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Optimization of Conditions for the Preparation of Activated Carbon from Mango Nuts using HCl

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***Abstract:* -** Activated carbon was prepared from mango nuts by chemical activation method using HCl, herein referred to as MNAC. The effect of experimental variables; temperature, concentration, impregnation ratio and carbonization time on the quality of the activated carbon- surface area, carbon yield and ash content were investigated. The response surface methodology (RSM) technique was used to optimize the production conditions. The influence of the studied production parameters on the activated carbon produced was investigated using the analysis of variance (ANOVA) to identify the significant variables. The optimum preparation conditions for preparation of the MNAC were obtained a follows: carbonization temperature of 212.1°C, HCl concentration of 100%, 30 min resident time and 1ml/g mix ratio. This resulted in the activated carbon with 5.92% ash content, 1142.3 m^2/g surface area and 63.2% carbon yield. It was observed that the experimental values obtained were in good agreement with the values predicted by the model with relatively small errors between the predicted and the actual values (0.33, 0.18 and 1.94 for ash content, surface area and carbon yield respectively).

***Keywords:* -** *Activated carbon, Conditions, HCl, Mango nuts, Optimization.*

I. INTRODUCTION

Mango, *magnifera indica,* is a major waste in Makurdi, the capital city of Benue state especially during its harvesting season as farmers from different part of the state find a ready market in Makurdi.The edible part of mango is the peel and the fibrous material. The pit is not a consumable part of mango and is usually discarded as waste. Mango has become and economically important species since its demand domestically and for export has increased tremendously. Due to the high consumption of the edible part, massive amount of mango nut are disposed causing gradual fermentation and subsequent release of odour [1]. To make better use of cheap and abundant agricultural waste, it is proposed to convert mango nut waste into activated carbon. This conversion will address problems of unwanted agricultural wastes been converted into useful, value- added adsorbent and also the use of agriculture by- products to represent potential source of adsorbent which will largely address problems of waste management. However, not many studies have been reported on converting mango nut into activated carbon. Some relevant studies found in literature were reported by other authors [2-5]. A challenge in activated carbon production is to produce very specific carbons which are suitable for certain application. The most important characteristics of an activated carbon is it adsorption capacity which is highly influenced by the preparation conditions [6]. In assessing the effect of the treatments on quality attribute, the use of an adequate experimental design is particularly important. Response Surface Methodology (RSM) has been found to be a useful tool to study the interaction of two or more variables [7]. Optimization of experimental conditions using RSM has widely been applied in various processes; however, its application in activated carbon production is rare. Some previous studies reported using RSM in optimizing the production of activated carbon with other agricultural wastes were reported by other authors [7- 10]. As far as known, no study has been carried out using RSM approach in analysing the production process of activated carbon with mango using HCl as activating agent.

In the present study, the optimal experimental conditions required to obtain adequate activated carbon with desirable properties in terms of carbon yield, surface area and ash content, which are critical in determining a good quality activated carbon for a wide range of adsorption applications were determined. A modelling technique was applied to relate the experimental conditions of the activation process with properties of activated carbon. A good quality activated carbon should have low ash content as possible. Faust and Aly [11], suggests that typical values of ash content should be in the range of 5 – 6% and about 85 – 90% for carbon content. As the carbon content of the activated carbon increase, the surface area also increases. High carbon content value is desired to achieve high surface area. Bacaoui *et al*, [8] reported that for economic viability, activated carbon should have a carbon yield of 10- 20% and a surface area of 1000- 1300 m^2/g. Using olive-waste cake waste, Ahmad and Alrozi [12] reported a carbon yield of 20.76%; Aloko and Adebayo [13] reported 1620m^2/g surface area, 148.20% ash content and 29.24% carbon yield using mango peel; Sahu *et al* [10] reported a carbon yield value of 46.08% using Tamarind wood; Hameed *et al*, [14] reported a carbon yield of 17.96% and a surface area of 1141m^2/g. The inorganic material contained in activated carbon is measured as the ash content and this value should be in range of 2-10 % [15]. The ash content generally gives a good idea about the inorganic constituents associated with carbon obtained by different carbonization methods. Low value of ash content indicates that the inherent carbon in the starting material is high [16]. Soleimani and Kaghazchi [17] reported that activated carbon with high ash content is undesirable because it reduces the absorption capacity and mechanical strength of activated carbon.

The main objective of the paper is to determine the suitable experimental conditions; carbonization temperature, activation time, concentration and impregnation ratio required to prepare activated carbons from mango nuts for effective use in a variety of adsorption application. Also, to select indigenous raw materials of agricultural origin (mango seeds), explore the potential of producing activated carbons from mango nut wastes and carry out studies to explore the possibility of obtaining high quality activated carbons.

II. MATERIALS AND METHODS.

2.1 Preparation of the activating agent (HCl). 25, 50 and 75 *ml* of hydrochloric acid was added to 75, 50 and 25 *ml* of distilled water to obtain 25, 50 and 75 % volume concentrations of acid activating agent respectively. For 100 % volume concentration, no distilled water was added (it was used undiluted) so that it remained in 100 % volume concentration [18].

