
Results and Discussion

4.0 RESULTS AND DISCUSSION

Industrial and municipal waste water frequently contain metal ions. The presence of heavy metal ions is a major concern due to their toxicity which can be harmful to aquatic life and human health. Nowadays frequently used methods for heavy metal removal from wastewater include precipitation, membrane filtration, ion exchange, sedimentation, membrane process, electrochemical techniques, biological process and chemical reactions. But each method has its merits and demerits in application. These methods have been found to be limited, since they are expensive, or ineffective and because of operational problems.

Studies on the treatment of effluent bearing heavy metal have revealed adsorption to be a highly effective technique for the removal of heavy metal from wastewater and activated carbon has been widely used as an adsorbent, because of the effectiveness for the removal of metal ions at trace quantities. But this process has not been used extensively for its high cost. Therefore, the use of low cost materials as sorbent for metal removal from wastewater has been highlighted.

In recent years, great effort has been contributed to the production of low cost alternatives to commercially available activated carbon. Agricultural by-products have been reported as having natural adsorbing and ion exchange capacity. The low cost agricultural waste by-products such as sugarcane bagasse (Chand *et al.*, 1994; Mohan and Singh, 2002; Khan *et al.*, 2001; Ayub *et al.*, 1998; Ayub *et al.*, 2001a; Ayub *et al.*, 2002), rice husk (Srinivasan *et al.*, 1998; Munaf and Zein, 1997; Ajmal *et al.*, 2003; Khan *et al.*, 2003a), saw dust (Ajmal *et al.*, 1996; Kadirvelu *et al.*, 2003; Selvi *et al.*, 2001), bagasse fly ash (Ali and Gupta, 2004), coconut husk (Chand *et al.*, 1994; Tan *et al.*, 1993), oil palm shell (Khan *et al.*, 2003b), neem bark (Ayub *et al.*, 2001b) and neem leaves (Gupta and Babu, 2006) for the elimination of heavy metals, from wastewater have been investigated by various researchers.

In general, an adsorbent can be termed as a low cost material if it requires little processing, is abundant in nature, or is a by-product or waste material from another industry and of course improved sorption capacity may compensate the cost of additional processing (Bailey *et al.*, 1999).

Therefore, there is an urgent need that all possible sources of agro-based inexpensive adsorbents should be explored for their feasibility for the removal of heavy metals. The use of natural waste materials like cotton (Robert and Rowland, 1973), walnut waste (Randall *et al.*, 1974), pea nut skins (Randall *et al.*, 1978), pea nut shell (Gonzo and Gonzo, 2005), sugarcane waste and onion skin (Kumar and Dara, 1980), coffee grounds, tea leaves, apple waste (Maranon and Sastre, 1991), wool fibre, green algae, rice hull, bark and other cellulosic material, cottonseed hull and rice straw are being proved to be promising adsorbents. These are used as low cost adsorbents because of low cost, high availability regeneration processes. These are widely used in the removal of metal ions in waste water.

Human hair, one of the adsorbents, was attempted for the removal of phenol from aqueous solutions (Banat and Al-Asheh, 2001). The present study was aimed for the removal of metal ions such as nickel(II) and chromium(VI) from synthetic metal solutions and from binary metal solution containing both nickel and chromium using human hair as adsorbent, due to its easy availability.

The results of the present study entitled “Adsorption of nickel(II) and chromium(VI) from synthetic metal solutions using powdered human hair as adsorbent” are presented and discussed as follows:

4.1 CHARACTERISTICS OF THE POWDERED HUMAN HAIR
4.2 ADSORPTION OF NICKEL(II) FROM SYNTHETIC NICKEL SOLUTION USING HUMAN HAIR
4.3 ADSORPTION OF CHROMIUM(VI) FROM SYNTHETIC NICKEL SOLUTION USING HUMAN HAIR
4.4 ADSORPTION OF NICKEL(II) AND CHROMIUM(VI) FROM BINARY METAL SOLUTION USING HUMAN HAIR
4.5 ADSORPTION ISOTHERM

4.1 CHARACTERISTICS OF THE POWDERED HUMAN HAIR

The ash content of human hair was 11.5%. According to Mahadevaswamy *et al.* (1998), the ash content of bagasse fly ash, lab grade activated carbon and commercial grade activated carbon were 30.98%, 2.65% and 8.78% respectively. Singh and Lal (1992) reported the ash content of tea leaf carbon as 8.63%.

The moisture content of the powdered hair was 1.5%. The bulk density was found to be 0.81g/ml. Periasamy *et al.* (1991) reported 0.42g/ml bulk density for groundnut husk carbon; 0.36g/ml for rice husk carbon was reported by Srinivasan *et al.* (1998); 0.14g/ml for coirpith carbon by Namasivayam and Kadirvelu (1998) and 0.34g/ml for palm seed coat carbon by Rengaraj *et al.* (2000).

The matter soluble in water and acid of the powdered human hair was found to be 0.09% and 0.21% respectively. According to Rengaraj *et al.* (2000), the percentage of matter soluble in water and matter soluble in acid were 0.65 and 1.21 respectively for palm seed coat carbon. Arulanantham *et al.* (1992) recorded the percentage of matter soluble in water and acid for coconut shell carbon as 1.32 and 2.25 respectively. In the present study, human hair was found to be acidic in nature (pH 5.4).

4.2 ADSORPTION OF NICKEL(II) FROM SYNTHETIC NICKEL SOLUTION USING HUMAN HAIR

Nickel is an essential element in animal nutrition and some microorganisms but at a higher level it is toxic causing dermatitis and its high occupational exposure has been associated with renal problems and lung cancer. Nickel is mainly used in the electroplating industry.

4.2.1 Effect of pH on nickel(II) adsorption

The adsorption of nickel(II) from synthetic nickel solution was found to be maximum at pH 6 (52.2%) and minimum at pH 8 (22.4%) and the levels were significantly different at all pH levels. Table 1 and Figure 2 present the influence of pH on nickel(II) adsorption by human hair.

TABLE 1
MEAN LEVELS OF NICKEL(II) IN THE SYNTHETIC SOLUTION AFTER ADSORPTION ON HUMAN HAIR AT DIFFERENT pH

pH	Nickel levels (mg/100ml)
4	12.02 (39.9)
5	11.18 (44.1)
6	9.56 (52.2)
7	11.00 (45.0)
8	15.52 (22.4)
CD(0.05)	0.063

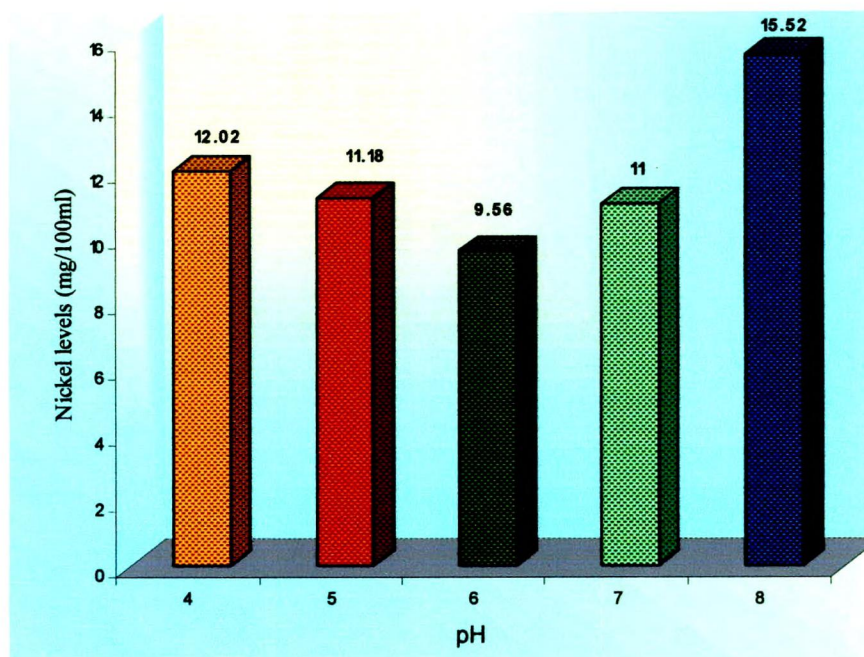
The values in parentheses denote percentage adsorption of nickel
Initial level of nickel in the synthetic solution: 20mg/100ml

Experimental condition

Dosage of adsorbent : 1g
Temperature : Room Temperature
Dilution : 1:1
Contact time : 4 hours

FIGURE 2

MEAN LEVELS OF NICKEL(II) IN THE SYNTHETIC SOLUTION AFTER ADSORPTION ON HUMAN HAIR AT DIFFERENT pH



According to Garg *et al.* (2007) the effect of pH on metal ion uptake was highest at pH 6 (59.7%) using sugarcane bagasse as an adsorbent. The maximum adsorption of Zn (II) was found to be at pH 6 using *Spirogyra sp.* (Singh, 2007a).

The percentage adsorption was found to increase with pH to attain a maximum at pH 6 and there after it decreased with further increase in pH (Meena *et al.*, 2008).

Kadirvelu *et al.* (2002) reported a maximum adsorption of nickel at pH 5 using activated carbon prepared from biomass as adsorbent.

