# Supplemental Material

# Inorganic ion exchangers for cesium removal from radioactive wastewater

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| **Material** | **Chemical Formula** | **CEC (meq g-1)** | ***K*d · 10-3 (cm3 g-1)** | ***K*´** | **Ref.** | **Observations** |
| **Zeolites** |
| clinoptilolite | |(K,Na,Ca0.5,Sr0.5,Ba0.5,Mg0.5)6(H2O)20|[Al6Si30O72] (1) | 0.64 – 1.84 (80,30) | 1.720 (V:m = 400 cm3·g-1),1.950 (V:m = 200 cm3·g-1),1.920 (V:m = 133 cm3·g-1)and 1.910 (V:m = 100 cm3·g-1)@ pH = 5and C0 = 0.012 M 134Cs (77) | - | (3,2,4) | The source influences the CEC value |
| 1.930 (pH = 3),1.950 (pH = 5),2.040 (pH = 7)and 1.950 (pH = 9)@ V:m = 100 cm3·g-1and C0 = 0.012 M 134Cs (77) |
| erionite | (Na2,K2,Ca)2Al4Si14O36·15H2O | ~1.90 | - | - | (3) | - |
| phillipsite | |(K,Na,Ca0.5)*x*(H2O)12|[Al*x*Si16-*x*O32] (1) | 0.40 | - | - | (5) | Theoretical CEC value of 2.08 |
| mordenite | |(K2,Na2,Ca)4(H2O)28|[Al8Si40O96] (1) | 1.93 | 4.770 (V:m = 400 cm3·g-1),4.490 (V:m = 200 cm3·g-1),4.130 (V:m = 133 cm3·g-1)and 4.510 (V:m = 100 cm3·g-1)@ pH = 5and C0 = 0.012 M 134Cs | - | (4) | - |
| 4.170 (pH = 3),4.480 (pH = 5),4.150 (pH = 7)and 4.120 (pH = 9)@ V:m = 100 cm3·g-1and C0 = 0.012 M 134Cs |
| Na-chabazite | Na0.15Ca0.90Al1.95Si4.05O12·6H2O | 2.07 | 4.290 (V:m = 400 cm3·g-1),4.780 (V:m = 200 cm3·g-1),4.510 (V:m = 133 cm3·g-1)and 4.800 (V:m = 100 cm3·g-1)@ pH = 5and C0 = 0.012 M 134Cs | - | (4) | - |
| 5.060 (pH = 3),4.780 (pH = 5),4.770 (pH = 7)and 4.920 (pH = 9)@ V:m = 100 cm3·g-1and C0 = 0.012 M 134Cs |
| nanometer-sized zeolite A | Na12Al12Si12O48·27H2O | ~3.2 | - | - | (6) | - |
| zeolite LTA | ~1.3 | - | - | (6) | Theoretical CEC value of 5.48 |
| zeolite X | |(Mg,Na2,Ca)29(H2O)240|[Al58Si134O384] (1) | 3.20 | - | - | (3) | Faujasite [FAU] structure |
| zeolite Y | 2.50 |
| zeolite P | Na7Al7Si9O32 | 1.76 (Cs+) and 3.76 (Sr2+) | **Sr2+**0.009 (pH = 3.2),0.055 (pH = 4.0),0.398 (pH = 4.9),0.603 (pH = 5.6),1.315 (pH = 7.3),1.173 (pH = 9.9),1.323 (pH = 10.0)and 1.308 (pH = 10.8)@ V:m = 300 cm3·g-1and C0 = 10 mg·L-1 | Cs/Sr = 0.468 A  | (7) | - |
| **Sr2+**12.98 (9.0x10-5 M Na+),18.29 (1.1x10-3 M Na+),5.23 (1.0x10-2 M Na+),0.38 (9.8x10-2 M Na+)and 0.02 (9.9x10-1 M Na+)@ V:m = 300 cm3·g-1and C0 = 10 mg·L-1 |
| **Cs+**0.009 (pH = 1.9),0.106 (pH = 3.4),0.466 (pH = 4.0),0.585 (pH = 4.3),0.735 (pH = 4.5),0.748 (pH = 6.4),0.648 (pH = 8.0)and 0.546 (pH = 8.8)@ V:m = 300 cm3·g-1and C0 = 10 mg·L-1 |
| **Cs+**21.23 (9.8x10-5 M Na+),18.29 (9.8x10-4 M Na+),3.50 (1.0x10-2 M Na+),0.54 (9.7x10-2 M Na+)and 0.07 (9.8x10-1 M Na+)@ V:m = 300 cm3·g-1and C0 = 10 mg·L-1 |
| **Tianosilicates** |
