The use of sawdust in the separation of copper from polluted water

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Abstract. Heavy metals in water supplies are a major source of concern around the world for a variety of reasons. For one, heavy metals can survive in water for lengthy stretches of time because they are not degraded by microorganisms. Second, heavy metals can build up to toxic levels in the humans and plants, posing a threat to living through the food. Presence of heavy metal in water causes serious health issues, including kidney failure and brain illnesses. As a result, the advancement of efficient water treatment technologies for heavy metal remediation is a top priority for scientists today. To extract copper, sawdust is used as a chemically active adsorbent in this study. The adsorption tests were done in a batch environment to see how various parameters like treating time, pH level, and adsorbent dosage affected the results. The results showed that the pH level that allowed the most copper to be removed was neutral. Following the batch trials, the optimal treating time was determined to be 165 minutes. The results showed that a 2.5 g/L dose of sawdust reduced copper pollution content in the water solution by 90 percent. Copper reduction has been successfully achieved using sawdust as a low-cost sorbent.

Keyword: Copper; water treatment; sawdust

1. Introduction
The pollution of heavy metal in water is regarded as the primary problem for wastewater treatment facilities around world because these metals can persist in water for lengthy time of time due to their inability to be degraded by microorganisms, and they can grow to harmful levels in the bodies, affecting humans by the food [1-4]. Furthermore, heavy metal contamination of water causes serious health issues for users, including kidney diseases, liver injury, brain disorders, and abortions[5-9]. Heavy metals like Cr, Cu, Se, As, Cd, and Ni, are toxic and cause diseases and disorders in living organisms [10-14]. Many factories, such as batteries, mines, tanneries, agrochemicals, and the paper industry, discharge heavy metals into the environment [3, 14-19]. These metals, which are considered the very dangerous, can affect humans even at low concentrations[20-23]. As a result, eliminating heavy metals from waterways is critical for human and wildlife protection. Copper is a radioactive heavy metal that accumulates in human bodies via the food chain and causes a variety of physiological problems [24-29]. Copper is used in a variety of industries, including fertilization, paint, dye processing, electroplating, and wood production [3, 14, 19, 30]. Copper concentrations of drinking water should not exceed 1.5 parts per million, according to the world health organization [30, 31]. Furthermore, China sets 0.5 ppm of copper concentration in industrial effluent,
According to GB25467-2010 [4, 32], increased copper concentrations may have severe toxic consequences when it affects the liver, skin, brain, and pancreas. This could result in kidney disease, headache, breathing problems, and nausea [19, 33, 34]. Electrocoagulation [35, 36], electrodialysis [37, 38], flotation [39], chemical precipitation [40], biological treatment [41-43], adsorption [44-47], and coagulation [28] are some of the heavy metal removal strategies. Most of these methods necessitate a long treatment time and are either expensive or inefficient at high pollutant concentrations [2, 10]. The cost of commercial adsorption materials, for example, limits the adsorption technique. As a result, choosing sorbent is critical for developing a simple, environmentally sustainable, and low-cost system [3, 14, 19].

Researchers have extensively studied the adsorption method in their experiments to strip toxins from waterways by using various natural resources like animal waste and industrial by-products, according to previous literature [1, 14, 39]. Corn stalks, tree bark, tea leaves, and sawdust are among the most common materials used [22, 23]. The natural sorbent materials used in this study can be used with or without alteration to improve adsorption performance [22, 34, 48]. Sawdust, peats, straw, tree bark, and other woody materials are considered low-cost sorbents and the perfect substitute for industrially processed sorbents [4, 14]. The benefits of using these sorbents to remove heavy metals are determined by many factors, including their adsorption potential, recovery capability, and removal selectivity [33, 43, 49]. Sawdust is a waste product from the timber industry that can also be used as a cheap adsorbent for processing acids, unneeded compounds, and dyes. Sawdust's adsorption characteristic is influenced by its structure which contains phenolic acids, lignin, and cellulose [4, 29, 50-52]. Sawdust usage as cheap adsorbent to remove metals supports the wood business by getting rid of waste in addition to saving the forest. Because of the increased release of industrial and agricultural wastewaters containing high concentrations of heavy metals, as well as global warming, which affects water supply and contamination, human must find effective treatment methods to reduce the impact of the pollution [32, 33, 49, 53, 54].

