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Chemical Regeneration of Activated Carbon After Adsorption of Ni(II) Ions

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***Abstract*—**The chemical regeneration of activated carbon (AC) has recently received greater attention because it allows high-cost granular AC and AC fibers to be reused with less effort and energy. The chemical regeneration of activated carbon after Ni(II) ions adsorption was investigated in this study. Various desorbing solutions were used to recover adsorbed Ni(II) ions to AC. The concentration of the most effective desorbing solution was optimized. The adsorption efficiency of the regenerated AC using merely an acidic desorbing solution was reduced. Therefore, additional treatment after desorption using an acidic desorbing solution was carried out using sodium hydroxide solution. The optimum concentration of sodium hydroxide was determined. Using 3% HCl and H_2SO_4 as desorbing solutions, more than 80% of Ni(II) ions could be desorbed from AC. However, the readsorption efficiency of Ni(II) ions by AC was reduced to less than 50% after the first regeneration. By treating the regenerated AC from the acidic desorbing solution with 1 % NaOH, the efficiencies in the Ni(II) ions adsorption and desorption were fully recovered to almost 100%.

***Keywords*—** Activated carbon; Chemical regeneration; Ni(II) ions.

1. INTRODUCTION

Nickel (Ni), a transition series element, is the 24th most prevalent element in the Earth's crust, accounting for around 3% of the total composition. Although it can exist in various oxidation states, under environmental conditions Ni, and Ni in the +2 valence state, Ni(II), is the most common [1]. It is used in the production of stainless steel, coins, metallic alloys, superalloys, copper sulfate, batteries, nonferrous metals, mineral processing, electroplating, forging, porcelain enameling, paint formulation, and steam-electric power plants because it is resistant to corrosion by air, water, and alkali [2,3].

Due to the Ni(II)'s widespread industrial use, significant amounts of Ni(II) end up in the aquatic environment. Ni(II) is a useful activator of several enzyme systems and participates in crucial metabolic events at non-toxic levels. However, the consumption of an excessive amount of Ni(II) can cause oxidative enzyme inhibition, severe damage to the lungs (pulmonary fibrosis, lung cancer), gastrointestinal distress (nausea, vomiting, diarrhea), kidney (renal edema), chest pain, skin dermatitis, shortness of breath, and other symptoms. Dermatitis, also known as Ni(II)-itch, is widespread among workers who manufacture Ni(II)-containing jewelry, and individuals who use Ni(II)-plated watches and Ni(II)-containing detergents. Ni(II) is highly carcinogenic. High quantities of this metal can cause nitrogen deficiency and stunted growth [1,4].

Several chemical and physical technologies have been developed and used to remove Ni(II) ions from water and wastewater, including complexation or membrane filtration [5]; nanofiltration [6]; ultrafiltration [7]; photocatalytic removal [8,9,10]; electro-permutation [11]; electro-deionization [12,13]; electro-chemical reduction/oxidation [14]; electro-coagulation [15,16]; hybrid electro-coagulation or microfiltration [17]; electro-flotation [18]; co-precipitation [19]; reverse osmosis [20,21,22] complexation or ultrafiltration [23]; flotation [24,25]; ion exchange [26-31]; precipitation [24]; and coagulation or flocculation [32]. Traditional approaches, on the other hand, have drawbacks, including lower removal efficiency, sensitive operating conditions, high operational costs, and the formation of secondary sludge, which requires extra treatment. Adsorption has several advantages over other physicochemical processes, including operational flexibility, feasibility in producing a high-quality product, economic viability in initial capital cost and chemical

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requirements, and effectiveness in treating pollutants at low concentrations.

Activated carbon is a fine granular microporous material produced from the pyrolysis of charcoal. The presence of micropores enables it to be an effective adsorbent [33]. Activated carbon is prepared commonly by the pyrolysis of wood pulp with low ash content, coal, lignite, and rye starch. It will undergo carbonization under high temperatures with a constant flow rate of CO_2 to increase the carbon content. To activate it, a series of treatment processes are carried out with steam, oxygen, CO_2, acids, and chemicals to remove impurities and create fine, small granules with larger pore sizes. Due to its microporosity, activated carbon can adsorb various types of chemicals, from organic contaminants, dyes, and pesticides to inorganic and heavy metal pollutants. [34].