| AM-2 | K2TiSi3O9·H2O | <4.03 (Cs+), <5.05 (Sr2+) and <5.39 (Mn2+ and Ca2+) | - | Cs/Sr = 0.799 A@ 1 M and V:m = 33 mL·g-1) | (8) | Theoretical CEC value of 5.64 |
| AM-3 | Na4Ti2Si8O22·5H2O | 0.98 (60Co) | 2.197 (t = 1.0 h),3.386 (t = 4.0 h),3.088 (t = 24.0 h),4.045 (t = 96.0 h),3.640 (t = 170.0 h)and 4.168 (t = 340 h)@ V:m = 200 cm3·g-1and C0 = 5.9 mg·L-1 | - | (9) | Initial concentration of 10 meq·L-1 |
| 0.661 (C0 = 0.01 mg·L-1),2.952 (C0 = 5.9 mg·L-1),1.726 (C0 = 58 mg·L-1)and 0.121 (C0 = 590 mg·L-1)@ 2 h and V:m = 200 cm3·g-1 |
| 1.454 (V:m = 100 cm3·g-1),3.100 (V:m = 200 cm3·g-1),6.203 (V:m = 300 cm3·g-1),8.194 (V:m = 400 cm3·g-1),9.341 (V:m = 500 cm3·g-1)and 13.703 (V:m = 800 cm3·g-1)@ 2 h and C0 = 5.9 mg·L-1 |
| AM-4 | Na3(Na,H)Ti2O2(SiO6)2·2H2O | 3.23 (UO22+) | 0.026 (t = 2.5 h),0.092 (t = 20 h),0.118 (t = 50 h),0.091 (t = 97 h),0.439 (t = 167 h),0.365 (t = 338 h),1.198 (t = 507 h),2.392 (t = 672 h)and 2.200 (t = 841 h)@ C0 = 250 mg·L-1and V:m = 200 cm3·g-1 | - | (10) | Theoretical CEC value of 7.63 |
| 0.1763 (C0 = 75 mg·L-1),0.361 (C0 = 791 mg·L-1),0.197 (C0 = 1534 mg·L-1),19.241 (C0 = 1891 mg·L-1), 68.332 (C0 = 2480 mg·L-1),0.663 (C0 = 9902 mg·L-1)and 0.979 (C0 = 19993 mg·L-1)@ 24 h and V:m = 200 cm3·g-1 |
| 0.054 (V:m = 100 cm3·g-1),0.104 (V:m = 200 cm3·g-1),0.464 (V:m = 400 cm3·g-1),0.467 (V:m = 600 cm3·g-1),0.686 (V:m = 800 mL·g-1)and 0.983 (V:m = 1000 cm3·g-1)@ 24 h and C0 = 250 mg·L-1 |
| ETS-10 | (Na,K)2TiSi5O13·*n*H2O | 4.8 (Sr2+) and 5.5 (Cs+) | - | Cs/Sr = 1.149 A@ 24 h, pH neutral, C0 = 4 - 90 meq·L-1, and V:m = 250 cm3·g-1 | (11) | Theoretical CEC value of 4.52 (12) |
| ETS-4 | Na9Si12Ti5O38(OH)·12H2O (13) | 6.2 (Cs+) and 4.8 (Sr2+) | - | Cs/Sr = 1.292 A@ 24 h, pH neutral, C0 = 4 - 90 meq·L-1, and V:m = 250 cm3·g-1 | (14,11) | Theoretical CEC value of 6.39 |
| H-crystalline silicotitanate | H2Ti2O3SiO4·1.5H2O | <1.9 (Cs+), <7.2 (Li+ and Na+) and <5.6 (Rb+ and K+) | - | **Li+/Na+** (Ẋ = 0.001), (Ẋ = 0.01), (Ẋ = 0.02),and (Ẋ = 0.04)@ C0 = 10-3 M LiCl–LiOH and V:m = 300 cm3·g-1 | (15,16) | Theoretical CEC value of 7.50. The highest exchange occurs at pH 12 |
| **K+/Na+**1.58 (Ẋ = 0.09),1.12 (Ẋ = 0.17),0.65 (Ẋ = 0.22),0.81 (Ẋ = 0.33),0.45 (Ẋ = 0.41),0.31 (Ẋ = 0.47),0.23 (Ẋ = 0.49),0.19 (Ẋ = 0.53),and 0.13 (Ẋ = 0.58)@ C0 = 10-3 M KCl–KOH and V:m = 300 cm3·g-1 |
| **Cs+/Na+**288.40 (Ẋ = 0.10),251.19 (Ẋ = 0.20),177.83 (Ẋ = 0.30),52.48 (Ẋ = 0.51),1.86 (Ẋ = 0.68),0.50 (Ẋ = 0.73),and 0.30 (Ẋ = 0.72)@ C0 = 10-3 M CsCl–CsOH and V:m = 300 cm3·g-1 |
| **Rb+/Na+**154.88 (Ẋ = 0.10),138.04 (Ẋ = 0.20),93.33 (Ẋ = 0.30),30.20 (Ẋ = 0.55),2.75 (Ẋ = 0.78),0.47 (Ẋ = 0.84),0.20 (Ẋ = 0.87),0.13 (Ẋ = 0.88),and 0.06 (Ẋ = 0.92)@ C0 = 10-3 M RbCl–RbOH and V:m = 300 cm3·g-1 |