Based on the above review of research literature, the key goal of this research is to evaluate the efficiency of carbonized sawdust in terms of removing copper from polluted water bodies. It also looks at how operational conditions including treatment duration, pH, and sawdust dosages affect the results of copper removal from polluted water bodies.

2. Method

Sawdust was sprayed with water to clean and eliminate any dust or other chemicals. The washed sawdust dried by espousing it to direct sun light to implement it as activated carbon. Then, cleaned sawdust was chemically activated through combining 1 unit of weigh of sawdust with 2 units of weigh of concentrated sulfuric acid (H2SO4). At the end of this step the carbonized sawdust was generated. Yet, for drying purposes, the activated sawdust was dried in oven under to a temperature of 160°C for 24 hours. After that, the generated substance was cleaned several times with water before being dried at 105°C to make sure that the uncontacted H2SO4 was removed.

The produced carbonized powder was used for copper adsorption in the present study. The adsorbent particles were between 0.6 and 0.10 mm in size. The specified volume of copper nitrates was dissolved in 300 mL of deionized water to generated water polluted with copper that contains 120 mg/L. The copper dilution from the stock solution was done properly. All the tests were carried out with a 150 mL copper solution and a specified dosage of sawdust. The polluted water were shook by a shaker at 200 revolution per minutes while the tests were carried out at a temperature of 20 ± 1°C.

3. Discussion of the findings

3.1. Influence of adsorbent dose

Figure 1 depicts the effects of adsorbent dosages the removal performance of copper. The dosage ranged from 1 to 4 g/L. In the tests, the mixing speed was set to 200 revolution per minutes. Furthermore, a steady copper concentration of 5 mg/L was kept in the solutions with a neutral pH level and a contact time of 200
minutes. From the figure, the removal of the copper from the water increases with the increase in the dosage of the sawdust. The available surface for adsorption increases proportionally as the sawdust concentration rises in the water solution. As a result, the adsorption increased to about 100% for elevated adsorbent doses of four gram per liter. Therefore, the copper pollution in the water was reduced. Lower adsorbent concentrations result in lower adsorption and no further pollutant can be adsorbed. The best results were achieved with a dose of 2.5 g/L of sawdust and a copper removal percentage reached about 90%.

![Figure 1: The relationship between copper removal and sawdust dosage.](image)

3.2. Influence of treatment time
To comprehensively investigate copper elimination from polluted water, the effect of treatment time on the effectiveness of pollutant adsorption is investigated. The pH level of the water was 5, and the mixing speed was 200 revolutions per minute. The copper concentration was maintained at 5 ppm and the adsorbent dose of 2.5 ppm. Figure 2 depicts the relationship between touch time and copper removal from polluted water. The performance of the adsorbent improved with increasing treatment duration until saturation, as seen in Figure 1. As the duration extended from 20 to 165 minutes, the removal productivity increased from 30% to 70 percent. The removal efficiency was about 70 percent between both 165 and 200 minutes of treatment time. As a result, it was recommended that 165 minutes of treatment time be included in further investigation in this study.
3.3. Influence of solution pH level

The level of the pH is thought to be a significant factor affecting metal adsorption, and is confirmed by previous research [2, 10]. This is because the useful clusters of the media and the chemical composition of the metal are affected by the pH of an aqueous solution. A pH range of 2 to 9 has been used in the experiments of this research to explore the influence of pH on adsorption preference. The sulfuric acid (H2SO4) was implemented to change the pH level of the polluted solution. The concentration of the copper maintained at 5 ppm, and the treatment duration was set to 165 minutes. Furthermore, the adsorbent dose was 2.5 ppm, with mixing speed at 200 revolutions per minute. Copper removal efficiencies vs. pH values are depicted in Figure 3. Adsorption improved as the pH value was raised from 2 to 6. After 7, the removal efficiencies declined marginally. In pH 7, the maximal removal was 81 percent. As the adsorbent surface allowed positively charged ion to be attached, removal performance was poor at acidic levels. That can be explained by the increased rivalry between H+ and the ions of the copper for usable adsorption sites. Removal efficiency began to decline slightly at pH 8 and 9, which may be due to the development of soluble hydroxyl complexes and Cu(OH)2.