2.2 Preparation and carbonization of mango seeds. In the preparation of the mango seeds, the procedure is described hence was follows. First, the dried mango nuts collected were cracked using hammer and the seeds were then removed from the nuts and were dried under sun light at room temperature for two weeks after which they were crushed using laboratory mortar and pestle. The resulting particles were again sun-dried for 5 hours to remove any residual moisture left in them. The particles were then sieved using 6*mm* sieve size and used for the rest of the experimental work. The sieved samples were then impregnated with different concentrations of the activation agents (25%, 50%, 75% and 100%). 50*g* of the samples was measured and impregnated (mixed) with 50*ml*, 100*ml*, 150*ml* and 200*ml* of the various activating agents to obtain ratios of 1:1, 1:2, 1:3 and 1:4 *ml/g* respectively. The impregnated samples were left at room temperature for 24 hours. After impregnation, the excess solutions were filtered off and the remaining material dried for three days at room temperature. Finally the resulting samples were carbonized in a pre- heated furnace at temperatures of 200, 400, and 600^oC for durations of 30, 60, 90 and 120 minutes. The activated carbons were rinsed with distilled water, dried at 750^oC temperature for 1 hour in the furnace and crushed to obtain particle sizes of *3mm* by passing the crushed carbon through sieve size 300μm. Care was taken to ensure the material was not forced through the sieve by hand pressure.

2.3 Characterizations of the products

Ash Content Determination: The ash content of MKAC produced was determined by the standard test method for ash content- ASTM D2866-94. A crucible was pre- heated in a furnace to about 500^oC, cooled in a desiccator and weighed. 1.0g of MKAC was transferred into the crucible and reweighed (oven dry weight). The crucible and sample were then placed in the furnace and temperature was raised to 500^oC. The sample was removed and allowed to cool in a desiccator to room temperature and reweighed (ash weight). The ash content was calculated using equation 1.

$$Ash\ content(\%) = \frac{Ash\ weig\ ht(g)}{Over\ dry\ weig\ ht(g)} \times 100 \qquad (1)$$

Surface Area Determination: The diameter (assuming spherical shape) of the activated carbon was obtained by passing the crushed carbon through sieve size of 300µm and the external surface area was calculated by the relation;

$$Surface\ area,\ S_A = \frac{6(cm^2/g)}{B_d P_d} \qquad (2)$$

B_b = bulk density

P_d= particle size (particle diameter)

A measuring cylinder was weighed, and then filled with the prepared sample of MKAC and gently tamped until no change in the level of the sample was observed. The volume occupied by the packed sample was recorded as V_s, if W_c is the weight of the empty cylinder and W, the weight of the cylinder and sample, then, weight of the sample W_s was obtained by $W_s = W - W_c$ [20]

The bulk density was calculated using equation 3.

$$B_d\left(\frac{g}{mL}\right) = \frac{W_s}{V_s} \qquad (3)$$

Where V_s, is the volume occupied by the packed sample

Activated Carbon Yield

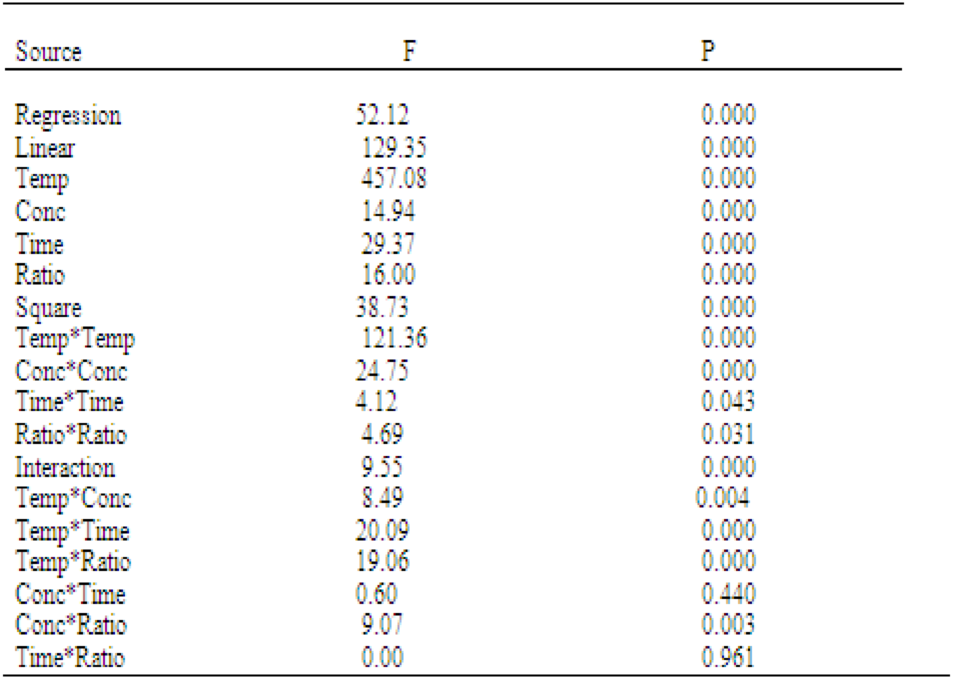
The dried weight, W_{ca} of each carbon sample was determined and the carbon yield (CY) was calculated as follows;

$$CarbonYield = \frac{W_{ca}}{W_f} \times 100\% \ [21] \qquad (4)$$

Where, W_{ca} = oven dried weight of carbon sample,
W_f = weight of carbon retrieved from the furnace.

