The adsorptive removal of cationic dye from aqueous solution using Poly (methacrylic acid) Hydrogels: Part-I. equilibrium studies
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ABSTRACT

In this work poly(methacrylic acid) hydrogels were prepared by free radical aqueous polymerization of methacrylic acid(MAc) using N,N'-methylene bisacrylamide (MB) as crosslinker and potassium persulfate (KPS) as initiator. The hydrogels were characterized by FTIR and TG analysis. The gels exhibited pH-dependent swelling behavior, with equilibrium percent mass swellings of about 110 and 403 at pH 1.0 and 7.4 respectively. The swelling exponent, n, was found to be 0.31 and 0.59 respectively, thus indicating a diffusion controlled and chain relaxation controlled swelling at these pH values respectively. The equilibrium adsorption of a cationic dye Methylene Blue (MB) was studied at 25\textdegree C using the Langmuir and the Freundlich adsorption isotherm models. The maximum sorption capacity \( Q_0 \) was found to be 169.43 mg/g . The equilibrium dye uptake was found to increase with the pH of the adsorbate medium and attained an optimum value of 77.8 mg/g for the initial dye concentration of 200 mg/L at 25\textdegree C at pH 5.2. The adsorption showed negative temperature dependency thus suggesting exothermic nature of the adsorption process. Finally, the various thermodynamic parameters were also evaluated.

Keywords: Adsorption, FT-IR, Thermodynamics, hydrogels, Isotherm

1. Introduction

It is well known that textile industries, pulp mills, and dyestuff manufacturing units discharge highly colored wastewaters which have provoked serious environmental concerns all over the world (Faria et al., 2004). Over 10.000 dyes with an annual production of 7x10\textsuperscript{5} tons worldwide have been reported to be commercially available (Asma et al., 2006). The dye effluents contain a large amount of suspended solids. They also have high chromaticity and high COD contents (Liu and Huang, 2006). Many dyes and pigments, although not toxic, present an aesthetic problem and reduce photosynthetic activity in the receiving waters into which they are discharged. Many dyes are designed for their chemical stability and don’t undergo biochemical degradation readily (Jain et al., 2010). Various treatment processes such as ozonization (Selcuk, 2005), coagulation (Shi et al., 2007), ultrafiltration (Majewska-Nowak, 1989), oxidization (Kim et al., 2004), photochemical degradation (Xia et al., 2008) and adsorption (Bajpai and Shrivastava,2011; Hamdaoui and Chiha,2007; Saha 2010; Bajpai and Jain, 2010) have been widely investigated to remove dyes from wastewaters.

Due to biological and chemical stability of dyestuff in a number of conventional water treatment methods, adsorption is considered as an attractive and favorable alternate for the
removal of dyes from wastewater streams. For an efficient adsorption process, rapid removal and high adsorption capacity of adsorbent is needed.

Among the various dyes, methylene blue (MB) is a thiazine cationic dye, which is most commonly used for coloring among all dyes of this category. Although not strongly hazardous, it can have various harmful effects. Recent past has witnessed tremendous research work on the adsorptive removal of methylene blue using low-cost adsorbents, but due to low adsorption capacity of these adsorbents environmental chemists have focused their attention on developing synthetic polymeric materials as new class of adsorbents with fair adsorption capacity (Rahchamani et al., 2011; Wang et al., 2010). Several polymers with different functional groups have attracted great interest due to their high adsorption capacity (Senkal and Yavuz, 2006).

In this connection, the proposed study has been undertaken for obtaining an effective removal of methylene blue dye using poly(methacrylic acid) hydrogel as a potential adsorbent. The presence of ionizable carboxylic groups in the polymer network led us to look into the possibilities of using this polymer as a potential adsorbent. Here it is worth mentioning that there have been some reports regarding the use of carboxylic acid groups containing polymers (Mak and Chan, 2004; Zendehdel et al., 2010) but in this study the variation in mesh size of poly(methacrylic acid) has been co-related with pH of the adsorption medium.

2. Materials and Method

2.1 Materials

The monomer methacrylic acid (MAc), crosslinker N,N’-methylene bisacrylamide (MBAm), initiator potassium persulfate (KPS), were obtained from High Media Chemicals, Mumbai, India and used as received. The dye MB (C_{16}H_{18}ClN_{3}S_{3}H_{2}O, molecular weight 373.9) was obtained from E. Merck Chemicals, Mumbai, India and was GR grade. All other chemicals used were also analytical grade. The double distilled water was used throughout the investigation.