4.2.2 Effect of temperature on nickel(II) adsorption

In the present study, the uptake of nickel(II) from synthetic metal solution was found to be maximum at 30°C (54.4%) and minimum at 20°C (19.35%) with significant difference ($P < 0.05$) at all temperature levels. The effect of temperature on nickel(II) adsorption by human hair is shown in Table 2 and Figure 3.

TABLE 2

MEAN LEVELS OF NICKEL(II) IN THE SYNTHETIC SOLUTION AFTER ADSORPTION ON HUMAN HAIR AT DIFFERENT TEMPERATURE

TEMPERATURE (°C)	Nickel levels (mg/100ml)
20	16.13 (19.35)
25	12.16 (39.20)
30	9.12 (54.44)
35	13.89 (30.55)
40	15.85 (20.75)
CD(0.05)	0.025

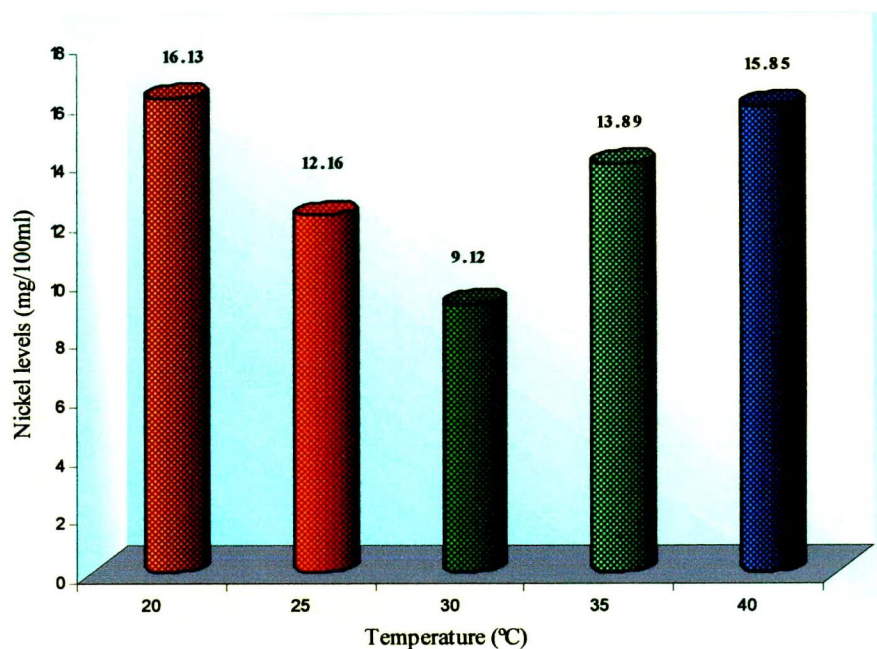
The values in parentheses denote percentage adsorption of nickel
Initial level of nickel in the synthetic solution: 20mg/100ml

Experimental condition

Dosage of adsorbent : 1g
pH : 6
Dilution : 1:1
Contact time : 4 hours

FIGURE 3

MEAN LEVELS OF NICKEL(II) IN THE SYNTHETIC SOLUTION AFTER ADSORPTION ON HUMAN HAIR AT DIFFERENT TEMPERATURE



Banat and Al-Asheh (2000), reported an increased uptake of phenol at room temperature using chicken feather as adsorbent. Kadirvelu *et al.* (2001b) reported a maximum adsorption of Ni(II) from aqueous solution at 30°C using coirpith.

Mohan and Singh (2002) reported that uptake of cadmium was found to be slightly greater than that of zinc and the adsorption capacity increased with increase in temperature.

4.2.3 Effect of adsorbent dosage on nickel(II) adsorption

The effect of adsorbent dosage on nickel(II) adsorption by human hair is shown in Table 3 and Figure 4.

The removal of nickel from synthetic solution was found to be maximum with 1g (57.1%) of the adsorbent and minimum with 4g (10.05%) of the adsorbent. There was significant difference in adsorption of nickel(II) ($P < 0.05$) at all dose of adsorbents.

Dadhich *et al.* (2004) found an increase in percentage reduction with continuous increase in adsorbent dosage which might be attributed to the fact that the surface area available for the adsorption also increased.

Removal of Cr(VI), Ni²⁺, Cu²⁺ and Pb²⁺ ions increased with increase in the dose of adsorbents (Rao *et al.*, 2003). The adsorption of nickel(II) was found to increase with increase the dose of adsorbents (Mukherjee *et al.*, 2006).

According to Garg *et al.* (2007) the percentage of Ni (II) removal increased with increase in adsorbent dose. A maximum of 59.7% adsorption was reported with 2500mg adsorbent dose.

TABLE 3

MEAN LEVELS OF NICKEL(II) IN THE SYNTHETIC SOLUTION AFTER ADSORPTION ON HUMAN HAIR WITH DIFFERENT DOSAGE OF ADSORBENT

Dose of adsorbent (g)	Nickel levels (mg/100ml)
1	8.58 (57.10)
2	17.76 (11.20)
3	17.58 (12.35)
4	17.99 (10.05)
5	17.76 (11.20)
CD(0.05)	0.140

The values in parentheses denote percentage adsorption of nickel

Initial level of nickel in the synthetic solution: 20mg/100ml

Experimental condition

Temperature : Room Temperature

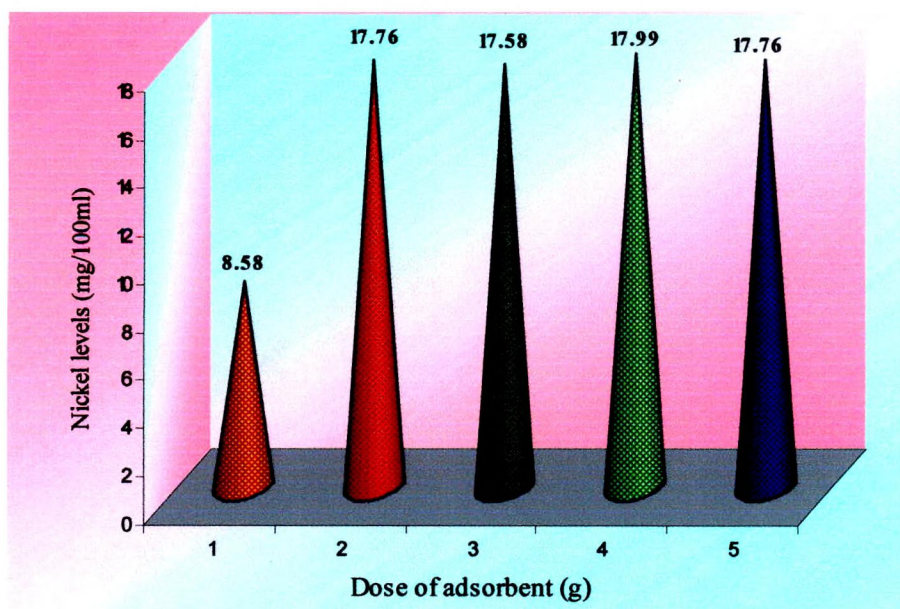
pH : 6

Dilution : 1:1

Contact time : 4 hours

FIGURE 4

MEAN LEVELS OF NICKEL(II) IN THE SYNTHETIC SOLUTION AFTER ADSORPTION ON HUMAN HAIR WITH DIFFERENT DOSAGE OF ADSORBENT



4.2.4 Effect of initial concentration on nickel(II) adsorption

The initial concentrations of nickel in synthetic metal solution were 10mg/100ml (1:1), 6.67mg/100ml (1:2), 5mg/100ml (1:3), 13.33mg/100ml (2:1) and 15mg/100ml (3:1). The influence of dilutions of the synthetic solution on the extent of adsorption of nickel is shown in Table 4 and Figure 5.

In the present study, the adsorption of nickel from synthetic solution was found to be maximum at 1:1 (55.25%) and minimum at 3:1 (13.1%) dilutions. There was significant difference in adsorption of nickel ($P < 0.05$) at all dilutions.

