**S1 Average Crystal size (nm) of adsorbents before and after (Fe2+) ion removal.**

|  |  |  |
| --- | --- | --- |
| **Character** | **Average crystal size (nm) before removal (Fe2+) ions** | **Average crystal size (nm) after removal (Fe2+) ions** |
| DCP | 47 | 48 |
| (DCP – CS1) | 41 | 42 |
| (DCP – CS2) | 32 | 44 |

**S2 IR spectra λ (cm-1) and assignments for adsorbents after removal** **(Fe2+) ions.**

|  |  |  |  |
| --- | --- | --- | --- |
| **(DCP)**  **+ Fe2+** | **(DCP-CS1) + Fe2+** | **(DCP-CS2) + Fe2+** | **Assignments** |
| 3447.46 | 3443.07 | 3443.50 | **O–H stretching of residual free water** |
| 2925.37  2857.41 | 2956.93  2924.02  2853.80 | 2960.66  2924.67  2854.29 | **(P) O–H stretching** |
| 1639.05 | 1630 | 1630 | **H –O–H bending and rotation of residual free water** |
| - | 1638.04 | 1645.02 | **C= O stretching of amide I** |
| - | 1451.51 | 1373 | **Amino II (-NH2)** |
| 1132.08  1072.30  1001.27 | 1131.04  1070.40  1000.16 | 1126.99  1069.85  1001.83 | **P–O stretching** |
| 897.48 | 894.49 | 896.14 | **P–O(H) stretching** |
| 575.09 | 565.54 | 563.59 | **O–P–O(H) bending mode** |

|  |  |
| --- | --- |
|  | A picture containing outdoor, nature  Description automatically generated |
| A picture containing white  Description automatically generated | |  |  |  | | --- | --- | --- | | **Element** | **Wt %** | **At %** | | C K | 4.68 | 9.63 | | O K | 29.75 | 46.02 | | Na K | 0.17 | 0.18 | | P K | 21.23 | 16.94 | | Ca K | 44.17 | 27.23 | | Total | 100 | 100 | |
|  | |

**S3 SEM images and EDX analysis of (DCP)**

|  |  |
| --- | --- |
| A picture containing outdoor, white, black, fungus  Description automatically generated | A picture containing white, black, people, old  Description automatically generated |
| A picture containing outdoor, white  Description automatically generated | |  |  |  | | --- | --- | --- | | **Element** | **Wt %** | **At %** | | C K | 8.04 | 14.73 | | N K | 3.23 | 3.13 | | O K | 30.21 | 45.02 | | Na K | 0.31 | 0.32 | | P K | 17.04 | 13.22 | | Ca K | 41.17 | 23.58 | | Total | 100 | 100 | |
|  | |

**S4 SEM images and EDX analysis of (DCP-CS2)**

|  |  |
| --- | --- |
| A picture containing nature, old  Description automatically generated | A close-up of a rock  Description automatically generated with low confidence |
| A picture containing white, store, fresh  Description automatically generated | |  |  |  | | --- | --- | --- | | **Element** | **Wt %** | **At %** | | C K | 5.53 | 11.55 | | O K | 27.97 | 43.84 | | Na K | 0.10 | 0.11 | | P K | 20.17 | 16.33 | | Ca K | 41.92 | 26.23 | | Fe K | 4.31 | 1.93 | | Total | 100 | 100 | |
| Chart  Description automatically generated | |

**S5 SEM images and EDX analysis of (DCP)** **after (Fe2+) ions uptake**

|  |  |
| --- | --- |
| A picture containing old, vintage  Description automatically generated |  |
| A picture containing decorated, fresh  Description automatically generated | |  |  |  | | --- | --- | --- | | **Element** | **Wt %** | **At %** | | C K | 9.59 | 19.63 | | N K | 3.11 | 3.10 | | O K | 23.16 | 36.06 | | Na K | 0.31 | 0.33 | | P K | 17.34 | 13.56 | | Ca K | 41.33 | 25.05 | | Fe K | 5.16 | 2.27 | | Total | 100 | 100 | |
| Chart  Description automatically generated | |

**S6 SEM images and EDX analysis of (DCP-CS1) after (Fe2+) ions uptake**

|  |  |
| --- | --- |
| A picture containing outdoor  Description automatically generated |  |
| A picture containing outdoor, white, black, old  Description automatically generated | |  |  |  | | --- | --- | --- | | **Element** | **Wt %** | **At %** | | C K | 9.82 | 20.28 | | N K | 3.24 | 3.21 | | O K | 27.14 | 40.47 | | Na K | 0.37 | 0.38 | | P K | 16.79 | 12.31 | | Ca K | 38.62 | 21.65 | | Fe K | 4.02 | 1.70 | | Total | 100 | 100 | |
| Chart  Description automatically generated | |

