Performance evaluation of Adsorbents under study and Application to Chrome Plating Effluents

The adsorbents investigated in this study are compared based on Langmuir adsorption capacity with literature reported adsorbents based on chitosan and polyaniline (Table A1).

Sr. No.	Adsorbent	Qmax	pH	Reference
1	Cross-linked Chitosan	50	5.0	(Schmuhl, Krieg, & Keizer, 2001)
2	Metal-ion imprinted chitosan	51	5.5	(Tianwei, Xiaojing, & Weixia, 2001)
3	Chitosan Cross-linked with epichlorohydrin	11.3	5.5	(Qian, Huang, Jiang, He, & Wang, 2000)
4	Chitosan coated ceramic alumina	153.8	4.0	(Boddu, Abburi, Talbott, & Smith, 2003)
5	chitosan/zeolite matrix	17.28	4	(Batista, Villanueva, Amorim, Tavares, & Campos-Takaki, 2011)
6	Chitin	2.32	4	(Saravanan, Hemalatha, & Sudha, 2011)
7	Protonated Chitin	12.72	4	(Saravanan et al., 2011)
8	Carboxylated Chitin	13.15	4	(Saravanan et al., 2011)
9	Grafted Chitin	14.45	4	(Saravanan et al., 2011)
10	Protonated Chitosan beads (PCB)	3.23	4	(Kousalya, Rajiv Gandhi, & Meenakshi, 2010)
11	Carboxylated Chitosan Beads (CCB)	3.64	4	(Kousalya et al., 2010)
12	Grafted Chitosan beads (GCB)	4.05	4	(Kousalya et al., 2010)
13	Quaternary chitosan salt	68.3	4.5	(Spinelli, Laranjeira, & Fa, 2004)
14	Magnetic chitosan	69.40	4.0	(Huang, Zhang, Shi, & Langrish, 2009)
15	Chitosan/cellulose	13.05	-	(Ferreira & Trierweiler, 2009)
16	Chitosan/montmorillonite	41.67	4.0	(Fan, Zhu, Xu, & Yan, 2006)
17	CACASC (chitosan-coated acid-treated Chrysophyllum albidum seed shells carbon)	84.31	3	(Amuda, Adelowo, & Ologunde, 2009)
18	CCASC (chitosan-coated Chrysophyllum albidum seed shells carbon)	76.23	3	(Amuda et al., 2009)
19	ACASC (acid-treated Chrysophyllum albidum seed shells carbon)	59.63	3	(Amuda et al., 2009)
20	Cross linked Magnetic Chitosan Beads	69.4	4	(Huang et al., 2009)
21	CH (Native Chitosan)	32.1	3	(Ramnani & Sabharwal, 2006)

22	CRC (Radiation Crosslinked Chitosan)	28.2	3	(Ramnani & Sabharwal, 2006)
23	CRCH (Hydrolysis product of Crosslinked Chitosan)	24.5	3	(Ramnani & Sabharwal, 2006)
24	Nanosized chitosan fibers	131.58	4.5	(Lei Li, Li, Cao, & Yang, 2015)
25	Chitosan/polycaprolactam nanofibrous filter paper	114.7	3	(Z. Li et al., 2016)
26	Plain Chitosan Flakes	34.4	3	(Udaybhaskar, Iyengar, & Rao, 1990)
27	Chitosan-montmorillonite	9.36	3.5	(An & Dultz, 2008)
28	Ethylenediamine-modified cross-linked magnetic Chitosan Resin	51.8	2	(Hu et al., 2011)
29	Chitosan-Citric acid nanoparticles	22.4	3	(Bagheri, Younesi, Hajati, & Borghei, 2015)
30	Magnetic Cyclodextrin–Chitosan/Graphene oxide	67.66	3	(Leilei Li et al., 2013)
31	Chitosan coated with Poly 3-methyl thiophene	127.62	2	(Hena, 2010)
32	Chitosan-g-Poly(Butyl acrylate)/Silica gel nanocomposite	55.71	7	(Nithya et al., 2016)
33	Chitosan-g-acrylonitrile copolymer	122.83	5	(Shankar, Gomathi, Vijayalakshmi, & Sudha, 2014)
34	Chitosan-coated fly ash composite	33.27	5	(Wen, Tang, Chen, & Gu, 2011)
35	Pyridinium-diethylenetriamine magnetic Chitosan	176	3	(Sakti, Narita, Sasaki, Nuryono, & Tanaka, 2015)
36	n-Butylacrylate grafted Chitosan	17.15	3.5	(Santhana Krishna Kumar, Uday Kumar, Rajesh, & Rajesh, 2014)
37	Chitosan micro/nanoparticles from seafood processing wastes	124	2.5	(Dima, Sequeiros, & Zaritzky, 2015)
38	CD	192.3077		Present study
39	CTMA	129.5337		Present study
40	CZrP	155.52		Present study
41	Polyaniline coated carbon fiber fabrics	18.1	1.0	(Qiu et al., 2015)

