

Chapter 4

Optimization and Characterization Study of Preparation Factors of Activated Carbon Derived from Coconut shell to Remove of H₂S from Wastewater

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ABSTRACT

The main point of this work is to investigate the preparations variables of activated carbon derived from coconut shell (CSAC) for removal of hydrogen sulfide (H₂S) from wastewater. The CSAC was chemically modified with potassium hydroxide (KOH). The central composite design (CCD) under response surface methodology (RSM) was employed to prepare the CSAC. The three preparation variables impact on the removal efficiency (%) of H₂S were examined. The preparation parameters to the responses were correlated by developing a quadratic model. The analysis of variance shows the significant impact of variable on each experimental design responses. The results show that the temperature of 857°C, chemical impregnation ratio of 3.4 wt% and activation time of 66 min were the optimum conditions for CSAC preparation of with removal efficiency of 88.8%.

Key Words: Coconut shell, Activated carbon, wastewater, hydrogen sulfide, Response surface methodology.

1.0 INTRODUCTION

Hydrogen sulfide (H₂S) is a very toxic and dangerous gas. There are many sources that contributed to the emission of H₂S to the environment. The petroleum refinery is considered as the main source contributor of H₂S. It is produced during the processing of crude oil to useful product. The crude oil normally contains sulfur component and to remove the sulfur, process

such as desulfurization, liquefied petroleum gases and distillation units in used in the crude oil refinery. Therefore, these processing procedures will generate many wastes which are dissolved inevitably in the water to produce hazardous sour water which consist of H_2S . Hence, it is a must the water to be treated before being discharge for reuse or discard to swamp (Kazmierczak-Razna *et al.* 2015). There are many methods to remove H_2S from wastewater, such as biological, chemical and physiochemical (adsorption) methods (Siefers *et al.* 2010). Amongst these methods, adsorption is the most effective method due to its excellent performance and low cost (Foo and Hameed 2010).

Activated carbons (ACs) from agricultural wastes, such as date stones (Sekirifa *et al.* 2013), sugar canes (Castro *et al.* 2000), nut shell (Hu and Vansant 1995), coconut shell (Yang *et al.* 2010), and sunflower straw (Foo and Hameed 2011) are the most widely used to remove the different types of pollutants from wastewater. ACs have large adsorption capacity due to its great permeability and large surface area which is created during the activation of carbonaceous substances and carbonization. ACs are commonly used in industries as well. The two common forms of ACs are granular forms with sizes ranging from 0.5 to 2.5mm to be used in adsorption and columns, while powder forms with a size predominantly less than 0.15 mm to be used in batch adsorption followed by filtration (Allen and Koumanova 2005) ; (Dabrowski *et al.* 2005). Adsorption using ACs has been reported to be an effective method for the removal of pollutants from water and air (Bansal and Goyal 2005). Availability, cost, low inorganic matter content, low degradation during storage and ease of activation are the criteria needed to be considered in the selection of the precursors (Dabrowski *et al.* 2005). Physical and chemical activation methods are normally used for activation of chosen precursor. Physical activation is used to activate the precursor to enhance the porosity, surface area and surface chemistry of materials. It consist of two steps: thermal carbonization and activation. The carbonization process of raw materials under high temperature is to increase the carbon content and reduced the other component in the materials used. The activation process is conducted under gasified with an oxidizing agent such as steam or carbon dioxide to enhance the porosity, surface area and functional groups on the carbon surfaces. Chemical activation is done by chemical agents such as alkaline hydroxides, zinc chloride, or phosphoric acid, and followed by carbonization under inert gas and high temperature. The impregnated product must be washed to remove excess chemical agent (Zhang, Shao, and Karanfil 2010). The chemical nature of ACs surface is very important to determine the textural properties and of the adsorption capacity ACs. The activated carbon surface is heterogeneous, consisting multiple faces/edges and layers of

graphite sheets. The located some of elements such as halogen hydrogen, nitrogen, and particularly oxygen on the edges are consisted of the chemisorbed foreign heteroatom (El-Sayed and Bandosz 2004). In the interior of the graphite sheets, the edge sites seem to be more reactive than the residing atoms. There are many processes that forms of surface chemical functional groups such as the activation process of precursor like heat treatment and chemical treatment (Moreno-Castilla 2004) ; (Derylo-Marczewska *et al.* 2008). There are two categories of surface functional groups. First, basic groups consisting of pyrone, chromene, ethers and carbonyls (Boehm 1994). Second, acidic groups which are mainly consisting of carboxylic, lactones and phenols.

Moreover, the caustic carbon surface could help to immobilize the H₂S species on the adsorbent surface and would allow for greater removal efficiency due to the H₂S is acidic. The caustic materials such as NaOH or KOH is capable to improve the pH level of the carbon surface which result an attractive adsorbent toward H₂S. In this study, the preparation factors of ACs produced from coconut shell are investigated. The design of experiment is implemented to optimize the preparations factors of ACs to remove of H₂S from wastewater. All the activities of experimental planning, conducting experiments, and fitting models to the out puts responses are involved in this method. Response surface methodology (RSM) is the useful tool for optimizing the factors using center composite design (CCD). The objectives on this work are to investigate the optimum preparation factors conditions needed to maximize the removal efficiency (RE) (%) to remove dissolved H₂S from wastewater.

