Short Communication:

Investigation of the Desalination Capacity of Activated Carbon Materials from Water Hyacinth (*Eichhornia crassipes*) Stems

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Abstract: *To reduce the hazards brought by water hyacinth, many applications of water hyacinth have been studied and continuously expanded. The large biomass of water hyacinth is applied in many fields such as for wastewater treatment, wastewater purification, biological raw material sources, animal feed production, medicine, antioxidants, agriculture, and household appliances. This research investigates the desalination capacity of freshwater hyacinths, raw materials from water hyacinths, biochar, and activated carbon materials from water hyacinth stems. Results have shown that the suitable temperature for charring fresh water hyacinth is 420 °C. The activated carbon from the water hyacinth stems with a BET surface area of 200.4 ± 1.9 m^2/g can be desalinated under the conditions of 0.4 g of activated carbon mass, 15 min of reaction time, 2.0 ppt of salt concentration, and at neutral pH. In contrast, raw materials from water hyacinths and biochar were unable to desalinate. This study evaluates the desalination ability of the activated carbon material of water hyacinth.*

Keywords: *activated carbon; desalination; water hyacinth*

■ INTRODUCTION

In recent years, attention has been on the research of clean and renewable energy sources, even on a large scale [1-6]. Saline intrusion during the dry season in the Mekong Delta has occurred in a complicated and unusual manner, at early and late times compared to the previous years. Normally, in the dry season of every year, the upstream water flow naturally decreases, and the tide strongly affects the main river systems and canals, leading to deep penetration of salt water into the inland soil [7]. Upon entering the delta, the salinity gradually decreases, and the water then becomes brackish. However, the rising sea level combined with the impacts of climate change has caused the saline intrusion to occur earlier and unpredictably. Saline water contains a lot of dissolved salts and salt-causing mineral ions such as K^+, Na^+, Ca^{2+}, Mg^{2+}, Al^{3+}, Fe^{2+}, Cl^-, and SO_4^{2-} (mainly due to NaCl) exceeding the allowable threshold [8-11]. It severely affects agriculture and daily life in Vietnam. To overcome the consequences caused by salinity intrusion, water purification, and salt reduction measures have been used by different technologies. Activated carbon is a typical adsorbent that is widely used in water treatment and has shown positive effects. Owing to the porous structure and good adsorption capacity, activated carbon can adsorb salt-causing ions in water, thereby reducing the consequences caused by salinization [9,12-13].

Water hyacinth, scientifically known as *Eichhornia crassipes*, is a tropical plant belonging to the family

Pontederiaceae and genus Eichhorinia [14]. This free-floating aquatic plant is renowned for its ability to produce and remove pollutants from water. Water hyacinth can be used to remove the radicals, NO_3^-, NH_4^+, and phosphorus dissolved in agricultural wastewater or wastewater treatment from dairy factories, tanneries, sugar mills, palm oil mill, distillery, pulp and paper industry [15-17].

Despite bringing many potential threats, water hyacinth is still favorably employed for its uses, such as agricultural wastewater treatment and adsorption of heavy metal ions [17-25]. Research to take advantage of this biomass in daily life is being expanded, in which the production of activated carbon from water hyacinth stems is also focused. Therefore, the present study investigated the desalination capacity of activated carbon from water hyacinths.

■ EXPERIMENTAL SECTION

Materials

All chemicals used were of analytical grade and purchased from Xilong Scientific Chemicals Ltd (sulfuric acid 98 wt.%, sodium hydroxide 96 wt.%, hydrochloric acid 36 wt.%, sodium chloride 99 wt.%, and potassium hydroxide 85 wt.%). Unless otherwise indicated, all chemicals were used as received. Deionized water was used for standard solution preparation. The raw material used to produce activated carbon in this study is mature water hyacinth from Ben Tre province, Vietnamese territory.

