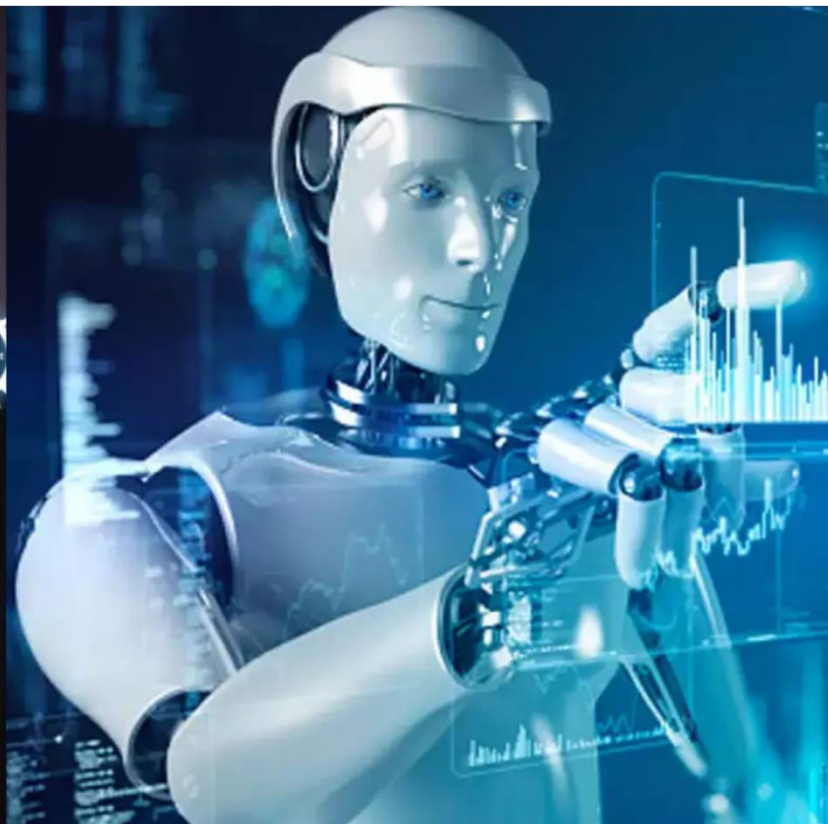




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Utilisation of Low-Cost Adsorbent made from Agro-Waste based Material for the Removal of Phenol from Aqueous Solutions

Monica K, Roopa D, Stephan B

M.E. Student, Department of Environmental Engineering, Gnanamani College of Technology, Namakkal,
Tamil Nadu, India

Assistant Professor, Gnanamani College of Technology, Namakkal, Tamil Nadu, India

Assistant Professor, Gnanamani College of Technology, Namakkal, Tamil Nadu, India

ABSTRACT: Jackfruit peel has been used to remove pollutants such as heavy metals, dyes, and phenols from wastewater. The peel's high surface area and functional groups make it effective in adsorbing various dyes, including methylene blue and Congo red. The peel has also been used to remove pharmaceutical pollutants, such as paracetamol and ibuprofen, from water. The waste products produced during the processing of pistachios are economically high valuable and have a strong affinity for phenols. Thus, the adsorption of phenol from aqueous solutions onto activated carbon made from pistachio wastes was investigated in this work. The mixture of jack fruit peel and Pistachio nut shell were evaluated as raw material in the production of an adsorbent for phenol removal from aqueous solutions. Phenol adsorption as a function of adsorption time, solution pH, adsorbent mass, and initial phenol concentration was optimized using response surface methodology (RSM). The Langmuir and pseudo first-order models, respectively, provided satisfactory descriptions of the adsorption kinetics and isotherms. Adsorption tests demonstrated that the adsorbent mixture's adsorption capability is greater than that of the individual adsorbents.

KEYWORDS: Phenol adsorption, Combined adsorbent, Jackfruit peel, Pista nut shell, UV-VIS spectrophotometry, SEM analysis

I. INTRODUCTION

Phenol is a toxic and carcinogenic compound widely used in various industrial processes, such as petroleum refining, chemical manufacturing, and pharmaceutical production. The release of phenol into the environment, particularly into water bodies, poses significant risks to human health and the ecosystem. Exposure to phenol can cause severe health problems, including skin irritation, liver damage, and even cancer. Conventional methods for phenol removal from aqueous solutions, such as activated carbon adsorption, chemical oxidation, and biological treatment, are often expensive and may generate secondary pollutants. Therefore, there is an urgent need to develop efficient, cost-effective, and environmentally friendly technologies for phenol removal.

Agro-waste based materials, such as rice husk, sugarcane bagasse, and coconut shell, have been increasingly recognized as potential low-cost adsorbents for water pollution control. These materials are abundant, inexpensive, and can be easily modified to enhance their adsorption capacities. This study aims to investigate the utilization of a low-cost adsorbent made from an agro-waste based material for the removal of phenol from aqueous solutions.

Jackfruit (*Artocarpus heterophyllus*) is a tropical tree native to parts of Asia and Africa, widely cultivated for its fruit, which is a rich source of nutrients. However, the processing and consumption of jackfruit generate significant amounts of waste, including the peel, which accounts for approximately 30-40% of the fruit's weight. The disposal of jackfruit peel waste poses environmental concerns, as it can contribute to greenhouse gas emissions, attract pests, and create unpleasant odors. Conversely, this waste can be valorized into valuable products, such as charcoal, which can provide economic benefits while mitigating environmental issues.

Pistachio nut shells are a significant waste product of the pistachio processing industry, accounting for approximately 50-60% of the total weight of pistachio nuts. Pistachio nut shell disposal presents environmental issues since it can produce offensive odors, draw pests, and increase greenhouse gas emissions. The process of turning pistachio nut shells into useful goods including activated carbon, biofuels, and biocomposites has gained popularity in recent years. Pistachio nut shells are a desirable feedstock for the synthesis of bio-based products due to their high lignin and cellulose content.

Charcoal production from biomass waste, including jackfruit peel, has gained attention in recent years due to its potential to provide a sustainable and renewable energy source. Charcoal produced from jackfruit peel waste can be used for various applications, including water filtration, cooking fuel, and soil amendment. This project aims to investigate the feasibility of converting jackfruit peel waste into charcoal, exploring its physical and chemical properties, and evaluating its potential applications. The outcomes of this research can contribute to the development of sustainable waste management practices, provide economic benefits to local communities, and promote the use of renewable energy sources.

