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Efficient Ammonia Removal in the Rosetta Branch of the River Nile using Activated Carbon: A Comprehensive Study

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Abstract

Water treatment plants in the northern region of Egypt encounter significant pollution and contamination at their inlets, primarily due to the discharge of sewage and industrial waste originating from factories situated along the Nile River. Elevated levels of ammonia have been associated with a multitude of illnesses, some of which may result in unconsciousness or even death. This study aimed to evaluate the effectiveness of different types of activated carbon for the removal of ammonia from water. The investigation involved the use of predetermined effective doses and specific varieties of activated carbon, the batch technique of jar tests, and the quantitative determination of ammonia concentration using ion chromatography. Various operating conditions were explored, including changes in raw water turbidity, ammonia concentration, and the application of activated carbon at varying doses. Four different types of activated carbon were used: P1SAC, P2JAC, G1JAC, P3AAC and P4IAC. Results showed that increasing the mass of activated carbon increased the removal of ammonia. A significant decrease in ammonia concentration was observed for doses ranging from 10 to 50 g/l, with a maximum reduction percent of 40%. However, for doses exceeding 50 g/l, a decrease in reduction percent was observed, ranging from 8% to 22%. The recorded maximum reduction percent was dependent on the type and dose of activated carbon being applied.

Keywords: Ammonia Pollution, Nile River, Drinking Water, Rosetta Branch, Agricultural Drains, wastewater treatment ,Water Quality

1. Introduction

The Nile River is the main source of water in Egypt; it covers more than 90% of the Egyptians' freshwater demands. Approximately 78 million individuals reside in the vicinity of the Nile, which constitutes roughly 4% of Egypt's total area [1]. The Nile River traverses a distance of approximately 950 km in Egypt, commencing from the southern regions of Egypt at Aswan and culminating at Cairo in the north, where it bifurcates into two branches known as Rosetta and Damietta [2]. The annual water inflow into the Nile stands at around 55.5 billion cubic meters (BCM) [3]. Egypt's primary reliance on conventional water resources is being further challenged by a decrease in water availability from Ethiopia caused by the Renaissance dam, which is compounded by population growth and increasing industrial demand, resulting in a continuous decrease in per capita water availability [4]. The scarcity of water is a major issue in Egypt, particularly in rural regions, where many Egyptians lack access to water [5]. The high demand for water in agriculture, which accounts for 80% of the water supply, while domestic and industrial demands consume about 10% and 9.5%, respectively, adds to the challenge of water scarcity [3]. Furthermore, surface water in Egypt is at risk of contamination, which poses risks to both human and aquatic ecosystems. Reports indicate that 80% of the untreated industrial sewage is discharged into the Nile River, further exacerbating the problem [6]. Since the Nile is still the main source of fresh water in the country, its water quality significantly affects the health of the Egyptians [7]. The increased water contamination has resulted in a rapid increase in severe diseases such as hepatitis, kidney failure, and congenital heart disease, with Egypt being the first country suffering from the hepatitis C virus, and around 20% of infected individuals are infected by the contaminated drinking water [1].

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The Rosetta branch of the Nile River serves as a source of drinking water, fishing, and irrigation, with a daily flow averaging 21,500,000 m^3/day [8]. However, the branch is also affected by the discharge of domestic, industrial, and agricultural wastes without any treatment, which poses serious environmental and health risks [9]. Reports indicate that over 900 MCM of wastes, consisting of agriculture, domestic, and industrial wastes from the Greater Cairo area, are discharged monthly into the Rosetta branch without any treatment [10]. The El-Rahawy drain has been identified as a major source of contamination, with studies showing that it is highly polluted by organic and inorganic contaminants [11].

Over the last few years, a steady rise in pollution levels has been observed in several parts of Rosetta branches that are of high environmental impact and significance [12]. These contaminants represent a load on the drinking-water treatment plants; especially in the winter closure period (WCP) via many governorates (i.e., Alexandria, Beheira, Kafr el Sheikh, and Gharbia) have been affected [13]. 19 million people are living in these provinces, served by 32 treatment plants to obtain clean drinking water [14]. These plants are producing about 3.6 Mm^3/day of drinking water [15]. Furthermore, these situations cause several environmental problems, these including widespread health problems outbreaks, and aquatic ecosystem disorders as well as water quality degradation [1]. Moreover, some of the water treatment plants are sometimes facing operational technical problems, as they got poor performance to deliver water with high standard specifications [16;17]. Rising Rosetta's water pollution levels are expected to be a chronic problem and will likely be a major issue for residential areas of Provinces bordering [18].

