Study on the Performance Identification of OpenCV in Cashew Nut Shell-based Activated Carbon

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Abstract. The demand for drinking water treatment in Cambodia is extremely urgent, which poses important obstacles to local construction and development. Activated carbon is a commonly used adsorption material in water treatment. In this experiment, Cambodian cashew nut shells were used as raw materials to prepare activated carbon. The total pore volume, specific surface area, pore size distribution, and micromorphology of the activated carbon were tested. Subsequently, using the characteristics of water exchange with air in activated carbon, OpenCV was used to characterize the pore structure and activity of activated carbon, and a mathematical model was established. The results show that cashew nut shell can successfully prepare activated carbon. OpenCV can be used to analyze the pore structure of activated carbon. The efficiency of OpenCV recognition is 94.3%. The pore size affects the ease of entry of water. When the pore size is less than 7.67 nm, water cannot enter. This study provides a feasible solution for water treatment in Cambodia.

1. Introduction
Cambodia has many rivers and abundant water resources. However, Cambodia is still very short of water, and it has not been able to effectively distribute and supply water for sanitation and grain production because of severe lack of water facilities [1]. Due to water pollution, Cambodian drinking water is used after filtering. Drinking water treatments are not done by large water treatment centers, but by users themselves. The water quality after filtration lacks convenient and effective assessment methods, thus it is easy to cause polluted water to be drunk. Currently, only 35% of the national population, 65% of urban residents and 26% of rural population have access to sanitary and safe drinking water, which in turn has become a major obstacle to Cambodia's construction and development. Activated carbon is a water-treated absorbent material with a porous structure and good adsorption properties that are prepared from high-carbon-containing raw materials [2], and it is convenient for drinkers by treating local drinking water [3].

The preparation methods of activated carbon can be roughly divided into three categories: physical activation methods, chemical activation methods, and physical-chemical combined activation methods [4]. Chemical activation method is an activated carbon preparation method often used in industry. Such chemical agents as ZnCl2, KOH, H3PO4, NaOH, H2SO4 and K2CO3 have been used as activating reagents [4]. Activated carbon is divided into microporous carbon (pore size less than 2 nm), mesoporous carbon (pore size between 2-50 nm) and macroporous carbon (pore size greater than 50 nm) according to the pore size [5]. Microporous carbon is mainly used to adsorb small molecular substances
in the air and liquid phase. Generally, the specific surface area of microporous activated carbon is large; mesoporous carbon has excellent adsorption performance for large molecular substances that cannot be adsorbed and held by micropores. It has great application value in solution decolorization, water treatment, catalysis, super-capacitor preparation, etc.; Compared with the first two types of activated carbon, macroporous activated carbon has weaker adsorption performance and smaller specific surface area, which is mainly used for specific large molecular pigment removal. Nutshell materials such as peanut shells, sunflower seeds and walnut shells are widely used in the preparation of activated carbon. Li Dawei used rice husks as raw materials to prepare a high mesoporous activated carbon with a new process of CO2 activation and lye boiling [6]. Li Shaoni and others used almond shells as raw materials, and used KOH, ZnCl2 and H3PO4 activation-electric furnace boiling process to prepare activated carbon with a mesoporosity of 61% [7].

Cambodia has an abundance of cashew nuts. The cashew nut shell is a solid residue produced during the processing of cashew nuts, which has become a waste during production, with an annual output of about 11 tons. The main chemical component of cashew nut shell is cashew nut shell liquid. The total content of comprehensive cellulose and acid-insoluble lignin in cashew nut shell is 41.81% [8]. The main components of cashew nut shell residue are 11.76% water, 2.04% ash, 34.81% organic extract, 11.20% acid-insoluble lignin, 30.62% synthetic cellulose, and 17.28% polypentose, which are similar to other nutshell main ingredients [8]. Therefore, cashew nut shells have the potential as raw materials for the production of activated carbon.