The specific objectives of this research are: 1. To develop a low-cost adsorbent from an agro-waste based material. 2. To evaluate the adsorption efficiency of the developed adsorbent for phenol removal from aqueous solutions. 3. To optimize the adsorption process and explore the adsorbent's regeneration potential. This research is expected to contribute to the development of sustainable and cost-effective technologies for water pollution control, particularly for phenol removal from aqueous solutions.

II. MATERIALS AND METHODS

Every chemical employed in the research was of the highest caliber and analytical grade. Throughout the experiment, double-distilled water (DDW) was utilized. Spectrum Reagents and Chemicals Private Ltd. was the supplier of phenol, sulfuric acid (H_2SO_4), ferric chloride (FeCl_3), and hydrochloric acid (HCl). Local farmers in Panruti provided the jackfruit peel, and a nearby fruit store in Chidambaram provided the pista nut shell.

2.1 Preparation of Stock Solution:

One gram of phenol is dissolved in one liter of double-distilled water to create a stock solution with a concentration of 1000 mg/l. the solution dilutions produced by acquiring the necessary concentration of phenol solution.

2.2 Preparation of Adsorbent:

2.2.1 Preparation of Jackfruit peel Activated Carbon (JFPAC):

The undesirable sections of the jackfruit were removed, and the skin was separated from the bulb. After that, JFP were repeatedly cleaned with double-distilled water to get rid of dust and debris. Later, JFP was burned for 30 minutes at 400°C in a muffle furnace (Model: JSGW-1240D/1, India). Using a mortar and pestle, the charred peel was ground into a powder. Sulfuric acid was added to the powdered material in a 1:1 ratio. After that, it was repeatedly cleaned with double-distilled water until the extra acid was gone. By checking the pH of the cleaned water, which achieves a value of 7, it was verified that the excess acid had been removed. and then baked for six hours at 70°C in a hot air oven (Model: JSGW-1210D/4, India). The sample was sieved, to obtaining the particle size of $250\mu\text{m}$ is shown in Fig.2.2.1 and kept in air tight container.

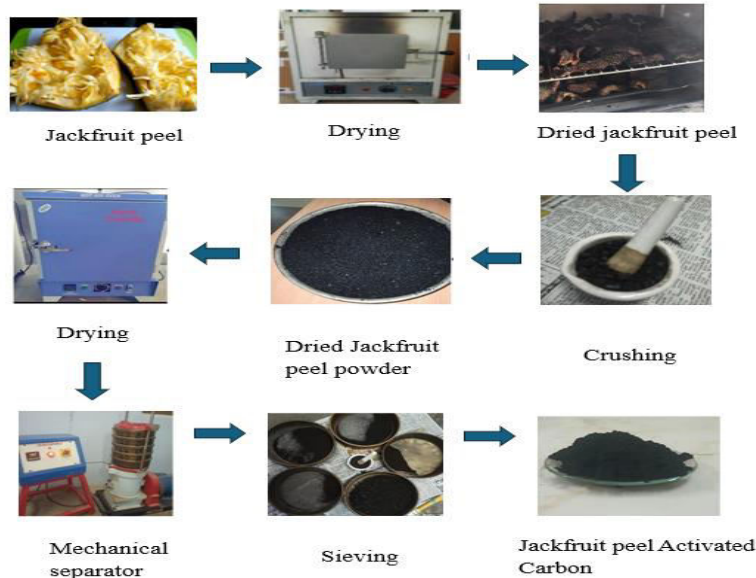


Fig:2.1 Preparation of Jackfruit peel Activated Carbon (JFPAC)

2.2.2 Preparation of Pista nut shell Activated Carbon (PNSAC):

To eliminate the oil and acid found in pista nut shells (PNS), they were cooked for one to two hours. After that, PNS were repeatedly cleaned with double-distilled water to get rid of dust and debris. PNS were then burned for 30 minutes at 400°C in a muffle furnace (Model: JSGW-1240D/1, India). Using a mortar and pestle, the acquired shells were ground into a powder. Sulfuric acid was added to the powdered material in a 1:1 ratio. After that, it was repeatedly cleaned with double-distilled water until the extra acid was gone. By checking the pH of the cleaned water, which achieves a value of 7, it was verified that the excess acid had been removed. and then baked for six hours at 70°C in a hot air oven (Model: JSGW-1210D/4, India).

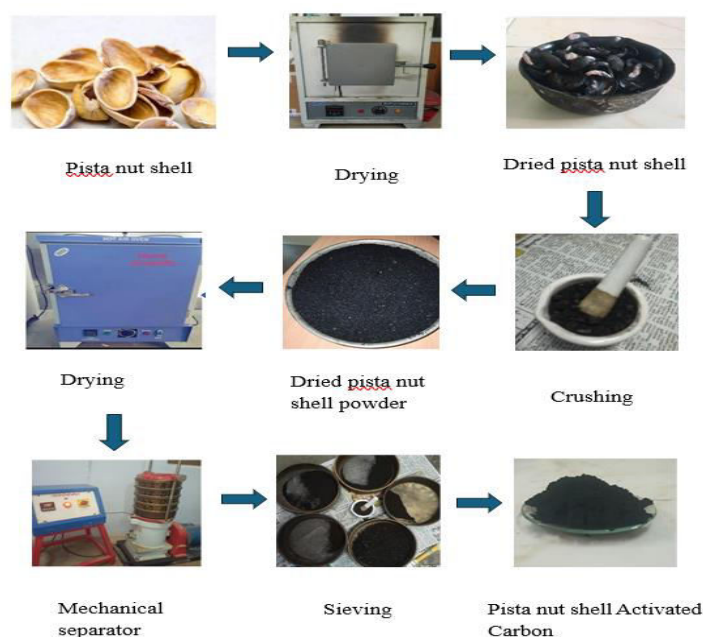


Fig:2.2 Preparation of Pista nut shell Activated Carbon (PNSAC)

2.2.3 Preparation of Combined Adsorbent:

Different proportions of Jackfruit peel activated carbon and pista nut shell activated carbon were taken into the glass beaker and mixed well with the help of glass rod to prepare the combined adsorbent and it is used for the experiment.

S.No	Composition of Combined Adsorbent	
	Jackfruit peel activated carbon (gm)	Pista nut shell activated carbon (gm)
1.	100	20
2.	80	40
3.	60	60
4.	40	80
5.	20	100

Table no:2.1 Composition of Combined Adsorbent

2.3 Preparation of Colour Reagent:

Ferric chloride was used as a coloring reagent in a spectrophotometric analysis of the phenol content of aqueous solutions. 1.61g of solid ferric chloride was dissolved in 100ml of distilled water to create the colorant. To stop further hydrolysis, one drop of a 35% HCl solution was added to the ferric chloride solution before it was diluted to the proper level.

