

Adsorption of phenol and resorcinol from aqueous solution by Chitosan/Poly(acrylamide-co-2-acrylamido-2-methyl-1-propanesulfonic acid) hydrogels: modeling and kinetic studies

¹C. Raja Kumar, ¹Y. Nagaiah, ²K.N. Shashi Kumar, ¹T. Veera Reddy and ¹Y. Vijaya*

¹Department of Chemistry, Vikrama Simhapuri University, Nellore, A.P., India.

²Annamacharya Institute of Technology & Sciences, Kadapa, A.P., India.

Abstract

The removal of phenol and resorcinol from aqueous solutions by the Chitosan/Poly(acrylamide-co-2-acrylamido-2-methyl-1-propanesulfonic acid) (CPAA) hydrogels has been investigated considering technique of batch mode adsorption. In this study chelating hydrogels are synthesized from Chitosan, acrylamide, 2-acrylamido-2-methyl-1-propanesulfonic acid by free radical polymerization method in the presence of *N,N*-methylene-bis-acrylamide and potassium persulphate act as a cross-linker and initiator. The resulting chelating hydrogels were characterized by Fourier transform infrared spectroscopy (FTIR) and Scanning electron microscopy (SEM). Swelling properties of CPAA hydrogels were also studied. In a batch adsorption system as a function of pH, contact time, adsorbent dose and initial concentration of phenol and resorcinol were investigated comprehensively; thereby the adsorption kinetics and adsorption isotherms are discussed systematically. The adsorption process followed pseudo-second order kinetic model. The analyzed data was correlated with Langmuir and Freundlich isotherm models, where in Langmuir model of adsorption best explained the adsorption process by the CPAA hydrogels. The adsorption capacity of CPAA hydrogels calculated from the Langmuir model was found to be 76.92 mg/g and 83.33 mg/g for phenol and resorcinol respectively.

Keywords: Phenol, Resorcinol, CPAA hydrogels, Isotherms, Kinetics

1. INTRODUCTION

The wastewater from industries is one of the major sources of pollution of our environment. Phenolic compounds released from industries such as fertilizer, pharmaceutical, paints, dye manufacturing, pesticide and oil refineries contaminate our environment and aquatic media [1–8]. In phenolic compounds, phenol and resorcinol are well known hazardous pollutants which cause harmful effects due to their toxicity, foul odour and carcinogenicity even at low concentrations. Prolonged exposure to even low levels of phenol in water causes liver and kidney damage, diarrhea, mouth ulcers and dark urine. Resorcinol can cause abdominal pain, nausea, skin irritation, unconsciousness and readily dissolves in water decreasing flora and fauna species of our environment and aquatic media [9-12].

The World Health Organization (WHO) recommends concentration of 0.001 mg/L in potable water as permissible limit for phenols. Environmental Protection Agency has set a phenol concentration less than 1mg/L in industrial effluents for safe discharge in to surface water. According to Bureau of Indian Standards (BIS), the permissible limit of phenol in drinking water as 1 mg/L while maximum concentration level set by Ministry of Environment and Forests (MOEF), Govt. of India for safe discharge of industrial effluents in to surface water is 1 mg/L and for safe discharge into public sewers and marine coastal areas is 5 mg/L. The removal of unsafe materials such as phenolic compounds from industrial effluents is one of the great concerns [13-16].

Therefore, it is necessary to explore an effective and cost efficient technology for the removal of phenolic compounds from industrial effluents before their release into the environmental water [17]. Various treatment methods like adsorption, ion exchange process, reverse osmosis, chemical oxidation, precipitation, distillation,

gas stripping, solvent extraction, complexation and bioremediation [18-23] are employed for the removal of phenolic compounds. Now a days, adsorption technique provides better advantages due to low cost, eco-friendliness and higher efficiency [24]. Recently adsorption technique using bio polymers with hydrogel plays an important role in the removal of phenolic compounds [25, 26].

In the present work, we have synthesized Chitosan / Poly (Acrylamide –co-2-Acrylamido -2-methyl -1-propane sulfonic acid) chelating CPAA hydrogels from chitosan with acrylamide(Am) and 2-acrylamido -2-methyl -1-propane sulphonic acid (AMPS) based hydrogel which increases the hydrophilic, anionic and chelation properties for the adsorption of phenol and resorcinol. Chitosan (B-(1-4)-linked –N-acetyl –D-glucosamine) is one of the naturally available polysaccharides in our environment. It is non-toxic, hydrophilic, good adhesion and has high mechanical properties of polymer, it consists of high percentage of amino groups and most capable for binding of phenolic, metallic compounds. Based on its strongly ionisable sulfonate groups, AMPS has received much attention in the past few years. It can dissociate completely throughout the pH range [27, 28].

The synthesized hydrogels were characterized by Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM), the Parameters such as pH, initial phenolic compound concentration, contact time and adsorbent dosage effects were investigated. Kinetic models such as Lelegerren first order, Pseudo second order and Weber Morris models were fitted. Langmuir and Freundlich adsorption isotherm models were applied to evaluate the adsorption process.

2. EXPERIMENTAL

2.1. Materials

Synthetic grade chitosan, 2-acrylamido -2-methyl -1-propane sulphonic acid (AMPS) is purchased from Sigma Aldrich Chemicals, USA. Potassium persulphate (KPS), Acryl amide (Am), HCl, NaOH were purchased from Merck, Mumbai, India. Analytical grade Phenol, Resorcinol, Acetic acid and Synthetic grade reagents of N,N'-methylene – bis– acrylamide (MBA) were purchased from S.D. Fine Chemicals, Mumbai, India. Double distilled water was used throughout the experiment.

2.2. Preparation of 4% chitosan solution

The chitosan solution (4% w/v) was prepared by dissolving 2.0 g chitosan powder in 50 mL of 4% aqueous acetic acid solution and stirred vigorously for 10 hours to obtain a homogeneous solution.

2.3. Preparation of Chitosan based hydrogels (CPAA hydrogel)

The CPAA hydrogels were synthesized from Chitosan with acrylamide (Am), 2-acrylamido -2-methyl -1-propane sulphonic acid (AMPS) and N,N'-methylene – bis– acrylamide (MBA) by a free radical polymerization in the presence of potassium persulphate as an initiator. This initiator is reduced to anion radical $[(SO_4)^{\cdot-}]$, these extracts hydrogen from the Am, AMPS and cross linker MBA to form respective vinyl radicals and undergo polymerization to produce CPAA hydrogels. The composition of Chitosan based hydrogels is mentioned in **Table.1**, where Chitosan act as a guest polymer. The structure of synthesized CPAA hydrogels is given in Fig.1.

At first 5.0 mL of chitosan solution (4%) is taken into a 100 ml beakers [5–formulations (A,B,C,D &E)] and added 0.5g of monomer Am in each beaker. Another monomer AMPS of certain weights were dissolved in 2.0 mL of distilled water, certain values of cross-linking agent MBA (3%) aqueous solution and 1.0 mL of initiator KPS (10%) aqueous solution were added in each beaker and stirred to obtain a homogeneous solution.

Table. 1: Different Formulations & Compositions of CPAA Hydrogels

| Formulation Code | Chitosan (4%) mL | Am (g) | AMPS(g) | MBA (3%) mL | KPS (10%)mL |
|------------------|------------------|--------|---------|-------------|-------------|
| A | 5.0 | 0.5 | 0.5 | 3.0 | 1.0 |
| B | 5.0 | 0.5 | 0.5 | 4.0 | 1.0 |
| C | 5.0 | 0.5 | 0.5 | 5.0 | 1.0 |
| D | 5.0 | 0.5 | 0.75 | 4.0 | 1.0 |
| E | 5.0 | 0.5 | 1.0 | 4.0 | 1.0 |

The resulting homogeneous solution [5–formulations] kept in water bath maintained at temperature of 60°C until (4h) the formation of hydrogels. Later the hydrogels are kept in double distilled water up to one week by rapidly changing the water for removing of KPS and the unreacted monomers, after which the produced hydrogels were kept in vacuum oven at 50° C for drying purpose.

