Adsorption of Toxic Gases on Iron-Incorporated Na-A Zeolites Synthesized from Melting Slag

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Iron incorporated zeolites were prepared from Na-A type zeolite synthesized from melting slag and FeCl₃ solution and applied as adsorbents for NH₃ and H₂S gases. Iron incorporated zeolite was pelletized, calcined and used for gas adsorption experiment. XRD analyses of the zeolite revealed that Fe³⁺ concentration of solution more than 90 mM could destruct the zeolite network structure. It was observed that the gas adsorption capacities of these zeolite pellets depend significantly on iron concentration of solution and calcination temperature. The type of binders affected a little on gas adsorption capacities. From adsorption results, adsorption capacity for NH₃ was proportional to Fe³⁺ concentration and it was increased with calcination temperature up to 500°C, but it was decreased over 600°C. Pellets prepared from 56 mM Fe³⁺ solution calcined at 500°C showed highest ammonia adsorption capacity (3.7%). This iron incorporated Na-A type zeolites showed much higher adsorption capacities for NH₃ (2.4–3.7%) than commercially available activated carbons (0.16–0.44%) and zeolites (0.23–0.60%). In the case of adsorption capacities for H₂S, adsorption capacity was proportional to Fe³⁺ concentration and inversely proportional to calcination temperature. Pellets prepared from 78 mM Fe³⁺ solution calcined at 200°C showed highest hydrogen sulfide adsorption capacity (1.5%). Adsorption capacity (0.2–1.5%) was found to be lower than that of the commercial activated carbons (1.2–2.4%) and higher than that of commercial zeolites 4A (0.15%) and 13X (0.91%). Higher ammonia adsorption in iron incorporated Na-A zeolites could be possibly due to development of number of acid sites on the zeolite surface due to incorporation of Fe³⁺ ion.

1. Introduction

Incineration of municipal solid waste generates ashes which are known to contain various hazardous substances including dioxins and heavy metals. Therefore, this material has been identified as secondary wastes, which could pose severe environmental problems if are land-filled without further treatment.1–3 In order to avoid this, incineration ashes have been found to be useful for synthesis of zeolites, and number of reports already have cited this.14–16 However, little information is available concerning synthesis of iron-incorporated Na-A type zeolites from melting slag and their potential application as toxic gas adsorbents. Introduction of transition metals into the zeolite structure can considerably enhance the reactivity and adsorption capacities.17,18 Although several studies have reported the enhanced catalytic activities of iron exchanged zeolites (ZSM-5) towards SCR (selective catalytic reduction) and SCO (selective catalytic oxidation) reactions,19,20 but gas adsorption properties of iron-incorporated zeolites (marked as “Fe-NaA”) are scantily investigated. Ammonia is known as one of the odorous gases and an air pollutant which leads to particulate matter formation.21 Hydrogen sulfide is one of the most common compounds that can be found in petrochemical plants, wastewater treatment plants and a source of acid rain.22 These two toxic gases can pose hazardous effect in the environment and therefore need to abate. Adsorption of ammonia and hydrogen sulfide has been carried out using various adsorbents, such as natural zeolite23 and activated carbon.24–28 Keeping in view above, the present communication deals with the study of iron incorporated Na-A type zeolites synthesized from melting slag, towards adsorption of toxic gases such as ammonia and hydrogen sulfide.

2. Experimental Procedure

2.1 Preparation of Fe-NaA

Initially Na-A type zeolite used in this study was synthesized from melting slag, using sodium silicate solution (Young Il Co.) and sodium aluminate (NaALO₂) as the key

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compound in the mixture. All reagents used are of analytical grade. Slag particles of less than 200 mesh size were used for synthesis. Sodium aluminate was prepared from Al(OH)₃ and NaOH for 30 min at 120°C at Na₂O/Al₂O₃ molar ratio of 1.2 : 1. The composition of reaction mixture was SiO₂/Al₂O₃ = 1.38, SiO₂/Na₂O = 1.00, H₂O/Na₂O = 60. The reaction was carried out for 10 h at temperature of 80°C. After the termination of reaction, the solid product was separated from the liquid by centrifugation and washed with water until the pH of the washed solution reached less than 12. The detailed chemical composition of the synthesized Na-A zeolite is shown in Table 1. Fe contents (Fe₂O₃) of Na-A zeolite were originated from melting slag which was melted at 1300°C, but these were chemically inert at about 100°C. This Na-A type zeolite was suspended in ferric chloride solutions (FeCl₃·6H₂O) of 18–90 mM at room temperature for 24 h for the preparation of iron-incorporated Na-A zeolites. After treatment, the mixture was centrifuged and obtained solid was washed with distilled water until the pH of the washed solution reached to 5, dried at 90°C for more than 24 h.