Activated carbon can be obtained at a relatively low cost compared to other adsorbents and can be prepared from various sources, such as palm kernel shell [35] and orange peel [36] after treatments and synthesis, and has sufficient efficiency in removing Ni(II) ions from the effluents. Another advantage of using activated carbon as an adsorbent is its ability to be regenerated under simple treatments, which can be recycled and reused, further reducing the material cost.

Exhausted or spent activated carbon is the activated carbon that has reached its maximum adsorption capacity and can no longer absorb contaminants. These spent activated carbons need to be replaced with fresh or regenerated activated carbon. For granular activated carbon and fiber activated carbon, regeneration is preferable over replacement due to its high cost. The two commonly used regeneration methods are thermal and chemical regeneration [37]. High heat is applied in the thermal regeneration method to activated carbon by removing the adsorbed contaminants on the activated carbon surface. However, this will lead to the burnt off of some carbons on the activated carbon surface caused by excessive heat [38]. Chemical regeneration is a technique that uses various possible regenerating agents, such as acids, alkalis, and chelating agents to desorb the adsorbates on the surface of the activated carbon, which involves possible toxic chemicals.

Previous reported studies on the desorption of Ni(II) using 0.2 M HCl, 46.3% of the adsorbed Ni(II) ions can be desorbed from Hickory wood alkaline-modified biochar (HMB) filled in a fixed-bed column [39]. Other reported Ni(II) desorption studies in the batch mode was 100% using 4 M HNO_3 and 1 M HCl from biogas production residue biochar, BCU400, 100% using 14.5 M HNO_3 and 1.5 M HCl from biogas production residue biochar, BCU600, and 98% and 100% using 4 M HNO_3 and 10 M HCl from Wheat straw biochar BCS600 [40]. It is also reported that the adsorption efficiency of Ni(II) ions after regeneration from Biochar/NaOH (ABC1) using 0.1 M NaOH is 88% in the first cycle and can be recycled up to 6 cycles [41]. The second reported adsorption efficiency for Ni(II) ions after regeneration from Pineapple leaf biochar (PLB) using 1 M HCl is 67% in the first cycle, and the efficiency drops to 3 % in the sixth cycle [42].

This study determines the type of acids suitable for regeneration using activated carbon saturated with Ni(II) ions and other conditions involved, such as the optimum acid concentration and treatment duration. This study is especially useful for manufacturing industries, such as heavy-metal plating and battery-manufacturing industries that produce heavy metal effluents because the developed activated carbon regeneration method enables them to reuse the activated carbon for a long period, which can significantly reduce the production cost. In addition, the desorbed heavy metal solution obtained from this method can be retrieved for further use.

2. EXPERIMENTAL SECTION

2.1. Material and Reagents

The 1000 ppm Ni(II) AAS standard solution used in preparing Ni(II) ion standard solution was purchased from Fisher Scientific. Various concentrations of Ni(II) sulfate solutions were prepared using $NiSO_4 \cdot 6H_2O$ salt solid, purchased from SYSTERM®. The activated carbon used in this work was purchased from R&M Chemicals. 37% HCl and 95% H_2SO_4 were purchased from Fischer Scientific and EMSURE. Boric acid (99.8% purity), NaOH (99.91% purity), and 30% H_2O_2 were purchased from R&M Chemicals. 98% formic acid and 65% HNO_3 were purchased from SYSTERM®.

2.2. Instrumentations

The concentrations of Ni(II) ions were measured using an Agilent-4200 Microwave-Induced Plasma Atomic Emission Spectroscopy (MP-AES) equipped with a multi-purpose sample introduction system consisting of a OneNeb nebulizer, a glass cyclonic double pass spray chamber, and multi-purpose pump tubing. The nitrogen gas flow rate used to generate plasma was fixed at 20 L/min, and the auxiliary gas (Argon) used to ignite the plasma was fixed at 1.5 L/min. The nebulizer gas flow rate was adjusted within the range of 0.3–1.0 L/min. The required volume per analysis without repetition was approximately 1.7 mL. The surface morphology of the activated carbon was scanned by Scanning Electron Microscopy (SEM) (Model Leo Supra 50VP Field Emission, UK). Shimadzu IRTracer-100 was used to scan the surface of the activated carbon particles to obtain functional groups on the surface of the activated carbon particles.