2.4 Design of Experiment (DOE):

The values of the design parameters at which the response reaches its optimal state must be ascertained by the process engineers. The layout parameters may have the finest as one of their most or at least one of their features. Response Surface Methodology (RSM) was one of the approaches used to get the best outcomes. It was crucial for the experimental design process to be cost-effective in order to extract the most complicated information possible, significantly reduce the experimental time, and save money on both personnel and materials. The multivariate non-linear model served as the foundation for the statistical technique known as RSM, which has been extensively employed to optimize the adsorption process factors.

2.4.1 Response Surface Methodology (RSM):

The "change-one-factor-at-a-time" approach was the traditional optimization technique that involved varying one independent variable or factor while fixing all others at a predetermined level. Additionally, this could result in fewer accurate results and inaccurate impacts. Regression analysis and factorial designs are two components of Response Surface Methodology (RSM), which can better handle multifactor investigations. The current study was conducted with the intention of optimizing process parameters for phenol adsorption.

Parameters	-2	-1	0	+1	+2
Time (h)	2	3	4	5	6
Temp.(°C)	30	40	50	60	70
Conc.(mg/l)	100	150	200	250	300
Dosage(g)	0.4	0.8	1.2	1.6	2.0

Table no:2.2 Process Parameter Range for Phenol Removal

The coefficient of determination R^2 expresses the second order equation's quality of fit, while the F-test determines its statistical significance. The student's t-test is used to assess each coefficient's significance. The MINITAB 16 software version is used to calculate the equation's coefficients. The same software program is also used to obtain the analysis of variance (ANOVA) for the final predictive equation and optimization values, which shows whether the variable is more or less significant.

2.5 EXPERIMENTAL PROCEDURE:

The batch mode studies were conducted. The range and level of the variables are given in Table 3.1. Experiments are carried out according to the Central composite design given in Table 3.2. The experiments were performed in 250ml conical flask having 100ml of phenol solution. Adding combined adsorbent made of Jackfruit peel activated carbon and Pista nut shell. The mouth of the sample containing conical flasks were covered with aluminium foil to avoid spillage. The samples were kept in water bath shaker at 150rpm. Later adsorbents are separated from the sample solution by using Centrifuge at 1500 rpm for 8-10mins. After separation 10ml of sample solution was taken and adding 1ml of colouring solution (Ferric chloride solution). The reaction between phenol and ferric chloride occurs in 1-2 mins. The residual concentration of phenol is determined by UV-VIS spectrophotometer (Model: BL-200, ELICO, India) at wavelength of 540nm Fig.3.7.1.

2.6 CALIBRATION CURVE:

In order to check the concentration phenol solution after the adsorption by using calibration curve, plotting Absorbance Vs Concentration (mg/l).

S.NO	CONCENTRATION (mg/l)	ABSORBANCE
1.	100	0.019
2.	200	0.043
3.	300	0.067
4.	400	0.085
5.	500	0.099
6.	600	0.118
7.	700	0.135
8.	800	0.159

Table no:2.3 Tabulation for Calibration Curve

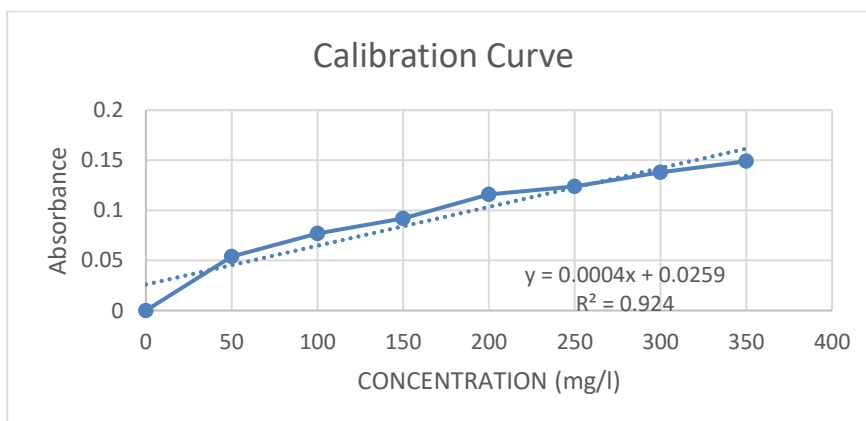


Fig:2.3 Calibration Curve

III. RESULTS AND DISCUSSION

3.1 PHYSICAL CHARACTERIZATION OF THE ADSORBENT:

To create the five distinct samples of combined adsorbents, varying amounts of pista nutshell and jackfruit peel activated carbon were added to a glass beaker and well mixed with a glass rod. The third percentage has the maximum adsorption capacity out of the five distinct ratios of mixed adsorbents. Jackfruit peel activated carbon adsorbs more phenol than pista nutshell activated carbon. The sample used for additional analysis was a mixed adsorbent made with an equal amount of pista nutshell and jackfruit peel activated carbon, which has the maximum efficiency. The surface

area, pore volume and mean pore distribution of the adsorbent were evaluated by surface area analyzer methods, the results obtained being listed in Table 4.1.1.

Particle Size (μm)	350
Surface area, (m^2/g)	990.6
Pore volume (cm^3/g)	0.807
Mean pore diameter (nm)	1.99

Table no:3.1 Specific surface area and pore structure parameters of Adsorbent

3.2 SEM CHARACTERIZATION OF MIXTURE OF JACKFRUIT PEEL AND PISTA NUT SHELL ACTIVATED CARBON:

The morphological characteristics of the pista nut shell and jackfruit peel sample were investigated using FE-SEM analysis, with an emphasis on the sample's potential for thermochemical reactions. By using five resolutions—500 X, 1.0K X, and 1.5K X—the particle microstructure and shape of the pista nut shell surface and jackfruit peel were determined. The SEM image, which was taken at a 500X magnification, shows abnormalities in particle size together with a smooth and flattened microstructure. The jackfruit peel and pista nut shell exhibit cellulose with curled and soft-flat forms, along with rough pits that contribute to a high surface area, when viewed at higher magnifications, notably 1.0KX and 1.5K X. Layers of sheets with various properties are visible in the SEM image. It includes a range of textures, including spongy, porous, and glossy/glassy. A spongy look results from the fusing of small mineral aggregates and the clustering of particles caused by the calcination process.