42	Polyaniline/silica gel composite	63.41	4.2	(Karthik & Meenakshi, 2014b)
43	Polyaniline coated chitin	24.65	4.2	(Karthik & Meenakshi, 2015)
44	Composite of Polyaniline and ethyl cellulose composites	38.76	1.0	(Qiu et al., 2015)
45	Phytic acid doped Polyaniline/Cellulose acetate composite membrane	94.34	2.0	(R. Li, Liu, & Yang, 2014)
46	Kapok fiber oriented-polyaniline nanofibers	65.66	4.5	(Zheng, Wang, Huang, & Wang, 2012)
47	Polyaniline coating on carbon fiber fabrics	18.1	1.0	(Qiu et al., 2014)
48	Polyaniline synthesized on jute fiber	62.9	3	(P. A. Kumar, Chakraborty, & Ray, 2008)
49	Polyaniline/poly(ethylene glycol) composite	68.97	5	(Samani, Borghei, Olad, & Chaichi, 2010)
50	PANI-Fe_3O_4	54		(Rezvani, Asgharinezhad, Ebrahimzadeh, & Shekari, 2014)
51	PANI/EPS nanocomposite	68.40		(Janaki et al., 2014)
52	PANI/Zeolite nanocomposite	25		(Shyaa, Hasan, & Abbas, 2015)
53	PPy-PANI	227	2	(Bhaumik, Maity, Srinivasu, & Onyango, 2012)
54	PANI	357.1	3	(Gao, Chen, Tan, Xu, & Zhu, 2016)
55	PANI@MoS_2	526.3	3.	(Gao et al., 2016)
56	Sulfuric acid doped Polyaniline	95.79	6	(R. Zhang, Ma, & Wang, 2010)
57	PANI/multiwalled carbon nanotubes	55.55	2	(R. Kumar, Ansari, & Barakat, 2013)
58	Cross linked Chitosan–grafted polyaniline composite	179.2	4.2	(Karthik & Meenakshi, 2014a)
59	Polyaniline nanorods array on graphene oxide	1149.32	3	(S. Zhang et al., 2013)
60	PANI-G10	192.3	6.5	(Harijan & Chandra, 2016)
61	PANI	91.32	5	Present study

From the Table A1 it is evident that CD ,CTMA and CZrP show greater adsorption capacity as compared to most of the chitosan based adsorbents studied for chromium except for chitosan coated ceramic alumina and chitosan nano fiber. This may be associated with larger number of carboxyl and anino groups available for binding in DTPA and carboxyls in CTMA.

In the case of PANI it was observed that though the adsorption capacity was reasonably comparable with many of the literature reported PANI materials, the adsorption capacities of many PANI composites reported in literature were higher such as ppy.PANI, PANI MoS_2 and polyaniline nanorods array on graphene oxide. The polyaniline nanorods array on graphene oxide reported the highest adsorption capacity of 1149.32mg/g to the best of our knowledge.

However, it is difficult to come to a conclusion about the efficacy of an adsorbent based on adsorption capacity alone as the qmax depends on the conditions enployed, mechanism of removal and also economical aspects

However when being practically applied for removal of chromium the comparison should be further critically studied in terms of pH, kinetics and isotherm and the cost..