Fe-NaA zeolite was prepared using 10 mass% sodium silicate (Coded as MFG series) or 2.5 mass% PVA (polyvinyl alcohol) as binder (Coded as MF series), and in both cases bentonite was used as a forming agent. While preparing the pellets, the ratio of zeolite : bentonite was kept constant at 9 : 1 for all the samples. These pellets were dried at 90°C, sieved to required mesh size (10–16 mesh) and then calcined at different temperature (200~800°C) for 5 h before applying in gas adsorption studies. Dried and calcined pellets were stored in desiccator for 7 days for further investigation. Samples were finally coded according to their binder type, iron concentration and calcination temperature. The first number denoted the concentration of Fe³⁺ and the second calcination temperature. For example, MFG-56-500 indicated iron-incorporated zeolite pellets prepared from Fe³⁺ solution of 56 mM, pelletized with sodium silicate as binder and calcined at 500°C. Both calcined and un-calced iron incorporated zeolite pellets were taken for gas adsorption studies.

2.2 Gas adsorption experiment
For gas adsorption study about 5 g of samples were packed into a column (length 30 cm & diameter 15 mm) which was housed inside an oven maintained at 30°C (Fig. 1). The adsorbates (NH₃ & H₂S gases) were passed through regulators and then mixed with N₂ for adjusting their concentration (N₂ containing 3% NH₃ or 1% H₂S, respectively) before passing into the adsorbent column. Flow rate of gases was 100 ml/min. After passing through the adsorbent column, the exit gases were analyzed by respective gas detector (Gastec) and breakthrough concentrations were monitored at regular intervals (one minute). The tests were stopped at a breakthrough concentration of 500 ppm for NH₃ and 2000 ppm for H₂S, respectively. The adsorption capacity was calculated by using the following relations:

\[
\text{Adsorption capacity} \ (%) = \frac{X}{Y} \times 100
\]

Where,

\[X = \text{Flow rate of gas (ml/min)} \times \frac{\text{g mol. wt. of gas (g)}}{22,414 \text{ ml}} \times \text{Breakthrough time (min)} \times \frac{\text{Conc. of gas} \ (%)}{100}\]

2.3 Analysis method
The chemical analysis was carried out to identify the chemical composition of Fe-NaA according to the Fe³⁺ concentration. Powder X-ray diffraction patterns were recorded on a Rigaku RU-200 (CuKα, 40 mA, 40 kV, scan speed 5°/min) spectrophotometer. Scanning electron microscopy images were obtained by a Hitachi FE-SEM S-4700 spectrophotometer and osmium tetroxide (OsO₄) was used as conductive material for coating. The FT-IR spectra were recorded by using a Thermo Nicolet 380 FT-IR spectrometer in the range of 4000~4000 cm⁻¹ with a resolution of 4 cm⁻¹. Specific surface areas of samples were obtained with a Micromeritics tristar instrument by adsorption of nitrogen at 77 K and calculated by BET method. In each case about 0.4 g of samples were degassed under vacuum at 200°C for 2 h prior to nitrogen adsorption. Mercury porosimeter (AutoPore IV 9500, Micromeritics, USA) was used for measuring the porosity of pellets in the pressure range of 0.44~60,000 psi. The CEC (cation exchange capacity) of zeolite samples were measured by ammonium acetate.
Two grams of zeolite sample was ion-exchanged with 100 ml of 1 M ammonium acetate solution for 24 h and titrated with 0.1N H$_2$SO$_4$ and calculated.

3. Results

3.1 Characterization of Fe-NaA

The results of chemical analysis of zeolite prepared from different Fe$^{3+}$ concentration was presented in Table 2. Increasing Fe$^{3+}$ concentration, Fe$_2$O$_3$ contents of zeolite was increased, whereas FeO and Na$_2$O content were rather decreased. During the same time little change was observed in case of SiO$_2$ and Al$_2$O$_3$ content.

