Method Article

Analysis using image segmentation for the elemental composition of activated carbon

Mohammed Danish\textsuperscript{a}, Mohammad Nishat Akhtar\textsuperscript{b}, Rokiah Hashim\textsuperscript{c}, Junita Mohamad Saleh\textsuperscript{d}, Elmi Abu Bakar\textsuperscript{b,∗}

\textsuperscript{a}Universiti Kuala Lumpur Malaysian Institute of Chemical and Bioengineering Technology (MICET), Lot 1988, Kawasan Perindustrian Bandar Vendor, Taboh Naning, 78000 Alor Gajah, Melaka, Malaysia
\textsuperscript{b}School of Aerospace Engineering, Universiti Sains Malaysia, Nibong Tebal, Penang 14300, Malaysia
\textsuperscript{c}School of Industrial Technology, Universiti Sains Malaysia, Penang 11700, Pulau Pinang, Malaysia
\textsuperscript{d}School of Electrical Engineering, Universiti Sains Malaysia, Nibong Tebal, Penang 14300, Malaysia

\textbf{A B S T R A C T}

This article encompasses the method related to image segmentation of the Field Emission Scanning Electron Microscope (FESEM) images of Acacia Mangium Wood derived Activated Carbons under different conditions. Image segmentation using Hue-Saturation-Value (HSV) thresholding method was adapted to identify the different pattern composition in the grayscale images by varying the intensity Value (V) and keeping Hue (H) and Saturation (S) to zero, and each pattern was considered as one type of element that constituted the Activated Carbon. The algorithm was developed to compute the percentage of each pattern using non-zero pixels, and on the basis different patterns, different elements having certain percentage of composition were recorded. Later, these results were compared with the Energy Dispersive X-ray Spectroscopy (EDS) to cross check the difference in percentage of each element present at the surface of the Activated Carbon. Part of this result is published in the article [1]. “Comparison of surface properties of wood biomass Activated Carbons and their application against rhodamine B and methylene blue dye” Surfaces and Interfaces vol. 11 (2018) pp1–13.

- The methods involved will be useful for characterization of Activated Carbon materials.
- Image segmentation using HSV thresholding will inspire other researchers to apply similar concept on other materials.
- Different patterns obtained for FESEM images using HSV thresholding was able to determine the presence of multiple elements present in the prepared Activated Carbon samples.

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* Corresponding author.
E-mail address: meelmidr@gmail.com (E.A. Bakar).

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Specifications Table

| Subject Area | Chemistry |
|--------------|-----------|
| More specific subject area: | Materials Chemistry |
| Method name: | HSV Thresholding |
| Name and reference of original method | HSV thresholding is derived from Otsu’s Thresholding: Ref: Otsu N. A threshold selection method from grey-level histograms. IEEE Trans. Syst. Man. Cybern. 1979;9:62–66. doi: 10.1109/TSMC.1979.4310076. [CrossRef] [Google Scholar] |
| Resource availability | OpenCV (Image Processing Library) |
| | https://github.com/opencv/opencv |
| C++ Source Code: | https://github.com/nishatakhtar/HSV-thresholding-for-FESEM- |

*Method details*

The technique implied to obtain the data using image thresholding using Hue-Saturation-Value (HSV) colour space could possibly provide a new corridor for research collaboration in those entire field where image analysis is used to determine the unique multiple component in an image which plays a vital role. The hue (H) component of any colour represents its similarity to any of the pure colour. The correspondence of any pure colour to any of the H component is denoted by a function value between zero and one as described in Fig. 1 which shows the single hexcone model to visualize the HSV values. The saturation (S) component of any colour shows the non-white element present in it. It is worth to be noted from colour wheel in Fig. 1 that for white colour, the value of $S = 0$. The

![Fig. 1. Single hexcone colour model for HSV.](image-url)
value of $S$ increases as it moves towards red colour. The value ($V$) component of any colour shows the lightness and darkness in any colour. It is to be noted from colour wheel in Fig. 1, that the black colour has $V = 0$ and as the value of $V$ increases, lighter colours could be mapped. The equivalence for the value of HSV in terms of Red-Green-Brown (RGB) colour varies from 0 to 255°.

