure 4: Correlation plot of model and experiments in phenol removal

Table 7: Comparison of the model result and confirmation experiment result

Factors	Optimum Operating Conditions	Effluent Phenol Value of Model Estimation (mg/L)	Effluent Phenol Value of Confirmation Experiment (mg/L)
A-Time (min)	120	8,14	4,89
B: H_2O_2/Phenol (g/g)	10		
C:H_2O_2/Fe^{+2} (g/g)	5		
D: Light Intensity (lamp number)	4		

The optimum parameter levels determined by the analysis of the experimental results with response surface method and the results of the confirmation experiment are shown in Table 7. While we were having an effluent phenol value of 8.14 mg/L according to the model estimation, confirmation experiment conducted at optimum parameter levels showed phenol value of 4.9 mg/L.

Several examples of academic studies on phenol removal by Fenton and photo-Fenton processes from oil refinery wastewater are given below. In oil refinery wastewater containing resistant organic pollutants, the amount of biodegradability increase and the removal of TOC, COD and phenol with Fenton treatment process was carried out. The optimum conditions of the Fenton process were determined as [H_2O_2]/[COD]:6, [H_2O_2]/[Fe]:10 and pH:3.0. As a result of the study, 76.5% COD, 45% TOC and 96% phenol removal were achieved. In addition, an increase in biodegradability of 37% was obtained [5]. In another photo-Fenton process application ([H_2O_2]/[Fe^{+2}]:10, pH:3, UV-C light) using real oil refinery wastewater, 50% COD removal was achieved in 90 minutes [6]. Photo-Fenton process ([H_2O_2]/[$FeSO_4$]:14, 250W UV light) was applied in oil refinery sour water in another study, resulting in 82% DOC removal after 60 minutes [3]. Hernández-Francisco and his/her friends showed that 75% TOC removal was achieved in 60 minutes by applying the photo-Fenton process ([H_2O_2]/[Fe^{+2}]:15.5, pH:3, 25W UV-A light) in oil refinery wastewater [8].

3.2.Potential Use of Treated Water at Optimum Operating Conditions

3 different potential usage areas of treated phenolic wastewater were considered at the beginning of the study as it is seen in Table 8. The first one is to sent treated water to conventional wastewater treatment plant for further treatment, the second one is to discharge to the water body which is Marmara Sea considering Water Polution Control Regulation in Turkey and the third one is to feed industrial wastewater recovery unit. After analyzing the data obtained from the study, the first option was chosen because of the high COD and low pH value of the treated water. Before sending the treated water to biological treatment, pH adjustment were determined to implement.

Table 8: 3 different potential use of treated water obtained from the study

Parameter	Unit	Confirmation Experiment at Optimum Parameter Levels			Option 1	Option 2	Option 3
		Raw Water	Treated Water	Removal Efficiency	WWTP Inlet Limits	Water Body Discharge Limits[7]	Waste Water Recovery Unit Inlet Limits
pH	-	10,2	3,03	-	6,0-9,0	6,0-9,0	6,0-9,0
Conductivity	uS/cm	367	4200	-	500 - 5000	Not Available	2500
TDS	mg/L	171	2121	-	250 - 2500	Not Available	1250
Sulfur	mg/L	0,172	< 0,1	-	0 - 5	1	< 2,0
Phenol	mg/L	80,6	4,89	93,9%	0 - 10	1	< 1,0
COD	mg/L	1682	1176	30,1%	200 - 2000	200	< 85
BOD	mg/L	28,5	22	22,8%	-	-	-
Total CN^-	mg/L	6	2,05	65,8%	<5	1	<5
Oil and Grease	mg/L	12,2	1	91,8%	20 - 100	10	< 15

CONCLUSIONS

As a result; at optimum test conditions for the treatment of oil refinery phenolic wastewaters for phenol removal by photo-Fenton-UVC_{254} process; reaction time was determined as 120 minutes, H_2O_2/phenol ratio was 10, H_2O_2/Fe^{+2} ratio was 5 and number of UVC_{254} lamps was determined as 4. Under these conditions, phenol and oil and grease removal efficiency were obtained 94% and 92% respectively. However, because of low COD removal efficiency and necessity of pH adjustment, option 1 which is sending treated water to WWTP for further biological treatment, is seleceted.

Results of 9 experiments and 1 confirmation test conducted within the scope of laboratory studies showed that the phenol removal efficiency increases as the H_2O_2/phenol ratio increases at constant phenol concentration. Increasing the dosage of H_2O_2 has a direct and positive effect on phenol removal. Again, the same test results showed that the phenol removal efficiency increases as the H_2O_2/Fe^{+2} ratio decreases. In other words, as the amount of Fe^{+2} entering the reaction increased, phenol removal by the photo-Fenton process increased. The increase in reaction time, which is another of the experimental variables, also increased the phenol removal. Finally, the increase in the light intensity used in the reaction, that is, the increase in the number of UVC_{254} lamps used, also increased the phenol removal by the photo-Fenton process.

