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Effectiveness of Reducing Ammonia Levels in Hospital Wastewater Using A Combination of Bagasse Bio Adsorbent and Nanofiltration Membrane

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ABSTRACT

The increasing environmental impact caused by hospital wastewater, particularly due to its ammonia content, necessitates innovative treatment methods. This study investigates the effectiveness of a combination of sugarcane bagasse-based activated carbon bio-adsorbent and nanofiltration membrane technology to reduce ammonia concentrations in hospital wastewater. The activated carbon was produced through carbonization at 550°C and chemical activation using 10% H_2SO_4. Adsorption experiments were conducted by varying bed heights (5, 7.5, and 10 cm) and flow rates (2, 3, and 4 L/min), followed by nanofiltration at 25, 30, and 35 Psi pressures. Results showed that the combined treatment reduced the wastewater pH from 9.08 to 6.53 and ammonia concentration from 4.61 mg/L to 0.02 mg/L, successfully meeting regulatory standards. This indicates that the integrated method effectively decreases ammonia levels and improves wastewater quality before discharge.

Keywords: *Adsorption; Ammonia removal; Hospital wastewater; Nanofiltration membrane; Sugarcane bagasse*

ABSTRACT

Dampak lingkungan yang semakin meningkat akibat limbah cair rumah sakit, terutama karena kandungan amonia di dalamnya, mengharuskan penerapan metode pengolahan inovatif. Studi ini meneliti efektivitas kombinasi bioadsorben karbon aktif berbasis ampas tebu dan teknologi membran nanofiltrasi dalam mengurangi konsentrasi amonia pada limbah cair rumah sakit. Karbon aktif diproduksi melalui karbonisasi pada suhu 550°C dan aktivasi kimia menggunakan 10% H_2SO_4. Eksperimen adsorpsi dilakukan dengan variasi ketinggian lapisan (5; 7,5; dan 10 cm) dan laju aliran (2; 3; dan 4 L/menit), diikuti dengan nanofiltrasi pada tekanan 25, 30, dan 35 Psi. Hasil studi menunjukkan bahwa perlakuan gabungan menurunkan pH limbah cair dari 9,08 menjadi 6,53 dan konsentrasi amonia dari 4,61 mg/L menjadi 0,02 mg/L, berhasil memenuhi standar regulasi. Hal ini menunjukkan bahwa metode terintegrasi secara efektif mengurangi kadar amonia dan meningkatkan kualitas limbah cair sebelum pembuangan.

Kata Kunci: *Adsorpsi; Ampas tebu; Limbah cair rumah sakit; Membran nanofiltrasi; Penghilangan amonia*

INTRODUCTION

Hospitals are public health services with quite busy operating hours every day. Hospital liquid waste is one of the dangerous sources of pollutants [1], [2]. Hospital wastewater contains organic compounds and chemical compounds such as ammonia. In addition, it also contains pathogenic compounds such as Escherichia coli, Bacillus subtilis, Staphylococcus aureus, and

Klebsiella pneumonia [3]. One of the potential sources of water pollutants that pollute the environment is wastewater from hospitals because it contains high concentrations of organic compounds and pathogenic microorganisms that cause disease in the community [4]. One of these pollutants is ammonia, which is present in wastewater. Ammonia is present in low concentrations, and the amount of discharge may be low if ammonia dissolved in wastewater cannot be evaporated because ammonia gas will cause serious problems [5].

Urine is a contributor to high ammonia levels. If the hospital wastewater is not treated correctly, it will impact the environment and humans [6]. The impact on the environment is that if the presence of ammonia is high enough in the aquatic environment, it will cause the biota in these waters to die. The effect on humans is that it will cause irritation to the respiratory tract and eyes and can even cause death [7]. The nature of ammonia, which is easily soluble in water, can raise the pH of the water to alkaline so that the water becomes polluted. For this reason, hospitals must treat their waste based on the requirements of quality standards [8].