| H-ivanyukite | H4Ti4O4(SiO4)3 | <4.2 (Cs+) and <3.80 (K+, Li+ and Na+) | < 0.001 (Li+),0.180 (Na+),1.800 (K+),11.000 (Cs+),0.011 (Mg2+),0.070 (Ca2+),0.330 (Sr2+)and 1.000 (Ba2+)@ C0 = 0.1 Mand V:m = 625 cm3·g-1 | - | (17) | Theoretical CEC value of 7.46. The highest exchange occurs at pH ~8.5 |
| Nb-crystalline silicotitanate | Na1.5Nb0.5Ti1.5O3SiO4·2H2O | <11.8 (90Sr) and < 3.2 (137Cs) | **Sr2+**0.605 (Nb-2 mmol),25.648 (Nb-4 mmol),20.221 (Nb-8 mmol),18.655 (Nb-12 mmol),and 7.809 (Nb-24 mmol)@ C0 = 0.1 M and V:m = 100 cm3·g-1 | - | (18) | Commercially available under the trade name IONSIV R-9120B (previously IE-911) from UOP LLC with CEC value of 0.52 meq·g-1 |
| **Sr2+**1.487 (t = 0.01 h),5.404 (t = 0.5 h),6.687 (t = 1.0 h),6.753 (t = 1.5 h),11.549 (t = 2.0 h),25.611 (t = 24.0 h)for Nb-4 mmol@ C0 = 0.1 M and V:m = 100 cm3·g-1 |
| **Cs+**0.550 (Nb-2 mmol),35.490 (Nb-4 mmol),26.136 (Nb-8 mmol),22.045 (Nb-12 mmol),and 7.762 (Nb-24 mmol)@ C0 = 0.1 M and V:m = 100 cm3·g-1 |
| **Cs+**2.162 (t = 0.01 h),2.904 (t = 0.5 h),5.065 (t = 1.0 h),6.618 (t = 1.5 h),9.927 (t = 2.0 h),35.476 (t = 24.0 h)for Nb-4 mmol@ C0 = 0.1 M and V:m = 100 cm3·g-1 |
| ivanyukite | HM3(AO)4(BO4)3·4-6H2O (19,20,21) | <2.4 (Sr2+) and < 3.12 (Cs+) | **Na-form and Sr2+**3.474 (0.1 M Na+),0.483 (0.5 M Na+),0.256 (1.0 M Na+),0.077 (2.5 M Na+),and 0.050 (5.0 M Na+)@ 24 h, C0 = 10-3 M and V:m = 200 cm3·g- | - | (22) | M = H, Na, K or Cs; A=Ti or Ge; B= Si or GeThe K-form selectively exchanges Sr while the Na-form exchanges preferentially CsTheoretical K- and Na-form CEC values of 6.16 and 6.65, respectively |
| **Na-form and Cs+**15.700 (0.01 M Na+),7.270 (0.1 M Na+),1.461 (0.5 M Na+),and 0.138 (5.0 M Na+)@ 24 h, C0 = 10-3 M and V:m = 200 cm3·g- |
| **K-form and Sr2+**29.027 (0.1 M Na+),2.989 (0.5 M Na+),0.483 (2.5 M Na+),and 0.308 (5.0 M Na+)@ 24 h, C0 = 10-3 M and V:m = 200 cm3·g- |
| **K-form and Cs+**2.308 (0.01 M Na+),1.344 (0.1 M Na+),and 0.049 (5.0 M Na+)@ 24 h, C0 = 10-3 M and V:m = 200 cm3·g- |
| sitinakite or crystalline silicotitanate | Na2Ti2O3SiO4·2H2O | <14.6 (90Sr) and < 4.4 (137Cs) | 9.725 (pH = 1.0),9.714 (pH = 2.0),9.933 (pH = 6.0),3.134 (pH = 8.0),1.573 (pH = 10.0),1.088 (pH = 12.0),0.918 (pH = 13.0)and 1.066 (pH = 14.0)@ C0 = 100 mg·L-1Cs+ (+ 5.7 M Na+)(23) | **Li+ /Na+** (15)0.17 (Ẋ = 0.04),0.15 (Ẋ = 0.07),0.13 (Ẋ = 0.09),0.13 (Ẋ = 0.11),0.14 (Ẋ = 0.15),0.11 (Ẋ = 0.22),0.07 (Ẋ = 0.24),0.07 (Ẋ = 0.28),0.07 (Ẋ = 0.32) and 0.03 (Ẋ = 0.35)@ C0 = 10-3 M RbCl–RbOH and V:m = 300 cm3·g- | (23,24,15) | The non-ideal formula of the exchanger is Na1.64H0.36Ti2O3SiO4·1.8H2O (25,26)  |
