

Reference List

Andrew, D.E., Lenore, S.C., Eugene, W.R., Arnold, E.G., 2005. 'Standard Method for the Examination of water and wastewater,' 21st Edition, American Public Health Association, Washington.

Baes, A.U., Okuda, T., Nishijima, W., Shoto, E., Okada, M., 1997. 'Adsorption and ion exchange of some groundwater anion contaminants in amine modified coconut coir'. *Water Science & Technology*, vol.35, p. 89-95.

Dinesh, M., Singh, K. P. and Singh, V. K., 2005. 'Trivalent Chromium removal from wastewater using low cost activated carbon derived from agricultural waste and activated carbon fabric cloth.', *Journal of Hazardous Material*, Elsevier, India.

El Nemr, A. A. K., Ola, A., and Amany, E. S., 2007. 'Treatment of wastewater containing toxic Chromium using new activated carbon developed from date palm seed.', *Journal of Hazardous Material*, Vol. 152:1 . p. 263-275. Elsevier, India.

Environmental Protection Agency (EPA), 1998, Human Health Fact Sheet: Chromium. Viewed on the 15th January 2005, < <http://www-cie.iarc.fr/>>

Fang, J., Zhinmang, G., Dinchen, G., Chongxuan, L., Eugene, S. L., Baolin, D., 2007. 'Cr (VI) Removal from Aqueous Solution by Activated Carbon coated with Quaternized Poly (4- vinylpyridine)'. *Environ. Sci & Technology*, Vol. 41:13, p. 4748-4753.

Fuller, C.C. and Davis, J.A., 1987. 'Process and kinetics of Cd²⁺ adsorption by calcareous aquifer sand.' *Geochim. Cosmochim. Acta*, Vol. 51:6, p. 1491-1502

Lazaridis, N.K. and Choriambus, C., 2005. 'Sorption Removal of Trivalent and Hexavalent Chromium from binary aqueous solutions by composite alginate- goethite beads.' vol 39:18, p. 4385 -4396.

Mohamed, H. I., Naimah, I., Hamidi, A.A., Moha, N.A., Nor, H.M. S., Ali, A.A., L.Z., Shamsul, R. M. K., 2007. 'Removal of Chromium (VI) from aqueous solution using treated oil palm fibre.' *Journal of Hazardous Material*, vol. 152:2, p. 662-668. Elsevier, India.

Perera, C. S., 2002. An Economic Analysis for relocating the Tanning Industry in Sri Lanka, Department of National Planning, Colombo.

Ronald, A. B., 2002, Chemistry of the Environment. Elsevier Ltd, England.

Shing chen, S.,Chin-Yu, C.,Chi-wang,Li.,Pao,-Huan, C., Yu-Min, C., 2006. 'Reduction of Chromate from electroplating waste water from pH 1 to 2 using fluidized zero valent iron process'. Viewed on 03rd October 2009. <<http://www.sciencedirect.com>>

Srinivasa R. P.,Ajithapriya,J., Kachireddy, V.N.S.R., Krishnaiah, A., 2007. Biosorption of hexavalent chromium using tamarind (*Tamarindus indica*) fruit shell-a comparative study. Electronic journal of biotechnology . Viewed on 03rd October 2009. <<http://www.esielo.cl>>

Srivatsava, V. C., Mall, I. D., and Mishra, I. M., 2007. 'Adsorption of toxic metal ions into activated carbon Study of sorption behaviour through characterization and kinetics' *Chemical Engineering and processing*. Vol. 47:8, p 1269-1280 Viewed on Viewed on 03rd October 2009. <<http://www.sciencedirect.com>>

Sujata M., Dash, S. S., and Parinda, K. M., 2005. 'Adsorption of hexavalent Chromium on manganese nodule leached residue obtained from NH₃- SO₂ leaching' *Journal of Colloid and Interface Science*. Vol. 297:2 p. 419-425. Viewed on the 10th October 2009 <<http://www.sciencedirect.com>>

WHO Guidelines for Drinking water Quality Act and Regulations, Act 127, 2002, 13th edition, MDC publishers and printers. Sdn. Bhd., Kuala Lumpur., P. 61.