The XRD patterns and FT-IR spectra of different Fe-NaA samples are presented in Fig. 2(a) and 2(b), respectively. The XRD patterns suggested that, increased iron concentration in solution has led to decrease the crystallinity of zeolite, which is due to the decrease of stability of crystal. This depicted that the peak intensities were almost halved by increasing iron concentration from 0 to 78 mM. By further increasing the iron concentration to 90 mM, the XRD pattern indicated complete destruction of the crystalline structure of Na-A zeolite. The FT-IR spectra of these samples essentially gave similar results (Fig. 2(b)). The intensities of characteristic doubling ring and T-O (T = Si or Al) vibration bands in Na-A type zeolites at 556 and 467 cm$^{-1}$, respectively are found to decrease by increasing the iron concentration from 0 to 78 mM. These bands are disappeared for the sample prepared from iron concentration of 90 mM. It can be inferred from these results that the maximum amount of iron concentration that can be accommodate into Na-A type zeolite is 78 mM and further increase in iron concentration resulted in complete destruction of zeolite structure.

The surface area and CEC of different iron incorporated Na-A zeolites are presented in Fig. 3 as a function of iron concentration. The CEC value of the initial Na-A zeolite was 220 cmol/kg and it decreased with increase in iron concentration. The maximum decrease of CEC value was obtained when iron concentration increased from 78 to 90 mM. Increase of Fe$^{3+}$ substitution may have decreased the structural stability as observed in XRD (Fig. 2(a)). Hence, the unstable structure may lead to decreasing trend in CEC. The surface area was found to increase almost linearly with increase in iron concentration from 0 to 78 mM and then almost doubled by increasing the iron concentration to 90 mM.

Table 2 Chemical composition of different iron-incorporated Na-A type zeolites. (unit: mass%)

<table>
<thead>
<tr>
<th>FeCl$_3$ concentration (mM)</th>
<th>18</th>
<th>36</th>
<th>56</th>
<th>78</th>
<th>90</th>
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<tr>
<td>SiO$_2$</td>
<td>30.3</td>
<td>30.5</td>
<td>29.6</td>
<td>29.6</td>
<td>29</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
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<td>22.5</td>
<td>21.8</td>
<td>22.2</td>
<td>21.7</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>8.3</td>
<td>7.15</td>
<td>6.08</td>
<td>5.36</td>
<td>1.37</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>11.4</td>
<td>16.2</td>
<td>17.2</td>
<td>18.1</td>
<td>26.8</td>
</tr>
<tr>
<td>FeO</td>
<td>5.23</td>
<td>3.89</td>
<td>4.42</td>
<td>3.79</td>
<td>2.45</td>
</tr>
<tr>
<td>Others</td>
<td>6.18</td>
<td>6.29</td>
<td>6.35</td>
<td>6.04</td>
<td>3.38</td>
</tr>
</tbody>
</table>

Fig. 2 (a) XRD and (b) FT-IR spectra of parent and Fe-incorporated Na-A zeolites.

Fig. 3 CEC and BET surface area of parent and different Fe-incorporated zeolite.
3.2 The result of gas adsorption on Fe-NaA pellets

3.2.1 The adsorption results of ammonia

Both uncalcined MF and MFG were used for ammonia adsorption experiment (Fig. 4). MF showed higher value than MFG at 36 mM and 78 mM of Fe$^{3+}$ concentration, but showed similar value at other concentrations. The highest gas adsorption capacities were observed 1.3% and 1.0% for MF-78 and MFG-78, respectively.

MF and MFG were calcined at 500°C for 5 h, and these calcined samples were taken for ammonia adsorption studies (Fig. 4). It is observed that for both MF and MFG samples, the highest gas adsorption capacities were observed at 3.4 and 3.7% for MF-56-500 and MFG-56-500, respectively. Comparing the adsorption capacities of un-calcined samples, where maximum adsorption capacities were observed for MF-78 and MFG-78. Also after calcination, MFG showed little higher ammonia adsorption capacities than MF in the concentration of 18, 36 and 56 mM, whereas in the case of 0 and 78 mM of Fe$^{3+}$ concentration, MF showed higher values. From adsorption capacity, it can be inferred that at 56 mM Fe$^{3+}$ concentration, adsorbent was more activated than at other concentration and also presence of sodium silicate added more value to the adsorbent than PVA. Surface area analysis result showed that the surface area values obtained before and after calcinations are proportional to Fe$^{3+}$ concentrations. It was observed that after calcinations surface area of all samples decreased (Fig. 5).