| **K+ /Na+** (15)12.59 (Ẋ = 0.11),19.05 (Ẋ = 0.22) ,13.18 (Ẋ = 0.33),12.59 (Ẋ = 0.44),12.30 (Ẋ = 0.51), and 0.52 (Ẋ = 0.97)@ C0 = 10-3 M RbCl–RbOH and V:m = 300 cm3·g- |
| 13.206 (pH = 1.3),20.084 (pH = 2.2),24.976 (pH = 6.0),2.895 (pH = 8.2),0.886 (pH = 12.0),0.839 (pH = 13.1),0.779 (pH = 13.6)and 1.352 (pH = 14.0)@ C0 = 100 mg·L-1Cs+ (+ 5.7 M Na+)(24) | **Cs+ /Na+** (15)(15)109.65 (Ẋ = 0.11),154.88 (Ẋ = 0.23),389.05 (Ẋ = 0.35),426.58 (Ẋ = 0.46),575.44 (Ẋ = 0.60),0.32 (Ẋ = 0.83) and 0.03 (Ẋ = 0.93)@ C0 = 10-3 M RbCl–RbOH and V:m = 300 cm3·g- |
| **Rb+/Na+** (15)467.74 (Ẋ = 0.12),831.76 (Ẋ = 0.24),1071.52 (Ẋ = 0.37),851.14 (Ẋ = 0.49),676.08 (Ẋ = 0.63) and 0.04 (Ẋ = 0.98)@ C0 = 10-3 M RbCl–RbOH and V:m = 300 cm3·g- |
| Nb-Sitinakite | Na1.5Nb0.5Ti1.5O3SiO4 \_ 2H2O | <2.02 (90Sr) and < 1.08 (137Cs) | **Cs+**27.627 (1.00 M Na+),21.921 (1.10 M Na+),15.834 (1.45 M Na+),10.145 (1.90 M Na+),3.760 (3.25 M Na+),1.186 (5.50 M Na+),@ 24 h and V:m = 250 cm3·g-1 |  | (27) |  |
| **Sr2+**10.849 (1.00 M Na+),10.306 (1.10 M Na+),9.304 (1.45 M Na+),6.834 (1.90 M Na+),4.464 (3.25 M Na+),2.438 (5.50 M Na+),@ 24 h and V:m = 250 cm3·g-1 |
| **Hexacyanoferrates** |
| potassium-cobalt hexacyanoferrate | 0.6 | 0.6-0.8 | 0.600 (t = 0.002 h),1.170 (t = 0.02),1.300 (t = 0.13 h),1.800 (t = 0.25 h),6.100 (t =0.5 h),10.100 (t = 1.0 h),and 10.500 (t = 2.0 h)@ C0 = 1.5 M NaOH, 4.7 M NaNO3, 1.2 M NaAlO2, 0.05 M Na2SO4, 5.0x10-3 M KNO3, 2.0x10-4 M CsNO3 traced with 5.0x104 disintegrations 137Cs/min/cm3 and V:m = 500 cm3·g-1 | - | (28,29) | - |
| potassium-nickel hexacyanoferrate | K0.87Ni0.57[NiFe(CN)6]·*n*H2O | < 2.6 | **Cs+ with NaNO3**323.12 (1.0 M Na+),183.47 (2.0 M Na+),187.71 (3.0 M Na+),243.05 (4.0 M Na+)and 162.85 (5.0 M Na+)@ 120 h, C0 = 10 mg·L-1 and V:m = 100 cm3·g-1 | **Cs+/K+** (Ẋ = 0.07), (Ẋ = 0.19), (Ẋ = 0.38),120.23 (Ẋ = 0.56),60.26 (Ẋ = 0.68),109.65 (Ẋ = 0.69),45.71 (Ẋ = 0.82),34.67 (Ẋ = 0.85),15.85 (Ẋ = 0.86),27.54 (Ẋ = 0.91),63.10 (Ẋ = 0.97)and 125.89 (Ẋ = 0.99)@ 120 h, pH = 8.21-8.49 and 0.1 M (Cs,K)Cl  | (30) | It is a non-stoichiometric compound |
| **Cs+ with NaCl**577.40 (1.0x10-4 M Na+), 235.19 (1.0x10-3 M Na+), 142.91 (0.01 M Na+),309.51 (0.1 M Na+),390.52 (0.5 M Na+),355.03 (1.0 M Na+),and 148.44 (2.0 M Na+)@ 120 h, C0 = 10 mg·L-1 and V:m = 100 cm3·g-1 |
| **Cs+, (K+,Ni2+)-form and NH4NO3**1535.75 (1.0x10-4 M NH4+), 774.32 (1.0x10-3 M NH4+), 452.83 (0.01 M NH4+),661.92 (0.1 M NH4+),38.48 (0.2 M NH4+),25.94 (0.3 M NH4+),12.67 (0.5 M NH4+),6.35 (1.0 M NH4+),2.49 (2.0 M NH4+),and 1.13 (5.0 M NH4+)@ 120 h, C0 = 10 mg·L-1 and V:m = 100 cm3·g-1 |