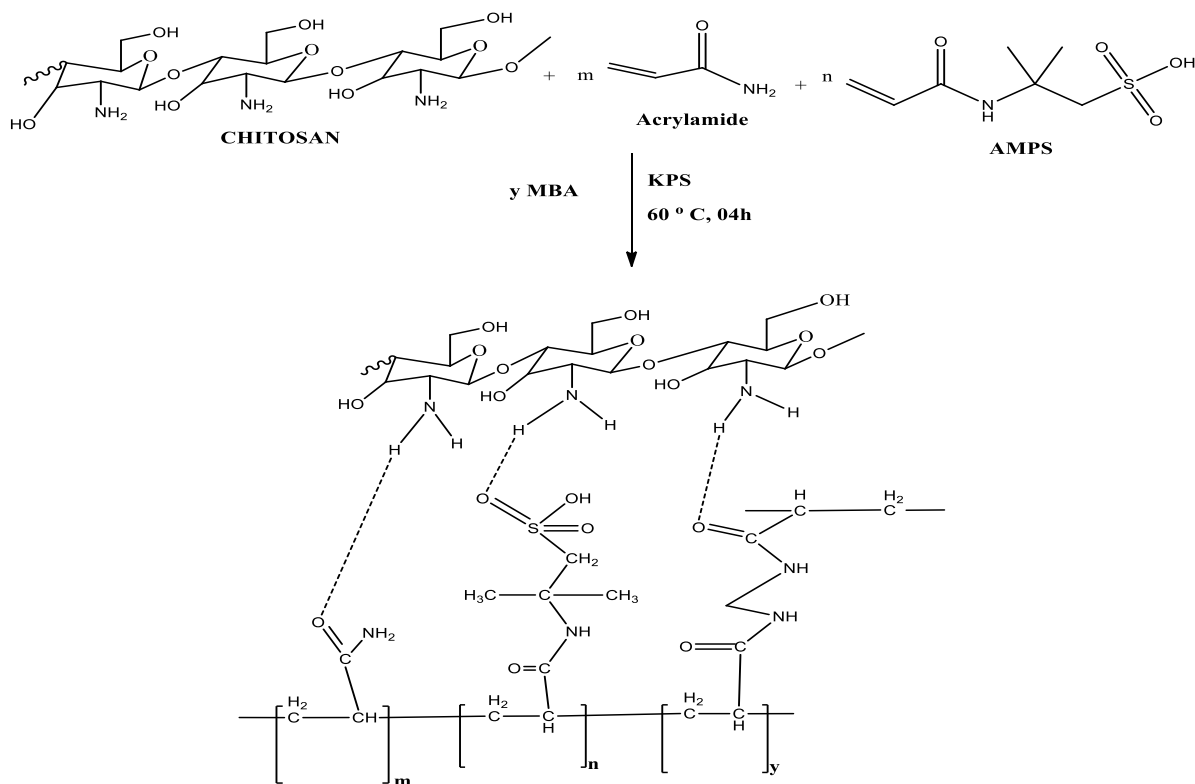


Fig.1. Schematic Representation Of CPAA Hydrogels

2.4. Swelling studies

The following procedure was used for analyzing of swelling characteristics of the CPAA hydro gels. At first different formulations of CPAA hydrogels were dried to acquire dry gels, these are used for swelling studies. A required amount of dried CPAA hydrogels were weighed and then immersed in 50 mL of double distilled

water at 25°C. The weight of swollen hydrogels was weighed after the removal of excess of water on the surface of hydrogels at certain intervals of time. This process was repeated until no significant change of weights was observed and swelling ratio (Q_s) was obtained by the following equation (1)

$$Q_s = \frac{W_s - W_d}{W_d} \quad (1)$$

Where W_s is the weight of the swollen CPAA hydrogel and W_d is the weight of the dried CPAA hydrogel.

2.5. Preparation of Phenol and Resorcinol standards

The stock solutions (1000 mg/L) of Phenol and Resorcinol were prepared by dissolving 1.0 g of phenol or resorcinol in 1L of distilled water. The experimental solutions of desired concentration were prepared by diluting stock solution with distilled water. The concentration of Phenol and Resorcinol were measured at a $\lambda_{max} = 270$ nm and $\lambda_{max} = 313$ nm using UV-Visible spectrophotometer (LAB INDIA, Model UV-3092) for phenol and resorcinol respectively. The pH of solutions was adjusted with 0.1 M concentrations of HCl and NaOH.

2.6. Characterization

FTIR (Fourier Transform Infrared Spectroscopy) measurements were performed with CPAA hydrogels, Phenol Sorbed CPAA hydrogels and Resorcinol Sorbed CPAA hydrogels by using Perkin Elmer FTIR Spectrometer (Beaconsfield, UK). The sample pellets were developed by grinding finely CPAA hydrogels with KBr and pressing them under the hydraulic pressure of 600 dynes/m². The spectra were obtained between 4000 to 500 cm⁻¹. The FTIR spectra were used to conform the presence of functional groups of CPAA hydrogels before and after cross linking. The CPAA hydrogels were evaluated by SEM (Scanning Electron Microscopy) for studying of surface morphology.

2.7. Batch adsorption experiments

The batch adsorption studies were carried out to examine the effects of pH (4.0-11.0), phenolic (adsorbate) concentration (100-300mg/L), contact time (30-300 min), adsorbent dose (0.05 to 0.5g) with 100 mL phenol and resorcinol solutions on the adsorption performance of CPAA hydrogels agitated in an electrical thermostatic shaker at 200 rpm, after each adsorption process the solutions were filtered and the liquid samples collected and analyzed for remaining phenol and resorcinol concentration by UV-Visible Spectro Photometer. The percentage (%) and amount Q_e (mg/g) of phenol and resorcinol adsorbed on the hydrogel, was obtained by the following equations.

The percentage removal of phenolic compounds was obtained using the equation

$$\% \text{removal} = \frac{(C_i - C_e)}{C_i} \times 100 \quad (2)$$

The amount adsorbed per unit mass of adsorbent at equilibrium q_e (mg/g) was obtained using the equation.

$$q_e = \left(\frac{C_i - C_e}{m} \right) \cdot V \quad (3)$$

where C_i and C_e denote the initial and equilibrium concentrations (mg/L) phenol and resorcinol respectively. V was the volume of the phenol and resorcinol in liters, and m was the mass of the adsorbent used (g).

3. RESULTS AND DISCUSSION

3.1 FTIR analysis

The FTIR Spectrum of CPAA hydrogel, Phenol loaded CPAA and Resorcinol loaded CPAA hydrogels are shown in Fig.2. Fig.2(a) shows the characteristic peaks of CPAA hydrogel. A broad peak at 3436 cm^{-1} corresponding to the -OH stretching vibrations of the hydroxyl group and -NH stretching vibrations of the NH_2 groups. The peak at 2927 cm^{-1} corresponding to the typical -C-H stretching vibrations. The peak at 1653 cm^{-1} results from the -C=O stretching vibrations of amide (-NH_2). The peak at 1384 cm^{-1} indicates in plane bending vibrations of -OH group (or) stretching vibrations of Sulphur group.