**Experimental design, materials and methods**

*Activated carbon sample preparation*

The *Acacia Mangium* Wood were collected from the Main Campus of Universiti Sains Malaysia. The wood logs were cut into small cubical chips of uniform size with the help of electrical saw and then dried up at 105 °C for 12 h in hot air oven. The dried cubical chips were ground into smaller particles, then sieved with sieve size 0.50 mm and 1.00 mm to ensure the uniform size of the *Acacia Mangium* Wood particles. The uniform size of the *Acacia Mangium* Wood particles were used to convert it into Activated Carbon using selected activating agents such as, $\text{H}_3\text{PO}_4$, $\text{ZnCl}_2$, KOH, and CaO in the absence of any external gaseous atmosphere. The Impregnation Ratio (IR) was kept fixed at 0.5 for each activating agent utilized in this research. The IR was defined as the weight ratio of chemical activating agent and Raw *Acacia Mangium* Wood particles. All chemical activating agents are in the form of solid except for $\text{H}_3\text{PO}_4$ (85% purity) which is in liquid form. Hence, for $\text{H}_3\text{PO}_4$, the dry mass was calculated by using mass, volume, and density formula. Then the mass ratio of $\text{H}_3\text{PO}_4$ and Raw *Acacia Mangium* Wood particles were represented in grams of $\text{H}_3\text{PO}_4$ per gram of dry raw material and moreover, similar method was used by Diao et al. [2]. The prepared mix was soaked at 90 °C inside hot air oven and then the soaked mix was subjected to activation at 500 °C in muffle furnace which finally lead to the formation of Activated Carbon. The complete preparation method is represented in the given block diagram (Fig. 2).
Table 1

| Sample | Activation atmosphere | Chemical treatment | IR | Activation temp. (°C) | Time (h) |
|--------|-----------------------|--------------------|----|-----------------------|----------|
| AM01   | Self-burn gas         | N.T.*              | -  | 500                   | 2        |
| AM04   | Self-burn gas         | H₃PO₄              | 0.5| 500                   | 2        |
| AM07   | Self-burn gas         | ZnCl₂              | 0.5| 500                   | 2        |
| AM10   | Self-burn gas         | KOH                | 0.5| 500                   | 2        |
| AM13   | Self-burn gas         | CaO                | 0.5| 500                   | 2        |

*N.T. No chemical treatment.

Table 1 represents the experimental variables used in this study for the conversion of *Acacia Mangium* Wood into Activated Carbons by changing chemical activating agents. Total five samples were prepared for a similar activation process in the existence of self-burnt gaseous atmosphere. The muffle furnace used for the self-burnt gaseous atmosphere was made up of Gotech (Model: GT-MF; Gotech Testing Machines Inc. Taiwan).

Image analysis method

The investigation has been performed on Intel® Core™ i7–2600 CPU @ 3.40 GHz with 8.00 GB RAM and 64-bit OS. In order to investigate the set of Field Emission Scanning Electron Microscope (FESEM) images using the HSV colorspace, Open Source Computer Vision (OpenCV) has been utilized. It is worth to be noted that OpenCV comprises of numerous image processing set of libraries. The OpenCV library has 2500 upgraded calculations in which there are exemplary and cutting edge machine learning and computer vision based calculations. It has Java, MATLAB, Python, C++ and C interfaces with backing of Windows, Linux, Android and Mac OS.

For the analysis of FESEM images, thresholding has been utilized at numerous dimensions. Thresholding is viewed as an essential strategy for the segmentation of images. As per Otsu’s thresholding algorithm [3], an image is a 2D grey scale intensity function which consists of $N$ pixels inclusive of grey levels ranging from 1 to $L$. For the examination of bi-level thresholding, the pixels could be partitioned into two classes $C_1$ and $C_2$, separately. $C_1$ comprises of first level of dark dimension ($I_{......,t}$) and $C_2$ consists of second level of dim dimension ($t + 1_{......,L}$).

For the proposed experiment, the significant task was to segregate the foreground and the background pixels with high precision tuning on the basis of different distribution of patterns. Let’s say in the HSV colour space for the boundary condition $[(0.1,0.1,0.255)] \in \{\text{Hue}_{\text{input}}, \text{Sat}_{\text{input}}, \text{Val}_{\text{input}}\}$, the region of interest (ROI) be a specific tuned colour object. Then, the threshold pairs ($\text{Hue}_{\text{lower}},\text{Hue}_{\text{upper}}$), ($\text{Sat}_{\text{lower}}, \text{Sat}_{\text{upper}}$) and ($\text{Val}_{\text{lower}}, \text{Val}_{\text{upper}}$) could be determined to form a binary image from an HSV colour image input such that:

$$
C(x, y) = \begin{cases} 
1, & \text{Hue}_{\text{lower}} \leq \text{Hue}_{\text{input}}(x, y) \leq \text{Hue}_{\text{upper}} \\
\text{Sat}_{\text{lower}} \leq \text{Sat}_{\text{input}}(x, y) \leq \text{Sat}_{\text{upper}} \\
\text{Val}_{\text{lower}} \leq \text{Val}_{\text{input}}(x, y) \leq \text{Val}_{\text{upper}} \\
0, & \text{Otherwise} 
\end{cases} \tag{1}
$$

Where $C(x,y)$ is the segmented part. The Eq. (1) illustrates that if the HSV values for the pixels of the input image lies within the range of lower bound to upper bound values, then its associated output pixel belongs to class object 1, otherwise it gets designated to null (0).