2.2 Preparation of poly (MAc) hydrogels

The polymeric hydrogels were prepared as described in our previous study (Bajpai and Dubey, 2004). In brief, 11.74 mM of MAc, and 0.029 mM of crosslinker MBAm, were dissolved in water to give a total volume of 5 mL. To this, 0.023 mM of initiator KPS was added and the resulting solution was transferred into test tube (Borocil, id 2.5 cm) and kept in an electric oven (Temp Star, India) at 60°C for a period of 2 h. After the polymerization was over, the test tube was broken, hydrogels were smashed, put in distilled water for a period of three days to remove un-reacted salts and finally dried in vacuum chamber at 40°C till they attained constant weight. The hydrogels synthesized were designated as HG(29) where the number in parenthesis denotes the number of milli moles of monomer multiplied by hundred. The adsorption studies were carried out with fine particles obtained by passing the adsorbent particles through standard sieve to get particles with mean geometrical diameter of 84 micrometer.

2.3 Characterization of poly (MAc) hydrogels

The FTIR spectrum of polymeric adsorbent was recorded on a Shimadzu, 8201 PC Spectrophotometer using KBr pelleting method. Thermal analysis was carried out using a
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thermo gravimetric analyzer (Mettler, Toledo, GmbH. Switzerland). About 12 mg of powdered sample was placed in a ceramic crucible and heated over a temperature range of 30 to 1000°C at the rate of 20°C per min under the flow of dry N₂ at flow rate of 30 mL per min. SEM images showing morphology of adsorbent were taken out by using JOEL JSM840A (Japan) Scanning Electron Microscope.

2.4 Swelling studies

Completely dried pre-weighed hydrogel sample was placed in distilled water or buffer solution under sink conditions at 25°C. The swollen gel was taken out at different time intervals, wiped superficially with filter paper to remove extra surface water weighed and then put in the same swelling medium. The mass measurements were continued till the gel attained a constant weight. The percent mass swelling was determined using the following expression:

\[
\% \text{Sm} = \left( \frac{M_t - M_0}{M_0} \right) \times 100 \quad \ldots (1)
\]

where \(M_0\) and \(M_t\) are the initial mass and mass at different time intervals respectively. All the experiments were carried out in triplicate and the average values are given in the data.

2.5 MB adsorption studies

A volume of 20 mL of methylene blue solutions, with concentrations ranging from 30 to 450 mg/L, were placed in 125 mL Erlenmeyer flasks. A weighed amount (0.05 g) of poly(MAc) particles was added to each solution and the flasks were shaken in a thermostated shaker (Rivotek, India) at a constant speed of 100 rpm at a desired temperature. After shaking the flasks for 2 h, the adsorbent particles were separated by centrifugation and the supernatant was analyzed for the remaining dye concentration spectrophotometrically at the wavelength of 430 nm.

The amount of MB adsorbed onto adsorbent was calculated using the following expression:

\[
Q_e = (C_0 - C_e) \times \frac{V}{m} \quad \ldots (2)
\]

where \(Q_e\) is the equilibrium adsorption capacity of MB adsorbed on unit mass of adsorbent(mg/g), \(C_0\) and \(C_e\) are the initial and the equilibrium concentrations (mg/L) respectively, \(V\) is the volume of adsorbate solution(L), and \(m\) is the amount of adsorbent (g). All the experiments were carried out in triplicate and average values are reported in the data.

2.6 Determination of mesh sizes of swelling network

In order to estimate the mesh size of polymer network at different pH of the swelling media, method of swelling measurements was followed as described by (Caykara et al., 2007) In brief, end-to-end distance of the polymer chains in the freely jointed state is given as:

\[
\left( r_f \right) = l N^{0.5} \quad \ldots (3)
\]

where \(l\) is carbon-carbon single bond length (1.54 Å) and \(N\) is number of links between two cross links,

\[
N = \frac{2M_c}{M_0} \quad \ldots (4)
\]

Here \(M_0\) is molecular weight between cross links and \(M_0\) is molar mass of the repeat unit.
The value of $M_c$ was calculated using equilibrium swelling data obtained at different pH using following relation,

$$M_c = -d_p V_s \Phi^{1/3} \left[ \ln (1- \Phi) + \Phi + \chi \Phi^2 \right]^{-1} \quad \ldots (5)$$

Where $d_p$, $V_s$, $\Phi$, and $X$ are density of polymer, molar volume of solvent, volume fraction of polymer in the swollen state, and Flory-Huggins parameter respectively. Finally, the mesh size of swelling network was calculated using the following expression,

$$\zeta = \Phi^{-1/3} C_n (r_i) \quad \ldots (6)$$

where $C_n$ is the rigidity factor of polymer.

