

# THE APPLICATION OF RESPONSE SURFACE METHODOLOGY FOR OPTIMIZATION IN THE PREPARATION OF ACTIVATED CARBON FROM COCONUT SHELLS

<sup>1\*</sup> J. IJI, <sup>1</sup> F.B IBRAHIM AND <sup>2</sup> A. GIWA

<sup>1</sup> Department of Water Resources and Environmental Engineering, ABU Zaria, Nigeria

<sup>2</sup> Department of Textile Science and Technology, ABU Zaria, Nigeria

\*Corresponding author: [phatpharmiji20@gmail.com](mailto:phatpharmiji20@gmail.com), 08066373328, [fbibrahim@abu.edu.ng](mailto:fbibrahim@abu.edu.ng)

## ABSTRACT

Modelling of adsorption process is important in determining the values of factors for which the response is at maximum. This study investigates the optimal process conditions for activated carbon production from coconut shells using response surface methodology (RSM). Central Composite Design technique was used to design the production process in order to determine the influence of activation temperature (°C), impregnation ratio using phosphoric acid as an activating agent and activation time (minutes) while the response variable is the iodine value (mg/g). Statistical analysis (ANOVA) was used to analyze the model developed. Experimental results in the chemical activation process showed that the optimum conditions for the production and activation of coconut shell are: carbonization temperature of 600°C for 2h, activation temperature of 400°C, activation time of 10mins and impregnation ratio of 1:1 which gave an iodine value of 568.512mg/g. The adsorbent with the optimum condition had bulk density and yield of 0.6402g/cm<sup>3</sup> and 96.69% respectively.

**Keywords:** Activated Carbon, Coconut shells, Activation Temperature, Activation Time, Impregnation Ratio, Response Surface Methodology

## 1.0 INTRODUCTION

Activated carbons exhibit a great adsorption capacity in wastewater and gas treatments as well as in catalysis, owing to their highly developed porosity, large surface area and variable surface chemistry. However, high cost and non-renewable sources of commercially available activated carbons limits its use as an adsorbent in developing countries (Cazetta *et. al.* 2011, Rao *et. al.* 2008). Disposal of agricultural by-products is currently a major economic and ecological issue, and the conversion of these agro products into adsorbents, such as activated carbon represents a possible outlet (Itodo *et. al.* 2009a).

In recent years, researchers have studied the production of activated carbons from cheap and renewable precursors such as nutshells, rice husk, bamboo etc. Coconut shell is a potential precursor for the production of activated carbons due to its excellent natural structure and low ash content. Coconut shells are agricultural wastes that are mainly disposed after extraction of their inner contents. Conversion of coconut shells into activated carbons which can be used as adsorbents in water purification or treatment of industrial and municipal effluents would add value to these agricultural commodities, help reduce the cost of waste disposal and provide a potentially cheap alternative to existing commercial carbons (Li *et. al.* 2008).

Coconut shell is a highly carbonaceous material which can easily be processed into activated carbon; which is widely used in liquid and gas phase separation, purification of products and water cleaning operation (Tharapong *et. al.* 1999). Even though all carbonaceous materials can be converted to activated carbon, coconut shells give a high-grade vapour-adsorbent carbon due to the inherent high

carbon content and mechanical strength (Kirubakaran *et. al.* 1991). Developed adsorbent from coconut shell and the likes is economically friendly, cost effective and durable. Coconut shell is made up of cellulose (33.61%), lignin (36.51%), pentosans (29.27%) and ash (0.61%) (Woodroof, 1979). Gimba *et. al.* (2014) argued that the features of activated carbon from coconut shell compete favourably with commercial activated carbon and this conforms to the finding of Shaki and Yenkie, (2002). These wastes can be converted to useful activated carbon which in turn can be used as adsorbents for several adsorption purposes.

As the production of activated carbon is influenced by many factors (such as carbonization temperature, acid concentration, activation time, impregnation ratio, etc.), a preliminary study on the effect of these factors on activated carbon production has been carried out in order to determine the most important ones and their regions of interest. From such studies, the carbonization temperature, impregnation ratio and activation time were determined as the most influential factors and were therefore selected for the experiments in the present study.