Hospitals should reduce the number of environmental pollution, one of which is by treating the liquid waste produced so that it meets quality standards and is safe for the environment [9]. For this reason, alternative technology is needed to reduce ammonia levels in hospital wastewater, using a combination method of activated carbon adsorption process made from bagasse combined with membrane technology [10]. Activated carbon is a versatile adsorbent because the size and distribution of pores in the carbon matrix can be controlled [11]. Bagasse is an activated carbon used to reduce pollutant levels in liquid waste [12]. Bagasse is a natural material that can be used to make activated carbon because it is more environmentally friendly so as not to cause new polluting substances [13]. In addition, the cost of making activated carbon from this natural material is quite cheap. Effluent containing high concentrations of NH_4^+ is usually treated using biological treatment systems, which are the most popular treatment levels [14]. Compared to biofilters, which require much energy and have high engineering requirements, absorption is a highly efficient and well-established process [15].

From several studies that have been conducted, the method that is expected to reduce ammonia levels in hospital wastewater is by combining the activated carbon adsorption method made from bagasse and the use of nanofiltration membranes so that the method's effectiveness can be known. Factors that affect the effectiveness of adsorbents include adsorbent properties (surface area, porosity, adsorption ability), the nature of the molecules absorbed (molecular size, polarity), environmental conditions (solution concentration, temperature, pH), contact time, operational conditions (flow speed, adsorbent concentration), adsorbent regeneration, other contaminants, and the shape and size of the adsorbent. Several factors influence membrane effectiveness, including membrane shaft size, surface charge, operating pressure, solution concentration, temperature, pretreatment, chemical conditions, membrane regeneration, and membrane thickness.

METHOD

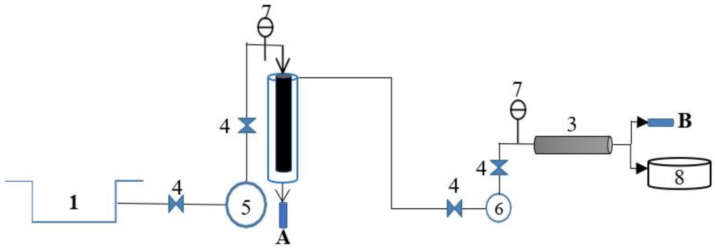
Preparation of bagasse-activated charcoal

The bagasse was dried in the sun for 2 days, then heated in an oven at 110°C for 30 minutes. Carbonation was carried out by pyrolysis using a furnace at 550 °C for 30 minutes. The carbon obtained was pulverized and filtered through a 100-mesh sieve. Chemical activation was carried out by soaking the carbon in 10% H_2SO_4 solution for 24 hours, followed by washing with distilled water until the pH reached 4–7. The samples were then dried at 105°C for 24 hours and stored in a desiccator until they reached room temperature. The samples were analyzed for quality by calculating the moisture and ash content.

Application of Bagasse Activated Charcoal as Adsorbent for Hospital Wastewater Treatment

Hospital wastewater was pumped into the adsorbent column with variations in bed height of 5, 7.5, and 10 cm and feed flow rates of 2, 3, and 4 L/min. The adsorbent column had two valves to regulate the feed flow rate, exhaust, and sample flow that had passed through the column to the nanofiltration process using a membrane with 25, 30, and 35 Psi operating pressure variations.

The adsorption and nanofiltration processes were run for 90 minutes, with permeate sampling every 30 minutes for pH and ammonia concentration analysis. A schematic of this wastewater treatment process is shown in Figure 1.



Description of Equipment:

1 = Wastewater storage pound	6 = Small pump
2 = Adsorbent column tank	7 = Flow rate and pressure gauge
3 = Nanofiltration membrane tank	8 = Retentate collector
4 = Valve	A = Sample point AB (after adsorption column)
5 = Large pump	B = Sample point MN (after nanofiltration membrane)

Figure 1. Hospital effluent treatment process using activated charcoal adsorbent from bagasse.

Characterization of Activated Carbon and Testing of Wastewater Quality

Activated carbon was characterized using energy-dispersive X-ray Spectroscopy (EDS) analysis to identify the elemental composition contained in the material. The processed activated carbon samples were ground and prepared using appropriate preparations for EDS analysis. Measurements were performed using a Scanning Electron Microscope (SEM) equipped with an EDS detector, enabling the identification of elements present on the surface of the activated carbon. The quality of the medical effluent was tested by measuring the ammonia content using an ammonia medium-range photometer (Milwaukee Instruments, model Mi 405). In addition, pH measurements were taken using a pH meter, as pH is an important parameter in determining the quality of a solution. The pH value describes the acidity or alkalinity of the solution, with water categorized as acidic if the pH is below 7 and alkaline if the pH is higher than 7.