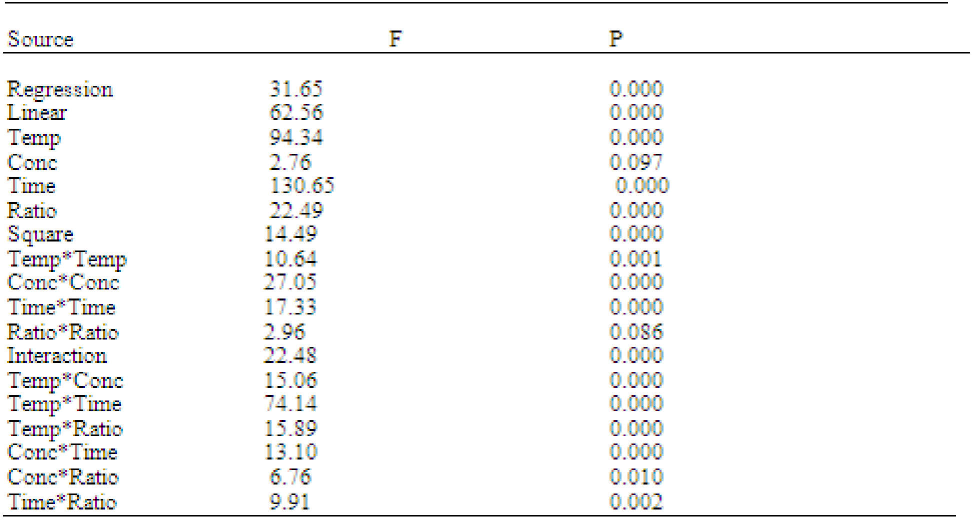
III. RESULTS

Table 1: ANOVA for ash content (HCl)



Source	F	P
Regression	52.12	0.000
Linear	129.35	0.000
Temp	457.08	0.000
Conc	14.94	0.000
Time	29.37	0.000
Ratio	16.00	0.000
Square	38.73	0.000
Temp*Temp	121.36	0.000
Conc*Conc	24.75	0.000
Time*Time	4.12	0.043
Ratio*Ratio	4.69	0.031
Interaction	9.55	0.000
Temp*Conc	8.49	0.004
Temp*Time	20.09	0.000
Temp*Ratio	19.06	0.000
Conc*Time	0.60	0.440
Conc*Ratio	9.07	0.003
Time*Ratio	0.00	0.961

Table 2: ANOVA for surface area (HCl)



Source	F	P
Regression	31.65	0.000
Linear	62.56	0.000
Temp	94.34	0.000
Conc	2.76	0.097
Time	130.65	0.000
Ratio	22.49	0.000
Square	14.49	0.000
Temp*Temp	10.64	0.001
Conc*Conc	27.05	0.000
Time*Time	17.33	0.000
Ratio*Ratio	2.96	0.086
Interaction	22.48	0.000
Temp*Conc	15.06	0.000
Temp*Time	74.14	0.000
Temp*Ratio	15.89	0.000
Conc*Time	13.10	0.000
Conc*Ratio	6.76	0.010
Time*Ratio	9.91	0.002

Table 3: ANOVA for carbon yield (HCl)

Source	F	P
Regression	16.75	0.000
Linear	21.52	0.000
Temp	20.75	0.000
Conc	0.04	0.840
Time	65.17	0.000
Ratio	0.12	0.726
Square	25.58	0.000
Temp*Temp	4.70	0.031
Conc*Conc	93.88	0.000
Time*Time	3.66	0.056
Ratio*Ratio	0.10	0.756
Interaction	7.69	0.000
Temp*Conc	28.78	0.000
Temp*Time	12.70	0.000
Temp*Ratio	3.75	0.053
Conc*Time	0.26	0.610
Conc*Ratio	0.45	0.502
Time*Ratio	0.21	0.651

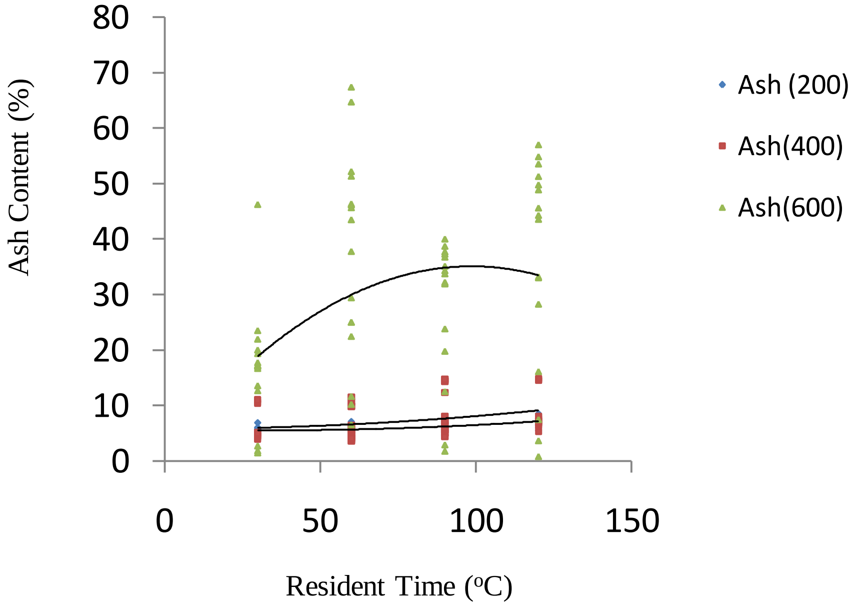


Fig. 1: Effect of Resident Time on Ash Content at the studied Temperatures (HCl)