In assessing the effect of treatments on quality attributes, the use of an appropriate experimental design is particularly important. Similarly, to study the interactions of two or more variables on certain response of interest, Response Surface Methodology (RSM) is a useful tool. RSM is a collection of statistical and mathematical techniques used for developing, improving and optimizing processes. It usually contains three stages: (i) design and experiments, (ii) response surface modeling through regression, and (iii) optimization (Myers *et. al.*, 1995). The main advantage of RSM is the reduced number of costly experimental trials needed to



evaluate multiple parameters and their interactions (Lee *et. al.*, 2000). The limitations posed by conventional analytical optimization method can be eliminated by optimizing all the affecting parameters collectively using RSM. In this present study, the Central Composite Design (CCD) of RSM was used to obtain the optimum conditions for the production of activated carbon from coconut shells.

## 2.0 METHODOLOGY

### 2.1 Procurement of coconut shell

The coconut shells were collected from Gaskiya Road by Agoro Round-about area, Zaria, Kaduna State, Nigeria.

### 2.2 Sample treatment

The method of sample treatment by (Mozammel *et. al.* 2002, Itodo *et. al.* 2009a & b) was adopted. The coconut shell materials were crushed manually to small chips of approximately equal sizes. The coconut shells were washed with plenty of clean water to remove surface impurities, placed inside the oven and then heated at 105°C for 24hours in order to remove the moisture in them. The dried coconut shells were placed in airtight plastic bags to prevent re-absorption of moisture from the atmospheric air.

### 2.3 Carbonization of Coconut Shells

The pre-treated sample was loaded in a heat treatment furnace and heated up to a carbonization temperature of 600°C without ash formation and was held for 2hrs at the carbonization temperature under N<sub>2</sub> gas flow to create an inert atmosphere in the furnace. As carbonization time was reached, the furnace heating source was switched off and allowed to cool with nitrogen gas still flowing. The carbonized samples were further cooled to room temperature. The carbonized samples were crushed and sieved to obtain particles greater than 4.75mm sieve.

### 2.4 Experimental design

A Central Composite Design (CCD) model of the Response Surface Methodology (RSM), Design Expert 6.0.6 software was employed in this study, which lead to a set of 20 experiments. The variables and their levels selected for the study of the optimization of activated carbon from coconut shell using phosphoric acid as activating agent were activation temperature (400-700°C), activating time (5–10mins) and impregnation ratio (1:1-1:2) based on the preliminary experiments using conventional optimization method as shown in Table 1.

**Table 1: Independent variables and their levels in the Central Composing Design model**

| Factors | Variables         | Unit | Range and level of actual values |             |
|---------|-------------------|------|----------------------------------|-------------|
|         |                   |      | Low actual                       | High actual |
| A       | Temperature       | °C   | 400                              | 700         |
| B       | Time              | Mins | 5                                | 10          |
| C       | Impregnation Time | -    | 1                                | 2           |

### 2.5 Experimental procedure

Chemical activation was performed with phosphoric acid (H<sub>3</sub>PO<sub>4</sub>) as the reagent. 200 grams of coconut shell char was separated from a bulk and then 10grams each was measured into 20 different beakers. The sample in each container was then impregnated with the prepared solution of 1M phosphoric acid to obtain the desired ratio (1:1 -1:2) of phosphoric acid and allowed to soak for 24hrs. Then, the impregnated chars were packed into small ceramic crucibles and placed inside a heat treatment furnace and heated to the desired temperatures (400-700°C). For each of these temperatures, one sample of each impregnation ratio was withdrawn at predetermined time interval (5-10mins). The time to withdraw the samples from the furnace was taken from the moment the furnace reached the desired temperature. The activated carbon obtained was removed from the heat treatment furnace. After cooling the activated carbon was repeatedly washed with distilled water. The products were then dried at 110°C for 24 h to give the activated carbon products.