Figure 2: The relationship between copper removal and treatment time.

![Figure 2: The relationship between copper removal and treatment time.](image-url)
Several recent reports questioned the adsorption methods’ cost-effectiveness and accuracy because used adsorption media have to be disposed of in disposal areas, which have elevated building and repair expenses [4, 9, 29, 49-53, 55-59]. These disadvantages may be overcome by recycling used adsorbent in building practices, like those described in the previous researches [60-65], and improving precision by using computerized sensors [66-69].

4. Conclusion
The sawdust which is considered as cheap material, has been tested for in this research as adsorption and non-extensive copper removal process. Copper adsorption is heavily dependent on the length of contact between adsorbent and pollutants, the amount of sawdust used, and the pH level. As the pH of the solution is increased from 1 to 6, the copper elimination from wastewater increases. However, after 7, the removal efficiency decreased. The best pH level for copper removal was at neutral pH, and best treatment time for copper removal was deemed to be 165 minutes. It has been revealed that raising the dose of adsorbent improved the treatment degree due to the accessible area for adsorption increased. A 2.5 g/L dosage of sawdust reduced the copper content in water by 90 percent. This research showed that the Sawdust is very good sorbent for removing copper from water. Research is required to solve the key disadvantages of adsorption processes, where several previous studies questioned their cost-effectiveness and accuracy.

References

[1] Hashim K S, Al-Saati N H, Hussein A H and Al-Saati Z N 2018 An investigation into the level of heavy metals leaching from canal-dredged sediment: a case study metals leaching from dredged sediment. In: First International Conference on Materials Engineering & Science, (Istanbul Aydin University (IAU), Turkey pp 12-22

[2] Abdulraheem F S, Al-Khafaji Z S, Hashim K S, Muradov M, Kot P and Shubbar A A 2020 Natural filtration unit for removal of heavy metals from water. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012034

[3] Jawad S F, Saddam N S, Adaami Q J, Kareem M M, Abdulredha M, Mubarak H A, Kot P, Gkantou M and AlKhayyat A 2021 Dye removal from textile wastewater using solar-powered...
electrocoagulation reactor. In: *IOP Conference Series: Materials Science and Engineering* (IOP Publishing) p 012016

[4] Abdulredha M, Kadhim N, Hussein A, Almutairi M, Alkhaddar R, Yeboah D and Hashim K 2021 Zeolite as a natural adsorbent for nitrogenous compounds being removed from water. In: *IOP Conference Series: Materials Science and Engineering* (IOP Publishing) p 012082

[5] Aayef A N, Al Masoodi W T M, Kamel R J, Abdulredha M, Almansoori N A, Kot P and Muradov M 2021 An experimental study for adapting electrocoagulation as a technique for fluoride removal from water. In: *IOP Conference Series: Materials Science and Engineering* (IOP Publishing) p 012012

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

[7] Abdulredha M, Al Khaddar R and Jordan D 2017 Hoteliers’ attitude towards solid waste source separation through mega festivals: A pilot study in Karbala. In: *International Conference for Doctoral Research: BUID*

[8] Abdulredha M, Al Khaddar R, Jordan D, Al-Attabi A and Alzeyadi A 2017 Public participation in solid waste management during mega festivals: A pilot study. In: *WCST World Congress on Sustainable Technologies Proceedings 2017: Infonomics Society* pp 38-41

[9] Abdulredha M, Al Khaddar R, Jordan D, Kot P, Abdulridha A and Hashim K J W M 2018 Estimating solid waste generation by hospitality industry during major festivals: A quantification model based on multiple regression 77 388-400