Ammonia is recognized as a contributing factor to water pollution. It is a commonly encountered impurity found in wastewater originating from various industrial and municipal origins. The expansion of the industrial sector, specifically in areas such as coking, chemical fertilizer, coal gasification, petroleum refining, pharmaceuticals, and catalyst, leads to the generation of a significant amount of wastewater containing ammonia [19]. The excessive presence of nitrogen in wastewater is widely recognized for its distinct properties and potential impact on the reduction of dissolved oxygen levels necessary for aquatic life. This nitrogen component has been identified as a significant contributor to the overall pollution burden. Furthermore, an excessive amount of nitrogen could potentially be attributed to the occurrence of fish toxicity, diminished efficacy of disinfection, and accelerated deterioration of metals and construction materials [20]. The process of wastewater purification is widely recognized as a prominent approach for addressing this issue. The utilization of innovative technology is a contributing factor to the high operational costs. Thus far, a diverse range of applications have employed the adsorption technique for the purpose of eliminating contaminated components from liquid or gas mixtures. Furthermore, the utilization of natural materials has been extensively employed for the purpose of eliminating contaminants. This is primarily due to their porous nature and large surface area, which provide ample active sites for the adsorption process.

The rationale of the proposed research plan is that increasing ammonia in the River Nile especially in the Rosetta Branch during low demand periods, affects aquatic life in the river, changing color and taste of drinking water in this area, in addition to many other problems appearing in water treatment plants such as the increase of chlorine dosing consumed by ammonia and organic matter [21], in addition to the release of secondary byproducts such as trihalomethane when using a high dose of chlorine to remove ammonia [16;22].

The aim of the present study is to determine the efficiency of different types of activated carbon in the removal of ammonia from raw water of the Nile River water source (Rosetta Branch). Various forms of activated carbon have been used to investigate the efficiency of ammonia removal, with a focus on five modified types that can accommodate variations in raw water turbidity, contaminants, and ammonia concentrations. To determine the effectiveness of activated carbon, batch-based experiments have been conducted

2. Experimental

In an effort to enhance our understanding of the relative effectiveness of different types of activated carbon, a study was undertaken that employed predetermined effective doses and specific varieties of activated carbon. The investigation entailed the use of a batch technique with jar tests and the quantitative determination of ammonia concentration utilizing ion chromatography. Various operating conditions were explored, such as changes in raw water turbidity, ammonia concentration, and the application of activated carbon at varying doses.

Different types of activated carbon (AC) were studied under diverse operational circumstances, such as the initial concentration of ammonia in raw water, raw water turbidity, and the quantity of adsorbents applied. The removal of ammonia improved gradually (albeit marginally) with increasing amounts of activated carbon, which can be attributed to the rise in active sites available for adsorption.

2.1 Area of Study

Rosetta Branch represents the main freshwater stream of the Nile River, which extends from the Delta Barrage at 30° 11' 04.4" N and 31° 07' 00.4" E for about 256 km on the western boundary of the Nile Delta [20], (Fig.1). It ends with the Edfina Barrage at 31° 18' 22.8" N and 30° 31' 07.9" E with a distance of 30 km upstream of the Mediterranean Sea [23;24]. Rosetta Branch has an average width of 180 m and provides water for agricultural, industrial, domestic, and fishery sectors [14].

The collection and disposal of drainage water into the Rosetta Branch is facilitated by five primary drains, including El Rahawy, Zaweit El Bahr, El Tahrir, Sabal, and Tala, which receive effluents from secondary drains [25;26].

Pollution along the branch mainly originates from these five main drains [27]. The Rosetta branch is subjected to various forms of pollution stemming from diverse sources, including but not limited to the discharge of sewage and domestic effluents from the El-Rahaway drains, which is estimated to produce more than 5 × 108 m3 of effluent on a daily basis. The discharge of agricultural wastes from the Sabale drain and industrial effluents from El-Malya and Soda companies in Kafr El-Zayat city have significant impacts on the Rosetta Branch aquatic environment.

2.2 Samples Collection and analysis

Subsurface water samples were collected from sampling site "Ezbet-Sherif" at a distance of 5km before El-Rahawy drain (figure 1).