TABLE 4
MEAN LEVELS OF NICKEL(II) IN THE SYNTHETIC SOLUTION AFTER
ADSORPTION ON HUMAN HAIR AT DIFFERENT INITIAL CONCENTRATIONS
OF NICKEL

Dilution	Concentration of nickel (mg/100ml)	Nickel levels (mg/100ml)
1:1	10.00	4.48 (55.25)
1:2	6.67	3.72 (44.30)
1:3	5.00	3.83 (23.55)
2:1	13.33	11.34 (14.90)
3:1	15.00	13.04 (13.10)
CD(0.05)	0.019	

The values in parentheses denote percentage adsorption of nickel

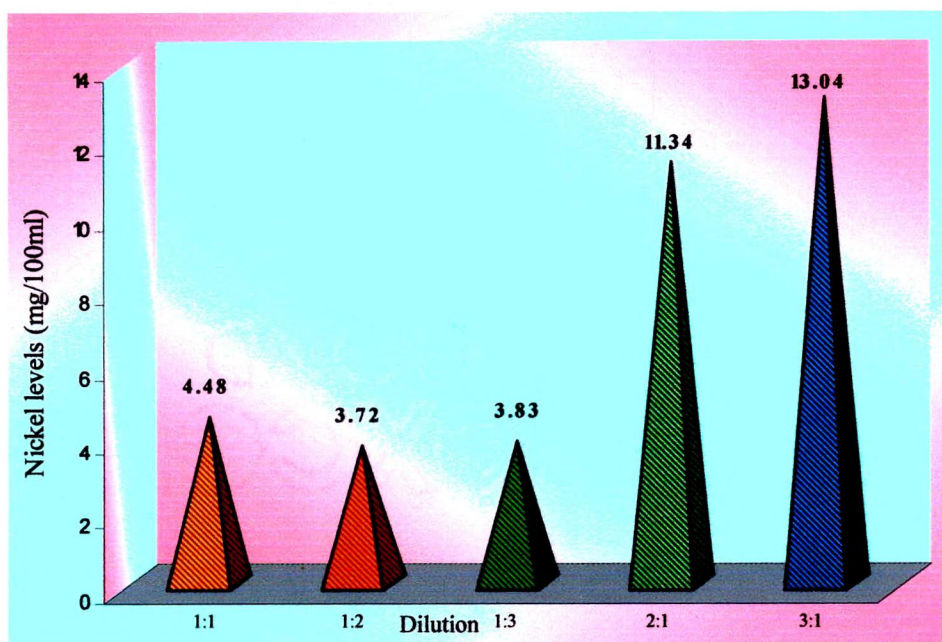
Experimental condition

Dosage of adsorbent : 1g
Temperature : Room Temperature
pH : 6
Contact time : 4 hours

Saeed *et al.* (2005b) reported that the biosorption of metal ions by black gram husk was found to increase as the initial metal concentration increased.

Ranganathan (2000) had studied on heavy metal adsorption by activated carbons prepared from *Casurina equisetifolia* leaves who concluded a maximum adsorption obtained in the initial metal concentration level i.e. with 1:1 dilution.

FIGURE 5
MEAN LEVELS OF NICKEL(II) IN THE SYNTHETIC SOLUTION AFTER ADSORPTION ON HUMAN HAIR AT DIFFERENT INITIAL CONCENTRATIONS OF NICKEL



Roy *et al.* (1993) studied on adsorption of heavy metals by green algae and ground rice hulls. They concluded that, metal adsorption increased as the initial metal concentration increased.

4.2.5 Effect of contact time on nickel(II) adsorption

Removal of nickel from synthetic solution at different contact time is shown in Table 5 and Figure 6.

The adsorption of nickel(II) was found to be maximum at 75 minutes (52.68%) and minimum at 15 minutes (20.75%) contact time. There was significant difference in adsorption of nickel ($P < 0.05$) at all contact time.

Garg *et al.* (2007) reported that the adsorption of metal ion increased with the increase in contact time. The percentage adsorption was 59.7% and after 60 minutes adsorption increase was not significant.

TABLE 5

MEAN LEVELS OF NICKEL(II) IN THE SYNTHETIC SOLUTION AFTER ADSORPTION ON HUMAN HAIR AT DIFFERENT TIME OF CONTACT

Time of Contact (min)	Nickel levels (mg/100ml)
15	15.85 (20.75)
30	14.78 (26.10)
45	15.19 (24.05)
60	14.45 (27.75)
75	9.46 (52.68)
CD(0.05)	0.081

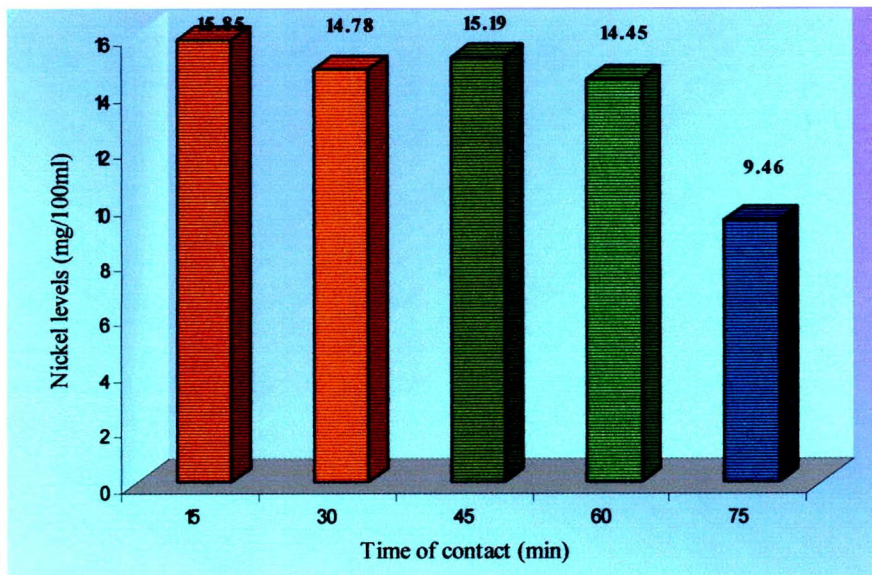
The values in parentheses denote percentage adsorption of nickel
Initial level of nickel in the synthetic solution: 20mg/100ml

Experimental condition

Temperature : Room Temperature
pH : 6
Dosage of adsorbent : 1g
Dilution : 1:1

FIGURE 6

MEAN LEVELS OF NICKEL(II) IN THE SYNTHETIC SOLUTION AFTER ADSORPTION ON HUMAN HAIR AT DIFFERENT TIME OF CONTACT



The effect of contact time on adsorption was studied and the results revealed that equilibrium time was obtained after 300 minutes at which 94% reduction was observed (Dadhich *et al.*, 2004). Nomanbhay and Palanisamy (2005) reported that removal efficiency increased with an increase in contact time before equilibrium is reached.

4.3 ADSORPTION OF CHROMIUM(VI) FROM SYNTHETIC NICKEL SOLUTION USING HUMAN HAIR

Chromium has both beneficial and detrimental properties. Cr(III) is essential in human nutrition. Most of the hexavalent compounds are toxic. Several of them can even cause lung cancer. While Cr(III) is relatively innocuous and immobile, Cr(VI) moves readily through soils and aquatic environments and is a strong oxidizing agent capable of being adsorbed through the skin (Park and Jung, 2001). Chromium and its compounds are widely used in electroplating, leather tanning, cement, dyeing, metal processing, wood preservatives, paint and pigments, textile, steel fabrication and canning industries.

4.3.1 Effect of pH on chromium(VI) adsorption

The effect of pH on adsorption of chromium by human hair from the synthetic solution is shown in Table 6 and Figure 7.

The uptake of free ionic chromium depends on pH, where optimal metal removal efficiency occurred at pH 4 (74%) declining at higher pH. The removal of chromium was found to be minimum at pH 8 (37.55%). There was a significant difference in adsorption of chromium ($P < 0.05$) at all pH levels.

Sharma and Bhattacharya (2004) reported that the adsorption of Cr(VI) was maximum in the pH range 4.5 to 7.5 using neem leaf powder. The adsorption of chromium(VI) was found to be maximum at low values of pH in the range of 1 to 3. The percentage adsorption of chromium(VI) was found to be decrease with increasing pH (Gupta and Babu, 2007).

TABLE 6
MEAN LEVELS OF CHROMIUM(VI) IN THE SYNTHETIC SOLUTION AFTER
ADSORPTION ON HUMAN HAIR AT DIFFERENT pH

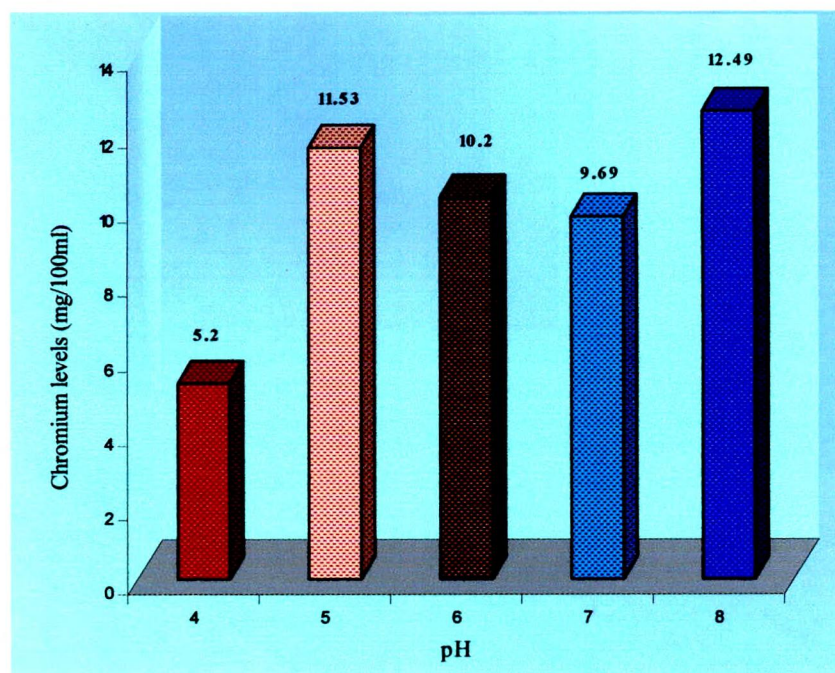
pH	Chromium levels (mg/100ml)
4	5.20 (74.00)
5	11.53 (42.35)
6	10.20 (49.00)
7	9.69 (51.55)
8	12.49 (37.55)
CD(0.05)	0.003

The values in parentheses denote percentage adsorption of chromium
 Initial level of chromium in the synthetic solution: 20mg/100ml

Experimental condition

Dosage of adsorbent : 1g
 Temperature : Room Temperature
 Dilution : 1:1
 Contact time : 4 hours

FIGURE 7
MEAN LEVELS OF CHROMIUM(VI) IN THE SYNTHETIC SOLUTION AFTER
ADSORPTION ON HUMAN HAIR AT DIFFERENT pH



Baisakh and Patnaik (2002) recorded an increased rate of Cr(VI) removal at lower pH. Pandey *et al.* (2007) reported that the maximum uptake of Cr(VI), Pb(II) and Cu(II) was obtained at pH 2. Above this pH, biosorption of metal ions by calcium alginate beads was found to be relatively constant for Pb(II) and Cu(II) ions and biosorption of Cr(VI) still increased upto pH 3 having 86% removal efficiently.