3. Results and discussion

3.1 FTIR spectral analysis

Figure 1 shows the FTIR spectrum of poly(MAc) hydrogel. The spectrum exhibits characteristic C=O stretching at 1720 cm\(^{-1}\). The $-\text{CH}_2$ deformation bending gives a band about 1477 cm\(^{-1}\) and $-\text{OH}$ bonded groups give rise to vibration band at about 2602 cm\(^{-1}\). In addition, C-O stretching band of carboxylic groups are observed at 1290 cm\(^{-1}\). Finally, a broad band in the region of 3400-3700 cm\(^{-1}\) is observed due to $-\text{OH}$ stretching of carboxylic acid and $-\text{NH}$ stretching from amide. Both peaks appear to have merged.

![Figure 1: FTIR spectrum of poly(methacrylic acid) hydrogels.](image)

3.2 Thermogravimetric analysis

The thermogram of poly (MAc) is shown in the Figure 2. The polymeric adsorbent shows fair thermal stability until about 180°C, then in the temperature range of 180-260°C a weight loss corresponding to first degradation process is observed. Above 260°C no relevant thermal event occurs till 300°C, when a second weight loss, corresponding to the decomposition of polymer starts. As reported by (McNeill et al., 1995) The first degradation process is related to the loss of water molecules through the formation of intra-molecular and inter-molecular

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anhydride linkages and also to the de-carboxylation of a fraction of the –COOH groups by which CO₂ is produced. In the second degradation stage, the polymer decomposes with the elimination of CO and CO₂ by way of abundant backbone scission and formation of a small concentration of unsaturation. Almost similar results have also been reported elsewhere (Polacco et al., 2000).

![Figure 2: Thermogravimetric analysis of poly(MAc) adsorbent.](image)

### 3.3 SEM analysis

The Figure 3(A & B) shows SEM images of plain and MB adsorbed polymer samples respectively. A close observation of the two images reveals that plain adsorbent surface is fairly rough whereas after adsorption of MB molecules there is quite smoothness on the surface of particles which may be due to filling of available spaces on adsorbent particles by dye molecules. This may also be taken as physical evidence to confirm the adsorption process.

![Figure 3: SEM images showing surface morphology of (A) plain adsorbent and (B) dye adsorbed adsorbent respectively.](image)
3.4 Water uptake behavior

The water absorbency of poly(MAc) hydrogel sample HG(29) was studied by monitoring the dynamic uptake of water in the media of pH 1.0 and 7.4 at 25°C. The results, shown in the Figure 4, which reveal that water uptake is higher in the pH 7.4 whereas a slower uptake is observed in the medium of pH 1.0. The total mass percent swelling, $M_s$, was found to be nearly 850 and 140 percent respectively. The observed findings may be attributed to the fact that in the acidic medium polymethacrylic acid chains remain in un-dissociated state and there exists strong H-bonding interactions between $-\text{COOH}$ groups, thus creating additional crosslinks (Bajpai and Sonkusley, 2002). This renders a compact structure to polymer matrix which discourages water entrance into the polymer matrix. However, when the hydrogel is placed in the medium of pH 7.4, the $-\text{COOH}$ groups, present along the macromolecular chains, get ionized to yield negatively charged $-\text{COO}^-$ groups along the polymer chains. These similarly charged groups repel each other, thus causing unfolding of polymeric chains. This results in more and more uptake of water molecules into the swelling network.

![Figure 4: Dynamic uptake of water by HG(29) hydrogel in the media of pH 1.0 and 7.4](image)

The portion of water absorption curve, more than 60 percent, was analyzed using Peppas equation (Peppas and Ritger, 1987):

$$\frac{M_t}{M_\infty} = k t^n$$  \(\text{(7)}\)

Where $M_t$ and $M_\infty$ are the masses of water absorbed at time t and at equilibrium respectively, k is the gel characteristic constant and ‘n’ is the swelling exponent describing the mode of penetrant transport mechanism. The constants n and k were evaluated from the slopes and intercept of linear plots obtained between $\ln \frac{M_t}{M_\infty}$ and $\ln t$ (see Figure 5). The values of n; k for water uptake in the media of pH 1.0 and 7.4 were found to be 0.31; 14.2x10^{-2} and 0.64; 13.1x10^{-2} respectively. The values of n obtained indicated that in the acidic pH the water transport mechanism was diffusion controlled ( n< 0.45 )while in the slightly alkaline pH water transport occurred through chain - relaxation controlled manner (n>0.45). This is a common phenomenon and has been reported by a number of researchers working on pH-sensitive hydrogels (Chen et al., 2004).
3.5 Effect of pH on equilibrium water uptake