To conclude, It was evaluated that refinery phenolic wastewater, which has a toxic effect on the biological treatment process, can be made biologically treatable only by adjusting the pH after photo-Fenton process. In addition, with alternative applications such as longer-term photo-Fenton application in the presence of higher Fe^{2+} and H_2O_2, the use of membrane processes after the oxidation process or hybrid processes (AOP/membrane and AOP/adsorption) for COD, TDS and NH_4^+-N removal, the treated water can be sent to the wastewater recovery unit or deep sea discharge.

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BIOGRAPHY

He completed his primary education at Denizli Muftu Ahmet Hulusi Primary School in Denizli and his secondary education at Aydin Adnan Menderes Anatolian High School. He completed his undergraduate education at the Department of Environmental Engineering at Middle East Technical University in January 2015 and graduated as an environmental engineer. Between September 2020 and June 2022, he completed his master's degree in Kocaeli University Institute of Science, Environmental Engineering Department. Between May and November 2015, he worked as a project engineer in a company that carries out infrastructure and water/wastewater treatment plant project works in Ankara. Then he started to work as an environmental process chief engineer in a private oil refinery company in Kocaeli in November 2015. He continued to his carreer as operations chief engineer of treatment units in the same company in October 2020.

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The Influence of Different Energy Dissipating Inlets on the Hydrodynamics within the Clarifiers

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Abstract

The conventional clarifiers do not always equip with an energy dissipating inlets (EDI). However, EDIs are useful equipment that facilitates dissipation of energy and promotes flocculation in the clarifiers. In this study, the benefits and detriments of retrofitting a conventional secondary clarifier with an opposing-jet nozzle type EDI was investigated. The flow and concentration fields were simulated using computational fluid dynamics (CFD) tools. The tranquilizing effect in the influent streams, the promotion of flocculation, the mitigation of density currents, the scouring of sludge blanket, and the short-circuiting of overflow and underflow consequent to the enhanced energy dissipation at the inlet diffusers were explored. This study verified that equipping the clarifiers with an EDI increases the capacity of the clarifiers and enables operating clarifiers with higher overflow rates. It was also uncovered that, on one hand, the EDIs prevent short-circuiting of overflow, on the other hand, they facilitate short-circuiting of the underflow. It is demonstrated that the sludge blankets could be easily deformed in clarifiers that were equipped with EDIs, particularly if the sludge is abstracted from a single point, although it was not a problem in conventional clarifiers. It was endorsed that the sludge thickening performance of the conventional clarifiers was better than the clarifiers equipped with EDIs. To conclude, clarifiers do not always require an EDI unless a high overflow rate was used in the design.

Keywords: Computational Fluid Dynamics, Energy Dissipating Inlet, Clarifier, WWTP

1. INTRODUCTION

The activated sludge process is an eminent treatment technology that has been universally implemented for over a century. The process takes place in multiple reactors; among them, clarifiers are the final step, where the activated sludge is isolated and well-clarified treated effluent is yielded.

The media in the activated sludge reactors are high in suspended solid content. The clarification (or sedimentation) is the process of isolation of activated sludge that is heavier than water through settling by gravity. The favorable conditions in the clarifier enhance the suspension to segregate into two phases, and while the solid phase submerges to the bottom, the fluid phase glides to the surface. In the meantime, the solids adhere to each other and the size of the flocs gradually increases during the sedimentation process. Consequent to the agglomeration of flocs, the heavy ones settle faster, while the light ones settle slower. The flocs that are deposited on the bottom of the tank compress the previously deposited ones and form a sludge layer which is called a sludge blanket. The depth of the sludge blanket is kept at an optimum level by adjusting the flowrate of the return activated sludge from the clarifier to the inlet of the aeration tanks, which also maintains the target MLSS concentration in the aeration tanks.

The empirical approaches based on experiments and basic mathematical models are used in the conventional design of the clarifiers. The most fundamental design parameters are the surface overflow rates (SOR) and the solids loading rates (SLR). These rates should be within the range that represents the successful examples

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performing well. Although some advanced design methods take into account the size distribution, shape, and specific gravity of the solid influx, and sludge settling characteristics, these parameters are seldomly known and can be used in the design.

Although much more attention is usually given to the overflowing and laundering of effluents from the weirs, the most important factor affecting the clarification efficiency in secondary clarifiers is the characteristics of the inlet structure (or influent well). The essential function of the inlet structure is to regulate the influent, dissipate the influent kinetic energy, and diffuse it uniformly in both horizontal and vertical directions. Unsuccessful designs of inlet structures can cause eddies in the clarification zone and worsen the effluent quality.

Even though the inlet structures significantly impact the performance of the clarifier, the design criteria are one-dimensional, and these can be listed as (Tchobanoglous, Burton, & Stensel, 2003): (i) influent wells should have a minimum diameter of 25% of the clarifier diameter; (ii) small solid-skirted cylindrical baffles, such as Stengel, Geiger and Stuttgarter-type (Stamou & Neofotistos, 1994), can be mounted opposite to the influent well orifices (or diffusers) to dissipate the energy and distribute flow evenly; (iii) the velocity at the influent well orifices should be less than 80 mm/s; and, (iv) flocculation (or feed) wells can be formed to promote flocculation in the center of the clarifier, and it should have a minimum diameter of 30% of the clarifier diameter. Therefore, the details of inlet structure designs are usually performed by the experience of designers from his/her previous installations.