4.3.2 Effect of temperature on chromium(VI) adsorption

The effect of temperature on the adsorption of chromium is shown in Table 7 and Figure 8. In the present study, removal of chromium(VI) from synthetic solution was found to be maximum at 30°C (76.8%) and minimum at 35°C (52.55%). There was a significant difference in adsorption of chromium ($P < 0.05$) at all temperature levels.

TABLE 7
MEAN LEVELS OF CHROMIUM(VI) IN THE SYNTHETIC SOLUTION AFTER ADSORPTION ON HUMAN HAIR AT DIFFERENT TEMPERATURE

TEMPERATURE (°C)	Chromium levels (mg/100ml)
20	8.42 (57.90)
25	6.53 (67.35)
30	4.64 (76.80)
35	9.49 (52.55)
40	9.29 (53.57)
CD(0.05)	0.069

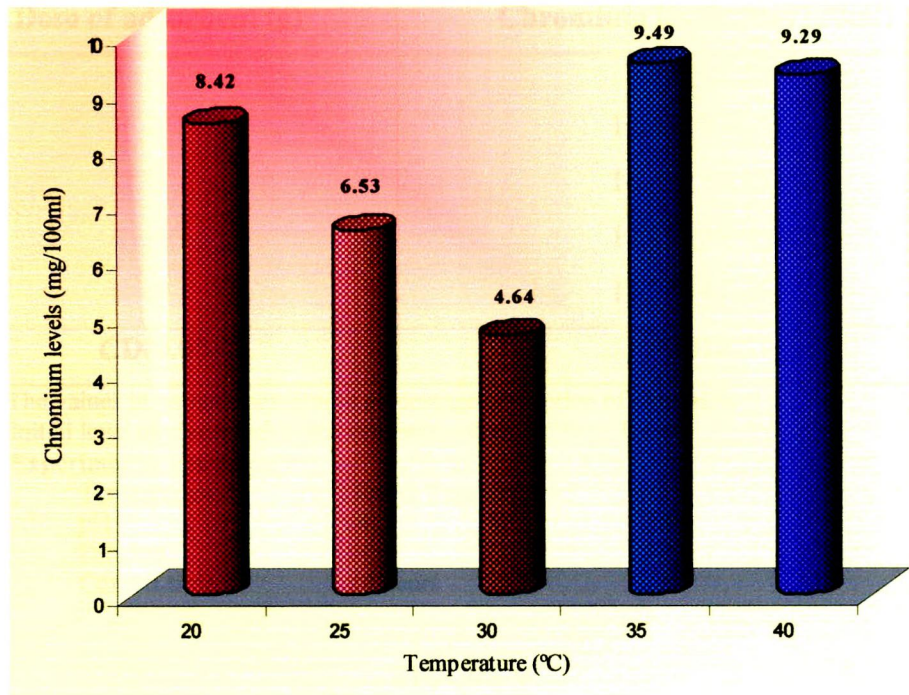
The values in parentheses denote percentage adsorption of chromium
Initial level of chromium in the synthetic solution: 20mg/100ml

Experimental condition

Dosage of adsorbent : 1g
pH : 4
Dilution : 1:1
Contact time : 4 hours

Hossain *et al.* (2005) reported that the adsorption of metal ion was found to be maximum at 50°C with increase or decrease in temperature resulting in a decrease in the metal ions uptake capacity using black tea leaves.

FIGURE 8
MEAN LEVELS OF CHROMIUM(VI) IN THE SYNTHETIC SOLUTION AFTER ADSORPTION ON HUMAN HAIR AT DIFFERENT TEMPERATURE



The maximum adsorption of Cr(VI) was found to be at 30°C. A further increase in temperature seemed to result in a decrease in the adsorption capacity (Gupta *et al.*, 1999). The adsorption of Cu using wheat bran decreased from 94 to 81% with a rise of temperature from 20°C to 40°C (Singh *et al.*, 2004).

4.3.3 Effect of dosage of adsorbent on chromium(VI) adsorption

The effect of adsorbent dosage on the adsorption of chromium from the synthetic solution is shown in Table 8 and Figure 9.

In the present study, adsorption of chromium(VI) from synthetic metal solution was found to be maximum with 1g (72.35%) and minimum with 3g (17.85%) of the adsorbent. There was a significant difference in adsorption of chromium ($P < 0.05$) at all dose of adsorbent levels.

TABLE 8

MEAN LEVELS OF CHROMIUM(VI) IN THE SYNTHETIC SOLUTION AFTER ADSORPTION ON HUMAN HAIR WITH DIFFERENT DOSAGE OF ADSORBENT

Dose of adsorbent (g)	Chromium levels (mg/100ml)
1	5.53 (72.35)
2	14.49 (27.55)
3	16.43 (17.85)
4	12.19 (39.05)
5	11.73 (41.35)
CD(0.05)	0.018

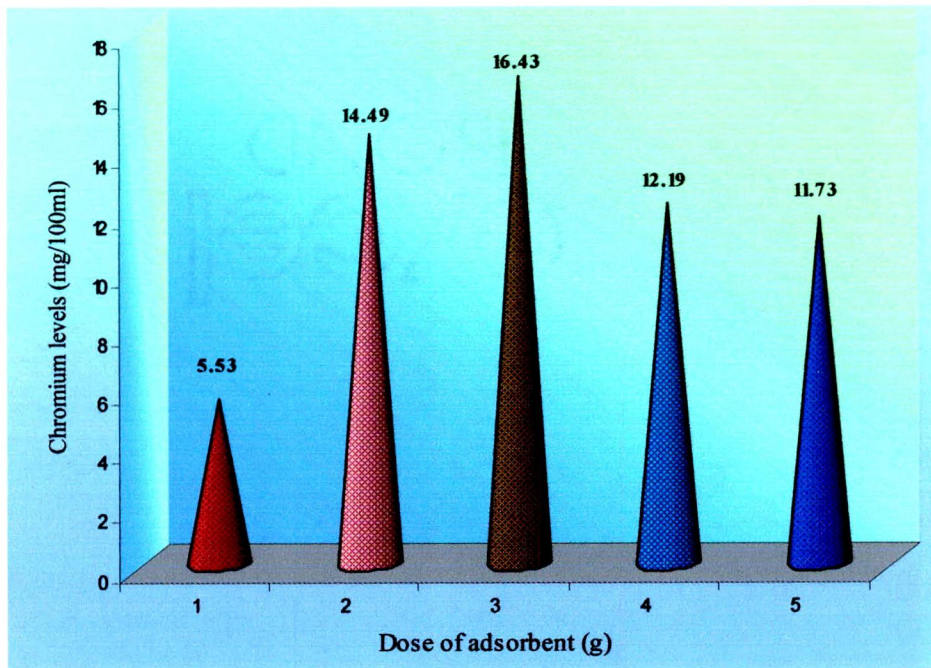
The values in parentheses denote percentage adsorption of chromium
Initial level of chromium in the synthetic solution: 20mg/100ml

Experimental condition

Temperature : Room Temperature
pH : 4
Dilution : 1:1
Contact time : 4 hours

FIGURE 9

MEAN LEVELS OF CHROMIUM(VI) IN THE SYNTHETIC SOLUTION AFTER ADSORPTION ON HUMAN HAIR WITH DIFFERENT DOSAGE OF ADSORBENT



Adsorption of Cr(VI) per unit mass increased gradually with increase in Cr(VI) concentration for a constant adsorbent amount (Sharma and Bhattacharya, 2004). The maximum adsorption of Cr(III) was found to be at 2g using bone charcoal (Dahbi *et al.*, 2002).

Gupta and Babu (2007) reported that the removal of chromium(VI) increased with increase in the adsorbent dosage. The percentage removal increased from 49 to 95% by increasing the adsorbent dosage.