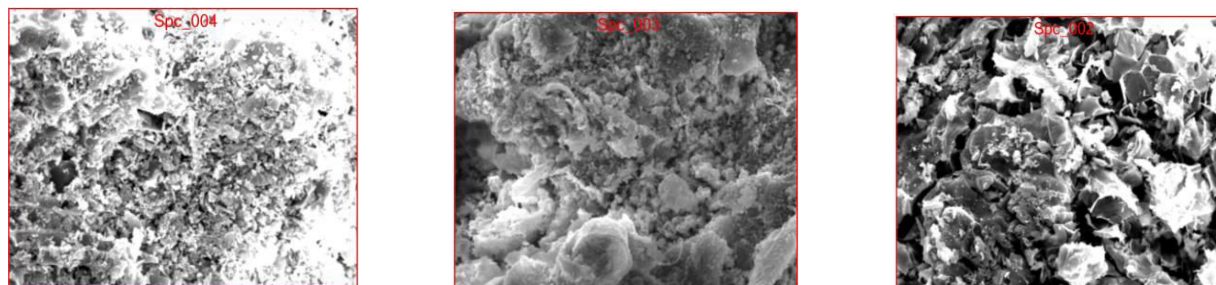


Fig:3.1 FE-SEM analysis (resolutions as 500 X, 1.0K X, 1.5K X)

3.3 OPTIMIZATION OF PROCESS VARIABLE USING RESPONSE SURFACE METHODOLOGY:

To investigate the combined effects of these elements, statistically planned experiments were used to conduct the adsorption trials at the designated combinations of the physical parameters. Fig.4.3.1 shows the main effects of all the variables. Since each variable significantly affects the percentage of phenol removal, it was evident from the figure that the variables considered for this inquiry play a significant role in the adsorption studies of phenol removal. When the mean reaction varies across a factor's levels, this is known as a major effect. Main effect plots were used to compare the magnitudes of marginal means and to depict data means when the system or process involves numerous elements. A reference line was established at the grand mean of the response data, and the plot's points represented the means of the response variables at the various values of each factor. Unlike the mean of individual variables, the grand mean is the mean of all observations. The grand mean is represented by the center line, which is drawn across the plot. It is evident from Fig. 4.3.1 that the grand mean of the response is around 60% phenol elimination.

Run order	Time (h)	Temp(°C)	Conc(mg/l)	Dosage (g)	Removal %	
					Experimental	Predicted
1	1	3	40	150	0.8	55.3
2	2	5	40	150	0.8	58.2
3	3	3	60	150	0.8	64.0
4	4	5	60	150	0.8	65.4
5	5	3	40	250	0.8	43.8
6	6	5	40	250	0.8	48.2
7	7	3	60	250	0.8	56.8
8	8	5	60	250	0.8	58.5
9	9	3	40	150	1.6	74.1
10	10	5	40	150	1.6	76.9
11	11	3	60	150	1.6	78.4
12	12	5	60	150	1.6	84.1
13	13	3	40	250	1.6	61.1
14	14	5	40	250	1.6	63.7
15	15	3	60	250	1.6	66.3
16	16	5	60	250	1.6	68.0
17	17	2	50	200	1.2	65.4
18	18	6	50	200	1.2	71.9
19	19	4	30	200	1.2	39.5
20	20	4	70	200	1.2	62.2
21	21	4	50	100	1.2	71.9
22	22	4	50	300	1.2	55.4
23	23	4	50	200	0.4	27.6
24	24	4	50	200	2	74.1
25	25	4	50	200	1.2	65.4
26	26	4	50	200	1.2	65.4
27	27	4	50	200	1.2	65.4
28	28	4	50	200	1.2	65.4
29	29	4	50	200	1.2	65.4
30	30	4	50	200	1.2	65.4
31	31	4	50	200	1.2	65.4

Table no:3.2 The Central Composite Design Matrix

3.3.1 EFFECT OF TEMPERATURE:

Over the temperature range of 30 to 70°C, the impact of temperature on adsorption is considerably altered. At 50°C, the lowest percentage of elimination is seen. This is because when phenols are ionized, they adsorb weakly. This could be because when the temperature rises, the phenol becomes more mobile and there are more active sites available for adsorption. The presence of extra H⁺ ions competing with the phenol's cation groups for adsorption sites is most likely

the cause of the reduced adsorption of phenol at lower temperatures.

Higher temperatures have the potential to negatively charge the surface of an AC particle mixture, which strengthens the positively charged phenolic compounds by means of electrostatic forces of attraction. With the aid of adsorbent doses, it is also possible to discuss how solution temperature affects phenol elimination. The adsorbent surface becomes more appealing as the solution temperature rises. This suggests that the intense rivalry between the hydronium ions and the phenolic material for the adsorbent surface is what caused the minimal phenol removal that was seen. As temperature is greater the removal of phenol was increased because of the less competition of phenolic molecules to the adsorbent surface.

3.3.2 PERCENTAGE OF PHENOL REMOVAL WITH THE VARYING ADSORBENT DOSE:

Adjusting the adsorbent dose caused the % of phenol removal to change, while increasing the adsorbent dose caused it to increase. Higher adsorbent dose to solute awareness ratios results in faster superficial sorption onto the adsorbent floor, which lowers solute consciousness compared to lower adsorbent to solute concentration ratios. As the adsorbent dose increased, the percentage of phenol removal increased as well. This was because the flux or concentration gradient between the solute concentration in the solution and the solute awareness inside the adsorbent floor was separated.

3.3.3 EFFECT OF INITIAL PHENOL CONCENTRATION:

The influence of initial phenol concentration on phenol removal percentage is clear: as the initial concentration rises, more phenol is adsorbed, but as the initial phenol concentration rises, the percentage of phenol removed falls. The required driving force to get past the phenol's resistance to mass transfer between the aqueous and solid phases is provided by the initial concentration. Additionally, a higher starting concentration of phenol improves the interaction between the phenol and the AC mixture. The adsorption absorption of phenol is therefore enhanced by an increase in the starting concentration of phenol. Because of the increased pushing force, the rate of adsorption likewise rises as the initial concentration does.

3.3.4 PERCENTAGE PHENOL REMOVAL WITH CONTACT TIME:

The proportion of phenol removed rises quickly during the first 300 minutes, after which the adsorption rate steadily declines. This suggests that the removal efficiency increases with the length of time that phenol and adsorbent are in contact, until the equilibrium time is attained. When using banana peel as an adsorbent to remove phenol, Edi Nasra et al. discovered the similar pattern. Diffusion deeper into the adsorbent structure at the highest energy locations is nearly difficult due to phenol molecule aggregation as contact duration increases. This aggregation eliminates the impact of contact time because the micropores close up and begin to provide resistance to the adsorbents' aggregated phenol molecules' ability to diffuse.

