Electrochemical remediation of wastewater contaminated by phenol

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Abstract. One of the most significant contributors to water contamination is the petroleum sector. Large volumes of refinery effluent contaminated with numerous sorts of contaminants are discharged into water sources, causing substantial environmental harm. As a result, researchers looked at the use of a variety of treatment techniques to mitigate the impacts of refinery effluent. Utilising hybrid electrodes (iron as cathodes, and aluminium as anodes) electrodes, this investigation intends to use the electrocoagulation method to minimise phenol contaminants from refinery effluent. In addition, the influence of experimental parameters such as electrical current density, electrode spacing, and duration of treatment on the elimination of phenols was investigated in this study. To eliminate the phenols from the effluent, batch flow investigations were employed. According to the findings, the electrocoagulation technique decreased the number of phenols in petroleum effluent. The hybrid electrocoagulation unit was able to decrease the phenol content by around 45%. With a current density of 4 mA/cm² and electrode separation of 2 cm, the highest removal efficiency was reached after 110 minutes of treatment. Other experiment factors, such as the original amount of the phenols, must be examined.

Keywords: Petroleum refinery wastewater, phenols, electrocoagulation.

Introduction
The petrol industry has become one of the world’s largest, most significant and vital sectors because it provides the primary energy source in several industrialised countries [1, 2]. Furthermore, for several countries throughout the world, the petroleum industry represents the main pile in their national revenue [3]. Nonetheless, this business is regarded as one of the most significant producers of contamination, significantly influencing the environment. The petroleum sector uses a lot of water and generates a lot of effluent from different systems, such as cooling and desalination systems. Researchers have found that to
create one barrel of crude oil, more than 250L of water are required. According to the available studies, the petroleum industry generates millions of barrels of polluted wastewater every day that is discharged (some times without proper treatment) to the sources of freshwater [1], adding to this the elevated level of energy consumption, which results in severe air pollution [1, 4]. The main problem in the treatment of petroleum wastewater is the variety of pollutants in this type of wastewater, for instance, the literature showed the wastewaters of the refineries usually contain high concentrations of organic compounds [5, 6], phenols [7], hydrocarbons [8, 9], heavy metals [10-12], greases [13, 14], nitrates [15, 16], phosphates [17, 18], dyes [19, 20], turbidity [21, 22], and biological pollutants [23, 24] other contaminants may be present in wastewater [3, 25].

Although there is a wide range of pollutants in petroleum wastewaters, phenol-based pollutants are highly expected in nearly all forms of petroleum wastewaters [7]. The reports and published studies confirmed that the concentrations of phenol-based pollutants in the wastewaters of the petroleum wastewater could be more than 180 mg/L, noting that the maximum allowable concentration of phenols in water is 1 mg/L, which cause a series of serious environmental and health problems. It has been found to be more than 180mg/L. There is a wide body of evidence about petroleum wastewater’s direct and indirect effects; for instance, the latter was strongly related to a wide range of diseases and poisoning events [1, 2]. The effects of the petroleum wastewaters are not, unfortunately, limited to water pollution, but also it could cause long-term soil pollution, especially near the refineries or oil production sites [1], and also air pollution [26], that was reflected in the global warming and climate change [27, 28]. As it is well-known the climate change causes serious problems, such as the increase in the global temperature [29, 30], changes in precipitations [31, 32], and water scarcity [33, 34].

The mentioned effects of the petroleum wastewaters highlighted the need to treat refinery wastewaters’ effluents properly before the final discharge to the rivers or any other forms of freshwater bodies [35-37]. Therefore, an increasing effort was noticed over the last years to develop proper (efficient and affordable) techniques to remediate the refineries effluents from the mentioned pollutants, which helps maintain the environment and the public health. For instance, physical [38, 39], biological [40, 41], and chemical [42-44] techniques were practised to remove all or some of the above-listed pollutants.