Appendices A - Experimental Data

01. Proton titration with ionic strength 0.001 M NaNO₃

Ionic strength 0.001 M NaNO₃

Titrant: 0.1 M NaOH

0.5 M HNO₃

Initial acid volume 0.1 mL

Base Titration

Sample volume: 50 mL

Sample content: 2 g/L

Specific surface area 1165 m²/g

V _{base} /mL	pH	C _A	H ⁺	X=C _A -H ⁺	C _B	OH ⁻	Y=C _B - OH ⁻	X-Y	Charge density/ Cm ⁻²
0	3.64	9.980E-04	2.291E-04	7.689E-04	0.000E+00	4.365E-11	-4.365E-11	7.689E-04	3.184E-02
0.05	3.86	9.970E-04	1.380E-04	8.590E-04	9.970E-05	7.244E-11	9.970E-05	7.593E-04	3.144E-02
0.1	4.2	9.960E-04	6.310E-05	9.329E-04	1.992E-04	1.585E-10	1.992E-04	7.337E-04	3.038E-02
0.15	4.73	9.950E-04	1.862E-05	9.764E-04	2.985E-04	5.370E-10	2.985E-04	6.779E-04	2.807E-02
0.2	5.36	9.940E-04	4.365E-06	9.897E-04	3.976E-04	2.291E-09	3.976E-04	5.921E-04	2.452E-02
0.25	5.98	9.930E-04	1.047E-06	9.920E-04	4.965E-04	9.550E-09	4.965E-04	4.955E-04	2.052E-02
0.3	6.43	9.921E-04	3.715E-07	9.917E-04	5.952E-04	2.692E-08	5.952E-04	3.965E-04	1.642E-02
0.35	6.86	9.911E-04	1.380E-07	9.909E-04	6.938E-04	7.244E-08	6.937E-04	2.973E-04	1.231E-02
0.4	7.28	9.901E-04	5.248E-08	9.900E-04	7.921E-04	1.905E-07	7.919E-04	1.982E-04	8.206E-03
0.45	7.63	9.891E-04	2.344E-08	9.891E-04	8.902E-04	4.266E-07	8.898E-04	9.932E-05	4.113E-03
0.5	8	9.881E-04	1.000E-08	9.881E-04	9.881E-04	1.000E-06	9.871E-04	9.900E-07	4.100E-05
0.55	8.4	9.872E-04	3.981E-09	9.872E-04	1.086E-03	2.512E-06	1.083E-03	-9.621E-05	-3.984E-03
0.6	8.79	9.862E-04	1.622E-09	9.862E-04	1.183E-03	6.166E-06	1.177E-03	-1.911E-04	-7.913E-03
0.65	9.09	9.852E-04	8.128E-10	9.852E-04	1.281E-03	1.230E-05	1.268E-03	-2.833E-04	-1.173E-02
0.7	9.32	9.843E-04	4.786E-10	9.843E-04	1.378E-03	2.089E-05	1.357E-03	-3.728E-04	-1.544E-02
0.75	9.48	9.833E-04	3.311E-10	9.833E-04	1.475E-03	3.020E-05	1.445E-03	-4.614E-04	-1.911E-02
0.8	9.61	9.823E-04	2.455E-10	9.823E-04	1.572E-03	4.074E-05	1.531E-03	-5.487E-04	-2.272E-02
0.85	9.73	9.814E-04	1.862E-10	9.814E-04	1.668E-03	5.370E-05	1.615E-03	-6.332E-04	-2.622E-02
0.9	9.82	9.804E-04	1.514E-10	9.804E-04	1.765E-03	6.607E-05	1.699E-03	-7.182E-04	-2.974E-02
0.95	9.9	9.794E-04	1.259E-10	9.794E-04	1.861E-03	7.943E-05	1.781E-03	-8.021E-04	-3.321E-02
1	9.96	9.785E-04	1.096E-10	9.785E-04	1.957E-03	9.120E-05	1.866E-03	-8.873E-04	-3.674E-02
1.05	10.2	9.775E-04	6.310E-11	9.775E-04	2.053E-03	1.585E-04	1.894E-03	-9.168E-04	-3.797E-02

02. proton titration with ionic strength 0.01 M NaNO₃

Ionic strength 0.01 M NaNO₃

Titrant: 0.1 M NaOH
0.5 M HNO₃

Initial acid volume 0.1 mL

Sample volume: 50 mL

Sample content: 2 g/L

Specific surface area 1165 m²/g

Base Titration

V _{base} /mL	pH	C _A	H ⁺	X=C _A -H ⁺	C _B	OH ⁻	Y=C _B - OH ⁻	X-Y	Charge density/ Cm ⁻²
0	3.68	9.980E-04	2.089E-04	7.891E-04	0.000E+00	4.786E-11	-4.786E-11	7.891E-04	3.268E-02
0.05	3.92	9.970E-04	1.202E-04	8.768E-04	9.970E-05	8.318E-11	9.970E-05	7.771E-04	3.218E-02
0.1	4.28	9.960E-04	5.248E-05	9.435E-04	1.992E-04	1.905E-10	1.992E-04	7.443E-04	3.082E-02
0.15	4.82	9.950E-04	1.514E-05	9.799E-04	2.985E-04	6.607E-10	2.985E-04	6.814E-04	2.822E-02
0.2	5.48	9.940E-04	3.311E-06	9.907E-04	3.976E-04	3.020E-09	3.976E-04	5.931E-04	2.456E-02
0.25	6.05	9.930E-04	8.913E-07	9.922E-04	4.965E-04	1.122E-08	4.965E-04	4.956E-04	2.053E-02
0.3	6.61	9.921E-04	2.455E-07	9.918E-04	5.952E-04	4.074E-08	5.952E-04	3.966E-04	1.642E-02
0.35	7.14	9.911E-04	7.244E-08	9.910E-04	6.938E-04	1.380E-07	6.936E-04	2.974E-04	1.232E-02
0.4	7.64	9.901E-04	2.291E-08	9.901E-04	7.921E-04	4.365E-07	7.916E-04	1.984E-04	8.218E-03
0.45	8.29	9.891E-04	5.129E-09	9.891E-04	8.902E-04	1.950E-06	8.883E-04	1.009E-04	4.177E-03
0.5	8.85	9.881E-04	1.413E-09	9.881E-04	9.881E-04	7.079E-06	9.811E-04	7.078E-06	2.931E-04
0.55	9.18	9.872E-04	6.607E-10	9.872E-04	1.086E-03	1.514E-05	1.071E-03	-8.358E-05	-3.461E-03
0.6	9.39	9.862E-04	4.074E-10	9.862E-04	1.183E-03	2.455E-05	1.159E-03	-1.727E-04	-7.152E-03
0.65	9.55	9.852E-04	2.818E-10	9.852E-04	1.281E-03	3.548E-05	1.245E-03	-2.601E-04	-1.077E-02
0.7	9.67	9.843E-04	2.138E-10	9.843E-04	1.378E-03	4.677E-05	1.331E-03	-3.469E-04	-1.437E-02
0.75	9.77	9.833E-04	1.698E-10	9.833E-04	1.475E-03	5.888E-05	1.416E-03	-4.328E-04	-1.792E-02
0.8	9.85	9.823E-04	1.413E-10	9.823E-04	1.572E-03	7.079E-05	1.501E-03	-5.186E-04	-2.148E-02
0.85	9.95	9.814E-04	1.122E-10	9.814E-04	1.668E-03	8.913E-05	1.579E-03	-5.978E-04	-2.476E-02
0.9	9.99	9.804E-04	1.023E-10	9.804E-04	1.765E-03	9.772E-05	1.667E-03	-6.866E-04	-2.843E-02
0.95	10.1	9.794E-04	8.913E-11	9.794E-04	1.861E-03	1.122E-04	1.749E-03	-7.693E-04	-3.186E-02

Ionic strength 0.01 M NaNO₃
 Titrant: 0.1 M NaOH
 0.5 M HNO₃
 Initial acid volume 0.1 mL
 Sample volume: 50 mL
 Sample content: 2 g/L
 Specific surface area 1165 m²/g