2.0 METHODS AND MATERIALS

2.1. Preparation of activated carbon

Coconut shell is used to produce CSAC. The details of raw material preparation method of precursors are detailed in our previous work (Habeeb *et al.*, 2016). In this study, the precursor was activated with KOH at different temperature and time with a constant heating rate of 10 °C/min. The KOH to precursor ratio was varied from 2:1 - 4:1. The precursor was blended with KOH at different fertilization proportion (IR), using equation (1):

$$IR = \frac{W_{KOH}}{W_c} \quad (1)$$

Where, W_{KOH} is the weight (g) of KOH pallets and W_C is the weight (g) of precursor.

The procedures for activation process are explained in details in our previous study (Omar Abed Habeeb, Ramesh Kanthasamy, Gomaa A.M. Ali and Yunus 2017). After activation process, the samples are rinsed with hot distillate water and 1.0 M hydrochloric acid until the pH of the washing solution achieved 6–7. The preparation factors ranges are shown in Table 1.

2.2. Modeling and optimization

2.2.1. Experiment design

Response surface methodology (RSM) is an accumulation of numerical and statistical methods that are important for illustrating, examination, demonstrating and investigation of problems in which a response of interest effected by a couple factors (Montgomery 2001). Central composite design (CCD), three-level factorial design and Box–Behnken design are considered the several classes of designs under RSM and they are the most common designs utilized by the scholars. However, in current study the CCD was employed to study optimization and the effect of factors toward their responses(Montgomery 2001). This method is suitable for fitting a quadratic surface and it spreads to enhance the influential parameters with a minimum number of experiments as well as examine the association between the parameters. The three parameters investigated were the activation temperatures (T), mass ratio of KOH to Precursor (IR) and the duration of time activation (t) and their related extends were 724– 1000 °C, 2:1– 4:1 and 60-120 min, respectively with response of removal efficiency.

The residual error was estimated by replicating the central point and based on the extend of each elements (factor), the independent factors are coded to the (-1, 1) interval. The different levels, that is to say, high and low, are coded +1 and -1 separately. The axial points are situated at (0, 0, ±α), (±α, 0, 0), (0, ±α, 0), what makes the design rotatable is the α which represents the axial point from the center. In order to set up an empirical model the responses were used which in turn correlate the responses to three preparation elements using a second degree polynomial equation as given by equation (2) (Zainudin et al. 2005):

$$Y = b_o + \sum_{i=1}^n b_i x_i + \left(\sum_{i=1}^n b_{ii} x_i^2 \right) + \sum_{i=1}^{n-1} \sum_{j=i+1}^n b_{ij} x_i x_j \quad (2)$$

where Y is the predicted response, b_0 the constant coefficient, b_i the linear coefficients, b_{ij} the interaction coefficients, b_{ii} the quadratic coefficients and x_i, x_j are the coded values of the activated carbon preparation variables.

Model fitting and statistical analysis are conducted using ANOVA statistical techniques. A coefficient of determination (R -squared), Fisher value (F -value), probability (P value), and residual were used as a standard of significance of the model equations (Hassani et al. 2014). Finally, optimization and validation are also conducted to find the optimum preparation factors conditions to enhance the removal of H_2S from wastewater.

2.2 Characterization of adsorbent

The surface structure morphology of CSAC adsorbent are characterized using scanning electron microscopy (SEM). Moreover, the elements of the adsorbent before and after adsorption process are examined by Energy-dispersive X-ray spectroscopy (EDX).

3.0 RESULT AND DISCUSSION

3.1 Model analysis of central composite design (CCD)

The independent variables such as activation temperature (724-1000 °C), activation mass ratio KOH: Precursor (2:1-4:1 w %), and activation contact time (60-120 min) are investigated. The factors names, coded, and ranges, are demonstrated in Table 1. The dependent response is the removal efficiency of H_2S from wastewater. The correlations between independent variables and dependent response are developed using quadratic polynomial model.

Table 1: The code, unit and ranges for optimization of independent variables of (CSAC)

Variables	code	Unit	Coded variable levels				
			$-\alpha$	-1	0	+1	$+\alpha$
Activation temperature	A	°C	630	724	862	1000	1094
KOH: Precursor ratio	B	Wt%	1.3	2	3	4	4.5
Activation contact time	C	min	39.5	60	90	120	140.5

3.2. Statistical Analysis

The interactions between three parameters (activation temperature, KOH: precursor ration, and activation contact time) for the removal efficiency of dissolved H₂S are analysed using response surface methodology (RSM). The central composite design results are allowed to develop a mathematic equation that can predict the response value. Moreover, the analysis of variance (ANOVA) is used to analysis obtained results as represented in Table 2. The goodness of fit and lack-of-fit are estimated from ANOVA Table. The ANOVA test is successfully conducted as seen in Table 2. The quadratic model is significant. While the lack of fit was not significant. The lack of fit describes the variation of the data around the fitted model. Thus, this is an indicated to prove the statistically corrected the relation between the factors and response. Moreover, the F-value of the quadratic model is (44.9). Consequently, the terms of significant model are A, B, C, A², B², C², AC and BC. While AB is the insignificant model terms. It can be observed that factors of KOH: Precursor ration has high contribution to the response of removal efficiency as seen in Table 2. This is attributed to the important of impregnation ratio that might be enhanced the surface chemistry of the adsorbent and it also provides the basic environment that could be attractive to acidic pollutant such H₂S. In addition, the residual value is very low that another indicator that shows the goodness fitted of the model.