The gaps in the design promoted wastewater engineers to invent Energy Dissipating Inlets (EDIs), which is a type of an influent well that is designed to enhance the diffusion of the influent into the clarifier without disturbance, and facilitate the formation of density currents in a horizontal direction. Plenty of EDIs has been invented in the last few decades, which are either patented or patent-pending. The EDIs are classified in four groups (Esler J. K., 2022): (i) gated-opening, (ii) scooped-opening (tangential port opening), (iii) multiple plate, and (iv) opposing-jet type inlets.

There are plenty of studies reporting the performance of invented products compared to their alternatives in the literature. It was reported that the LA-EDI superiors among its alternatives, due to the fact that the multiple outlet nozzles that were configured to create flow impingement by opposing jets can effectively dissipate energy and promote flocculation. There are two configurations of the LA-EDI. In the LA-EDI Type I, the multiple wing-type outlet nozzles are mounted below the periphery of the influent-well, and a flocculation well is created on the periphery of the influent-well. In the LA-EDI Type II, instead of forming a flocculation well on the periphery of the influent well, the multiple wing-type outlet nozzles are placed not on the periphery, but closer to the center of the influent well; besides, the periphery of the influent well is lowered to a distance to form a buffer wall like a skirt to mimic a flocculation well. The two types of LA-EDIs were illustrated in Figure 1.

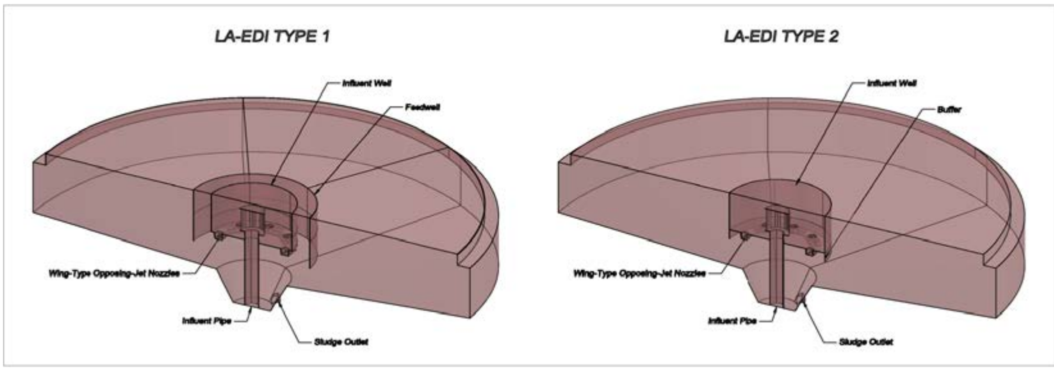


Figure 2. Illustration of LA-EDI Type 1 and Type 2

EDIs are rarely included in initial designs, and prolonged operational problems usually lead clarifiers to be retrofitted with an EDI. Therefore, it is necessary to go beyond the one-dimensional approaches and focus more on real hydrodynamic behavior in the clarifiers, to examine the impacts of fluid flow on overall clarification efficiency as well, while designing an EDI. Fluid flow patterns in clarifiers may be investigated by solving the partial differential equations that characterize mass and momentum conservation. Since the analytical solutions of these equations are not available, numerical solutions could be achieved using Computational Fluids Dynamics (CFD) tools.

CFD has been practiced to solve basic to complex wastewater engineering problems. Although it was not very much preferred by wastewater engineers before particularly due to its lengthy computation time requirement, in recent years, CFD tools have been widely applied as commercial software has been getting affordable, open-source software has been remarkably developed faster than commercial software, the graphical user interfaces of the software have been attractively developed, and high-performance computers have been affordable as a consequence of developments in computer science.

The earliest CFD modeling study in the field of wastewater treatment was conducted by Larsen (1977) in which sedimentation mechanisms of activated sludge in rectangular tanks were researched using solid transport and sedimentation models. Although almost forty-five years have passed since the publication of the first study, most of the important studies were published in the last decade. Undoubtedly, the most extensively researched process is the sedimentation mechanism. Recent studies related to sedimentation processes are case studies focused on optimizing reactor geometry and improving process efficiency.

A recent study on clarifiers was published by Patziger (2016), in which hydrodynamic conditions in existing shallow circular clarifiers were investigated using CFD tools. A strong interaction was exhibited between the depth of the inlet –where activated sludge suspension was introduced to the system– and the length of the circular density jet. In order to shorten the length of the circular density jet, the depth of the inlet of the clarifier was lowered.

Another recent study on clarifiers was about the improvement of influent wells (Griborio & McCorquodale, 2006). It was exhibited that influent wells enhanced the aggregation of dispersed particles and impacted the removal efficiency of the clarifier at utmost level. It was also mentioned that the influent wells prevented not only the interaction between clarified supernatant and activated sludge inflow, but also the up-flow movement of inflow towards weirs. Lastly, it was delivered that the inflow concentration was not an important parameter if the reactor dimensions were optimized.