2.3. Procedure

2.3.1. Preparation of standard reagents and Ni(II) ions saturated activated carbon

The Ni(II) ions standard solutions used for calibration were prepared by diluting 1000 ppm AAS stock solution to the lower concentrations from 1 to 5 ppm. The purchased activated carbon powder was pretreated by heating at 150 °C for 24 h and left to cool in a desiccator filled with drying agents. The activated carbon powder saturated with Ni(II) ions was prepared by mixing 5 g of the heated pretreated activated carbon powder in 45 mL of 0.01 M $NiSO_4$ solution. The mixture was shaken with an orbital shaker at 200 rpm for 24 h before centrifuging at 8000 rpm for 15 min. The precipitated activated carbon saturated with Ni(II) ions was obtained by decanting the $NiSO_4$ solution. All acids with lower concentrations were prepared by diluting from the concentrated stock solutions using distilled water. Boric acid, H_3BO_3, solution was prepared by dissolving a suitable amount of boric acid solids in distilled water.

2.3.2. Selection of suitable desorbing reagent and its optimum concentration

The Ni(II) ions adsorbed on the surface of the activated carbon powder were desorbed by shaking the activated carbon powder saturated with Ni(II) ions in 45 mL of 1 % HCl, H_2SO_4, H_3BO_3, formic acid, HNO_3, H_2O_2, respectively for 10 min at 200 rpm. All mixtures were centrifuged at 8000 rpm for 15 min before 5 mL of the acid solution was sampled from each solution. The remaining Ni(II) ions in each sample solution were determined using MPAES. An acid capable of desorbing a high amount of adsorbed Ni(II) ions from activated carbon powder was selected for further optimization. In the optimization of acid concentration, the activated carbon powder saturated with Ni(II) ions was shaken in 45 mL of the respective acid with a concentration ranging from 0.2 to 3.5% for 10 min at 200 rpm before precipitating the activated carbon powder at centrifuging at 8000 rpm for 15 min. 5 mL of the respective acid solution was sampled to be analyzed to determine the amount of desorbed Ni(II) ions in the acid solution. The percentage desorption efficiency was computed by dividing the obtained desorbed amount of the Ni(II) ions by the adsorbed amount of the Ni(II) ions onto the activated carbon before multiplying by 100. The adsorption efficiency was computed to be equal to the desorption efficiency by substituting the amount desorbed with the amount adsorbed.

2.3.3. Study the readsorption of Ni(II) ions onto the regenerated activated carbon powder

Three batches of used activated carbon powder were prepared by desorbing the saturated Ni(II) ions adsorbed onto the activated carbon powder surface using optimum acid concentration. After the desorption of the saturated Ni(II) ions using HCl and H_2SO_4, respectively. The activated carbon powder was precipitated using centrifugation and the acid solution was decanted. A similar step was repeated once again with distilled water to remove all the residual acids that were still adsorbed onto the activated carbon powder.

One batch of the regenerated activated carbon powder was left in wet condition; whereas the other two batches were heated overnight at 100 °C and 150 °C, respectively. Fourty five mL of 0.01 M $NiSO_4$ solution was added into these three batches of used activated carbon powder, respectively, to study their readsorption capability of Ni(II) ions. All mixtures were shaken with an orbital shaker at 200 rpm for 24 h before centrifuging at 8000 rpm for 15 min. After the centrifugation, 5 mL of the $NiSO_4$ solution was drawn from each batch to be used to determine the adsorption efficiency of the regenerated activated carbon powder toward Ni(II) ions. After decanting the remaining $NiSO_4$ solution, 45 mL of the acid at optimum concentration was added to the activated carbon powder to desorb the Ni(II) ions adsorbed onto the used activated carbon powder. The amount of the Ni(II) ions desorbed from the regenerated activated carbon powder into the acid solution was determined after the activated carbon powder was precipitated using centrifugation.

2.3.4. Optimizing the sodium hydroxide treatment conditions toward regenerated activated carbon

Two batches of regenerated activated carbon powder in wet and dry conditions were prepared as in the previous section. NaOH solutions with concentrations from 0.01 to 0.6% were added to the regenerated activated carbon powder and shaken at 200 rpm for 24 h. The readsorption of Ni(II) ions onto the NaOH-treated regenerated activated carbon powder was carried out after the NaOH-treated regenerated activated carbon powder was retrieved from the NaOH solution using centrifugation. The same volume and concentration of $NiSO_4$ used previously was added to the NaOH-treated regenerated activated carbon powder and shaken using an orbital shaker at 200 rpm for 24 h followed by centrifugation at 8000 rpm for 15 min. The remaining amount of the Ni(II) ions in the solution was determined using MPAES.