4.3.4 Effect of initial concentration on chromium(VI) adsorption

The initial concentrations of chromium in synthetic metal solution were 10mg/100ml (1:1), 6.67mg/100ml (1:2), 5.0mg/100ml (1:3), 13.33mg/100ml (2:1) and 15mg/100ml (3:1). The influence of dilutions of the synthetic solution on the extent of adsorption of chromium is shown in Table 9 and Figure 10.

In the present study, adsorption of chromium from synthetic solution was found to be maximum at 1:1 (74%) and minimum at 3:1 (26.3%) dilutions. There was a significant difference in adsorption of chromium ($P < 0.05$) at all dilutions.

Baral *et al.* (2008) observed that the percentage adsorption increased when the concentration of metal solution decreased.

The percentage removal of chromium(VI) around 97% was observed with 1:2 impregnated activated carbon at pH 3 (Neelavathi *et al.*, 2004).

Kaya and Oren (2005) reported that the removal of zinc was found to increase when the initial metal ion concentration was increased.

TABLE 9

MEAN LEVELS OF CHROMIUM(VI) IN THE SYNTHETIC SOLUTION AFTER ADSORPTION ON HUMAN HAIR AT DIFFERENT INITIAL CONCENTRATIONS OF CHROMIUM

Dilution	Concentration of chromium (mg/100ml)	Chromium levels (mg/100ml)
1:1	10.00	2.60 (74.00)
1:2	6.67	2.11 (68.35)
1:3	5.00	1.82 (63.60)
2:1	13.33	8.51 (36.20)
3:1	15.00	11.06 (26.30)
CD(0.05)	0.009	

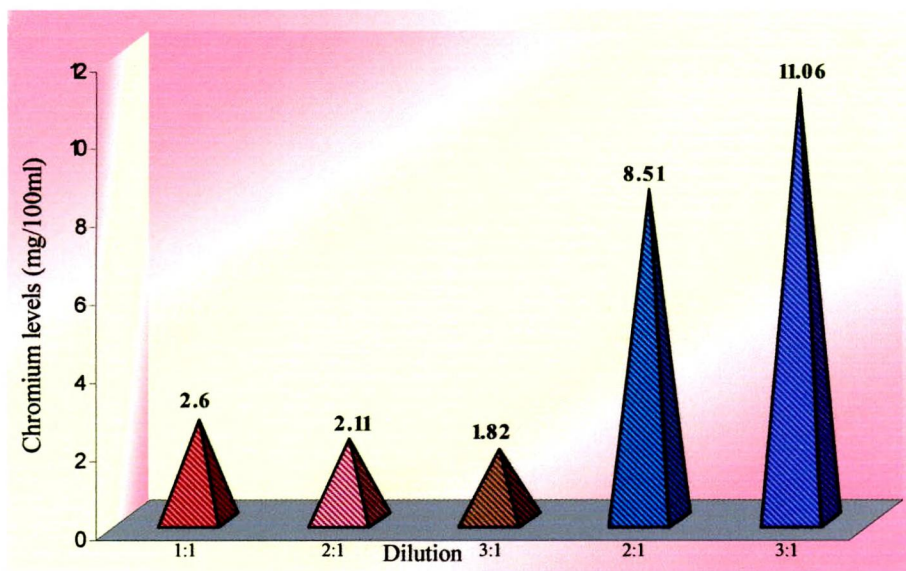
The values in parentheses denote percentage adsorption of chromium

Experimental condition

Dosage of adsorbent : 1g
 Temperature : Room Temperature
 pH : 4
 Contact time : 4 hours

FIGURE 10

MEAN LEVELS OF CHROMIUM(VI) IN THE SYNTHETIC SOLUTION AFTER ADSORPTION ON HUMAN HAIR AT DIFFERENT INITIAL CONCENTRATIONS OF CHROMIUM



4.3.5 Effect of contact time on chromium(VI) adsorption

The effect of contact time of the adsorbent with the synthetic solution on the extent of adsorption of chromium is shown in Table 10 and Figure 11.

The adsorption of chromium from the synthetic metal solution was found to be maximum at 75 min (56.89%) and minimum at 30 min (10.95%) contact time. There was a significant difference in adsorption of chromium ($P < 0.05$) at all contact time.

The removal of chromium at different concentrations of adsorbent takes place in two stages. The first stage of solute uptake, the 'immediate solute removal' was obtained within first two hours and the 'subsequent removal', continued for a longer period of time (Gupta *et al.*, 1999).

TABLE 10
MEAN LEVELS OF CHROMIUM(VI) IN THE SYNTHETIC SOLUTION AFTER ADSORPTION ON HUMAN HAIR AT DIFFERENT TIME OF CONTACT

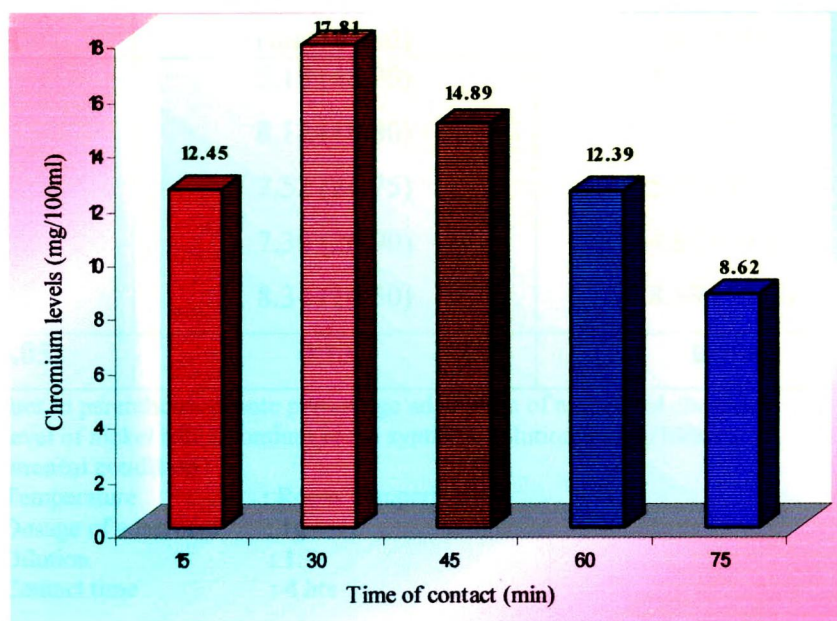
Time of Contact (min)	Chromium levels (mg/100ml)
15	12.45 (37.75)
30	17.81 (10.95)
45	14.89 (25.55)
60	12.39 (38.05)
75	8.62 (56.89)
CD(0.05)	0.020

The values in parentheses denote percentage adsorption of chromium
Initial level of chromium in the synthetic solution: 20mg/100ml

Experimental condition

Temperature : Room Temperature
pH : 4
Dosage of adsorbent : 1g
Dilution : 1:1

FIGURE 11
MEAN LEVELS OF CHROMIUM(VI) IN THE SYNTHETIC SOLUTION AFTER ADSORPTION ON HUMAN HAIR AT DIFFERENT TIME OF CONTACT



Hassan *et al.* (2006) reported that the removal of chromium was increased with increase in the contact time using sorel's cement. According to Akhtar *et al.* (2006), percent sorption of phenol increased from 26 to 97% at a contact time of 10 minutes using rice husk.

4.4 ADSORPTION OF NICKEL(II) AND CHROMIUM(VI) FROM BINARY METAL SOLUTION USING HUMAN HAIR

The synthetic binary metal solution (Ni & Cr) was prepared to see the interference in the adsorption of one metal ion in the presence of the other metal ion.

4.4.1 Effect of pH on adsorption of nickel(II) and chromium(VI) from binary metal solution

The effect of pH of the synthetic binary solution on the extent of adsorption of nickel(II) and chromium(VI) is shown in Table 11 and Figure 12.

TABLE 11

ADSORPTION OF NICKEL(II) AND CHROMIUM(VI) FROM SYNTHETIC BINARY METAL SOLUTION AT DIFFERENT pH USING HUMAN HAIR

pH	Nickel levels (mg/100ml)	Chromium levels (mg/100ml)
4	5.18 (48.20)	4.51 (54.90)
5	8.12 (18.80)	7.15 (28.50)
6	7.52 (24.75)	5.93 (40.70)
7	7.30 (26.90)	4.96 (50.40)
8	8.34 (16.50)	8.39 (16.10)
CD(0.05)	0.132	0.106