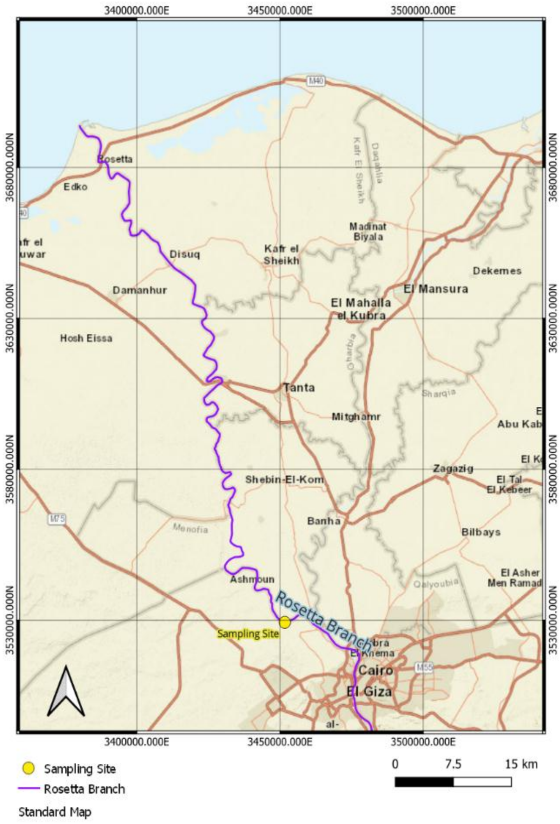

Figure 1: Rosetta Branch and Sampling

The sampling glass and plastic containers were previously washed then stored in an ice box before delivery to the laboratory according to the limited storage timing referring to the applied reference standard methods.

This study encompasses bench scale techniques to comprehensively investigate the research objectives. It involves conducting experiments on a bench scale, which allows for controlled laboratory conditions to assess the effectiveness of various parameters, treatments, or processes. This step serves as a preliminary evaluation and provides valuable insights into the feasibility and potential outcomes of subsequent larger-scale investigations.

Water samples were collected during 2022 from January to October 2022. Activated carbon has been investigated for ammonia removal in both natural and fortified raw water samples containing ammonium chloride [28;29].

2.2.1. Jar Test

Jar test was held for optimum alum dose and different activated carbon doses [29;30].

This procedure involves using alum (aluminum sulfate) and activated carbon to optimize water treatment. First, add raw water to test beakers and record temperature (19.5), pH (7.91), and turbidity (12.6) using (SS-30 8in Ro-Tap Sieve Shaker) [30]. Next, prepare a stock solution by dissolving alum/activated carbon in distilled water. Dose each beaker with increased amounts of the solution. The optimum dose for alum/activated carbon is determined using a six-gang jar tester. The results can help optimize plant performance. The optimum dose for alum/activated carbon is determined by comparing the optimum dose for different types of AC, (Figure2).

The optimum dose for the different types of activated carbon was applied (1 to 100 g)

These doses of different activated carbon types were tested for raw water with ammonia concentration in the range of (5-6) mg/l.

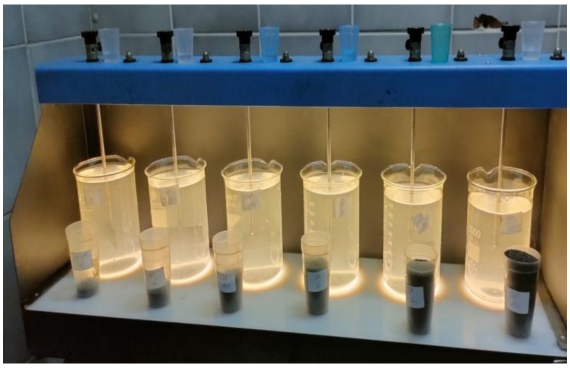

Figure (2): Jar test procedure

The tested samples were analyzed for different physicochemical parameters, (conductivity, temperature, pH, turbidity, alkalinity, chloride, and ammonia concentration) using standard methods [31] for determining the removal percent of ammonia for different types of modified activated carbon, (Table 1). All analyses were held at the drinking water reference laboratory of Holding Company for Water and Wastewater (HCWW). All reagents used were of analytical grade and provided by international companies such as Sigma-Aldrich, Merck, and Fisher Scientific. Ion Chromatography Apparatus (Metrohm, multi modules system with 830 IC interface), was mainly used for ammonium ion (Cation) concentration analyses. The analysis procedure was also done according to standard methods. [31]. After analysis, residues were disposed of safely.