3. RESULT AND DISCUSSION

3.1. FTIR and SEM Scanning of The Studied Activated Carbon Particles

The distinct functional groups presented in activated carbon were identified using FTIR analysis. The results are shown in **Fig. 1** along with the FTIR spectrum. The spectrum showed various peaks. Many functional groups are presented in the activated carbon and aid in the adsorption process represented by these peaks. According to the IR spectra, the carbonyl group (–C=O) is present because of the prominent and intense peak at 1690.64 cm^{-1}. It is possible to attribute the broadband at 3010.93 cm^{-1} to a carboxyl group. On the other hand, the peak at 1629.88 cm^{-1} is attributable to unsaturated aliphatic compounds stretching the C=C band [43]. The activated carbon comprises oxygen functional groups, such as carboxyl and carbonyl groups, according to the IR spectra.

Fig. 2 shows an image of activated carbon captured by a scanning electron microscope (SEM). The image shows that the surface of the activated carbon contains high porosity properties with cavities. This high-porosity surface is advantageous for the adsorption of metal ions, which can bind to the micro- and meso-pores in activated carbon, which serve as adsorption sites for metal ions.

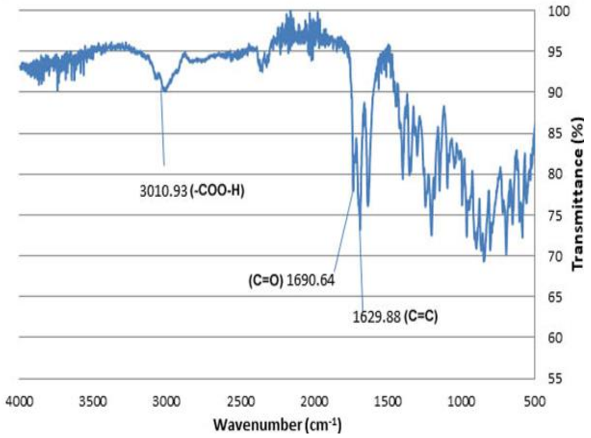

Fig. 1. The FTIR spectrum of the studied activated carbon.

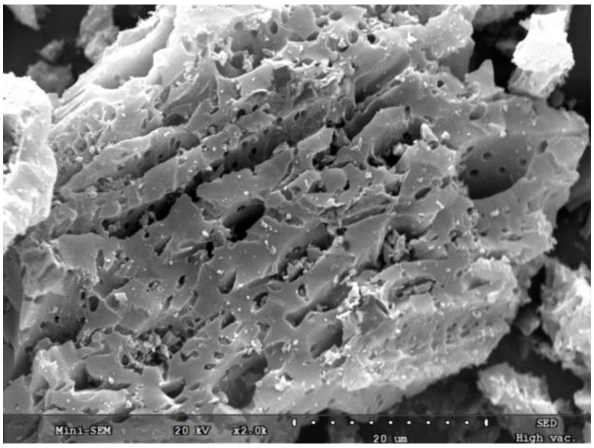

Fig. 2. SEM image of the studied activated carbon.

3.2. Selection of Suitable Type of Desorbing Solutions

Various acid solutions with the same concentration were used to desorb the adsorbed Ni(II) ions onto the activated carbon powder. The concentration of the Ni(II) ions leached into the acid solutions was determined using MPAES. The desorption efficiency of Ni(II) ions from the activated carbon into each acid solution was calculated based on the amount of Ni(II) ions adsorbed onto the activated carbon powder. The calculated desorption efficiencies are shown in **Fig. 3.** The desorption efficiencies of Ni(II) ions in HCl and H_2SO_4 solutions were 50.37% and 58.29%. These figures are the two highest desorption efficiencies among all the desorption efficiencies obtained. The formic acid and hydrogen peroxide desorb 16.43% and 17.6% of Ni(II) ions from activated carbon in each solution, respectively. Nitric acid and boric acid solutions desorb insignificant amounts of Ni(II) ions from the activated carbon. A high amount of Ni(II) ions desorbed from the activated carbon into the acidic solutions is due to the protonation occurring on the adsorbent surface [44]. Ni(II) ions adsorbed onto the activated carbon was mainly through the physisorption mechanism rather than chemisorption based on the observations of the high amount of Ni(II) ions desorb into the acidic solutions and low desorption amount in formic acid solution [45]. The ion exchange equilibrium shift can be used to explain why conducting the desorption process under acidic circumstances is effective. The active sites in the functional groups shift toward the protonated form at low pH due to the high concentration of hydrogen ions in the medium. Due to the smaller radius of H^+, it has a larger diffusivity coefficient than Ni^{2+} ions [46].