Table 2: Analysis of variance (ANOVA) and lack-of-fit test for response surface quadratic model for removal efficiency (RE %).

Sources	Sum of squares	df	Mean square	F-value	P value	Comment
Model	110.89	9	12.32	44.95	< 0.0001	significant
A-activation temperature	2.83	1	2.83	10.31	0.0037	significant
B-KOH:AC ratio	11.12	1	11.12	40.57	< 0.0001	significant
C-Activation contact time	1.35	1	1.35	4.94	0.0359	significant
AB	2.500E-003	1	2.500E-003	9.121E-003	0.9247	insignificant
AC	7.29	1	7.29	26.60	< 0.0001	significant

BC	3.24	1	3.24	11.82	0.0021	significant
A ²	75.64	1	75.64	275.94	< 0.0001	significant
B ²	25.46	1	25.46	92.87	< 0.0001	significant
C ²	2.57	1	2.57	9.39	0.0053	significant
Residual	6.58	24	0.27			
Lack of Fit	2.12	5	0.42	1.80	0.1609	not significant

3.3 Development of the equation of regression model

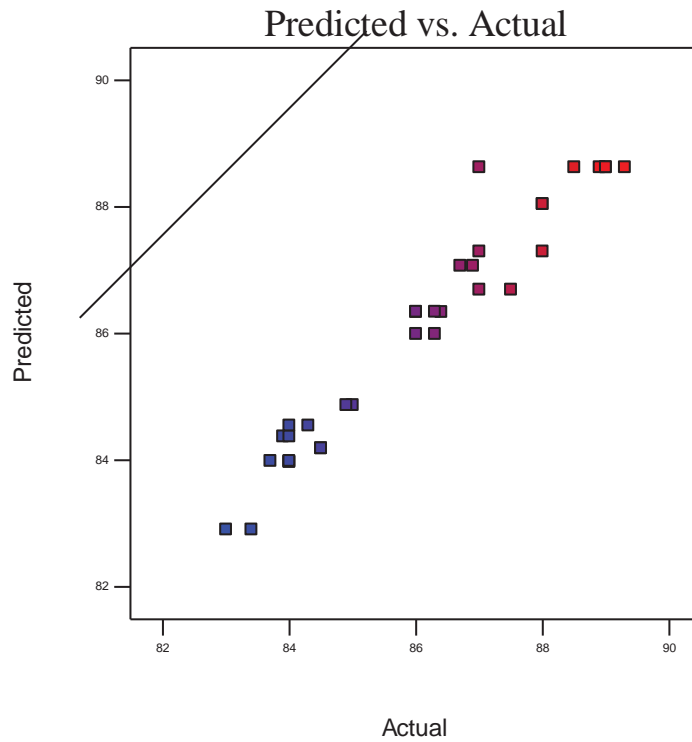
In addition, the CCD software is implemented to improve the empirical model. The correlation coefficient and standard deviation were used to obviate the model developed fitness. The better the model in forecasting the response is the smaller the standard deviation and the closer the R^2 value is to unity (Alam *et al.* 2009). The statistical analysis of quadratic model for removal efficiency is demonstrated in Table 3. It can be seen clearly that the R^2 value of 0.944 with small standard deviation 0.52. Moreover, the predicted R^2 is in agreement with the adjusted R^2 with only small differences between them. Therefore, the quadratic model is successfully developed. The quadratic model equation suggested by the software can be written as shown in equation (3). This equation can be used to predict the value of response (removal efficiency).

Furthermore, predicted vs actual values and normal plot of residual graphs are shown in Figure 1 (a, b) respectively. Figure 1 (a) represents the predicted vs actual values. This figure shows a sufficient agreement between the predicted data from the mode and the ones obtained from experiments. It is observed that the values are very close to the line which indicated the experimental values are closed to predict one. Figure 1 (b) shows the normal plot of residual error which demonstrated the residual error deviation from the model.

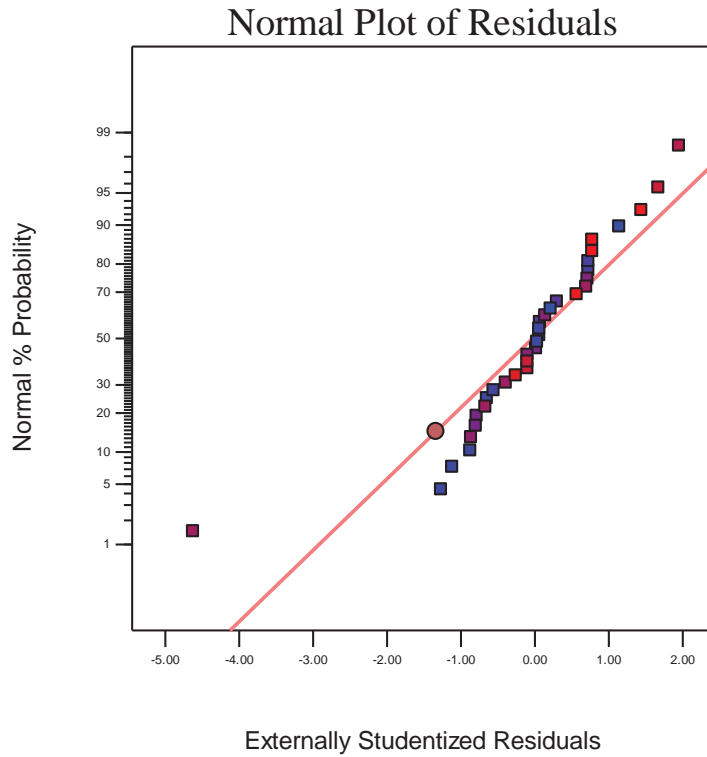
Table 3: Regression statistics for removal efficiency RE (%) at equilibrium.