### 2.6 Characterization of activated carbon

Characterization of the activated carbons was mainly focused on determination of surface area by iodine value test in order to determine the optimal conditions for preparing activated carbon from coconut shell. Some portion of the produced activated carbon were collected and pounded followed by sieving with a 4.75mm sieve. The less than 4.75mm sample were stored in airtight containers and characterized as follows:

### 2.7 Iodine value of the activated carbon (I.V)

The iodine number is the amount of iodine, in milligrams, adsorbed per gram of carbon when the equilibrium concentration of iodine is 0.02 M. It has been established that the iodine number in mg/g gives an estimate of the surface area in m<sup>2</sup>/g (Gergova *et. al.*, 1994), and measures the porosity for pores with dimensions between 1.0 - 1.5nm (Collin *et. al.*, 2006).



Several methods are available for iodine value determination but Hanus method (Association of Analytical Chemist 1975) was used in this work.

1g of the samples was placed in a 250ml conical flask followed by 30ml Hanus solution and the flask stoppered. The content was mixed and placed in the drawer for exactly 30mins. It was then titrated against 0.1N  $\text{Na}_2\text{S}_2\text{O}_3$  until the solution became light yellow. 2ml of 1% starch indicator was added and the titration continued until the blue colour just disappeared. A blank determination was also carried out under the same conditions and the I.V calculated as thus;

$$IV = (B - S) \times 126.9 \times \frac{N}{\text{weight of sample}} \quad (1)$$

Where;

B= blank titre

S= sample titre

N= normality  $\text{Na}_2\text{S}_2\text{O}_3$

W= weight of sample

**2.8 Bulk density:** The weight of a small empty bottle was determined using an electronic weighing balance. The bottle was then filled to the brim with the sample and then the weight of the bottle and the samples determined.

$$\text{Bulk density} = \frac{(W_2 - W_1)}{V} \quad (2)$$

Where  $W_2$ = weight of bottle + sample

$W_1$ = weight of empty bottle

V= volume of sample

### 3.0 RESULTS AND DISCUSSIONS

#### 3.1 Responses obtained from the experiment

The experimental design for the optimization of the preparation conditions yielded twenty (20) distinct activated carbons from coconut shells as shown in Table 2.

The iodine value of the activated carbons changed significantly with temperature while time and impregnation ratio slightly affected the iodine value. The effect of change in activation time and temperature, which most significantly influenced the physicochemical characteristics including: bulk density and yield of the adsorbent were studied and discussed.

#### 3.2 Percentage yield of prepared activated carbon

The yield of the prepared carbon varied widely with the temperature, impregnation ratio and time of activation. Table 3 showed that carbons activated at 802.27°C had the least percentage yield. This is because increase in temperature of activation resulted in more volatile component being lost, and hence a decreasing percentage yield. The percentage yield was not significantly affected by the activation time and impregnation ratio. The highest

observable percentage yield was 96.69% and was obtained at an experimental condition of 400°C for a time of 10 minutes and impregnation ratio of 1:1. This was about two hundred

times the yield obtained at activation condition of 802.27°C for 7.5minutes at impregnation ratio of 1: 1.5 which was 0.35%. The time of activation did not influence the yield remarkably, relative to the activation temperature. The percentage yield increased as activation temperature decreased from 802.27°C to 297.72°C. The effect of activation temperature is therefore most felt at the highest experimental temperature of 802.27°C. Optimization results as displayed in Table 4 shows that the most optimal operating condition is at impregnation ratio 1:1, 400°C activation temperature at an activation time of 10mins and produces activated carbon from coconut shell of an estimated iodine value of 568.512m<sup>2</sup>/g.

#### 3.3 Effect of temperature on yield of activated carbon

The optimum temperature for activation was earlier experimentally determined to be 400°C above which high level of residual ash sets in. Result in tables 3 shows that there was a resultant low % yield at activation temperature higher than 400°C. The percentage yield was least for the 2-step chemical activation process as a result of a double thermal decomposition with more ash deposition or volatilization, due to the initial pyrolysis followed by activation.