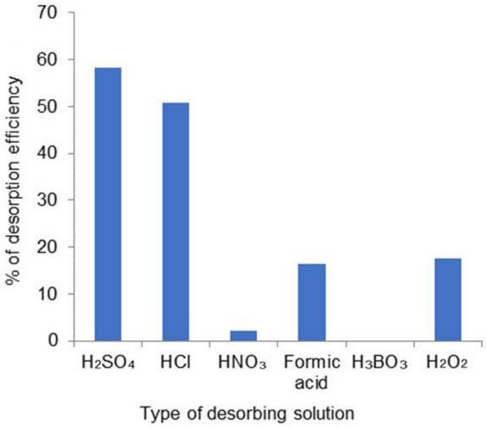

Fig. 3. The percentages of the desorption efficiency of the Ni(II) ions from AC in various types of desorbing solutions.

3.3. Optimizing the Acid Concentrations

Both HCl and H_2SO_4 acid solutions are selected to optimize their concentrations toward the desorption of the Ni(II) ions from the activated carbon powder. Various concentrations of both acid solutions ranging from 0.2 to 3.5% are used to desorb Ni(II) ions from the

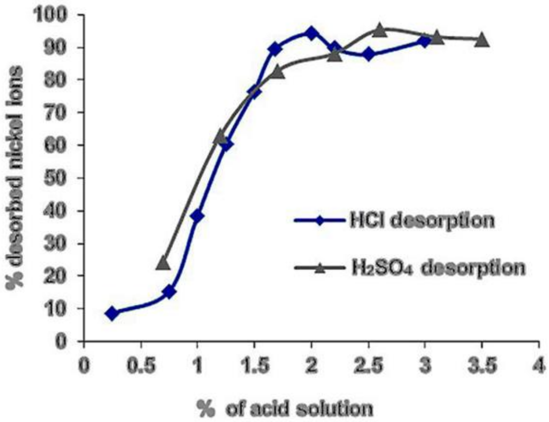

Fig. 4. The percentages of the desorption efficiency of the Ni(II) ions in various concentrations of HCl and H_2SO_4 solutions.

activated carbon powder saturated with Ni(II) ions. According to the results shown in **Fig. 4**, the percentages of the Ni(II) ions desorption in both acids increase when the acid concentrations increase. The increments of both acid concentrations reached a maximum desorption efficiency at 1.7% for HCl and 2.2% for H_2SO_4, with desorption percentages of 89.5% and 88.1%, respectively. However, to ensure maximum desorption efficiency using both desorbing solutions, the concentration of 3%, which is higher than the respective optimum concentrations, is used for further studies.

3.4. Study the readsorption of Ni(II) ions onto AC after desorption and acid interference test

The adsorbed Ni(II) ions onto the three batches of activated carbon powder were desorbed using HCl and H_2SO_4 acid solutions, respectively, followed by repeatedly rinsed with distilled water five times until less than 1 ppm Ni(II) ions were detected in the rinsed distilled water. The two batches of the obtained activated carbon powder were dried at 100 °C and 150 °C, respectively, overnight before being used to readsorb the Ni(II) ions and desorbed using HCl and H_2SO_4 acid solutions, respectively. The remaining batch in wet condition was used directly to readsorb Ni(II) ions and desorbed with HCl and H_2SO_4 acid solutions, respectively.

Based on the result shown in **Table 1**, all batches of activated carbon powder show reductions in adsorption and desorption efficiencies in the second Ni(II) ions adsorption and desorption processes. The adsorption efficiencies of the wet activated carbon powder to the Ni(II) ions were reduced to approximately 20%. There was no Ni(II) ion desorbed when HCl and H_2SO_4 are used to desorb the adsorbed Ni(II) ions from the wet activated carbon powder. For the batch of activated carbon powder heated at 100 °C, the activated carbon powder desorbed using HCl, adsorbed 22.8% of Ni(II) ions. Whereas the second set that was desorbed using H_2SO_4 adsorbed merely 3.9% of Ni(II) ions.