Membrane processes, electrocatalytic, oxidation, absorption, and filtration are some of the technology that has been utilised to determine the effect of one or more contaminants detected in petroleum effluents [38, 39]. Phosphates, nitrates, microbes, organic materials, and heavy metals are among the contaminants eliminated by these methods [40, 41]. Nonetheless, due to changes in the quantity or composition of contaminants in wastewater generated by the petroleum sector, many of these approaches are either too expensive or inefficient to entirely remove or satisfy the disposal requirements limitations. Furthermore, it must be admitted that the refinery industry is not the only source of water and air pollution, but other industry like the cement manufacturing [45-47] and concrete industry [48-51] contribute to the water and air pollution. Also, the rapid expansion in urbanisation contributes to water pollution [52-55]. Moreover, an increasing number of studies are involved in the electrocoagulation technique, which has been shown to eliminate a variety of contaminants from different types of wastewater, such as heavy metals, phosphates, organic matter, colour, and other contaminants [38, 39].

Furthermore, scientists found that electrocoagulation is inexpensive, simple to use, does not need additives, and takes up little space [40, 41]. Additionally, the electrocoagulation sludge includes a high concentration of heavy metals, making it ideal for recycling, particularly in civil engineering applications [47, 56, 57]. This might result in a considerable reduction in trash transfer to landfills and the preservation of landfill sites for other waste kinds [58-60].

This study aims to see if the electrocoagulation technique can be used to remove phenols from refinery effluents. The electrocoagulation unit will be provided with a hybrid electrode, iron (cathodes) and aluminium (anodes)
1. Material and methods

An electrocoagulation system (ES) was used to water purification effluent from a crude oil refining facility. An electrocoagulation system is rectangular, with a wide of 100 mm, a height of 150 mm, and a length of 250 mm, with four electrodes; two iron cathodes and two aluminium anodes. Every electrode is 160 mm in length and a width of 100 mm and contains 38 openings with a diameter of 5 mm. The openings in electrodes mix the effluent throughout treatment and improve the removal of the contaminants.

110 mg/L of phenols was used in this study to investigate the effectiveness of the ES in the removal of phenol. The effects of electric current density (ECD), treatment period and electrodes displacement (ED) on the performance of the ES regarding phenols elimination from refinery effluent. Table 1 lists the characteristics of the wastewater utilised in this study.

| Parameter               | Value      |
|-------------------------|------------|
| Colour                  | Brown      |
| PH                      | 7.3        |
| Conductivity (Ms/cm)    | 9.60       |
| Total suspended solid (mg/l) | 114       |
| Phenol (mg/l)           | 110        |

By constructing a DC rectifier, three desirable ECDs of 4 mA/cm², 8 mA/cm², and 12 mA/cm² were given EC to eliminate the phenols out from refinery effluent. Furthermore, three-electrode distances of 1.5 cm, 2.5 cm, and 3.5 cm were employed in this study to investigate the influence of the ED on the ES’s removal performance. The distances were carefully adjusted.

The elimination of phenols from oil refinery effluent was accomplished by continuously running the effluent through the ES and electrodes. The treatment duration for the phenols in the effluent varied from 1 minute to 2 hours. Throughout that time, specimens of 20 mL of the treated wastewater were taken every 10 minutes to investigate how well the ES was removed. A spectrometry (Hach Lange DR 2800) and the standardised cuvette testing LCK 345, which were chosen based on the residual phenol content, were used to measure the residual phenols in the effluent. The degree of the effluent utilised in this study was kept at 25±5°C, which is room temperature. The percentage removal of phenols from refinery effluent may be estimated using the following techniques by using formula 1.

\[
\text{Removal Percentage}\% = \frac{L_1 - L_f}{L_1} \times 100\%
\]

$L_I$ and $L_f$, respectively, represent the original and ultimate concentrations of phenols in refinery effluent in mg/L.

2. Results and discussion

2.1. The effect of electrical current density

In the electrocoagulation approach, the current density is a key element because it influences the frequency of coagulant production, which significantly impacts ES removal efficacy. Depending on this, the latter investigation looked at the influence of the ECD impact on the removal performance of phenol from refinery effluent. This was accomplished by employing several ECDs to treat effluent specimens containing 110 mg/l of the contaminant. ECDs of 4 mA/cm², 8 mA/cm², and 12 mA/cm² were utilised in this study.
Furthermore, the ED was maintained at 20 mm, and the treatment time was 110 minutes. The findings (figure 1) revealed that increasing the ECD improves the phenol percentage removal from refinery effluent. After 110 minutes of treatments, the phenol elimination effectiveness rose from 22% to more than 70% when the current density was raised from 4 to 12 mA/cm. This improvement in phenol elimination effectiveness can be attributed to the higher in coagulant production rate.