#### 3.4 Statistical Analysis.

The model equations selected were further evaluated using ANOVA component of the software. Table 5 shows that response surface quadratic model for iodine value has *F*-value of 22.36 indicating that the model is significant. For the model terms, *P* value less than 0.05 implies that model term is significant (Basu *et. al.* 2012) and largest *F*-value signifies the model term having the most significant effect on the response (Tan *et. al.* 2008). In this study, the significant model term is A with *F*-value of 183.45 and *A*<sup>2</sup> while B, C, AB, AC, BC, B<sup>2</sup> and C<sup>2</sup> are the insignificant model terms. Therefore, the quadratic models for the response become:

$$\begin{aligned} \text{Iodine value} = & +399.60 - 189.00A + 19.47B + 9.91C \\ & - 44.81A^2 - 26.73B^2 - 16.39C^2 \\ & - 19.12AB - 3.98AC \\ & - 5.11BC \end{aligned} \quad (2)$$

The residual of the response surface models presented in Tables 6 shows that the highest-lowest error (residual) for response is 97.04–69.16mg/g. This also signifies the quality of the model in terms of predicting the responses.



**TABLE 2: COMPLETED DESIGN LAYOUT**

| Std | Run | Block   | Factor 1<br>A: Temperature<br>Degree C | Factor 2<br>B: Time<br>mins | Factor 3<br>C: Impregnation<br>ratio | Responses 1<br>Iodine Value<br>mg/g |
|-----|-----|---------|----------------------------------------|-----------------------------|--------------------------------------|-------------------------------------|
| 3   | 1   | Block 1 | 400.00                                 | 10.00                       | 1.00                                 | 568.512                             |
| 2   | 2   | Block 1 | 700.00                                 | 5.00                        | 1.00                                 | 75.701                              |
| 6   | 3   | Block 1 | 700.00                                 | 5.00                        | 2.00                                 | 75.615                              |
| 19  | 4   | Block 1 | 550.00                                 | 7.50                        | 1.50                                 | 397.610                             |
| 17  | 5   | Block 1 | 550.00                                 | 7.50                        | 1.50                                 | 401.001                             |
| 15  | 6   | Block 1 | 550.00                                 | 7.50                        | 1.50                                 | 397.610                             |
| 7   | 7   | Block 1 | 400.00                                 | 10.00                       | 2.00                                 | 563.930                             |
| 14  | 8   | Block 1 | 550.00                                 | 7.50                        | 2.34                                 | 399.366                             |
| 20  | 9   | Block 1 | 550.00                                 | 7.50                        | 1.50                                 | 397.782                             |
| 12  | 10  | Block 1 | 550.00                                 | 11.70                       | 1.50                                 | 366.210                             |
| 18  | 11  | Block 1 | 550.00                                 | 7.50                        | 1.50                                 | 400.972                             |
| 11  | 12  | Block 1 | 550.00                                 | 3.30                        | 1.50                                 | 309.636                             |
| 1   | 13  | Block 1 | 400.00                                 | 5.00                        | 1.00                                 | 468.261                             |
| 9   | 14  | Block 1 | 297.73                                 | 7.50                        | 1.50                                 | 521.559                             |
| 13  | 15  | Block 1 | 550.00                                 | 7.50                        | 0.66                                 | 335.016                             |
| 10  | 16  | Block 1 | 802.27                                 | 7.50                        | 1.50                                 | 52.032                              |
| 5   | 17  | Block 1 | 400.00                                 | 5.00                        | 2.00                                 | 502.331                             |
| 8   | 18  | Block 1 | 700.00                                 | 10.00                       | 2.00                                 | 78.949                              |
| 16  | 19  | Block 1 | 550.00                                 | 7.50                        | 1.50                                 | 397.691                             |
| 4   | 20  | Block 1 | 700.00                                 | 10.00                       | 1.00                                 | 81.233                              |