APPLICATION OF ADSORBENTS UNDER STUDY FOR REMOVAL OF CHROMIUM FROM CHROME PLATING EFFLUENT

Cr^{6+} is commonly found in chrome plating industry. Chrome plating is a process of electroplating a thin layer of chromium onto a metal surface. In chrome plating process, chromium is used in two forms, Cr^{3+} and Cr^{6+}. It is possible to do chrome plating in yellow, green and transparent color. Yellow chromate makes plating as Cr^{6+}, green and transparent chromate makes plating as Cr^{3+}. The purpose of the chrome plating applied on metals to provide better retention and to improve the corrosion resistance. Besides all these outstanding features of chrome plating, unfortunately chemicals that using in the chrome plating process are very toxic. Chromium metal is very resistant to heat, wear-resistant metal is very hard and cannot be oxidized in the air and retains its brightness. The most important is a range of coatings in terms of pleasing decorative feature (Kaya, Onac, Alpoguz, Yilmaz, & Atar, 2016). The chromium bath is a mixture of chromium trioxide (CrO_3), nitric acid (HNO_3) and sulfuric acid (sulfate, SO4).

The efficiency of CH, CD and CTMA to remove chromium from an effluent from a Chrome plating industry of GIDC, Ankleshwar, India, was examined. The sample from chrome plating effluent contained not only chromium, but also other metals. 1M HNO3was

used to adjust the pH of the effluent to 3 and the concentration of metals after adsorption using 0.05 g CH, CD and CTMA was determined through ICP.

The data from this experiment was used to calculate distribution coefficient (Kd) and selectivity coefficient and are presented in Table 6.1. The distribution coefficient (Kd) was calculated by the following equation (Han, Jia, & Liang, 2010)

$$Kd = (Co - Ce)/Ce \times V/W$$

Where, Co is Actual Concentration of metal in Effluent, Ce is Remaining Concentration of metal, V is volume of solution phase (mL) and M is mass of the adsorbent (gL^{-1})

Selectivity Coefficient = $\beta = Kd1 / Kd2$

Where KD1 and Kd2 are the metal ion under study and the interfering metal ion

Table 6.1 Application of adsorbents under study to chrome Plating Effluent

	Actual Concentration (Co)				Remaining concentration (Ce)				% Extraction				Distribution ratio Kd				Selectivity coefficient for Cr			
	CD	CTMA	CZrP	PANI	CD	CTMA	CZrP	PANI	CD	CTMA	CZrP	PANI	CD	CTMA	CZrP	PANI	CD	CTMA	CZrP	PANI
Cr	62.5	65.0	61.0	62.5	3.3	3.8	12.0	5.8	94.7	94.2	80.3	90.7	1.2	1.2	1.0	1.1				
Mg	38.8	38.8	41.0	38.8	37.5	31.3	34.0	36.3	3.2	19.4	17.1	6.5	0.0	0.2	0.2	0.1	29.4	4.9	5.5	14.7
Cd	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.2	36.5	34.6	31.1	53.9	0.5	0.4	0.4	0.7	2.6	2.7	3.0	1.8
Ni	14.0	15.0	13.7	14.0	11.5	12.0	11.2	11.0	17.9	20.0	18.3	21.4	0.2	0.3	0.2	0.3	5.3	4.7	5.2	4.4
Cu	10.1	14.0	9.1	10.1	7.9	5.8	4.8	9.0	21.8	58.6	47.3	10.9	0.3	0.7	0.6	0.1	4.3	1.6	2.0	8.7
Pb	4.4	3.4	3.6	4.4	0.0	0.2	0.6	2.1	100.0	94.1	83.3	52.3	1.3	1.2	1.0	0.7	0.9	1.0	1.1	1.8
Hg	1.1	1.1	0.9	1.1	0.9	0.7	0.6	1.0	18.2	36.4	33.3	9.1	0.2	0.5	0.4	0.1	5.2	2.6	2.8	10.4
Al	15.0	16.0	15.5	15.0	12.9	12.2	12.2	13.6	14.0	23.8	21.3	9.3	0.2	0.3	0.3	0.1	6.8	4.0	4.4	10.1
Zn	236.3	265.0	243.0	236.3	203.8	196.2	211.0	208.8	13.8	26.0	13.2	11.6	0.2	0.3	0.2	0.1	6.9	3.6	7.2	8.1
Fe	232.0	255.0	200.0	232.0	8.6	22.9	78.0	121.5	96.3	91.0	61.0	47.6	1.2	1.1	0.8	0.6	1.0	1.0	1.6	2.0