Source	Standard deviation	R ²	Adjusted R ²	Predicted R ²	Comment
Linear	1.85	0.1302	0.0433	-0.0604	
2FI	1.84	0.2199	0.0465	-0.0027	
<u>Quadratic</u>	<u>0.52</u>	<u>0.9440</u>	<u>0.9230</u>	<u>0.9011</u>	<u>Suggested</u>
Cubic	0.48	0.9609	0.9355	0.9253	Aliased

Removal efficiency = $88.6+0.32A+0.638B-0.2226C-0.0125AB+0.675AC-0.45BC-1.83A^2-1.0625B^2-0.337C^2$ (3)



(a)



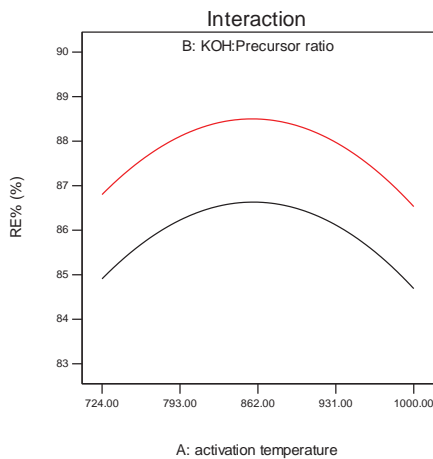
(b)

Figure1 (a) Actual and predicted curve. (b) Normal plot of residual

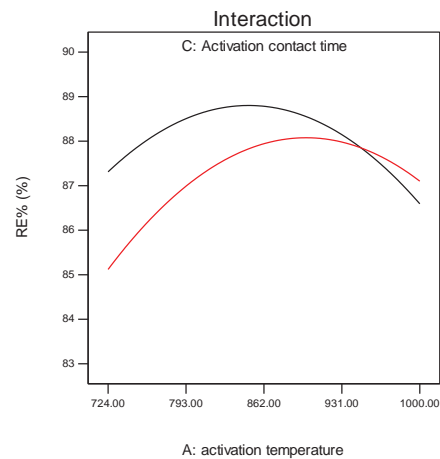
3.4 Effect of interaction factors

The effect of the factors interaction on the removal efficiency is demonstrated in Figure 2 (a, b, & c). The interaction between activation temperature and KOH: Precursor ratio are represented in Figure 2 (a). The two factors have affected the removal efficiency. It can be seen there is no interaction as the activated temperature increasing, the impregnation ration increased. However, the impact of the activation agent ratio has more significant effect on removal efficiency than activation temperature. While, the Figure 2 (b) represents the effect of interaction between activation temperature and activation contact time. The activation temperature has a significant effect on the removal efficiency of H_2S . The removal efficiency was low at lower temperature of $724\text{ }^\circ\text{C}$ and higher activation contact time of 120 min. Then, it start increasing when the temperature increased and the time decreased until reach the optimum removal efficiency of 88.8 % at activation temperature of $857\text{ }^\circ\text{C}$ and activation contact time of 70 min.

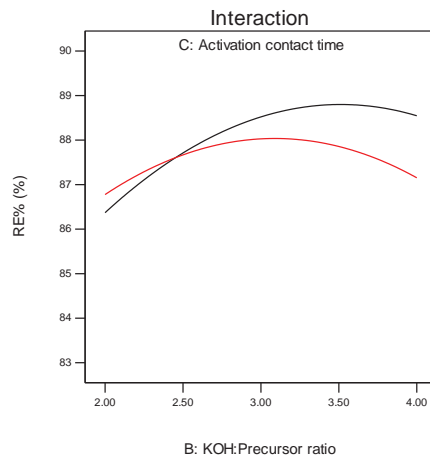
Figure 2 (c) shows the interactions between activation time and the impregnation ratio. The interaction plot shows the removal efficiency was very low at lower impregnation ratio and activation contact time. In fact, the graph demonstrated that high contact time of 120 min and low contact time of 60 min with low impregnation ratio are negatively affected the removal efficiency (as seen from Figure 2 (c)). After that, the removal of H₂S increasing with increased of impregnation ratio and activation contact time until reach the optimum removal efficiency of 88.8 % with impregnation ratio of 3.4 wt% and activation contact time of 70 min.



(a)



(b)



(c)

Figure 2. The effect of interactions between factors on the removal efficiency

3.5 Effect of combined factors

The effect of activation temperature and KOH: Precursor ratio on the removal efficiency show in Figure 3. The 3D plot presents impact of activation temperature with range between 724 to 1000 °C and activation agent mass ratio (KOH: Precursor) with range of (2:1-4:1 w%) on removal efficiency. From the trend of plot, it can be observed that, impregnation ratio and activation temperature have parallel contribution on removal efficiency. As increased in activation temperature and impregnation ratio, the removal efficiency increased. At the low activation temperature around 724 °C, the value of removal efficiency was very low. After that, the removal efficiency start increased with increasing the activation temperature and impregnation ratio until reach the optimum requirement of activation temperature and impregnation ration for getting the optimum removal efficiency.