RESULTS AND DISCUSSION

Activated Carbon Analysis

Bagasse that has been dried in the sun and oven, followed by the carbonization process using a furnace. The results of burning bagasse can be seen in Figure 2.

(a) (b)

Figure 2. (a) Dried bagasse, and (b) Bagasse carbonization.

Activated carbon produced from bagasse is tested for water and ash content to see the quality of activated carbon before and after activation using 10% H_2SO_4. The results of testing the moisture and ash content of activated carbon can be seen in Table 1.

Table 1. Calculation results of moisture content and ash content.

Sample #	Water Content		Ash Content	
	Before Activation	After Activation	Before Activation	After Activation
Sample 1	10.28	3.92	5.4	4.1
Sample 2	9.80	3.88	5.2	3.9
Sample 3	8.62	3.81	4.7	3.4
Average	9.57	3.87	5.1	3.8

The water content after activation by H_2SO_4 10% in samples 1, 2, and 3 decreased significantly, whereas the water content before activation was 10.28%, 9.80%, and 8.62% to 3.92%; 3.88% and 3.81%, respectively (Figure 3). The average moisture content value before activation was 9.57%, and after activation was 3.87%. The same result was also achieved by the ash content of samples 1, 2, and 3, which had an ash content of 5.4%, 5.2% and 4.7% before activation. After activation using 10% H_2SO_4, they became 4.1%, 3.9%, and 3.4%. The average ash content before activation was 5.1%, and after activation was 3.8%. Based on SNI 06-3730-1995, the maximum water content in activated carbon is 15%, and the maximum ash content is 10%.

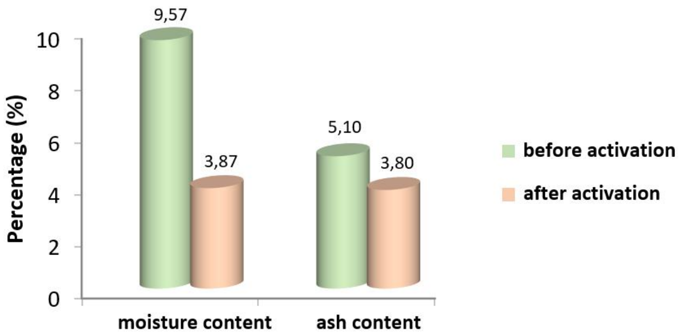
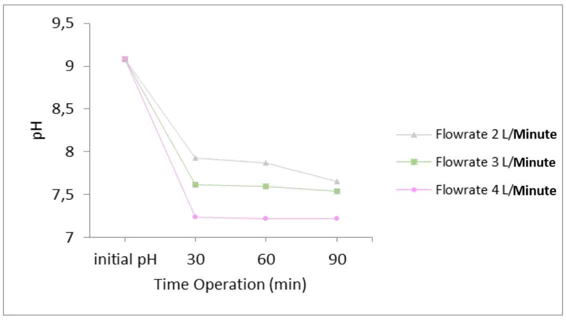


Figure 3. Moisture content and ash content of activated carbon

Effect of Time, Bed Height, and Flow Rate on Adsorption Effluent pH

The degree of acidity (pH) measures the relative levels of free hydrogen and hydroxyl ions in water. High levels of free hydrogen ions indicate that water is acidic, while high levels of free hydroxyl ions indicate alkaline water [16]. The effect of time, bed height, and flow rate on the change in acidity (pH) of medical waste liquid from the adsorption process using bagasse adsorbent is shown in Figure 4.

Based on Figure 4, it is known that the flow rate and operating time influence the pH of the wastewater after the adsorption process. The initial pH of the wastewater before the adsorption process was 9.08. After the adsorption process, the pH decreased in all flow rate variations and operating time. The flow rate of 2 L/min decreased pH in all three variations of bed height and operating time. The highest decrease was at a bed height of 10 cm when the process lasted 90 minutes. The pH of the wastewater decreased from 9.08 to 7.32. There was also a decrease in pH value at flow rates of 3 L/min and 4 L/min. The decrease in pH value aligns with the increasing bed height and the longer operating time. At a flow rate of 3 L/min, the longer the operating time, the lower the pH of the resulting wastewater. The lowest pH was at a bed height of 10 cm of 7.23 at an operating time of 90 minutes. This also applies to the flow rate of 4 L/min, where the longer the operating time, the pH value will decrease. The lowest pH value of 7.12 occurred at a bed height of 10 cm and an operating time of 90 minutes. These results show that the highest pH decrease was at a flow rate of 4 L/min for 90 minutes, where the pH of the wastewater decreased from 9.08 to 7.12. So, it can be concluded that the flow rate and operating time affect the decrease in pH in the adsorption process. This is in line with research conducted by Latifah, which explained that activated carbon made from bark using H_2SO_4 could reduce the pH of leachate wastewater by 5.13 from the initial pH of 12.45 to 7.32 [17].