The results of the application of CD , CTMA, CZrP and PANI onto chrome plating effluent as adsorbents with per cent extraction of major metal ions present in the effluent, their Kd values and selectivity coefficient of chromium over other metals are shown in Table 6.1.

The application of the adsorbents to the effluent were not studied at the same time but were done as and when studies were being performed for a particular adsorbent under study. The reported values and the observed values of the different metal ions present in the effluent when collected for applying to each adsorbent have been reported in Table. The results show that there is no significant variation in the composition of the effluent

It is seen that all the adsorbents that have been investigated in this study are effective adsorbents for chromium. However, CD and CTMA are capable of removing Pb and Fe also. CD was observed to be a good and better adsorbent for lead especially. The distribution coefficient was found to be highest for Pb followed by chromium and iron for CD and CTMA while in the case of CZrP the distribution coefficients were same for lead and chromium followed by iron. The distribution coefficient was highest for chromium when PANI was used as adsorbent. PANI did not prove to be a good adsorbent for the removal of other metal ions. However, the presence of other metal ions even Fe and Pb did not significantly affect the removal of chromium in the concentration range present in the effluent under the pH conditions optimal for removal of Cr^{6+} except for CZrP (about 9% decrease). In fact CD and CTMA proved to be effective adsorbents for removal of chromium, lead and iron when present simultaneously in the concentration range present in the chrome plating effluent. PANI showed highest selectivity towards chromium. However, further investigations are warranted in this direction.

References

Amuda, O. S., Adelowo, F. E., & Ologunde, M. O. (2009). Kinetics and equilibrium studies of adsorption of chromium(VI) ion from industrial wastewater using Chrysophyllum albidum (Sapotaceae) seed shells. *Colloids and Surfaces B: Biointerfaces*, *68*(2), 184–192. doi:10.1016/j.colsurfb.2008.10.002

An, J. H., & Dultz, S. (2008). Adsorption of Cr(VI) and As(V) on chitosan-montmorillonite: Selectivity and pH dependence. *Clays and Clay Minerals*, *56*(5), 549–557. doi:10.1346/CCMN.2008.0560508

Bagheri, M., Younesi, H., Hajati, S., & Borghei, S. M. (2015). Application of chitosan-citric acid nanoparticles for removal of chromium (VI). *International Journal of Biological Macromolecules*, *80*, 431–444. doi:10.1016/j.ijbiomac.2015.07.022

Batista, A. C. L., Villanueva, E. R., Amorim, R. V. S., Tavares, M. T., & Campos-Takaki, G. M. (2011). Chromium (VI) ion adsorption features of chitosan film and its chitosan/zeolite conjugate 13X film. *Molecules*, *16*(5), 3569–3579. doi:10.3390/molecules16053569

Bhaumik, M., Maity, A., Srinivasu, V. V., & Onyango, M. S. (2012). Removal of hexavalent chromium from aqueous solution using polypyrrole-polyaniline nanofibers. *Chemical Engineering Journal*, *181-182*, 323–333. doi:10.1016/j.cej.2011.11.088

Boddu, V. M., Abburi, K., Talbott, J. L., & Smith, E. D. (2003). Removal of Hexavalent Chromium from Wastewater Using a New Composite Chitosan Biosorbent Removal of Hexavalent Chromium from Wastewater Using a New Composite Chitosan Biosorbent. *Environmental Science & Technology*, *37*(Vi), 4449–4456. doi:10.1021/es021013a

Dima, J. B., Sequeiros, C., & Zaritzky, N. E. (2015). Hexavalent chromium removal in contaminated water using reticulated chitosan micro/nanoparticles from seafood processing wastes. *Chemosphere*, *141*, 100–111. doi:10.1016/j.chemosphere.2015.06.030

Fan, D. H., Zhu, X. M., Xu, M. R., & Yan, J. L. (2006). Adsorption properties of chromium (VI) by chitosan coated montmorillonite. *Journal of Biological Sciences*, *6*(5), 941–945.