Moreover, the effect on the interaction between activation temperature and contact time on the removal efficiency are demonstrated in Figure 4. The activation temperature with range (724-1000 °C) and activation contact time range (60-120 min) have a significant effect on response removal of H₂S. The temperature of activated of adsorbent has more effect on removal of H₂S than activation time as seen in Figure 4. From the trend of 3D plot was observed that H₂S experienced lowest residual at a preparation conditions of activation temperature of 857 °C and activation contact time of 66 min. Furthermore, the 3D plot of the interaction effect between activation time and KOH: Precursors on the removal efficiency are shown in Figure 5. It can be observed that the KOH: Precursors has a significant impact compared with the activation time which has less contribution on the removal of H₂S. The same trend was reported by Chaudhary (Chaudhary and Balomajumder 2014) As can be concluded that all the preparation factors of CSAC have a significant effect in different percentage that could contribute to enhance the removal of H₂S from synthetic wastewater.

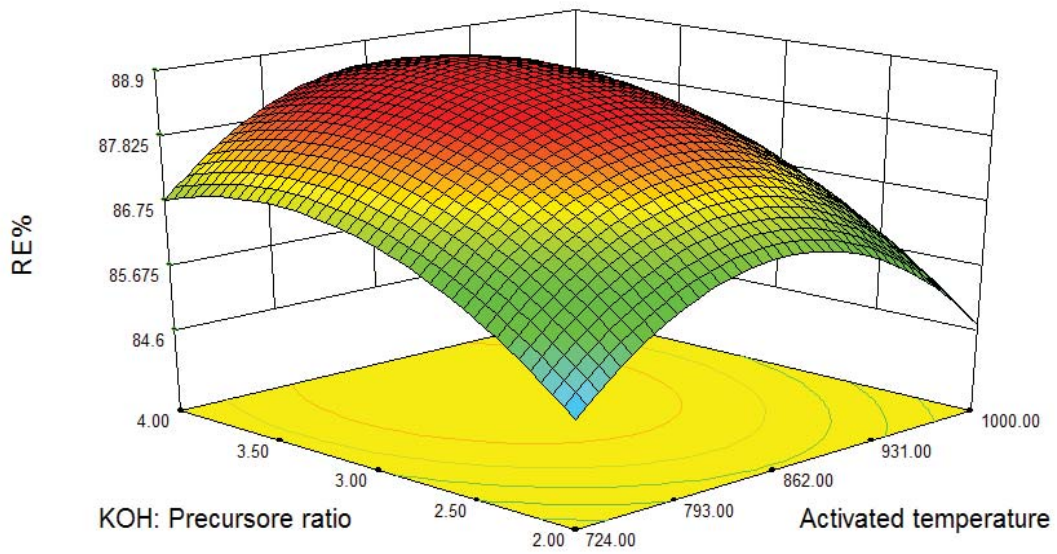


Figure 3: Combined impact of activation temperature and KOH: Precursor ratio on RE (%).

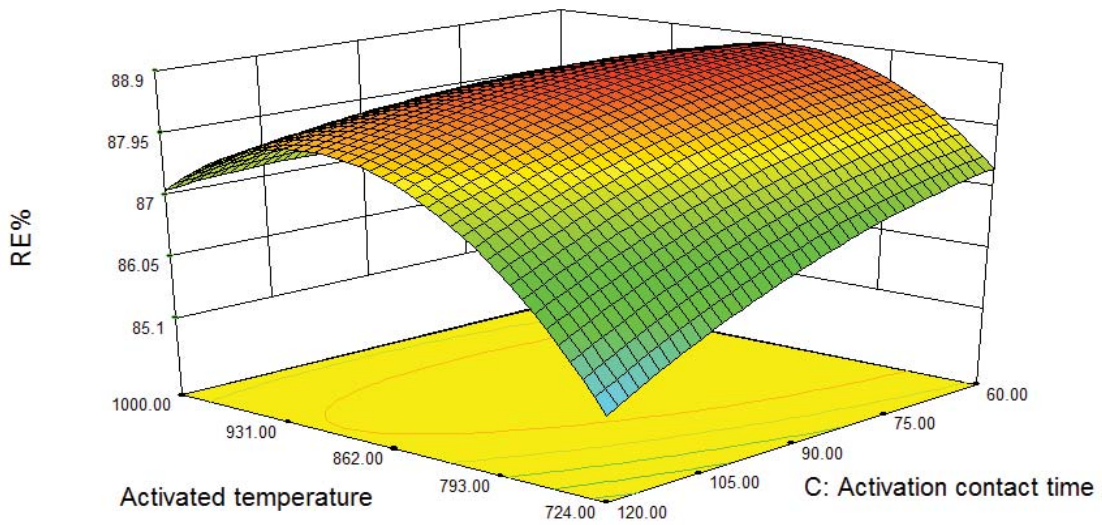


Figure4: Combined impact of activation time and activation temperature of AC on of RE (%).