The efficiency of activated carbon in water treatment is related to the pore structure of activated carbon. The activity of activated carbon is relative with its pore structure. A simple evaluation method is needed to achieve the purpose of quickly evaluating the efficiency of activated carbon. When activated carbon is placed in water, water molecules replace the gas in the pores of the activated carbon. As a result, air bubbles appear in the water. The relevant parameters of activated carbon pores can be correlated with the total volume of air bubbles in water. OpenCV (Open Source Computer Vision Library) is an open source vision and machine learning library containing a complete set of vision algorithms and machine learning [9]. OpenCV can observe and count air bubbles in water, which provides a way to study the pore structure of activated carbon. This paper first used cashew shells as raw materials to prepare activated carbon and studies its pore structure. Subsequently, Open CV was used to perform statistical and data processing on air bubbles generated by activated carbon in water. The data obtained by OpenCV are correlated with the actual experimental results of activated carbon and a mathematical model is established to achieve the purpose of quickly evaluating the efficiency of activated carbon.

2. Experiment of preparing activated carbon from cashew nut shell

2.1. Experimental materials
Purchased from the cashew nut shell of Shangding Province, Cambodia; sodium hydroxide, analytical grade, ≥96.0%, Shanghai test; zinc chloride, analytical grade, Xicang Chemical Co., Ltd.; distilled water, laboratory-made.

2.2. Preparation method
The cashew nut shells were rinsed and thoroughly soak them with NaOH (4 mol / L). After that, the cashew nut shells were rinsed again until pH neutral, then were left to dry and were crushed to 10-40 mesh. Then the samples were calcined in a muffle furnace, the calcination temperature was 800 degrees Celsius, the calcination time was 2 hours, and the heating rate was 20 K / min. After calcination, the cashew nut shells were further subjected to activation treatment, and were rinsed to keep the pH neutral and left to dry.

2.3. Testing method
1) Using BET for nitrogen adsorption test to obtain the specific surface area.
Isothermal adsorption line detection was carried out by ASAP 2020 automatic specific surface area and porosity analyzer produced by Mike Company of the United States. Nitrogen adsorption measurement was performed at 77 K and relative pressure (P / P0) in the range of 10^{-6} ~ 1 with nitrogen as the adsorption medium. Before the measurement, the sample was degassed at 350 °C for 2 h [10]. The specific surface area was calculated using the BET method based on the nitrogen adsorption isotherm; the total pore volume was calculated from the total nitrogen single point adsorption at a relative pressure of 0.995; the micropore pore volume was calculated from the difference between the total pore volume and the medium and large pore volume.

2) Observing the micro-morphology of the sample with SEM.

Scanning electron microscopy was used to analyze the microstructure and pore morphology of coconut shell raw materials and activated carbon. The instrument was a Toshiba S-3400 scanning electron microscope. Prior to observation, the material was sprayed with gold using an E-1010 ion coater.

3) OpenCV image recognition detection

Weigh 5.0 g of the prepared activated carbon sample and place it in a rectangular transparent acrylic open cup, and paste a black background on one side to facilitate the shooting and identification of air bubbles. Place the camera 10 cm from the open cup. Place the activated carbon in the water and start shooting until no bubbles are generated. The computer system crops the captured image into a thin horizontal strip of 900 times 350 pixels. The pictures were binarized and a threshold is chosen. If the data value of the pixel is higher than the threshold, it is then converted into a pure white pixel with a data value of 255; otherwise, it is converted into a pure black pixel with a data value of 0. Each bubble is transformed into a corresponding white outline. Assuming the bubble is a sphere, the shape of the bubble in the picture is circular. Use OpenCV to read the pixel area contained in the outline of each bubble in each frame, and the radius of each bubble was obtained, and the average radius of all bubbles are found. This radius was used to calculate the average rising velocity of the bubble according to Figure 1, and the frame interval N of the video interception was then determined. By taking the picture from the video every N frames to identify the radius of each bubble, the corresponding volume of each bubble is obtained, and the overall bubble volume is obtained.

