CHAPTER 7

COMPARISON OF ADSORPTIVE BEHAVIOR OF METAL IONS

7.1. Introduction

7.2. Adsorptive behavior of metal ions on MMT

7.3. Adsorptive behavior of metal ions on MMT-1

7.4. Adsorptive behavior of metal ions on MMT-2

7.5. Adsorptive behavior of metal ions on MMT-3

7.6. Adsorptive behavior of metal ions on CHITO-B

7.7. Adsorptive behavior of metal ions on MMT-4

7.8. Adsorptive behavior of metal ions on MMT-5

7.9. Conclusions
7.1 Introduction

The US Environmental Protection Agency (EPA) currently recognizes a handful of technologies including ion exchange, lime softening, filtration/membrane processes and adsorption as qualifying for best available technology for the removal of toxic metal/s.

Adsorption has been known to perform many separations that are impossible or impractical by conventional techniques such as distillation, absorption as well as membrane based systems. Lately application for adsorption has expanded rapidly because of sharply rising environmental or quality requirements. Likewise, advances in adsorption technology have been made to meet the demands. Thus, adsorbent are now available “off-the-shelf” that perform satisfactorily in most cases [001].

Going hand-in-hand with these advances and understanding the mechanism of adsorption and correlating it with chemistry of the toxic metal/s adsorbent/have been developed with dramatically improved properties which translate into better performance for an efficient adsorption capacity.

The inorganic pollutants as toxic metals occur in water and can be of natural or anthropogenic origin and their toxicity increases with accumulation in water. Some of
them are toxic even if their concentration is very low as assigned by the WHO or US Environmental Protection Agency (EPA) [002, 003].

The important attributes of an adsorbent for any application are: capacity, selectivity, regenerability, kinetics and cost. Adsorption capacity (or loading) is the most important characteristic of an adsorbent. It is the amount of adsorbate taken up by the adsorbent per unit mass (or volume) of the adsorbent [004, 005].

Some attempts have been made to collect a body of knowledge concerning the relation of standard water quality parameters of the concentration of toxicity level of the three metal ions studied [Chapter 4, 5, 6] to the potential application of a particular adsorbent.

This Chapter examines the interaction of adsorbent with respective metals under optimized conditions and the comparative study of the extraction efficiency of the adsorbent and hence the applicability of adsorbent/s for purification of water from toxic metal/s.

7.2 Adsorptive behavior of metal ions on MMT

The behavior of MMT for adsorptive extraction of arsenic (III), antimony (III) and vanadium (V) respectively was comparatively studied using the batch extraction data during the contact time of 60 minutes.

The extraction efficiency of arsenic (III), antimony (III) and vanadium (V) using MMT was compared at optimized pH and contact time with 100µgml⁻¹ of respective metal ion solution.

The pH of the metal ion was observed to be the most important parameter influencing the metal-solution and adsorbent-surface chemistry.

The comparative study of adsorptive behaviour of MMT shows that the adsorption of metal ion was observed to increase at intermediate pH to near complete adsorption over a relatively small pH range that is referred to as the pH-adsorption edge [006]. The adsorption of arsenic (III) was observed to be a pH dependant process that shows 73%
adsorption at pH 2·0 and increased up to pH 8·0. Thus, pH of arsenic (III) solution was maintained at 8·0. The adsorption of antimony (III) was observed to be 67% at pH 2·0 that increased up to pH 7·0 that was considered as the optimized pH. The adsorption of vanadium (V) appears to be a pH independent process after pH 3·0 with an adsorption of 57% of metal ion at pH 2·0. The maximum adsorption of vanadium (V) was observed in the pH range of 8·0-9·5. Therefore, pH 8·0 was considered as the optimized pH for adsorption.

The comparison of the adsorptive behavior of MMT as a function of initial concentration of metal ion/s shows that the extraction of arsenic (III) from aqueous solution was found to increase from 87% to 90% with an increase in concentration of metal ion from 10µgml⁻¹ to 100µgml⁻¹ during contact time of 60 minutes.

The extraction of antimony (III) from aqueous solution, using MMT was found to increase from 75% to 82% with increase in concentration from 10µgml⁻¹ to 100µgml⁻¹ during contact time of 60 minutes.

An extraction efficiency of MMT was observed to increase from 84% to 90% from an initial concentration of 10µgml⁻¹ and 100µgml⁻¹ of vanadium (V) respectively during contact time of 60 minutes [Figure 7.1a].