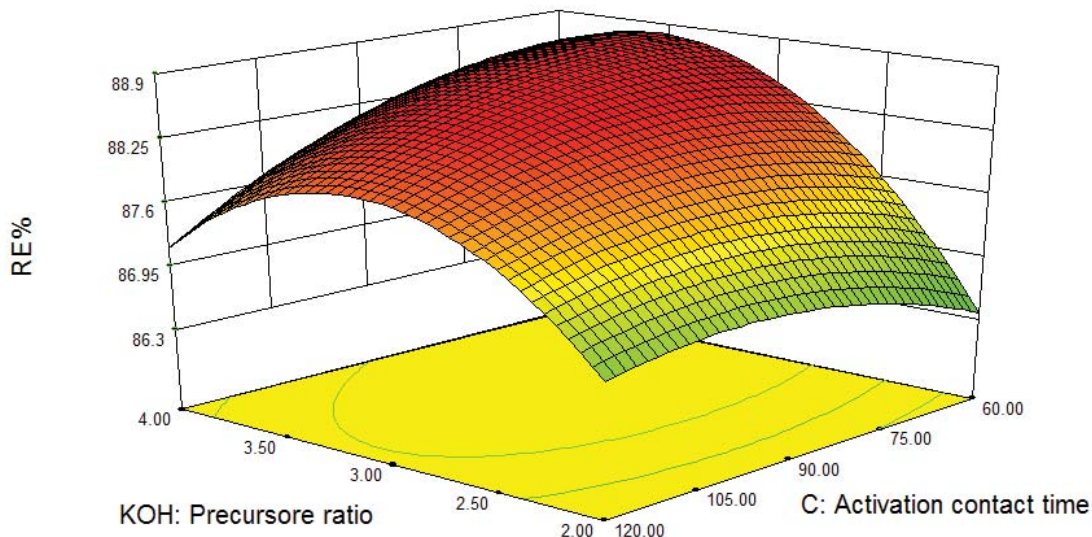


Figure 5: Combined impact of activation contact time and KOH: Precursor (IR) on RE (%)

3.6. Characterization of the optimally prepared activated carbon

3.6.1. Surface morphology (SEM / EDX)

Figure 6 (a, b) represent the SEM test for fresh and spent CSAC adsorbent respectively. As can be observed from Figure 6 (a) the chemical activation process with KOH was effective in creating well-developed pores on the surfaces of the activated carbon leading to produce activated carbon with a huge porous structure as seen in Figure 6 (a). The well-developed porosity on the surface of CSAC is attributed to the preparation factors such as activation temperature, activation contact time and KOH: Precursor ratio. The impregnation ratio with temperature have a significant contributed on developing the pore structure of the adsorbent due to during combustion of raw materials. It is attributed to chemical activations using of KOH. It possibly create more pores in CSAC structure due to the reaction between carbon and KOH as shown in equation (4). Pore generation is based on dehydration of KOH to K_2CO_3 , which reacts with CO_2 produced by the water-shift reaction, affording K_2CO_3 as well as promoting the diffusion of KOH and CO_2 molecules into the pores, thereby increasing its porosity (Stavropoulos and Zabaniotou 2005). As seen in Figure 6 (a).

However, the image of SEM in Figure (b) indicating the morphology of adsorbent surface after adsorption process which could be seen that there is some blocked in porosity due to stick of

sulfur on the pore hole and also can be seen the some white particle on the surface which indicated that the sulfur already stick on porous area.

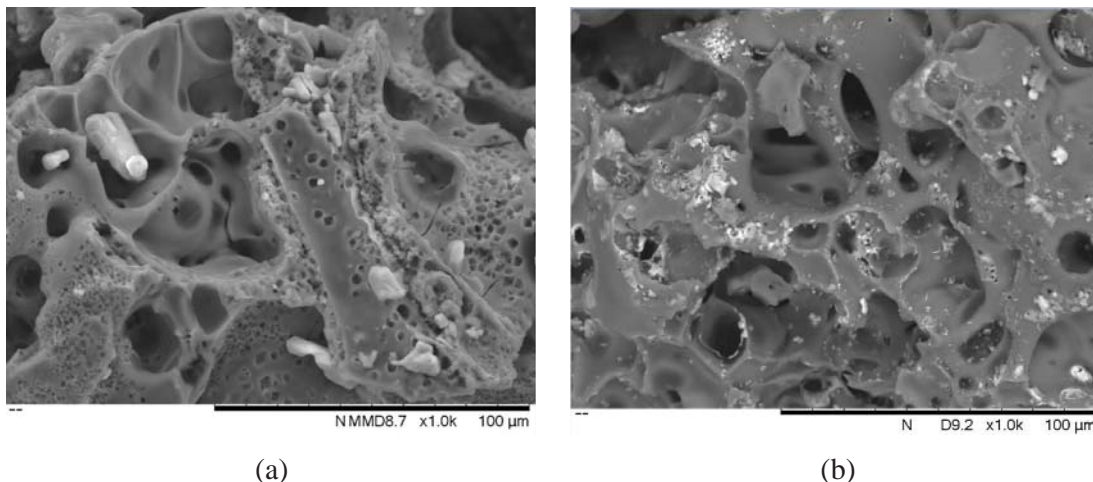
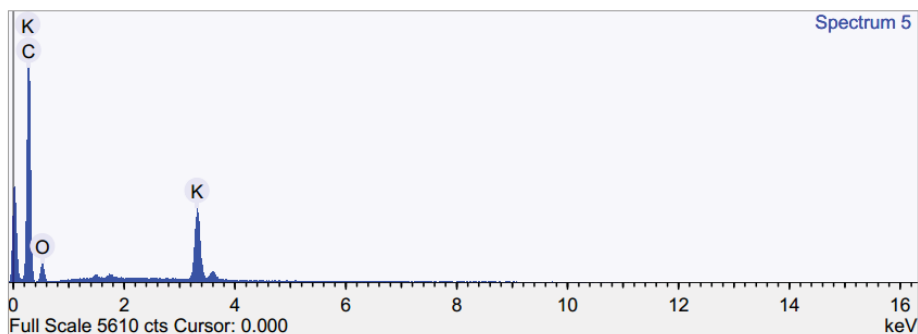