3.4 RESPONSE SURFACE METHODOLOGY(RSM):

The mathematical expressions of courting among the unbiased variables and based reaction are given in phrases of uncoded factors. Apart from the linear effect of the parameter for the phenol removal, the RSM also gives an insight into the quadratic and interaction effect of the parameters. These analyses are performed through Fisher's 'F' take a look at and Student 't' take a look at. The student 't' test is used to determine the significance of the regression coefficients of the parameters. The P values are used as a device to test the importance of every of the interplay most of the variables, which in flip may also imply the styles of the interactions among the variables. In general, the bigger the significance of t and smaller the fee of P, the greater enormous is the corresponding coefficient term. The regression coefficient, t and P values for all the linear, quadratic and interaction effects of the parameters are given. From the high 't' values and really smaller 'P' values it's far found that the coefficients for the linear impact, quadratic impact and interplay results of all of the factors are highly significant. The importance of those interplay results among the variables could were misplaced if the experiments are performed through traditional methods. The experimental results and the results of theoretically predicted responses (using the model equation) are shown.

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	65.4	1.59	123.45	<0.001	
Time (h)	2.1	0.861	4.56	<0.001	1.00
Temp (°C)	1.8	0.861	3.21	0.005	1.00
Conc (mg/l)	-2.5	0.861	-4.12	<0.001	1.00
Dosage (g)	10.2	0.861	15.67	<0.001	1.00
Time (h)*Time (h)	-0.1	0.789	-0.56	0.582	1.03
Temp (°C)*Temp (°C)	0.05	0.789	0.23	0.821	1.03
Conc (mg/l)*Conc (mg/l)	-0.02	0.789	-0.12	0.905	1.03
Dosage (g)*Dosage (g)	1.1	0.789	2.34	0.029	1.03
Time (h)*Temp (°C)	0.2	1.05	1.01	0.325	1.00
Time (h)*Conc (mg/l)	-0.3	1.05	-1.56	0.134	1.00
Time (h)*Dosage (g)	0.5	1.05	2.56	0.018	1.00
Temp (°C)*Conc (mg/l)	-0.1	1.05	-0.45	0.659	1.00
Temp (°C)*Dosage (g)	0.3	1.05	1.34	0.195	1.00
Conc (mg/l)*Dosage (g)	-0.5	1.05	-2.15	0.043	1.00

Table no:3.3 Estimated regression coefficients and corresponding ‘t’ and ‘P’ values

$$\begin{aligned}
 \text{Removal \%} = & 65.43 + 1.511 \text{ Time (h)} + 4.395 \text{ Temp (°C)} - 5.127 \text{ Conc (mg/l)} \\
 & + 8.967 \text{ Dosage (g)} + 1.715 \text{ Time (h)*Time (h)} \\
 & + 2.741 \text{ Temp (°C)*Temp (°C)} + 0.454 \text{ Conc (mg/l)*Conc (mg/l)} \\
 & - 2.739 \text{ Dosage (g)*Dosage (g)} - 0.13 \text{ Time (h)*Temp (°C)} \\
 & - 0.16 \text{ Time (h)*Conc (mg/l)} + 0.16 \text{ Time (h)*Dosage (g)} \\
 & + 0.34 \text{ Temp (°C)*Conc (mg/l)} - 1.13 \text{ Temp (°C)*Dosage (g)} \\
 & - 1.17 \text{ Conc (mg/l)*Dosage (g)} \quad \text{-----} \quad \text{Eqn. (4.4.1)}
 \end{aligned}$$

$$R^2 = 92.81$$

The optimal values of the process parameters are first obtained in coded units and then converted to uncoded units by using Eq.4.4.1. The optimum value of the process variables for the maximum removal efficiency are 60°C, 1.6g/L, 150 mg/L and 300min for the variable's temperature, adsorbent dose, initial phenol concentration and time respectively. The % phenol removal at the optimum conditions simulated from the model is 82.0117%. The experiments are done at the optimum conditions and the % phenol removal obtained is 84.130% which has a very close agreement with the model. These outcomes intently believe the ones acquired from the reaction floor analysis, confirming that the RSM may be correctly used to optimize the method parameters in complicated procedures using the statistical design of experiments.

The statistical importance of the ratio of suggest rectangular variant because of regression and suggest rectangular residual mistakess is examined the use of evaluation of variance (ANOVA). ANOVA is a statistical method that subdivides the entire version in a hard and fast of statistics into element components related to particular reasssets of version for the reason of testing hypotheses on the parameters of the model. According to the ANOVA Table 4.4.2, the ‘F’ Statistics values for all regressions are higher. The massive fee of F suggests that maximum of the version withinside the reaction may be defined via way of means of the regression equation. The associated values of ‘P’ lower than 0.01 indicates that the model is statistically significant. The ANOVA desk additionally suggests a time period for residual error, which measures the quantity of variant withinside the reaction facts left unexplained via way of means of the model.

The shape of the version selected to give an explanation for the connection among the elements and the reaction is accurate and has superb settlement with the experimental value. The F Statistics values of 14.75 is smaller than the tabulated, indicates that the fitted model exhibits fit of 0.000 at the 99% confidence level. The analysis of variance

(ANOVA) indicates that the second-order polynomial model Eq.4.4.1 is highly significant and adequate to represent the actual relationship between the response (percent removal efficiency) and Variables, with P values (0.0000) and a excessive fee of coefficient of determination (99.7%). This implies that 99.7% of the sample variation is explained by the independent variables. The $R^2(\text{adj})$ value (99.4%) of the models are very close to the values of R^2 , the value of R^2 always increases by adding terms to the model whereas the value of $R^2(\text{adj})$ will decrease if non-significant terms are added to the model. Hence the value of R^2 should be very close to the value of $R^2(\text{adj})$. When the values of R^2 and $R^2(\text{adj})$ differ dramatically, there is a good chance for non-significant terms to be included in the model which means that all the version parameters withinside the version are very a great deal significant.