The objective of this paper is to investigate the benefits and detriments of retrofitting a conventional secondary clarifier with an opposing-jet nozzle type EDI. To this end, the Type-1 and Type-2 configurations of the Los Angeles Energy Dissipating Inlet (LA-EDI) were designed for the clarifier under investigation as per the description available in the patent document (US Patent No. 6,276,537 B1, 2001). The performance of alternative designs was examined using CFD tools, along with the existing inlet structure of the investigated clarifier to compare and contrast the advantages and drawbacks of retrofitting. In this context, the flow and concentration fields were simulated, considering the rheological properties of settling sludge and the effect of stratification on the turbulent diffusion. The tranquilizing effect in the influent streams, the promotion of flocculation, the mitigation of density currents, the scouring of sludge blanket, and the short-circuiting of overflow and underflow consequent to the enhanced energy dissipation at the inlet diffusers were explored.

2. Study Area

The simulations were performed for an urban WWTP in Turkey. The name of the treatment facility was not written as per the confidentiality agreement with the relevant administration. In order to give an idea to the reader about the investigated urban area, this urban area was grouped under the second-grade socioeconomically-developed urban areas among six classes in Turkey. The facility treats domestic, commercial, and industrial effluents generated in this urban area. The treatment plant was designed in two stages, where the first stage was projected to serve until 2025 and the second stage was projected to serve for 2040. The first stage was designed to serve 111.000 PE. The design flow was estimated as 13.762 m^3/d. The treatment units were designed as per the design manual ATV-DVWK-A 131E (2000).

The 14-month recorded operational data after the commencement reflected that the real conditions did not align with the design. The influent flow rate measured in the current year (2019) was almost 5% more than the estimated influent flow rate for 2025. Besides, although the influent wastewater characteristics were estimated to be 336 mg/L BOD, 73 mg/L TN, and 14,6 mg/L TP, the median of 14-months measured influent parameters were 156 mg/L BOD, 37,6 mg/L TN, and 4,7 mg/L TP. Since the measured parameters are way more divergent than the estimated design parameters, the design had to be reviewed to take necessary actions for the improvement and optimization of the treatment performance. In this context, a design-check was performed using the operational records (median and upper -third- quartile values) instead of assumed design parameters. The following issues were detected: (i) the denitrification volume was 3 times larger than the required volume;

(ii) the sludge age was 10-15 days in the operation, although it should be 20 days as per design criteria; (iii) the wasted sludge was 5-8 times greater than the required amount; (iv) the aeration tank volume was 2 times larger than the required volume; (v) the internal recycle was 6-7 times more than the required recycle; and (vi) the supplied air flow was 2-3 times more than the required air volume. Besides, it was concluded that, although the average flowrate is used in the design of biological treatment units, the designer followed the approach of oversizing the units to ignore unwanted, and unexpected situations, in other words masking the inadequate design.

The clarifier was also examined since clarifiers are part of the biological treatment system. The diameter of the existing clarifiers is 30 m. The existing clarifiers have a 27,4 $m^3/m^2/day$ overflow rate and a 6,8 $kg/m^2/h$ sludge loading rate. These values satisfy the limit values in the literature, which are between 24 and 32 $m^3/m^2/day$ for overflow rates and lower than 7 $kg/m^2/h$ for sludge loading rates. Besides, the current clarifier has an influent well, that has a diameter of 13% of the clarifier diameter, and each has 4 large openings to diffuse the influent into the clarification zone. The influent well was not equipped with energy dissipating baffles.

3. Material and Method

Ansys Fluent 2020 R2, which is licensed to the Dokuz Eylul University, was used to perform CFD modelling in this study. The CFD modeling was performed as per the Good Modelling Practices in wastewater CFD applications (Wicklein, 2015) determined by the International Water Association (IWA) working group on Computational Fluid Dynamics. Accordingly, the objective of the problem was determined to investigate the benefits and detriments of retrofitting a conventional secondary clarifier with an opposing-jet nozzle type EDI. The problem was decided to be solved as time-dependent in a 3D domain; besides, rigid-lid approximation was implemented considering that the fluctuations on the water surface of the clarifiers are negligible. The Type-1 and Type-2 configurations of the Los Angeles Energy Dissipating Inlet (LA-EDI) were dimensioned following the description available in the patent document (US Patent No. 6,276,537 B1, 2001) and the geometry of the problem was drafted in 3D in AutoCAD. Then the geometries were imported to Ansys and discretized into computation cells using meshing methods. Since the geometries were very complex, the mesh generated by the software seemed acceptable. Over 4,5M triangular elements were used in meshing per clarifier. A grid dependency study was also performed to verify that simulation will be accurate, stable, and easily convergable with minimum computational time.

The boundary conditions were inputted as followed: The inlet was defined as velocity inlet, the water outlet was defined as pressure outlet, the sludge outlet was defined as velocity inlet, the top was defined as symmetry, and other surfaces were defined as walls.

The solver settings were inputted as followed: The fundamental governing equations (the continuity and momentum) were solved under transient conditions in a 3D domain using the Finite Volume Method. The double-precision pressure-based solver was selected with second-order implicit as its unsteady formulation in order to achieve a more accurate result. Semi-Implicit Method for Pressure-Linked Equations (SIMPLE) scheme was utilized for pressure-velocity coupling calculations. The k-ε turbulence model was utilized to involve mean flow components for turbulent flow conditions, and close the set of equations. The standard discretization scheme was used for the pressure equation, but second-order upwind discretization was chosen for both momentum and energy equations. The under-relaxation factors were used for numerical stability. The convergence criteria were set to be 10^{-6}.