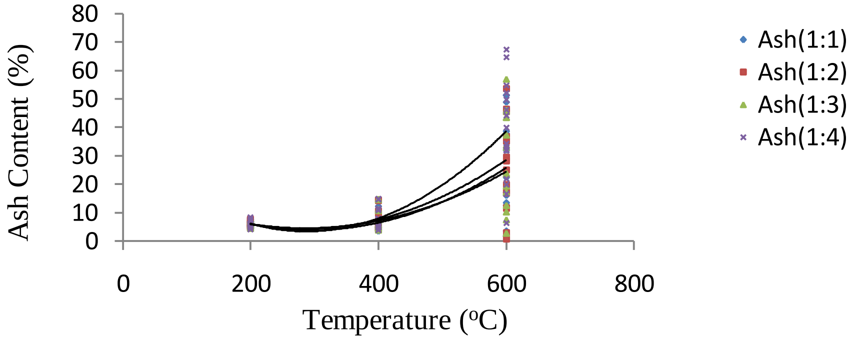


Fig. 2: Effect of Temperature on Ash Content at the studied Impregnation Ratios (HCl)

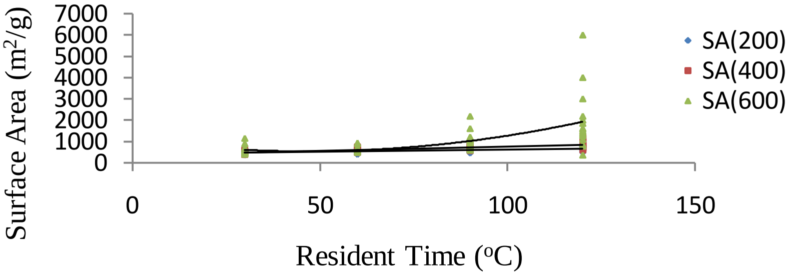


Fig. 3: Effect of Resident Time on Surface Area at the studied Temperature (HCl)

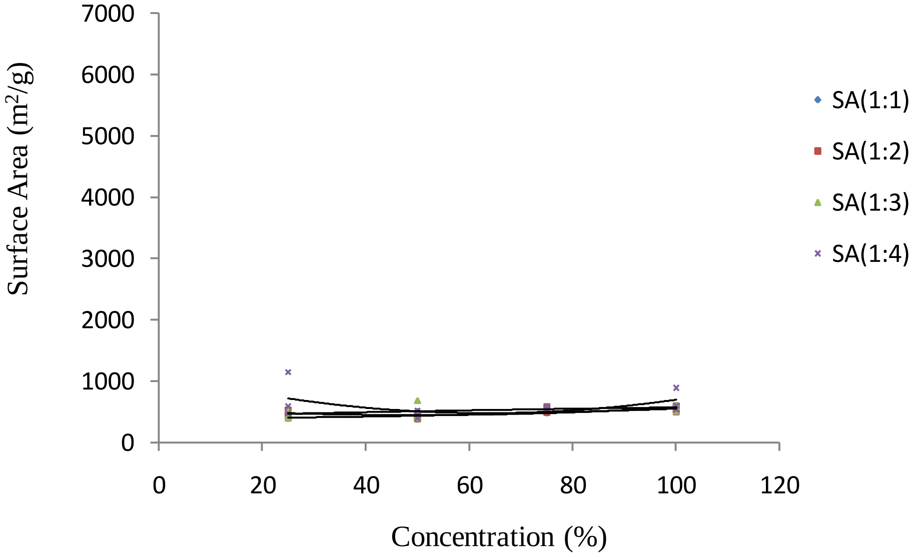


Fig. 4: Effect of Concentration on Surface Area at the studied Impregnation Ratios (HCl)

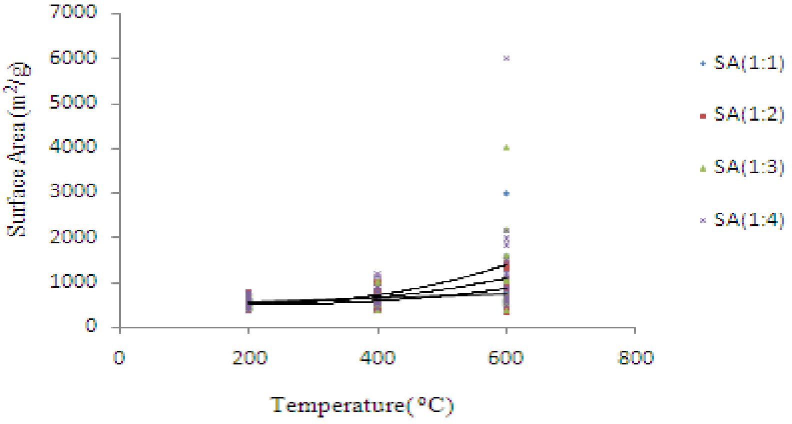


Fig. 5: Effect of Temperature on Surface Area at the studied Impregnation ratios (HCl)