Instrumentation

Thermal gravimetric analysis (TGA) was used with temperature or time based on the TA Instruments TGA 550 (USA). The surface area and porosity were measured on a Micromeritics TriStar II Plus 3.03 instrument (USA). The surface morphology of samples was characterized with the scanning electron microscopy (SEM) method using JSM – IT200 device (Jeol – Japan).

Procedure

Preparation and characterization of activated carbon

The procedures for processing and creating activated carbon from water hyacinth are carried out at a laboratory scale with 3 main processes: raw material processing, biochar creation, and activated carbon creation by chemical activation method.

Freshwater hyacinth was washed with water, cut into 2–3 cm pieces, dried to 10% moisture, and then crushed. Biochar was made from the process of heating raw materials at 420 °C in the air for 60 min. The mixture of biochar, 70% KOH solution, and water in the ratio 1:1:5 was soaked and incubated for 24 h. After soaking, the sample was dried at 100 °C and further heated at 500 °C in the air for 60 min. Finally, the sample was washed to neutral pH, and dried at 100 °C to obtain activated carbon.

Investigation of the active desalination capacity of water hyacinth

A total of 6 L of water with different NaCl concentrations (1.0, 1.5, 2.0, and 2.5 ppt) was placed into 8 containers, followed by mixing with 500 g of water hyacinth plants and culturing for 14 d under sunlight and shade conditions.

Investigation of desalination capacity of activated carbon from water hyacinth

The conductivity representing the salinity was measured by Hanna's Groline EC/TDS conductivity meter and the results were processed using Excel 2016 and SPSS Statistic version 22.0 (SPSS Inc., Chicago, IL, USA). The factors affecting the desalination process of activated carbon materials from water hyacinth such as material mass, reaction time, NaCl concentration, and pH were investigated according to the following methods. All experiments were repeated three times.

The influence of activated carbon mass on desalination: the fixed conditions for the experiment included 100 mL of NaCl solution (2 ppt of concentration), room temperature, and 15 min of reaction time. The mass of activated carbon material was varied from 0.1 to 0.8 g. The conductivity of the solution was measured after 15 min.

The effect of time on the desalination of activated carbon materials: the optimal amount of activated carbon in the first experiment was mixed with 100 mL of NaCl solution at 2 ppt of concentration at room temperature. The reaction time varied from 5 to 45 min. The conductivity of the solution was recorded.

The influence of NaCl concentration on the desalination process of activated carbon: The pre-determined activated carbon mass was dissolved in 100 mL of NaCl at varied concentrations (0.5, 1.5, 2.0, and 2.5 ppt). The conductivity of the solution was recorded.

The influence of pH on the desalination process: the fixed factors for the experiment are 100 mL of NaCl solution, the optimal mass of the first experiment, the optimal reaction time of the second experiment, and the optimal concentration of the NaCl solution of the third experiment. Determine the pH of the solution with NaOH and HCl at intervals of 4, 5, 6, 7, and 8. The activated carbon was dissolved in the solution and allowed for reaction. The conductivity of the solution was recorded.

The desalination capacity of raw materials and carbon coal from water hyacinth: desalination capacity between raw materials and carbon coal with activated carbon from water hyacinth was compared. The optimal activated carbon mass, reaction time, NaCl salt concentration, and pH were selected for the experiment. The results were recorded after the reaction was completed.

■ RESULTS AND DISCUSSION

Thermogravimetry Analysis of Raw Materials from Water Hyacinth

The samples were analyzed for TGA under normal atmospheric conditions. The highest temperature was 600 °C, and the temperature rise rate was 10 °C/min as shown in Fig. 1. From the results of TGA, the temperature range that showed a significant change in mass of the water hyacinth stem material is from 300 to 420 °C. At around 300 °C, a large number of substances (e.g., impurities, organic compounds) evaporated and the carbon conversion took place strongly, leading to a large change in the mass in the vicinity. At around 420 °C, mass changes in the vicinity were also observed, yet evaporation and mass loss were less. The results from Fig. 1 show that the suitable temperature for the process of charring raw materials to carbon coal was selected as 420 °C.