The effect of pH of the swelling medium on the water absorbency of hydrogel HG(29) was investigated by measuring equilibrium water uptake of poly(MAc) gels in different solutions with pH ranging from 1.0 to 9.0 at 25°C. The results, as shown in the Figure 6, indicate that percent mass swelling increases with pH of the swelling medium, attains an optimum value of about 1570 percent at pH 8.6 and then begins to decrease. The observed findings are attributable to the pH-dependent ionization of –COOH groups of poly (methacrylic acid) chains as has been discussed in the previous section (Kim and Peppas, 2002). However, as the pH of the swelling medium increases, the –COOH groups begin to ionize into –COO⁻ groups which repel each other owing to similar charges thus causing the polymer chains to relax or unfold. This finally results in greater water uptake. In this way the gel attains an optimum percent swelling of 1570 percent at pH 8.6. However, as the pH is increased further, the mass swelling begins to decrease. This might be due to formation of un-crosslinked poly(MAc) hydrogel which must has a fair tendency to dissolve in alkaline medium (Ravi et al., 2005).
3.6 Equilibrium MB adsorption study

The equilibrium adsorption of dye was investigated in the concentration range of 30 to 450 mg/L at 25°C. The plot of $C_e$ versus $q_e$ is shown in the Figure 7. It is clear that the observed isotherm typically belongs to L2 type i.e. Langmuir type of adsorption isotherm. It is also apparent that the shape of the isotherm is fairly steep, thus suggesting stronger interactions between the active sites of adsorbent and adsorbate molecules. The stronger interactions may probably be attributable to the fact that at the experimental pH of 7.2 (which is self pH of the MB solution), the polymeric chains of adsorbent carry negative charges due to presence of ionized –COO\(^-\) groups, which bind electrostatically with the adsorbate MB\(^+\) molecules. Thus strong attractive forces appear to be responsible for adsorption process. Therefore the dye adsorption is occurring through physical adsorption.

![Figure 7: Equilibrium dye uptake, $q_e$ as a function of equilibrium concentration $C_e$ for MB adsorbent onto HG (29) hydrogel adsorbent particles.](image)

3.7 Modeling of equilibrium MB adsorption data

The equilibrium adsorption isotherms are of fundamental importance in the design of adsorption systems. In a batch system, equilibrium is established between the liquid phase (free adsorbate solution) and the solid phase (adsorbent-attached solute) concentrations. It can be described by adsorption isotherm models at a fixed temperature. In general, the Langmuir and the Freundlich isotherm models describe the equilibrium uptake data in a quite satisfactory manner.

The Langmuir isotherm model (Langmuir, 1916) is given as

$$\frac{C_e}{q_e} = \frac{1}{Q_0 K_L} + \frac{C_e}{Q_0} \quad \ldots(8)$$

Where $q_e$ (mg/g) is the amount of dye adsorbed onto poly(MAc) adsorbent at equilibrium, $C_e$ is the equilibrium concentration(mg/L), $K_L$(L/mg) is the Langmuir constant related to the energy of adsorption, and $Q_0$(mg/g) is the adsorption capacity corresponding to complete monolayer coverage. The Langmuir adsorption isotherm is based on the assumption of a structurally homogeneous adsorbent and a monolayer coverage with no interactions between the adsorbent molecules.

Using the equilibrium MB uptake data, a linear plot was obtained between $C_e/q_e$ and $C_e$ as shown in the Figure 8 with a fair regression value of 0.9975. The slope and intercept of linear...
plot were used to calculate parameters $Q_0$ and $K_L$ which were found to be 169.49 mg/g and 0.098 (L/mg) respectively.

\[
y = 0.0059x + 0.0598
\]

$R^2 = 0.9975$

\[
\frac{C_e}{q_e} = 0.0059C_e + 0.0598
\]