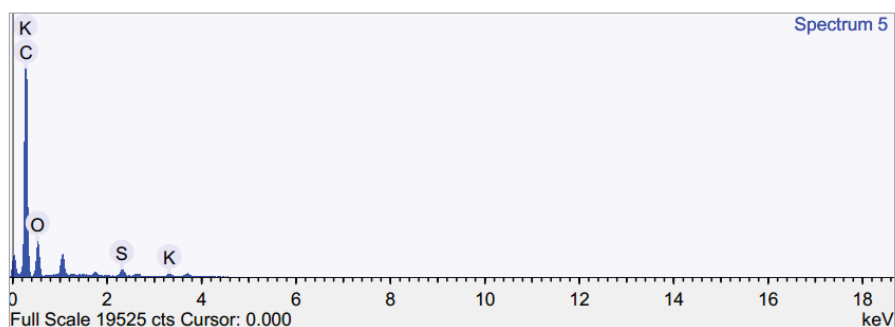
Figure 6 SEM image of (a) fresh (b) spent CSAC adsorbent

Moreover, the EDX test for the CSAC before and after adsorption process are shown in Figure 7 (a, b). As can be seen the peaks for the fresh CSAC represents the adsorbent components which is (C, O and K). However, the peaks for the spent CSAC is representing the adsorbent components after adsorption process which is shown clearly that there more peaks which is represent the different components such as (C, O, K, and S). All composite components of the adsorbent before and after adsorption process shown in Table 4. It can be seen that the percentage of C, O, and K are decreased after the adsorption process. In fact, the most interesting finding was that the percentage of K decreased to around 0.93 % after adsorption, indicating that acid–base reaction occurs. Moreover, S content detected as 0.724, which is another indicator for the possible occurrence of oxidation. In fact, during the adsorption process, the acid/base reaction is occurred. The KOH provides a basic environment on the active sites on the adsorbent which attracted the acidic dissolved H_2S and its ions to produce the sulfide salt and water as seen in equation (5). The reactions occurred on the surface of CSAC. From that the percentage of C, O, and K are decreased as noticed in Table 4.





(a)



(b)

Figure 7 EDX test (a) Fresh. (b) Spent CSAC adsorbent.

Table 4: The components of activated carbon derived from coconut shell fresh and spent adsorbent.

Element	Component of fresh adsorbent (Weight %)	Components of spent adsorbent (Weight %)
Carbon (C)	76.575	73.24
Oxygen (O)	17.9	25.6
Potassium (K)	5.511	0.38
Sulfur (S)	0	0.724

4.0 CONCLUSIONS

In this study the variables for preparations of CSAC for H₂S removal from wastewater was investigated. The optimum preparation variables conditions are examined. SEM and EDX

characterizations are conducted. The result shows that the optimum conditions of factors are temperature of 857 °C, chemical impregnation ratio of 3.4 wt% and activation time of 66 min with removal efficiency of 88.8 %.

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REFERENCES

- Alam, Md Zahangir, Emad S Ameen, Suleyman A Muyibi, and Nassereldeen A Kabbashi. 2009. "The Factors Affecting the Performance of Activated Carbon Prepared from Oil Palm Empty Fruit Bunches for Adsorption of Phenol." *Chemical Engineering Journal* 155 (1). Elsevier: 191–98.
- Allen, S J, and B Koumanova. 2005. "Decolourisation of Water/wastewater Using Adsorption." *Journal of the University of Chemical Technology and Metallurgy* 40 (3): 175–92.
- Bansal, Roop Chand, and Meenakshi Goyal. 2005. *Activated Carbon Adsorption*. CRC press.
- Boehm, H P. 1994. "Some Aspects of the Surface Chemistry of Carbon Blacks and Other Carbons." *Carbon* 32 (5). Elsevier: 759–69.
- Castro, Javier Blanco, Pablo R Bonelli, Elsa G Cerrella, and Ana L Cukierman. 2000. "Phosphoric Acid Activation of Agricultural Residues and Bagasse from Sugar Cane: Influence of the Experimental Conditions on Adsorption Characteristics of Activated Carbons." *Industrial & Engineering Chemistry Research* 39 (11). ACS Publications: 4166–72.
- Chaudhary, Neeru, and Chandrajit Balomajumder. 2014. "Optimization Study of Adsorption Parameters for Removal of Phenol on Aluminum Impregnated Fly Ash Using Response Surface Methodology." *Journal of the Taiwan Institute of Chemical Engineers* 45 (3). Elsevier: 852–59.
- Dabrowski, a, P Podkościelny, Z Hubicki, and M Barczak. 2005. "Adsorption of Phenolic Compounds by Activated Carbon--a Critical Review." *Chemosphere* 58 (8): 1049–70.
- Derylo-Marczewska, Anna, Andrzej Swiatkowski, Stanisław Biniak, and Mariusz Walczyk. 2008. "Effect of Properties of Chemically Modified Activated Carbon and Aromatic Adsorbate Molecule on Adsorption from Liquid Phase." *Colloids and Surfaces A: Physicochemical and Engineering Aspects* 327 (1). Elsevier: 1–8.
- El-Sayed, Yehya, and Teresa J Bandosz. 2004. "Adsorption of Valeric Acid from Aqueous Solution onto Activated Carbons: Role of Surface Basic Sites." *Journal of Colloid and Interface Science* 273 (1). Elsevier: 64–72.
- Foo, K. Y., and B. H. Hameed. 2010. "Insights into the Modeling of Adsorption Isotherm Systems."