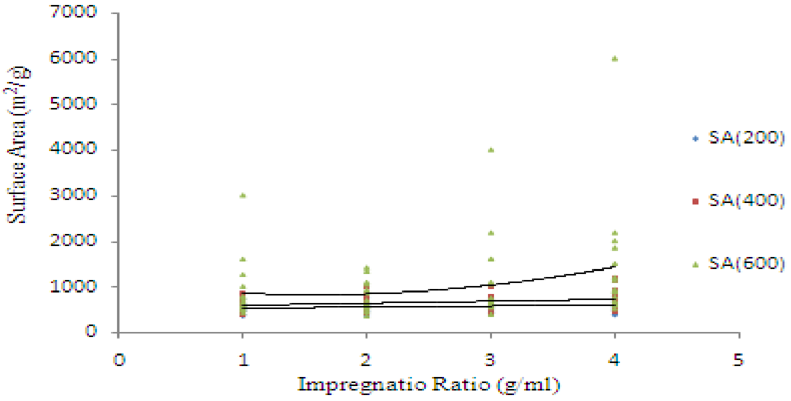


Fig. 6: Effect of Impregnatio Ratio on Surface Area at the studied Temperatures (HCl)

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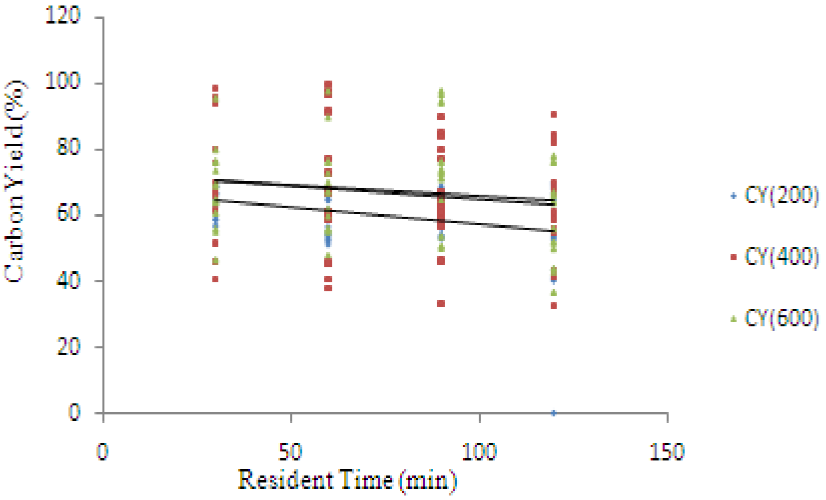

Fig. 7: Effect of Resident Time on Carbon Yield at the studied Temperature (HCl)

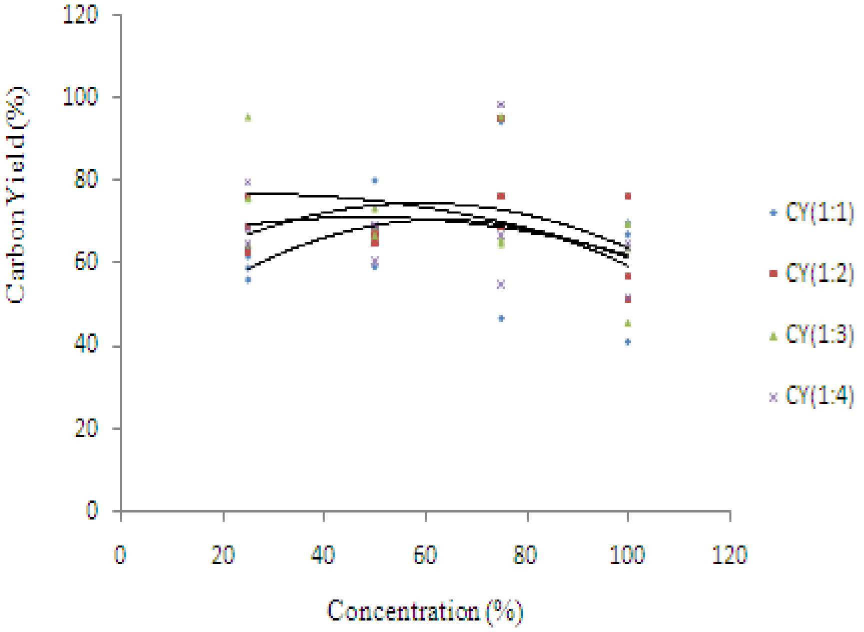

Fig. 8: Effect of Concentration on Carbon Yield at the studied Impregnation Ratios (HCl)

Table 4: Software generated conditions responses at optimal global conditions with desirability

Activating Agent	Ash Content (%)	Surface Area (m^2/g)	Carbon Yield (%)
HCl	5.92	1142.3	63.27
(Desirability)	(1)	(0.903850)	(1)

Table 5: Model validation analysis

Temp.(%)	Conc.(%)	RT(min)	IR(ml/g)	Ash (%)		SurfaceArea (m^2/g)		Carbon Yield (%)	
				Prtd.	Extl.	Prtd.	Extl.	Prtd.	Extl.
212.1	100	30	1	5.92	5.90	1142.3	1140.2	63.27	64.5

Prtd = Predicted value
Extl = Experimental value
RT = Resident Time
IR = Impregnation Ratio