Fig.2(b) & 2(c) shows phenol loaded CPAA and resorcinol loaded CPAA hydrogels, The broad peaks observed at 3431 cm^{-1} & 3430 cm^{-1} for phenol and resorcinol loaded hydrogels were caused by the -OH stretching vibrations of the hydroxyl group and -NH stretching vibrations of the NH_2 groups that the two groups are undergo in adsorption process. The peaks are shifted from 1653 to 1635 & 1640 cm^{-1} in case of phenol & resorcinol loaded hydrogels indicates N-H deformation, A sharp peaks were observed at 1384 & 1385 cm^{-1} for phenol & resorcinol loaded hydrogels. It indicates that the CPAA hydrogels have higher adsorption capacity for phenol and resorcinol.

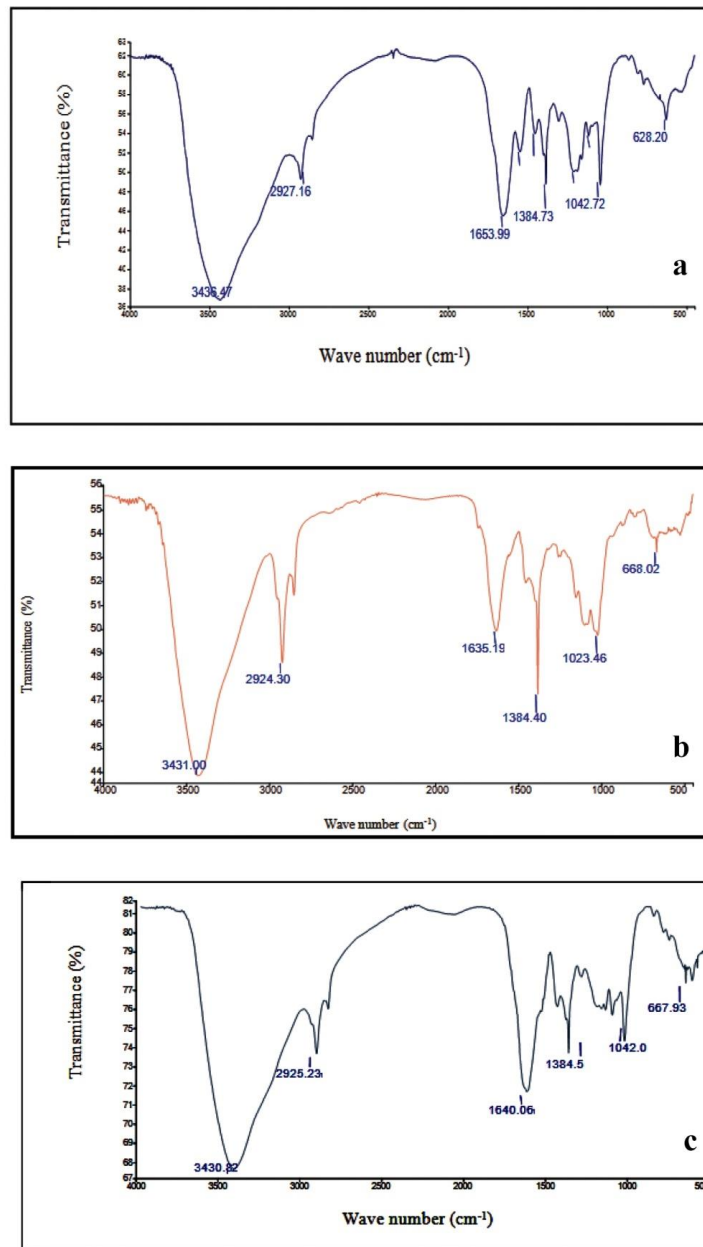


Fig.2: FTIR Spectra of (a) Pure CPAA hydrogels (b) CPAA hydrogels loaded with Phenol and (c) CPAA hydrogels loaded with Resorcinol

3.2. Scanning Electron Microscopy (SEM) analysis

The SEM was used to observe the changes in the surface morphology of the hydrogels. It was carried out on the CPAA hydrogels to study its surface texture before and after adsorption (Fig. 3). The adsorption capacity of an adsorbent was depend upon surface area i.e the surface area increases, more binding sites are available for the adsorbate to be adsorbed. Fig.3(a-c) shows the SEM micrographs of CPAA hydrogels before and after

phenol and resorcinol adsorption. It is clear that CPAA hydrogels has numbers of layer of pores where there is a good possibility for phenolic compounds to be adsorbed.

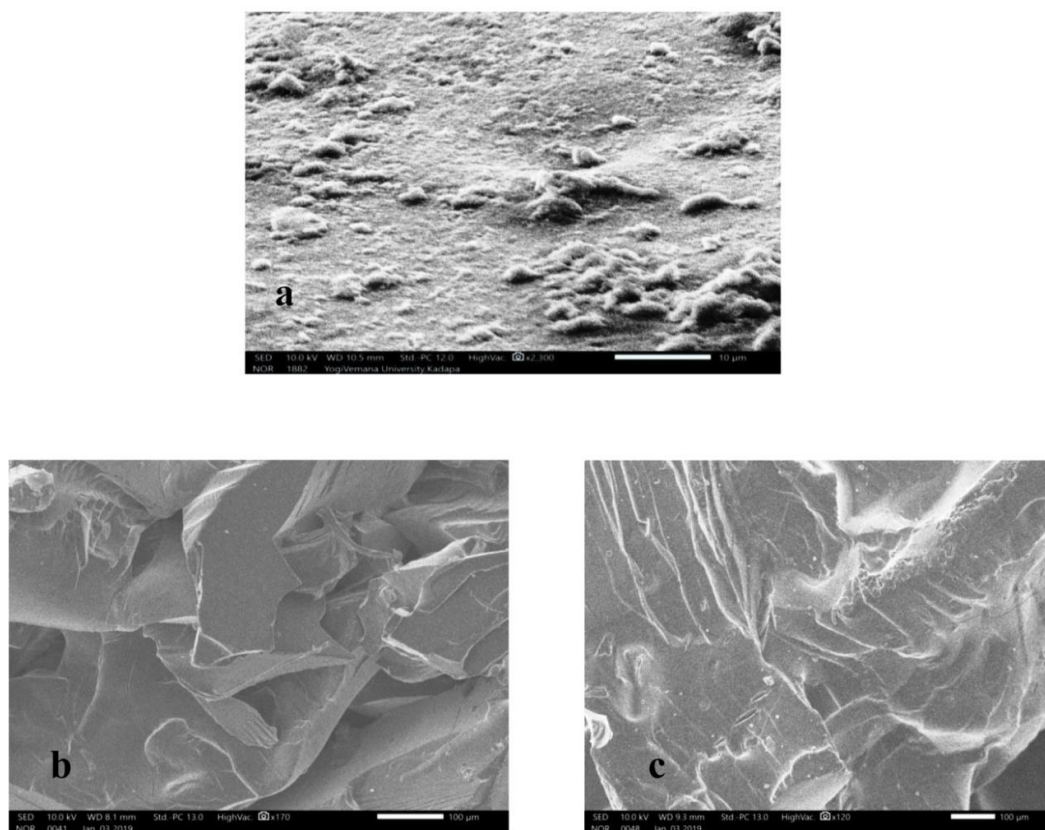


Fig. 3: SEM images of (a) Pure CPAA hydrogels (b) CPAA hydrogels loaded with Phenol and (c) CPAA hydrogels loaded with Resorcinol

3.3. Swelling Studies

The CPAA hydrogels swelling studies in water with time are shown in Fig.4. The figure indicates that the hydrogels maximum swelling is obtained at 720 min. swelling ratio of CPAA hydrogels in water is minimum for formulation C and maximum for formulation E. The maximum swelling ratio of different formulations (shown in Table.1) of CPAA hydrogels were 18, 16, 15, 21, 25 in double distilled water. Equilibrium swelling ratio of formulations A, B and C is low due to presence of less amount of AMPS monomer and increased amount of cross linking agent. Equilibrium swelling ratio of formulations D, E is relatively high due to increased amount of AMPS monomer and less amount of cross linking agent. The AMPS monomer concentration change from 0.5 to 1.0 g, the swelling ratio is increased. This is due to an increase in the hydrophilic nature of CPAA hydrogels as increase in the hydroxyl, sulfonic acid groups of CPAA hydrogels.