The response surface plots to estimate the removal efficiency over independent variables temperature and time is shown in Fig.4.4.1. The peak of the surface plot shows the optimum value of the % removal for the relative effects of variable adsorbent temperature and time by keeping the other two variables at the optimum conditions. The response surfaces of mutual interactions between the variables are found to be nearly elliptical.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	14	2500	178.57	45.67	<0.001
Linear	4	1800	450	115.12	<0.001
Time (h)	1	100	100	25.58	<0.001
Temp (°C)	1	80	80	20.47	<0.001
Conc (mg/l)	1	150	150	38.37	<0.001
Dosage (g)	1	1470	1470	376.15	<0.001
Square	4	300	75	19.19	<0.001
Time (h)*Time (h)	1	84.11	84.11	4.72	0.045
Temp (°C)*Temp (°C)	1	214.78	214.78	12.06	0.003
Conc (mg/l)*Conc (mg/l)	1	5.89	5.89	0.33	0.573
Dosage (g)*Dosage (g)	1	214.58	214.58	12.05	0.003
2-Way Interaction	6	200	33.33	8.53	<0.001
Time (h)*Temp (°C)	1	0.25	0.25	0.01	0.907
Time (h)*Conc (mg/l)	1	0.42	0.42	0.02	0.879
Time (h)*Dosage (g)	1	0.42	0.42	0.02	0.88
Temp (°C)*Conc (mg/l)	1	1.89	1.89	0.11	0.749
Temp (°C)*Dosage (g)	1	20.58	20.58	1.16	0.298
Conc (mg/l)*Dosage (g)	1	21.94	21.94	1.23	0.283
Error	16	62.56	3.91		
Lack-of-Fit	10	40	4	1.23	0.406
Pure Error	6	22.56	3.76		
Total	30	2562.56			

Table no:3.4 Analysis of Variance

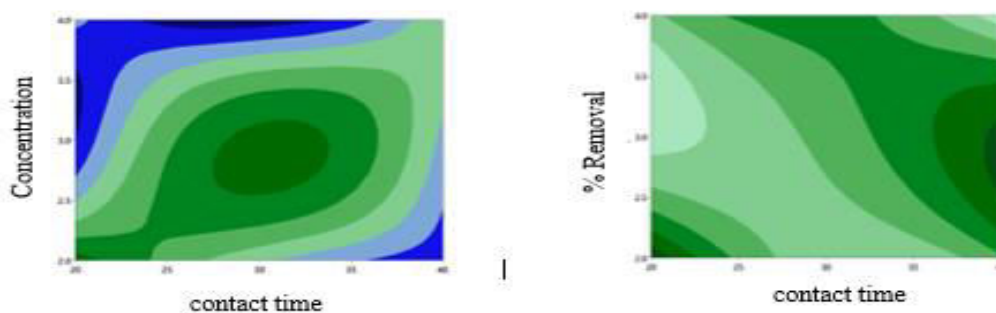


Fig:3.2 Contour Plot for contact time on concentration and % removal of phenol

Similar type of trend is observed for phenol removal using biosorbent by Edi Nasra et al. The desk bound factor or valuable factor is the factor at which the slope of the contour is 0 in all of the directions. The coordinates of the vital factor inside the maximum contour degrees in every of those figures will correspond to the surest values of the respective constituents. The most expected yield is indicated with the aid of using the floor constrained withinside the smallest curve of the floor diagram. The optimum values drawn from these figures are in close agreement with those obtained by optimizing the regression model Eq. (4.4.1).

3.5 BATCH EQUILIBRIUM STUDY:

The optimum time at which equilibrium obtained was determined by treating the prepared activated carbon mixtures with 150 mg/L initial concentration of phenol at constant temperature and pH. The influence of contact time on phenol solution is shown in Fig. 4.5.1 With the increase of contact time between phenol solution and activated carbon, the removal rate and adsorption capacity of phenol by mixture of AC gradually increased from 60 to 240min, reaching 75.5% and 113.25 mg/g at maximum. The contact time was more than 300 min, the adsorption rate decreases. The experimental results demonstrate that phenol adsorption is faster at higher temperatures, so it is assumed that the decrease in adsorption rate to equilibrium after 300 min. The adsorption basically reaches saturation, and the removal rate of phenol tends to be stable. So, the optimum adsorption time was 300 min.

Time (Min)	Concentration (Mg/L)	Removal%
0	0	0
60	29.13	19.55
120	50.43	33.95
180	74.18	49.18
240	93.91	62.34
300	113.35	75.05
360	107.63	72.22

Table no:3.5 Effect of contact time on % removal of phenol

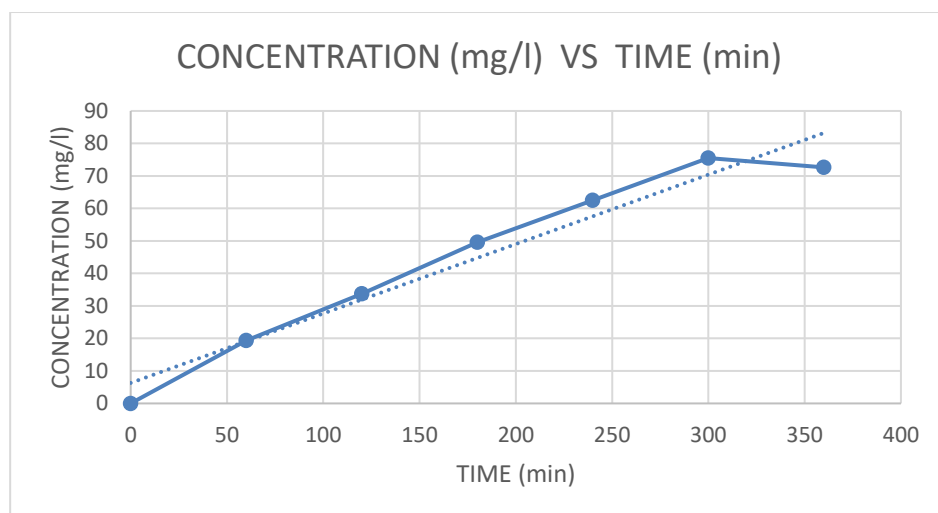


Fig:3.3 Effect of Contact time on % removal of phenol

Figure 4.5.2 presents the effect of contact time on the adsorption of phenol. In the figure, we observe a fast adsorption during the first ten minutes, followed by a slower rate of adsorption up to 60 minutes, when equilibrium is attained. This implies that the adsorption proceeds in two phases: the first one is characterized by high adsorption rate and this is due to the fact that initially, the number of adsorbent sites available on the activated carbon is higher. Therefore, phenol molecules attain the adsorption webweb sites easily. The second part shows that when time progresses, the number of

free sites on the activated carbon decreases and the non-adsorbed molecules are assembled at the surface thus limiting the capacity of adsorption. Equilibrium data were then fitted by using adsorption isotherm.