Base Titration

V _{base} /mL	pH	C _A	H ⁺	X=C _A -H ⁺	C _B	OH ⁻	Y=C _B - OH ⁻	X-Y	Charge density/ Cm ⁻²
0	3.63	9.980E-04	2.344E-04	7.636E-04	0.000E+00	4.266E-11	-4.266E-11	7.636E-04	3.162E-02
0.05	3.88	9.970E-04	1.318E-04	8.652E-04	9.970E-05	7.586E-11	9.970E-05	7.655E-04	3.170E-02
0.1	4.27	9.960E-04	5.370E-05	9.423E-04	1.992E-04	1.862E-10	1.992E-04	7.431E-04	3.077E-02
0.15	4.91	9.950E-04	1.230E-05	9.827E-04	2.985E-04	8.128E-10	2.985E-04	6.842E-04	2.833E-02
0.2	5.62	9.940E-04	2.399E-06	9.916E-04	3.976E-04	4.169E-09	3.976E-04	5.940E-04	2.460E-02
0.25	6.81	9.930E-04	1.549E-07	9.929E-04	4.965E-04	6.457E-08	4.965E-04	4.964E-04	2.056E-02
0.3	7.34	9.921E-04	4.571E-08	9.920E-04	5.952E-04	2.188E-07	5.950E-04	3.970E-04	1.644E-02
0.35	7.88	9.911E-04	1.318E-08	9.911E-04	6.938E-04	7.586E-07	6.930E-04	2.981E-04	1.234E-02
0.4	8.51	9.901E-04	3.090E-09	9.901E-04	7.921E-04	3.236E-06	7.888E-04	2.013E-04	8.334E-03
0.45	9.03	9.891E-04	9.333E-10	9.891E-04	8.902E-04	1.072E-05	8.795E-04	1.096E-04	4.540E-03
0.5	9.39	9.881E-04	4.074E-10	9.881E-04	9.881E-04	2.455E-05	9.636E-04	2.455E-05	1.017E-03
0.55	9.56	9.872E-04	2.754E-10	9.872E-04	1.086E-03	3.631E-05	1.050E-03	-6.241E-05	-2.584E-03
0.6	9.7	9.862E-04	1.995E-10	9.862E-04	1.183E-03	5.012E-05	1.133E-03	-1.471E-04	-6.093E-03
0.65	9.82	9.852E-04	1.514E-10	9.852E-04	1.281E-03	6.607E-05	1.215E-03	-2.295E-04	-9.504E-03
0.7	9.91	9.843E-04	1.230E-10	9.843E-04	1.378E-03	8.128E-05	1.297E-03	-3.124E-04	-1.294E-02
0.75	9.99	9.833E-04	1.023E-10	9.833E-04	1.475E-03	9.772E-05	1.377E-03	-3.939E-04	-1.631E-02
0.8	10.08	9.823E-04	8.318E-11	9.823E-04	1.572E-03	1.202E-04	1.451E-03	-4.692E-04	-1.943E-02

04. Experimental surface titrations data – bare PAC

Titrated with Base		Titrated with Base		Titrated with Base	
0.001= Ionic strength		0.01= Ionic strength		0.1 =Ionic strength	
Acid added		Acid added		Acid added	
0.5 M	0.1 mL	0.5 M	0.05 mL	0.5 M	0.05 mL
0.1 M	0.0 mL	0.1 M	0.25 mL	0.1 M	0.25 mL
	pH		pH		pH
0	3.64	0	3.63	0	3.68
0.05	3.86	0.05	3.88	0.05	3.92
0.1	4.2	0.1	4.27	0.1	4.28
0.15	4.73	0.15	4.91	0.15	4.82
0.2	5.36	0.2	5.62	0.2	5.48
0.25	5.98	0.25	6.81	0.25	6.05
0.3	6.43	0.3	7.34	0.3	6.61
0.35	6.86	0.35	7.88	0.35	7.14
0.4	7.28	0.4	8.51	0.4	7.64
0.45	7.63	0.45	9.03	0.45	8.29
0.5	8	0.5	9.39	0.5	8.85
0.55	8.4	0.55	9.56	0.55	9.18
0.6	8.79	0.6	9.7	0.6	9.39
0.65	9.09	0.65	9.82	0.65	9.55
0.7	9.32	0.7	9.91	0.7	9.67
0.75	9.48	0.75	9.99	0.75	9.77
0.8	9.61	0.8	10.8	0.8	9.85
0.85	9.73			0.85	9.95
0.9	9.82			0.9	9.99
0.95	9.9			0.95	10.05
1	9.96				
1.05	10.2				

05. Experimental Results of different pH values at ionic strength 0.001 M for PAC

Sample No	PAC g/L	Initial Cr ⁺⁶ / ppm	NaNO ₃ mole/L	pH	Remaining total Chromium / ppm	Adsorbed total Chromium / ppm	Chromium removal %
1	5.0	20.0	0.001	2.35	9.874	10.126	50.64
2	5.0	20.0	0.001	3.48	3.82	16.18	80.90
3	5.0	20.0	0.001	5.45	5.332	14.668	73.34
4	5.0	20.0	0.001	6.89	7.318	12.682	63.41
5	5.0	20.0	0.001	8.70	12.2	7.8	39.00
6	5.0	20.0	0.001	9.59	13.806	6.194	30.97
7	5.0	20.0	0.001	10.20	16.288	3.712	18.56

06. Experimental results of different pH values at ionic strength 0.01 M for PAC

Sample No	PAC g/L	Initial Cr ⁺⁶ / ppm	NaNO ₃ mole/L	pH	Remaining total Chromium / ppm	Adsorbed total Chromium/ ppm	Chromium removal %
1	5.0	20.0	0.01	2.35	11.298	8.702	43.51
2	5.0	20.0	0.01	3.48	5.774	14.226	71.13
3	5.0	20.0	0.01	5.45	7.328	12.672	63.36
4	5.0	20.0	0.01	6.89	10.202	9.798	48.99
5	5.0	20.0	0.01	8.70	17.4	2.6	13.00
6	5.0	20.0	0.01	9.59	19.7	0.3	1.50
7	5.0	20.0	0.01	10.20	19.502	0.498	2.49