**Figure 8:** Langmuir plot for MB uptake of HG (29) hydrogel adsorbent at 25°C.

The equilibrium dye uptake data was also studied using Freundlich adsorption isotherm model (Freundlich, 1906), which can be expressed as:

\[
q_e = K_F C_e^{1/n}
\]  \(\cdots(9)\)

which may be represented in the logarithmic form as,

\[
\log q_e = \log K_F + (1/n) \log C_e
\]  \(\cdots(10)\)

where $q_e$ is solid phase equilibrium concentration (mg/g), $C_e$ is liquid phase equilibrium concentration (mg/L), and, $K_F$ and $n$ are Freundlich constants with ‘n’ giving an indication of the facility with which adsorption process takes place, $K_F$ (mg/g(L/mg)$^{1/n}$) is the adsorption capacity of the adsorbent. It is generally stated that value of $n$ in the range of 2-10 represents good, 1-2 moderately difficult and less than 1 poor adsorption characteristics (Yao et al., 2010).

Figure 9 shows linear plot obtained between $\log q_e$ and $\log C_e$ with a linear regression of 0.9052. The values of Freundlich constants $K_F$ and $n$ were found to be 42.88 (mg/g(L/mg)$^{1/n}$) and 3.386 respectively. As the value of $n$ lies between 2 and 10, it indicates a fair adsorption of MB onto polymeric adsorbent. However, as the regression value obtained was low as compared to that obtained for Langmuir model, it can be inferred that in the present study MB uptake is best interpreted in the terms of Langmuir isotherm model. This indicates that a monolayer adsorption process occurs on the homogeneously distributed active sites of poly(MAc) adsorbent.
3.8 Effect of pH on the MB uptake

pH plays a significant role in affecting the extent of adsorption, particularly when the adsorbent and adsorbate, both are charged species. In the current study the adsorbate methylene blue is a cationic dye while the adsorbent poly(MAc) contains ionizable carboxylic acid groups along polymer chains. In order to investigate the effect of pH adsorption studies were carried out at various pH of adsorbate solutions, in the range of 1 to 9. The results, as shown in the Figure 10, reveal that at low pH values adsorption is very poor and it increases gradually with pH of the dye solution, attains an optimal adsorption capacity of about 77.85 mg/g at pH 8.6 and then it levels off. The observed findings can be explained as follows: when pH of the solution is quite low, there is excess of H$^+$ ions in the solution which compete with the cationic MB$^+$ molecules and are preferentially adsorbed on the available active sites. In addition, since the –COOH groups are also in the un-ionized state in the polymer network, the adsorption is not favored and it may only be due to H-bonding interactions between N and S atoms of methylene blue molecules and H atoms from –COOH groups of polymeric adsorbent. Therefore the adsorption is poor. However, as the pH of the adsorbate solution increases, number of H$^+$ ions continues to decrease and the carboxylic groups along the polymer chains begin to ionize to yield –COO$^-$ groups which act as binding sites and show strong attraction towards incoming MB$^+$ molecules. This results in an enhancement in the adsorption. As the pH of the adsorbate solution exceeds 6.0, the MB uptake attains a saturation value of about 77.85 mg/g for initial dye concentration of 200 mg/L at 25°C. Similar results have also been reported elsewhere (Almeida et al., 2009).

The observed increase in MB uptake with pH can also be correlated with the increase in the mesh size of the polymeric networks with pH of the surrounding medium. Figure 10 also shows a variation in mesh size of polymer network of adsorbent with pH of the medium. It can be seen that in the pH range of 1-3, the mesh size of the polymer network lies between 5 to 8 Å thus providing an area of about 25 to 65 Å$^2$ (on the basis of assumption that square of the mesh size may be taken as approximate area of opening of the mesh network) for incoming dye molecules. Since molecular size of cationic dye methylene blue molecule (Hoppe et al., 1993) is almost 112 Å, its entrance into the polymer network is almost restricted. However as the pH of the medium is further increased, the mesh size of the swelling network also increases and beyond pH 4.0, it acquires an approximate length of 12 Å (i.e. offered area exceeds 144 Å$^2$) and hence MB molecules may be allowed to enter into
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3.9 Mechanism of MB uptake

From the above discussion it is clear that the cationic methylene blue molecules are adsorbed onto poly methacrylic acid hydrogel adsorbent due to electrostatic attraction between cationic MB⁺ molecules and negatively charged –COO⁻ groups present along the polymeric segments of poly(MAc). The formation of an ionic pair between the imine groups of MB and the carboxylate groups of poly(MAc) are shown in the Figure 11. Almost similar type of electrostatic attraction has also been reported by (Paulino et al., 2006) for the adsorption of methylene blue onto poly(acrylamide) and poly(acrylate) hydrogels.