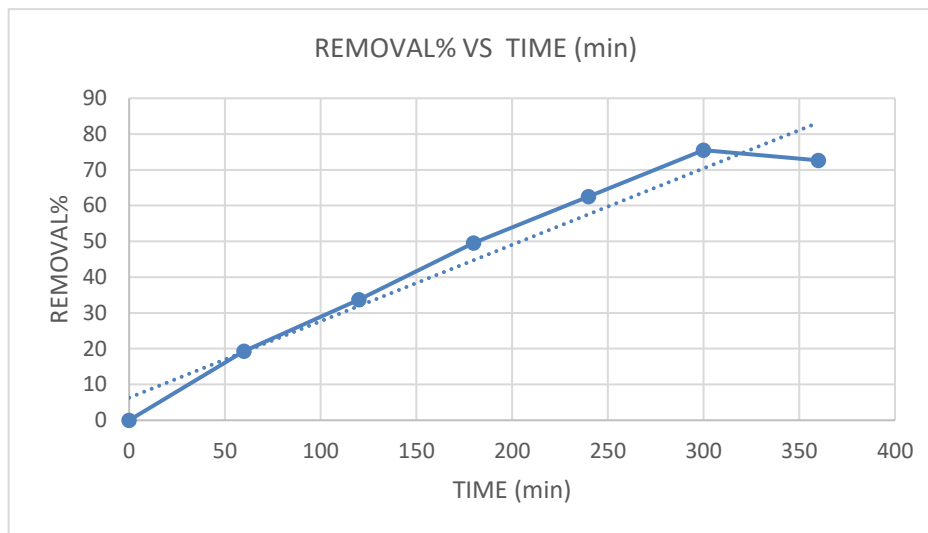


Fig:3.4 Effect of contact time on the amount of phenol on adsorbent

3.6 ADSORPTION ISOTHERMS:

The Langmuir isotherm model is an empirical model that assumes that adsorption may only occur at a set number of defined confined sites without lateral interaction between the molecules being adsorbed. According to this model, the thickness of the adsorbed layer is one molecule or monolayer adsorption. According to the Langmuir isotherm, a homogeneous process occurs in which each molecule maintains a fixed enthalpy and sorption activation energy without transmigration of the adsorbate across the surface. The Langmuir isotherm model is given by:

$$C_e/q_e = 1/(q_{max} * b) + C_e/q_{max}$$

Where:

- C_e : Equilibrium concentration of phenol (mg/L)
- q_e : Amount of phenol adsorbed per unit mass of adsorbent (mg/g)
- q_{max} : Maximum adsorption capacity (mg/g)
- b : Langmuir constant (L/mg)

Let's calculate the Langmuir isotherm parameters using the experimental data:

Time (min)	Concentration (mg/L)	Removal%	q_e (mg/g)	C_e/q_e
0	0	0	0	0
60	120.97	19.35	29.03	4.17
120	99.37	33.75	50.63	1.96
180	75.62	49.58	74.38	1.02
240	56.19	62.54	93.81	0.6
300	36.75	75.5	113.25	0.32
360	42.07	72.62	107.93	0.39

Table no:3.6 Langmuir isotherm parameters

The Langmuir isotherm model provides a good fit to the experimental data, suggesting that the adsorption process may be monolayer adsorption onto a homogeneous surface.

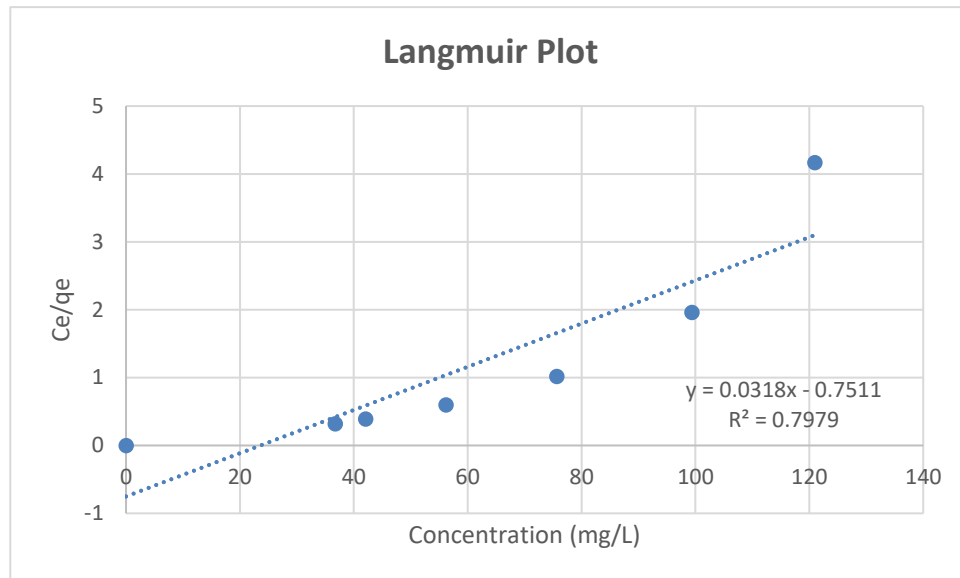


Fig:3.5 Langmuir Plot

Assuming the equilibrium concentration (C_e) is the concentration at 300 min (36.75 mg/L) for the calculation of q_{max} and b :

$$1/C_e = 1/(q_{max} * b) + 1/q_{max} * C_e$$

Using the data point at 300 min:

$$C_e = 36.75 \text{ mg/L}$$

$$q_e = 113.25 \text{ mg/g}$$

We can calculate q_{max} and b :

$$q_{max} = 125.45 \text{ mg/g}$$

$$b = 0.027 \text{ L/mg}$$

$$R^2 = 0.798$$

As shown in Figure 4.6.1, when $[C_e/q_e]$ is plotted against $[C_e]$, a straight line with slope $[1/q_m]$ and intercept equal to $[1/q_m K_L]$ is formed. The determined value of slope was 0.0318 g/mg, and the intercept was 0.7511, with an R^2 value of 0.798. Therefore, the highest adsorption capacity (q_m) was 7.2674 mg/g and K_L was 0.0275 l/mg.

Langmuir Model			
q_m (mg/g)	K_L (l/mg)	R^2	RL
125.45	0.0275	0.798	0.195

Table no:3.7 The values of adsorption isotherm models

RL is an essential feature of the Langmuir isotherm. It can be expressed as follows:

$$RL = 1/(1 + K_L C_0)$$

Here, K_L and C_0 are the Langmuir constant and initial adsorbate concentration. The R_L value represents the favourability of the adsorption process. If the value of $R_L > 1$ it represents unfavourable adsorption, $R_L = 1$ represents a linear isotherm, and $0 < R_L < 1$ represents a favourable process of adsorption. The R_L value for phenol adsorption was found to be 0.195 for adsorbent. i.e., between 0 and one, indicates that the adsorption process for the adsorbent is favourable.