3. Results and Discussion

For Type 1 (P1SAC), applied doses were in the range of 0.3 g/l to 20 g/l, where there was slight reduction in ammonia concentration in reference to raw water ammonia concentration (5.901 mg/l) as there was no reduction effect for doses from 0.3 to 1.2 g/l and a slight reduction percent range from a minimum reduction percent of 1.8 % for a dose of 1.5 g/l of AC to a maximum reduction percent of 4.246 % resulting for a dose of 15 g/l of AC applied, as shown in figure (3).

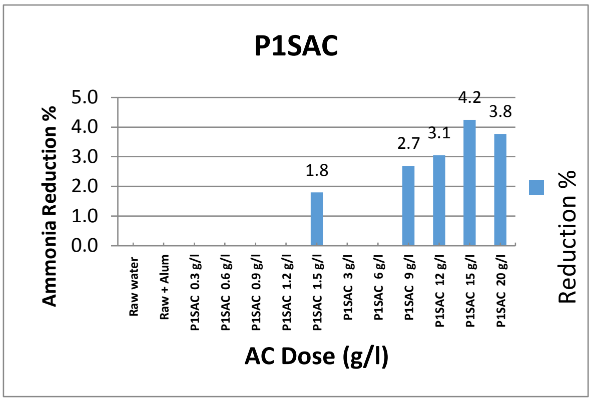

Figure 3: Reduction % of ammonia concentration (5.901 mg/l) for different applied doses (0.3-20 g/l) of activated carbon (P1SAC).

For Type 2 (P2JAC), applied doses were in in the range of 0.3 g/l to 50 g/l, where the reduction in ammonia concentration is in reference to raw water ammonia concentration (5.2 mg/l) as there was no reduction effect for doses from 0.3 to 1.2 g/l and a slight reduction percent range from a minimum reduction percent of 1.0 % for a dose of 1.5g/l of AC to a maximum reduction percent of 40.7 % resulting for a dose of 40 g/l of AC applied, as shown in figure (4).

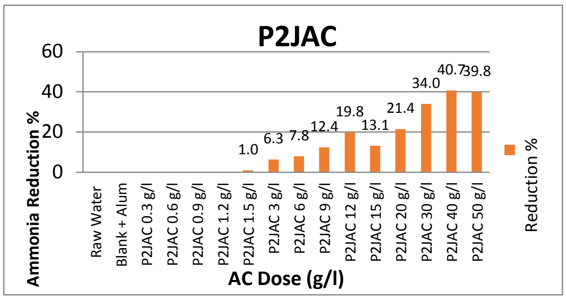

Figure 4: Reduction % of ammonia concentration (5.2 mg/l) for different applied doses (0.3-50 g/l) of activated carbon (P2JAC)

Table (1): Specifications of Different types of activated carbon applied

Type	**1**	**2**	**3**	**4**	**5**
ID	P1SAC	P2JAC	G1JAC	P3AAC	P4IAC
Appearance	Powder AC	Powder AC	Granular-Catalytic AC	Powder AC	Powder AC
Iodine Number (mg/g)	900-1100	min. 900	1200	800-1000	min.1200
Molasses Number (EU)	180 - 220	250 - 310	200 - 250	150 - 200	200 - 250
Total Ash Content	max. 10 %	max. 8.5 %	max. 10 %	max. 12 %	max. 10 %
Moisture Content, as packed	max. 12 %	max. 10 %	max. 12 %	max. 15 %	max. 12 %
pH	6-8	5-7	6-8	6-8	5-7
Surface Area (BET)	800 - 900 m2/g	950 m2/g	1,000 m2/g	700 - 800 m2/g	1,000 m2/g
Water soluble matter	2.50%	1.80%	2%	3%	2%
Mesh size	12-20	4-8	8-12	10-20	8-12
Density (kg/m3)	0.6	0.65	0.65	0.55	0.65
Type	Wood-based	Coconut shell	Coal-based	Coconut shell	Coal-based

For Type 3 (G1JAC), applied doses were in the range of 10 g/l to 100 g/l, where the reduction in ammonia concentration in reference to raw water ammonia concentration (5.2 mg/l). As reduction percent ranges from a minimum reduction percent of 3.3 % for a dose of 10 g/l of AC to a maximum reduction percent of 21.6 % resulting for a dose of 100 g/l of AC applied, as shown in figure (5).