Ferreira, L. S., & Trierweiler, J. O. (2009). Modeling and simulation of the polymeric nanocapsule formation process. *IFAC Proceedings Volumes (IFAC-PapersOnline)*, *7*(PART 1), 405–410. doi:10.1002/aic

Gao, Y., Chen, C., Tan, X., Xu, H., & Zhu, K. (2016). Polyaniline-modified 3D-flower-like molybdenum disulfide composite for efficient adsorption/photocatalytic reduction of Cr(VI). *Journal of Colloid and Interface Science*, *476*, 62–70. doi:http://dx.doi.org/10.1016/j.jcis.2016.05.022

Han, D., Jia, W., & Liang, H. (2010). Selective removal of 2,4-dichlorophenoxyacetic acid from water by molecularly-imprinted amino-functionalized silica gel sorbent. *Journal of Environmental Sciences*, *22*(2), 237–241. doi:http://dx.doi.org/10.1016/S1001-0742(09)60099-1

Harijan, D. K. L., & Chandra, V. (2016). Polyaniline functionalized graphene sheets for treatment of toxic hexavalent chromium. *Journal of Environmental Chemical*

Engineering, *4*(3), 3006–3012. doi:http://dx.doi.org/10.1016/j.jece.2016.06.014

Hena, S. (2010). Removal of chromium hexavalent ion from aqueous solutions using biopolymer chitosan coated with poly 3-methyl thiophene polymer. *Journal of Hazardous Materials*, *181*(1-3), 474–479. doi:10.1016/j.jhazmat.2010.05.037

Hu, X. jiang, Wang, J. song, Liu, Y. guo, Li, X., Zeng, G. ming, Bao, Z. lei, … Long, F. (2011). Adsorption of chromium (VI) by ethylenediamine-modified cross-linked magnetic chitosan resin: Isotherms, kinetics and thermodynamics. *Journal of Hazardous Materials*, *185*(1), 306–314. doi:10.1016/j.jhazmat.2010.09.034

Huang, G., Zhang, H., Shi, J. X., & Langrish, T. A. G. (2009). Adsorption of chromium(VI) from aqueous solutions using cross-linked magnetic chitosan beads. *Industrial and Engineering Chemistry Research*, *48*(5), 2646–2651. doi:10.1021/ie800814h

Janaki, V., Shin, M.-N., Kim, S.-H., Lee, K.-J., Cho, M., Ramasamy, A. K., … Kamala-Kannan, S. (2014). Application of polyaniline/bacterial extracellular polysaccharide nanocomposite for removal and detoxification of Cr(VI). *Cellulose*, *21*(1), 463–472. doi:10.1007/s10570-013-0100-7

Karthik, R., & Meenakshi, S. (2014a). Facile synthesis of cross linked-chitosan-grafted-polyaniline composite and its Cr(VI) uptake studies. *International Journal of Biological Macromolecules*, *67*, 210–219. doi:10.1016/j.ijbiomac.2014.03.035

Karthik, R., & Meenakshi, S. (2014b). Journal of Water Process Engineering Removal of hexavalent chromium ions using polyaniline / silica gel composite. *Journal of Water Process Engineering*, *1*, 37–45. doi:10.1016/j.jwpe.2014.03.001

Karthik, R., & Meenakshi, S. (2015). International Journal of Biological Macromolecules Synthesis , characterization and Cr (VI) uptake study of polyaniline coated chitin. *International Journal of Biological Macromolecules*, *72*, 235–242. doi:10.1016/j.ijbiomac.2014.08.022

Kaya, A., Onac, C., Alpoguz, H. K., Yilmaz, A., & Atar, N. (2016). Removal of Cr(VI) through calixarene based polymer inclusion membrane from chrome plating bath water. *Chemical Engineering Journal*, *283*, 141–149. doi:10.1016/j.cej.2015.07.052