2.4. Data processing

2.4.1. OpenCV black and white threshold processing. In OpenCV, the API for threshold processing is defined as: cv2.threshold (src, thresh, maxval, type). Among them, src is a single-channel (grayed) original picture, thresh is a threshold value of 0-255, maxval is a fill color of 0-255, and type is a threshold type. The return value is the threshold and the original image after binarization. The type type used in this article is cv2.THRESH_BINARY, that is, the pixel values of pixels whose pixel value is less than the threshold are converted to 0, and the pixel values of pixels whose pixel value is greater than the threshold are converted to maxval. We set maxval to 255. The setting of the threshold is discussed below.

2.4.2. findContours function in OpenCV. The API of the findContours function used in cv2 in this article is defined as:

`cv2.findContours (image, mode, method [, contours [, hierarchy [, offset]]])`. The first parameter image is the image to find the contour; the second parameter mode indicates the retrieval mode of the contour. There are four types. The cv2.RETR_EXTERNAL used in this paper indicates that only the outer contour is detected. The third parameter method is the approximate method of the contour. This paper uses cv2.CHAIN_APPROX_SIMPLE to compress the elements in the horizontal, vertical, and diagonal directions, and retain only the coordinates of the end point of the direction. For example, a rectangular contour only needs 4 points to save the contour information. This function returns two values, the contour itself and the attributes of the contour. The number of contours is the length of the contour value list returned by this function.
2.4.3. **Bubble velocity.** By reading the pixel area contained in the outline of each bubble of each frame, the radius of each bubble is obtained, and the average radius of all bubbles is obtained. With this radius, the average velocity of the bubbles can be calculated according to Figure 1.

![Figure 1. velocity of air bubbles in water](image1)

3. **Results and discussion**

3.1. **Pore structure of activated carbon**

![Figure 2. Pore distribution of activated carbon](image2)
The pore distribution and adsorption-desorption curve of the sample prepared by cashew nut shell are shown in Fig.2 and Fig.3. The specific surface area is 884 $m^2/g$, the total pore volume is 1.39 $cm^3/g$, the micropore volume is 0.21 $cm^3/g$, the mesopore volume is 0.98 $cm^3/g$. In the process of activated carbon adsorption, micropores play a dominant role, which determines the amount of activated carbon adsorption. Mesopores play an important role in the adsorption of macromolecular pollutants. Capillary condensation occurs under a certain pressure and can also be used as a channel for adsorbing molecules. Macropores are generally used as channels to allow the adsorbate to enter the micro/mesopores inside the activated carbon. Generally speaking, the specific surface area of activated carbon for water treatment is more than 800 $m^2/g$, so the preparation process used in this experiment can successfully prepare activated carbon for water treatment[19]. According to the pore size distribution curve of the activated carbon in Fig. 2, the cashew nut shell activated carbon has a large pore volume between 0. nm and 5. nm. Cashew nut shell activated carbon is largest in its mesopore volume, with a distribution range of 20. nm-80. nm. Therefore, the cashew nut shell activated carbon has a high mesoporosity. According to the classification of IUPAC, the nitrogen adsorption-desorption isotherm curve of cashew nut shell activated carbon belongs to the model of IV (a) in Fig. 3. When the relative pressure is low ($P / P_0 <0.1$), the nitrogen adsorption curve of cashew nut shell activated carbon rises rapidly, and microporous filling mainly occurs in this section, indicating that cashew nut shell activated carbon contains a certain number of microporous structures. As the pressure increases ($P / P_0 = 0.1 \sim 0.3$), the curve gradually deviates from the Y-axis and rises slowly, indicating that the micropore pore size distribution range of the activated carbon is relatively wide and contains a narrow mesoporous structure (less than 2.5 nm). As the relative pressure continues to increase ($P / P_0 > 0.4$), the amount of nitrogen adsorbed by the activated carbon remained basically unchanged and an adsorption platform appears. When the relative pressure is large, the nitrogen adsorption and desorption curve gradually deviates and a hysteresis loop appears, indicating that the cashew nut shell activated carbon is rich in mesoporous structure.
Figure 4. SEM images of (a) surface pores of cashew nut shell activated carbon and (b) pore channels of cashew nut shell activated carbon

Fig. 4 (a) and Fig. 4 (b) show the surface morphology of cashew nut shell activated carbon samples. Fig. 4 (a) shows the surface pores of cashew nut shell activated carbon, which has a dense structure and a smooth surface. We observed oval pores with a long diameter of 3.3 μm and a short diameter of 1.0 μm that were arranged in a parallel structure. Fig. 4 (b) shows the circular pore channels of activated carbon. The direction of the pore channels is perpendicular to the direction of long diameter of the oval pores. The inner surface of pore channels is smooth without obvious cracks and defects. SEM observation shows that the pore structure of the activated carbon is composed of circular channels and oval pores on the surface.