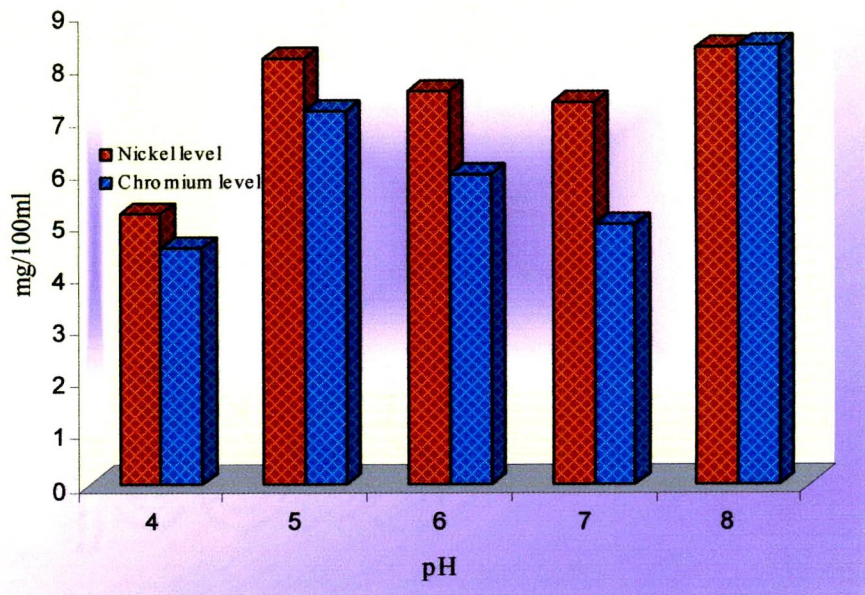
The values in parentheses denote percentage adsorption of nickel and chromium
Initial level of nickel and chromium in the synthetic solution: 10mg/100ml

Experimental condition

Temperature : Room Temperature
Dosage of adsorbent : 1g
Dilution : 1:1
Contact time : 4 hrs

FIGURE 12

ADSORPTION OF NICKEL(II) AND CHROMIUM(VI) FROM SYNTHETIC BINARY METAL SOLUTION AT DIFFERENT pH USING HUMAN HAIR



In the present study, the removal of both nickel and chromium from binary metal solution was found to maximum at pH 4 for nickel (48.2%) and chromium (54.9%), minimum at pH 8 for both nickel and chromium. There was a significant difference in adsorption of chromium ($P < 0.05$) at all pH levels.

Seng *et al.* (2001) reported that the maximum adsorption capacities of Cr(VI) and Ni(II) ions were obtained at lower pH level.

4.4.2 Effect of temperature on the adsorption of nickel(II) and chromium(VI) from binary metal solution

The effect of temperature on the adsorption of nickel and chromium from the synthetic metal solution is shown in Table 12 and Figure 13.

TABLE 12
ADSORPTION OF NICKEL(II) AND CHROMIUM(VI) FROM SYNTHETIC BINARY METAL SOLUTION AT DIFFERENT TEMPERATURE USING HUMAN HAIR

TEMPERATURE (°C)	Nickel levels (mg/100ml)	Chromium levels (mg/100ml)
20	9.43 (05.68)	6.91 (30.92)
25	7.85 (21.50)	6.85 (31.50)
30	4.37 (56.30)	4.26 (57.40)
35	9.21 (07.92)	8.87 (11.20)
40	8.92 (10.83)	9.09 (09.10)
CD(0.05)	0.056	0.048

The values in parentheses denote percentage adsorption of nickel and chromium
Initial level of nickel and chromium in the synthetic solution: 10mg/100ml

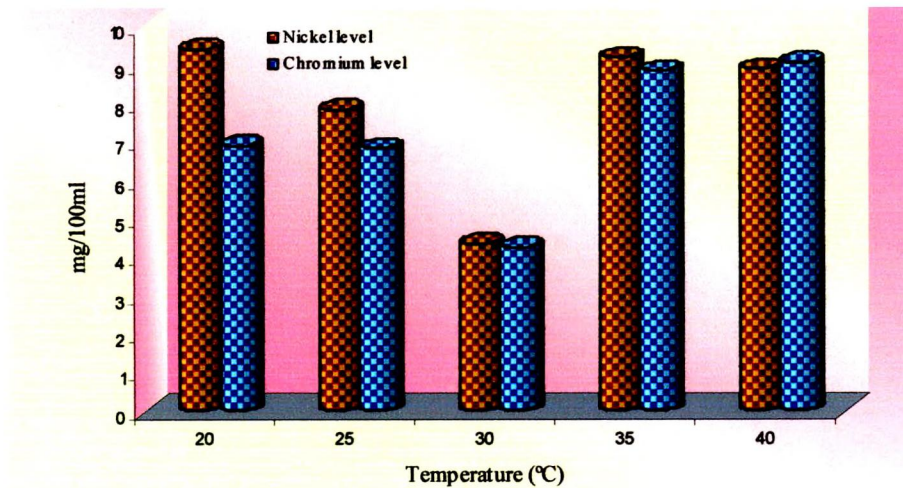
Experimental condition

pH : 4
Dosage of adsorbent : 1g
Dilution : 1:1
Contact time : 4 hrs

Removal of both nickel and chromium from binary synthetic solution was found to be maximum at 30°C for nickel (50.3%) and chromium (57.4%) and minimum at 20°C for nickel (5.68%) and 40°C for chromium (9.1%). There was a significant difference in adsorption of chromium ($P < 0.05$) at all temperature levels.

FIGURE 13

ADSORPTION OF NICKEL(II) AND CHROMIUM(VI) FROM SYNTHETIC BINARY METAL SOLUTION AT DIFFERENT TEMPERATURE USING HUMAN HAIR



Heavy metal resistant fungi and bacteria were isolated from the soil samples of an electroplating industry and the optimum pH and temperature conditions for the removal of Cr(VI) and Ni(II) ions were determined for each isolate (Congeevaram *et al.*, 2007).

4.4.3 Effect of dosage of adsorbent on adsorption of nickel(II) and chromium(VI) from binary metal solution

The effect of adsorbent dosage on the adsorption of nickel and chromium from synthetic binary metal solution is shown in Table 13 and Figure 14.

The maximum adsorption of nickel(II) and chromium(VI) from binary synthetic solution was found to be 1g of human hair for nickel (56.9%) and chromium (76.67%), minimum with 4g for nickel (13.8%) and chromium (16.1%). There was a significant difference in adsorption of chromium ($P < 0.05$) at all doses of adsorbent levels.

TABLE 13

ADSORPTION OF NICKEL(II) AND CHROMIUM(VI) FROM SYNTHETIC BINARY METAL SOLUTION USING DIFFERENT DOSES OF HUMAN HAIR AS ADSORBENT

Dose of adsorbent (g)	Nickel levels (mg/100ml)	Chromium levels (mg/100ml)
1	4.31 (56.90)	2.33 (76.67)
2	5.51 (44.90)	5.36 (46.37)
3	8.14 (18.60)	6.94 (30.61)
4	8.62 (13.80)	8.39 (16.10)
5	8.52 (14.80)	6.82 (31.83)
CD(0.05)	0.054	0.043

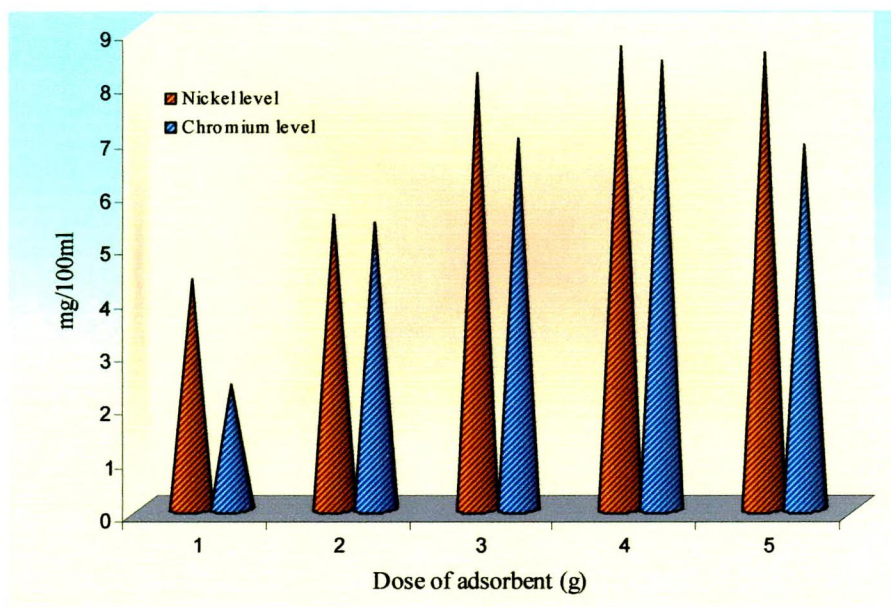
The values in parentheses denote percentage adsorption of nickel and chromium
Initial level of nickel and chromium in the synthetic solution: 10mg/100ml

Experimental condition

Temperature : Room Temperature
pH : 4
Dilution : 1:1
Contact time : 4 hrs

FIGURE 14

ADSORPTION OF NICKEL(II) AND CHROMIUM(VI) FROM SYNTHETIC BINARY METAL SOLUTION USING DIFFERENT DOSES OF HUMAN HAIR AS ADSORBENT



4.4.4 Effect of initial concentration of nickel(II) and chromium(VI) on their adsorption in synthetic binary metal solution

The effect of dilution of the synthetic binary metal solution on the extent of adsorption of nickel and chromium is shown in Table 14 and Figure 15.

The removal of both nickel and chromium from binary metal solution was found to be maximum with 1:1 dilution for both nickel (59.3%) and chromium (78.2%), minimum with 3:1 for nickel and chromium dilution. There was a significant difference in adsorption of chromium ($P < 0.05$) at all dilutions.