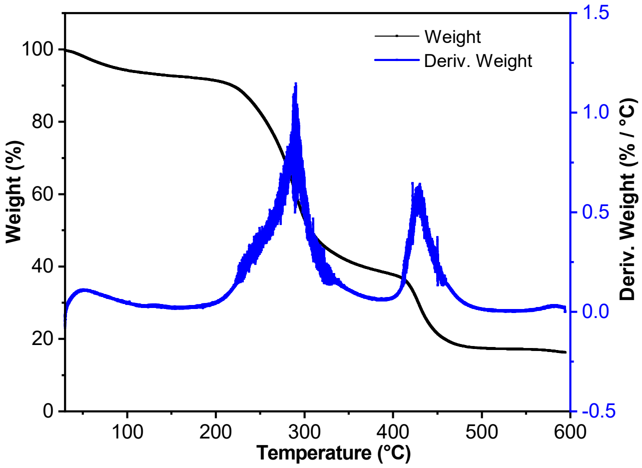

Fig 1. TGA of raw materials

Determination of Morphology and Structure of Activated Carbon from Water Hyacinth

SEM

SEM images were taken at magnification of the sample at two different positions. On the surface of the water hyacinth-activated carbon, the porosity was formed after becoming activated carbon (Fig. 2). In another position, the SEM image has a different structure. The structure on the coal surface is the long sliding grooves (slots) with different shallow depths (Fig. 2(b)). Thus, according to the texture analysis, the pore formation is mainly responsible for surface development. At the magnification of 10,000× (1 μm) in both positions, we were unable to observe the smaller pores, showing that activated carbon is impregnated with 70% KOH solution and activated at 500 °C has created activated carbon with a macropore structure.

BET analysis

The N_2 adsorption analysis was conducted at 300 °C for 2 h. The specific surface area was measured as the ratio between the adsorption equilibrium pressure and the adsorption saturation pressure (P/P_0) within the range from 0.01 to 0.12 with a translational curve on the multipoint plot (Fig. 3). According to the BET results, the specific surface area of the activated carbon sample was found to be 200.4 ± 1.9 (m^2/g).

KOH is the most widely used activator for the production of activated carbon from biomass, as KOH works at a lower activation temperature to form pores. This study has shown that the specific surface area of activated carbon is 3× higher than that reported by Nurhilal [26]. Due to the appropriate impregnation ratio, KOH was better mixed and adsorbed to the carbon sample better.

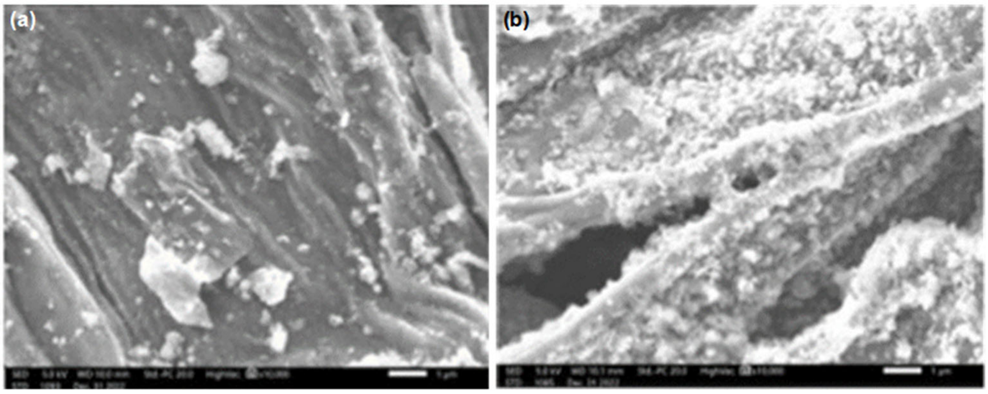

Fig 2. SEM images of the water hyacinth activated carbon at (a) position 1 and (b) position 2