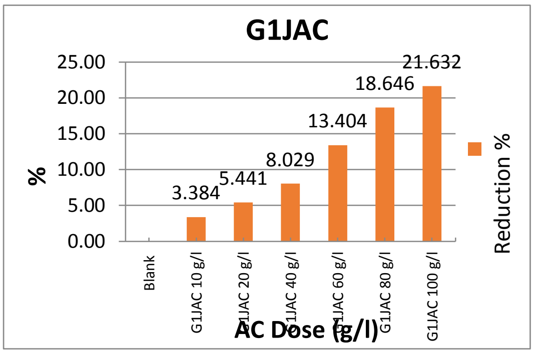

Figure 5: Reduction % of ammonia concentration (5.2 mg/l) for different applied doses (1-100 g/l) of activated carbon (G1JAC)

For Type 4 (P3AAC), applied doses were in the range of 20 g/l to 60 g/l, where the reduction in ammonia concentration in reference to raw water ammonia concentration (5.39 mg/l). As reduction percent ranges from a minimum reduction percent of 1.46 % for a dose of 20 g/l of AC to a maximum reduction percent of 9.68 % resulting for a dose of 50 g/l of AC applied, as shown in figure (6).

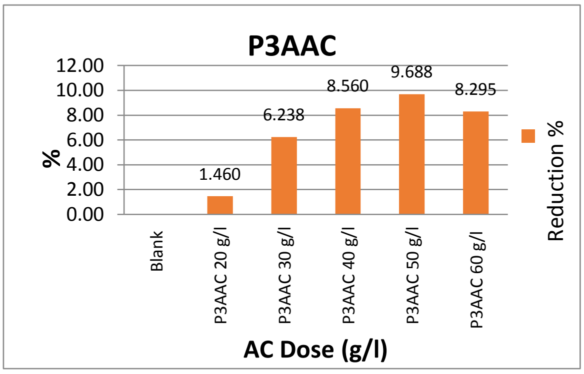

Figure 6: Reduction % of ammonia concentration (5.39 mg/l) for different applied doses (20-60 g/l) of activated carbon (P3AAC)

Table (2): Reduction in ammonium concentration related to applied activated carbon dose.

Applied Activated Carbon dose	Ammonia Reduction %
<1-2 g	1-2%
3 - 6 g	6 - 8%
6 -10g	3-12%
10-20 g	3- 21%
30 g	6-34%
40 -50 g	8- 41%
60 -70 g	8-13%
80-100 g	20 - 22%

Considering the comparative study for the initial doses of activated carbon applied, as shown in Table (2), an applied dose in the range of less than 2 g/l gives no obvious reduction in ammonia concentration, even when used in addition to the determined optimum dose of alum. Higher doses applied in the middle range of activated carbon doses (from 2.0 to 10.0 g/l) were investigated and resulted in a maximum removal efficiency of 12% of ammonia. In a further study for the application of activated carbon doses from 10.0 to 50.0 g/l, a significant decrease in ammonia concentration was observed, with a maximum reduction percent reaching 40% for increased doses exceeding 50 g/l and an obvious decrease in reduction percent of ammonia concentration lower than 40%, ranging from 8.0 to 22% for doses from 60 to 100 g/l AC dose, as shown in figure (7).

The recorded maximum reduction percent is in reference to the activated carbon dose and type being applied, the recorded maximum reduction percent is in reference to the activated carbon dose and type being applied. The removal of ammonia from water using activated carbon (AC) is an adsorption process; the amount of ammonia that can be adsorbed to the surface of the AC particles is limited by the surface area of the AC particles and the strength of the attraction between the ammonia molecules and the AC surface. Increasing the dose of AC will increase the surface area available for adsorption, but it will also increase the concentration of ammonia molecules in the vicinity of the AC surface. This can actually lead to a decrease in the removal efficiency as the ammonia molecules will start to compete with each other for adsorption sites [32].

Compared with previous studies on the removal techniques of ammonia from drinking water and wastewater in Egypt and developing countries, this study investigated the efficiency of different types of activated carbon for the removal of ammonia from different raw water sources (rainwater, groundwater, and Nile water) [33].

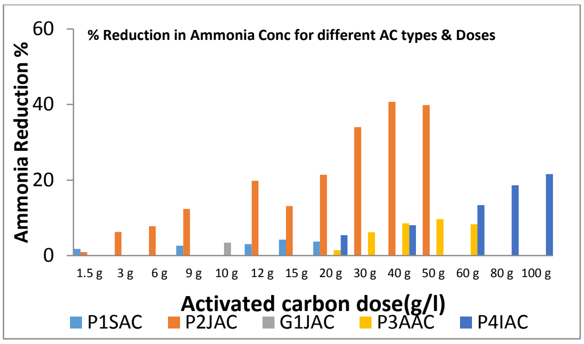

Figure 7: Reduction in Ammonia Conc. (5-6 mg/l) for different AC types & Doses (1.5-100g/l).