![Figure 1: The influence of the ECD on the phenol percentage removal utilising ES.](image)

2.2. The effect of electrodes displacement

Another factor that has been observed to have an impact on the electrocoagulation technique’s efficacy in terms of different contaminants removal is the distance between electrodes. As a result, the influence of the electrode spacing on the efficiency of electrocoagulation in terms of phenols elimination from refinery effluent has been investigated in this study. The ED was manually adjusted with three separate spacings of 2, 3, and 4 cm. ECD, starting phenol content, and treatment period were retained at 4 mA/cm², 120 ppm, and 110 minutes, respectively, for the other experimental factors. Figure 2 shows that when the ED decreases, the percentage removal of phenols using ES rises. Whenever the ED was raised from 2cm to 4cm, the percentage removal of the phenols fell from 40.5% to 12%, as shown in figure 2. Thus, the variation in the electrostatic force of attraction between the electrodes can lead to variation in removal efficiency.

![Figure 2: The impact of ED on the effectiveness of phenol removal with ES](image)
2.3. Influence of treatment time

Treatment time has been demonstrated to substantially impact the effectiveness of different treatment techniques and applications. In electrocoagulation, Khalid et al., [23] found a favourable relationship between treatment time and coagulant production. The influence of treatment time on the elimination of phenols from petroleum effluent using the suggested ES have been investigated depending on this. To accomplish so, specimens with phenolic concentrations of 110 ppm were treated in the ES for 110 minutes with an ECD of 6 mA/cm² and an ED of 2 cm. As seen in Figure 3, the proportion of phenols removed increased continuously with the treatment period. When the treatment period was prolonged from 20 minutes to 110 minutes, the elimination effectiveness of phenols rose from 15% to 59%.

![Figure 3: The influence of treatment time on the phenol removal efficiency utilising ES.](image)

Finally, the positive effects of current density on the removal of pollutants from water, unfortunately, is accompanied by power consumption; therefore, it is important to optimise the current density. This can be done using a wide range of technologies, such as wired [61, 62] and wireless [63-65] sensors.

3. Conclusion

Depending on the results observed from this experimental study, the investigation might be summarised in the following:

- The electrocoagulation technique may considerably minimise the amount of phenol contaminants in refinery effluent.
- The elimination of phenols decreased when the current intensity was minimised.
- The elimination of phenols rose when the distance between the electrodes was reduced.

More studies are needed to determine the impact of the original contamination levels on the coagulation/flocculation technique’s removal performance.

References

[1] Diya’uddeen B H, Daud W M A W and Aziz A A 2011. Treatment technologies for petroleum refinery effluents: A review. *Process safety and environmental protection*, 89 95-105.
[2] Abdulredha M, Kadhim N, Almutairi M, Yeboah D and Hashim K 2021. Zeolite as a natural adsorbent for nitrogenous compounds being removed from water. *IOP Materials Science and Engineering*, 012082.

[3] Aljuboury D, Palaniandy P, Abdul Aziz H and Feroz S 2017. Treatment of petroleum wastewater by conventional and new technologies-A review. *Glob. Nest J*, 19 439-52.

[4] Abdulredha M, Rafid A, Jordan D and Alattabi A J P e 2017. Facing up to waste: how can hotel managers in Kerbela, Iraq, help the city deal with its waste problem? *196* 771-8.

[5] Zanki A K, Mohammad F H, Hashim K S, Muradov M, Kot P, Kareem M M and Abdulhadi B 2020. Removal of organic matter from water using ultrasonic-assisted electrocoagulation method. *IOP Conference Series: Materials Science and Engineering*, 012033.