3.2. OpenCV test

This paper makes the following three assumptions: 1) Each bubble is a sphere, which becomes a circle in a two-dimensional picture; 2) The radius and volume of the bubble will not change when the bubbles rise; 3) Since the velocity of the bubbles are all different, the video can capture all the bubbles. It is determined by preliminary tests that the air and water replacement process in the pores of the activated carbon is divided into three phases: i) an active period in which large number of bubbles are generated ii) a deceleration period in which the rate of bubble generation is slowed iii) a stationary period in which bubbles are very slowly generated. The entire process of activated carbon reaction consists of three videos, video 1 is the active period, video 2 is the deceleration period, and video 3 is the stationary period. The threshold combination of different videos has a significant impact on the experimental results. This paper analyzes the threshold of each video separately. The orthogonal table is used to study the best selection results of the three video thresholds. The selection of the threshold involved in this experiment should meet the following conditions: 1) the ratio of the number of bubbles recognized by the machine to the number of bubbles in the original image is 1.00 ± 0.05; 2) for the same bubble, the ratio of pixel area of the bubbles recognized by the machine to the pixels of the original bubble area is 1.00 ± 0.05;

   Through preliminary testing, three different thresholds were determined for each video. Video 1 corresponds to threshold 1, and its levels are 160, 165, 170. Video 2 corresponds to threshold 2, and its levels are 155, 160, 165. Video 3 corresponds to threshold 3, and its levels are 150, 155, 160. The orthogonal factors are shown in Table 2. According to the factors in Table 1, design L9 (3^3) orthogonal experiment. The results are shown in Table 2.
Table 1. Orthogonal test factors and levels

| No. | Threshold 1 | Threshold 2 | Threshold 3 |
|-----|-------------|-------------|-------------|
| 1   | 160         | 155         | 150         |
| 2   | 165         | 160         | 155         |
| 3   | 170         | 165         | 160         |

Table 2. Result of L9 (33) orthogonal experiment

| No. | Threshold 1 | Threshold 2 | Threshold 3 | Volume Difference/ cm³ · g⁻¹ |
|-----|-------------|-------------|-------------|-----------------------------|
| 1   | 160         | 155         | 150         | 0.102610525                |
| 2   | 160         | 160         | 155         | 0.091264107                |
| 3   | 165         | 165         | 150         | 0.191601676                |
| 4   | 165         | 155         | 155         | 0.079899125                |
| 5   | 165         | 160         | 150         | 0.279727063                |
| 6   | 165         | 165         | 150         | 0.19727063                 |
| 7   | 170         | 155         | 160         | 0.44015355                 |
| 8   | 170         | 160         | 150         | 0.389660555                |
| 9   | 170         | 165         | 155         | 0.409912107                |
| K1  | 0.128492103 | 0.207554383 | 0.229847237 |
| K2  | 0.185632273 | 0.253550575 | 0.19369178  |
| K3  | 0.413242054 | 0.266261471 | 0.303827413 |
| R   | 0.284749951 | 0.058707088 | 0.110135633 |

The absolute value of the difference between the bubble volume measured by OpenCV and the total pore volume measured by the BET test is the main investigation indicator. From the range R, the influence order of each factor on OpenCV recognition is: threshold 1 > threshold 3 > threshold 2. The smaller the K value, the more accurate the result. The optimal threshold combination is determined based on the minimum value of K at each level: the active period threshold is 160, the deceleration period threshold is 155, and the static period threshold is 155. Fig. 5 (a), Fig. 5 (c) and Fig. 5 (e) are the pictures of the rising bubbles captured in the active period, deceleration period and stationary period, respectively. Figures 5 (b), 5 (d), and 5 (f) are the images after black and white processing using the optimal threshold combination in Figures 5 (a), 5 (c), and 5 (e), respectively. And presented as a white pixel grid. This procedure processed about 210,000 images. Comparing the results before and after the processing in FIG. 5, it shows that the threshold combination can most accurately identify the bubbles in the video.