[10] Abdulla G, Kareem M M, Hashim K S, Muradov M, Kot P, Mubarak H A, Abdellatif M and Abdulhadi B 2020 Removal of iron from wastewater using a hybrid filter. In: *IOP Conference Series: Materials Science and Engineering* (IOP Publishing) p 012035

[11] Hashim K S, Shaw A, Al Khaddar R, Pedrola M O and Phipps D 2017 Iron removal, energy consumption and operating cost of electrocoagulation of drinking water using a new flow column reactor *Journal of Environmental Management* 189 98-108

[12] Al-Saati N H, Hussein T K, Abbas M H, Hashim K, Al-Saati Z N, Kot P, Sadique M, Aljefery 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

[13] 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

[14] Isra'a S S, Al-Janabi A, Abdulredha M, Alkandari A, Abdellatif M and Yeboah D 2021 Reusing of furnace bottom ash as an adsorbent for phosphate removal from water. In: *IOP Conference Series: Materials Science and Engineering* (IOP Publishing) p 012006

[15] Hashim K S, Idowu I A, Jasim N, Al Khaddar R, Shaw A, Phipps D, Kot P, Pedrola M O, Alattabi A W and Abdulredha M 2018 Removal of phosphate from River water using a new baffle plates electrochemical reactor *MethodsX* 5 1413-8

[16] Abdulhadi B A, Kot P, Hashim K S, Shaw A and Khaddar R A 2019 Influence of current density and electrodes spacing on reactive red 120 dye removal from dyed water using electrocoagulation/electroflotation (EC/EF) process. In: *First International Conference on Civil and Environmental Engineering Technologies (ICCEET)*, (University of Kufa, Iraq pp 12-22

[17] Hashim K S, Hussein A H, Zubaidi S L, Kot P, Kraidi L, Alkhaddar R, Shaw A and Alwash R 2019 Effect of initial pH value on the removal of reactive black dye from water by electrocoagulation (EC) method. In: *2nd International Scientific Conference*, (Al-Qadisiyah University, Iraq pp 12-22

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

[19] Hashim K S, Idowu I A, Jasim N, Al Khaddar R, Shaw A, Phipps D, Kot P, Pedrola M O, Alattabi A W and Abdulredha M J M 2018 Removal of phosphate from River water using a new baffle plates electrochemical reactor 5 1413-8

[20] Abdulhadi B, Kot P, Hashim K, Shaw A, Muradov M and Al-Khaddar R 2021 Continuous-flow electrocoagulation (EC) process for iron removal from water: Experimental, statistical and economic study Science of The Total Environment 756 1-16

[21] Hashim K S, Khaddar R A, Jasim N, Shaw A, Phipps D, Kot P, Pedrola M O, Alattabi A W, Abdulredha M and Alawsh R 2019 Electrocoagulation as a green technology for phosphate removal from River water Separation and Purification Technology 210 135-44

[22] Alenazi M, Hashim K S, 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. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012064

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

[24] Alhendal M, Nasir M J, Hashim K S, Amoako-Attah J, Al-Faluji D, Muradov M, Kot P and Abdulhadi B 2020 Cost-effective hybrid filter for remediation of water from fluoride. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012038

[25] Al-Marri S, AlQuzzweeni S S, Hashim K S, ALKhaddar R, Kot P, AlKizwini R S, Zubaidi S L and Al-Khaifaji Z S 2020 Ultrasonic-Electrocoagulation method for nitrate removal from water. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012073

[26] Alyafei A, AlKizwini R S, Hashim K S, Yeboah D, Gkantou M, Al Khaddar R, Al-Faluji D and Zubaidi S L 2020 Treatment of effluents of construction industry using a combined filtration-electrocoagulation method. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012032

[27] Hashim K S, Shaw A, Al Khaddar R, Ortoneda Pedrola M and Phipps D 2017 Defluoridation of drinking water using a new flow column-electrocoagulation reactor (FCER) - Experimental, statistical, and economic approach Journal of Environmental Management 197 80-8