[6] Emamjomeh M, Kakavand S, Jamali H, Alizadeh S M, Safdari M, Mousavi S and Mousazade M 2020. The treatment of printing and packaging wastewater by electrocoagulation–flotation: the simultaneous efficacy of critical parameters and economics. *Desalination and water treatment*, 205 161-74.

[7] Emamjomeh M, Mousazadeh M, Mokhtari N, Jamali H A, Makkiaabadi M, Naghdali Z, Hashim K and Ghanbari R 2020. Simultaneous removal of phenol and linear alkylbenzene sulfonate from automotive service station wastewater: Optimisation of coupled electrochemical and physical processes. *Separation Science and Technology*, 55 3184-94.

[8] Grmasha R, Al-sareji O, Salman J and Jasim J A 2020. Polycyclic Aromatic Hydrocarbons (PAHs) in Urban Street Dust Within Three Land-Uses of Babylon Governorate, Iraq: Distribution, Sources, and Health Risk Assessment. *Journal of King Saud University - Engineering Sciences*, 33 1-18.

[9] Hashim K, ALKhaddar R, Kot P, Al-Jumeily D, Alwash R and Aljefery M 2020. Electrocoagulation as an eco-friendly River water treatment method. In Advances in Water Resources Engineering and Management, Berline: Springer.

[10] Abdulla G, Kareem M, Hashim K, Muradov M, Mubarak H, Abdellatif M and Abdulhadi B 2020. Removal of iron from wastewater using a hybrid filter. *IOP Materials Science and Engineering*, 012035.

[11] Abdulraheman F, Al-Khafaji Z, Muradov M, Kot P and Shubbar A 2020. Natural filtration unit for removal of heavy metals from water. *IOP Materials Science and Engineering*, 012034.

[12] Omran I I, Al-Saati N H, Hashim K S, Al-Saati Z N, Patryk K, Khaddar R A, Al-Jumeily D, Shaw A, Ruddock F and Aljefery M 2019. Assessment of heavy metal pollution in the Great Al-Mussaib irrigation channel. *Desalination and Water Treatment*, 168 165-74.

[13] Alhendal M, Nasir M, Amoako-Attah J, Muradov M, Kot P and Abdulhadi B 2020. Cost-effective hybrid filter for remediation of water from fluoride. *IOP Materials Science and Engineering*, 012038.

[14] Alyafei A, Yeboah D, Al-Falufji D and Zubaidi S 2020. Treatment of effluents of construction industry using a combined filtration–electrocoagulation method. *IOP Materials Science and Engineering*, 88.

[15] Al-Marri S, ALKizwini R S, Zubaidi S L and Al-Khafaji Z S 2020. Ultrasonic-Electrocoagulation method for nitrate removal from water. *IOP Materials Science and Engineering*, 012073.

[16] Mohammed A, Hussein A, Yeboah D, Abdulhadi B, Shubbar A and Hashim K 2020. Electrochemical removal of nitrate from wastewater. *IOP Materials Science and Engineering*, 012037.

[17] Hashim K S, Ewadh H M, Muhsin A A, Zubaidi S L, Kot P, Muradov M, Aljefery M and Al-Khadder R 2020. Phosphate removal from water using bottom ash: Adsorption performance, coexisting anions and modelling studies. *Water Science and Technology*, 83 1-17.

[18] Alenezi A K, Hasan H, Amoako-Attah J, Gkantou M, Muradov M, Kot P and Abdulhadi B 2020. Zeolite-assisted electrocoagulation for remediation of phosphate from calcium-phosphate solution. *IOP Conference Series: Materials Science and Engineering*, 012031.

[19] Aqeel K, Mubarak H, Amoako J, Abdellatif F, Al-Janabi A and Hashim K 2020. Electrochemical removal of brilliant green dye from wastewater. *IOP Materials Science and Engineering*, 012036.

[20] Hashim K, Alquzweeni S, Kraidi L, Hussein A H, Andy K and Alwash R 2019. Decolourisation of dye solutions by electrocoagulation: an investigation of the effect of operational parameters. *1st Int. Conference on Civil and Environmental Engineering Technologies, University of Kufa, Iraq.*
[21] Alenazi M, Hassan A A, Muradov M, Kot P and Abdulhadi B 2020. Turbidity removal using natural coagulants derived from the seeds of strychnos potatorum: statistical and experimental approach. *IOP Conference Series: Materials Science and Engineering*, 012064.

