A novel fibre-coated sorbent for rapid removal of heavy metals from wastewater. Sorption of Zinc(II) from dilute aqueous solutions in the presence of high concentrations of common salts

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The commercial acrylic fibre “Cashmilon” was partially hydrolyzed to convert a fraction of its nitrile (-CN) groups to carboxylic acid (-COOH) groups and then coated with polyethylenimine (PEI) resin and cross-linked with glutaraldehyde to produce a novel gel-coated fibrous sorbent with multiple functionalities of cationic, anionic and chelating types, and significantly faster sorption kinetics than bead-form sorbents. The sorption properties of the fibrous sorbent were measured using Zn(II) in aqueous solution as the sorbate to determine the effects of pH and the presence of common ions in the solution on the sorption capacity. The rate of sorption on the gel-coated fibre was measured in comparison with that on Amberlite IRA-68 weak-base resin beads, to demonstrate the marked difference between fibre and bead-form sorbents in their kinetic behaviour.

Keywords: Acrylic fibre, zinc ion, ion-exchange resin, polyacrylonitrile, polyethylenimine, sorbent, sorption

Discharge of heavy metals with aqueous effluents is a loss of valuable resources besides being a recognized source of environment hazards. Removal and recovery of these metals from effluents is essential for protection of environment, sustainable development and possible economic gain. Ion-exchange technology is increasingly used for this purpose. Although methods other than ion-exchange (e.g. chemical precipitation) can be used for treating these wastes, ion-exchange sorption is often preferred as it offers the advantages of possible recovery of metal values, minimum space requirement, and recovery of water for reuse.

Commercial ion-exchange sorbents are usually available in the form of beads and thus suffer from a drawback in that the sorption capacity realized in practice is often much less than the theoretical capacity, which is due to the inaccessibility of many sorption sites buried inside the resin matrix. This difference between the observed and the theoretical capacity, moreover, increases with the increase in bead size of the sorbent.

The relative inaccessibility of sorption sites inside resin beads is also responsible for relatively slow rate of sorption, which is one of the more important factors preventing large scale and wider industrial application of the ion-exchange method of separation. Considerable research has, therefore, been directed in recent years at developing ion exchange/chelating sorbents of significantly faster kinetics. Shell functionalization is a common approach used by several workers to achieve faster kinetics. Different methods have been used to prepare shell-functionalized sorbents. In one method1, monomers are polymerized on crosslinked polymer beads, followed by functionalization of the outer polymeric shell. In another approach2, shell-functionalization is achieved by using a reagent system and a particulate resin in which the functionalization rate is faster than the rate of diffusion of the reagent and stopping the reaction when the most readily accessible sites are functionalized.

Chanda and Rempel3-8 developed a simple process of shell-functionalization in which ion-exchange or chelating resins are gel-coated as a thin layer on a solid support, such as silica or polystyrene, using Cu(II) ions as a transient host. The process employs Cu(II) host ions pre-loaded on a solid substrate, such as silica3-6 or polystyrene7 to build a surface layer of gel resin which is then stabilized by reacting with a suitable cross linking agent before eventually leaching out the host copper ions. The process gives thin, uniform and firmly adherent layer of the sorbent resin on a solid substrate of any physical shape and geometry.

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Only polymers which readily react with Cu(II) ions and can readily undergo cross-linking reactions with suitable reagents can be used for gel coating by this process, yielding sorbents of both high capacity and fast kinetics. Thus, a sorbent prepared in this way by gel-coating poly(4-vinyl pyridine) and quaternized poly(4-vinyl pyridine) on silica using 1,4-dibromobutane as the cross-linking agent, showed a significant increase in the rate of sorption and elution, as compared to conventional bead-form resins, in the sorption of uranium and organic sulphonates, respectively, from dilute aqueous solutions. A similar process was later used for gel-coating polyethyleneimine (PEI) and polyacrylic acid on silica using glutaric dialdehyde and diepoxide as crosslinking agents.

Gel-coating on inert organic base resin, however, requires an initial surface functionalization to afford pre-loading of Cu(II) that acts as host ions to attract functionalized polymers from an aqueous solution onto the base resin, forming an outer gel layer that is then stabilized by cross-linking followed by acid-leaching to remove the Cu(II) host ions. Thus, polystyrene resin beads were partially oxidized, creating carboxyl groups to bind the Cu(II) host ions. In a later study, polyacrylonitrile (PAN) cross-linked with divinylbenzene was used as the particulate base resin to make gel-coated sorbents, as it would open up an exciting possibility of producing gel-coated sorbent as fibre or woven fabric for a wide variety of applications, since PAN is readily available in these forms.