**TABLE 3: PERCENTAGE YIELD OF PREPARED ACTIVATED CARBON**

| Activation<br>Temperature °C | Activating<br>(mins) | Time | Impregnation<br>Ratio | % Yield | Iodine Value IV (mg/g) |
|------------------------------|----------------------|------|-----------------------|---------|------------------------|
| 802.27                       | 7.5                  |      | 1:1.5                 | 0.35    | 52.032                 |
| 700                          | 10                   |      | 1:2                   | 2.62    | 78.949                 |
| 700                          | 10                   |      | 1:1                   | 2.63    | 81.233                 |
| 700                          | 5                    |      | 1:2                   | 2.64    | 75.615                 |
| 700                          | 5                    |      | 1:1                   | 2.68    | 75.701                 |
| 550                          | 11.7                 |      | 1:1.5                 | 4.76    | 366.210                |
| 550                          | 3.3                  |      | 1:1.5                 | 5.88    | 309.636                |
| 550                          | 7.5                  |      | 1:0.66                | 5.38    | 335.016                |
| 550                          | 7.5                  |      | 1:2.34                | 6.17    | 399.366                |
| 550                          | 7.5                  |      | 1:1.5                 | 7.03    | 397.782                |
| 550                          | 7.5                  |      | 1:1.5                 | 7.04    | 401.001                |
| 550                          | 7.5                  |      | 1:1.5                 | 7.02    | 397.610                |
| 550                          | 7.5                  |      | 1:1.5                 | 7.03    | 397.782                |
| 550                          | 7.5                  |      | 1:1.5                 | 7.02    | 400.972                |
| 550                          | 7.5                  |      | 1:1.5                 | 7.03    | 397.691                |
| 400                          | 5                    |      | 1:1.5                 | 63.18   | 468.261                |
| 400                          | 10                   |      | 1:2                   | 79.69   | 563.930                |
| 400                          | 5                    |      | 1:2                   | 74.41   | 502.331                |
| 400                          | 10                   |      | 1:1                   | 96.69   | 568.512                |
| 297.73                       | 7.5                  |      | 1:1.5                 | 91.46   | 521.559                |

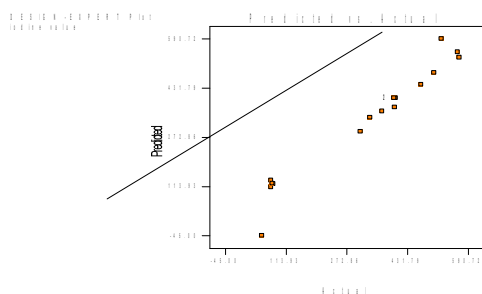


**TABLE 4: ANOVA FOR RESPONSE SURFACE QUADRATIC MODEL**

| Source         | Sum of squares | DF | Mean square | F value | P value | Comment     |
|----------------|----------------|----|-------------|---------|---------|-------------|
| Model          | 5.352E+005     | 9  | 59471.15    | 22.36   | <0.0001 | Significant |
| A              | 4.879E+005     | 1  | 4.879E+005  | 183.45  | <0.0001 |             |
| B              | 5175.60        | 1  | 5175.60     | 1.95    | 0.1932  |             |
| C              | 1341.25        | 1  | 1341.25     | 0.50    | 0.4938  |             |
| A <sup>2</sup> | 28938.11       | 1  | 28938.11    | 10.88   | 0.0080  |             |
| B <sup>2</sup> | 10300.31       | 1  | 10300.31    | 3.87    | 0.0774  |             |
| C <sup>2</sup> | 3869.82        | 1  | 3869.82     | 1.46    | 0.2555  |             |
| AB             | 2925.51        | 1  | 2925.51     | 1.10    | 0.3189  |             |
| AC             | 126.87         | 1  | 126.87      | 0.048   | 0.8315  |             |
| BC             | 208.59         | 1  | 208.59      | 0.078   | 0.7851  |             |
| Residual       | 26592.51       | 10 | 2659.25     |         |         |             |

**TABLE 5: ACTUAL-PREDICTED VALUES OF IODINE VALUE AND RESIDUAL**

| Standard | Actual Value | Predicted Value | Residual |
|----------|--------------|-----------------|----------|
| 1        | 468.26       | 443.08          | 25.18    |
| 2        | 75.70        | 111.29          | -35.59   |
| 3        | 568.51       | 530.48          | 38.03    |
| 4        | 81.23        | 122.19          | -40.96   |
| 5        | 502.33       | 481.08          | 21.25    |
| 6        | 75.61        | 133.36          | -57.74   |
| 7        | 563.93       | 548.05          | 15.88    |
| 8        | 78.95        | 123.83          | -44.89   |
| 9        | 521.56       | 590.72          | -69.16   |
| 10       | 52.03        | -45.00          | 97.04    |
| 11       | 309.64       | 291.25          | 18.39    |
| 12       | 366.21       | 356.73          | 9.48     |
| 13       | 335.02       | 336.59          | -1.57    |
| 14       | 399.37       | 369.92          | 29.44    |
| 15       | 397.61       | 399.60          | -1.99    |
| 16       | 397.69       | 399.60          | -1.91    |
| 17       | 401.00       | 399.60          | 1.40     |
| 18       | 400.97       | 399.60          | 1.37     |
| 19       | 397.78       | 399.60          | -1.82    |
| 20       | 397.78       | 399.60          | -1.82    |