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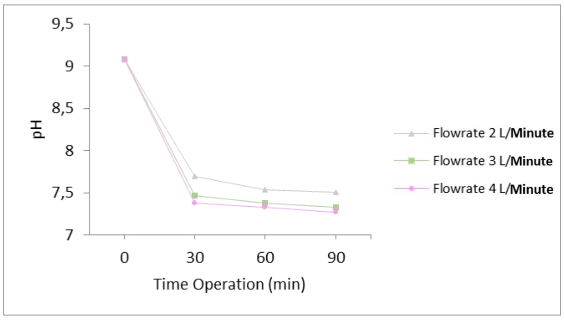

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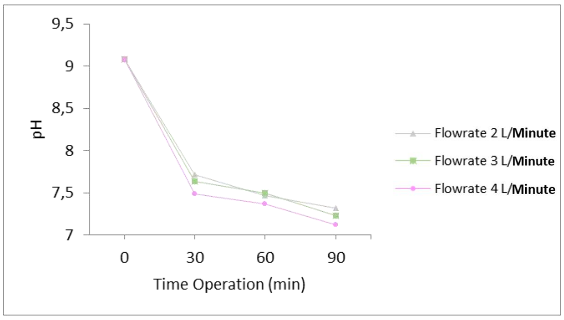

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Figure 4. Effect of time and flow rate on effluent pH with variations in bed height, (a) 5 cm, (b) 7.5 cm, and (c) 10 cm.

The decrease in pH in wastewater after the adsorption process indicates that the adsorbent made from bagasse has absorbed acidic metal ions, such as H^+ ions or other metal ions, resulting in changes in the chemical composition of wastewater, such as a reduction in the concentration of basic substances. Based on the EDS test results on 10% H_2SO_4 activated bagasse adsorbent, it is known that there are atoms of C (carbon), O (oxygen), Al (Aluminum), and Ta (Tantalum). The percentage of atom content in the adsorbent can be seen in Table 2.

Table 2. Atomic content in 10% H_2SO_4 activated adsorbent.

Elements	Wt(%)
C	53.1
O	38.7
Al	1.0
Ta	7.2

The adsorbent's OH (hydroxyl) groups that bind to Al (aluminum) atoms can reduce pH. OH and Al bonds form the $Al(OH)_3$ compound. A solution of $Al(OH)_3$ can release H+ ions (protons), which causes a decrease in pH. The reaction that occurs is:

$$Al(OH)_3 \rightarrow Al(OH)_2^+ + H^+ \quad \text{.…. (1)}$$

The released H^+ ions can increase the concentration of hydrogen ions in the solution, thus causing a decrease in pH in wastewater. In addition, aluminum can also react with water to form aluminum hydroxide and release H^+ ions, which cause a decrease in pH, as shown in the following equation:

$$2Al + 6H_2O \rightarrow 2Al(OH)_3 + 3H_2 \quad \text{.…. (2)}$$

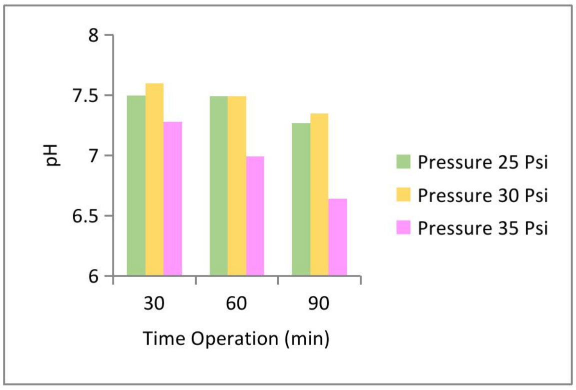
The element Al (Aluminum) in activated carbon can affect the ability of activated carbon to reduce the pH of wastewater. In activated carbon aluminum helps activate activated carbon by increasing the ability to absorb ions associated with the pH element. It also changes the structure of activated carbon, which can increase the surface area and ability to absorb ions. At high pH conditions, active groups are deprotonated and tend to be negatively charged, accompanied by increased OH^- ions in the solution. Increasing the concentration of OH^- ions will cause competition between active sites on the adsorbent surface with OH^- ions to bind to Al ions. The decrease in wastewater pH also causes the amount of Al ions to decrease due to precipitation [18]. The decrease in Al ions after the adsorption process can be seen from the EDS test results in Table 3.

Table 3. Atomic content in adsorbent after the adsorption process.

Elements	Wt(%)
C	53.2
O	41.5
Al	0.7
CA	0.4
Ta	4.2

Effect of Time, Bed Height, and Pressure on Permeate pH

The effect of time, bed height, and pressure on the permeate of the infiltration membrane is analyzed to determine the change in the degree of acidity of wastewater after passing through the nanofiltration membrane can be seen in Figure 5.



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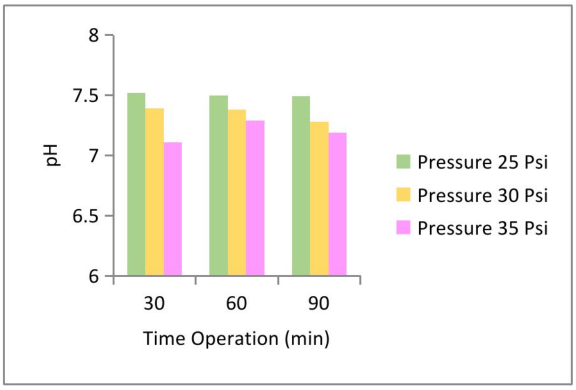

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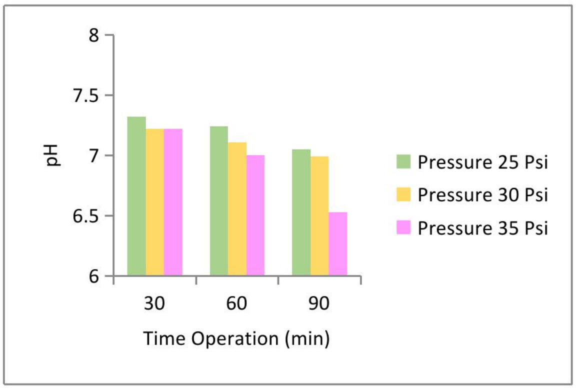

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Figure 5. Effect of time and pressure on permeate pH with variations in bed height, (a) 5 cm, (b) 7.5 cm, and (c) 10 cm.

From the figure, it can be seen that the three variations of time and pressure decreased the pH value. At a pressure of 25 Psi, the pH decreased as the operating time increased. The highest pH decrease occurred at a bed height of 5 cm for 30 minutes with an adsorption effluent pH value of 7.93 and a permeate pH value of 7.5, which decreased by 0.43. The lowest pH at 25 Psi pressure of 7.05 was at a bed height of 10 cm for 90 minutes. At a pressure of 30 Psi, there is also a decrease in the pH value of the permeate as the operating time gets longer. The lowest pH is 6.99 at a bed height of 10 cm and an operating time of 90 minutes. However, the highest decrease occurred at a bed height of 10 cm and an operating time of 30 minutes. The pH value decreased from 7.63 to

7.22. Similarly, at a pressure of 35 Psi. Where the lowest pH value is at a bed height of 10 cm of 6.53 during the process for 90 minutes, this value is the highest decrease of 0.59 from the previous pH of 7.12, which is the pH value of the absorption effluent.

The hospital wastewater treatment process in reducing the pH value through adsorption pretreatment followed by the use of nanofiltration membranes resulted in the highest pH reduction at a bed height of 10 cm, a pressure of 35 Psi for 90 minutes, showing that the process variation was able to reduce the initial pH value from 9.08 to 7.12 and decreased to 6.53 when the process was carried out using nanofiltration membranes. From the data, it can be seen that the greater the pressure and the longer the operating time, the higher the pH decrease. The decrease in pH in hospital wastewater after passing through the nanofiltration membrane is influenced by pressure, which can increase the flow rate and efficiency of reducing pH. Higher pressure can cause the nanofiltration membrane's pore size to shrink, increasing the efficiency of reducing pH. The mechanism of reducing pH in nanofiltration membranes is to remove H ions in wastewater to cause a decrease in pH.