07. Experimental Results of different contact time for PAC with 20mg/L initial Cr (VI)

Sample No	PAC g/L	Initial Cr ⁺⁶ / ppm	NaNO ₃ mole/L	Time/min	Remaining total Chromium / ppm	Adsorbed total Chromium
1	5.0	20.0	0.01	05	11.300	8.700
2	5.0	20.0	0.01	30	7.2425	12.7575
3	5.0	20.0	0.01	90	5.8795	14.1205
4	5.0	20.0	0.01	120	4.6455	15.3545
5	5.0	20.0	0.01	150	4.545	15.455
6	5.0	20.0	0.01	180	4.864	15.136
7	5.0	20.0	0.01	210	4.8741	15.1259
8	5.0	20.0	0.01	1440	4.8742	15.1258

08. *Experimental Results of different contact time for PAC with 50mg/L initial Cr (VI)*

Sample No	PAC g/L	Initial Cr ⁺⁶ / ppm	NaNO ₃ mole/L	Time/min	Remaining total Chromium / ppm	Adsorbed total Chromium
1	5.0	50.0	0.01	05	23.7435	26.2565
2	5.0	50.0	0.01	30	20.075	29.925
3	5.0	50.0	0.01	90	17.644	32.356
4	5.0	50.0	0.01	120	16.1235	33.8765
5	5.0	50.0	0.01	150	14.321	35.679
6	5.0	50.0	0.01	180	14.0436	35.9564
7	5.0	50.0	0.01	210	14.1005	35.8995
8	5.0	50.0	0.01	1440	14.1005	35.8995

09. *Experimental Results of different contact time for PAC with 80mg/L initial Cr (VI)*

Sample No	PAC g/L	Initial Cr ⁺⁶ / ppm	NaNO ₃ mole/L	Time/min	Remaining total Chromium / ppm	Adsorbed total Chromium
1	5.0	80.0	0.01	05	35.7935	44.2065
2	5.0	80.0	0.01	30	32.211	47.789
3	5.0	80.0	0.01	90	23.7965	56.2035
4	5.0	80.0	0.01	120	20.9035	59.0965
5	5.0	80.0	0.01	150	15.7945	64.2055
6	5.0	80.0	0.01	180	15.6925	64.3075
7	5.0	80.0	0.01	210	15.7925	64.2075
8	5.0	80.0	0.01	1440	15.7925	64.2075

10. *Experiment Results with different initial chromium concentration at pH 6.50 for bare PAC*

Sample No	PAC g/L	initial Cr ⁺⁶ / ppm	NaNO ₃ mole/L	pH	remaining total Chromium/ ppm	Adsorbed total Chromium/ ppm
1	5.0	20.0	0.01	6.5	8.163	11.837
2	5.0	40.0	0.01	6.5	21.793	18.207
3	5.0	80.0	0.01	6.5	49.474	30.526
4	5.0	120.0	0.01	6.5	73.429	46.571
5	5.0	160.0	0.01	6.5	97.634	62.366
6	5.0	200.0	0.01	6.5	124.114	75.886

11. *Experimental Results with different initial chromium concentration at pH 9.0 for bare PAC*

Sample No	PAC g/L	initial Cr ⁺⁶ / ppm	NaNO ₃ mole/L	pH	remaining total Chromium / ppm	Adsorbed total Chromium/ ppm
1	5.0	20.0	0.01	9.0	10.942	9.058
2	5.0	40.0	0.01	9.0	18.159	21.841
3	5.0	80.0	0.01	9.0	33.362	46.638
4	5.0	120.0	0.01	9.0	45.055	74.945
5	5.0	160.0	0.01	9.0	63.422	96.578
6	5.0	200.0	0.01	9.0	76.354	123.646

12. *Experimental Results with different initial chromium concentration at pH 4.0 for bare PAC*

Sample No	PAC g/L	Initial Cr ⁺⁶ / ppm	NaNO ₃ mole/L	pH	Remaining total Chromium /ppm	Adsorbed total Chromium/ ppm
1	5.0	20.0	0.01	4.0	0.844	19.156
2	5.0	40.0	0.01	4.0	9.729	30.271
3	5.0	80.0	0.01	4.0	34.590	45.410
4	5.0	120.0	0.01	4.0	64.578	55.422
5	5.0	160.0	0.01	4.0	87.805	72.195
6	5.0	200.0	0.01	4.0	108.939	91.061

13. *Experimental Results of different pH of the solution at 0.01M ionic strength for HA treated PAC.*

Sample No	PAC /g/L	HA/ ppm	NaNO ₃ mole/L	Initial Cr ⁺⁶ / ppm	pH	Remaining total Chromium/ ppm	Adsorb total Chromium / ppm	Cr removal %
1	5.00	100.0	0.01	20.0	2.35	1.706	18.294	91.47
2	5.00	100.0	0.01	20.0	3.48	1.332	18.668	93.34
3	5.00	100.0	0.01	20.0	5.45	1.456	18.544	92.72
4	5.00	100.0	0.01	20.0	6.89	5.93	14.07	70.35
5	5.00	100.0	0.01	20.0	8.7	13.11	6.89	34.45
6	5.00	100.0	0.01	20.0	9.59	17.278	2.722	13.61
7	5.00	100.0	0.01	20.0	10.20	19.102	0.898	4.49

14. Experimental Results of different pH of the solution at 0.001M ionic strength for HA treated PAC.

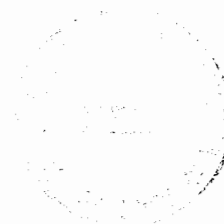
Sample No	PAC /g/L	HA/ ppm	NaNO ₃ mole/L	Initial Cr ⁺⁶ / ppm	pH	Remaining total Chromium/ ppm	Adsorb total Chromium / ppm	Cr removal %
1	5.0	100.0	0.001	20.0	2.35	0.322	9.6780	96.78
2	5.0	100.0	0.001	20.0	3.48	0.012	9.9876	99.88
3	5.0	100.0	0.001	20.0	5.45	0.138	9.8625	98.63
4	5.0	100.0	0.001	20.0	6.89	0.252	9.7484	97.48
5	5.0	100.0	0.001	20.0	8.7	0.490	9.5104	95.10
6	5.0	100.0	0.001	20.0	9.59	0.795	9.2055	92.06
7	5.0	100.0	0.001	20.0	10.2	0.959	9.0406	90.41