For coating PAN fibre with PEI, a limited amount of carboxylic acid functionality (as a sodium salt) was generated on the surface and Cu(II) was loaded as host ions to help attract PEI onto the fibre surface from solution, followed by insolubilization of the PEI by crosslinking with glutaraldehyde and finally leaching out the Cu(II) host ions. Subsequently, the process has been simplified to enable direct coating of PEI, without Cu(II) mediation, on the partially hydrolyzed PAN fibre, followed by insolubilization with glutaraldehyde. The polymeric sorbent thus obtained in fibre from, designated as PAN(CO2Na)(PEI.XG), contains both carboxylic-type cation exchange functionality and secondary/tertiary amine groups to serve as anion-exchange and chelating sites.

In the present work, the sorption of Zn(II) ions from aqueous solution has been studied using this multifunctional fibrous sorbent made from commercial acrylic fibre. Zinc(II) is present in wastewater effluents from viscose rayon manufacture, cooling tower blowdown, rinse tanks following plating tanks, power generation using high-temperature brine of geothermal wells, pickle liquor of steel plants, battery manufacture, sodium hydrosulphite manufacture, and agrochemical production. In trace amounts, zinc is a nutritional element but is toxic at higher concentrations.

Ion-exchange methods are often used for removing and recovering zinc from water effluents and are preferred for the difficult separation of zinc present in low concentrations. In the viscose process, when the fibre is rinsed a waste solution of sulphuric acid and zinc sulphate is obtained. Containing approximately 100 ppm zinc, this solution is treated with a strong-acid cation exchanger to remove the zinc. If removal of Zn(II) and Cr(III) is required after chromate recovery from cooling tower blowdown, a sodium-form weak acid exchanger is used. Pickle liquor from steel plants containing ZnCl2 in HCl media is treated with anion exchange resin to remove zinc as the anionic complex (ZnCl4)2- in the Metsep ion-exchange process.

Because of its varied chemical properties Zn(II) can be removed from water by both cationic and anionic exchanges as well as by chelation. Since the new sorbent PAN(CO2Na)(PEI.XG) satisfies all these three types of functional requirements for ion-exchange sorption, it was considered of interest to study the sorption behaviour of Zn(II) on this sorbent. Sorption properties of the novel fibrous sorbent both under equilibrium conditions and as a function of time are being reported here. The effect of pH and common ions on the zinc(II) sorption capacity of the fibrous sorbent has also been investigated.

**Experimental Procedure**

**Sorbent**

Textile-grade acrylic fibre, *Cashmilon*, having composition (by wt.)—acrylonitrile 92, methyl acrylate 6, and sodium methyl sulphonate 2% (henceforth referred to simply as PAN fibre) was manufactured by Indian Petrochemical Corporation Ltd., Baroda. The method of gel-coating the fibre with polyethyleneimine (PEI) is shown schematically in Fig. 1.

The nitrile group on the fibre was partially converted to -CO2Na by reacting with boiling ethanolic NaOH under reflux for 10 h (Step 1) and then washed with ethanol to remove free alkali. The product was designated as PAN(CO2Na). In Step 2, PAN
(CO$_2$Na) was treated with dilute solution of HCl in ethanol to convert the partially hydrolyzed fibre into free acid (COOH) form which was then added to 5% (w/v) PEI (Aldrich, Cat. No. 18, 197-8, weight average molecular weight 750,000) resin solution in ethanol and refluxed for 10 h (Step 3). The resulting PEI-coated fibre was washed with ethanol to remove any free resin and treated with 5% (w/v) aqueous solution of glutaraldehyde for 4 h for crosslinking, i.e., gel formation and insolubilization of PEI (Step 4). The gel-coated fibre was then treated with 0.5N NaOH (aq.) to convert the carboxylic function to the Na$^+$ salt form (Step 5). It was washed till free of alkali and dried in oven at 70°C. The fibrous sorbent was designated as PAN (CO$_2$Na) (PEI.XG).