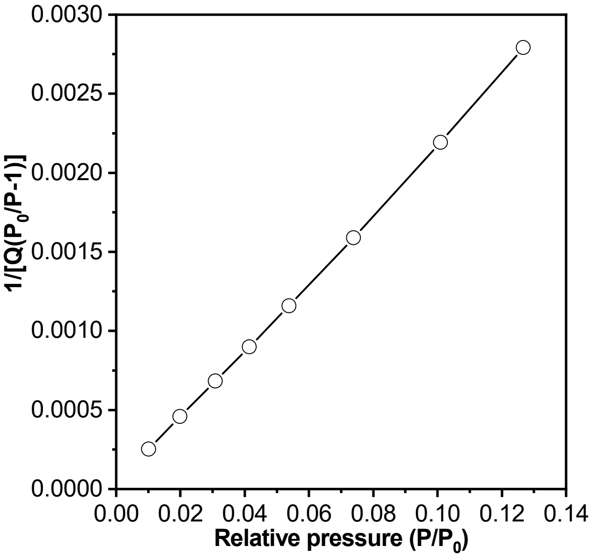

Fig 3. The graph shows the adsorption ratio relative to absolute pressure

Investigation of the Active Desalination Capacity of Water Hyacinth

As can be seen in Fig. 4, the salt adsorption capacity of water hyacinth roots is possible. In both growing conditions under sunlight or shade, the conductivity at each salt concentration decreased, as compared to the original. With water hyacinth grown under sunlight, the salt concentration was most strongly adsorbed at 2.5 ppt salt concentration from the first 7 until 14 d, indicated by the decreasing conductivity from 0.56 to 0.69 mS/cm. With hyacinth cultured in the shade, the salt adsorption was also the most effective at 2.5 ppt, with conductivity being decreased from 0.26 to 0.37 mS/cm within 7 d.

In both culture conditions, the electronegativity and desalination capacity followed the opposite trend under different salt concentrations. The adsorption process takes place effectively when increasing salt concentration under outdoor conditions. Results obtained under the sunlight were better as compared to the shade. This can be explained by the density of ions that exist in the solution and the ambient temperature. With the same volume of solution, the high salt concentration would result in greater ion density in the solution and a larger concentration gradient difference, helping the ion-carrying process to take place more effectively. Upon sunlight exposure, water hyacinth received a greater amount of heat than in the shade, thereby promoting root metabolism and affecting the desalination capacity of water hyacinth [27].

Thus, at a high salt concentration, water hyacinth would absorb salt-causing ions as long as it does not reach the threshold [28].

Investigation of the Factors Affecting the Desalination Process of Activated Carbon

Effect of the activated carbon mass

At the end of the experiment, we found that the conductivity of the solution decreased compared to the original, indicating that the mass of activated carbon affects the desalination process. A total of 0.4 g of activated carbon produces the highest conductivity of 0.367 mS/cm) (Fig. 5). In the presence of NaCl, despite the increased pore area, the adsorption of activated carbon, as well as the bonding force between the surface and the ions, were reduced. When the amount of activated carbon increases excessively, it will promote