The extraction efficiency for the three metals (arsenic (III), antimony (III) and vanadium (V)) was found to decrease up to almost 9%, 3% and 14% respectively from an initial concentration of 0·004µgml⁻¹ of the respective metal ion solution.

The adsorption isotherm study shows that Freundlich isotherm is the most appropriate model for the adsorption of arsenic (III), antimony (III) and vanadium (V) in the investigated concentration range (0·004-100ppm). Although Langmuir isotherm was observed to be favorable in the concentration range of 0·004-0·05µgml⁻¹ for arsenic (III). The favorable concentration range for monolayer adsorption of antimony (III) adsorption was 0·004-0·06µgml⁻¹ whereas 0·004-0·07µgml⁻¹ for vanadium (V).
7.3 Adsorptive behavior of metal ions on MMT-1

The extraction efficiency of arsenic (III), antimony and vanadium (V) using MMT was comparatively studied at optimized pH and contact time from 100µgml⁻¹ of metal ion solution during contact time of 60 minutes [Section 7.2].

The adsorption of metal ion was observed to increase at intermediate pH to maximum adsorption over the pH-adsorption edge. The adsorption of arsenic (III) shows a decrease in efficiency after pH 10·0 reaching around 83% at pH 12·0 appears to be a pH independent process with 95% adsorption at pH 2·0. The adsorption of antimony (III) and vanadium (V) on MMT-1 was observed to be a pH dependant process with almost 57% and 57% of respective metal ion adsorption at pH 2·0.

The comparative study of adsorption as a function of initial concentration of metal ion shows that the extraction of arsenic (III) from aqueous solution was found to increase from 85% to 97% on increasing the concentration from 10µgml⁻¹ to 100µgml⁻¹ during the contact time of 60 minutes.

The amount of antimony (III) extracted from its aqueous solution, using MMT-1 was found to decrease from 83·10% to 90·00% on increasing the concentration from 10µgml⁻¹ to 100µgml⁻¹ during contact time of 60 minutes [Figure 7.1b].

An extraction efficiency of 84·0% and 97·8% of vanadium (V) from an initial concentration of 100µgml⁻¹ and 10µgml⁻¹ of vanadium (V) respectively has been observed using MMT-1 during contact time of 60 minutes.

Bearing significant similarities with arsenic in chemical properties and toxicity, antimony also exhibits significant dissimilarities, with arsenic in behaviors during adsorption.

An important evidence of comparative behaviors of arsenic (III), antimony (III) and vanadium (V) during adsorption is that the removal of arsenic (III) is relatively preferable to antimony (III). In our study, when 0·1g of MMT-1 was dosed to water with 0·004µgml⁻¹ of arsenic (III), extraction efficiency of the metal ion at favorable pH 8·0 was 18%. Under the similar conditions, only 15% of vanadium (V) could be
attained. The extraction efficiency of antimony (III) from an initial concentration of 0·004µgml⁻¹ of metal ion solution was observed to be only 10% at pH 6·0.

The Langmuir isotherm depicts monolayer adsorption to be favorable in the concentration range of 0·004 - 0·1µgml⁻¹ for arsenic (III), in the concentration range of 0·004 - 0·08µgml⁻¹ for antimony (III) and in the concentration range of 0·004 - 0·1µgml⁻¹ for vanadium (V).

7.4 Adsorptive behavior of metal ions on MMT-2

The extraction efficiency of arsenic (III), antimony and vanadium (V) using MMT-2 was comparatively studied at optimized pH (8·0, 6·0 and 8·0 respectively) and contact time from 100 µgml⁻¹ of metal ion solution during contact time of 60 minutes. The pH of arsenic (III), antimony (III) and vanadium (V) solution was maintained at 8·0, 6·0 and 8·0 respectively [Chapter 4, 5 and 6].

The adsorption of arsenic (III) appears to be a pH independent process with 98% adsorption at pH 2·0. The adsorption of antimony (III) and vanadium (V) on MMT-1 was observed to be a pH dependant process with almost 75·00% and 61·00% of respective metal ion adsorption at pH 2·0.

The percentage of arsenic (III) efficiently extracted from its aqueous solution, using MMT-2 was found to decrease from 98% to 98% on increase in concentration from 10µgml⁻¹ to 100µgml⁻¹ during contact time of 60 minutes.