15. Experimental Results of different contact time of the solution for HA treated PAC with initial Cr (VI) 20.0 mg/L.

Sample No	PAC g/L	HA/ ppm	Initial Cr ⁺⁶ / ppm	NaNO ₃ mole/L	Time/min	Remaining total Chromium / ppm	Adsorbed total Chromium/ ppm	Cr removal %
1	5.0	100.0	20.0	0.01	5	8.7028	11.30	56.49
2	5.0	100.0	20.0	0.01	30	7.2252	12.77	63.87
3	5.0	100.0	20.0	0.01	60	5.88058	14.12	70.60
4	5.0	100.0	20.0	0.01	90	4.4773	15.0557	77.61
5	5.0	100.0	20.0	0.01	120	4.601	15.1455	77.00
6	5.0	100.0	20.0	0.01	150	5.462	15.1546	72.69
7	5.0	100.0	20.0	0.01	180	5.462	15.1545	72.69
8	5.0	100.0	20.0	0.01	210	5.461	15.44	72.69
9	5.0	100.0	20.0	0.01	1440	5.462	15.44	72.69

16. Experimental Results of different contact time of the solution for HIA treated PAC with initial Cr (VI) 50.0 mg/L.

Sample No	PAC g/L	HA/ppm	Initial Cr ⁺⁶ / ppm	NaNO ₃ mole/L	Time/min	Remaining Total Chromium / ppm	Adsorbed Total Chromium/ ppm	Cr removal %
1	5.0	100.0	50.0	0.01	5	21.7475	28.2525	56.505
2	5.0	100.0	50.0	0.01	30	17.0795	32.9205	65.841
3	5.0	100.0	50.0	0.01	60	15.696	34.304	68.608
4	5.0	100.0	50.0	0.01	90	12.4375	37.5625	75.125
5	5.0	100.0	50.0	0.01	120	11.4975	38.5025	77.00
6	5.0	100.0	50.0	0.01	150	11.1744	38.8256	77.65
7	5.0	100.0	50.0	0.01	180	11.1745	38.8255	77.65
8	5.0	100.0	50.0	0.01	210	11.1746	38.8254	77.65
9	5.0	100.0	50.0	0.01	1440	11.1744	38.8256	77.65



17. *Experimental Results of different contact time of the solution for HA treated PAC with initial Cr (VI) 80.0 mg/L*

Sample No	PAC g/L	HA/ppm	Initial Cr ⁺⁶ / ppm	NaNO ₃ mole/L	Time/min	Remaining total Chromium / ppm	Adsorbed total Chromium/ ppm	Cr removal %
1	5.0	100.0	80.0	0.01	5	34.242	45.758	57.1975
2	5.0	100.0	80.0	0.01	30	24.2245	55.7755	69.71938
3	5.0	100.0	80.0	0.01	60	21.0455	58.9545	73.69313
4	5.0	100.0	80.0	0.01	90	18.0465	61.9535	77.44188
5	5.0	100.0	80.0	0.01	120	15.6945	64.3055	80.38188
6	5.0	100.0	80.0	0.01	150	12.6925	67.3075	84.13438
6	5.0	100.0	80.0	0.01	180	12.6925	67.3075	84.13438
6	5.0	100.0	80.0	0.01	210	12.692	67.3080	84.135
6	5.0	100.0	80.0	0.01	1440	12.692	67.3080	84.135

18. *Experiment results of different initial Cr (VI) concentration at pH 4.0*

Sample No	PAC g/l	HA / ppm	initial Cr ⁺⁶ / ppm	NaNO ₃ / mole/l	pH	remaining total Chromium / ppm	Adsorbed total Chromium/ ppm
1	5.0	100.0	20.0	0.01	4.0	0.397	19.603
2	5.0	100.0	40.0	0.01	4.0	8.280	31.720
3	5.0	100.0	80.0	0.01	4.0	25.354	54.646
4	5.0	100.0	120.0	0.01	4.0	48.564	71.436
5	5.0	100.0	160.0	0.01	4.0	66.411	93.589
6	5.0	100.0	200.0	0.01	4.0	83.029	116.971

19. *Experiment results of different of initial Cr (VI) concentration at pH 9.0*

Sample No	PAC g/L	HA / ppm	initial Cr ⁺⁶ / ppm	NaNO ₃ / mole/L	pH	remaining total Chromium / ppm	Adsorbed total Chromium/ ppm
1	5.0	100.0	20.0	0.01	9.0	19.680	0.320
2	5.0	100.0	40.0	0.01	9.0	34.486	5.514
3	5.0	100.0	80.0	0.01	9.0	53.531	26.469
4	5.0	100.0	120.0	0.01	9.0	72.487	47.513
5	5.0	100.0	160.0	0.01	9.0	92.867	67.133
6	5.0	100.0	200.0	0.01	9.0	121.912	78.088

20 Experimental data and Modeling data for bare PAC at pH 6.5

sample no	carbon g/L	initial Cr ⁺⁶ /ppm	NaNO ₃ mole/L	pH	remaining total Chromium/ ppm	Adsorbed total Chromium/ ppm	Cr eqL(mol/L)	Cr eqL(mol/m ³)	Cr adsorb(mol/L)	Ads density (mol/m ²)
1	5	20.0	0.01	6.5	4.6542462	15.35	8.95E-05	0.089504735	0.0002951	1.18E-07
2	5	40.0	0.01	6.5	12.425175	27.57	0.0002389	0.238945673	0.0005303	2.12E-07
3	5	80.0	0.01	6.5	28.964371	51.04	0.000557	0.557007135	0.0009815	3.93E-07
4	5	120.0	0.01	6.5	41.864469	78.14	0.0008051	0.805085942	0.0015026	6.01E-07
5	5	160.0	0.01	6.5	55.666921	104.33	0.0010705	1.070517712	0.0020064	8.03E-07
6	5	200.0	0.01	6.5	66.803867	133.2	0.0012847	1.28468975	0.0025615	1.02E-06