For un-calcined samples, both MF and MFG samples showed similar surface area values, while after calcination at 500°C, MF has little higher surface area than MFG for particular iron concentration. Although BET surface area for MFG-78-500 and MF-78-500 are higher than that of corresponding MFG-56-500 and MF-56-500 samples, but ammonia adsorption capacities are decreased for samples prepared from 78 mM solution. It may be inferred from these studies that the ammonia adsorption capacities of Na-A zeolites more depend on their iron concentration rather than on the type of binders used during pelletization.

It was observed that calcined Na-A zeolites prepared from iron solution of 56 mM (MF-56-500 and MFG-56-500) showed maximum ammonia adsorption capacities. Therefore, zeolite pellets prepared from 56 mM iron concentration (MF-56 & MFG-56) were calcined at different temperatures (200~800°C) for 5h to study the effect of calcination temperature on their gas adsorption capacities (Fig. 6). Increase in calcination temperature increased the NH$_3$ adsorption capacities for both MF and MFG samples up to 500°C, then decreased with further increase in calcination temperature. Below 400°C, MF showed higher adsorption capacities (0.8~2.5%) than those of MFG (0.8~1.9%), but...
above 500 °C the reverse was observed. The activation of adsorbent surface is expected to increase with increase of calcinations temperature up to 500 °C. However, beyond that (>600 °C) there is occurrence of destabilization in adsorption site and thereby decreasing the adsorption capacity.

BET surface area of both MF and MFG were measured as a function of their calcination temperature and the results are shown in Fig. 7. BET surface area was found to decrease with increase in calcination temperature. Above 600 °C, surface area value diminished rapidly, and the sample calcined at 800 °C showed BET surface area below 5 m²/g. The SEM image of two samples calcined at 500 and 800 °C is shown in Fig. 8. The SEM image of the 800 °C calcined sample (Fig. 8(b)) suggested that the crystal of zeolite was melted, which resulted in significant loss of surface area.

Clearer evidence was obtained from the XRD pattern (Fig. 9) where 800 °C calcined sample showed transformation of Na-A type zeolite into nepheline (NaAlSiO₄). The crystal structure of the Na-A type zeolite was found to be preserved up to 700 °C calcination temperature.

3.2.2 The adsorption results of hydrogen sulfide

Figure 10 shows the H₂S adsorption capacities of both MF and MFG zeolite pellets as a function of iron concentration before and after calcination at 200 °C. For all samples, the adsorption capacities (0.1~1.5%) for H₂S are less than that for NH₃ (0.4~3.7%).

Adsorption capacity for H₂S was directly proportional to iron concentration, which was similar trend with ammonia adsorption. Samples calcined at 200 °C (0.1~1.5%) have higher capacity than un-calcined samples (0.1~0.8%). MF (0.2~0.8%) and MF-200 (0.1~1.5%) showed higher adsorption capacities than corresponding MFG (0.1~0.7%) and MFG-200 (0.1~1.0%), respectively. Increase of adsorption capacity was similar trend with that of surface area (Fig. 5). Non-incorporated sample showed lowest capacity, and adsorption capacities increased almost linearly with increase in Fe³⁺ concentration up to 78 mM.

The results of H₂S adsorption capacities of MF and MFG as a function of calcination temperature are shown in Fig. 11. The highest adsorption capacity was observed in the sample calcined at 200 °C. Whereas, minimum adsorption was observed for samples calcined at 500 °C, which is in contrast to the trends observed for ammonia adsorption. It is well known that NH₃ gas is basic and H₂S is acidic. Adsorption of these two gases depends upon the surface acidity of the adsorbent. With increase of calcination temperature, there may be change in surface acidity of the adsorbent. Therefore differences observed in adsorption capacity for both the gases according to calcination temperature. In any case, the H₂S adsorption capacities are quite low in comparison to NH₃ adsorption capacities.
ties of zeolites. Structural modification also affect the gas adsorption capacities. These results indicate that, besides surface area, factors such as surface acidity and water content. Heating the zeolite leads to the various structural changes such as contraction of unit cell, removal of water, phase transformation and breaking of bonds.

