

Main features of the tested sorbents.

A) CATION EXCHANGE

Geopolymer KG_2 , $NaG_{1.2}$, and KG_3

They are metakaolin-based materials with Si/Al ratios of 2, 1.2 and 3, respectively, sodium or potassium as counterion. KG_2 also coded G13 in [29], for instance, has a specific surface area (SSA) of 77 m²/g, a true density of 2.27 g/cm³, and a bulk density of 0.70 g/cm³. These geopolymers are particularly effective for CO₂ capture and ammonium removal, with G13 exhibiting a cation exchange capacity (CEC) of 3.0 meq/g.

Molecular Sieve MS13X

It is a synthetic zeolite with the chemical formula $Na_8(AlO_2)_8(SiO_2)_{16} \cdot xH_2O$. It has a high SSA of 600-800 m²/g, a bulk density of 0.7-0.8 g/cm³, and a true density of 2.2 g/cm³. This material is highly hydrophilic, thermally stable up to 600°C, and effective for ammonium and metal cation removal due to its high CEC.

Molecular Sieve MS4A

It has the formula $Na_{12}[(AlO_2)_{12}(SiO_2)_{12}] \cdot xH_2O$. It features of an SSA of 400–600 m²/g, a bulk density of 0.6–0.8 g/cm³, and a true density of 2.2 g/cm³. Its uniform pore openings of 4 Å make it suitable for small molecule adsorption and ionexchange, particularly for removing calcium, magnesium, and ammonium ions

Natural Zeolite Chabazite/Phillipsite

It is a mixture of two zeolites with the formula $(Ca,Na_2,K_2)_4(Al_8Si_{40}O_{96}) \cdot 24H_2O$. It has an SSA of 400-600 m²/g, a bulk density of 0.7-1.0 g/cm³, and a true density of 2.2 g/cm³. This material is effective for ammonium and heavy metal removal, with a CEC of 2.4 meq/g and thermal stability up to 300-400°C.

Clinoptilolite

It is another natural zeolite that has the formula $(Na,K,Ca)_{2-3}Al_3(Al,Si)_2Si_{13}O_{36} \cdot 12H_2O$. Its SSA ranges from 20 to 40 m²/g, with a bulk density of 0.7-1.1 g/cm³ and a true density of 2.2 g/cm³. It is effective for ammonium and heavy metal removal, with a CEC of 2.3 meq/g and thermal stability up to 500-600°C.

Zeolite N

It is a synthetic zeolite with an SSA of 300-800 m²/g and a high CEC of 0.120-0.150 meq/g. It is thermally stable up to 500-600°C and is used for ammonium removal, water softening, and gas adsorption.

Montmorillonite

Montmorillonite, a smectite clay, has the formula $(Na,Ca)_{0.35-0.05}Al_4Si_8O_{204} \cdot nH_2O$. It boasts a high SSA of 700-800 m²/g and a bulk density of 1.0-1.5 g/cm³. Its high CEC (70-150 meq/g) makes it effective for heavy metal and nutrient adsorption, and its expandable interlayer spacing enhances its adsorption capabilities.

Vermiculite

Vermiculite, a hydrated magnesium-aluminum-iron silicate, has an SSA of 20-30 m²/g in its natural form, which increases after exfoliation. It has a high CEC (0.1-0.15 meq/g) and is used in soil conditioning and environmental remediation. It is thermally stable up to 900°C.

Sepiolite

Sepiolite, a fibrous clay mineral with the formula Mg₄Si₆O₁₅(OH)₂·6H₂O, has an SSA of 100-300 m²/g. It has moderate CEC (0.02-0.04 meq/g) but is highly absorbent, making it suitable for environmental remediation. It is thermally stable up to 500-700°C.

Kaolinite

Kaolinite, with the formula Al₂Si₂O₅(OH)₄, has a low SSA of 10-15 m²/g and a bulk density of 2.6 g/cm³. Its low CEC (0.03-0.15 meq/g) limits its ion-exchange capabilities, but it is chemically stable and widely used in ceramics, paper coating, and as a filler.

Siral 30 by Sasol^{RT}

Siral 30, a commercial ion-exchange resin produced by Sasol^{RT}, is based on a styrene-divinylbenzene copolymer with sulfonic groups. It has a high SSA and is effective for heavy metal and ammonium removal, with particle sizes ranging from 300 to 1200 µm.

Terrana P61, P62, and P63

The Terrana P61, P62, and P63 products are bentonite-based adsorbents with different activation processes. P61 is acid-activated and effective for COD reduction and heavy metal removal, operating in a pH range of 4-14. P62 is a natural bentonite used as a flocculant and filter aid, with a pH range of 7.5-8.3. P63 is alkaline-activated and effective for colloidal impurity and heavy metal removal, with a pH range of 8-9.

b) ANION EXCHANGE

Pural 50, Pural 61 and Pural 70 by Sasol^{RT}

Hydrotalcites, a class of Layered Double Hydroxides (LDH), are characterized by the general formula Mg₆Al₂CO₃(OH)₁₆·4H₂O. The commercial variants Pural 50, Pural 61, and Pural 70 by Sasol^{RT} differ in composition: Pural 50 (50% MgO, 50% Al₂O₃), Pural 61 (61% MgO, 39% Al₂O₃), and Pural 70 (70% MgO, 30% Al₂O₃). Their specific surface areas are 2.9 m²/g (Pural 50), 166 m²/g (Pural 61), and 180 m²/g (Pural 70), with a pore volume of 0.2 ml/g. Bulk densities range from 450-650 g/L (Pural 50), 150 g/L (Pural 61), to 350-550 g/L (Pural 70). These materials were also tested after calcination at 500°C for 5 hours.

Sorbacid911

It is a hydrotalcite, a chemical compound with the general formula [Mg₂Al₃(OH)_{2(2+x)}](CO₃)_n·nH₂O (where x ranges from 4 to 6, and n from 0 to 10). It appears as a fine, white, and odorless powder and is characterized as a hydrated aluminum-magnesium carbonate hydroxide. Physically, it has a BET surface area of ≤ 15 m²/g, a bulk density of approximately 350 g/l, and a particle size distribution with D₅₀ ≤ 1 µm and D₉₀ ≤ 10 µm. This material is primarily used as a stabilizer in flexible PVC

Pyroaurite

Pyroaurite, a hydrotalcite-like material with the formula $\text{Mg}_6\text{Fe}_2(\text{OH})_{16}[\text{CO}_3]\cdot 4\text{H}_2\text{O}$, was synthesized via co-precipitation of magnesium and iron nitrates (Mg:Fe ratio of 3:1) at 50°C and pH 10.5, using sodium carbonate and NaOH. The precipitate was aged, washed, dried at 110°C, and calcined at 450°C for 5 hours to form a porous Mg/Fe/O structure. Both dried and calcined samples were pelletized, crushed, and sieved to a particle size range of 0.355-0.710 mm.

Pural 50, 61 and 70, Sorbacid 911 and Pyroaurite were calcined at 500 °C before testing their sorption capacities. Calcination was conducted with a 2.5°C/minute temperature ramp, followed by exposure to 500°C for 5 hours.