Figure 5. Bubble rise in active period

In order to further evaluate the efficiency and widen the application of the OpenCV test, the cashew nut shell activated carbon sample was tested for its total bubble volume V1 and total pore volume V, where its efficiency C can be characterized by the ratio of V1 and V, as shown in Equation 1: Efficiency C = total bubble volume V1 / total pore volume V. Water as the carrier of the adsorbent can exchange with the air in the pores of the activated carbon. The water molecules replace the air in the pores of the
activated carbon. The air escapes the activated carbon in the form of bubbles, enters the external water and is captured by the camera. Therefore, the total volume $V_1$ of air bubbles in the water is equal to the volume of the activated carbon pores replaced by water. Efficiency $C$ therefore also evaluates the amount of pores in which the activated carbon can be replaced by water. The air in the pores of activated carbon cannot be completely replaced by water, which is related to the pore size distribution. In theory, there is a certain pore size $M$. When the pore size is less than $M$, water molecules cannot enter the pore. When the pore size is greater than $M$, water molecules can completely occupy the volume in the pore and replace air. Therefore, the volume measured by OpenCV corresponds to the area under the curve where the pore size distribution is larger than $M$. The pore distribution graph is printed and the sheet is cropped into two parts, each part corresponding to a continuous interval of the area under the curve. The parts are weighed so that the two pieces have a mass ratio $C = m_1 / m_2$, $m_1$ is the weight of the paper sheet corresponding to the graph where the pore size is greater than $M$, and $m_2$ is the weight of the paper sheet corresponding to the graph where the pore size is less than $M$. Because the paper density is the same, the ratio of the weight of the paper is the ratio of the area under the curve. The result of the calculation is shown in Fig.6

![Figure 6. Result of M value calculation](image)

In the result shown in Fig. 6, $V_1$ is measured to be 1.31 cm$^3$/g, and $V$ is 1.39 cm$^3$/g, thus the value of $C$ is 0.943. According to the calculation method of $M$ above, the pore distribution graph is printed and the sheet is cropped and weighed so that the two pieces have a mass ratio equal to $C$. As shown in Fig. 6, the mass of area A is 0.087g, and the mass of B is 1.336g. The area of A represents the volume of pore size from 0. nm-7.67 nm, and the area of B represents the volume of pore size from 7.67 nm-200 nm. Therefore, the $M$ value is 7.67 nm, meaning that when the pore size is less than 7.67nm, the water molecules cannot enter such pores.

4. Conclusion
Cashew nut shells can be used to prepare activated carbon that meets market water treatment needs, and has high economic transformation potential. Its technology needs further study. OpenCV, as a new machine identification method, has been successfully applied to the identification of activated carbon quality. According to the recognition results of OpenCV, the pore structure of activated carbon can be divided into large pores accessible by water and small pores inaccessible by water according to the $M$ value. For water treatment applications, impurities dissolved in water and successful entry into the pores of activated carbon are a prerequisite for successful removal of impurities. Therefore, under the condition of the same specific surface area, the smaller the $M$ value, the more favorable the activated
carbon is for water treatment. This is of great significance for the rapid evaluation of the effectiveness of activated carbon in water treatment applications. The conclusion can be summed up as the following:

(1) When the calcination temperature is 800 ° C, the calcination time is 2 hours, and the heating rate is 20K / min, an activated carbon having a specific surface area of 884 m²/g and a total pore volume of 1.39 cm³/g.

(2) The OpenCV test activated carbon efficiency C is 94.3%, and the minimum pore size M through which water can enter is 7.67 nm.

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