**S7 SEM images and EDX analysis of (DCP-CS2) after (Fe2+) ions uptake**

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**S8 Effect the dose of (DCP) and (DCP-CS1) at 120 min., (DCP-CS2) at 60 min. on (Fe2+) ions , initial concentration of 100 mgL-1, natural pH of 4.9 at temperature 25±1oC**

**S9** **Effect** **the dose of (DCP) on the** **(Fe2+) ions Adsorption**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.NO.** | **Adsorbent dose (mg)** | **C e (mg/L)** | **Amount adsorbed, q (mg/g)** | **Removal % of (Fe2+) ions** |
| 1 | 20 | 60 | 20 | 40 |
| 2 | 40 | 38 | 15.5 | 62 |
| 3 | 60 | 25 | 12.5 | 75 |
| 4 | 80 | 21.33 | 9.83 | 78.67 |
| 5 | 100 | 12.5 | 8.75 | 87.5 |

**S10 Effect the dose of (DCP – CS1) on the** **(Fe2+) ions Adsorption**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.NO.** | **Adsorbent dose (mg)** | **C e (mg/L)** | **Amount adsorbed, q (mg/g)** | **Removal % of (Fe2+) ions** |
| 1 | 20 | 58 | 21 | 42 |
| 2 | 40 | 40 | 15 | 60 |
| 3 | 60 | 24 | 12.6 | 76 |
| 4 | 80 | 20 | 10 | 80 |
| 5 | 100 | 12 | 8.8 | 88 |

**S11 Effect** **the dose of (DCP – CS2) on the (Fe2+) ions Adsorption**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.NO.** | **Adsorbent dose (mg)** | **C e (mg/L)** | **Amount adsorbed, q (mg/g)** | **Removal % of (Fe2+) ions** |
| 1 | 20 | 36 | 32 | 64 |
| 2 | 40 | 15.33 | 21.16 | 84.67 |
| 3 | 60 | 12.66 | 14.55 | 87.34 |
| 4 | 80 | 12.66 | 10.91 | 87.34 |
| 5 | 100 | 8 | 9.2 | 92 |

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**S12 Effect of contact time on (Fe2+) ions adsorption (pH=4.9) from solutions under conditions of** **(DCP), (DCP-CS1) and (DCP-CS2) mass 100 mg/10 mL, 50 mg/L (Fe2+) ions concentration at temperature 25±1oC**

**S13** **Equilibrium Data for (Fe2+) ions removal by (DCP) at Different Times**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.NO.** | **Contact Time / minutes** | **C e (mg/L)** | **Amount adsorbed, q (mg/g)** | **Removal % of (Fe2+) ions** |
| 1 | 1 | 41.25 | 0.875 | 17.5 |
| 2 | 2 | 37.6 | 1.240 | 24.8 |
| 3 | 5 | 27.25 | 2.275 | 45.5 |
| 4 | 10 | 23 | 2.70 | 54 |
| 5 | 15 | 19.25 | 3.075 | 61.5 |
| 6 | 20 | 12 | 3.80 | 76 |
| 7 | 25 | 10 | 4 | 80 |
| 8 | 30 | 7 | 4.30 | 86 |
| 9 | 40 | 4.50 | 4.55 | 91 |
| 10 | 50 | 3.75 | 4.625 | 92.5 |
| 11 | 60 | 2.80 | 4.720 | 94.4 |
| 12 | 70 | 2.33 | 4.767 | 95.34 |
| 13 | 80 | 2.33 | 4.767 | 95.34 |
| 14 | 100 | 2.33 | 4.767 | 95.34 |

**S14 Equilibrium Data for (Fe2+) ions removal by (DCP – CS1) at Different Times**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.NO.** | **Contact Time / minutes** | **C e (mg/L)** | **Amount adsorbed, q (mg/g)** | **Removal % of (Fe2+) ions** |
| 1 | 1 | 40 | 1 | 20 |
| 2 | 2 | 34.75 | 1.525 | 30.5 |
| 3 | 5 | 22 | 2.8 | 56 |
| 4 | 10 | 18.5 | 3.15 | 63 |
| 5 | 15 | 14.1 | 3.59 | 71.8 |
| 6 | 20 | 10 | 4 | 80 |
| 7 | 25 | 7.75 | 4.22 | 84.5 |
| 8 | 30 | 6 | 4.40 | 88 |
| 9 | 40 | 4 | 4.60 | 92 |
| 10 | 50 | 3.25 | 4.675 | 93 |
| 11 | 60 | 2.55 | 4.745 | 94.9 |
| 12 | 70 | 2 | 4.8 | 96 |
| 13 | 80 | 2 | 4.8 | 96 |
| 14 | 100 | 2 | 4.8 | 96 |