The simulations were run and since they were found well-modelled, the post-processes were performed to illustrate the results.

4. Results and Discussion

The simulated flow and concentration fields, considering the rheological properties of settling sludge and the effect of stratification on the turbulent diffusion, were depicted in the following figures.

The velocity field on the elevation where the influent is diffused to the clarification zone is depicted in Figure 2. The satisfying energy dissipation in LA-EDI Type-1 can easily be caught the eye. The energy dissipation in LA-EDI Type-2 is better compared to the conventional clarifier, but worse than in LA-EDI Type-1. The velocities are simulated below 0.01 m/s in the clarification zone in LA-EDI Type-1. There are regions, where flow velocity varies between 0.015 and 0.020 m/s in the clarification zone in LA-EDI Type-2. The flow velocity in the conventional clarifier is variant across the radial direction; while the flow velocity is as high as 0.05 m/s on the periphery of the influent well, it ranges from 0.015 m/s to 0.025 m/s across the clarifier.

The essential duty of EDIs is to dissipate energy and distribute the flow evenly at the outlet of the influent well. Figure 3 depicts how the opposing jets form at the nozzles of the wing-type outlets, and also the performance of flow impingement, and energy dissipation. While velocity at the inner nozzles was almost 0.15 m/s, it was almost 0.1 m/s at the outer nozzles and the velocity of the influent plume decreased below 0.025 m/s in LA-EDI Type 1. However, the velocity of the plume in LA-EDI Type 2 was around 0.1 m/s.

Figure 4 is the cross-section of the flow velocity field in the clarifier. First, it is worth noting that the influent well in the conventional clarifier performs fair enough to dissipate the influent energy; although the influent velocity is over 0.6 m/s, the velocity diminished down to 0.05 m/s. However, the flow exited from the influent-well-orifices could not be dissipated more until the flow reaches 2/3rd of the radius of the clarifier, since there were no other measures for energy dissipation at the influent-well-orifices.

In both configurations of LA-EDI, the opposing jet nozzles were found very effective in dissipating energy. Although the energy dissipated well enough at the opposing-jet nozzles in LA-EDI Type-2, the remaining energy could not be mitigated by the baffle lowered from the periphery of the influent well, and the plume exited from the influent-well-orifices travelled not only in the horizontal direction (as it was in the conventional clarifier), but also climbed in the vertical direction. In such cases, the clarifiers are usually equipped with baffles at the side wall below (such as Crosby-type weirs) the effluent weir to mitigate up-flow short-circuiting of sludge.

The flow field in the clarifier with LA-EDI Type-1 was calmer than the conventional clarifier and the clarifier with LA-EDI Type-2. The potential up-flow short-circuiting of sludge in the clarifier with LA-EDI Type-1 is expected minimum compared to the conventional clarifier and the clarifier with LA-EDI Type-2.

It could be observed in Figure 4 that sludge abstraction velocity was high, and the velocity profile was not symmetrical as expected in a circular clarifier, since the abstraction was performed from a single point.

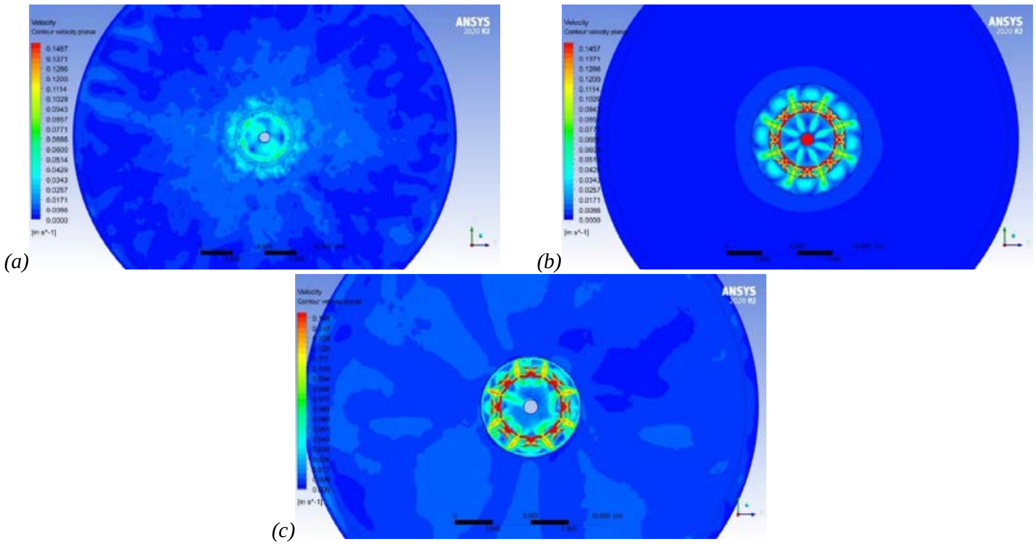


Figure 3. The flow velocity contours on the elevation where the influent is diffused in the clarifier, (a) Current Status, (b) LA-EDI Type 1, (c) LA-EDI Type 2