[22] Al-Saati N H, Hussein T K, Abbas M H, Hashim K, Al-Saati Z N, Kot P, Sadique M, Aljeferi M H and Carnacina I 2019. Statistical modelling of turbidity removal applied to non-toxic natural coagulants in water treatment: a case study. *Desalination and Water Treatment*, 150 406-12.

[23] Hashim K, Kot P, Zubaid S, Alwash R, Al Khaddar R, Shaw A, Al-Jumeily D and Aljeferi M 2020. Energy efficient electrocoagulation using baffle-plates electrodes for efficient Escherichia Coli removal from wastewater. *Journal of Water Process Engineering*, 33 101079-86.

[24] Hashim K S, Ali S, AlRifaie J K, Kot P, Andy A, Al Khaddar R, Idowu I and Gkantou M 2020. Escherichia coli inactivation using a hybrid ultrasonic–electrocoagulation reactor. *Chemosphere*, 247 125868-75.

[25] Abdulredha M, Muhsin A, Al-Janabi A, Ala'imi B, Gkantou M, Amaoko-Attaah J, Al-Jumeily D, Mustafina J and AlKhayyat A 2021. Using SF and CKD as cement replacement materials for producing cement mortar. *IOP Conference Series: Materials Science and Engineering*, 012007.

[26] Al-Sareji O, Grmasha R, Salman J M, Idowu I and Hashim K S 2021. Street dust contamination by heavy metals in Babylon governorate, Iraq. *Journal of Engineering Science and Technology*, 16 3528 - 46.

[27] Zubaidi Salah L, Al-Bugharbee H, Ortega Martorell S, Gharghan S, Olier I, Hashim K, Al-Bdairi N and Kot P 2020. A Novel Methodology for Prediction Urban Water Demand by Wavelet Denoising and Adaptive Neuro-Fuzzy Inference System Approach. *Water, 12* 1-17.

[28] Zubaidi S L, Al-Bugharbee H, Muhsin Y R, Hashim K, Alkhaddar R M, Al-Jumeily D and Aljaaf A J 2019. The Prediction of Municipal Water Demand in Iraq: A Case Study of Baghdad Governorate. *12th International Conference on Developments in eSystems Engineering (DeSE), Kazan, Russia 274-7*.

[29] Zubaidi S, Ortega-Martorell S, Al-Bugharbee H, Olier I, Hashim K S, Gharghan S K, Kot P and Al-Khaddar R 2020. Urban Water Demand Prediction for a City that Suffers from Climate Change and Population Growth: Gauteng Province case study. *Water, 12* 1-18.

[30] Zubaidi S, Kot P, Hashim K, Alkhaddar R, Abdellatif M and Muhsin Y 2019. Using LARS–WG model for prediction of temperature in Columbia City, USA. *IOP Materials Science and Engineering*, 012026.

[31] Salah Z, Ortega S, Kot P, Alkhaddar R, Abdellatif M, Gharghan S, Ahmed M and Hashim K 2020. A Method for Predicting Long-Term Municipal Water Demands Under Climate Change. *Water Resources Management*, 34 1265-79.

[32] Zubaidi S, Al-Bugharbee H, Muhsin Y and Alkhaddar R 2020. Forecasting of monthly stochastic signal of urban water demand: Baghdad as a case study. *IOP Materials Science and Engineering*, 012018.

[33] Salah Z, Abdulmaleem I, Al-Bugharbee H, Ridha H, Gharghan S, Al-Qaim F and Alkhaddar R 2020. Hybridised Artificial Neural Network model with Slime Mould Algorithm: A novel methodology for prediction urban stochastic water demand. *Water, 12* 1-18.

[34] Salah Z, Hashim K, Ethaib S, Al-Bdairi S, Al-Bugharbee H and Gkantou S 2020. A novel methodology to predict monthly municipal water demand based on weather variables scenario. *Journal of King Saud University-Engineering Sciences*, 32 1-18.

