Adsorption of nickel and mercury from drinking water simulant by activated carbon

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1. Introduction

Quality of drinking water has become the main international subject in the last decade. Presence of trace metals in drinking water has been related to the occurrence of certain cancers, cardiovascular diseases and other severe health problems in animals and human beings (Forstner, 1984; Masironi, 1969; Salomons and Kurkland, et al., 1971). In the majority of cases, the problem of heavy metals is not related to a single metal but to a combination of metals originating from one or several sources. Meanwhile, there is still a lack of effective means for the treatment of water and wastewater containing heavy metals. Many methods, namely sulfide precipitation, ion-exchange, alum coagulation, iron coagulation and activated carbon, are suggested for metals removal (Abdel-Shafy et al., 1989; Abo-El-Wafa et al., 1981; Patterson 1975 and Vernkobachar, 1989). A monog these treatment methods, activated carbon appears particularly effective in the effective removal of trace pollutants (Abdel-Shafy and Abo-El-Wafa, 1987; Guo et al., 1993; Huang et al., 1981; Lu et al., 1993 and Martin et al., 1985). GAC is most effective in removing cadmium, chromium and cobalt (Huang and Ostovic, 1978; Jiang et al., 1992; Kenji and Kawaiamura 1981 and Kim et al., 1977). In addition, removing of both organic and inorganic Hg from water was efficiently achieved by powdered, as well granular, carbon (Huang and Blankenship, 1984 and Pandey and Chaudhuri, 1980).

The aim of the present study is investigate the efficiency of activated carbon on Ni and Hg removal from water. Both PAC and GAC were used. This investigation was carried out through batch and continuous systems. In addition, the adsorption isotherm of Ni and Hg by both PAC and GAC were also studied.

2. Materials and methods

Double distilled (DD) water was artificially contaminated by Ni and Hg to a concentration of 2mg/l each. The salt of these were added as chlorides.

2.1 Batch treatment

PAC and Filtrasorb-200 GAC (size 0.5-0.8mm) were used in the present study.

2.1.1 Adsorption equilibria

Batch experiments were carried out in order to define the optimum operating conditions. For this purpose, accurately 0.07g of PAC was placed in “Teflon” bottles each containing 100ml of the artificially contaminated DD water. The bottles were then shaken, along with other bottles containing the contaminated water without the carbon addition, to be a control for the experiment. At successive time intervals, one of the experimental bottles and one of the control bottles were removed from the shaker, in order to verify the time to maintain equilibrium. A similar study was carried out for GAC. However, three different doses of GAC namely 2g/l, 3g/l and 4g/l were used. Metals were determined in each bottle.

2.1.2 Adsorption isotherm

A further study was carried out for both types of activated carbon, separately, to investigate the effect of carbon dose on the removal of metal at the equilibrium time. For this purpose, variable PAC doses ranging from 0.25g/l to 4.50g/l and variable GAC doses ranging from 0.2g/l to 20.0g/l were added to the Teflon bottles containing the artificially contaminated water. The bottles were shaken for 24 hours, after which they were removed, filtered through Whatman filter paper No. 4 and acidified by nitric acid. The residual concentrations of Ni and Hg were ascertained in each bottle.

2.2 Continuous treatment

A glass column was used for this purpose in which the effective depth of the GAC bed was 38cm and the diameter was 2.0cm. To study
the effect of the contact time, different detention periods; namely 5, 10, 20, 30 and 40 minutes, were examined. The rest of the variables were kept constant. The amount of GAC required was calculated from Freundlich’s equation (1) (Freundlich, 1926):

\[ \frac{X}{m} = K \cdot C^{1/n} \]

Where \( X \) is the adsorbed mass (\( C_0 \)-\( C \)), \( C_0 \) and \( C \) are the initial and final metal concentrations respectively, \( m \) is the mass of carbon and \( K \) and \( 1/n \) are constants, which can be determined by plotting the adsorbed mass \( (X/m) \) as the function of the equilibrium concentration in a log-log relationship. \( 1/n \) is the slope of the line to the ordinate when \( \log C = 0 \). The only unknown in equation (1) is the value \( m \) which has been calculated.