A comparison of the IR spectra of PAN, PAN(CO$_2$Na) and PAN (CO$_2$Na) (PEI.XG) in Fig. 2 confirms the chemical changes brought about by partial hydrolysis of the C≡N groups and the gel-coating of PEI. The presence of C=O peak, in addition to the C≡N peak in Fig. 2(a) is attributed to the content of methyl acrylate (6%) in PAN fibre. From the measured proton capacities, namely, 0.67, 2.45 and 8.25 meq/g (dry), of PAN (CO$_2$Na), PAN (CO$_2$Na) (PEI.XG) and PEI.XG (gel), respectively, the PEI.XG gel content of the fibrous sorbent PAN(CO$_2$Na) (PEI.XG) is estimated to be 100 (2.45-0.67)/(8.25 – 0.67) or 23.5% (w/w). The nitrogen content (21.6%) of the sorbent fibre calculated on the basis of 23.5% resin content of the latter is in good agreement with the nitrogen content (20.7%) determined by elemental analysis (Table 1). The BET surface area and the pore volume of the gel-coated fibre were measured to be 1.2 m$^2$/g (dry) and 0.50 cm$^3$/g (dry), respectively.

The resin gel-coat on the fibre is found to have remarkably good adhesion and stability to repeated cycles of sorption and regeneration. This may be attributed to three factors: (a) the coating takes place via reaction of the polyimine from the solution with the surface carboxyl groups on the fibre, thus producing contact at the molecular level; (b) the polyimine chains on the fibre surface are highly cross-linked; (c) as the PAN fibre is made by the wet spinning process, it has extremely rough surface with longitudinal serrations which facilitate strong adherence of the coated resin to the fibre surface.

**Analysis**

The concentration of Zn(II) in aqueous solution was determined by volumetric analysis using the

![Fig. 1—A Schematic of the method of preparation of gel-coated fibrous sorbent PAN (CO$_2$Na) (PEI.XG) by chemically coating and crosslinking polyethyleneimine (PEI) on textile-grade polyacrylonitrile (PAN) fibre.](image)

![Fig. 2—FTIR spectra of (a) polyacrylonitrile fibre (Cashmilon$^\text{TM}$), (b) partially hydrolyzed fibre PAN (CO$_2$Na) and (c) gel-coated fibre PAN (CO$_2$Na) (PEI.XG).](image)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Elemental composition, % (w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>PAN</td>
<td>66.4</td>
</tr>
<tr>
<td>PAN (CO$_2$Na)</td>
<td>62.1</td>
</tr>
<tr>
<td>PAN (CO$_2$Na) (PEI.XG)</td>
<td>61.4</td>
</tr>
</tbody>
</table>
EDTA method\textsuperscript{13}. The concentration was also measured occasionally by atomic absorption spectrometry for comparison with the chemical method of analysis.

Sorption experiments

Sorption measurements were made separately with PAN(CO\textsubscript{2}Na) and PAN(CO\textsubscript{2}Na)(PEI.XG) using Zn(II) as the test sorbate. For equilibrium sorption measurements, a small scale dynamic contact between the sorbent fibres cut into small pieces and the sorbate solution of specified composition was effected in tightly stoppered flasks at 30\degree C on a mechanical shaker for 10 h, since the sorption rate reduces considerably after the initial very fast sorption. The extent of sorption was calculated from the residual concentration of the sorbate in the equilibrated solution. A range of concentrations of the sorbate were used.

For the measurement of sorption kinetics, PAN(CO\textsubscript{2}Na)(PEI.XG) fibre, cut into 20 mm long strands and pre-soaked in water for 1 h, was used. A rectangular basket (25\times20\times50 mm) made of polypropylene mesh (0.65 mm opening) was used to hold the sorbent. The basket was fitted to the shaft of a motor and rotated while the sorbate solution was brought into contact for a specified period. In this way, the sorbent could be instantly separated from the sorbate solution at any desired time and the residual concentration of the sorbate measured to determine the rate of sorption. A fresh amount of the sorbent from the same stock was used for each experiment. The sorption rates were also measured under the same conditions using the commercial amine-type weak-base sorbent Amberlite IRA-68.

Sorption rates were also measured at different stirring speeds using a low solution concentration (2.0 mmo1/L) to determine the minimum speed, above which the sorption rate was not influenced by the degree of agitation and hence not controlled by film diffusion. All kinetic experiments were performed at stirring speeds (200-300 rpm) well above the minimum.