**Fig 1: Actual-predicted plot for response (Iodine Value)**

The plot of actual versus predicted values of response Iodine Value in Figure 1 shows minimal divergence of points from the diagonal indicating that these response surface model equations can be

used to adequately represent the interaction of the three factors.

### 3.5 Combined Effect of Temperature and Time at Constant impregnation ratio.

The combined effect of temperature and time on iodine value at constant impregnation ratio is as shown in Figure 2. The figure shows that the combined effect is almost completely as a result of the singular effect of temperature with time having very small effect. It was also observed that iodine value slightly increased with increase in time whereas increase in temperature results in relative decrease in iodine value

### 3.6 Combined Effect of Temperature and Impregnation ratio at Constant Time



The combined effect of temperature and impregnation ratio at constant time on iodine value is as shown in Figure 3. The result shows that the combined effect is almost completely as a result of the singular effect of temperature with impregnation ratio having very small effect. It was also observed that iodine value is slightly increased with increase in impregnation ratio whereas increase in temperature results in relatively small decrease in iodine value.

### 3.7 Combined Effect of Time and Impregnation ratio at Constant Temperature.

Figure 4 shows the combined effect of temperature and impregnation ratio on iodine value. It was observed that the two factors had combined effect on iodine value and increase in any of the factors increased the iodine value. The combined effect was observed to be greater at higher values of the two factors

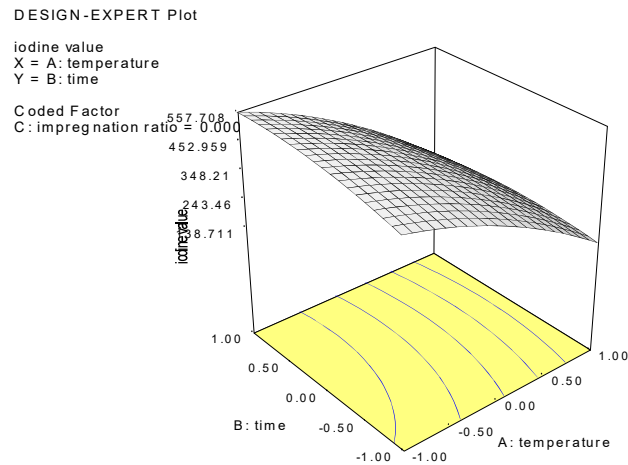


Figure 2: Combined effects of factors A-B on response (Iodine Value)

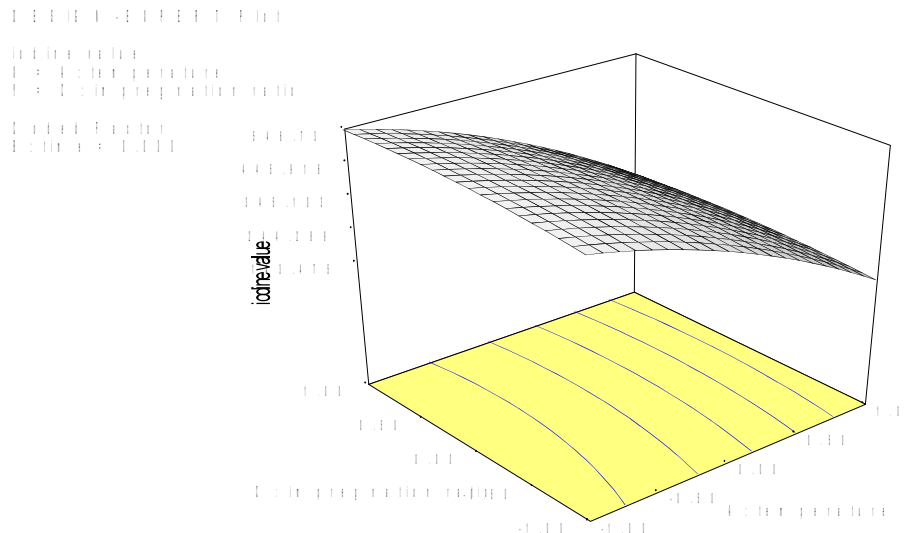


Fig 3: Combined effects of factors A-C on response (Iodine Value)