[35] Alattabi A, Harris C, Alkhaddar R, Alzeyadi A and Abdulredha M 2017. Online Monitoring of a sequencing batch reactor treating domestic wastewater. *Procedia engineering*, 196 800-7.

[36] Alwan H, Saleh L and Abdulredha M 2020. Experimental prediction of the discharge coefficients for rectangular weir with bottom orifices. *Journal of Engineering Science and Technology*, 15 3265-80.

[37] Abdulredha M, Rafid A, Jordan D and Alattabi A 2017. Facing up to waste: how can hotel managers in Kerbala, Iraq, help the city deal with its waste problem? *Procedia engineering*, 196 771-8.

[38] Hashim K, Hussein A, Zubaid S, Kraidi L and Alwash R 2019. Effect of initial pH value on the removal of reactive black dye from water by electrocoagulation (EC) method. *2nd International Scientific Conference, Al-Qadisiyah University, Iraq 12-22.*
[39] Hashim K, AlKhaddar R, Kot P and Al-Shamma’a A 2021. Water purification from metal ions in the presence of organic matter using electromagnetic radiation-assisted treatment. *Journal of Cleaner Production*, **280** 1-17.

[40] Al-Saati N H, Omran I I, Salman A A, Al-Saati Z and Hashim K S 2021. Statistical modeling of monthly streamflow using time series and artificial neural network models: Hindiya Barrage as a case study. *Water Practice and Technology*, **16** 681-91.

[41] Hashim K, Al-Saati N, Hussein A and Al-Saati Z 2018. An investigation into the level of heavy metals leaching from canal-dreged sediment: a case study metals leaching from dreged sediment. *First International Conference on Materials Engineering & Science*, Istanbul Aydin University, Turkey 12-22.

[42] Abdulhadi B, Hashim K, Muradov M and Rafid M 2021. Continuous-flow electrocoagulation (EC) process for iron removal from water: Experimental, statistical and economic study. *Science of The Total Environment*, **760** 1-16.

[43] Abdulhadi B, Andy S and Khadder R 2019. Influence of current density and electrodes spacing on reactive red 120 dye removal from dyed water using electrocoagulation/electroflotation (EC/EF) process. *1st Int. Conference on Civil and Environmental Engineering Technologies*, University of Kufa, Iraq 12-22.

[44] Alnaimi H, Idan I, Al-Janabi A, Hashim K, Gkantou M, Zubaidi S and Muradov M 2020. Ultrasonic-electrochemical treatment for effluents of concrete plants. *888* 1-9.

[45] Shubbar A, Al-Shaer A, AlKizwini R, Hawesah H and Sadique M 2019. Investigating the influence of cement replacement by high volume of GGBS and PFA on the mechanical performance of cement mortar. *1st Int. Conference on Civil and Environmental Engineering Technologies*, University of Kufa, Iraq 31-8.

[46] Shubbar A, Sadique M, Nasr M, Al-Khafaji Z and Hashim K 2020. The impact of grinding time on properties of cement mortar incorporated high volume waste paper sludge ash. *Karbala International Journal of Modern Science*, **6** 1-23.

[47] Shubbar A, Sadique M, Shanbara H and Hashim K 2020 *The Development of a New Low Carbon Binder for Construction as an Alternative to Cement*. In *Advances in Sustainable Construction Materials and Geotechnical Engineering*, Berlin: Springer.

[48] Kadhim A, Sadique M, Al-Mufti R and Hashim K 2020. Long-term performance of novel high-calcium one-part alkali-activated cement developed from thermally activated lime kiln dust. *Journal of Building Engineering*, **32** 1-17.

[49] Kadhim A, Sadique M and Hashim K 2020. Developing One-Part Alkali-Activated metakaolin/natural pozzolan Binders using Lime Waste as activation Agent. *Advances in Cement Research*, **32** 1-38.