Results and Discussion

Sorption isotherm

The equilibrium sorption data of ZnSO\textsubscript{4} on the fibrous sorbents PAN(CO\textsubscript{2}Na) and PAN(CO\textsubscript{2}Na)(PEI.XG) are presented in Fig. 3. While the sorption on PAN(CO\textsubscript{2}Na) takes place by ion-exchange reaction:

\[
\text{F-CO}_2\text{Na}^+ + \frac{1}{2}\text{Zn}^{2+} \leftrightarrow \text{F-CO}_2\text{Zn}^{2+}/2 + \text{Na}^+
\]  

... (1)

where F represents PAN fibre, the sorption of PAN(CO\textsubscript{2}Na)(PEI.XG) takes place both by ion-exchange [Eq. (1)] and chelation due to the imine groups:

\[
\text{> NH} + \frac{1}{2}\text{Zn}^{2+} \leftrightarrow \text{> NH} \rightarrow \text{Zn}^{2+}/2
\]  

... (2)

where > NH represents the imine groups in the sorbent, the overbar being used to represent the resin phase. The striking difference between the two curves as shown in Fig. 3, highlights the significant contribution to sorption by the gel-coated resin.

The equilibrium sorption data for Zn(II) on both the sorbents, PAN(CO\textsubscript{2}Na) and PAN(CO\textsubscript{2}Na)(PEI.XG), fitted well to both the Langmuir and Freundlich isotherms, though the former gave a somewhat better fit. Defining the parameters \(A_s\) and \(K_b\) as the saturation sorption capacity [mmol Zn(II)/g (dry) sorbent] and the sorption binding constant (L/mol), respectively, the Langmuir isotherm is written as

\[
x^* = \frac{(10^{-3}K_b)A_s C^*}{1 + (10^{-3}K_b)C^*}
\]  

... (3)

where \(x^*\) is the equilibrium sorption [mmol Zn(II)/g (dry) sorbent] and \(C^*\) is the equilibrium sorbate concentration [mmol Zn (II)/L] in the solution.
Table 2—Langmuir and Freundlich isotherm parameters for sorption of Zn(II) on PAN (CO2Na) and PAN (CO2Na) (PEI.XG)

<table>
<thead>
<tr>
<th>Sorbent</th>
<th>Langmuir isotherm, Eq. (3)</th>
<th>Freundlich isotherm, Eq. (4)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>$A_s$, mmol Zn (II)/g (dry)</td>
<td>$p$</td>
</tr>
<tr>
<td>PAN (CO2Na)</td>
<td>0.103 649</td>
<td>0.088 2.704</td>
</tr>
<tr>
<td>PAN (CO2Na) (PEI.XG)</td>
<td>0.431 9600</td>
<td>0.371 5.443</td>
</tr>
</tbody>
</table>

The Freundlich isotherm is written as

$$x^* = p (C^*)^{1/q} \quad \ldots (4)$$

where $p$ and $q$ are parameters, and $x^*$ and $C^*$ are as defined above.

The values of $A_s$, $K_b$, $p$ and $q$ determined by least squares fit of the sorption data in Fig. 3 are presented in Table 2. The much higher value of $A_s$ obtained for PAN(CO2Na) (PEI.XG) is due to the resin (PEI.XG) gel-coat on the fibrous sorbent. For both PAN (CO2Na) and PAN (CO2Na) (PEI.XG), the $K_b$ values are quite large, indicating strong binding of Zn²⁺ on both the carboxylic and imine sites.

**Effect of pH**

To determine the effect of pH on the sorption capacity, Zn(II) sorbate solution was made using ZnSO₄ and ZnCl₂, with pH in the acidic range being adjusted with H₂SO₄ and HCl, respectively, while the pH in the alkaline range in both cases was adjusted with NH₄OH. The results, presented in Figs 4 and 5, show that the sorption is highly sensitive to pH in the acidic range decreasing rapidly at lower pH, which may be attributed to the deactivation of the carboxylic and amine sites by protonation:

$$\text{F-CO}_2\text{Na}^+ + \text{H}^+ \rightleftharpoons \text{F-CO}_2\text{H} + \text{Na}^+ \quad \ldots (5)$$

$$\text{NH}_3^- + \text{H}^+ \rightleftharpoons \text{NH}_4^+ \quad \ldots (6)$$

In strongly acidic media (pH < 3), the sorption of ZnCl₂ on PAN (CO2Na) (PEI.XG) is seen to be slightly higher than that of ZnSO₄. This may be attributed to the formation of complex anion, such as $[\text{ZnCl}_4]^{2-}$, in solution and of anionic sites on the sorbent, due to the presence of HCl, leading to anion-exchange sorption by the reaction:

$$\text{NH}_3^- + \frac{1}{2} [\text{ZnCl}_4]^{2-} \rightleftharpoons \text{NH}_4^+ \frac{1}{2} [\text{ZnCl}_4]^{2-} \quad \ldots (7)$$