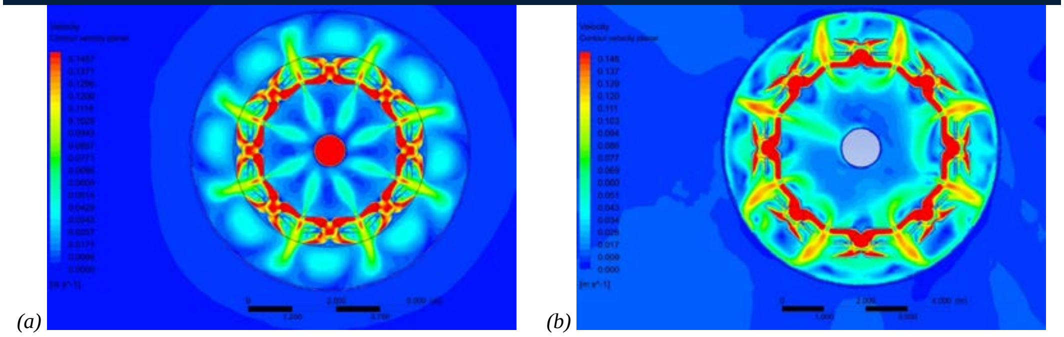


Figure 4. The flow velocity contours on the elevation that reflect the formation of opposing jets; (a) if the existing inlet is replaced with an LA-EDI Type-1, and (b) if the existing inlet is replaced with an LA-EDI Type-2

The settling process, which was modeled by the Takács function (Takács, Patry, & Nolasco, 1991), is represented in Figure 5. The most favorable zone for sludge settling in clarifiers is the region between the influent well orifices and the sludge blanket; therefore, the colors that reflect the settling velocity change in the figures below have a wide range of the spectrum in that region. The settling velocity values were found low at the bottom of the clarifier, as expected, due to the fact that the sludge blanket was formed and thickened at the bottom, and therefore settling is minimum in this region. The settling velocity values were found maximum at the plume existing the influent well (or nozzles), as expected. The plume exiting the influent well dispersed in a skirt shape in the vertical direction in the clarifier with LA-EDI Type-2, since the lowered baffle below the periphery of the influent well was short and did not bear a function of a flocculation well. Moreover, the plume was found dispersed in a conical shape in the horizontal direction both in the conventional clarifier and the clarifier with LA-EDI Type-2, due to the fact that the kinetic energy was not sufficiently dissipated. Among three modifications, the clarifier with LA-EDI Type-1 has enabled the most favorable conditions for sedimentation, since the energy was well-dissipated in this clarifier. This finding also supported that flocculation wells facilitate sedimentation conditions in clarifiers.

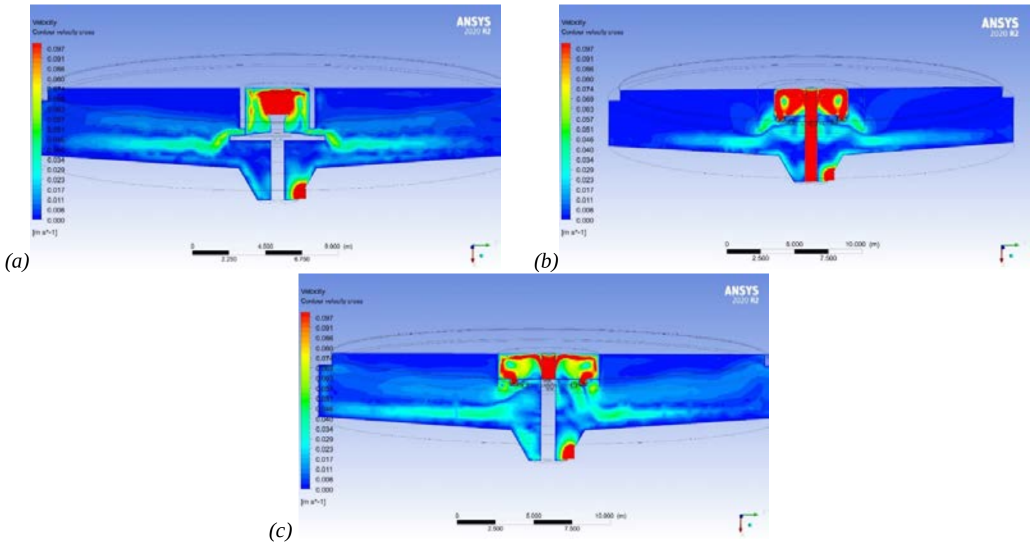


Figure 5. Flow velocity contours in the clarifier (a) under the current conditions, (b) if the existing inlet is replaced with an LA-EDI Type-1, and (c) if the existing inlet is replaced with an LA-EDI Type-2.