Fig. 3 shows the original input FESEM images to be processed. The images processed using HSV image thresholding are represented in Fig. 4, and the composition of different patterns obtained in the FESEM images are represented in the Table 2. The input FESEM images and the processed FESEM images have been included in supplementary file. The Energy Dispersive X-ray Spectroscopy (EDS) output are represented in Fig. 5, and percentage of the surface elemental composition are represented in Table 3.
**Fig. 3.** FESEM images of *Acacia Mangium* Wood Activated Carbon.
Fig. 4. Processed images of *Acacia Mangium* Wood Activated Carbon.
Table 2
The percentage of different patterns of colors in FESEM images identified through HSV thresholding (N.Z.P = count of non-zero pixel).

| Raw Acacia Mangium Wood (RAMW) | Pattern 1 (Carbon) | Pattern 2 (Oxygen) | Pattern 3 | Pattern 4 |
|--------------------------------|--------------------|--------------------|-----------|-----------|
| HSV Thresholding | | | | |
| AM01 | Pattern 1 (Carbon) | Pattern 2 (Oxygen) | Pattern 3 (Potassium) | Pattern 4 |
| AM04 | Pattern 2 (Oxygen) | Pattern 3 (Potassium) | Pattern 4 |
| AM07 | Pattern 1 (Carbon) | Pattern 2 (Oxygen) | Pattern 3 (Zinc) | Pattern 4 (Chlorine) |
| AM10 | Pattern 2 (Oxygen) | Pattern 3 (Potassium) | Pattern 4 (Phosphorus) |

Table 3
Image analysis using EDX spectroscopy.

| Raw Acacia Mangium Wood (RAMW) | Carbon | Oxygen | Nitrogen | Potassium |
|--------------------------------|--------|--------|----------|-----------|
| EDX analysis | 51.75 | 48.25 | – | – |
| AM01 | Carbon | Oxygen | Potassium | Nitrogen |
| AM04 | Oxygen | Phosphorous | – |
| EDX analysis | 76.22% | 17.80% | 5.98% | – |
| AM07 | Carbon | Oxygen | Zinc (Zn) | Chlorine (Cl) |
| EDX analysis | 76.64% | 14.91% | 7.08% | 1.36% |
| AM10 | Carbon | Oxygen | Potassium (K) | Phosphorus (P) |
| EDX analysis | 54.31% | 17.92% | 22.19% | 5.58% |
| AM13 | Carbon | Oxygen | Chlorine (Cl) | Calcium (Ca) |
| EDX analysis | 74.72% | 18.89% | 2.15% | 4.24% |

It is to be noted that the elemental analysis of Activated Carbon samples was done on the basis of numerous pattern(s) where the variation of V value has been done and the value of H and S has been kept set at zero, as there was no presence of Hue and Saturation component in the FESEM input grayscale images. The Flowchart in Fig. 6 illustrates the image segmentation process in the HSV colour space. The input image could either be taken as RGB (Red, Green, Blue) or grey-scale format. The setting up of OpenCV is done using GitHub (https://github.com/opencv/opencv).

Some of the active collaborations in which the similar method of image analysis is performed are as follows:

1. Warm-mix Asphalt study i.e., to analyse the adhesion failure of warm-mix asphalt [4,5].
Fig. 5. EDS spectrum of the Acacia Mangium Wood Activated Carbon prepared with different activating agents.

2. To segment bulk input images for pattern classification using Hadoop framework i.e., to perform image segmentation to analyse different patterns [6,7].

Supplementary material and/or Additional information

Source code for HSV thresholding for FESEM

Declaration of Competing Interests

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.

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FESEM input image in RGB

Start

Define the resolution of the input image shown in Phase 2 of C++ code

Set the resolution of the FESEM input image shown in Phase 5 of C++ code

Trackbar setting and formation for Hue\textsubscript{upper}, Hue\textsubscript{lower}, Sat\textsubscript{upper}, Sat\textsubscript{lower}, Val\textsubscript{upper}, Val\textsubscript{lower}

Output the value of non-zero pixels and display the threshold image shown in Phase 7 of C++ code

Iterate over Hue\textsubscript{upper}, Hue\textsubscript{lower}, Sat\textsubscript{upper}, Sat\textsubscript{lower}, Val\textsubscript{upper}, Val\textsubscript{lower} to find different patterns shown in Phase 5 of C++ code

Compute non-zero pixels for each pattern obtained at different value of H,S and V shown in Phase 6 of C++ code

Convert the input image to HSV color space shown in Phase 5 of C++ code

Define the resolution of the input image shown in Phase 2 of C++ code

Stop

Fig. 6. Flowchart for the analysis of FESEM images.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.mex.2020.100983.

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