21 Experimental data and Modeling data for bare PAC at pH 9.0

sample no	carbon g/L	initial Cr ⁺⁶ /ppm	NaNO ₃ mole/L	pH	remaining total Chromium /ppm	Adsorbed total Chromium/ ppm	Cr eqL(mol/L)	Cr eqL(mol/m ³)	Cr adsorb(mol/L)	Ads density (mol/m ²)
1	5	20.0	0.01	9	2.2393019	17.76	4.31E-05	0.043063498	0.0003416	1.37E-07
2	5	40.0	0.01	9	7.353323	32.65	0.0001414	0.141410058	0.0006278	2.51E-07
3	5	80.0	0.01	9	15.020669	64.98	0.0002889	0.288859019	0.0012496	5.00E-07
4	5	120.0	0.01	9	25.117494	94.88	0.000483	0.483028731	0.0018247	7.30E-07
5	5	160.0	0.01	9	36.159456	123.84	0.0006954	0.695374154	0.0023815	9.53E-07
6	5	200.0	0.01	9	43.532637	156.47	0.0008372	0.837166096	0.003009	1.20E-06

22. Experimental data and Modeling data for bare PAC at pH 4.0

sample no	carbon g/L	initial Cr ⁺⁶ /ppm	NaNO ₃ mole/L	pH	Remaining total Chromium /ppm	Adsorbed total Chromium/ ppm	Cr eqL(mol/L)	Cr eqL(mol/m ³)	Cr adsorb(mol/L)	Ads density (mol/m ²)
1	5	20.0	0.01	4	2.781	17.2189	5.35E-05	0.053483506	0.0003311	1.32E-07
2	5	40.0	0.01	4	7.547	32.453	0.0001451	0.145134394	0.0006241	2.50E-07
3	5	80.0	0.01	4	17.721	62.2788	0.0003408	0.340791942	0.0011977	4.79E-07
4	5	120.0	0.01	4	36.818	83.1816	0.000708	0.708046385	0.0015996	6.40E-07
5	5	160.0	0.01	4	50.762	109.238	0.0009762	0.9761905	0.0021007	8.40E-07
6	5	200.0	0.01	4	57.264	142.736	0.0011012	1.101227885	0.0027449	1.10E-06

23. *Experimental data and Modeling data for HIA treated PAC at pH 4.0*

PAC g/L	HA /ppm	initial Cr ⁺⁶ /ppm	remaining total Chromium /ppm	Adsorbed total Chromium/ppm	Cr eqL(mol/L)	Cr eqL (mol/m ³)	Cr adsorption (mol/L)	Ads density (mol/m ²)
5.0	100.0	20.0	0.224	19.776	4.31279E-06	0.004312788	4.31279E-06	1.72512E-09
5.0	100.0	40.0	4.682	35.318	9.00312E-05	0.090031154	9.00312E-05	3.60125E-08
5.0	100.0	80.0	14.335	65.665	0.000275673	0.275673269	0.000275673	1.10269E-07
5.0	100.0	120.0	27.457	92.543	0.000528025	0.528024615	0.000528025	2.1121E-07
5.0	100.0	160.0	37.548	122.452	0.000722072	0.722071538	0.000722072	2.88829E-07
5.0	100.0	200.0	46.943	153.057	0.000902759	0.902759231	0.000902759	3.61104E-07

24. *Experimental data and Modeling data for H.A treated PAC at pH 9.0*

PAC g/L	HA /ppm	initial Cr ⁺⁶ /ppm	remaining total Chromium /ppm	Adsorbed total Chromium/ppm	Cr eqL(mol/L)	Cr eqL (mol/m ³)	Cr adsorption (mol/L)	Ads density (mol/m ²)
5	100	20.0	11.127	8.873	0.000213972	0.213972308	0.000853215	3.41286E-07
5	100	40.0	19.498	20.502	0.000374961	0.3754960962	0.000985675	3.9427E-07
5	100	80.0	30.265	49.735	0.000582027	0.582027115	0.001295543	4.78217E-07
5	100	120.0	40.983	79.017	0.000788131	0.788131154	0.001266301	5.0652E-07
5	100	160.0	52.506	107.494	0.001009723	1.0097225	0.001292	5.1687E-07
5	100	200.0	68.927	131.073	0.001325523	1.3255225	0.001260316	5.04126E-07

25. *Experimental results of different concentration of PAC at pH 4.0*

Sample no	carbon g/L	Cr (mg/L)	NaNO ₃ mole/ L	pH	remaining total Chromium /ppm	Adsorbed total Chromium ppm	Cr removal %
1	5.0	20.0	0.01	4.0	15.078	4.9	24.61
2	5.0	20.0	0.01	4.0	11.220	8.8	43.9
3	5.0	20.0	0.01	4.0	8.919	11.1	55.405
4	5.0	20.0	0.01	4.0	7.518	12.5	62.41
5	5.0	20.0	0.01	4.0	5.774	14.2	71.13

26. *Experiment results of different concentration of HA treated PAC at pH 4.0*

Sample no	carbon g/L	HA /ppm	NaNO ₃ / mole/ L	pH	remaining total Chromium /ppm	Adsorbed total Chromium/ ppm	Cr removal %
1	5.0	20.0	0.01	4.0	10.631	9.4	46.845
2	5.0	20.0	0.01	4.0	9.723	10.3	51.385
3	5.0	20.0	0.01	4.0	6.204	13.8	68.98
4	5.0	20.0	0.01	4.0	2.52	17.5	87.4
5	5.0	20.0	0.01	4.0	1.728	18.3	91.36



University of Moratuwa, Sri Lanka.
 Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Appendices B

HAYCARB PLC		SAMPLE ANALYSIS REPORT			Ref no.	
Issue No: 01		Date:		Amend.No: Nil		
SAMPLE REF		2008/273				
GRADE		PHO M325	QUANTITY	2kg		
FOR		Hiroshi Sooriyabandara -	ISSUED DATE	23/6/2008		
		University of Moratuwa				
TEST			Reading 1	Reading 2		
ACTIVITY % (CTC)			55.5	56.3		
MOISTURE %			7.1	7.3		
CBD g/cc			0.56	0.57		
IODINE NO mg/g			1115	1107		
ASH %			4.6			
PARTICLE SIZE DISTRIBUTION (ASTM)	200		0.0	0.0		
	325		2.6	3.0		
	400		7.3	6.8		
	500		8.4	8.8		
	-500		81.7	81.4		
ASTM pH			10.0			
SPECIAL TESTS						
SURFACE AREA, m ² /g (CALCULATED)			1165			