| **Cs+, K+-form and NH4NO3**20.80 (0.5 M NH4+),7.55 (1.0 M NH4+),3.11 (2.0 M NH4+),0.74 (5.0 M NH4+)@ 120 h, C0 = 10 mg·L-1 and V:m = 100 cm3·g-1 |
| **Cs+ and Ca(NO3)2**620.43 (1.0x10-4 M Ca2+), 2035.09 (1.0x10-3 M Ca2+), 646.97 (0.01 M Ca2+),542.28 (0.1 M Ca2+),274.68 (0.5 M Ca2+),317.43 (1.0 M Ca2+),585.02 (2.0 M Ca2+)@ 120 h, C0 = 10 mg·L-1 and V:m = 100 cm3·g-1 |
| **Cs+ with KNO3**418.62 (1.0x10-3 M K+),221.44 (0.01 M K+),272.78 (0.1 M K+),133.85 (0.5 M K+),55.62 (1.0 M K+)and 51.00 (2.0 M K+)@ 120 h, C0 = 10 mg·L-1 and V:m = 100 cm3·g-1 |
| **Cs+ with 0.1 M (N,Na)Cl**76.53 (pH = 1.3),73.66 (pH = 1.7),25.26 (pH = 2.8),359.76 (pH = 6.0),130.67 (pH = 7.7),314.72 (pH = 9.0),308.76 (pH = 9.2)and 236.29 (pH = 9.3)@ 120 h, C0 = 10 mg·L-1 and V:m = 100 cm3·g-1 |
| **Rb+ with NaNO3**17.66 (0.001 M Na+),23.24 (0.1 M Na+),6.65 (1.0 M Na+),1.01 (3.0 M Na+)and 0.33 (5.0 M Na+)@ 120 h, C0 = 10 mg·L-1 and V:m = 100 cm3·g-1 |
| **Metallic/hydrous metallic oxides** |
| Hydrous manganese oxide | Mn(OH)2 | 50.2 | 0.512 (T=303 K)0.604 (T=313 K)0.655 (T=323 K)0.768 (T=333 K)@ V:m=100 cm3·g-1,pH=3.85 and C0 = 1x10-5 M Cs |  | (31) |  |
| Hydrous stannic oxide | SnO2·H2O | 78.1 | 0.653 (T=303 K)0.785 (T=313 K)0.906 (T=323 K)1.093 (T=333 K)@ V:m=100 cm3·g-1,pH=3.85 and C0 = 1x10-5 M Cs  |  | (31) |  |
| Hydrous manganese oxide | MnO2·H2O | 171.9 (Ce3+) and 64.2 (Cs+) | **Cs+**0.514 (T=303 K)0.599 (T=313 K)0.668 (T=323 K)0.771 (T=333 K)@ V:m=100 cm3·g-1,pH=3.8 and C0 = 1x10-5 M Cs | Cs/ Ce = 0.165 A(T=303 K) | (32) |  |
| **Ce3+**3.117 (T=303 K)3.617 (T=313 K)4.008 (T=323 K)4.652 (T=333 K)@ V:m=100 cm3·g-1,pH=6.2 and C0 = 1x10-5 M Ce |
| Hydrous manganese oxide | MnO2·H2O |  | **Cs+**4.245 (V:m=300 cm3·g-1)@ pH=5 and C0 = 5x10-5 M Cs |  | (33) |  |
| **Co2+**0.821 (V:m=300 cm3·g-1)@ pH=5 and C0 = 5x10-6 M Co |
| Todorokite-Type Manganese Oxide | Mg0.88Mn5.84O12·4.9H2O | 6.58 | **Cs+**20.700 (pH=1.20)50.350 (pH=7.20)38.000 (pH=12.96)@ V:m=100 cm3·g-1 and C0 = (2.0-37.0)x10-5 M Cs | 7550 (Cs/Mg)50 (Sr/Mg) | (34) | Theoretical CEC based on the magnesium contents of the hydrated exchangers |
| **Sr2+**0.001 (pH=1.20)>103 (pH=7.20)>103 (pH=12.96)@ V:m=100 cm3·g-1 and C0 = (1.5-3.1) x10-6 M Sr |
| **Co2+**1.970 (pH=1.20)83.500 (pH=7.20)0.011 (pH=12.96)@ V:m=200 cm3·g-1 and C0 = (3.6-7.3) x10-11 M Co |
| Cryptomelane-Type Manganese Oxide | K(Mn4+, Mn2+)8O16 | 2.05 | **Cs+**0.127 (pH=1.08)7.420 (pH=4.07)0.045 (pH=12.95)@ V:m=100 cm3·g-1 and C0 = (2.0-37.0) x10-5 M Cs | 0.6 (Cs/K)1 (Sr/K) | (34) | Theoretical CEC based on the magnesium contents of the hydrated exchangers |