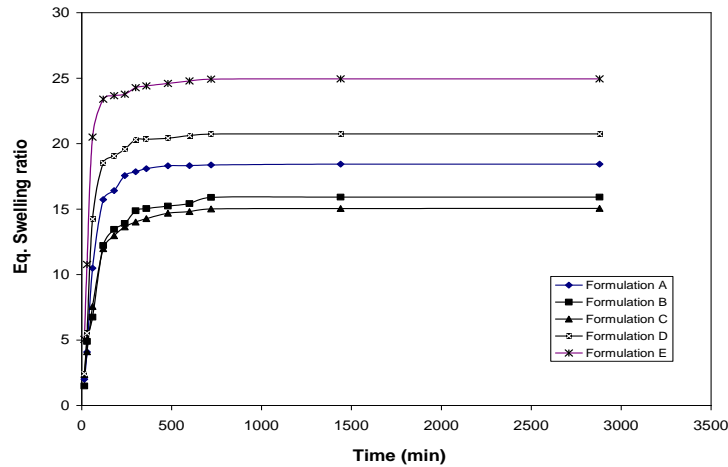


Fig. 4: Swelling kinetics of CPAA hydrogels (A-E)

3.4 Effect of pH

The pH of the test solutions shows to greatly effect on the adsorption process. That means it estimates the state of adsorbate and surface charge of the adsorbent in the test solutions. In acidic conditions the molecular form influences and in alkaline conditions the anionic form is dominant. In order to optimize the pH for maximum adsorption efficiency, experiments were conducted. For effect of pH on adsorption capacity was conducted by weighing about 100 mg of CPAA adsorbents after mixing in 100mL of 100mg/ L solution of phenol and resorcinol with different PH value ranging from 4.0-11. The effect of pH on adsorbing of phenol and resorcinol from their aquatic solutions by CPAA hydrogels at different pH values was studied and the results are shown in Fig.5.

At lower pH value, the adsorption capacity is low is due to the fact that the reactive functional groups in polymer networks are in protonated form, which can hinder the interaction of adsorbent and adsorbate. Further formation of non ionic bonding mechanism (Ex : hydrogen bonding) among sulphonic acid groups occurs at low pH. Increase in the pH value shows as in increase in the adsorption capacity because of dissociation of sulphonic acid groups and formation of bonds between polymer and phenolic compounds. The adsorption capacities increase with increase in pH up to pH 7 and decreases after pH 7.

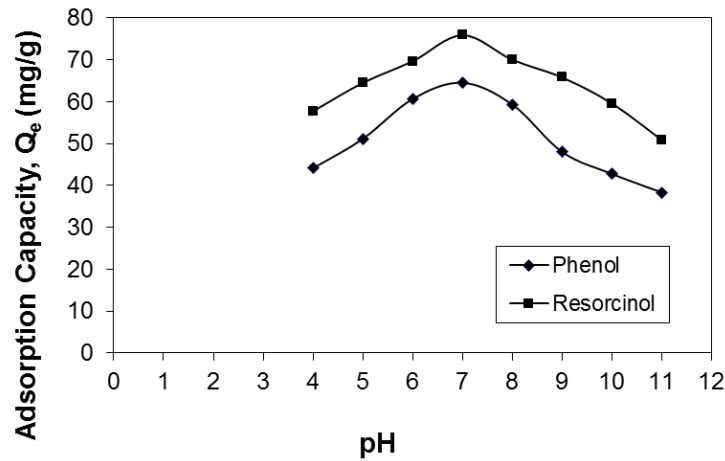


Fig. 5: Effect of pH on adsorption of phenol and resorcinol on CPAA hydrogels

3.5 Effect of Contact time

The effect of contact time on the adsorption capacity of CPAA hydrogels were carried out with 100 mL of 100, 200 and 300 mg/ L of concentration of phenol and resorcinol solutions maintaining pH at 7 and to it about 100 mg of CPAA hydrogels was added. The results of effect of contact time on adsorbing of phenol and resorcinol from their aquatic solutions by CPAA hydrogels were shown in Fig.6 and7. The equilibrium conditions of the adsorption were reached after about 240 min (4h) for phenol and resorcinol solutions. The maximum adsorption of phenol and resorcinol from aquatic solutions on CPAA hydrogels equilibrium time is 240 minutes.