The former activated carbon powder desorbed 56.9% of the adsorbed Ni(II) ions into the HCl solution. Whereas the latter desorbed 0% of the adsorbed Ni(II) ions in the H_2SO_4 solution. For the batch of activated carbon powder heated at 150 °C, the activated carbon powder that was desorbed using HCl adsorbed 54.1% Ni(II) ions and desorbed 100% of the adsorbed Ni(II) ions in the HCl acid solution. The second set desorbed using H_2SO_4 did not adsorb Ni(II) ions anymore. Therefore, no Ni(II) ions were desorbed. The addition of the acidic desorbing reagents is suspected as the main reason, reducing the adsorption and desorption efficiencies in the second attempt of the adsorption and desorption processes. These reductions are most probably due to the acidic desorbing solutions changing the charges on the surface of the activated carbon to positive charges when the pH of the acidic desorbing solutions is lower than the pH at zero point of charge (pH_{zpc}) on the activated carbon surface.

Table 1. Comparison between the adsorption and desorption efficiencies of Ni(II) ions from three batches of regenerated activated carbon.

Batches	Desorbing agents	Adsorption efficiency, %	Desorption efficiency, %
Wet AC	HCl	21.7	0
	H_2SO_4	23.5	0
100°C AC	HCl	22.8	56.9
	H_2SO_4	3.9	0
150°C AC	HCl	54.1	101.3
	H_2SO_4	0	0

This further causes electrostatic repulsion between the positively charged surface of the activated carbon and the positively-charged heavy metal ions. On heating treatment at 100 °C and 150 °C, HCl-desorbed activated carbon showed increments in adsorption and desorption efficiencies when the heating temperature increased from 100 to 150 °C, while H_2SO_4 desorbed activated carbon showed decrements in both adsorption and desorption efficiencies. This is most probably due to the different amounts of HCl and H_2SO_4 being evaporated during the heating process.

An acid interference test is conducted to investigate whether the acidic desorbing solutions used in the first desorption process cause lower adsorption and desorption efficiencies in the second adsorption and desorption processes. In this study, the same amount of fresh activated carbon was added to 45 mL of distilled water rather than $NiSO_4{\cdot}6H_2O$ solution in the first adsorption process. The same acidic desorbing solutions were used in the following desorption and rinsing processes. After that, the same concentration and volume of Ni(II) ion solution was added to the activated carbon for the second adsorption followed by desorption using the same acidic desorbing solutions at the optimum concentration. The results shown in **Table 2** indicate that the adsorption and desorption efficiencies of activated carbon toward Ni(II) ions reduce at an almost similar rate compared to the activated carbon that adsorbed Ni(II) ions in the first adsorption, as shown in **Table 1**.

All batches show that less than 50% of Ni(II) ions were adsorbed in the second adsorption and 0% of Ni(II) ions were desorbed except for the activated carbon powder heated at 100 °C and 150 °C, which were desorbed using HCl. Based on these results, the HCl and H_2SO_4 desorbing solutions used in the first desorption process reduce the following adsorption and desorption efficiencies. The possible reason is that the acidic desorbing solutions used in the first desorption process change the surface characteristic of the activated carbon to be positively charged, which reduces the following second adsorption and desorption efficiencies.

Table 2. Comparison between the adsorption and desorption efficiencies of Ni(II) ions in three batches of regenerated activated carbon in distilled water.

Batches	Desorbing agents	Adsorption efficiency, %	Desorption efficiency, %
Wet AC	HCl	10.6	0
	H_2SO_4	23.2	0
100°C AC	HCl	37.7	76.1
	H_2SO_4	0	0
150°C AC	HCl	43.2	96.1
	H_2SO_4	0.15	0

3.5. Optimizing The Sodium Hydroxide Concentration in The Regeneration of Activated Carbon

A few batches of activated carbon used to adsorb Ni(II) ions at the same concentration as previously used were prepared before desorbing using HCl and H_2SO_4 acidic desorbing solutions at optimum concentrations. After the first desorption, the activated carbon, which had been rinsed five times, was treated with various concentrations of NaOH solution. The NaOH-treated activated carbons were used to adsorb Ni(II) ions again at the same concentration used previously in the second adsorption followed by desorption using HCl and H_2SO_4 acidic desorbing solutions at the optimum concentration. The second adsorption and desorption efficiency calculations are shown in **Fig. 5** and **Fig. 6**.