In ammoniacal media, the sorption on both PAN(CO2Na) and PAN(CO2Na) (PEI.XG) is significantly higher than the sorption in acidic media and reaches maxima with 1.5 to 2 fold increase at pH ~ 10.5, indicating that Zn (NH₃)₄²⁺ has much greater dissolution tendency at higher pH.
affinity than Zn\(^{2+}\) (aq.) on the carboxylate anionic sites. Sorption was not measured in the pH range 4-10 because of precipitation. While the sorption on PAN (CO\(_2\)Na) in the presence of ammonia takes place by the ion-exchange reaction:

\[
F-\text{CO}_2^-\text{Na}^+ + \frac{1}{2} \text{Zn} (\text{NH}_3)_{\text{aq}}^{2+} \rightleftharpoons F - \text{CO}_2[\text{Zn} (\text{NH}_3)_{\text{aq}}^{2+}/2] + \text{Na}^+ \quad \ldots \quad (8)
\]

that on PAN(CO\(_2\)Na)(PEI.XG) takes place both by this reaction and by the amine coordination to the complex ion:

\[
> \text{NH} + \text{Zn} (\text{NH}_3)_{\text{aq}}^{2+} \rightleftharpoons \]

\[
> \text{NH} \rightarrow \text{Zn}(\text{NH}_3)^{2+} + \text{NH}_3 (\text{H}_2\text{O}) \quad \ldots \quad (9)
\]

The greater basicity of > NH (pK\(_b\) = 3.2) as compared to NH\(_3\) (pK\(_b\) = 4.7) facilitates this reaction. The sorption decreases only slightly at pH > 10.5.

**Effect of common ions**

The equilibrium sorptions of ZnSO\(_4\) on PAN(CO\(_2\)Na) and PAN(CO\(_2\)Na) (PEI.XG) in the presence of varying concentrations of Na\(_2\)SO\(_4\) are plotted in Fig. 6. On both the sorbents, the sorption of Zn(II) decreases only slightly even in the presence of large excess of Na\(_2\)SO\(_4\). This phenomenon may be explained by the strong binding of Zn\(^{2+}\) to the carboxylate ion and the amine sites, as shown by the markedly high values of \(K_b\) (6495 and 9600 L/mol) and by the fact that the sorption on PAN(CO\(_2\)Na) (PEI.XG) takes place largely by chelation which is not sensitive to the presence of non-complexing ions.

Due to the complexing nature of the Cl\(^-\) ion, NaCl can produce markedly different effects on ionic and chelating sorbents. Though PAN(CO\(_2\)Na) is a cation exchanger, the sorption of Zn(II) is little affected even in a saturated solution (~6 M) of NaCl (Fig. 7). This is evidently due to strong binding of Zn\(^{2+}\) to the carboxylate ion, as mentioned above. The effect of Cl\(^-\) on the Zn(II) sorption by PAN(CO\(_2\)Na)(PEI.XG) is noteworthy for its enhancing effect (Fig. 7). Since in the presence of Cl\(^-\) ion a variety of complex anions, (ZnCl\(_x\))\(^{x-2}\) are formed, the most common being (ZnCl\(_4\))\(^2-\) and the zinc chloride can be regarded as the complex of zinc salts, such as Zn[ZnCl\(_4\)], the sorption on PAN (CO\(_2\)Na)(PEI.XG) can be represented by

\[
> \text{NH} + \text{Zn}[\text{ZnCl}_4] \rightleftharpoons > \text{NH} \rightarrow \text{Zn} [\text{ZnCl}_4] \quad \ldots \quad (10)
\]

to account for the enhanced Zn(II) uptake.
of equilibrium sorption is attained in 10s, while in comparison, only 10% of equilibrium sorption is attained on the bead-form sorbent in 10 min.