[28] Hashim K S, Shaw A, Al Khaddar R, Pedrola M O and Phipps D 2017 Energy efficient electrocoagulation using a new flow column reactor to remove nitrate from drinking water - Experimental, statistical, and economic approach Journal of Environmental Management 196 224-33

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

[30] Jaishankar M, Tssten T, Anbalagan N, Mathew B B and Beeregowda K N 2014 Toxicity, mechanism and health effects of some heavy metals Interdisciplinary toxicology 7 60-72

[31] Aqeel K, Mubarak H A, Amoako-Attah J, Abdul-Rahaim L A, Al Khaddar R, Abdellatif M, Al-Janabi A and Hashim K S 2020 Electrochemical removal of brilliant green dye from wastewater. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012036

[32] Al-Sareji O J, Abdulredha M, Mubarak H A, Grmasha R A, Alnowaishry A, Kot P, Al-Khaddar R and Alkhayyat A 2021 Copper removal from water using carbonized sawdust. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012015

[33] Alattabi A W, Harris C, Alkhaddar R, Alzeyadi A and Abdulredha M J P e 2017 Online monitoring of a sequencing batch reactor treating domestic wastewater 196 800-7
[34] Shubbar A A, Jafer H, Abdulredha M, Al-Khafaji Z S, Nasr M S, Al Masoodi Z and Sadique M J o B E 2020 Properties of cement mortar incorporated high volume fraction of GGBFS and CKD from 1 day to 550 days 30 101327

[35] Emamjomeh M M, Mousazadeh M, Mokhtari N, Jamali H A, Makhiaabadi M, Naghdali Z, Hashim K S and Ghanbari R 2020 Simultaneous removal of phenol and linear alkylbenzene sulfonate from automobile service station wastewater: Optimization of coupled electrochemical and physical processes Separation Science and Technology 55 3184-94

[36] Hashim K S, AlKhaddar R, Shaw A, Kot P, Al-Jumeily D, Alwash R and Aljefery M H 2020 Electrocoagulation as an eco-friendly River water treatment method. In Advances in Water Resources Engineering and Management (Berline: Springer)

[37] Hashim K S, Al-Saati N H, Alquzweeni S S, Zubaied S L, Kot P, Kraidy L, Hussein A H, Alkhaddar R, Shaw A and Alwash R 2019 Decolourization of dye solutions by electrocoagulation: an investigation of the effect of operational parameters. In: First International Conference on Civil and Environmental Engineering Technologies (ICCEET), (University of Kufa, Iraq pp 25-32

[38] Mohammed A-H, Hussein A H, Yeboah D, Al Khaddar R, Abdulhadi B, Shubbar A A and Hashim K S 2020 Electrochemical removal of nitrate from wastewater. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012037

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

[40] 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. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012033

[41] Alattabi A W, Harris C, Alkhaddar R, Algeyadi A and Hashim K 2017 Treatment of Residential Complexes’ Wastewater using Environmentally Friendly Technology Procedia Engineering 196 792-9

[42] Alattabi A W, Harris C B, Alkhaddar R M, Hashim K S, Ortoneda-Pedrola M and Phipps D 2017 Improving sludge settleability by introducing an innovative, two-stage settling sequencing batch reactor Journal of Water Process Engineering 20 207-16

[43] Hashim K S, Al Khaddar R, Jasim N, Shaw A, Phipps D, Kot P, Pedrola M O, Alattabi A W, Abdulredha M, Alwash R J S and Technology P 2019 Electrocoagulation as a green technology for phosphate removal from River water 210 135-44

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

[45] Hassan Alnaimi I J I, Abuduljaleel Al-Janabi, Khalid Hashim, Michaela Gkantou, Salah L. Zubaidi, Patryk Kot, Magomed Muradov 2020 Ultrasonic-electrochemical treatment for effluents of concrete plants Ultrasonic-electrochemical treatment for effluents of concrete plants. In: IOP Conference Series Materials Science and Engineering (University of Kufa, Najaf, Iraq pp 1-9