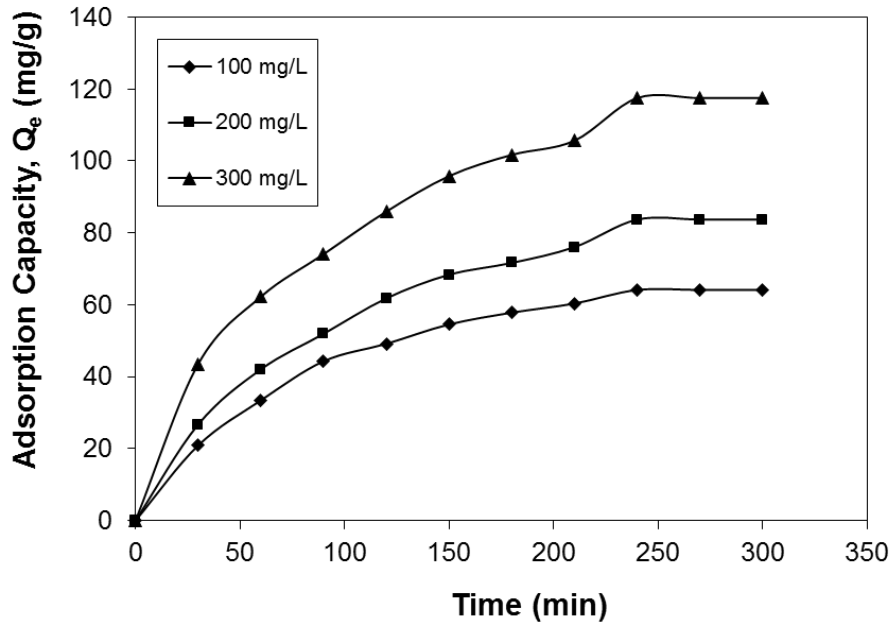


Fig. 6: Effect of contact time on adsorption of phenol on CPAA hydrogels

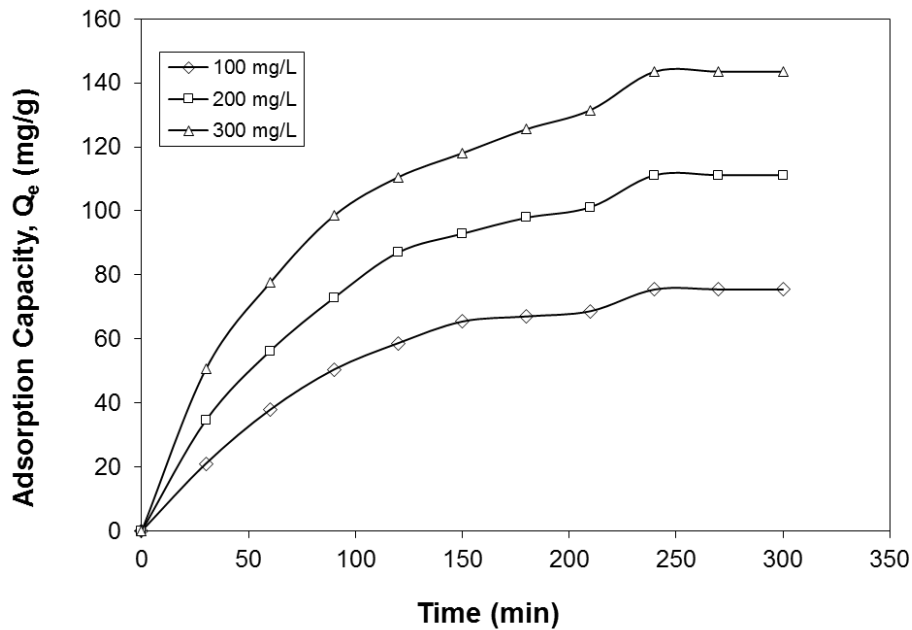


Fig. 7: Effect of contact time on adsorption of resorcinol on CPAA hydrogels

3.6 Effect of Adsorbent dose

To investigate the effect of adsorbent dosage a range of 0.05-0.5g of quantities of adsorbent was used and the results are shown in Fig 8. Accordingly, the adsorption capacity increased with increase in dosage of CPAA hydrogels up to 0.4 g where the maximum adsorption of the phenolic compounds was reached. It is mainly due to increases of dosage of adsorbent in the phenolic solutions as well as increases of availability of replaced sites. But, the adsorption capacity remained same at CPAA hydrogels dosage up to 0.5 g which shows saturation. Therefore, the adsorbent dosage was fixed as 0.4 g for further experiment, the maximum percent removal is about 86 % for phenol, about 91 % for resorcinol.

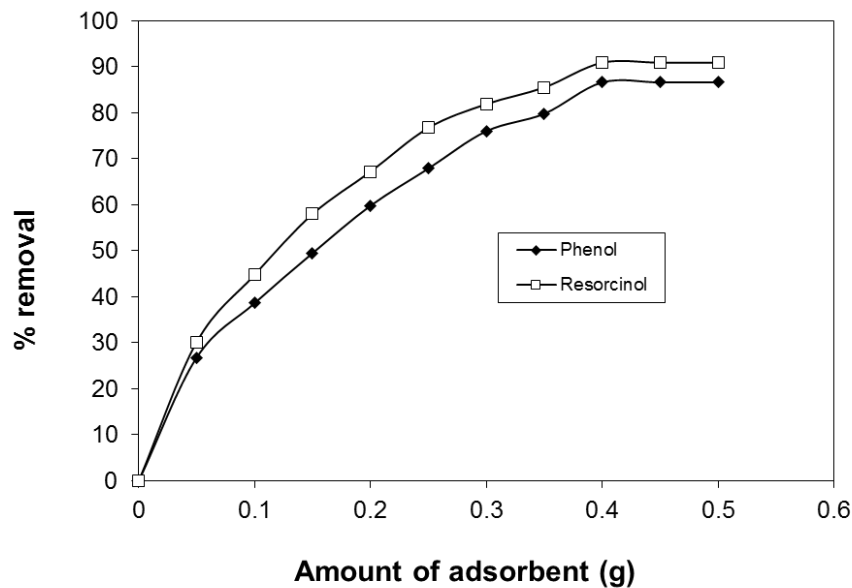


Fig. 8: Effect of adsorbent dose on adsorption of phenol and resorcinol on CPAA hydrogels.

3.7 Adsorption Dynamics

We have analyzed the pseudo first order and second order kinetic model for both phenol and resorcinol by fitting the experimental data obtained from the adsorption experiments at three different initial concentrations 100, 200 and 300 mg/L using CPAA hydrogels. The experimental data obtained were fitted in pseudo first order and second order kinetic model using the respective linear equations. The Pseudo-first order kinetic model is given by the following equation (4)

$$\log (Q_e - Q_t) = \log Q_e - \frac{K_1}{2.303} t \quad (4)$$

Where Q_e and Q_t are the amount adsorbed at equilibrium and time t in mg/g, K_1 is the rate constant of Pseudo-first order adsorption (min^{-1}). A plot of $\log(Q_e - Q_t)$ against time (t) gives a straight line which gives K_1 is the rate constant of Pseudo-first order adsorption (min^{-1}).

The linear form of the second order kinetic model is given by the following equation (5)

$$\frac{t}{Q_t} = \frac{1}{Q^2 e K_2} + \frac{t}{Q_e} \quad (5)$$

A plot of t/Q_t against time (t) gives a straight line which gives K_2 , the rate constant of Pseudo-second order adsorption ($\text{g mg}^{-1} \text{min}^{-1}$).

A kinetic study of adsorption offers information about the mechanism and effectiveness of the adsorption process. The experimental data obtained were analyzed by both pseudo first order and second order kinetic models. The kinetic parameter R^2 values obtained for both the models are given in Table. 2 and 3 and the kinetic plots are given in Figs.09,10,11 and 12. It is observed from the data obtained that Based on the Correlation Coefficient (R^2) acquired from Pseudo-first order and Pseudo -second order models, the best fit for the experimental kinetic data is Pseudo -second order model.[29]

Diffusion based model

The results are also analyzed in terms intraparticle diffusion model to investigate whether the intraparticle diffusion is the rate controlling step in adsorption of phenol and resorcinol on CPAA hydrogels.

The mathematical expression for Weber-Morris intraparticle diffusion model [30]

$$Q_e = k_{id} t^{0.5} + C \quad (6)$$

where k_{id} is the intraparticle diffusion rate constant ($\text{mg/g min}^{-0.5}$) and C is the intercept. It can be seen that all the plots have an initial curved portion, followed by a linear portion and a plateau regions. The initial curve of the plot is due to the diffusion of phenol and resorcinol through the solution to the external surface of CPAA hydrogels. The linear portion of curves describes the gradual adsorption stage, where intraparticle diffusion of phenol and resorcinol on CPAA takes place and final plateau region indicates equilibrium uptake. The rate constants of Weber- Morris intraparticle diffusion model are shown in Table.4 and the plots are given in Figs. 13 and 14. Based on the results it may be concluded that intra particle diffusion is not only the rate determining factor.

Table 2: Legergren first-order rate constants for phenol and resorcinol adsorption on CPAA hydrogels

| Initial concentration | Phenol | Resorcinol |
|-----------------------|--------|------------|
|-----------------------|--------|------------|

| (mg/L) | K_1 | R^2 | K_1 | R^2 |
|--------|--------|--------|--------|--------|
| 100 | 0.0133 | 0.9951 | 0.0122 | 0.9831 |
| 200 | 0.0110 | 0.9963 | 0.0117 | 0.9960 |
| 300 | 0.0103 | 0.9973 | 0.0110 | 0.9974 |

Table 3: Pseudo second-order rate constants for phenol and resorcinol adsorption on CPAA hydrogels

| Initial concentration (mg/L) | Phenol | | Resorcinol | |
|---------------------------------|----------------------|--------|----------------------|--------|
| | K_2 | R^2 | K_2 | R^2 |
| 100 | 1.3×10^{-4} | 0.9962 | 9.3×10^{-5} | 0.9843 |
| 200 | 8.4×10^{-5} | 0.9951 | 6.8×10^{-5} | 0.9948 |
| 300 | 7.3×10^{-5} | 0.9922 | 6.6×10^{-5} | 0.9968 |

Table 4: Weber-Morris rate constants for phenolic compounds adsorption on CPAA hydrogels

| Initial concentration (mg/L) | Phenol | | | Resorcinol | | |
|---------------------------------|----------|--------|--------|------------|--------|--------|
| | K_{id} | C | R^2 | K_{id} | C | R^2 |
| 100 | 3.9104 | 2.8023 | 0.9721 | 4.6805 | 1.7793 | 0.9664 |
| 200 | 5.1098 | 3.9223 | 0.9855 | 6.8059 | 3.5134 | 0.9748 |
| 300 | 6.9953 | 5.5471 | 0.9859 | 8.5690 | 8.0426 | 0.9762 |