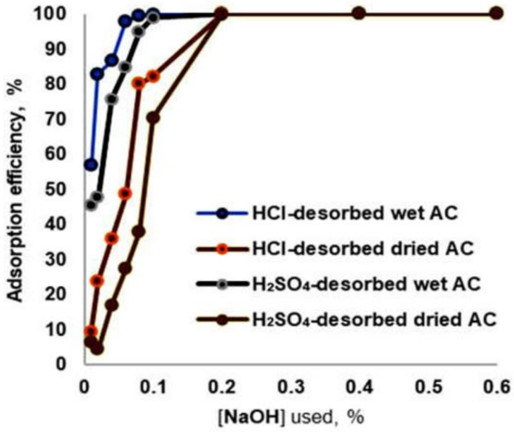

Fig. 5. Adsorption efficiencies of all batches of AC treated using various NaOH concentrations.

In **Fig. 5**, the adsorption efficiency for the activated carbon dried at 100 °C started to recover at lower adsorption efficiencies at 6% and 9% compared to the wet activated carbon at 57% and 45% for both HCl and H_2SO_4 desorbed batches in the first adsorption. When a higher NaOH concentration was used to treat the regenerated activated carbon from the first Ni(II) ions adsorption-desorption process, the adsorption efficiency in the second Ni(II) ions adsorption increased to 100% after 0.1 % and 0.2 % of NaOH solutions were used to treat both wet and dried activated carbon batches. The optimum concentration of HCl and H_2SO_4 acidic desorbing solutions was used in all the desorption processes.

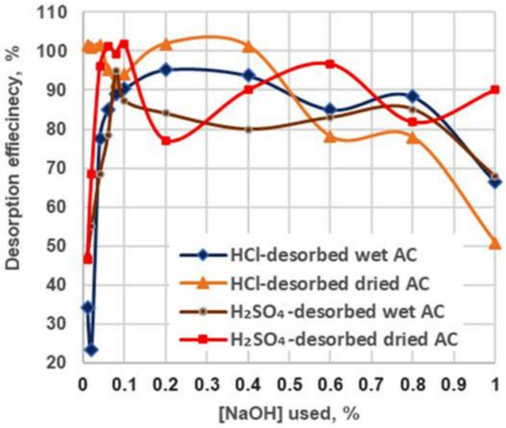

Fig. 6. Desorption efficiencies of all batches of AC treated using various NaOH concentrations

The desorption efficiency increased gradually starting from 34%, 48%, and 46% for HCl-desorbed wet activated carbon and H_2SO_4-desorbed wet and dried activated carbons. Except for HCl-desorbed dried activated carbon, the desorption efficiency started at 100% at the lowest NaOH concentration. While the NaOH concentration increased, the desorption efficiencies for the HCl-desorbed wet activated carbon, H_2SO_4-desorbed wet and dried activated carbons increased to a maximum of 95.2%, 95%, and 101.8% after being treated with 0.2 %, 0.08%, and 0.1% NaOH solutions. The desorption efficiencies for the HCl-desorbed dried activated carbon were maintained above 90% until 0.6% NaOH concentration. Based on the optimum adsorption and desorption efficiencies shown in **Fig. 5** and **Fig. 6**, the most suitable NaOH concentration to be used to recover the efficiency of the used activated carbon was 0.2%.

CONCLUSION

The optimum conditions for regenerating the Ni(II) ions saturated activated carbon were studied. HCl and H_2SO_4 were two acidic solutions capable of desorbing more than 50% Ni(II) ions adsorbed on activated carbon. HCl and H_2SO_4 solutions could desorb more than 85% of the adsorbed Ni(II) ions at concentrations of more than 1.7 % and 2.2 % for HCl and H_2SO_4 desorbing solutions. However, the adsorption efficiency of the regenerated activated carbon using HCl and H_2SO_4 solutions was reduced drastically by less than 60% in the following adsorptions. The acid interference test proved that HCl and H_2SO_4 solutions changed the surface characteristic of the activated carbon. Further treatment with NaOH could fully regenerate the adsorption efficiency of the activated carbon. 0.2% NaOH treatments could be fully regenerated in almost 100% adsorption and 77 to 102% desorption efficiencies for acids desorbed wet and dried activated carbons.

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CONFLICT OF INTEREST

No potential conflicts of interest were reported by the authors.

AUTHOR CONTRIBUTIONS

KHC conducted the experiment and calculations, KWC wrote and revised the manuscript. All authors agreed to the final version of this manuscript.

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