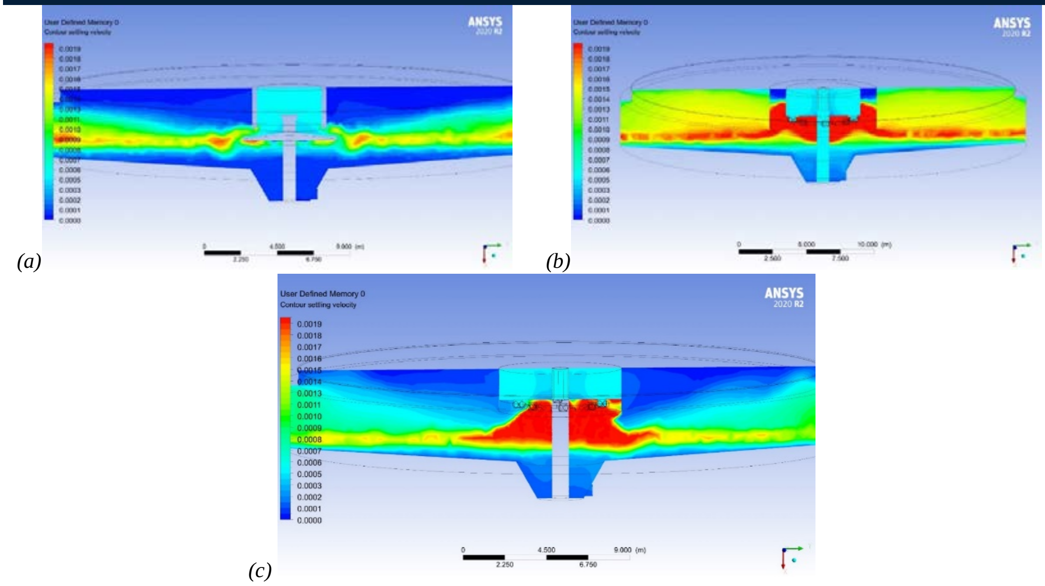


Figure 6. Sludge settling velocity contours (a) under the current conditions, (b) if the existing inlet is replaced with an LA-EDI Type-1, and (c) if the existing inlet is replaced with an LA-EDI Type-2.

It could be also observed in Figure 5(c) that the plume exiting the influent well dispersed in a skirt shape in the vertical direction in the clarifier with LA-EDI Type-2 was not symmetrical, as expected. The problem was derived due to the turbulence within the clarifier as a consequence of abstracting sludge from a single point.

The main objective of having clarifiers in treatment plants is to facilitate the sedimentation of solids. In this regard, the performance of achieving this objective could be best visualized by observing solid concentration in the clarifier. Figure 6 represents the sludge concentration in the clarifier. Any reader will first focus on the red region in Figure 6, at first sight. This red region represents the most thickened sludge among the three modifications of the clarifier. Obviously, the conventional clarifiers enable the best conditions for the thickening of settled sludge compared to the clarifiers with EDIs. Although it was suspected that it could be due to the poor formation of the sludge blanket, it was displayed in Figure 6 that the sludge blanket was well-formed in all modifications of clarifiers. This could be due to the fact that most of the solids settle within the flocculation well and abstracted from the sludge outlet in a short while, consequently the solids have less retention time to be compacted in clarifiers with EDIs than the conventional clarifiers. Although the settling performance of clarifiers with EDIs was regarded as good, the sludge thickening performance was not as satisfactory as the original clarifier.

The sludge concentration difference across the diameter of the sludge outlet was well-depicted on the sludge concentration profile in Figure 6(c). This difference could be addressed as a sort of deformation of sludge, resulted not exactly due to the LA-EDI type inlet structures, but also from the non-uniform abstraction of sludge from the clarifier. Due to the fact that the sludge is abstracted from a single point, consequently, the sludge is abstracted from a pipe in larger dimensions, and discharge velocity is high to discharge the required volume. The streamlines (Figure 7) also confirmed that sludge abstraction from a single point promoted turbulence within the clarifier. In order to mitigate this problem, a new outlet pipe must be designed that supports the uniform abstraction of sludge from the sludge hopper.