The amount of antimony (III) extracted from its aqueous solution, using MMT-2 was found to increase from 85% to 95% on increase in concentration from 10µgml⁻¹ to 100µgml⁻¹ during contact time of 60 minutes [Figure 7.1c].

An extraction efficiency of 87% and 97% of vanadium (V) from an initial concentration of 100µgml⁻¹ and 10µgml⁻¹ of vanadium (V) respectively has been observed using MMT-2 during contact time of 60 minutes.

An important indication of comparative behavior of arsenic (III), antimony (III) and vanadium (V) during adsorption using MMT-2 is that the removal of arsenic (III) is relatively more preferable to antimony (III). In the batch adsorption study, when 0·1g of
MMT-2 was dosed to water with 0·004 µg ml\(^{-1}\) of arsenic (III), extraction efficiency of the metal ion at favorable pH 8·0 was 35%. Under the similar conditions, only 25% of vanadium (V) extraction could be attained. The extraction efficiency of antimony (III) at pH 6·0 from an initial concentration of 0·004 µg ml\(^{-1}\) of metal ion solution was observed to be only 13%.

The Langmuir isotherm depicts monolayer adsorption to be favourable in the concentration range of 0·004 - 0·3µg ml\(^{-1}\) for arsenic (III), in the concentration range of 0·004 - 0·1µg ml\(^{-1}\) for antimony (III) and in the concentration range of 0·004 - 0·1µg ml\(^{-1}\) for vanadium (V).

### 7.5 Adsorptive behavior of metal ions on MMT-3

The extraction efficiency of arsenic (III), antimony and vanadium (V) using MMT-3 was comparatively studied at optimized pH [Section 7.1] and contact time from 100µg ml\(^{-1}\) of metal ion solution during contact time of 60 minutes.

The adsorption of arsenic (III) appears to be a pH independent process with 91·06% adsorption at pH 2·0. The adsorption of antimony (III) and vanadium (V) on MMT-3 was observed to be a pH dependant process with almost 78% and 62% of respective metal ion adsorption at pH 2·0.

The percentage of arsenic (III) efficiently extracted from its aqueous solution, using MMT-3 was found to decrease from 97% to 98% on increase in concentration from 10µg ml\(^{-1}\) to 100µg ml\(^{-1}\) during contact time of 60 minutes.

The amount of antimony (III) extracted from its aqueous solution, using MMT-3 was found to increase from 87% to 97% on increase in concentration from 10µg ml\(^{-1}\) to 100µg ml\(^{-1}\) during contact time of 60 minutes [Figure 7.1(d)].

An extraction efficiency of 89% and 98% of vanadium (V) from an initial concentration of 10µg ml\(^{-1}\) and 100µg ml\(^{-1}\) of vanadium (V) respectively has been observed using MMT-2 during contact time of 60 minutes.
The comparative behavior of arsenic (III), antimony (III) and vanadium (V) during adsorption using MMT-2 suggests that the removal of arsenic (III) is relatively more preferable to antimony (III).

![Graphs showing adsorption behavior of metal ions](image)

Figure 7.1. Comparative adsorption of metal ions on (a) MMT (b) MMT-1 (c) MMT-2 (d) MMT-3

In the batch adsorption study, when 0·1g of MMT-3 was dosed to water with 0·004 µgml⁻¹ of arsenic (III), extraction efficiency of the metal ion at favorable pH 8·0 was 37·00%. Under the similar conditions, only 29·90% of vanadium (V) extraction could be attained. The extraction efficiency of antimony (III) at pH 7·0 from an initial concentration of 0·004µgml⁻¹ of metal ion solution was observed to be only 17·90%. Thus, MMT-3 has proved to be an efficient adsorbent for arsenic (III) as compared to antimony (III) and vanadium (V).

The Langmuir isotherm depicts monolayer adsorption to be favorable in the concentration range of 0·004 - 0·1µgml⁻¹ for arsenic (III), in the concentration range of 0·004 - 0·1µgml⁻¹ for antimony (III) and in the concentration range of 0·004 - 0·1µgml⁻¹ for vanadium (V).
7.6 Adsorptive behavior of metal ions on CHITO-B

The extraction efficiency of arsenic (III), antimony and vanadium (V) using CHITO-B was comparatively studied at optimized pH (8·0, 7·0 and 8·0 respectively) and contact time from 100 µgml⁻¹ of metal ion solution during contact time of 60 minutes. The pH of arsenic (III), antimony (III) and vanadium (V) solution was maintained at 8·0, 7·0 and 8·0 respectively [Chapter 4, 5 and 6].