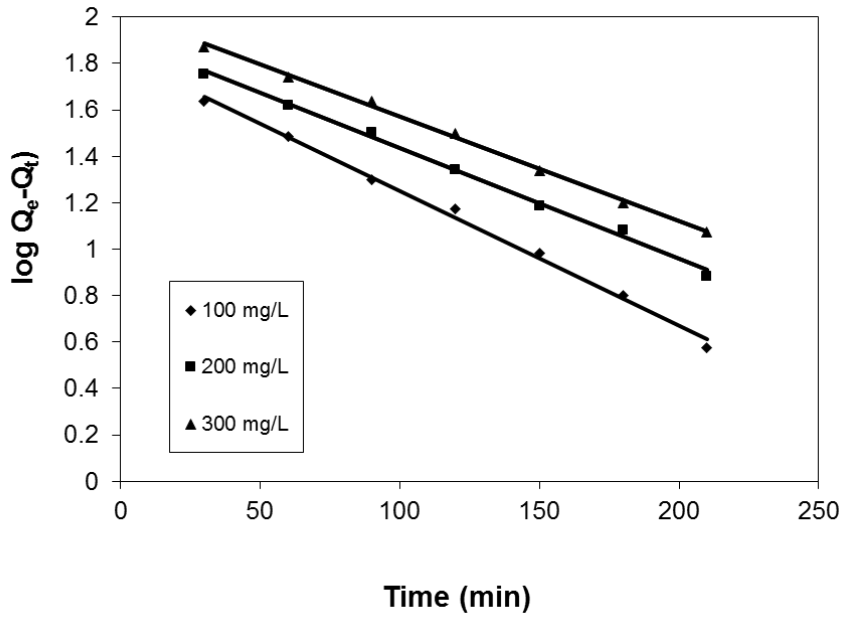


Fig. 9: Lagergren first-order kinetic plots at different initial concentrations of phenol on CPAA hydrogels

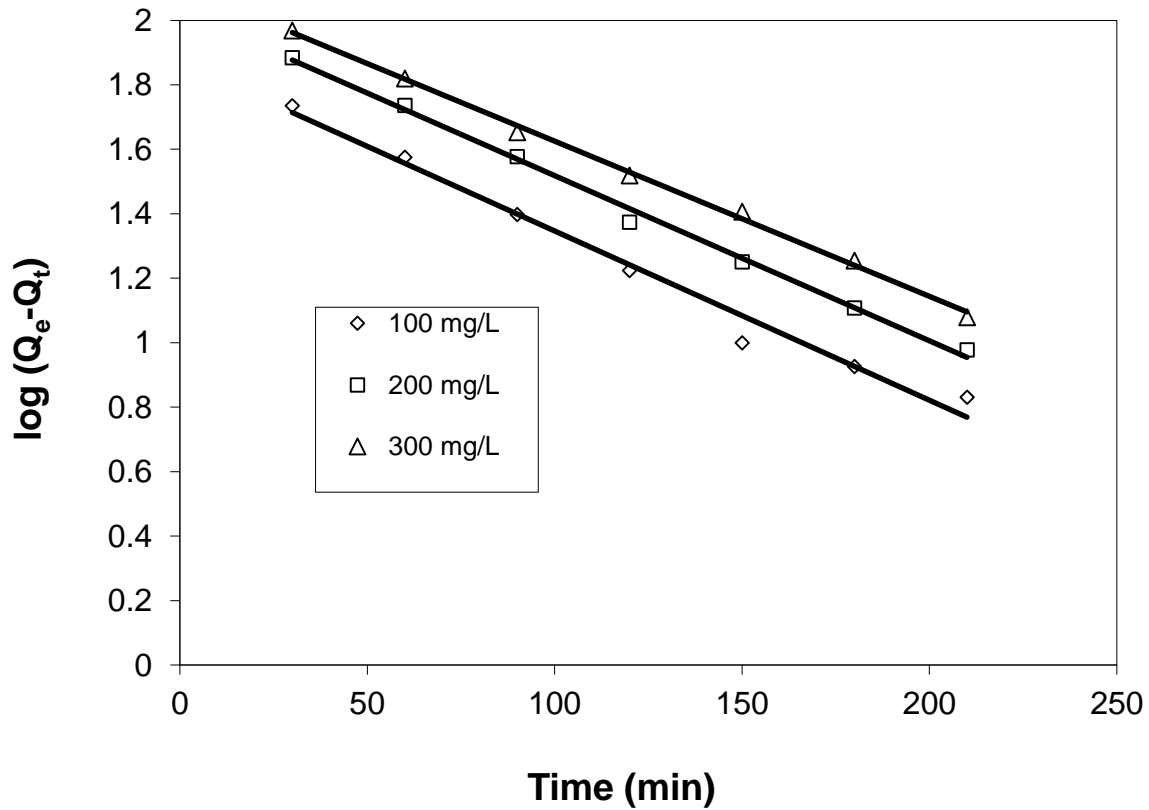


Fig. 10: Lagergren first-order kinetic plots at different initial concentrations of resorcinol on CPAA hydrogels.

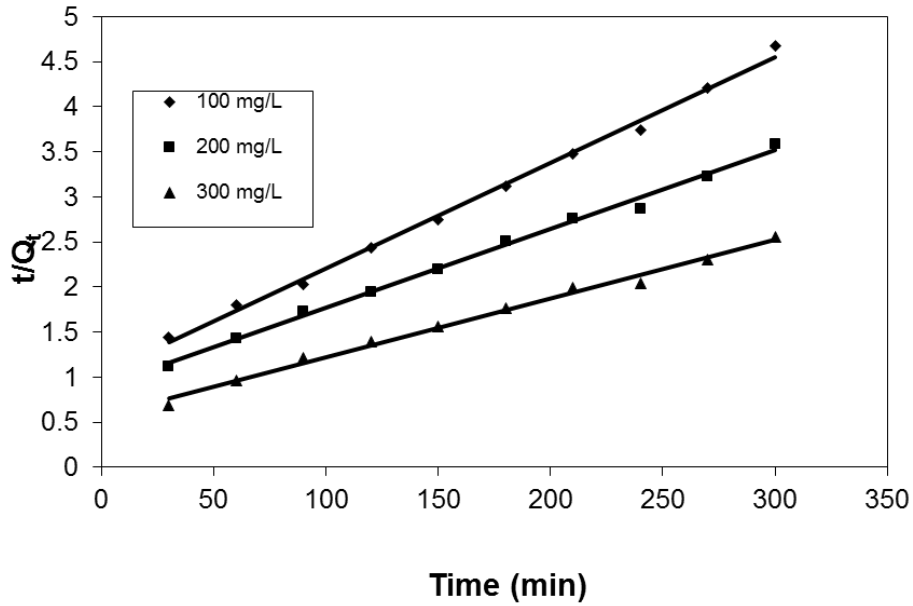


Fig. 11: Psuedo- second order kinetic plots at different initial concentrations of phenol on CPAA hydrogels