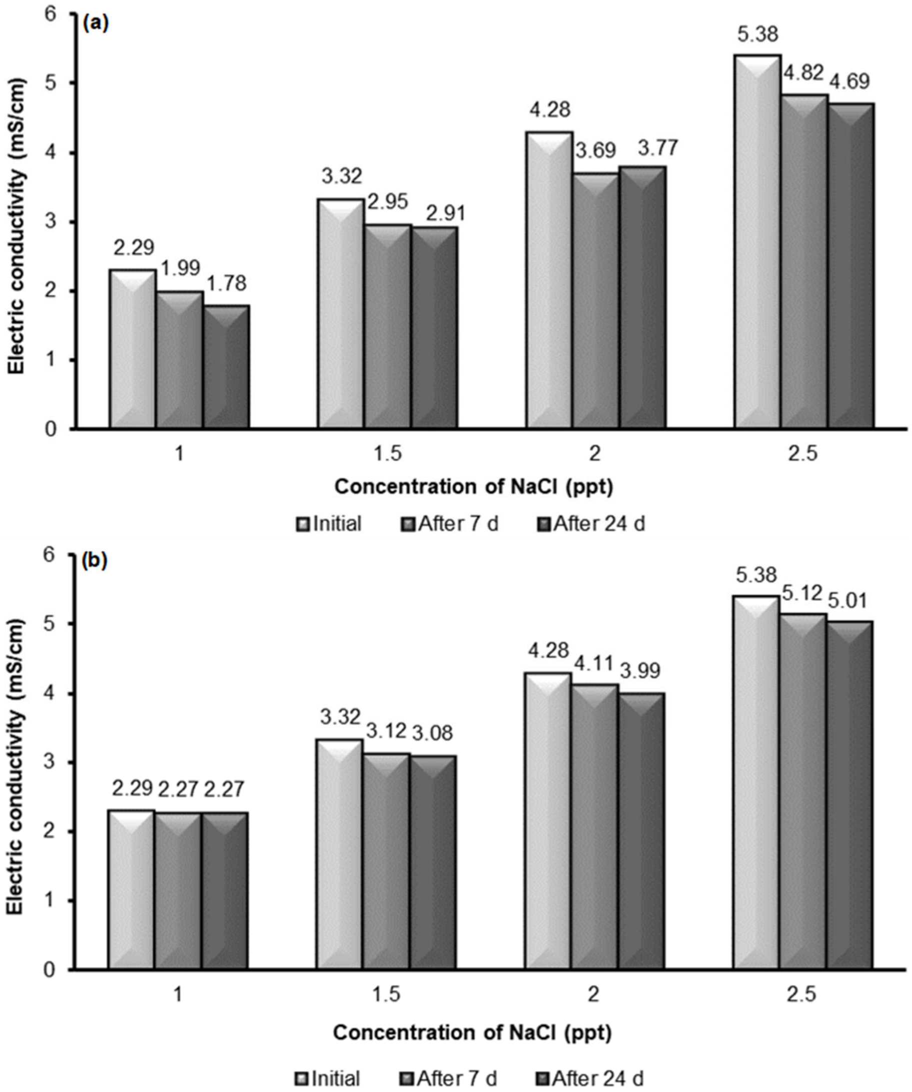

Fig 4. The salt adsorption capacity of water hyacinth in (a) sunlight and (b) shade conditions

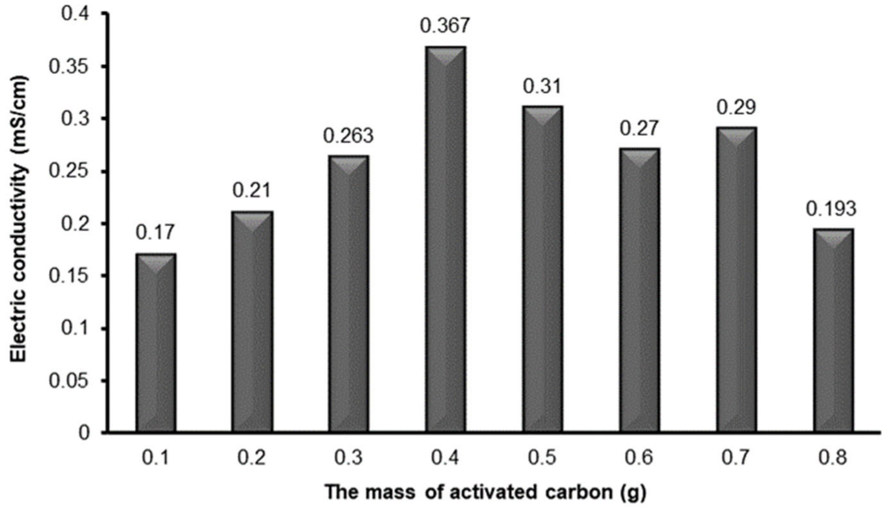

Fig 5. Effect of activated carbon mass on the desalination process

competition for ion adsorption on the coal surface, thus limiting the number of ions adsorbed per unit area. Therefore, the mass of activated carbon of 0.4 g yielded the highest salt absorption ($p < 0.05$), yet increasing the mass would reversely reduce the adsorption capacity. Overall, 0.4 g of activated carbon was selected as the most suitable for subsequent experiments.