The present study also revealed that for all Fe-NaA, NH$_3$ adsorption capacities are much higher than H$_2$S adsorption capacities. It was well known that H$_2$S is acidic gas and NH$_3$ is basic gas. Although H$_2$S has smaller molecular size than NH$_3$, but the higher adsorption capacities for the latter is due to the acidic surface properties of Fe-NaA. Similar results were obtained previously from the study of gas adsorption of NH$_3$ and H$_2$S using acid and base treated activated carbon (AC). Acid treated AC showed higher adsorption capacity for NH$_3$ than that of H$_2$S. Whereas, base treated AC showed higher adsorption capacity for H$_2$S than that of NH$_3$. In the present study, even in the dried samples, gas adsorption capacities for NH$_3$ (0.4–1.3%) were 1.5–4 times higher than that for H$_2$S (0.1–0.8%). This indicates that addition of Fe$^{3+}$ lead to the effect of increasing the surface acidity of adsorbent. This may be the case for the heat treated samples, where heating up to 500°C increased the ammonia adsorption capacities in 3 times and decreased the H$_2$S adsorption capacities in half.

Different ammonia adsorption behavior was also noticed for uncalcined and calcined Fe-NaA with respect to their Fe$^{3+}$ concentration. For both un-calcined MF and MFG, increasing iron concentration up to 78 mM linearly increased their ammonia adsorption capacities. However, for samples calcined at 500°C, the iron concentration for maximum ammonia adsorption was found to be MF-56 and MFG-56. In both cases (MF & MFG) for samples from iron concentration ≤ 56 mM, calcination at 500°C increased their ammonia adsorption capacities almost three times.

But, after calcination, MF-78 (2.8%) and MFG-78 (2.4%) showed lower value than MF-56 (3.4%) and MFG-56 (3.7%). Earlier study made by Díaz et al. indicated that lattice parameter of CaA zeolite changes with Fe exchange. In this study, incorporated Fe affects increasing lattice parameter and surface area in 78 mM concentration leading to the improved adsorption capacity. But, after calcination at 500°C oxidation of incorporated Fe leads to the structural modification of zeolite and thus decreases the adsorption capacity for ammonia. The lattice parameters of Fe-NaA zeolites were presented in Table 3. As shown in Table 3, lattice parameter value changed with increase of Fe$^{3+}$ concentration.

In another study, Lee et al. claimed that ammonia adsorption capacities of natural zeolites depend on their water content. Heating the zeolite leads to the various structural changes such as contraction of unit cell, removal of water, phase transformation and breaking of bonds.

### Table 3 The lattice parameter of Fe-NaA.

<table>
<thead>
<tr>
<th>FeCl$_3$ Concentration (mM)</th>
<th>Lattice parameter (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dried</td>
</tr>
<tr>
<td>0</td>
<td>2.433</td>
</tr>
<tr>
<td>18</td>
<td>2.467</td>
</tr>
<tr>
<td>36</td>
<td>2.474</td>
</tr>
<tr>
<td>56</td>
<td>2.485</td>
</tr>
<tr>
<td>78</td>
<td>2.502</td>
</tr>
</tbody>
</table>

Several interesting observations have been obtained during preparation of Fe-NaA, and studying their gas adsorption capacities with respect to their iron concentration during preparation, calcination temperature and type of binders used for making pellets. The maximum concentration of iron that can be accommodated into Na-A zeolite network structure is 78 mM. Further increasing the iron concentration destroyed the zeolite structure, which was evident from the results of XRD and FT-IR (Fig. 2). Although BET surface area was found to increase with increase in iron concentration up to 90 mM, but ammonia adsorption capacities decreased above 78 mM iron concentration. These results indicate that, besides surface area, factors such as surface acidity and structural modification also affect the gas adsorption capacities of zeolites.