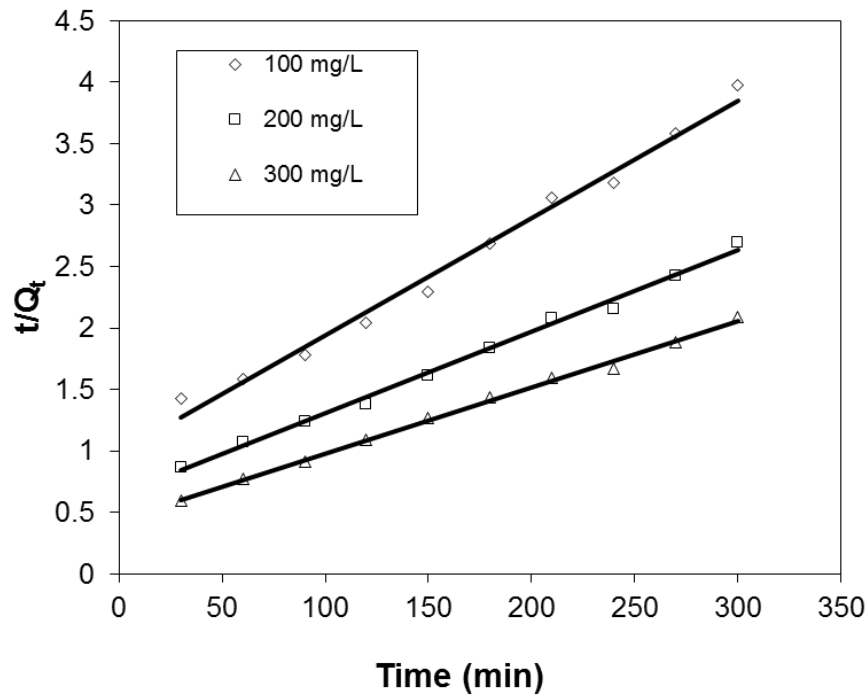


Fig. 12: Psuedo- second order kinetic plots at different initial concentrations of resorcinol on CPAA hydrogels.

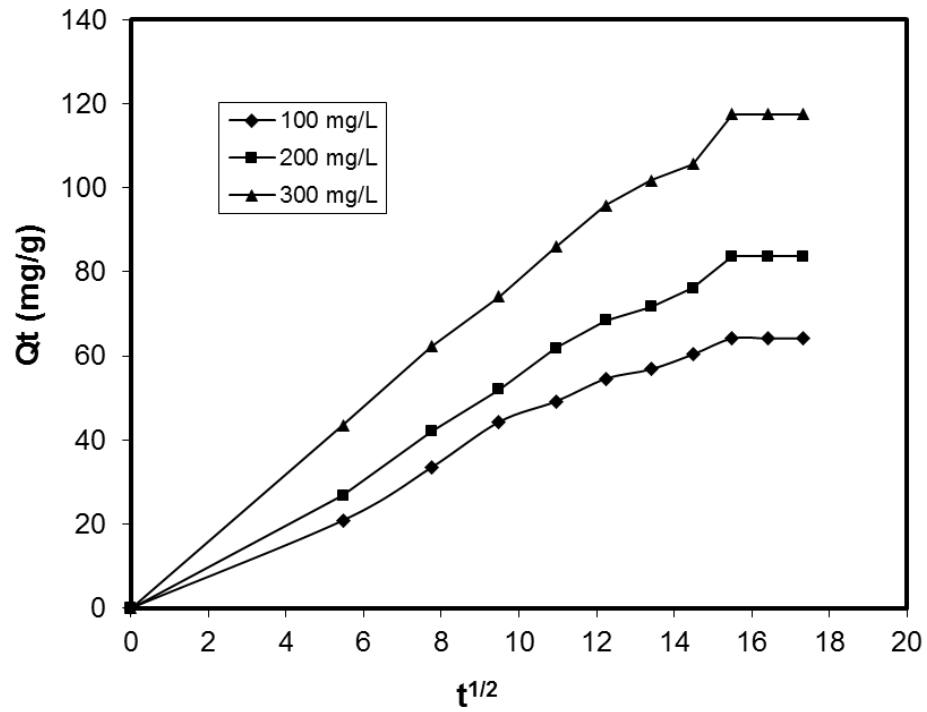


Fig. 13: Weber-Morris plots at different initial concentrations of phenol on CPAA hydrogels

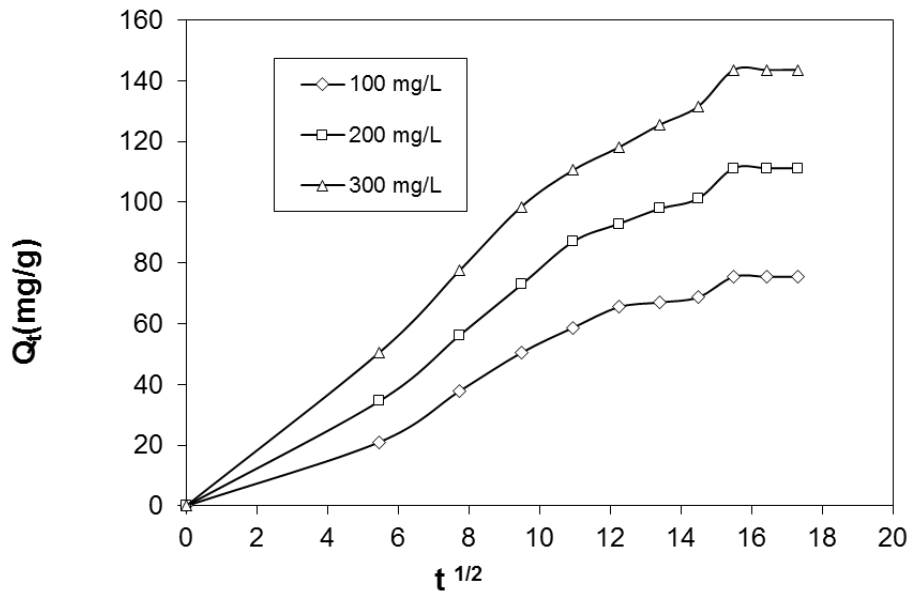


Fig. 14: Weber-Morris plots at different initial concentrations of resorcinol on CPAA hydrogels.

3.10 Adsorption Isotherm models

Adsorption Isotherms studies is an important to investigate the efficiency and the capacity of adsorption process. Based on Adsorption Isotherms like Langmuir, Freundlich models gives the valuable information is maximum adsorption capacity of phenolic compounds on CPAA hydrogels.

In order to study the effect of initial phenolic concentration on the adsorption uptake, Both phenol and resorcinol solutions with initial concentrations of 50 – 100 mg/L with the adsorbent dose 0.1g/100 mL of CPAA hydrogels. The adsorption capacity of the CPAA hydrogels increased with increase in initial phenolic concentration. Increase in the initial concentration of phenolic provides more sorption sites and increases sorption sites and increases sorption successful application of the adsorption technique demands the studies based on various adsorption isotherm models, because adsorption isotherm models clearly depict the relationship between the concentration of phenolic in solution and the amount of phenolic adsorbed on the solid phase when both phases are in equilibrium. In this study, the two adsorption isotherm models, Langmuir and Freundlich isotherm equations were used to describe the adsorption capacity of CPAA hydrogels

It is applicable for mono layer and the linear form of the Langmuir isotherm [31] is

$$\frac{1}{Q_e} = \frac{1}{Q_m b C_e} + \frac{1}{Q_m} \quad (7)$$

Where is the C_e equilibrium concentration of the adsorbate (mg/L), Q_e is the amount of adsorption at equilibrium (mg/g), Q_m and b are Langmuir constants. The experimental data were plotted as $1/C_e$ against $1/Q_e$ in order to get the values of Langmuir constants Q_m and b and the plots are given in Figs.15 and 16 for adsorption of phenolic compounds on CPAA hydrogels.

The Freundlich isotherm[32] is applicable for heterogeneous layer (or) multi layer and the Freundlich isotherm is

$$\log Q_e = \log K_f + \frac{1}{n} \log C_e \quad (8)$$

where, K_f and n are Freundlich constants. The experimental data were plotted as $\log Q_e$ against $\log C_e$ in order to get the values of Freundlich constants K_f and n and the plots are given in Figs. 17 and 18, the constants values like Langmuir and Freundlich isotherms are shown in table 5 for adsorption of phenolic compounds on CPAA hydrogels.