Sorption can be assumed to follow a shell-core scheme if the reaction is irreversible and is fast compared to diffusion. For systems which exhibit significant reversibility in the sorption isotherm, Bhandari et al.\textsuperscript{14} modified the shrinking core model by incorporating the effect of the reversibility of sorption. The modified model, however, reduces to the conventional shell-core model as the equilibrium sorption reaches the saturation capacity. In the present study, the sorption isotherms (Fig. 3) of Zn(II) on PAN(CO\textsubscript{2}Na)(PEI.XG) clearly indicate that the sorption tends to attain saturation levels at sorbate concentrations greater than 2 mM. Thus, at the feed concentration \(C_0 = 10\) mM, used in the kinetic study, the reversibility of sorption may be ignored and the conventional form of shell-core model based on irreversibility of the sorption reaction may be used. Such a model was derived by Chanda and Rempel\textsuperscript{9} for a cylindrical sorbent of very large length/diameter ratio, representing a fibre-like sorbent. The rate of sorption derived from the model is given by the equation:

\[
\left( \frac{D\lambda C_0}{C_r} \right) t = \frac{\ln \beta}{2 \alpha} \ln \left( \frac{\beta^2 + R^*}{\beta^2 + 1} \right) + \sum_{n=1,2,...} \frac{\beta^{2n}}{4 \alpha n^2} \left( \frac{1}{(\beta^2 + R^*)^n} - \frac{1}{(\beta^2 + 1)^n} \right)
\]  

... (11)

where \(D = \) resin diffusivity, \(\lambda = \) molar distribution coefficient, \(C_0 = \) initial sorbate concentration in solution, \(C_r = \) sorption capacity per unit volume of unreacted sorbent, \(r_o = \) radius of cylindrical sorbent, \(R^* = \) radial position (dimensionless) of moving boundary, \(\alpha = \) ratio (dimensionless) of sorption on resin at saturation and total amount of sorbate initially in substrate, and

\[
\beta = \left( \frac{1 - \alpha}{\alpha} \right)^{1/2}
\]  

... (12)

In order to test the model with experimental sorption data, Eq. (11) can be written in terms of fractional conversion \(X\) by noting that

\[
R^* = \left( 1 - X \right)^{1/2}
\]  

... (13)

Equation 11 combined with Eq. (13) gives the sorbent conversion as a function of time. The right hand side (RHS) of Eq. (11) can be plotted against \(t\) and \(\lambda D\) can be evaluated from the slope of the linear plot. The sorption data collected for PAN(CO\textsubscript{2}Na)(PEI.XG), as shown in Fig. 8, are plotted in Fig. 9. As can be seen from this figure, the kinetic data shown an approximately linear fit in the initial region extending from 0 to ~ 80% conversion of the fibrous sorbent, followed by a sharp deviation. This reflects the fact that, as can be seen from Fig. 8, beyond about 80% conversion, the rate of sorption slows down abruptly, which may be attributed to several factors, the more important among them being the possible decrease in the reacted layer diffusivity with conversion.

From the slope of the linear plot in the initial (Fig.
9), $\lambda D$ was calculated, yielding a value of $1.5 \times 10^{-6}$ cm$^2$/s corresponding to the initial sorbate concentration of 10 mM used in the experiment. The markedly high initial rate of sorption on the gel coated fibre is attributed to a high percentage of surface area being directly exposed to the external solution, as compared to spherical particles of commercial resins.

**Conclusion**

Textile-grade polyacrylonitrile (PAN) fibre Cashmilon™ containing 92% (w/w) acrylonitrile has been chemically coated with polyethyleneimine (PEI) resin of weight average molecular weight 750,000 after converting about 10% of the nitrile groups on the fibre to carboxylic acid groups by hydrolysis and finally crosslinking the gel-coated PEI resin with glutaraldehyde. The sorbent fabric PAN(CO$_2$Na)(PEI.XG) thus obtained exhibits strong binding to Zn(II), attaining the saturation sorption even at low concentrations (~2 mM) of the sorbate. The Zn(II) sorption capacity of the sorbent is marginally reduced in the presence of high concentrations of Na$_2$SO$_4$ but increases in the presence of NaCl in substrate solutions and reaches a maximum due to the formation of anionic complexes of Zn(II). The sorption capacity is highly sensitive to pH, decreasing sharply at lower pH, but the sorption increases markedly with increasing pH in ammoniacal media. The characteristic feature of the Zn(II) sorption behaviour of the PEI resin-coated acrylic fibre is that nearly 75% of the saturation sorption is reached very fast (in 10 s), followed by an abrupt fall or leveling off trend in the rate of sorption, in sharp contrast to the sorption behaviour of conventional bead-form weak-base resin, such as Amberlite IRA-68, which attains only 10% of equilibrium sorption in 10 min. The sorption in the initial short period on the resin-coated fibre fit to the shell-core model for a cylindrical sorbent with large length/diameter ratio.

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**References**