**S15 Equilibrium Data for** **(Fe2+) ions adsorption by (DCP – CS2) at Different Times**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.NO.** | **Contact Time / minutes** | **C e (mg/L)** | **Amount adsorbed, q (mg/g)** | **Removal % of (Fe2+) ions** |
| 1 | 1 | 35.5 | 1.45 | 29 |
| 2 | 2 | 29 | 2.1 | 42 |
| 3 | 5 | 19.5 | 3.05 | 61 |
| 4 | 8 | 13 | 3.70 | 74 |
| 5 | 10 | 10.5 | 3.95 | 79 |
| 6 | 12 | 9 | 4.1 | 82 |
| 7 | 15 | 7 | 4.3 | 86 |
| 8 | 20 | 5.5 | 4.45 | 89 |
| 9 | 25 | 4.75 | 4.525 | 90.5 |
| 10 | 30 | 3.75 | 4.625 | 92.5 |
| 11 | 40 | 3 | 4.7 | 94 |
| 12 | 50 | 2.25 | 4.775 | 95.5 |
| 13 | 60 | 1.33 | 4.867 | 97.34 |
| 14 | 70 | 1 | 4.9 | 98 |
| 15 | 80 | 1 | 4.9 | 98 |

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**S16: Effect of intial concentration on the adsorption of (Fe2+) ions at pH= 4.9,from solution by (DCP), (DCP-CS1) and (DCP-CS2) under conditions of mass 100 mg/10 mL at 120 min. and temperature of 25±1oC**

**S17** **Initial (Fe2+) ions metal concentration effect on (DCP) adsorption Mechanism**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.NO.** | **C 0 (mg/L)** | **C e (mg/L)** | **Amount adsorbed, q (mg/g)** | **Removal % of (Fe2+) ions** |
| 1 | 25 | 1.13 | 2.38 | 95.48 |
| 2 | 50 | 2.33 | 4.76 | 95.34 |
| 3 | 100 | 12.5 | 8.75 | 87.5 |
| 4 | 150 | 39 | 11.1 | 74 |
| 5 | 200 | 88 | 11.2 | 56 |
| 6 | 250 | 113.33 | 13.66 | 54.66 |

**S18 Initial (Fe2+) ions metal concentration effect on (DCP – CS1) adsorption Mechanism**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.NO.** | **C 0 (mg/L)** | **C e (mg/L)** | **Amount adsorbed, q (mg/g)** | **Removal % of (Fe2+) ions** |
| 1 | 25 | 0.73 | 2.43 | 97.08 |
| 2 | 50 | 2 | 4.8 | 96 |
| 3 | 100 | 12 | 8.8 | 88 |
| 4 | 150 | 33.99 | 11.60 | 77.34 |
| 5 | 200 | 73.33 | 12.67 | 63.34 |
| 6 | 250 | 101.66 | 14.83 | 59.34 |

**S19 Initial (Fe2+) ions metal concentration effect on (DCP – CS2) adsorption Mechanism**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.NO.** | **C 0 (mg/L)** | **C e (mg/L)** | **Amount adsorbed, q (mg/g)** | **Removal % of (Fe2+) ions** |
| 1 | 25 | 0.23 | 2.48 | 99.08 |
| 2 | 50 | 1.33 | 4.86 | 97.34 |
| 3 | 100 | 8 | 9.2 | 92 |
| 4 | 150 | 13.99 | 13.60 | 90.67 |
| 5 | 200 | 28 | 17.2 | 86 |
| 6 | 250 | 65 | 18.5 | 74 |

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**S20 Pseudo-first-order of (Fe2+) ions (pH=4.9), adsorbed on (DCP), (DCP – CS1) and(DCP – CS2) at conditions of 50 mg/L metal ions concentration, mass 100 mg/10 mL at 25±1oC**

**S21 Experimental and calculated parameters of pseudo-first and second order kinetic of** **(Fe2+) ions (natural pH of 4.9)** **on (DCP), (DCP – CS1) and (DCP – CS2)**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Kinetic parameters**      **Adsorpent** | **qe  experimental** | **Pseudo- first- order** | | | **Pseudo- second- order** | | |
| **qe calculated** | **K1** | **R2** | **qe  calculated** | **K2** | **R2** |
| **DCP** | 4.767 | 3.7899 | 0.07195 | 0.99177 | 5.2929 | 0.02519 | 0.99299 |
| **(DCP – CS1)** | 4.8 | 3.3498 | 0.0691 | 0.99048 | 5.0836 | 24.5061 | 0.9993 |
| **(DCP – CS2**) | 4.9 | 2.3097 | 0.06752 | 0.9466 | 5.0831 | 0.067421 | 0.99991 |