Effect of Time, Bed Height, and Flow Rate on Ammonia Content of Adsorption Effluent

An initial analysis of ammonia levels in hospital wastewater was carried out, and a value of 4.61 mg/L was obtained. Based on South Sumatra Governor Regulation No. 8 of 2012, the ammonia content allowed in hospital liquid waste is 0.1 mg/L. So, the liquid waste content of the Regional General Hospital of Ogan Ilir Regency does not meet the required quality standard content and must be processed first before being discharged into the environment. The results of the adsorption process using bagasse in reducing ammonia levels in hospital wastewater can be seen in Figure 6. In the three variations of flow rates, it can be seen that the decrease in ammonia levels occurs along with the longer operating time of the adsorption process. At a flow rate of 2 L/min, it can be seen that the longer the operating time, the decrease the ammonia levels. The highest decrease occurred at a bed height of 10 cm during an operating time of 90 minutes by 3.04, where ammonia levels dropped to 1.57 mg/L. At a flow rate of 3 L/min, the highest decrease occurred at a bed height of 10 cm with an operating time of 90 minutes of 3.02 from the initial ammonia level of 4.61 mg/L to 1.59 mg/L. This also occurred at a flow rate of 4 L/min, with the highest decrease in ammonia levels at an operating time of 90 minutes and at a bed height of 10 cm, where ammonia levels decreased to a value of 1.26 mg/L.

In the three flow rate variations, it can be seen that the decrease in ammonia levels occurs along with the longer operating time of the adsorption process. At a flow rate of 2 L/min, it can be seen that the longer the operating time, the decrease the ammonia levels. The highest decrease occurred at a bed height of 10 cm during an operating time of 90 minutes by 3.04, where ammonia levels dropped to 1.57 mg/L. At a flow rate of 3 L/min, the highest decrease occurred at a bed height of 10 cm with an operating time of 90 minutes of 3.02 from the initial ammonia level of 4.61 mg/L to 1.59 mg/L. This also occurred at a flow rate of 4 L/min, with the highest decrease in ammonia levels at an operating time of 90 minutes and at a bed height of 10 cm, where ammonia levels decreased to a value of 1.26 mg/L.

This study shows that the adsorption process using an adsorbent made from bagasse can reduce ammonia levels in hospital wastewater. However, the resulting value does not meet the quality standards of liquid waste based on the Regulation of the Governor of South Sumatra Number 8 of 2012 concerning Liquid Waste Quality Standards for Industrial Activities, Hotels, Hospitals, Domestic, and Coal Mining ammonia parameters are allowed a maximum of 0.1 mg/L. So, further processing is needed to reduce the ammonia levels contained. The bond between OH (Hydroxyl) and Al (Aluminum) can form an Aluminum Hydroxide compound ($Al(OH)_3$) which can reduce ammonia levels in liquid waste. Aluminum Hydroxide ($Al(OH)_3$) is a compound commonly used as a coagulant in wastewater treatment. This compound can help remove ammonia from wastewater through precipitation and adsorption processes. The reaction that occurs is as follows:

$$Al(OH)_3 + NH_3 \rightarrow Al(OH)_3(NH_3) + H_2O \qquad \ldots. (2)$$

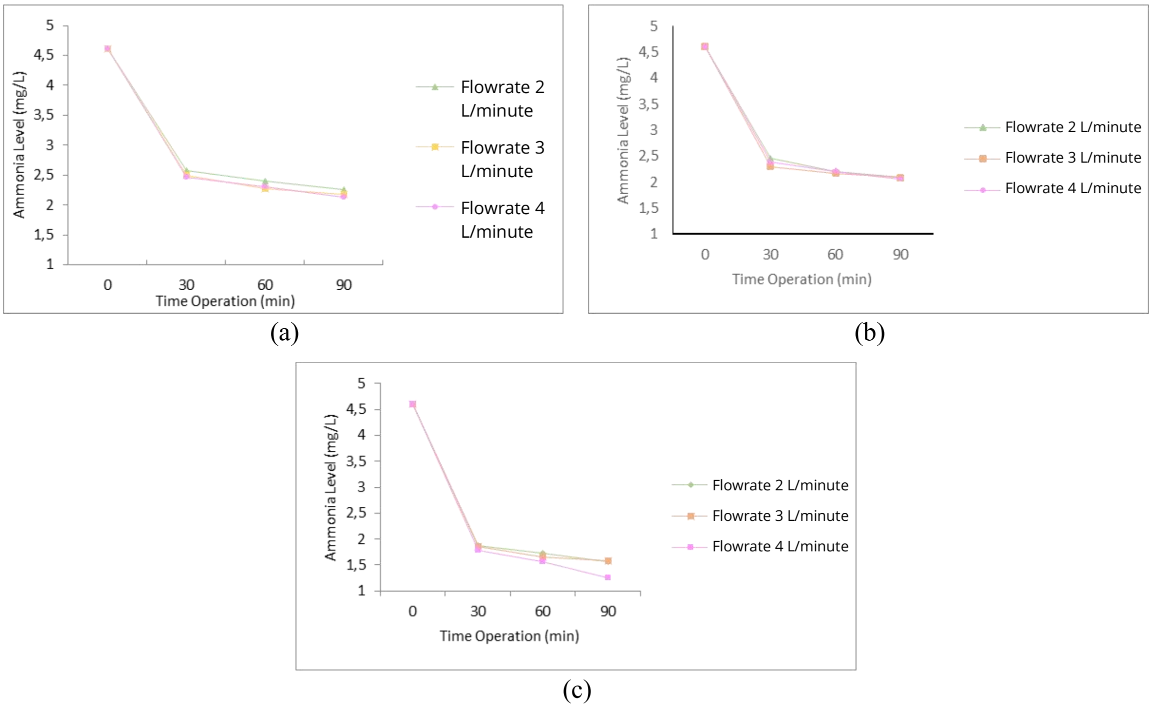
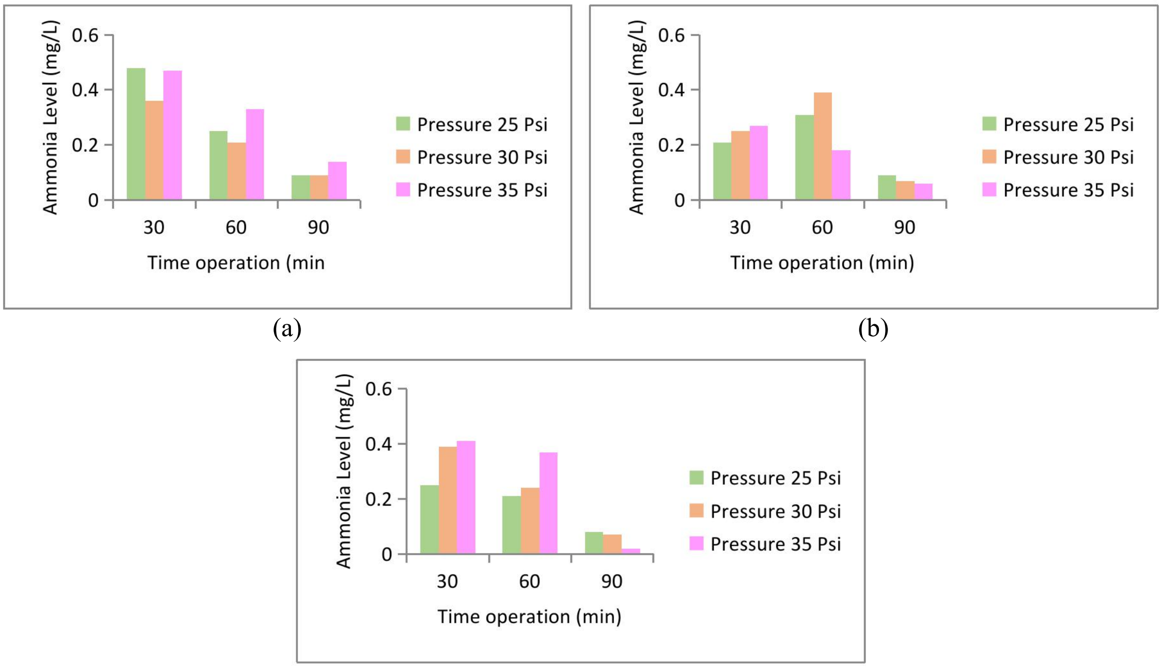


Figure 6. Effect of time and flow rate on ammonia content with variations in bed height, (a) 5 cm, (b) 7.5 cm, and (c) 10 cm.