IV. DISCUSSION

Fig. 1 shows the effects of residence time on ash content at the various temperatures studied. The interaction of temperature and time was observed to be significant as seen in the ANOVA for ash content in Table 1, with a P- value of 0.000. This indicates that the effect of temperature on ash content depends on the residence time. It was observed that the ash content of the MNAC increases with increase in residence time at all the temperatures studied, showing significant quadratic relationship with ash content (P- value of 0.043). Generally, ash content increases as the carbonization temperature increases. At 600°C however, ash content starts to decrease. The ANOVA for ash content indicates that, the interaction of temperature and impregnation ratio was significant with a P- value of 0.000. This suggests that the effect of temperature on ash content was also dependent on the impregnation ratio. Also, Table 1 suggests that impregnation ratio has significant quadratic relationship with ash content with a P- value of 0.031. The quadratic coefficient for impregnation ratio was -4.9546 indicating that as the impregnation ratio increases the ash content decreases. A similar trend was observed by Usmani *et al*, [22]. They observed that increasing the impregnation ratio gradually decreases the ash content using $CaCl_2$ as the activating agent. KCl however showed no effect. Generally HCl, $ZnCl_2$ and $CaCl_2$, have good ash reduction action especially on raw materials of vegetable origin.

Fig. 2 shows the effect of temperature on ash yield at all levels of impregnation ratios studied. It was observed that ash output increases as the temperature increases at all impregnation ratios. Temperature effect on ash content at the various mix ratios was however discussed in the paragraph above. The ANOVA for ash content in Table 1 shows that the interaction of temperature and mix ratio is significant (P- value of 0.000). This suggests that the effect of temperature on ash content depends on the mix ratio. The increase in ash yield was however within accepted range of 5-6% when activation was carried out at lower temperatures. This observation could be due to the highly corrosive nature of HCl on the precursor such that longer activation became detrimental to targeted yield of carbon. Longer activation durations intensify dehydration and elimination reactions increasing volatiles in the system resulting in ash increase [23]. The trend observed was consistent with results of Adel *et al*, [24] using HCl. In their report, the ash yield increases from (20.79-21.95) for rice husk while the ash content for beans husk decreased from (1.63-1.48). The discrepancies could be due to the lignocellulosic content of the precursors used. The nature of the result could be traced to the fact that the low boiling point of the activating agent (HCl) caused it to vaporize easily leaving a dry precursor thus enhancing burn-off yielding ash as the duration of carbonization increases. Also the difference in behaviour could be due to the different lignocellulosic composition of the precursor thus reacting differently when in contact with the activating agent. According to the other studies, the difficulties arising from the complex composition of lignocellulosic materials and the activating agents as well as from the large number of complex reactions involved in the pyrolysis process makes it difficult to achieve precise models describing pyrolysis mechanism [5]. The interaction of temperature and concentration was significant with a P-value of 0.004 as seen in Table 1. This suggests that the effect of temperature on ash content also depends on the concentration which in turn depends on the impregnation ratio. Generally, the effect of the studied parameters on ash content can be said to be synergistic with all the parameters contributing significantly to the ash content of the MNAC produced. In Table2 the ANOVA for surface area suggests that the model is significant with the linear, quadratic and interaction terms all significant. Table 2 also indicates that the interactions of temperature and concentration, temperature and time, temperature and ratio, concentration and time, concentration and ratio as well as time and ratio are all significant with P- values of 0.000, 0.000 0.000, 0.000, 0.010 and 0.002 respectively. This observation suggests that the effect of temperature on ash content depends on both the concentration of HCl as well as the impregnation ratio. The effect of concentration on surface area depends on carbonization temperature and impregnation ratio and the effect of carbonization time on the ash content depends on the impregnation ratio. Fig. 3 shows the effect of carbonization time on the surface area at the temperatures studied. The Fig. indicates that as the carbonization duration increase, the surface area also increases. The increase was observed to be gradual at lower temperatures of 200 and 400°C. However, at 600°C, the increase was sharp. In Table 2, resident time and carbonization temperature play decisive role in the surface area of MNAC produced. This observation was similar to that of Tan [6] using KOH as activating agent. Generally, as the temperature rises and duration in the furnace increases, the C- HCl and C- CO_2 reaction rates increase resulting in increasing devolatilization which further develop the rudimentary pore structure in the char and also enhance the existing pores thus creating higher surface area and higher porosities. Besides, the increase in temperature also caused the CO_2 and the surface metal complexes to further gasify the carbon leading to widening of mesopore to macropore [23]. Fig. 4 shows the effect of concentration on the surface area at the ratios studied. The Fig. shows a little increase, though significant, in surface area as the concentration increases. However, it was observed from the graph that within the concentrations used in the research, no maximum point was reached. In Fig. 7, the increasing trend of surface area observed can be explained by the fact that carbon gasification was enhanced by increase in impregnation ratio and residence time thus causing the removal of carbon atoms on pore walls, which increase surface area [25]. Fig. 5 shows the effect of temperature on surface area at the studied residence time. The ANOVA for surface area in Table 2 suggests that the interaction of temperature and impregnation ratio was highly significant (P- value of 0.000). This indicates that, the effect of temperature on surface area was largely due to the resident ratio. The increase of temperature and impregnation ratio enhances the existing pores leading to higher surface area and higher absorption rates. In Fig. 5, surface area was observed to increase with increasing temperature. This observation could probably be due to drastic expansion of the carbon material leading to the creation of large surface area. Similar results were obtained by Diao *et al*,[26] using sorghums, they found that, for temperatures lower than 500°C, microporous carbons with small surface areas were observed, however, at temperature of 600°C, high surface areas were observed. Prahas *et al*, [27] also observed similar results. They found that as temperature and impregnation ratio increase the surface area also increases. The optimum activation temperature for higher surface area was found to be 450°C for coconut shells impregnated with phosphoric acid [28] and 500°C for rubber wood dust [29]. The observation in the present work could probably be due to the depolymerization of cellulose in the reaction as concentration increases resulting in tar formation. The temperature of activation has significant effects on the development of carbon's porous networks and should just be enough to eliminate all the moisture and most of volatile components in the precursor to cause pores to develop. Since the end of the volatile evolution marks the formation of the basic pore structure, activation should be limited up to a point. Higher temperatures cause enlargement of pores at the expense of the surface area. Also, control of the activation temperature is of economic interest since shorter durations are generally desired as this is equivalent to reduction in energy consumption. Fig. 6 shows the increase of surface area with increasing impregnation ratio. It was found that the highest surface area was obtained at ratio 1:4 for temperature of 600°C. At temperatures of 200 and 400°C, only a gradual increase in surface area was observed after undergoing activation process, it was expected that the volatile matter content decreases significantly whereas the fixed carbon content increases. This observation could have been due to pyrolytic effect at high temperature where most of the organic substance have degraded and discharged both as gas and liquid tars living the material with high carbon purity [6].