HAYCARB PLC.
 400, DEANS ROAD, COLOMBO 10, SRI LANKA.
 PHONE: +94 112 687565, E-MAIL. haycarb@haycarb.com, FAX. +94 112 699630

Appendices C

CEA effluent discharges limits

01. General standards criteria for the discharge of industrial effluents in to inland surface waters. (page 55)
02. Tolerance limits for industrial effluents discharged on land for irrigation purpose. (page 56)
03. Tolerance limits for industrial and domestic effluents discharged in to marine coastal areas. (page 57)
04. Tolerance limits for effluents in to public sewers with central treatment plants. (page 58)
05. Tolerance limits for effluents from text file industry being discharged in to inland surface waters. (page 59)



GENERAL STANDARDS CRITERIA FOR THE DISCHARGE OF INDUSTRIAL EFFLUENTS INTO INLAND SURFACE WATERS

NO	PARAMETER	UNIT TYPE OF LIMIT	TOLERANCE LIMIT VALUES
01	Total suspended solids	mg/l, max	50
02	Particle size of the total suspended solids	µm, less than	850
03	pH at ambient temperature		6.0 - 8.5
04	Biochemical oxygen demand (BOD ₅ in five days at 20°C or BOD ₃ in three days at 27°C)	mg/l, max	30
05	Temperature of discharge	°C, max	Shall not exceed 40°C in any section of the stream within 15 m down stream from the effluent outlet.
06	Oils and greases	mg/l, max	10
07	Phenolic compounds (as C ₆ H ₅ OH)	mg/l, max	1
08	Chemical oxygen demand (COD)	mg/l, max	250
09	Colour	Wavelength Range 436 nm (Yellow range) 525 nm (Red range) 620 nm (Blue range)	Maximum spectral absorption coefficient 7m ⁻¹ 5m ⁻¹ 3m ⁻¹
10	Dissolved phosphates (as P)	mg/l, max	5
11	Total kjeldahl nitrogen (as N)	mg/l, max	150
12	Ammoniacal nitrogen (as N)	mg/l, max	50
13	Cyanide (as CN)	mg/l, max	0.2
14	Total residual chlorine	mg/l, max	1.0
15	Fluorides (as F)	mg/l, max	2.0
16	Sulphide (as S)	mg/l, max	2.0
17	Arsenic (as AS)	mg/l, max	0.2
18	Cadmium (as Cd)	mg/l, max	0.1
19	Chromium, total (as Cr)	mg/l, max	0.5
20	Chromium, Hexavalent (as Cr ⁶⁺)	mg/l, max	0.1
21	Copper (as Cu)	mg/l, max	3.0
22	Iron (as Fe)	mg/l, max	3.0
23	Lead (as Pb)	mg/l, max	0.1
24	Mercury (as Hg)	mg/l, max	0.0005
25	Nickel (as Ni)	mg/l, max	3.0
26	Selenium (as Se)	mg/l, max	0.05
27	Zinc (as Zn)	mg/l, max	2.0
28	Pesticides	mg/l, max	0.005
29	Detergents/surfactants	mg/l, max	5
30	Faecal Coliform	MPN/100 ml, max	40
31	Radio Active Material: (a) Alpha emitters (b) Beta emitters	Micro curie/ml, max Micro curie/ml, max	10 ⁻⁸ 10 ⁻⁷

Note 1 All efforts should be made to remove unpleasant odour ad dar as possible.

55

Note 2 These value are based on dilution of effluents by at least 8 volumes of clean receiving water. If the dilution is below 8 times, the permissible limits are multiplied by the 1/8 of the actual dilution

Note 3 The above mentioned general standards shall cease to apply with regard to a particular industry when industry specific standards are notified for that industry

Note 4 Pesticides as per World Health Organization (WHO) and Food and Agriculture Organization (FAO) requirements

**TOLERANCE LIMITS FOR INDUSTRIAL EFFLUENTS DISCHARGED
ON LAND FOR IRRIGATION PURPOSE**

NO	PARAMETER	UNIT TYPE OF LIMIT	TOLERANCE LIMIT VALUES
1	Total dissolved solids	mg/l, max	2100
2	pH at ambient temperature	-	5.5 - 9.0
3.	Biochemical oxygen demand (BOD ₅ in five days at 20°C or BOD ₃ in three days at 27°C)	mg/l, max	250
4.	Oils and greases	mg/l, max	10.0
5.	Chemical Oxygen Demand (COD)	mg/l, max	400
6.	Chlorides (as Cl)	mg/l, max	600
7.	Sulphates (as SO ₄)	mg/l, max	1000
8.	Boron (as B)	mg/l, max	2.0
9.	Arsenic (as As)	mg/l, max	0.2
10.	Cadmium (as Cd)	mg/l, max	2.0
11.	Chromium, total (as Cr)	mg/l, max	1.0
12.	Lead (as Pb)	mg/l, max	1.0
13.	Mercury (as Hg)	mg/l, max	0.01
14.	Sodium adsorption ratio (SAR)		10-15
15.	Residual sodium carbonate (RSC)	mol/l, max	2.5
16.	Electrical conductivity	μS/cm, max	2250
17.	Faecal coliform	MPN/100ml, max	40
18.	Copper (as Cu)	mg/l, max	1.0
19.	Cyanide (as CN)	mg/l, max	0.2
20.	Radio Active Material: (a) Alpha emitters (b) Beta emitters	micro curie/ml, max micro curie/ml, max	10 ⁻⁹ 10 ⁻⁸

Hydraulic loading applicable for different Solis.