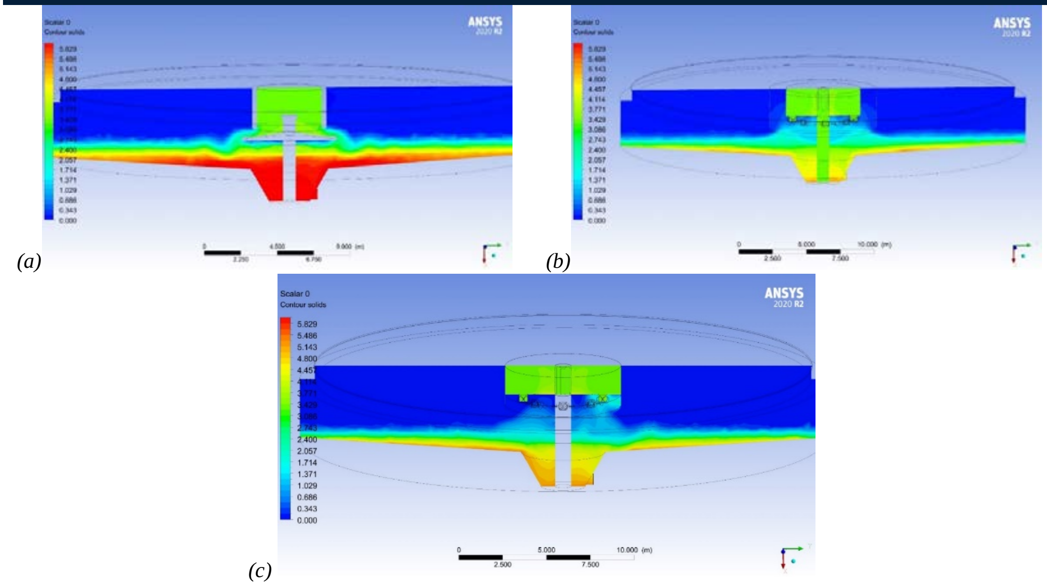
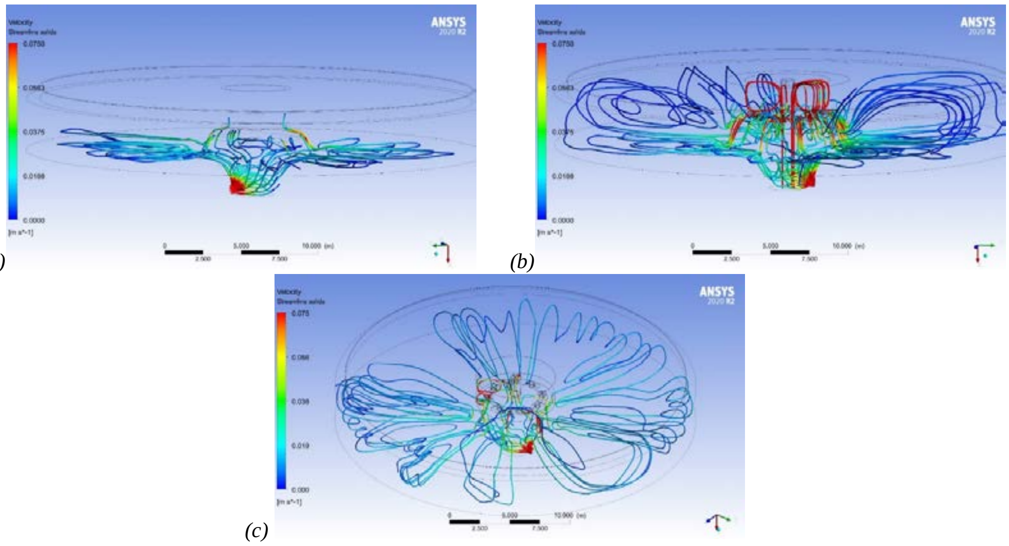


Figure 7. Sludge concentration contours(a) under the current conditions, (b) if the existing inlet is replaced with an LA-EDI Type-1, and (c) if the existing inlet is replaced with an LA-EDI Type-2.

Figure 7 represents the streamlines that occurred during sludge abstraction. The streamlines in the conventional clarifier are remarkably different than the clarifiers with LA-EDI. The streamlines in the conventional clarifier have only appeared in the lower half of the sidewall, where the sludge blanket occurs; in other words, the abstracted sludge was thickened. However, the streamlines were displayed arbitrarily scattered within clarifiers with LA-EDI, which means not only settled sludge but also clarified water with low solid content is abstracted from the sludge outlet. Besides, if the reader follows the red noodles in Figure 7(b), they were mostly moved within the influent well, indicating that the influent was not retained in the clarifier sufficiently to thicken, and it discharged right after it was diffused in the clarification zone. This causes low sludge concentration in the abstracted sludge. This phenomenon was entitled short-circuiting into the underflow; however, it has not been discussed in detail in the literature (Grau & Aquanova, 2022; Esler J. K., 2022). It was uncovered that, on one hand, the EDIs prevent short-circuiting of overflow, on the other hand, they facilitate short-circuiting of the underflow.

The change in the sludge concentration during the abstraction of sludge from the beginning of the simulation was computed. The sludge concentration abstracted from the conventional clarifier was found to have reached the fourth phase of the sedimentation phase, which is compression. This is the fact why the most thickened sludge was found to be achieved in the conventional clarifier, as depicted in Figure 6(a). However, the abstracted sludge concentration from the clarifiers with EDIs were found to have reached the third phase of the sedimentation phase, which is transition. Therefore, the thickened sludge in the clarifiers with EDIs was not as concentrated as in the conventional clarifiers.



(a) *(b)* *(c)*

Figure 8. Streamlines during sludge suction (a) under the current conditions, (b) if the existing inlet is replaced with an LA-EDI Type-1, and (c) if the existing inlet is replaced with an LA-EDI Type-2.

CONCLUSION

The conventional clarifiers do not always equip with an EDI. However, EDIs are useful equipment that facilitates dissipation of energy and promotes flocculation in the clarifiers. This study demonstrated that conventional clarifiers do not always require an EDI unless a high overflow rate was used in the design. However, equipping the clarifiers with an EDI increases the capacity of the clarifiers and enables operating clarifiers with higher overflow rates.

It was endorsed that the sludge thickening performance of the conventional clarifiers was better than the clarifiers equipped with EDIs. Subsequently, it was uncovered that, on one hand, the EDIs prevent short-circuiting of overflow, on the other hand, they facilitate short-circuiting of the underflow.

Finally, this study demonstrated that the sludge blankets could be easily deformed in clarifiers that were equipped with EDIs, if the sludge is abstracted from a single point, although it was not a problem in conventional clarifiers.

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