Kousalya, G. N., Rajiv Gandhi, M., & Meenakshi, S. (2010). Sorption of chromium(VI) using modified forms of chitosan beads. *International Journal of Biological Macromolecules*, *47*(2), 308–315. doi:10.1016/j.ijbiomac.2010.03.010

Kumar, P. A., Chakraborty, S., & Ray, M. (2008). Removal and recovery of chromium from wastewater using short chain polyaniline synthesized on jute fiber. *Chemical Engineering Journal*, *141*(1-3), 130–140. doi:10.1016/j.cej.2007.11.004

Kumar, R., Ansari, M. O., & Barakat, M. A. (2013). DBSA doped polyaniline/multi-walled carbon nanotubes composite for high efficiency removal of Cr(VI) from aqueous solution. *Chemical Engineering Journal*, *228*, 748–755. doi:10.1016/j.cej.2013.05.024

Li, L., Fan, L., Sun, M., Qiu, H., Li, X., Duan, H., & Luo, C. (2013). Adsorbent for hydroquinone removal based on graphene oxide functionalized with magnetic cyclodextrin-chitosan. *International Journal of Biological Macromolecules*, *58*, 169–175. doi:10.1016/j.ijbiomac.2013.03.058

Li, L., Li, Y., Cao, L., & Yang, C. (2015). Enhanced chromium (VI) adsorption using nanosized chitosan fibers tailored by electrospinning. *Carbohydrate Polymers*, *125*(Vi), 206–213. doi:10.1016/j.carbpol.2015.02.037

Li, R., Liu, L., & Yang, F. (2014). Removal of aqueous Hg (II) and Cr (VI) using phytic acid doped polyaniline / cellulose acetate composite membrane. *Journal of Hazardous Materials*, *280*, 20–30. doi:10.1016/j.jhazmat.2014.07.052

Li, Z., Li, T., An, L., Liu, H., Gu, L., & Zhang, Z. (2016). Preparation of chitosan/polycaprolactam nanofibrous filter paper and its greatly enhanced chromium(VI) adsorption. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *494*, 65–73. doi:10.1016/j.colsurfa.2016.01.021

Nithya, R., Gomathi, T., Sudha, P. N., Venkatesan, J., Anil, S., & Kim, S.-K. (2016). Removal of Cr(VI) from aqueous solution using chitosan-g-poly(butyl acrylate)/silica gel nanocomposite. *International Journal of Biological Macromolecules*, *87*(Vi), 545–54. doi:10.1016/j.ijbiomac.2016.02.076

Qian, S., Huang, G., Jiang, J., He, F. E. I., & Wang, Y. (2000). Studies of Adsorption Behavior of Crosslinked Chitosan for Cr (VI), Se (VI), *77*(September 1999), 3216–3219.

Qiu, B., Xu, C., Sun, D., Wang, Q., Gu, H., Zhang, X., … Wei, S. (2015). Polyaniline coating with various substrates for hexavalent chromium removal. *Applied Surface Science*, *334*, 7–14. doi:10.1016/j.apsusc.2014.07.039

Qiu, B., Xu, C., Sun, D., Wei, H., Zhang, X., Guo, J., & Wang, Q. (2014). Polyaniline coating on carbon fiber fabrics for improved hexavalent chromium removal. *RSC Advances*, *4*, 29855–29865. doi:10.1039/c4ra01700e

Ramnani, S. P., & Sabharwal, S. (2006). Adsorption behavior of Cr(VI) onto radiation crosslinked chitosan and its possible application for the treatment of wastewater containing Cr(VI). *Reactive and Functional Polymers*, *66*, 902–909. doi:10.1016/j.reactfunctpolym.2005.11.017

Rezvani, M., Asgharinezhad, A. A., Ebrahimzadeh, H., & Shekari, N. (2014). A polyaniline-magnetite nanocomposite as an anion exchange sorbent for solid-phase extraction of chromium(VI) ions. *Microchimica Acta*, *181*(15), 1887–1895. doi:10.1007/s00604-014-1262-1