The concentrations of Ni and Hg were determined in the acidified samples using atomic absorption spectrophotometer.

### 3. Results and discussion

#### 3.1 The use of powdered activated carbon

The results show that an initial rapid uptake of the metals examined was observed within the first 15 minutes, after which the removal efficiency increases slowly but gradually until an equilibrium is attained after two-and-a-half hours. The rate of metal adsorption as a function of the corresponding amount of carbon used at the predetermined equilibrium time (i.e. adsorption isotherm), is presented in Figure 1.

The results obtained revealed that the adsorption of Ni and Hg follow Freundlich’s equation (1). According to this equation, straight lines were obtained by plotting \( X/m \) versus \( \log C \). Adsorption efficiency can be determined on the basis of Freundlich’s constants. In general, the higher the \( K \) value, the greater the capacity of the adsorbent. However, the dosage of carbon required for the removal of either Ni or Hg is dependent on both parameters (\( K \) and \( 1/n \)), initial concentration of metals \( C_0 \), and final concentration required in treated water \( C \).

The slope Freundlich’s isotherm \( (1/n) \) was found to be 1.586 for Ni and 1.206 for Hg. Corresponding constants \( K \) were 1.02 and 1.91 respectively. It can be concluded that Hg is more liable to be adsorbed on PAC than Ni.

#### 3.2 The use of granular activated carbon

In drinking water treatment plants, GAC is used in the form of bed column. Batch experiment technique permits the prediction of the adsorption parameters which control the uptake process. Time required to reach equilibrium was first assessed. Results obtained (Figure 2) showed that 18 hours were sufficient to maintain equilibrium. Meanwhile, the effect of carbon to nickel ratio \( (C/Ni) \) and carbon to mercury ratio \( (C/Hg) \) on the equilibrium adsorption capacity at different contact times are also illustrated (Figure 2). These results indicate that higher carbon to metal \( (Ni \ or \ Hg) \) ratio increases the metal adsorption capacity and increases the initial removal rate. However, the time necessary for reaching equilibrium adsorption was unchanged. Such results approximate with the findings of other investigators (Abdel-Shafy and Abo-El-Wafa, 1987; Huang and Ostovic, 1978).

The adsorption isotherm of Ni and Hg at the predetermined equilibrium time is given in

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**Figure 1**
Effect of different powdered carbon doses on the adsorption of mercury and nickel
Figure 3, which demonstrates that increasing the carbon doses from 0.2 g/l to 20.0 g/l raises the nickel removal efficiency from 9.7 per cent to 80 per cent. Also, by increasing the carbon doses from 0.2 g/l to 7.0 g/l raises the mercury removal from 31.4 per cent to 91.4 per cent.

It was found that the adsorption isotherm is confirmed by Freundlich’s equation rather than Langmuir (Langmuir, 1918) or BET (Brunauer et al., 1938). The corresponding (K) values for Ni and Hg were 0.219 and 1.134 and 1.036. This indicated the stronger tendency of Hg to be adsorbed on carbon compared to Ni.

3.3 Continuous flow system

Such studies can throw light on the data necessary for optimum design of adsorbents in drinking water plants. To study the variation of contact time on the adsorptive capacity, different contact times of 5, 10, 20, 30 or 40 minutes were examined.

The experiment for each contact time system took eight days. The operating conditions are given in Table I. Breakthrough was followed by monitoring the effluent at regular time intervals.

Table I
Operating conditions carbon column

<table>
<thead>
<tr>
<th>Contact time (minutes)</th>
<th>Flow rate (cm/ minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Five</td>
<td>23.88</td>
</tr>
<tr>
<td>Ten</td>
<td>11.94</td>
</tr>
<tr>
<td>Twenty</td>
<td>5.97</td>
</tr>
<tr>
<td>Thirty</td>
<td>3.98</td>
</tr>
<tr>
<td>Forty</td>
<td>2.99</td>
</tr>
</tbody>
</table>

Notes: carbon depth = 38 cm for each column; bed volume = 119.4 m³ for each column; total carbon weight = 61.4 g.