Soil Texture Class	Recommended dosage of settled industrial effluents (m ³ /hectare, day)
1. Sandy	225 - 280
2. Sandy loam	170 - 225
3. loam	110 - 170
4. clay loam	55 - 110
5. clay	35 - 55

**TOLERANCE LIMITS FOR INDUSTRIAL AND DOMESTIC
EFFLUENTS DISCHARGED INTO MARINE COASTAL AREAS**

NO	PARAMETER	UNIT TYPE OF LIMIT	TOLERANCE LIMIT VALUES
01	Total suspended solids	mg/l, max	150
02	Particle size of - (a) Floatable solids (b) Setttable solids	mm, max μ m, max	3 850
03	pH at ambient temperature	-	5.5 - 9.0
04	Biochemical oxygen demand (BOD ₅ in five days at 20°C or BOD ₃ in three days at 27°C)	mg/l, max	100 30
05	Temperature of discharge	°C, max	45°C at the point of discharge
06	Oils and greases	mg/l, max	20
07	Phenolic compounds (as Phenolic OH)	mg/l, max	5.0
08	Chemical oxygen demand (COD)	mg/l, max	250
09	Total residual chlorine	mg/l, max	1.0
10	Ammoniacal Nitrogen (as N)	mg/l, max	50
11	Cyanide (as N)	mg/l, max	0.2
12	Sulphides (as S)	mg/l, max	5.0
13	Fluorides (as F)	mg/l, max	15
14	Arsenic (as As)	mg/l, max	0.2
15	Cadmium (as Cd)	mg/l, max	2.0
16	Chromium, total (as Cr)	mg/l, max	2.0
17	Chromium, Hexavalent (as Cr ⁶⁺)	mg/l, max	1.0
18	Copper (as Cu)	mg/l, max	3.0
19	Lead (as Pb)	mg/l, max	1.0
20	Mercury (as Hg)	mg/l, max	0.01
21	Nickel (as Ni)	mg/l, max	5.0
22	Selenium (as Se)	mg/l, max	0.1
23	Zine (as Zn)	mg/l, max	5.0
24	Pesticides	mg/l, max	0.005
25	Organo-Phosphorus compounds	mg/l, max	1.0
26	Chlorinated hydrocarbons (as Cl)	mg/l, max	0.02
27	Faecal coliform	mg/l, max	60
28	Radio Active Material: (a) Alpha emitters (b) Beta emitters	micro curie/ml, max micro curie/ml, max	10 ⁻⁸ 10 ⁻⁷

Note 1 All efforts should be made to remove unpleasant odour and colour as far as practicable.

Note 2 These value are based on dilution of effluents by at least 8 volumes of clean receiving water. if the dilution is below 8 times, the permissible limits are multiplied by the 1/8 of the actual dilution

**TOLERANCE LIMITS FOR EFFLUENTS INTO PUBLIC SEWERS WITH
CENTRAL TREATMENT PLANTS**

NO	PARAMETER	UNIT TYPE OF LIMIT	TOLERANCE LIMIT VALUES
01	Total suspended solids	mg/l, max	500
02	pH at ambient temperature	mg/l, max	5.5 - 10.0
03	Temperature	°C, max	45
04	Biochemical oxygen demand (BOD ₅ in five days at 20°C or BOD ₃ in three days at 27°C)	mg/l, max	350
05	Chemical oxygen demand (COD)	mg/l, max	850
06	Total kjeldahl nitrogen (as N)	mg/l, max	500
07	Free ammonia (as N)	mg/l, max	50
08	Ammoniacal nitrogen (as N)	mg/l, max	50
09	Cyanide (as CN)	mg/l, max	2
10	Total residual chlorine	mg/l, max	3.0
11	Chlorides (as Cl)	mg/l, max	900
12	Fluorides (as F)	mg/l, max	20
13	Sulphide (as S)	mg/l, max	5.0
14	Sulphates (as SO ₄)	mg/l, max	1000
15	Arsenic (as AS)	mg/l, max	0.2
16	Cadmium (as Cd)	mg/l, max	1.0
17	Chromium, total (as Cr)	mg/l, max	2.0
18	Copper (as Cu)	mg/l, max	3.0
19	Lead (as Pb)	mg/l, max	1.0
20	Mercury (as Hg)	mg/l, max	0.005
21	Nickel (as Ni)	mg/l, max	3.0
22	Selenium (as Se)	mg/l, max	0.05
23	Zinc (as Zn)	mg/l, max	5.0
24	Pesticides	mg/l, max	0.2
25	Detergents/surfactants	mg/l, max	50
26	Phenolic compounds (as phenolic OH)	mg/l, max	5
27	Oil and Grease	mg/l, max	30
28	Radio Active Material: (a) Alpha emitters (b) Beta emitters	Micro curie/ml, max Micro curie/ml, max	10 ⁻⁸ 10 ⁻⁷

Notes : The Following conditions should be met:

- ❖ discharge of high viscous material should be prohibited
- ❖ Calcium Carbide sludge should not be discharged
- ❖ Substances producing inflammable vapours should be absent

**TOLERANCE LIMITS FOR EFFLUENTS FROM TEXTILE INDUSTRY
BEING DISCHARGED INTO INLAND SURFACE WATERS**

NO	PARAMETER	UNIT TYPE OF LIMIT	TOLERANCE LIMIT VALUES
1.	pH at ambient temperature		6.5 to 8.5
2.	Temperature	°C, max	40 measured at site of sampling
3.	Total suspended solids	mg/l, max	50
4.	Biochemical oxygen demand (BOD ₅ in five days at 20°C or BOD ₃ in three days at 27°C)	mg/l, max	60
5.	Clour	Wavelength Range 436 nm (Yellow range) 525 nm (Red range) 620 nm (Blue range)	Maximum spectral absorption coefficient 7m ⁻¹ 5m ⁻¹ 3m ⁻¹
6.	Oils and grease	mg/l, max	10
7.	Phenolic compounds (as phenolic OH)	mg/l, max	1.0
8.	Chemical oxygen demand (COD)	mg/l, max	250
9.	Sulphides (as S)	mg/l, max	2.0
10.	Chromium total (as Cr)	mg/l, max	2.0
11.	Hexavalent Chromium (as Cr ⁺⁶)	mg/l, max	0.5
12.	Copper, total (as Cu)	mg/l, max	3.0
13.	Zinc, total (as Zn)	mg/l, max	5.0
14.	Ammoniacal nitrogen (an N)	mg/l, max	60
15.	Chloride (as Cl)	mg/l, max	70

Note 1: All efforts should be made to remove unpleasant odour and colours as far as practicable.

Note 2: These value are based on dilution of effluents by at least 8 volumes of clean receiving water. if the dilution is below 8 times, the permissible limits are multiplied by the 1/8 of the actual value.