The adsorption of arsenic (III), antimony (III) and vanadium (V) appears to be a pH independent process with 90%, 90% and 89% adsorption respectively at pH 5·0. The CHITO-B were unstable at pH <5·0 hence no data was attained at pH 2·0.

The percentage of arsenic (III) efficiently extracted from its aqueous solution, using CHITO-B was found to decrease from 86% to 93% on increase in concentration from 10µgml⁻¹ to 100µgml⁻¹ during contact time of 60 minutes.

The amount of antimony (III) extracted from its aqueous solution, using CHITO-B was found to decrease from 87·00% to 97·40% on increase in concentration from 10µgml⁻¹ to 100µgml⁻¹ during contact time of 60 minutes.

An extraction efficiency of 87% and 96% of vanadium (V) from an initial concentration of 100µgml⁻¹ and 10µgml⁻¹ of vanadium (V) respectively has been observed using CHITO-B during contact time of 60 minutes [Figure 7.2(a)].

The comparative behavior of arsenic (III), antimony (III) and vanadium (V) during adsorption using CHITO-B suggests that the sensitivity of CHITO-B towards arsenic (III) was found to be up to 0·008µgml⁻¹, 0·006µgml⁻¹ for antimony (III) and vanadium (V). Theremoval of arsenic (III) is relatively more preferable to antimony (III). In the batch adsorption study, when 0·1g of CHITO-B was dosed to water with 0·006µgml⁻¹ of arsenic (III), extraction efficiency of the metal ion at favorable pH 8·0 was 15%. Under the similar conditions, only 19% of vanadium (V) extraction could be attained. The extraction efficiency for antimony (III) was found to decrease up to almost 11% at pH 7·0 from an initial concentration of 0·006µgml⁻¹ of metal ion solution. The Langmuir isotherm depicts monolayer adsorption to be favorable in the concentration range of 0·004 - 0·05µgml⁻¹ for arsenic (III), in the concentration range of 0·004 - 0·04µgml⁻¹ for antimony (III) and in the concentration range of 0·004 - 0·05µgml⁻¹ for vanadium (V).
7.7 Adsorptive behavior of metal ions on MMT-4

The extraction efficiency of arsenic (III), antimony and vanadium (V) using MMT-4 was comparatively studied at optimized pH (8·0, 7·0 and 8·0 respectively) and contact time from 100 μgml⁻¹ of metal ion solution during contact time of 60 minutes. The pH of arsenic (III), antimony (III) and vanadium (V) solution was maintained at 8·0, 6·0 and 8·0 respectively [Chapter 4, 5 and 6].

The adsorption of arsenic (III) and vanadium (V) using MMT-4 was observed to be a pH independent process with 53% and 73% adsorption respectively at pH 2·0. The adsorption of antimony (III) on MMT-4 was observed to be a pH dependant process with almost 47·40% of metal ion adsorption at pH 2·0.

The percentage of arsenic (III) efficiently extracted from its aqueous solution, using MMT-4 was found to decrease from 90% to 99% on increase in concentration from 10μgml⁻¹ to 100μgml⁻¹ during contact time of 60 minutes.

The amount of antimony (III) extracted from its aqueous solution, using MMT-4 was found to decrease from 90% to 98% on increase in concentration from 10μgml⁻¹ to 100μgml⁻¹ during contact time of 60 minutes [Figure 7.2(b)].

An extraction efficiency of 98% and 99% of vanadium (V) from an initial concentration of 100μgml⁻¹ and 10μgml⁻¹ of vanadium (V) respectively has been observed using MMT-4 during contact time of 60 minutes.