TABLE 14
ADSORPTION OF NICKEL(II) AND CHROMIUM(VI) FROM SYNTHETIC BINARY METAL SOLUTION AT DIFFERENT DILUTIONS USING HUMAN HAIR AS ADSORBENT

Dilution	Initial concentration of each metal (mg/100ml)	Nickel levels (mg/100ml)	Chromium levels (mg/100ml)
1:1	10.00	4.07 (59.30)	4.48 (55.20)
1:2	3.33	1.38 (58.60)	1.54 (53.90)
1:3	2.50	1.05 (58.43)	1.63 (34.90)
2:1	6.67	4.87 (26.98)	5.86 (12.20)
3:1	7.50	6.17 (17.71)	6.82 (09.10)
CD(0.05)	0.018		0.001

The values in parentheses denote percentage adsorption of nickel and chromium

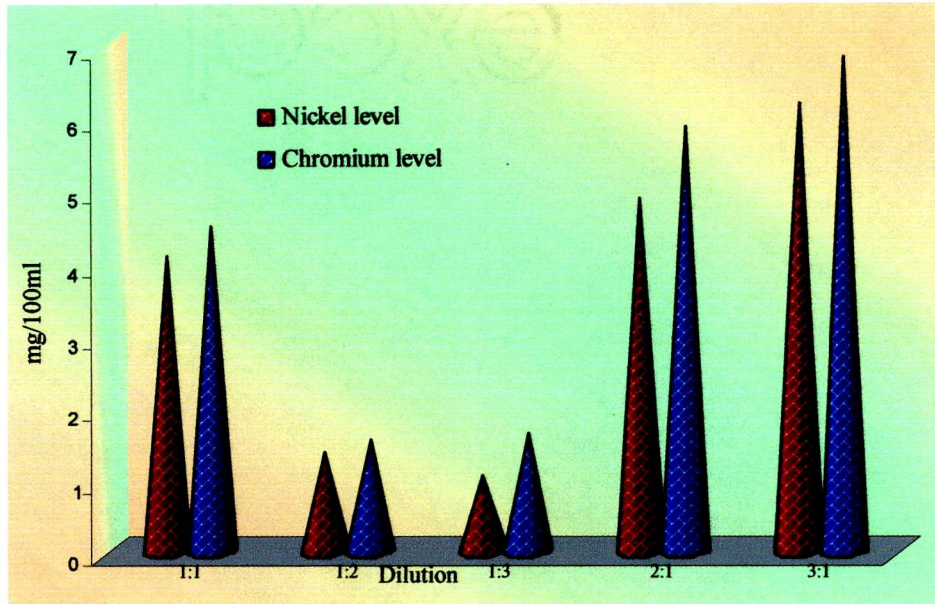
Experimental condition

pH : 4
 Temperature : Room Temperature
 Dosage of adsorbent : 1g
 Contact time : 4 hrs

Kovacevic et al. (2000) reported that the presence of chloride ions significantly decreased the biosorption efficiency of Cu^{2+} , Zn^{2+} , Ni^{2+} and CrO_4^{2-} .

FIGURE 15

ADSORPTION OF NICKEL(II) AND CHROMIUM(VI) FROM SYNTHETIC BINARY METAL SOLUTION AT DIFFERENT DILUTIONS USING HUMAN HAIR AS ADSORBENT



4.4.5 Effect of contact time on adsorption of nickel(II) and chromium(VI) from synthetic binary metal solution

The effect of contact time on the adsorption of nickel and chromium from synthetic binary metal solution is shown in Table 15 and Figure 16.

The adsorption of nickel(II) and chromium(VI) from binary metal solution was found to be maximum at 75 minutes for both nickel (63.1%) and chromium (66.4%), minimum at 15 minutes for nickel (27.6%) and 45 minutes for chromium (39.4%). There was a significant difference in adsorption of chromium ($P < 0.05$) at all contact time levels.

Quintelas and Tarvares (2001) reported efficient removal of Cr(VI) and Cd(II) from solutions with initial concentrations between 4 – 11 mg/l and a flow residence time of 1.2 minutes.

TABLE 15

ADSORPTION OF NICKEL(II) AND CHROMIUM(VI) FROM SYNTHETIC BINARY METAL SOLUTION AT DIFFERENT CONTACT TIME USING HUMAN HAIR

Time of contact (min)	Nickel levels (mg/100ml)	Chromium levels (mg/100ml)
15	7.24 (27.60)	8.03 (19.70)
30	5.57 (44.33)	5.58 (44.25)
45	3.92 (60.82)	6.06 (39.40)
60	4.60 (53.95)	5.82 (41.82)
75	3.69 (63.10)	3.76 (66.40)
CD(0.05)	0.173	0.097

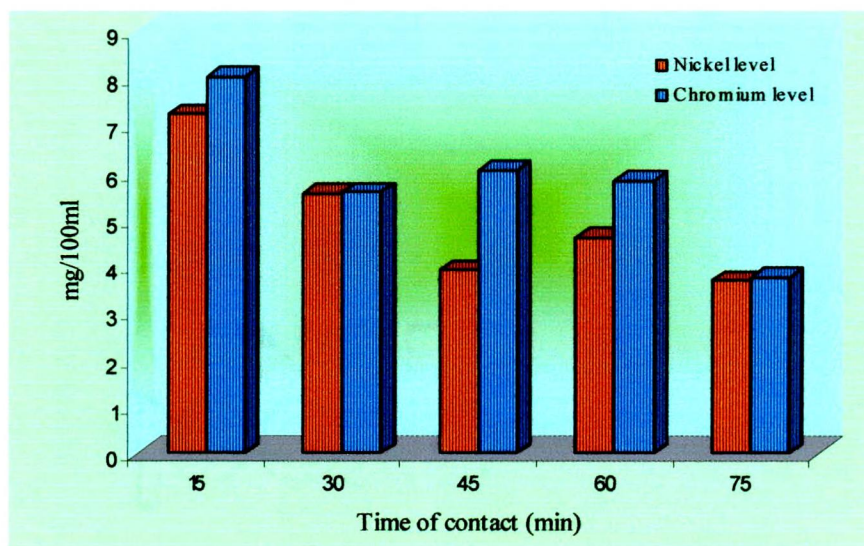
The values in parentheses denote percentage adsorption of nickel and chromium
Initial level of nickel and chromium in the synthetic solution: 10mg/100ml

Experimental condition

pH : 4
Temperature : Room Temperature
Dosage of adsorbent : 1g
Dilution : 1:1

FIGURE 16

ADSORPTION OF NICKEL(II) AND CHROMIUM(VI) FROM SYNTHETIC BINARY METAL SOLUTION AT DIFFERENT CONTACT TIME USING HUMAN HAIR



4.5 ADSORPTION ISOTHERM

The adsorption equilibrium data obtained for the removal of nickel(II) and chromium(VI) using human hair was analyzed using Freundlich and Langmuir equations.

The Freundlich isotherm theory explains that the ratio of the amount of solute adsorbed on to a given mass of sorbent to the concentration of the solute in the solution is not a constant at different solution concentrations. The Langmuir isotherm is valid for monolayer sorption on a surface containing a finite number of binding sites. The treatment assumes uniform energies of sorbate in the plane of the surface (Brown *et al.*, 2000).

Tables 16, 17, 18 and 19 show the different initial concentration of nickel(II) and chromium(VI) with a constant adsorbent dose of 1g fitted to linearised Freundlich and Langmuir adsorption isotherm. The linearised form of equation is

$$\log x/m = \log k_f + 1/n \log C_e$$

where, x/m is the amount of the metal sorbed per unit weight of sorbent (mg/g), k_f is the measure of sorption capacity, $1/n$ is the measure of sorption intensity,

C_e is the equilibrium concentration of the residual metal ions in solution (Ramu *et al.*, 1992).

The linear plots of $\log 1/n$ versus C_e suggest the applicability of the Freundlich model for nickel(II) and chromium(VI) sorption. Fig 17 shows the plot of $\log x/m$ versus $\log C_e$ for nickel(II), chromium(VI) and binary metal ions [Ni(II), Cr(VI)]. Fig 18 shows the plot of $1/(x/m)$ versus $1/C_e$ for nickel(II), chromium(VI) and binary metal ions [Ni(II), Cr(VI)] removal using human hair.

The values of $1/n$ less than 1 are indicative of favourable adsorption (Anirudhan and Sreedhar, 1999). In the present investigation, the values of $1/n$ were found to be less than 1, which suggests the favourable adsorption behaviour of nickel(II) and chromium(VI) on human hair.

Shukla *et al.* (2006) observed the value of $1/n$ less than 1 in their adsorption studies with modified coir fibres for the removal of Ni(II), Zn(II) and Fe(II), which indicated a favourable adsorption.

The linear plots of $1/(x/m)$ versus $1/C_e$ suggest the applicability of the Langmuir model, which is in the form.

$$1/(x/m) = 1/q_0 + 1/q_0(b) \times 1/C_e$$

where, x/m is the amount of nickel and chromium adsorbed at equilibrium (mg/g), q_0 and b are Langmuir constants related to the adsorption capacity and equilibrium constant respectively (Swamy *et al.*, 1998). The constants b and q_0 can be evaluated from the intercept and slope of the linear plot of the experimental data of $1/(x/m)$ versus $1/C_e$, respectively (Nagda *et al.*, 2007).