[50] Majdi H, Shubbar A, Nasr M, Al-Khafaji Z, Jafer H, Abdulredha M, Masoodi Z, Sadique M and Hashim K 2020. Experimental data on compressive strength and ultrasonic pulse velocity properties of sustainable mortar made with high content of GGBFS and CKD combinations. *Data in Brief*, **31** 105961-72.

[51] Idowu I, Hashim K, Andy S and Nunes L 2021. Enhancing the fuel properties of beverage wastes as non-edible feedstock for biofuel production. *Biofuels*, **14** 1-8.

[52] Al-Jumeily D, Hashim K, Alkaddar R, Al-Tufaily M and Lunn J 2019. Sustainable and Environmental Friendly Ancient Reed Houses (Inspired by the Past to Motivate the Future). *11th International Conference on Developments in eSystems Engineering (DeSE)*, Cambridge, UK 214-9.

[53] Farhan S, Antón D, Akif V, Zubaidi S and Hashim K 2021. Factors influencing the transformation of Iraqi holy cities: the case of Al-Najaf. *Scientific Review Engineering and Environmental Sciences*, **30** 365-75.

[54] Al-Maliki L A, Farhan S L, Jasim I A, Al-Mamoori S K and Al-Ansari N 2021. Perceptions about water pollution among university students: A case study from Iraq. *Cogent Engineering*, **8** 1895473.

[55] Jasim I, Farhan S and AL-Mamoori S 2021. Climatic Treatments for Housing in the Traditional Holy Cities: A Comparison between Najaf and Yazd Cities. *IOP Earth and Environmental Science*, 012017.

[56] Shubbar A, Jafer H, Dulaime A, Atherton W and Sadique M 2018. The development of a low carbon binder produced from the ternary blending of cement, ground granulated blast furnace slag and high calcium fly ash: An experimental and statistical approach. *Construction and Building Materials*, **187** 1051-60.
[57] Shubbar A, Sadique M, Nasr M, Al-Khafaji Z and Hashim K 2020. The impact of grinding time on properties of cement mortar incorporated high volume waste paper sludge ash. *Karbala International Journal of Modern Science*, 6 1-23.

[58] Abdulredha M, Abdulridha A, Alkhaddar R, Kot P and Jordan D 2020. Estimating municipal solid waste generation from service processions during the Ashura religious event. *IOP Conference Series: Materials Science and Engineering*, 012075.

[59] Abdulredha M, Jordan D and Abdulridha A 2018. Benchmarking of the Current Solid Waste Management System in Karbala, Iraq, Using Wasteaware Benchmark Indicators. *World Environmental and Water Resources Congress 2018: Groundwater, Sustainability, and Hydro-Climate/Climate Change*, 40-8.

[60] Abdulredha M, Jordan D and Abdulridha A 2020. Investigating municipal solid waste management system performance during the Arba’een event in the city of Kerbala, Iraq. *Environment, Development and Sustainability*, 22 1431-54.

[61] Gkantou M, Muradov M, Kamaris G, Atherton W and Kot P 2019. Novel Electromagnetic Sensors Embedded in Reinforced Concrete Beams for Crack Detection. *Sensors*, 19 5175-89.

[62] Kot P, Muradov M, Gkantou M, Kamaris G S, Hashim K and Yeboah D 2021. Recent Advancements in Non-Destructive Testing Techniques for Structural Health Monitoring. *Applied Sciences*, 11 1-28.

[63] Ryecroft S, Shaw A, Fergus P, Kot P, Moody A and Conway L 2019. A First Implementation of Underwater Communications in Raw Water Using the 433 MHz Frequency Combined with a Bowtie Antenna. *Sensors*, 19 1813-23.

[64] Kot P, Muradov M and Al-Khaddar R 2021 *How can sensors be used for sustainability improvement?. In Methods in Sustainability Science*, Elsevier, United Kingdom: Joe Hayton, p 426.

[65] Omer G, Kot P, Atherton W, Muradov M, Gkantou M, Shaw A, Riley M, Hashim K and Al-Shamma’a A 2021. A Non-Destructive Electromagnetic Sensing Technique to Determine Chloride Level in Maritime Concrete. *Karbala International Journal of Modern Science*, 7 61-71.