#### DESIGN-EXPERT Plot

iodine value  
X = B: time  
Y = C: impregnation ratio

Coded Factor  
A: temperature = 0.000

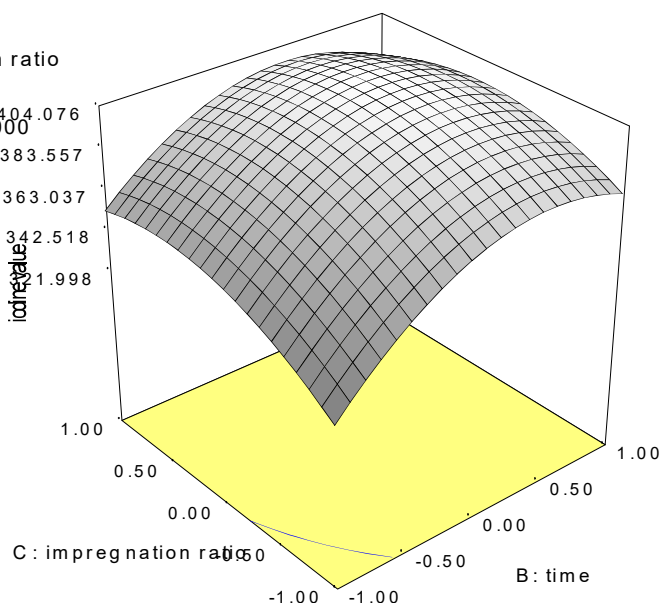


Fig 4: Combined effects of factors B-C on response (Iodine Value)

### 3.8 Bulk Density

Bulk density is also an important characteristic of activated carbon as it is a measure of the amount of adsorbate the carbon can hold per unit volume. The experiment revealed that the bulk density of the coconut shell activated carbon produced at 400°C, 10mins and 1:1 impregnation ratio was 0.6402g/cm<sup>3</sup>. This value could be due to the fact that the parameter depends largely on the starting raw material (coconut shells) as well as the temperature and time of activation. It was observed that the bulk density of the prepared coconut shell activated carbon was high and similar to those reported in literature. Bulk density of commercial carbons in the range of 0.47 to 0.54g/cm<sup>3</sup> have been reported by a previous researcher (Rao *et. al.* 2003). Higher bulk density also imparts more mechanical strength on activated carbon (Balakrishnan and Satyawali 2007).

### 4.0 CONCLUSION

This study indicates that activated carbon can be obtained from coconut shell by controlled activation with phosphoric acid using RSM software. Optimization revealed that the optimum production condition for coconut shell granular activated carbon is 400°C activation temperature at activating time of 10mins and impregnation ratio 1:1. Characteristics of activated carbon produced at this condition were; yield of 96.69 %, bulk density of 0.6402 g/cm<sup>3</sup> and iodine value of 568.512 mg/g. Experimental data showed that moderately high temperature resulted in better activation as demonstrated by the trend of

iodine value; however very high temperatures reduced the yield of the activated carbon produced. The iodine value increased with activation temperature up to 400°C, beyond which it gradually decreased, presumably due to excessive carbonization. Also, yield was low for the two steps chemical activation method due to the double thermal decomposition.