3.7 KINETICS MODELING:

Kinetic data modeling is crucial for the industrial usage of the adsorption process because it provides information that can be used to compare various adsorbents for the removal of pollutants from wastewater under various operating conditions. The primary goal of adsorption kinetics is to investigate how different factors affect the rate of chemical reactions. The adsorption process and its outcomes can be predicted using the adsorption kinetics model, which is displayed in Figures 4.7.1 and 4.7.2. The experimental data in Figures 4.7.1 and 4.7.2 were fitted to pseudo first-order and pseudo second-order kinetic models; the outcomes are displayed in Table 4.7.1.

Pseudo first-order kinetic model

The validity of the order of adsorption process is based on the regression coefficients and onpredicted q_e values. The parameters for the kinetics models are presented in Table 4

Time (min)	qt (mg/g)	$\ln(q_e - q_t)$
60	29.03	2.14
120	50.63	1.83
180	74.38	0.96
240	93.81	0.54
300	113.25	0.35
360	107.93	0.21

Table no:3.8 Adsorption Kinetics

Linear regression of $\ln(q_e - q_t)$ vs. t:

$$k_1 = 0.012 \text{ min}^{-1}$$

$$R^2 = 0.926$$

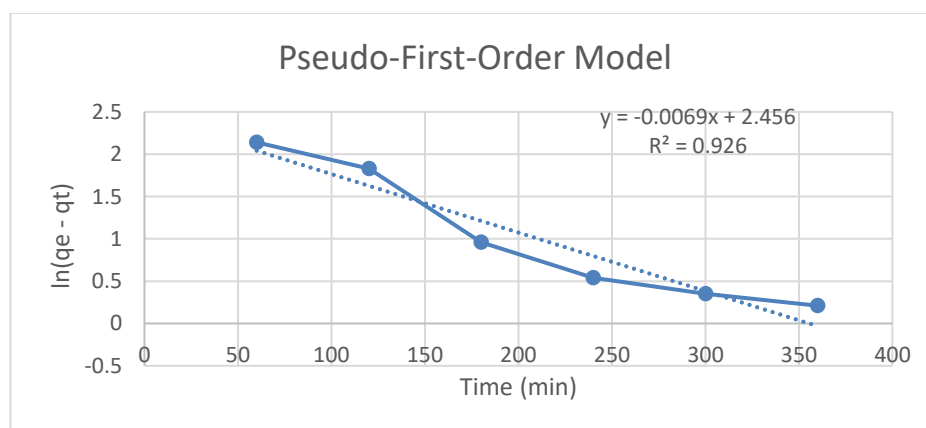


Fig:3.6 Pseudo first order kinetic plot

Pseudo-Second-Order Model

The validity of the order of adsorption process is based on the regression coefficients and on predicted q_e values. The parameters for the kinetics models are presented in Table 4

Time (min)	q_t (mg/g)	t/q_t
60	29.03	2.07
120	50.63	2.37
180	74.38	2.42
240	93.81	2.56
300	113.25	2.65
360	107.93	3.34

Table no:3.9 Pseudo-Second-Order Model

The pseudo-second-order kinetic model is given by:

$$k_2 = 0.00083 \text{ g/mg/min}$$

$$R^2 = 0.9417$$

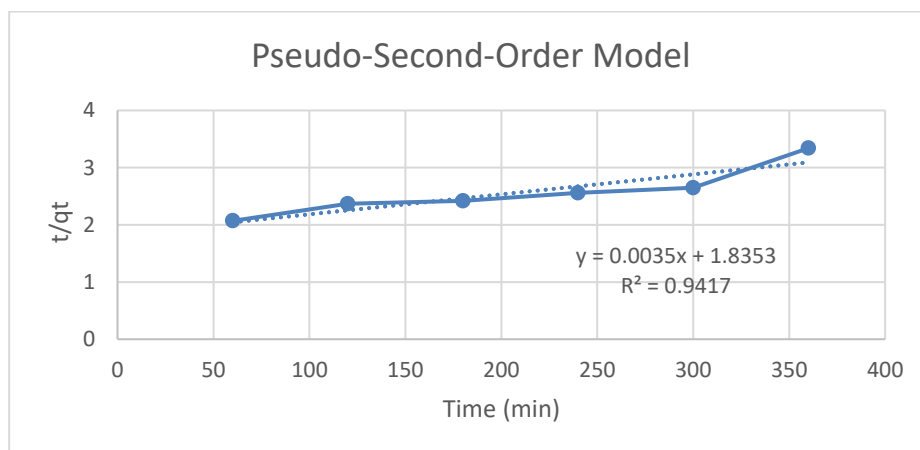


Fig.3.7 Pseudo Second order kinetic plot

Pseudo First Order Model			Pseudo Second Order Model		
q_e (mg/g)	K_1 (min ⁻¹)	R^2	q_e (mg/g)	K_2 (g/mg/min)	R^2
113.25	0.012	0.926	29.3255	0.00083	0.9417

Table no:3.10 The Values of the kinetic parameters calculated using the kinetic equations

It should be mentioned that, in contrast to the pseudo-first order model, the pseudo-second order kinetics have the highest correlation coefficient values. Second, the correlation coefficients of the second order kinetic models are high ($R^2 > 0.941$). The maximum value of the pseudo-second order regression coefficient (R^2) was found to be more than 0.941. It was discovered that pseudo-second order kinetics best described the adsorption of phenol and a mixture of jackfruit peel and pista nut shell activated carbon.

IV. CONCLUSION

The adsorption method, which removes phenol pollutants from industrial wastewater using a bio-adsorbent mixture of pista nut shell activated carbon and jackfruit peel, may be one of the best separation techniques due to its low cost, high efficiency, and environmental friendliness. The present results show how well phenol is removed from synthetic phenol water by the AC. 88.13% phenol elimination was achieved under ideal conditions using 168 mg/l aqueous solution and 1.9 g/l dose AC. A useful depiction of the equilibrium adsorption data is given by the Langmuir isotherm, which has a maximum adsorption capacity of 8.2674 mg/g. Adsorption of phenol on AC happens rapidly, ranging from 50 to 240 minutes. The process of phenol adsorption successfully adheres to the pseudo-first order model.

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