Refer to Figure 2 for the effect of variable times on the adsorption of mercury and nickel on granular activated carbon using different carbon doses.

Refer to Figure 3 for the effect of different granular carbon doses on the adsorption of mercury and nickel.
Figure 4
Breakthrough curves of mercury and nickel at different contact times

RESIDUAL METAL CONCENTRATION (mg/l)

Curves for Ni and Hg at different contact times are shown in Figure 4. The results obtained indicated that the breakthroughs of Ni and Hg reflect the removal efficiency of each.

The breakthrough points of nickel, at which the concentration was 0.05 mg/l (i.e. the permissible level in drinking water) were reached after 1.4, 3.5, 13.4, 25.1 and 40 hours, corresponding to the contact times 5, 10, 20, 30 and 40 minutes. The breakthrough points of Hg, at which the concentration was 0.01 mg/l (i.e. the permissible level in drinking water) were reached after 0.265, 2.5, 9.0, 18.0 and 26.0 hours at the contact times 5, 10, 20, 30 and 40 minutes respectively.

Table II shows the relation between the removed amount of Ni and Hg at different contact times before breakthrough point on one hand, and the amount of metal removed per amount of carbon (mg/g) on the other. The obtained results proved that when extending the contact time from five to 40 minutes, the removal increased from 0.063 to 0.228 mg Ni/g carbon and from 0.030 to 0.151 mg Hg/g carbon. This finding is in agreement with previous studies (Abdel-Shafy and Abo-El-Wafa, 1987; Huang and Ostovic, 1978 and Moursy and Abdel-Shafy, 1984).

Thus, a linear relationship was obtained between the logarithm of contact time and the volume of the contaminated water before the breakthrough points for Ni and Hg (Figure 5).

### Conclusion and recommendation

Therefore, it can be concluded from the overall results that the use of both PAC and GAC for the removal of Ni and Hg from drinking water is a promising process. It is worth mentioning that the obtained results revealed that the adsorbability of Hg is much

| Table II |
| Amounts of nickel and mercury removed at different contact times |
|---|---|---|---|
| Metal | Contact time (minutes) | Throughput volume (litre) | Amount of metal removed before breakthrough point (mg/l) | Metal removals per amount of carbon (mg/g) |
| Nickel | 5 | 1.98 | 3.86 | 0.063 |
| | 10 | 2.50 | 4.88 | 0.79 |
| | 20 | 4.80 | 9.36 | 0.150 |
| | 30 | 6.00 | 11.70 | 0.191 |
| | 40 | 7.18 | 14.0 | 0.228 |
| Mercury | 5 | 0.93 | 1.85 | 0.030 |
| | 10 | 1.80 | 3.58 | 0.058 |
| | 20 | 3.22 | 6.41 | 0.104 |
| | 30 | 4.30 | 8.50 | 0.139 |
| | 40 | 4.66 | 9.27 | 0.151 |

Notes: Volume of effluent passed before breakthrough at 0.05 mg/l for Ni, and at 0.01 mg/l for HG.
higher than that of Ni with respect to both PAC and GAC. The use of a GAC column bed in continuous system showed a remarkable removal efficiency. Increasing the contact time in this continuous system increases the removal efficiency of carbon. The breakthrough points of Ni and Hg in this continuous system reflect their adsorption isotherms. Therefore, adding an activated carbon filter to the conventional drinking water treatment plant when such water is contaminated by heavy metals can be recommended.

References


Figure 5

Relationship between logarithm of contact time and the throughput volume of mercury and nickel
Hussein I. Abdel-Shafy, Mamdouh F. Abdel-Sabour and Raouf O. Aly
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