[46] Hashimi K S, Shaw A, 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

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

[48] Majdi H S, Shubbar A, Nasr M S, Al-Khafaji Z S, Jafer H, Abdulredha M, Al Masoodi Z, Sadique M and Hashim K J D i B 2020 Experimental data on compressive strength and ultrasonic pulse velocity properties of sustainable mortar made with high content of GGBFS and CKD combinations
[49] Abdulredha M, Rafid A, Jordan D and Hashim K J P E 2017 The development of a waste management system in Kerbala during major pilgrimage events: determination of solid waste composition 196 779-84

[50] Abdulredha M, al-Khaddar R, Kot P, Jordan D and Abdulridha A 2018 Benchmarking of the Current Solid Waste Management System in Karbala, Iraq, Using Wasteaware Benchmark Indicators. In: World Environmental and Water Resources Congress 2018: Groundwater, Sustainability, and Hydro-Climate/Climate Change: American Society of Civil Engineers Reston, VA) pp 40-8

[51] Abdulredha M, Kot P, Al Khaddar R, Jordan D, Abdulridha A J E, Development and Sustainability 2020 Investigating municipal solid waste management system performance during the Arba’een event in the city of Kerbala, Iraq 22 1431-54

[52] Abdulredha M, Muhsin A A, Al-Janabi A, Alajmi B N, Gkantou M, Amoako-Attah J, Al-Jumeily D, Mustafina J and AlKhayyat A 2021 Using SF and CKD as cement replacement materials for producing cement mortar. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012007

[53] Al-Anbari R, Alnakeeb A, Abdulredha M J E and Journal T 2013 Landfill site selection for Kerbala municipal solid wastes by using geographical information system techniques 32 13

[54] ALWAN H H, SALEH L A, AL-MOHAMMED F M, ABDULREDHA M A J J o E S and Technology 2020 EXPERIMENTAL PREDICTION OF THE DISCHARGE COEFFICIENTS FOR RECTANGULAR WEIR WITH BOTTOM ORIFICES 15 3265-80

[55] Idowu I A, Atherton W, Hashim K, Kot P, Alkhaddar R, Alo B I and Shaw A 2019 An analyses of the status of landfill classification systems in developing countries: Sub Saharan Africa landfill experiences Waste Management 87 761-71

[56] 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

[57] Abdulredha M, Kot P, Al Khaddar R, 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

[58] Abdulredha M, Rafid A, Jordan D and Hashim K 2017 The development of a waste management system in Kerbala during major pilgrimage events: determination of solid waste composition Procedia Engineering 196 779-84

[59] Abdulredha M, Al Khaddar R, Jordan D, Kot P, Abdulridha A and Hashim K 2018 Estimating solid waste generation by hospitality industry during major festivals: A quantification model based on multiple regression Waste Management 77 388-400

[60] Shubbar A A, Jafer H, Dulaimi A, Hashim K, 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

[61] Shubbar A A, Al-Shaer A, Alikizwini R S, Hashim K, Hawselah H A and Sadique M 2019 Investigating the influence of cement replacement by high volume of GGBS and PFA on the mechanical performance of cement mortar. In: First International Conference on Civil and Environmental Engineering Technologies (ICCEET), (University of Kufa, Iraq pp 31-8

[62] 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

[63] Kadhim A, Sadique M, Al-Mufti R 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
[64] Shubbar A A, Sadique M, Nasr M S, Al-Khafaji Z S and Hashim K S 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

[65] Shubbar A A, Sadique M, Shanbara H K 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)

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

[67] Ryecroft S, Shaw A, Fergus P, Kot P, Hashim K, 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

[68] Ryecroft S P, shaw A, Fergus P, Kot P, Hashim K and Conway L 2019 A Novel Gesomin Detection Method Based on Microwave Spectroscopy. In: *12th International Conference on Developments in eSystems Engineering (DeSE)*, (Kazan, Russia pp 429-33

[69] Teng K H, Kot P, Muradov M, Shaw A, Hashim K, Gkantou M and Al-Shamma’a A 2019 Embedded Smart Antenna for Non-Destructive Testing and Evaluation (NDT&E) of Moisture Content and Deterioration in Concrete *Sensors* **19** 547-59