3.10 Effect of temperature on MB uptake

The effect of temperature on the adsorption of MB was investigated by carrying out equilibrium adsorption studies at 16°C, 25°C and 37°C. The Langmuir isotherm models were applied on the adsorption data (see Figure 12) and the values of maximum adsorption capacity Q₀ were determined using slopes and intercepts of linear plots. The Q₀ values were found to be 243.90, 169.49 and 112.35 mg/g respectively. These values indicated that the adsorption decreased with increase of temperature. This may be attributed to the fact that the kinetic energy of adsorbate molecules increase with temperature, thus weakening the

Figure 10: Effect of pH of dye solutions on the equilibrium uptake at 25°C.

Figure 11: Illustration showing binding of methylene blue molecules to the polymethacrylic acid adsorbent.
adsorbate-adsorbent interactions. This also supports our observation that adsorption process is physical in nature. It is to be noted that there are a number of studies reported where the increase in temperature causes an enhancement in the degree of adsorption. This happens due to development of new pores in the adsorbent and reduction in the viscosity of the medium.

**Figure 12:** Langmuir plots showing equilibrium dye uptake at different temperatures.

In order to estimate the standard free energy change $\Delta G^0$, the Langmuir constant $K_L$ was used as per following equation:

$$\Delta G^0 = \text{-}RT \ln K_L \quad \ldots(11)$$

where $T$ is the absolute temperature (K), and $R$ is gas constant (8.314 J/mol K). The standard enthalpy change ($\Delta H^0$) and entropy change ($\Delta S^0$) were calculated using the slope and intercept of van’t Hoff plot of $\ln K_L$ versus $1/T$ (see Figure 13) as per the following relationship,

$$\ln (K_L) = \frac{\Delta S^0}{R} - \frac{\Delta H^0}{RT} \quad \ldots(12)$$

**Figure 13:** The plot of $\ln K_L$ versus $1/T$ for the evaluation of standard enthalpy and entropy change

The values of $\Delta G^0$, $\Delta H^0$ and $\Delta S^0$ are given in the Table 2. The negative values of $\Delta G^0$ are indicative of the spontaneous nature of the adsorption process. In addition, the negative value of $\Delta H^0$ suggests exothermic nature of the adsorption process while positive entropy change
shows increased randomness during the adsorption process. The observed increase in randomness may be attributable to the fact that due to adsorption of dye molecules, water molecules are released from solid surface into the bulk solution.

Table 2: Evaluation of thermodynamic parameters

| Temperature | $\Delta G^0$(kJ mol$^{-1}$) | $\Delta H^0$(kJ mol$^{-1}$) | $\Delta S^0$(J/mol/K) |
|-------------|-----------------------------|-----------------------------|-----------------------|
| 16°C        | -21.527                     |                             |                       |
| 25°C        | -26.053                     | -126.572                    | 512.25                |
| 37°C        | -28.729                     |                             |                       |

4. Conclusion / Suggestions/ Findings

From the above study it may be concluded that poly(MAc) adsorbent has potential to remove cationic dye MB from aqueous solution. The adsorption is exothermic in this study and it will be favorable to carry out dye removal at lower temperature. Although a number of low cost adsorbents have been used in recent past, but they showed low adsorption capacity. For comparison, $Q_0$ values, obtained using various cost-effective adsorbents are shown in the Table-1. The data displayed also establishes the superiority of poly (methacrylic acid) as an effective adsorbent for dye removal. Here it is worth mentioning that the studies about the dynamic uptake of MB onto this adsorbent are under investigation, and shall be documented in next part.

Table 1: A comparative depiction of maximum sorption capacity of various adsorbents for dye uptake

| Adsorbent                                                      | $Q_0$(mg/g) | Reference            |
|---------------------------------------------------------------|-------------|----------------------|
| Polyacrylamide grafted attapulgite                            | 9.27        | Liu and Guo, 2006    |
| Chitosan-g-poly(acrylicacid)/montmorillonite                  | 1859        | Wang et al.,2008     |
| Polyacrylic acid – bound iron oxide                           | 199         | Mak and Chan, 2004(a)|
| Poly( acrylic acid )containing core- shell type resin         | 300         | Yavuz et al., 2011   |
| Poly(vinyl acetate)                                           | 2.612       | Malana et al., 2010  |
| Poly( acrylamide-co-maleic acid)                              | 2.2         | Saraydin et al., 1996|
| Polymethacrylic acid                                         | 169.64      | This work            |
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