The comparative behavior of arsenic (III), antimony (III) and vanadium (V) during adsorption using MMT-4 suggests that the sensitivity of MMT-4 towards arsenic (III) was found to be up to 0·006μgml⁻¹, 0·008μgml⁻¹ for antimony (III) and 0·004μgml⁻¹ for vanadium (V) respectively. The removal of arsenic (III) is relatively more preferable to antimony (III). In the batch adsorption study, when 0·1g of MMT-4 was dosed to water with 0·006μgml⁻¹ of arsenic (III), extraction efficiency of the metal ion at favorable pH 8·0 was 40%. Under the similar conditions, only 37% of vanadium (V) extraction could be attained. The extraction efficiency of antimony (III) at pH 7·0 was observed to be 32% from an initial concentration of 0·006μgml⁻¹ of metal ion.
The Langmuir isotherm depicts monolayer adsorption to be favorable in the concentration range of 0·004 - 0·5µgml\(^{-1}\) for arsenic (III), in the concentration range of 0·004 - 0·4µgml\(^{-1}\) for antimony (III) and in the concentration range of 0·004 - 0·5µgml\(^{-1}\) for vanadium (V).

7.8 Adsorptive behavior of metal ions on MMT-5

The extraction efficiency of arsenic (III), antimony and vanadium (V) using MMT-5 was comparatively studied at optimized pH (8·0, 7·0 and 8·0 respectively) and contact time from100 µgml\(^{-1}\) of metal ion solution during contact time of 60 minutes. The pH of arsenic (III), antimony (III) and vanadium (V) solution was maintained at 7·0, 7·0 and 8·0 respectively [Chapter 4, 5, 6].

The adsorption of arsenic (III) and vanadium (V) appears to be a pH independent process after pH 3·0 with 43% and 66% adsorption respectively at pH 2·0. The adsorption of antimony (III) on MMT-4 was observed to be a pH dependant process with almost 43% of metal ion adsorption at pH 2·0.

The percentage of arsenic (III) efficiently extracted from its aqueous solution, using CHI - MMT was found to decrease from 89%to 99% on increase in concentration from 10µgml\(^{-1}\) to 100µgml\(^{-1}\) during contact time of 60 minutes.

The amount of antimony (III) extracted from its aqueous solution, using MMT-5 was found to decrease from 88% to 94% on increase in concentration from 10µgml\(^{-1}\) to 100µgml\(^{-1}\) during contact time of 60 minutes.An extraction efficiency of 94% and 98% of vanadium (V) from an initial concentration of 100µgml\(^{-1}\) and 10µgml\(^{-1}\) of vanadium (V) respectively has been observed using MMT-5 during contact time of 60 minutes [Figure 7.2(c)].

The extraction efficiency for the three respective metals (arsenic (III), antimony (III) and vanadium (V)) was found to decrease up to almost 35%, 14% and 25% respectively from an initial concentration of 0·004µgml\(^{-1}\) of metal ion solution.
Chapter 7: Comparison of Adsorptive Behavior of Metal Ions

Figure 7.2. Comparative adsorption of metal ion/s on (a) CHITO-B (b) MMT-4 (c) MMT-5

The Langmuir isotherm depicts monolayer adsorption to be favorable in the concentration range of 0·004 - 0·2µgml\(^{-1}\) for arsenic (III), in the concentration range of 0·004 - 0·2µgml\(^{-1}\) for antimony (III) and in the concentration range of 0·004 - 0·2µgml\(^{-1}\) for vanadium (V).

7.9 Conclusions

The adsorption capacity is considered to be of paramount importance to the capital cost of the adsorbent because it dictates the amount of adsorbent required. The need to the development of a methodology wherein the adsorbent has maximum possible adsorption capacity has been attained.

The MMT-1 was observed to possess maximum adsorption capacity for arsenic (III) (48mgg\(^{-1}\)) as well as vanadium (V) (47mgg\(^{-1}\)). The MMT-2 was observed to possess maximum adsorption capacity for arsenic (III) (48·49mgg\(^{-1}\)) as well as vanadium (V) (49mgg\(^{-1}\)). The MMT-3 was observed to possess maximum adsorption capacity for antimony (III) (49mgg\(^{-1}\)) followed by arsenic (III) as 49mgg\(^{-1}\) of adsorbent respectively.
The CHITO-B was observed to possess maximum adsorption capacity for antimony (III) (49mg\textsuperscript{-1}g\textsuperscript{-1}). The MMT-4 was observed to possess maximum adsorption capacity for vanadium (V) (50mg\textsuperscript{-1}g\textsuperscript{-1}) followed by arsenic (III) that was observed to be 49mg\textsuperscript{-1}g\textsuperscript{-1} of adsorbent. The MMT-5 was observed to possess maximum adsorption capacity for arsenic (III) (49mg\textsuperscript{-1}g\textsuperscript{-1}). Thus, maximum adsorption capacity for arsenic (III) was attained by MMT-3 as well as MMT-4. The maximum adsorption capacity for antimony (III) was attained by MMT-3 whereas maximum adsorption capacity for vanadium (V) was attained by MMT-4. The efficiency of MMT-3 and MMT-4 was generally observed to be highest for vanadium (V) and arsenic (III) thereby proving to be an efficient and competent adsorbent/s for adsorption of respective metal/s.