The ANOVA for carbon yield in Table 3 suggests that the regression model was significant. All the levels of the model, linear quadratic and interaction terms, were significant with P- values 0.000 for each. The interactions of temperature and concentration, time and temperature as well as temperature and ratio were significant with P- values of 0.000, 0.000 and 0.053 respectively. The quadratic effects of temperature and concentration were also significant with P- values of 0.031 and 0.000 respectively. Fig. 7 shows the effect of residence time on carbon yield using HCl at the temperatures studied. The Fig. suggests the linear relationship of time with carbon yield. It shows that carbon yield decreases as the residence time increases at all temperatures of activation studied. The interaction of time and temperature was also significant. This could be because longer carbonization durations mean higher probability of the carbon to be exposed to the steam atmosphere; hence higher chance for the activation reaction to take place. Based on the activation, higher temperature and longer reaction time means more carbon will react and more gasification will occur that will increase the ash content with extra reactions taking place, more carbon will be consumed and there will be low carbon yield [30]. Similar trends were observed by Chan *et al*, [30] using HCl and tyres precursor, Adel *et al* [24] using Rice husk and beans husk with HCl activation agent. However the yield obtained using HCl was higher than fixed carbon of the mango nuts. Essentially, mango nuts are complex composite material formed of natural polymers (cellulose, lignin and hemicellulose) during carbonization at high temperatures; these polymeric structures decompose and liberate most of the non-carbon elements, mainly hydrogen, oxygen and nitrogen in form of liquid (tars) and gasses leaving behind a rigid carbon skeleton in the form of aromatic sheet strips. The presence of HCl during activation promotes depolymerization, dehydration and redistribution of constituents' biopolymers and also favours the conversion of aliphatic to aromatic compounds thus increasing the yield of carbon yield [25].

The observation in Fig. 7 agrees with that observed by Sundaryanto *et al*, [31] where activated temperature was found to play an important role in the yield of activated carbon. The increase in temperature would release increasing volatiles as a result of intensifying dehydration, which HCl is noted for, elimination reaction and increase C-HCl reaction rates, thereby resulting in decreasing carbon yield [32- 33]. Indeed, the increase in temperature and time quickens the gasification reactions of carbon and therefore, attack the amorphous component which obstructs the pores causing decrease in carbon yield [8]. Sentorun- Shalaby *et al* [34] observed that at higher activation temperatures, activation of apricot stones becomes more extensive resulting in lower solid yield with more widened porous structure. The yield of activated carbon prepared from fir wood was also found to decrease gradually with carbonization duration. However, impregnation ratio promoted the yield of activated carbons. Similar trends were observed by Prahas *et al*,[27] although they used H_3PO_4 and Jack fruit peel waste as precursors. The observed result for carbon yield in the present work could be because; the reaction of lignocelluloses with HCl begins as soon as the components are mixed. The acid first attack hemicelluloses and lignin because cellulose is more resistant to acid hydrolysis [35]. Here, the acids will hydrolyse glycosidic linkages in lignocellulosic and cut aryl ether bond in lignin. These reactions are accompanied by further chemical transformations that include dehydration, degradation and condensation. As the temperature increase, aromatic condensation reactions also take place among the adjacent molecules which results in the activation of gaseous products, from hydro-aromatic structure of carbonized char leading to decrease carbon yield. Similar observation was reported by Adel *et al,* [24] using rice husk, when temperature was increases from 80-120°C using HCl as activating agent. However an increase in carbon yield was observed when they used HCl and beans husk. The differences would be due to the original lignocellulosic content and elemental composition of precursors used.

It is worthy of note in Figs. 2 and 5 that while ash yield was much at 600°C, carbon yield decreased at this same temperature and surface area increases at 600°C. Figs. 1, 3 and 7 show relationships of ash content surface area and carbon yield with time. Many researchers reported that there will be a drop in surface area after certain decrease of ash content. It was observed that the surface area of carbon produced will start to decrease when the ash content reached around 50% and up to 68% [36- 38]. Also, when there is a collapse in the micro pores, this might lower surface area but at the same time there is micro pore and meso pore formation which would increase the surface area [30]. As a result, the overall surface area increases despite high ash yield.