| **Sr2+**0.002 (pH=1.08)>103 (pH=4.07)>103 (pH=12.95)@ V:m=100 cm3·g-1 and C0 = (1.5-3.1) x10-6 M Sr |
| **Co2+**0.024 (pH=1.08)43.300 (pH=4.07)0.050 (pH=12.95)@ V:m=200 cm3·g-1 and C0 = (3.6-7.3)x10-11 M Co |
| **Other Materials** |
| Eu-AV-20 | Na1.08K0.5Eu1.14Si3O8.5·1.78H2O | 0.093 | - | - | (35) | Theoretical CEC value of 2.55 |
| gallium-antimony-sulphide | [(CH3)2NH2][Ga2Sb2S7] | - | - | - | (36,37) | Cs+ exchanges with (CH3)2NH2+ |
| Bentonite |  | 0.28 (Cs+)0.42 (Eu3+)0.44 (Sr2+)0.28 (Ba2+) | **Cs+**1.055 – 0.071 (Co= 50 – 800 mg·L-1) @ V:m = 100 cm3·g-1; pH=6 and T=298 K | Cs/Sr = 0.911–1.821 BCs/Eu = 0.077–1.919 BCs/Br = 2.110–2.029 B | (38) |  |
| **Sr2+**1.158– 0.039 (Co= 50 – 800 mg·L-1) @ V:m = 100 cm3·g-1; pH=6 and T=298 K |
| **Eu3+**13.710– 0.037 (Co= 50 – 800 mg·L-1) @ V:m = 100 cm3·g-1; pH=6 and T=298 K |
| **Ba2+**0.500 – 0.035 (Co= 50 – 800 mg·L-1) @ V:m = 100 cm3·g-1; pH=6 and T=298 K |
| Na-Bentonite |  | .22 (Cs+)0.39 (Eu3+)0.54 (Sr2+)0.24 (Ba2+) | **Cs+**1.120 – 0.056 (Co= 50 – 800 mg·L-1) @ V:m = 100 cm3·g-1; pH=6 and T=298 K | Cs/Sr = 0.864–1.273 BCs/Eu = 0.246–1.556 BCs/Br = 2.534–1.867 B | (38) |  |
| **Sr2+**1.297– 0.044 (Co= 50 – 800 mg·L-1) @ V:m = 100 cm3·g-1; pH=6 and T=298 K |
| **Eu3+**4.550– 0.036 (Co= 50 – 800 mg·L-1)@ V:m = 100 cm3·g-1; pH=6 and T=298 K |
| **Ba2+**0.442 – 0.030 (Co= 50 – 800 mg·L-1)@ V:m = 100 cm3·g-1; pH=6 and T=298 K |
| Bentonite |  | 0.75 (298 K)0.67 (303 K)0.59 (308 K) | 0.044 (pH=1.5)0.058 (pH=3.1)0.087 (pH=5.4)0.279 (pH=7.7)0.472 (pH=8.6)0.558 (pH=9.9)0.585 (pH=10.9)@ V:m = 20 cm3·g-1; Co= 10-3 M and T=313 K |  | (39) |  |
| KMS-1 | K2*x*Mn*x*Sn3-*x*S6 | 1.70 | 11.642 (Na/Cs = 5),6.447 (Na/Cs = 11),2.230 (Na/Cs = 21),1.176 (Na/Cs = 37),and 0.547 (Na/Cs = 47)@ 12 h, C0 = 1.0x10-3 M and V:m = 1000 cm3·g-1 | - | (40) | (x = 0.5–0.95) |
| 0.403 (Ca/Cs = 3.2),0.248 (Ca/Cs = 6.4),0.034 (Ca/Cs = 12.9)and 0.023 (Ca/Cs = 29.0)@ 12 h C0 = 1.0x10-3 M and V:m = 1000 cm3·g-1 |
| KMS-2 | K2*x*Mg*x*Sn3-*x*S6 | 4.0 | **Cs+**1.18 (pH = 3),18 (pH = 7 in the presence of 5.0 M of Na+),4.56 (pH = 10)@ C0 = 6 mg·L-1and V:m = 1000 cm3·g-1 |  | (41) | (x = 0.5–0.95) |
| **Sr2+**63.3 (pH = 3),17 (pH = 7 in the presence of 5.0 M of Na+),145 (pH = 10)@ C0 = 6 mg·L-1and V:m = 1000 cm3·g-1 |
| **Ni2+**186.0 (pH = 3),180 (pH = 7 in the presence of 5.0 M of Na+),196 (pH = 10)@ C0 = 6 mg·L-1and V:m = 1000 cm3·g-1 |
| rare-earth sodium titanate | RE*x*H*y*Na4-(*x*+*y*)TiO4·*n*H2O | 0.40 (Ce3+), 0.35 (Nd3+) and 0.50 (Sm3+) | - | - | (42) | RE = Ce3+, Nd3+ and Sm3+ |
| sodium titanate | Na2TinO2n+1 or Na4TinO2n+2 | 3 – 6 | - | - | (43) | - |