The batch extraction experimental data shows that the adsorption reaction between natural and modified adsorbent/s surfaces and the respective metal ion/s are generally considered to control the concentration of the respective metal in water. Adsorption of metal ion/s is a complex mechanism and is a function of the interrelationship between the nature of surface of adsorbent, pH of metal ion solution and initial concentration of metal ion. The development of a simple and rapid adsorption methodology can be applied for discrete extraction of arsenic (III), antimony (III) and vanadium (V) respectively from solution at the respective pH value/s that is drinking water compatible during batch extraction process.

The relative investigations of the efficiency of adsorbents indicate an efficient adsorption of metal ions. The maximum adsorption was observed to be 77% of arsenic (III), 75% of antimony (III) and 76% of vanadium (V) respectively was attained from an initial concentration of 0·1µgml\textsuperscript{-1} of metal ion.

Figure 7.3 shows an increase in adsorption of arsenic (III) and vanadium (V) (on Z-axis) as we move from left to right on X-axis (except for CHITO-B). The antimony (III) adsorption also shows similar trend up till MMT-2 after which it shows a decrease for two adsorbents (MMT-3 and CHITO-B) and rises thereafter the efficiency of arsenic (III) and vanadium (V) adsorption was observed to be maximum resulting in 65% of arsenic (III) and 57% of vanadium (V) adsorption respectively from an initial concentration of 0·01µgml\textsuperscript{-1} as shown in Figure 7.4. The adsorption capacity of MMT-
MMT-5, MMT-3 and MMT-2 was found to be higher than that of MMT and CHITO-B.

Initial concentration of metal ion/s: $0.1 \mu g mL^{-1}$; optimized pH and contact time

**Figure 7.3. Comparative adsorption of metal ion/s using various adsorbent/s**

Initial concentration of metal ion/s: $0.01 \mu g mL^{-1}$; optimized pH and contact time

**Figure 7.4. Comparative adsorption of metal ion/s using various adsorbent/s**
The efficiency of vanadium (V) adsorption was observed to be maximum using MMT-4 as adsorbent with an adsorption efficiency of 57% from an initial concentration of 0·01µgml$^{-1}$. The efficiency of antimony (III) adsorption was observed to be maximum using MMT-5 as adsorbent that shows an adsorption efficiency of 60% from an initial concentration of 0·01µgml$^{-1}$ of metal ion. Thus, in general it can be concluded that adsorption capacity of the best adsorbent/s decreases by almost 10% in dilute metal ion solution.

Thus, there are two general mechanisms observed for adsorption of metal ion/s on the surface of adsorbent/s: non-specific adsorption and specific adsorption. The studies indicate that arsenic (III) adsorption is favorable at neutral pH values that decreases with increase in pH due to an increased competition of hydroxyl ions with HAsO$_3^{2-}$ as well as AsO$_3^{-}$ at pH>9·0.

The adsorption of Vanadium (V) has a relatively wider optimum pH (4·0 - 9·0). This could be due to the electrostatic interaction that occurs between the adsorbent and [H$_2$VO$_4$]$^-$ up till pH 9·0 after which the competing hydroxyl ions also come into play. Vanadium exists as a positive specie at pH<3·0. Arsenic (III) and antimony (III) species with same oxidation state show similar trend of adsorption efficiency on MMT as a function of pH, although their actual removal degree is considerably different. As demonstrated in the studies, MMT and CHITO-B exhibit poor adsorption efficiency of the respective metal ion/s. The poor adsorption capacity of MMT and CHITO-B is possibly attributed to the low adsorption enthalpy of metal ion/s in binding with the adsorbent/s that represents the bonding energy between the adsorbate ion and the metal (hydro)oxide of the adsorbent.
Chapter 7: Comparison of Adsorptive Behavior of Metal Ions

References