Sakti, S. C. W., Narita, Y., Sasaki, T., Nuryono, & Tanaka, S. (2015). A novel pyridinium functionalized magnetic chitosan with pH-independent and rapid adsorption kinetics for magnetic separation of Cr(VI). *Journal of Environmental Chemical Engineering*, *3*(3), 1953–1961. doi:10.1016/j.jece.2015.05.004

Samani, M. R., Borghei, S. M., Olad, A., & Chaichi, M. J. (2010). Removal of chromium from aqueous solution using polyaniline - Poly ethylene glycol composite. *Journal of Hazardous Materials*, *184*(1-3), 248–254. doi:10.1016/j.jhazmat.2010.08.029

Santhana Krishna Kumar, A., Uday Kumar, C., Rajesh, V., & Rajesh, N. (2014). Microwave assisted preparation of n-butylacrylate grafted chitosan and its application for Cr(VI) adsorption. *International Journal of Biological Macromolecules*, *66*, 135–143. doi:10.1016/j.ijbiomac.2014.02.007

Saravanan, D., Hemalatha, R., & Sudha, P. N. (2011). Synthesis and characterization of cross linked chitin/bentonite polymer blend and adsorption studies of Cu (II) and Cr (VI) on chitin. *Der Pharma Chemica*, *3*(6), 406–424.

Schmuhl, R., Krieg, H. M., & Keizer, K. (2001). Adsorption of Cu(II) and Cr(VI) ions by chitosan: Kinetics and equilibrium studies. *Water SA*, *27*(1), 1–7. doi:10.4314/wsa.v27i1.5002

Shankar, P., Gomathi, T., Vijayalakshmi, K., & Sudha, P. N. (2014). Comparative studies on the removal of heavy metals ions onto cross linked chitosan-g-acrylonitrile copolymer. *International Journal of Biological Macromolecules*, *67*, 180–188. doi:10.1016/j.ijbiomac.2014.03.010

Shyaa, A. A., Hasan, O. A., & Abbas, A. M. (2015). Synthesis and characterization of polyaniline/zeolite nanocomposite for the removal of chromium(VI) from aqueous solution. *Journal of Saudi Chemical Society*, *19*(1), 101–107. doi:http://dx.doi.org/10.1016/j.jscs.2012.01.001

Spinelli, V. A., Laranjeira, M. C. M., & Fa, V. T. (2004). Preparation and characterization of quaternary chitosan salt : adsorption equilibrium of chromium (VI) ion, *61*, 347–352. doi:10.1016/j.reactfunctpolym.2004.06.010

Tianwei, T., Xiaojing, H., & Weixia, D. (2001). Adsorption behaviour of metal ions on imprinted chitosan resin. *Journal of Chemical Technology and Biotechnology*, *76*(2), 191–195. doi:10.1002/jctb.358

Udaybhaskar, P., Iyengar, L., & Rao, A. V. S. P. (1990). Hexavalent chromium interaction with chitosan. *Journal of Applied Polymer Science*, *39*(3), 739–747. doi:10.1002/app.1990.070390322

Wen, Y., Tang, Z., Chen, Y., & Gu, Y. (2011). Adsorption of Cr(VI) from aqueous solutions using chitosan-coated fly ash composite as biosorbent. *Chemical Engineering Journal*, *175*(1), 117–123. doi:10.1016/j.cej.2011.09.066

Zhang, R., Ma, H., & Wang, B. (2010). Removal of chromium(VI) from aqueous solutions using polyaniline doped with sulfuric acid. *Industrial and Engineering Chemistry Research*, *49*(20), 9998–10004. doi:10.1021/ie1008794

Zhang, S., Zeng, M., Xu, W., Li, J., Li, J., Xu, J., & Wang, X. (2013). Polyaniline nanorods dotted on graphene oxide nanosheets as a novel super adsorbent for Cr(VI). *Dalton Transactions (Cambridge, England : 2003)*, *42*, 7854–8. doi:10.1039/c3dt50149c

Zheng, Y., Wang, W., Huang, D., & Wang, A. (2012). Kapok fiber oriented-polyaniline nanofibers for efficient Cr(VI) removal. *Chemical Engineering Journal*, *191*, 154–161. doi:10.1016/j.cej.2012.02.088