| Tb/Eu-AV-9 | Na4K2Eu0.4Tb1.6Si16O38·*x*H2O | 3.47 | - | - | (44) | - |
| AMP |  | 1.57 | 6.000 (Cs)0.230 (Ru)@ 0.1 M NH4NO3  | Cs/Ru = 26.08 B | (45,46) | In practice only about 0.94 meq·g-1 is obtained |
| **Composite Materials** |
| Manganesedioxide-polyacrylonitrile | MnO2–PAN | 2.42 | 0.944 (T=298 K)0.983 (T=308 K)1.013 (T=318 K)1.041 (T=328 K)1.058 (T=338 K)@ V:m=100 cm3·g-1,pH=4.0 and C0 = 1x10-4 M Cs |  | (47) |  |
| AMP-PAN |  | 0.619 | 2.944 (pH=1.0)2.999 (pH=2.0)3.009 (pH=3.0)3.038 (pH=4.0)3.051 (pH=5.0)3.048 (pH=6.0)3.046 (pH=7.0)@ V:m=100 cm3·g-1, Ambient temperature and C0 = 1.0x10-4 M Cs |  | (48) |  |
| 3.055 (T=298 K)3.120 (T=308 K)3.168 (T=318 K)3.208 (T=328 K)3.278 (T=338 K)@ V:m=100 cm3·g-1, pH=7.0 and C0 = 1.0x10-4 M Cs |
| AMP-Zeolite Y |  |  | Cs: 2.57Na: 0.43Li: 0.40Rb: 0.65Sr: 0.24Ca: 0.20Mg: 0.19@ V:m=100 cm3·g-1, T=298 KCCs, Rb = 5.0x10-3 MCSr, Li, Mg, Ca = 5.0x10-2 M CNa = 5.0x10-1 M  | Cs/Na = 5.98 BCs/ Li = 6.43 BCs/Rb= 3.95 BCs/Sr = 10.70 BCs/Ca = 12.85 BCs/Mg = 13.53 B | (49) |  |
| AMP-Silica matrix |  | 0.283 | 0.775-0.8 @ V:m=1000 cm3·g-1, T=298 KCo= 5.0x10-3 M Cs(0.001-3 M HNO3) |  | (50) |  |
| AMP-PAN |  | 0.61 (Cs)0.36 (Sr)0.32 (Co) | 0.460 (Cs)0.007 (Sr)0.019 (Co)@ V:m=30 cm3·g-1, T=298 KCo= 1.0x10-4 M Cs, Sr, Co | Cs/Sr = 65.71 BCs/ Co= 38.33 B | (51) |  |
| AMP-Alumina |  |  | 0.751 (T=303 K)2.245 (T=308 K)3.338 (T=313 K)68.634 (T=318 K)@ V:m=100 cm3·g-1 and Co= 1.0x10-3 M Cs |  | (52) |  |
| AMP/PAN nanofiber adsorbent |  | 0.39 (Cs)0.29(Co)0.02 (Sr)0.62 (Mg)0.15 (Ca) | 1.092 (Cs)0.094 (Co)0.009 (Sr)0.081 (Mg)0.031 (Ca)@ V:m=1000 cm3·g-1, pH=5.0 and Co= 100 g·cm-3 for Cs, Co, Sr, Mg, and Ca | Cs/Co= 11.6 BCs/Sr= 120.3 BCs/Mg= 13.5 BCs/Ca= 35.1 B | (53) |  |
| AMP - Calcium Alginate |  | 0.43 | 44.003 (Cs)0.005 (Am)0.002 (Co)9.607x10-1 (Sr)6.310x10-2(Eu)5.600x10-2 (Na)@ V:m=100 cm3·g-1, [HNO3]=1.0 M and Co= 10 ppm for Cs, Na, Sr, Co and Eu; Co= 2.1x10-9 M for Am | **Cs+/NH4+**415.91 (Ẋ = 0.05),288.40 (Ẋ = 0.10),169.82 (Ẋ = 0.45),40.93 (Ẋ = 0.61),19.72 (Ẋ = 0.73),and 8.34 (Ẋ = 0.78) @ 72 h and 0.1 M (Cs, NH4)Cl | (54) |  |
| AMP-Silica |  | 0.61 | 3.275 ([HNO3]=0.1 M)0.848 ([HNO3]=1.0 M)0.635 ([HNO3]=2.0 M)0.381 ([HNO3]=4.0 M)0.188 ([HNO3]=6.0 M)0.062 ([HNO3]=8.0 M)@ V:m=100 cm3·g-1  |  | (55) |  |
| Crystalline silicotitanate-polyacrylonitrile | - | 0.17 | 0.607 (t = 20 h),1.790 (t = 40 h),3.085 (t = 60 h),5.483 (t = 80 h),7.817 (t = 100 h),8.440 (t = 120 h),8.488 (t = 180 h)and 8.472 (t = 260 h)@ C0 = 10-4 Mand V:m = 100 cm3·g-1 | - | (56) | Dynamic capacity at 100% cesium breakthrough in column experiments |