### REFERENCES

- Balakrishnan M. and Satyawali Y.(2007), Removal of color from biomethanated distillery spentwash by treatment with activated carbons, *Bioresource Technology*, 98, 2629-2635
- Basu J.K, D. Monal, and G. Pinaki,(2012) "Statistical optimization for the prediction of ibuprofen adsorption capacity by using microwave assisted activated carbon," *Archives of Applied Science Research*, vol. 4, no. 2, pp. 1053–1060.
- Cazetta, A.L.; Vargas, A.M.M.; Nogami, E.M.; Kunita, M.H.; Guilherme, M.R.; Martins, A.C.; Silva, T.L.; Moraes, J.C.G.; Almeida, V.C (2011). NaOH-activated carbon of high surface area produced from coconut shell: Kinetics and equilibrium studies from the methylene blue adsorption. *Chem. Eng. J.*, 174, 117–125.
- Collin G.J., Fauziah A.A., Hasnul F.M.Z. & Siti F.D. (2006). Treatment of landfill leachate in



- Gergova, K., Petrov, N., and Eser, S. (1994). Adsorption properties and microstructure of activated carbons from agricultural by-products by stream pyrolysis. *Carbon*, 32 (4), 693-702.
- Gimba C, Ocholi O, Nok A (2004). Preparation of A.C from Agricultural wastes II. Cyanide binding with activated carbon matrix from groundnut shell. *Nigerian Journal of Scientific Research*; 4(2): 106-110
- Itodo AU, Abdulraham FW, Hassan LG Maigandi SA, Happiness UO (2009a). Thermodynamic equilibrium, kinetics and adsorption mechanism of industrial dye removal by chemically modified poultry droppings activated carbon. *Nigerian Journal of Basic and Applied Science*; 17(1): 38-43
- Itodo AU, Abdulrahman FW, Hassan LG, Maigandi SA, Abubakar MN (2009b). Activation Chemistry and kinetic studies nut shells biosorbent for textile waste water treatment I. *Journal of research in Science, Education, Information And Communication Technology*; 1(1):168-177.
- Kirubakaran, C. J., Krishnaiah, K. and Seshadri, S.K. (1991), "Experimental Study of the Production of Activated Carbon from Coconut Shells in a Fluidized Bed Reactor". *Ind. Eng. Chem. Res.*, Vol. 30, 2411-2416.
- Lee, J., Ye, L., Landen, W.O. and Eitenmiller, R.R. (2000) 'Optimization of an extraction procedure for the quantification of vitamin E in tomato and broccoli using response surface methodology', *Journal of Food Composition Analysis*, Vol. 13, pp.45-57.
- Li, W.; Yang, K.; Peng, J.; Zhang, L.; Guo, S.; Xia, H (2008). Effects of carbonization temperatures on characteristics of porosity in coconut shell chars and activated carbons derived from carbonized coconut shell chars. *Ind. Crop. Prod.*, 28, 190-198.
- Myers, R.H. and Montgomery, D.C. (1995) *Response Surface Methodology: Process and Product Optimization Using Designed Experiments*, first ed., John Wiley & Sons, Inc., New York.
- Rao R.M., Bansode R.R., Losso J.N., Marshall W.E. and Portier R.J. (2003), Adsorption of volatile organic compounds by pecan shell and almond shell-based granular activated carbons, *Bioresource Technology*, 90, 175-184
- Rao, M.M.; Rao, G.P.C.; Seshiah, K.; Choudary, N.V.; Wang, M.C (2008). Activated carbon from Ceiba pentandra hulls, an agricultural waste, as an adsorbent in the removal of lead and zinc from aqueous solutions. *Waste Manag.*, 28, 849-858.
- Shaski S, and Yankie H (2002). Evaluation of different grade of granular activated carbon adsorbent for scavenging priority pollutant from waste water. *Asian journal of chemistry*; 14(2): 1009-1026
- Tan I.A.W, A. L. Ahmad, and B. H. Hameed, (2008) "Preparation of activated carbon from coconut husk: optimization study on removal of 2,4,6-trichlorophenol using response surface methodology," *Journal of Hazardous Materials*, vol. 153, no. 1-2, pp. 709- 717.
- Tharapong, V., Terachai, S. and Somsak, D. (1999), "Production of Activated carbon from Palm-oil Shell by Pyrolysis and Steam Activation in a Fixed Bed Reactor", *Science Asia*, Vol. 25, 211-222
- Woodroof, J. G. (1979), "Coconuts: Production Processing Product", 2nd Edition, AVI Publishing Co, Inc.
- Mozammel MH, Masahiro O, and Bhattacharya SC (2002). Activated charcoal from coconut shell using  $ZnCl_2$  activation. *Biomass and Bioenergy*; 22(5):397- 400