Fig. 8 shows the effect of concentration on the carbon yield at the various ratios considered. The interaction effect of concentration and ratio as seen in Table 3 was not significant (P-value = 0.45). The quadratic effect of concentration on surface area is significant with a P- value of 0.022. The Fig. suggests that surface area increase to a point where average concentration is 55% beyond which the surface area begins to drop. It was observed from the ANOVA in Table 3 that, for carbon yield, impregnation ratio generally did not show any significant contribution to carbon yield at both linear and quadratic levels. The interaction of temperature and ratio was almost not significant with a P- value of 0.053.

4.1 Prediction equations for HCl.

Response Surface Methodology (RSM) which is a collection of mathematical and statistical technique that is useful for modelling and analysis of problems in which a response of interest is influenced by several variables [38]. A 2FI (two factor interaction) polynomial regression model was developed to analyse the factor interaction and to identify the significant factors contributing to the model. The surface area, carbon yield and ash content are utilized in the quadratic model according to the propositions of the software. Analysis of variance was carried out to justify the adequacy of the model. The final empirical models for ash content, surface area and carbon yield respectively are shown in equations (5), (6) and (7). The suitability and quality of the model developed was evaluated using the correlation coefficient R^2 which are 66% for equation 5 above, 55% for equation 6 and 39% for equation 7. The high values of R^2 indicate good agreement between experimental data and the model prediction [39]. The coefficient with one factor represents the effect of the particular factor; while the coefficient with two factors and those with second- order terms represent the interaction between two factors and quadratic effect respectively. The positive sign in front of the terms indicates synergistic effect, whereas negative sign indicates antagonistic effect

$$\begin{aligned}&\mathrm{ASH=9.9970+11.5905TEMP+2.2958CONC+3.2186TIME+2.3756RATIO+10.3445TEMP^2-4.9546CONC^2-}\\&\mathrm{2.0221TIME^2+2.1572RATIO^2+2.1192TEMP*CONC+3.2600TEMP*TIME+}\\&\mathrm{3.1752TEMP*RATIO+0.6154CONC*TIME-2.3991CONC*RATIO-0.0385TIME*RATIO}\end{aligned} \tag{5}$$

$R^2 = 66\%$

$$\begin{aligned}&\mathrm{SA=382.21+236.48TEMP-44.31CONC+304.84TEMP+126.47RATIO+}\\&\mathrm{137.55TEMP^2+232.61CONC^2+186.19TEMP^2+76.90RATIO^2-}\\&\mathrm{126.75TEMP*CONC+281.25TEMP*TIME+130.19TEMP*RATIO-129.50CONC*TIME-}\\&\mathrm{93.05CONC*RATIO+112.67TIME*RATIO}\end{aligned} \tag{6}$$

$R^2 = 55\%$

$$\begin{aligned}&\mathrm{CY=70.0662-4.6502TEMP-0.2257CONC-9.0287TEMP+0.3921RATIO+3.8343TEMP2-18.1731CONC2-}\\&\mathrm{3.5889TIME2-0.5832RATIO2-7.3487TEMP*CONC-4.8825TEMP*TIME-}\\&\mathrm{2.6534TEMP*RATIO+0.7653CONC*TIME-1.007CONC*RATIO-0.6797TIME*RATIO}\end{aligned} \tag{7}$$

$R^2 = 39\%$

Low R^2 value for ash could be due to due to difficulty in handling combustion processes, however agreeable carbon yield of 63.27% was obtained as carbon yield from the raw materials.

4.2 Process optimization.

In the production of commercial activated carbons, high quality products are expected in terms of high surface area, high carbon yield and low ash content for effective adsorption capacity and economic viability.

However, to optimize all these responses under the same condition is difficult since the interest regions of factors are different. This is because, while higher carbon yield and surface area are desirable, ash content has to be low for a good quality activated carbon. In order to compromise between these three responses, the function of desirability was employed using MINITAB version 16 software as shown in table 4. The experimental conditions with the highest desirability were selected to be verified. The MNAC was then prepared using the experimental conditions given in table 5 including the predicted and experimental values. The optimal activated carbon using preparation conditions as: 212.1^{o}C carbonization temperature, 100% concentration of HCl, 30 min resident time and 1ml/g mix ratio which resulted in 5.92% ash content, 1142.3m^2/g surface area and 63.27% carbon yield. It was observed that the experimental values obtained were in good agreement with the values predicted from the model, with relatively small errors between the predicted and the actual values as seen in Table 5, which were only 0.33, 0.18 and 1.94 respectively for ash content, surface area and carbon yield. Through the process optimization, mango nut was proved to be a potential precursor for production of activated carbons with high surface area, high carbon yield and low ash content as required.

V. CONCLUSION

Mango nuts are good precursor for the production of activated carbons with characteristic high quality. The RSM methodology is an appropriate tool to study the optimization of the activation process of preparing activated carbons to be used in a given technological process. In the present paper, the optimization was done to obtain activated carbons from mango nuts with high surface, high carbon yield, low ash content suitable for adsorption applications. The experimental parameters analysed were temperature, concentration, and carbonization time and impregnation ratio. The optimal activated carbon was obtained using preparation conditions as: 212.1°C carbonization temperature, 100% concentration of HCl, 30 min resident time and 1ml/g mix ratio which resulted in 5.92% ash content, 1142.3 m^2/g surface area and 63.27% carbon yield which are quite satisfactory and suitable for a wide range of adsorption applications.

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