Table 5: Langmuir and Freundlich isotherm constants for phenolic compounds biosorption on CPAA hydrogels

| Phenolic compound | Langmuir | | | Freundlich | | | |
|-------------------|--------------|------------|-------|------------|-------|-------|-------|
| | Q_m (mg/g) | b (L/mg) | R^2 | K_f | $1/n$ | n | R^2 |
| Phenol | 76.92 | 0.0225 | 0.972 | 4.666 | 0.548 | 1.824 | 0.971 |
| Resorcinol | 83.33 | 0.0277 | 0.991 | 6.260 | 0.517 | 1.934 | 0.993 |

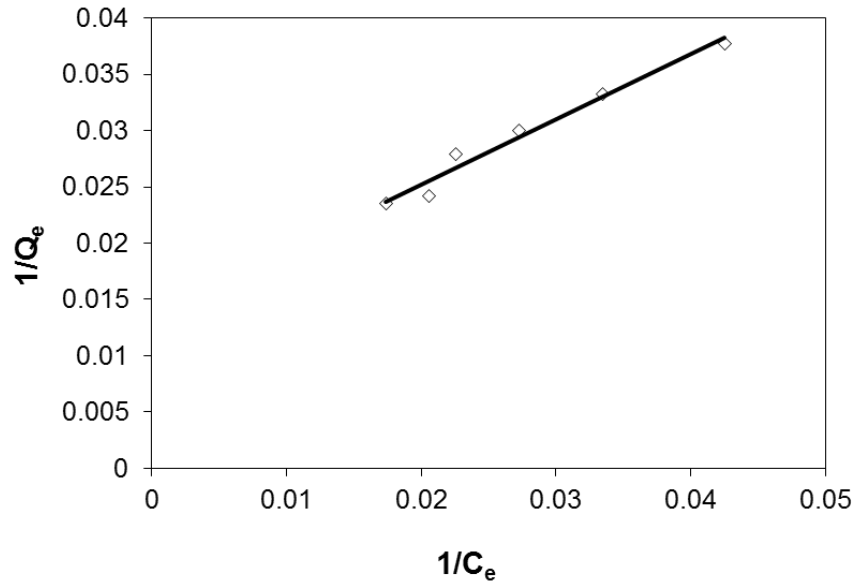


Fig. 15: Langmuir isotherm plot for adsorption of phenol on CPAA hydrogels

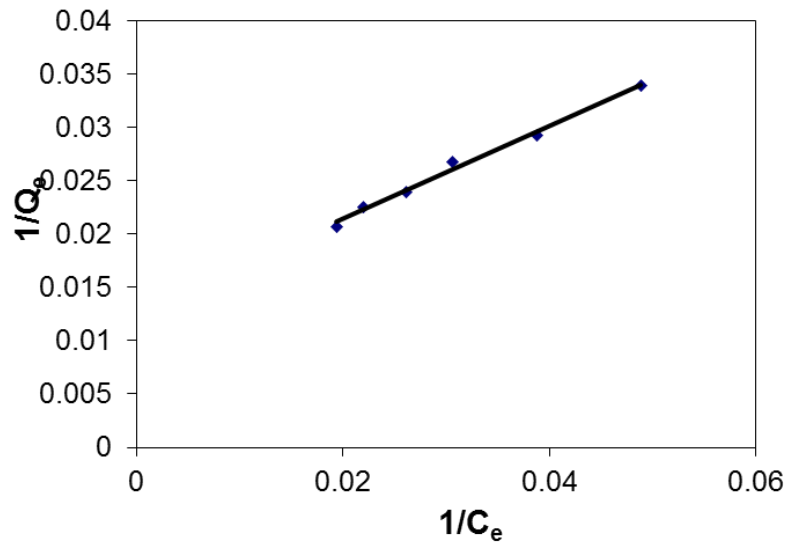


Fig. 16: Langmuir isotherm plot for adsorption of resorcinol on CPAA hydrogels

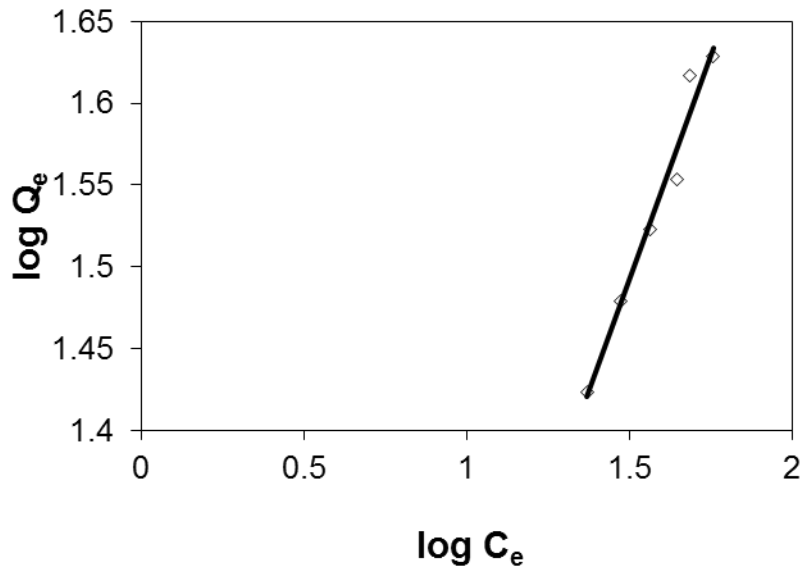


Fig. 17: Freundlich isotherm plot for adsorption of phenol on CPAA hydrogels.

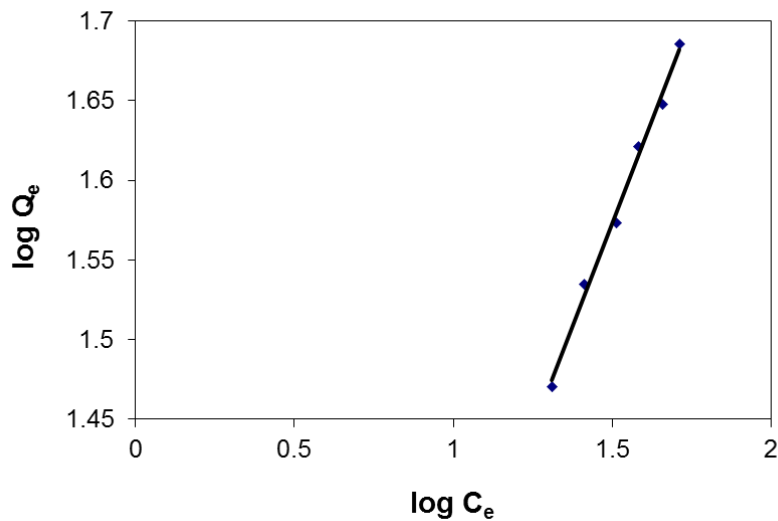


Fig. 18: Freundlich isotherm plot for adsorption of resorcinol on CPAA hydrogels.

4. CONCLUSIONS

The present study, focuses on the synthesis of new CPAA hydrogels, and their characterization by FTIR, SEM and finally the adsorption studies of phenol and resorcinol on CPAA hydrogels from aqueous solution. Adsorption of phenol and resorcinol is depending on pH of the solution and it is found to be at pH 7. The effect of applying parameters such as pH, contact time, adsorbent dosage and initial phenolic compounds concentration on the uptake of phenol and resorcinol. The kinetic study of the adsorption process

was follow the pseudo-first order, pseudo-second order and Weber-Morris kinetic model. The equilibrium data were described by the Langmuir and Freundlich isotherm models, from the Langmuir isotherm model the maximum adsorption capacity of 76.92 and 83.33 mg/g for phenol and resorcinol respectively. The study was analyzed on the adsorption Based on the above all results, it can be concluded that the hydrogels of CPAA is an effective, low cost, natural and alternative adsorbent for the adsorption of phenol and resorcinol from aqueous solutions.

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