Chemical Engineering Journal 156 (1): 2–10.

Foo, K Y, and B H Hameed. 2011. “Preparation and Characterization of Activated Carbon from Sunflower Seed Oil Residue via Microwave Assisted K_2CO_3 Activation.” *Bioresource Technology* 102 (20). Elsevier: 9794–99.

Habeeb O A, Ramesh K, Ali Gomaa A M, Yunus MYM, T K Thanusha, and O A Olalere. 2016. “Modeling and Optimization For H_2S Adsorption From Astewater Using Coconut Shell Based Activated Carbon.” *Australian Journal of Basic and Applied Sciences* 10 (17 Sp.). AENSI Publishing: 136–47.

Hassani, A., L. Alidokht, A. R. Khataee, and S. Karaca. 2014. “Optimization of Comparative Removal of Two Structurally Different Basic Dyes Using Coal as a Low-Cost and Available Adsorbent.” *Journal of the Taiwan Institute of Chemical Engineers* 45 (4). Elsevier: 1597–1607.

Hu, Zhonghua, and E F Vansant. 1995. “Carbon Molecular Sieves Produced from Walnut Shell.” *Carbon* 33 (5). Elsevier: 561–67.

Kazmierczak-Razna, Justyna, Barbara Gralak-Podemska, Piotr Nowicki, and Robert Pietrzak. 2015. “The Use of Microwave Radiation for Obtaining Activated Carbons from Sawdust and Their Potential Application in Removal of NO_2 and H_2S .” *Chemical Engineering Journal* 269. Elsevier B.V.: 352–58.

Montgomery, D C. 2001. “Design and Analysis of Experiments Fifth Edition. By John Wiley & Sons.” *Inc. All Rights Reserved.*

Moreno-Castilla, Carlos. 2004. “Adsorption of Organic Molecules from Aqueous Solutions on Carbon Materials.” *Carbon* 42 (1). Elsevier: 83–94.

Omar Abed Habeeb, Ramesh Kanthasamy, Gomaa A.M. Ali, Rosli bin Mohd., and Yunus. 2017. “Optimization of Activated Carbon Synthesis Using Response Surface Methodology to Enhance H_2S Removal from Refinery Wastewater.” *Journal of Chemical Engineering and Industrial Biotechnology* 1: 1–17.

Sekirifa, Mohamed L., Mahfoud Hadj-Mahammed, Stephanie Pallier, Lotfi Baameur, Dominique Richard, and Ammar H. Al-Dujaili. 2013. “Preparation and Characterization of an Activated Carbon from a Date Stones Variety by Physical Activation with Carbon Dioxide.” *Journal of Analytical and Applied Pyrolysis* 99. Elsevier B.V.: 155–60.

Siefers, Andrea, Ning Wang, Andrew Sindt, John Dunn, James McElvogue, Eric Evans, and Tim Ellis. 2010. “A Novel and Cost-Effective Hydrogen Sulfide Removal Technology Using Tire Derived Rubber Particles.” *Proceedings of the Water Environment Federation* 2010 (12). Water

Environment Federation: 4597–4622.

Stavropoulos, G. G., and A. A. Zabaniotou. 2005. “Production and Characterization of Activated Carbons from Olive-Seed Waste Residue.” *Microporous and Mesoporous Materials* 82 (1–2). Elsevier: 79–85.

Yang, Kunbin, Jinhui Peng, C. Srinivasakannan, Libo Zhang, Hongying Xia, and Xinhui Duan. 2010. “Preparation of High Surface Area Activated Carbon from Coconut Shells Using Microwave Heating.” *Bioresource Technology* 101 (15). Elsevier Ltd: 6163–69.

Zainudin, Nor Fatiha, Keat Teong Lee, Azlina Harun Kamaruddin, Subhash Bhatia, and Abdul Rahman Mohamed. 2005. “Study of Adsorbent Prepared from Oil Palm Ash (OPA) for Flue Gas Desulfurization.” *Separation and Purification Technology* 45 (1). Elsevier: 50–60.

Zhang, Shujuan, Ting Shao, and Tanju Karanfil. 2010. “The Effects of Dissolved Natural Organic Matter on the Adsorption of Synthetic Organic Chemicals by Activated Carbons and Carbon Nanotubes.” *Water Research* 45 (3): 1378–86.