Effect of Time, Bed Height, and Pressure on Permeate Ammonia Content

The results of advanced processing analysis in reducing the ammonia content of hospital wastewater through nanofiltration membranes can be seen in Figure 7. At a pressure of 25 Psi, ammonia levels decreased in the variation of bed height along with the longer operating time. The resulting ammonia levels are in the range of 0.08 mg/L to 0.48 mg/L, with the lowest ammonia levels occurring at a bed height of 10 cm, and the process lasts for 90 minutes at 0.08 mg/L. At a pressure of 30 Psi, ammonia levels decreased with increasing time. Similarly, at a pressure of 25 Psi, the highest decrease was achieved at a bed height of 10 cm during an operating time of 90 minutes when ammonia levels decreased to 0.07 mg/L. The longer time decreases ammonia levels, which is also achieved at a pressure of 35 Psi adsorbent bed height variation of 10 cm. Ammonia levels decrease from 1.26 mg/L to 0.02 mg/L. The decrease in ammonia levels with a combination of adsorbents and membrane filtration aligns with the results of reducing ammonia levels with adsorbents alone, where long operating times will produce smaller ammonia levels. This membrane filtration process also proves that filtration preceded by adsorption pretreatment produces ammonia levels smaller than without using nanofiltration membranes.

These results show that the pressure on the nanofiltration membrane causes a decrease in ammonia levels, whereas the increase in pressure on the membrane can increase the flow rate and efficiency of reducing ammonia levels. The higher pressure can cause the membrane pore size to shrink, increasing the decrease in efficiency. In nanofiltration membrane separation, particle sizes larger than the membrane pore size will be retained on the membrane surface, while particle sizes smaller than the membrane pore size will escape to the permeate. Ion separation on nanofiltration membranes occurs due to electrostatic interactions between ions and the membrane surface. When the membrane is contacted with wastewater containing ammonia, the membrane surface charge density becomes positive. Separation based on pore size also plays a role in separating NH_3 [19]. Contact between NH_3 (ammonia) and the surface of the nanofiltration membrane results in the adsorption of NH_3 on the membrane surface, especially if the membrane has hydrophilic properties (like water).



(c)

Figure 7. Effect of time and pressure on permeate membrane with variation of bed height, (a) 5 cm, (b) 7.5 cm, and 10 cm

CONCLUSION

The findings of this study demonstrated that the amalgamation of an adsorption process employing activated charcoal derived from sugarcane bagasse waste and nanofiltration membrane technology constitutes a practical methodology for the reduction of ammonia concentration in hospital wastewater. Adsorption with activated charcoal has been demonstrated to be an effective method of reducing ammonia levels. This phenomenon can be explained by the fundamental principle of adsorption, which elucidates the propensity of ammonia molecules to bind with the porous surface of the adsorbent. However, the adsorption results alone did not meet the stringent effluent regulation standards. Consequently, a subsequent stage involving nanofiltration at elevated pressure effectively reduced the ammonia concentration to 0.02 milligrams per liter (mg/L), significantly below the maximum permissible limit of 0.1 mg/L. The effectiveness of nanofiltration is consistent with the principles of membrane filtration theory, which underscores molecular separation based on pore size and membrane surface interactions. In addition to reducing ammonia, the treatment process also lowered the effluent pH from 9.08 to 6.53, indicating an enhancement in effluent quality that is more stable and environmentally friendly. These findings substantially support the concept of integrated effluent treatment, in which the combination of physico-chemical methods with membrane technology complement each other to achieve maximum pollutant removal efficiency. Therefore, integrating adsorption and nanofiltration provides a practical and effective solution for hospital effluent treatment. Furthermore, it strengthens the theoretical foundation of environmental science and wastewater treatment technology. This is particularly evident in ammonia reduction and effluent quality improvement following applicable environmental standards.

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