Prepared activated carbon from activated date pits (ADP); results showed that the maximum adsorption capacity of ADPs for ammonia removal was about 37% at 60°C. The concentration of ammonia ranged from 5 to 90 mg/l with 0.5 to 2.5 g of adsorbent. In the same way, the adsorption of activated carbon from rice straw for ammonia in batch mode [34]. The results were statistically compared using the linear least squares method and the trial-and-error non-linear method for the most common isotherms. A wide range of initial concentrations was used, ranging from 10 to 350 mg/l, at temperatures of 25, 40, 50, and 60 °C, with a fixed adsorbent amount of 0.1 g, and the adsorption capacity reached 96.4 mg/g for 180 min. contact time. These studies confirmed that the removal efficiency of activated carbon depends on the type of activated carbon used, the physical and chemical characteristics of water samples, and the conditions of operation (temperature, pH, the dose of activated carbon, the initial concentration of ammonia in water samples, the technique of ammonia determination methods, and ways to simulate contaminated water [16]. The optimal dose of activated carbon (AC) for ammonia removal is 20-50 g/L, with higher doses causing a decrease in efficiency. The effectiveness of ammonia removal from water is influenced by the water's pH, temperature, and the presence of other substances like dissolved organic matter. Lower pH results in higher ammonia adsorption, while higher temperatures increase efficiency. Additionally, the presence of other substances like dissolved organic matter can compete with ammonia molecules for adsorption sites on the AC surface, reducing efficiency, [35; 36; 37].

4. Conclusion

Based on the findings of this study, it can be concluded that the effectiveness of different types of activated carbon in removing ammonia from water is dependent on the type of activated carbon used, the initial concentration of ammonia in raw water, the raw water turbidity, and the dose of activated carbon applied. Increasing the mass of activated carbon slightly improved the removal of ammonia, which can be attributed to the increase in active sites available for adsorption. Type 1 (P1SAC) showed a slight reduction in ammonia concentration, and doses of 15 g/l showed the maximum reduction percentage 4.246%. Type 2 (P2JAC) showed a maximum reduction percentage of 40.7% at a dose of 40 g/l. Type 3 (G1JAC) showed a maximum reduction percentage of 21.6% at a dose of 100 g/l, while Type 4 (P3AAC) showed a maximum reduction percentage of 9.68% at a dose of 50 g/l.

The results also revealed that for doses for all types of activated carbon in this study, less than 2.0 g/l, there was no obvious reduction in ammonia concentration, even when used in addition to the determined optimum dose of alum. The maximum removal efficiency of ammonia was observed for doses ranging from 2.0 to 10.0 g/l of activated carbon, and a significant decrease in ammonia concentration was observed for doses ranging from 10 to 50 g/l. However, an obvious decrease in reduction percentage was observed for doses exceeding 50 g/l.

The removal of ammonia from water using activated carbon (AC) is an adsorption process, which means that the ammonia molecules are attracted to the surface of the AC particles. The amount of ammonia that can be adsorbed is limited by the surface area of the AC particles and the strength of the attraction between the ammonia molecules and the AC surface. Increasing the dose of AC will increase the surface area available for adsorption, but it will also increase the concentration of ammonia molecules in the vicinity of the AC surface. This can actually lead to a decrease in the removal efficiency, as the ammonia molecules will start to compete with each other for adsorption sites. In general, the optimum dose of AC for ammonia removal is in the range of 20-50 g/L. At higher doses, the removal efficiency will start to decrease.

When designing an activated carbon system for ammonia removal, it is important to consider main factors including pH, temperature and other substances present, as in general the removal efficiency is higher at a lower pH, at a higher temperature and at decreased presence of their substances competing with ammonia molecules for adsorption sites n AC surface.

In summary, this study provides useful information for the selection and optimization of the application of different types and doses of activated carbon for the removal of ammonia from water under different operating conditions.

5. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

6. Ethical approval

This paper does not contain any studies with human participants or animals performed by any of the authors.

7. Data Availability

All data are available in this manuscript.

8. Acknowledgment

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