**Fig. 10** Hydrogen sulfide adsorption capacities of MF and MFG samples uncalcined and calcined at 200°C.

**Fig. 11** Hydrogen sulfide adsorption capacities of MF-78 and MFG-78 samples calcined at various temperatures.
Fe-NaA pellets showed much higher adsorption capacity (2.4~3.7%) than any other adsorbents (0.16~0.6%). Thus Fe-NaA pellets are a promising adsorbent for ammonia and can be used commercially.

5. Conclusion

Iron incorporated zeolites were prepared reacting with 0~90 mM FeCl₃ solution and Na-A type zeolite synthesized from municipal waste incineration melting slag. These iron-incorporated zeolites were further pelletized and calcined to study their adsorption capacities for NH₃ and H₂S gasses. The detail study showed several interesting observations which can be summarized below.

1) The maximum concentration of iron that can be accommodated into the Na-A zeolite is 78 mM, higher iron concentration resulted in destruction of Na-A zeolite structure.

2) The BET surface area was found to increase with increase in iron concentration of solution, e.g. surface area increased from 20 m²/g to 85 m²/g by increasing the iron concentration from 0 to 78 mM. However cation exchange capacity decreased with increase in iron concentration of solution.

3) The ammonia adsorption capacities of iron incorporated Na-A zeolite pellets found to vary with varying the iron concentration and calcination temperature, but less depended on the type of binders used during their pelletization.

4) The highest gas adsorption capacities were observed for Na-A zeolites prepared from 56 mM FeCl₃ solution and calcined at 500°C for ammonia and 78 mM FeCl₃ solution and calcined at 200°C for hydrogen sulfide.

5) The ammonia adsorption capacities (2.4~3.7%) of iron incorporated Na-A type zeolite calcined at 500°C are found to be much higher than several commercial activated carbons (0.16~0.44%) and zeolites (0.23~0.60%).

6) The hydrogen sulfide adsorption capacities (0.2~1.5%) of iron incorporated Na-A type zeolite pellets are found to be lower than commercial activated carbons (1.2~2.4%), but higher than commercial zeolites (4A (0.15%) and 13X (0.91%)).

7) Surface acidity, induced due to incorporation of Fe³⁺ seems to be the principal factor increasing the ammonia adsorption capacities.

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Table 4 The results of Hg porosimeter measurements.

<table>
<thead>
<tr>
<th>Calcination Temperature, °C</th>
<th>200°C</th>
<th>300°C</th>
<th>400°C</th>
<th>500°C</th>
<th>600°C</th>
<th>700°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>total intrusion volume (mL/g)</td>
<td>0.6022</td>
<td>0.5563</td>
<td>0.5743</td>
<td>0.654</td>
<td>0.6412</td>
<td>0.5864</td>
</tr>
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Table 5 Comparison of various adsorbents.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Adsorption Capacity, %</th>
<th>N₂/H₂S Flow rate, ml/min</th>
<th>Column diameter, mm [sample mass, g]</th>
<th>Adsorption Capacity, %</th>
<th>N₂/NH₃ Flow rate, ml/min</th>
<th>Column diameter, mm [sample mass, g]</th>
</tr>
</thead>
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<tr>
<td>Coconut AC</td>
<td>1.2~1.8</td>
<td>90/10</td>
<td>15 [5]</td>
<td>0.16</td>
<td>70/30</td>
<td>15 [5]</td>
</tr>
<tr>
<td>Coal AC</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.25</td>
<td>70/30</td>
<td>15 [5]</td>
</tr>
<tr>
<td>Bamboo AC</td>
<td>2.4</td>
<td>90/10</td>
<td>15 [5]</td>
<td>0.44</td>
<td>70/30</td>
<td>15 [5]</td>
</tr>
<tr>
<td>4A zeolite</td>
<td>0.15</td>
<td>90/10</td>
<td>15 [5]</td>
<td>0.3~0.6</td>
<td>70/30</td>
<td>15 [5]</td>
</tr>
<tr>
<td>13X zeolite</td>
<td>0.91</td>
<td>90/10</td>
<td>15 [5]</td>
<td>0.23</td>
<td>70/30</td>
<td>15 [5]</td>
</tr>
<tr>
<td>FeNaA (calcined)</td>
<td>0.2~1.5</td>
<td>90/10</td>
<td>15 [5]</td>
<td>2.4~3.7</td>
<td>70/30</td>
<td>15 [5]</td>
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</table>
Acknowledgement

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REFERENCES