Effect of reaction time

The conductivity after 45 min of the experiment was lower than the beginning, thus indicating that the reaction time affects the desalination process. As shown in Fig. 6, the conductivity reached the lowest value of 0.357 mS/cm at 15 min. When the activated carbon is in contact with the solution, the force imbalance occurs on the surface of activated carbon, along with the porous structure on the activated carbon surface. According to the force balance mechanism, the ions in the solution would be drawn into and retained in the pores [29]. The presence of numerous active points on the surface of the coal quickly bonds with ions in the solution, leading to a significant decrease in conductivity. However, the active points saturate at a certain time, the bonding force between the ions and the coal surface weakens, and the ions return to the solution. After obtaining the highest adsorption at about 15 min ($p < 0.05$), the desalination capacity decreases with increasing reaction time. Therefore, 15 min is selected as the most suitable reaction time.

Effect of salt concentrations

Results have shown that different concentrations would yield different conductivity, showing that the concentration of NaCl salt affects the adsorption process of activated carbon. As can be seen in Fig. 7, the adsorption capacity significantly increased at the concentration, from 1 to 2 ppt, then decreased at 2.5 ppt concentration ($p < 0.05$). This can be explained by the fact that when the NaCl concentration increases, the contact between the ions and the coal surface increases, thus increasing adsorption capacity [30]. However, in the presence of high salt concentration, the ions would compete for the adsorption site, which can lead to