| 4.636 (pH = 1.0),5.817 (pH = 2.0),6.382 (pH = 3.0),7.205 (pH = 4.0),7.949 (pH = 5.0),8.455 (pH = 6.0),8.355 (pH = 7.0),8.088 (pH = 8.0)and 8.018 (pH = 9.0)@ C0 = 10-4 Mand V:m = 100 cm3·g-1 |
| Cobalt hexacyanoferrate anchored to Glass-Py | - | 0.04 | >104 (sea water, C0 = 10 mg·L-1 ) and 800 (radioactive sea water, C0 = 29 kBq·L-1) | - | (57) | - |
| Cobalt hexacyanoferrate anchored to Silica-Py | - | 0.13 | 103 (sea water, C0 = 10 mg·L-1 ) and 300 (radioactive sea water, C0 = 29 kBq·L-1) | - | (58) | - |
| Potassium-nickel hexacyanoferrate anchored on chabazite | - | 1.87, 1.45, 1.44 and 1.51 | **with KNO3**14.306 (0.001 M K+),31.384 (0.01 M K+),62.127 (0.1 M K+),13.866 (1.0 M K+) and 7.917 (5.0 M K+)@ 168 h, C0 = 10 mg·L-1and V:m = 100 cm3·g-1 | - | (59) | The CEC values are for the following Ni(NO3)2 impregnation concentrations: 0.5 M, 1 M, 2 x 1 M and 3 x 1 M, respectively. |
| **with NH4NO3**10.244 (0.001 M NH4+),4.236 (0.01 M NH4+),3.002 (0.1 M NH4+),0.411 (1.0 M NH4+) and 0.042 (5.0 M NH4+)@ 168 h, C0 = 10 mg·L-1and V:m = 100 cm3·g-1 |
| **with NaNO3**19.464 (0.001 M Na+),67.800 (0.01 M Na+),14.012 (0.1 M Na+),27.722 (1.0 M Na+)and 28.764 (5.0 M Na+)@ 168 h, C0 = 10 mg·L-1and V:m = 100 cm3·g-1 |
| Potassium-nickel hexacyanoferrate anchored on chitin | - | < 0.60 | - | - | (60) | - |
| Prussian blue/ferrite composite | - | 0.41 | 12.0@ pH = 7, V:m = 600 mL·g-1 and C0 = 10 mg·L-1  | - | (61) | - |
| Prussian blue/ferrite/graphene oxide composite | - | 0.35 | 51.4@ pH = 7, V:m = 600 mL·g-1 and C0 = 10 mg·L-1  | - | (61) | The removal mechanism of Cs+ was revealed to be H+-exchange and/or ion trapping |
| Zinc hexacyanoferrate/ferrite/polyacrylonitrile composite | - | 14.78 | **WO**0.059 (pH = 1.8),0.095 (pH = 2.5),0.080 (pH = 4.6),0.090 (pH = 6.2),0.087 (pH = 8.6)and 0.073 (pH = 10.2)@ 4 h, RT, V:m = 200 cm3·g-1 and 0.1 M HNO3 and/or 0.1 MNaOH | - | (62) | - |
| **RF1**0.204 (pH = 1.8),0.215 (pH = 2.5),0.261 (pH = 4.6),0.283 (pH = 6.2),0.305 (pH = 8.6)and 0.303 (pH = 10.2)@ 4 h, RT, V:m = 200 cm3·g-1 and 0.1 M HNO3 and/or 0.1 MNaOH |
| **RZ1**0.603 (pH = 1.8),1.036 (pH = 2.5),1.203 (pH = 4.6),1.502 (pH = 6.2),1.463 (pH = 8.6)and 1.510 (pH = 10.2) @ 4 h, RT, V:m = 200 cm3·g-1 and 0.1 M HNO3 and/or 0.1 MNaOH |
| **RZ3**1.484 (pH = 1.8),1.712 (pH = 2.5),1.987 (pH = 4.6),2.057 (pH = 6.2),2.067 (pH = 8.6)and 2.149 (pH = 10.2)@ 4 h, RT, V:m = 200 cm3·g-1 and 0.1 M HNO3 and/or 0.1 MNaOH |
| **RZ2**4.815 (pH = 1.8),5.876 (pH = 2.5),6.235 (pH = 4.6),6.282 (pH = 6.2),6.665 (pH = 8.6)and 6.554 (pH = 10.2)@ 4 h, RT, V:m = 200 cm3·g-1 and 0.1 M HNO3 and/or 0.1 MNaOH |

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