Based on the correlation coefficients (r), the equilibrium data was slightly better fitted in the Freundlich adsorption isotherm than the Langmuir equation. The higher value of k_f , the Freundlich constant, showed easy uptake of phenol from aqueous solution as reported by Khalid *et al.* (2000). The higher value of n reflects the intensity of adsorption which signifies that the surface of biosorbents is heterogenous in nature and high enough for effective separation.

In the present study, the correlation coefficient (r) obtained by the regression analysis of Langmuir isotherm were -0.02, -0.91, 0.73 and -0.23 determined for nickel(II) and chromium(VI) in the experimental solutions, both in the respective synthetic metal solutions and in the binary metal solution.

Siddiqui *et al.* (1999) showed that the adsorption data for Zn^{2+} and Ni^{2+} sorption on phosphate treated saw dust were fitted to the linear form of both Freundlich and Langmuir models whereas Cu^{2+} did not follow Freundlich and Langmuir isotherms. In the present study, it was found out that the selected human hair adsorbent obey both Freundlich and Langmuir adsorption models.

TABLE 16
ADSORPTION OF NICKEL(II) ON HUMAN HAIR WITH VARYING INITIAL METAL
CONCENTRATIONS

Dilutions	Initial concentration of nickel (mg/100ml)	Freundlich isotherm				Langmuir isotherm	
		Ce	x/m	Log Ce	Log x/m	1/Ce	1/(x/m)
1:1	10.00	4.48	5.52	0.6513	0.7419	0.2232	0.1812
1:2	6.67	3.72	2.95	0.5705	0.4698	0.2688	0.3389
1:3	5.00	3.83	1.17	0.5832	0.068	0.2611	0.8547
2:1	13.33	11.34	1.99	1.0546	0.2989	0.0881	0.5025
3:1	15.00	13.04	1.96	1.1153	0.2923	0.0767	0.5102
r			-0.21				-0.02
1/n			0.53				-

TABLE 17

ADSORPTION OF CHROMIUM(VI) ON HUMAN HAIR WITH VARYING INITIAL METAL CONCENTRATIONS

Dilutions	Initial concentration of chromium (mg/100ml)	Freundlich isotherm				Langmuir isotherm	
		Ce	x/m	Log Ce	Log x/m	1/Ce	1/(x/m)
1:1	10.00	2.60	7.40	0.4149	0.8692	0.1923	0.0106
1:2	6.67	2.11	4.56	0.3243	0.6589	0.1580	0.1656
1:3	5.00	1.82	3.18	0.2600	0.5024	1.1374	0.0234
2:1	13.33	8.51	4.82	0.9299	0.6830	0.0784	0.0083
3:1	15.00	11.06	3.94	1.0438	0.5955	0.0679	0.0074
r		0.03				-0.91	
1/n		0.67				-	

TABLE 18

**ADSORPTION OF NICKEL(II) FROM BINARY METAL SOLUTION ON HUMAN HAIR
WITH VARYING INITIAL METAL CONCENTRATIONS**

Dilutions	Initial concentration of nickel (mg/100ml)	Freundlich isotherm				Langmuir isotherm	
		Ce	x/m	Log Ce	Log x/m	1/Ce	1/(x/m)
1:1	10.00	4.07	5.93	0.6095	0.7731	0.2457	0.1686
1:2	3.33	1.38	1.95	0.1398	0.2900	0.2415	0.5128
1:3	2.50	1.05	1.45	0.0211	0.1614	0.2392	0.6897
2:1	6.70	4.87	1.80	0.6875	0.2553	0.1370	0.5555
3:1	7.50	6.17	1.33	0.7902	0.1239	0.1220	0.7518
r		1.87				0.73	
1/n		0.26				-	

TABLE 19

ADSORPTION OF CHROMIUM(VI) FROM BINARY METAL SOLUTION ON HUMAN
HAIR WITH VARYING INITIAL METAL CONCENTRATIONS

Dilutions	Initial concentration of chromium (mg/100ml)	Freundlich isotherm				Langmuir isotherm	
		Ce	x/m	Log Ce	Log x/m	1/Ce	1/(x/m)
1:1	10.00	4.48	5.52	0.6513	0.7419	0.2232	0.0105
1:2	3.33	1.54	1.79	0.1875	0.2529	0.6494	0.0315
1:3	2.50	1.63	0.87	0.2122	0.0605	0.6135	0.0428
2:1	6.70	5.86	0.81	0.7679	0.0915	0.1706	0.0164
3:1	7.50	6.82	0.68	0.8338	0.1675	0.1466	0.0147
r		0.16				-0.23	
1/n		0.18				-	

FIGURE 17

FREUNDLICH ADSORPTION PLOTS FOR HUMAN HAIR AT DIFFERENT INITIAL METAL CONCENTRATIONS

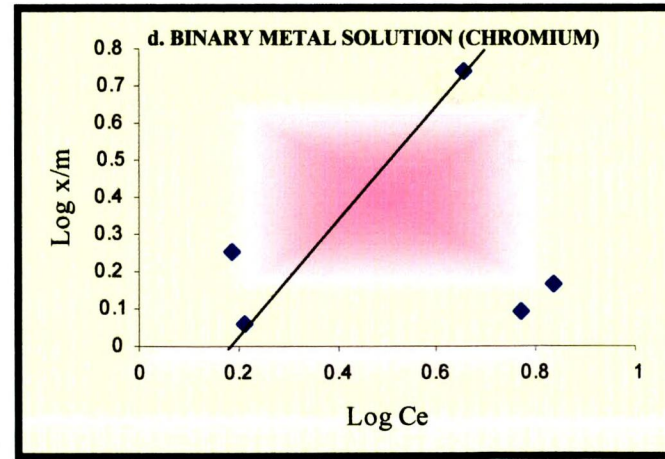
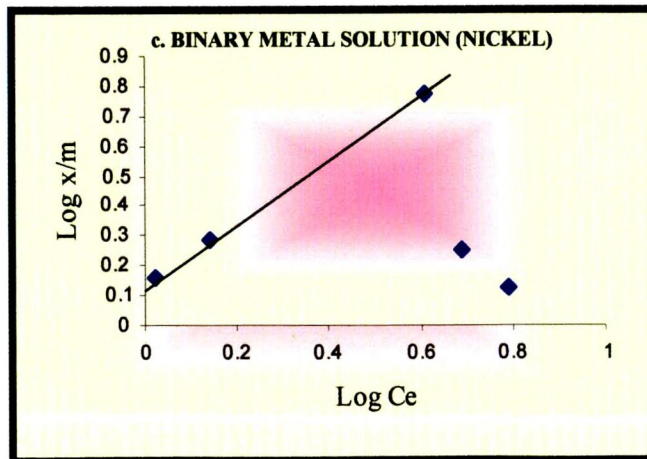
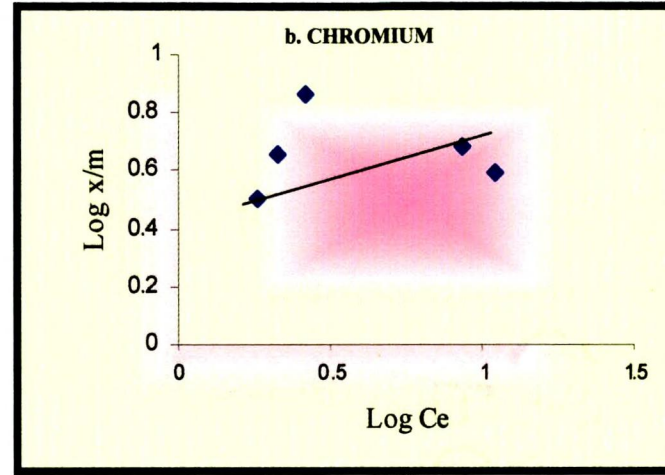
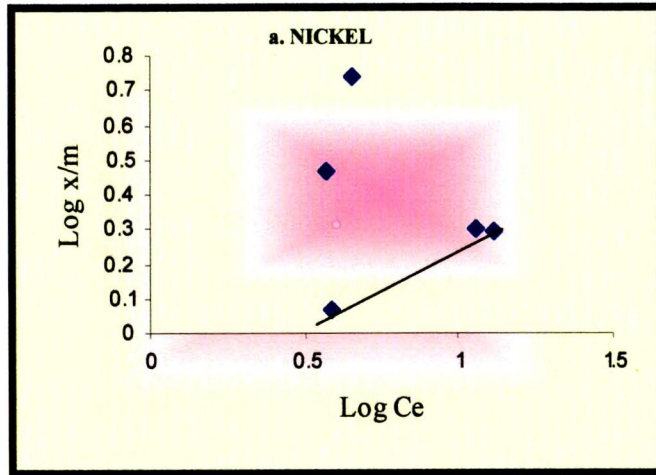


FIGURE 18

LANGMUIR ADSORPTION PLOTS FOR HUMAN HAIR AT DIFFERENT INITIAL METAL CONCENTRATIONS