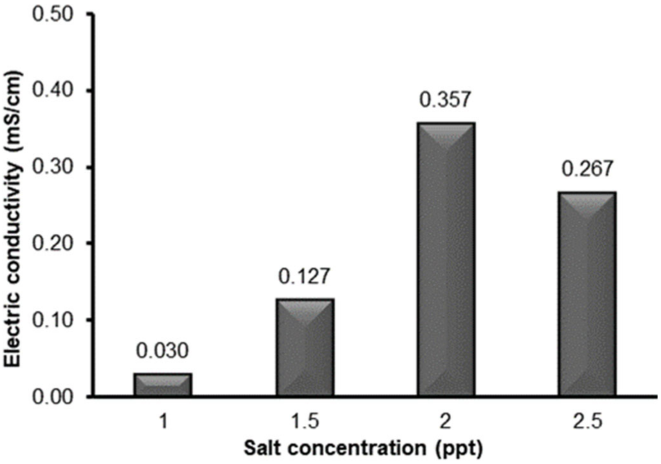

Fig 7. Effect of salt concentration on desalination of active carbon

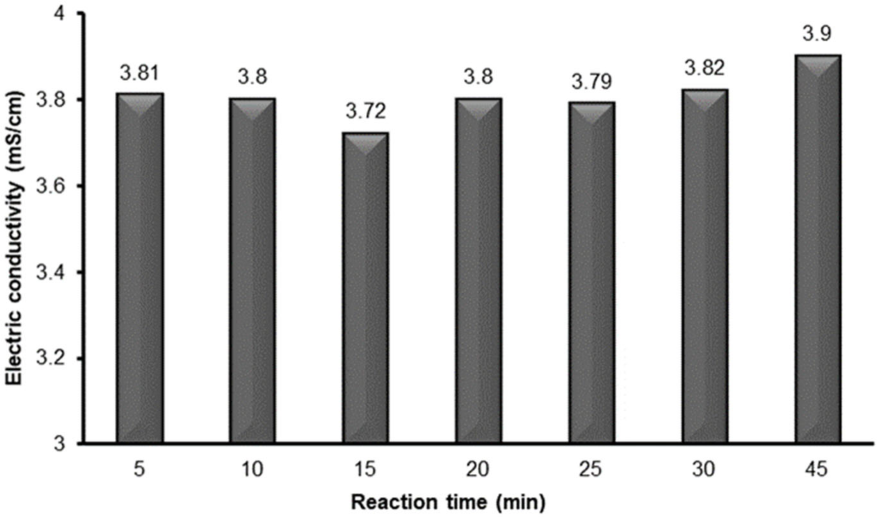

Fig 6. Effect of reaction time on desalination of active carbon

saturation on the activated carbon surface and, hence lowered adsorption capacity [29]. Overall, the NaCl concentration of 2 ppt is the most suitable concentration for subsequent experiments.

Effect of pH

As can be seen in Fig. 8, solution pH also affects the desalination process of activated carbon, in which the lowest conductivity (0.177 mS/cm) was obtained at pH 6. At low pH solutions, many H^+ ions are present in the solution, and the surface of the activated carbon becomes positively charged, thus effectively absorbing Cl^- ions [31]. A large number of H^+ ions on the surface will interfere with and reduce the amount of adsorption for Cl^- ions. In contrast, when the solution pH is increased, activated carbon adsorbs Na^+ ions well, yet similar to low pH, the surface also interfered with and experiences ion competition. Thus, pH 6 is the most suitable pH level for the experiment.

Several studies using water hyacinth as an adsorbent in water treatment have been published. Specifically, Kiridi et al. [32] use water hyacinth in water desalination for agricultural and industrial purposes. The effect is obvious after conducting the experiment on 10 L of brackish water (7.69 ppt salinity), after 3 d the results recorded 0.075 ppt/g/d for salinity. In 2017, Damayanti and Daia [33] created a cellulose acetate membrane in water hyacinth to desalinate seawater into clean water. On the other hand, freshwater hyacinth is remarkably effective in recovering contaminated water without causing negative consequences for the ecosystem [34].

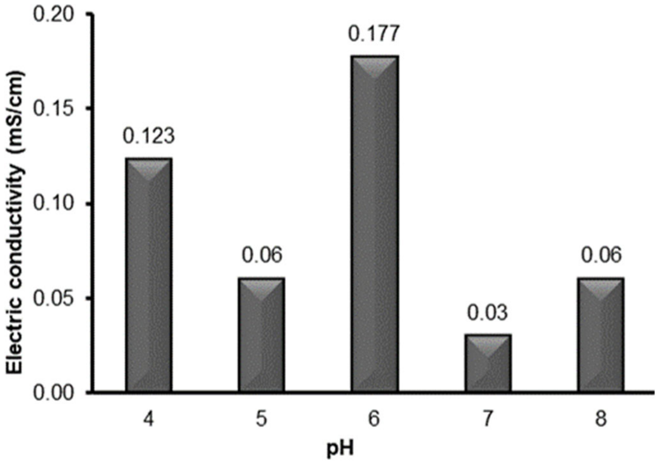

Fig 8. Effect of solution pH on desalination of active carbon

■ CONCLUSION

The present study showed that both raw materials and carbon coal of water hyacinth did not exhibit desalination ability. Upon activation of activated carbon, the desalination ability of the water hyacinth occurred. The most suitable conditions for desalination of activated carbon included 0.4 g of activated carbon mass and 2 ppt of salt concentration at neutral pH for 15 min. For freshwater hyacinths, the desalination capacity depends on the culture conditions and the salt concentration in the solution. The presence of light and increased salt concentration promotes the desalination of freshwater hyacinths, as long as the inhibitory threshold, which is lethal to hyacinths, is achieved.

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■ AUTHOR CONTRIBUTIONS

Van Phuoc Nguyen and Dinh Duy Duong conducted the experiment; Thi Kim Ngan Tran and Huynh Cang Mai conducted the calculations; Van Tan Lam, Thi Tuu Tran, and Long Giang Bach wrote and revised the manuscript. All authors agreed to the final version of this manuscript.

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