



SACRED HEART RESEARCH PUBLICATIONS

Journal of Functional Materials and Biomolecules

Journal homepage: www.shcpub.edu.in



ISSN: 2456-9429

EFFECTIVE ADSORBENT MATERIAL FOR REMOVAL OF CHROMIUM (VI) USING ACTIVATED CHARCOAL PREPARED FROM PIGEON PEA STEM

N. Rajesh Kumar¹, L. Alphonse Lazar¹, S. Jemimah lims¹, S. Jothi Selvam¹, V Dinesh¹, B. Mohammad Nawaz², T. Jeyabalan Thavasi-kani^{1}*

Received on 07 October 2025, accepted on 17 November 2025,

Published online on December 2025

Abstract

The increase in industrial activity during recent years is greatly contributing to the increase of heavy metals in the environment, mainly in the aquatic systems. Water pollution due to heavy metals is an issue of great environmental concern. Heavy metal ions like chromium (VI) are detected in the waste streams from mining operations, tanneries, electronics, electroplating, batteries and petrochemical industries as well as textile mill products. Major chromium (VI) pollution is through automobiles and battery manufacturers. Activated carbon is used for adsorption of organic substances. Adsorption is commonly used in the treatment of industrial wastewaters containing organic compounds not easily biodegraded during secondary (biological) treatment or toxic.

Keywords: Pigeon pea stem (PPS), Activated carbon, Adsorption, chromium (VI), waste waters treatment.

1. Introduction

The quality of our environment is deteriorating day by day, with the largest cities reaching saturation points and being unable to cope with the increasing pressure on their infrastructure. Industrial effluents, sewage and farm wastes are the major pollutants contaminating the environment. Most of the industries discharge

wastewater and their effluents containing toxic materials into rivers without adequate treatment. Environmental pollution, particularly from heavy metals and minerals in the wastewater water is the most serious problem in India [1,2]. Mobilization of heavy metals in the environment due to industrial activities is of serious concern as these metals are toxic to all forms of life, including humans. Chromium compounds are widely used in various industries [3]. To avoid health hazards, it is essential to remove these toxic heavy metals from wastewater before its disposal. Most of the heavy metals discharged into the wastewater are found to be toxic and carcinogenic and cause a serious threat to the human health. Chromium occurs in natural water is in two main oxidation states,

*Corresponding author: E-mail: jayabalandr@gmail.com

¹Department of Chemistry, Sacred Heart College (Autonomous), Tirupattur-635 601, Tamil Nadu, India. Affiliated to Thiruvalluvar University, Serkkadu-632 115 Vellore, Tamil Nadu, India.

²Department of Chemistry, Islamia College (Autonomous), Vaniyambadi, Affiliated to Thiruvalluvar University, Serkkadu-632 115 Vellore, Tamil Nadu, India

Chromium (III) and Chromium (VI) [4]. Although Chromium (III) is an essential nutrient in mammalian metabolism, Chromium (VI) is highly toxic and mutagenic [5-7].

Activated carbon is a black solid substance resembling granular or powder charcoal and are carbonaceous material that has highly developed porosity, internal surface area and relatively high mechanical strength [8-9]. Most of the heavy metals are dangerous to health or to the environment. Heavy metals in industrial wastewater include lead, chromium, mercury, uranium, selenium, zinc, arsenic, cadmium, silver, gold, and nickel. The main threats to human health from heavy metals are associated with exposure to lead, cadmium, chromium, mercury and arsenic [10]. The adsorption of toxic waste from industrial wastewater using agricultural waste and industrial by-products has been massively investigated [11-15]. The number of efficient methods has been reviewed for the removal of heavy metals, such as chemical precipitation, ion exchange, reverse osmosis, electro dialysis, ultrafiltration, coagulation, flocculation, floatation, etc. [16-17]. With the ever-accelerating use of heavy metals by hospitals, universities, research laboratories, nuclear weapons and others, coupled with the "Atom for Peace" programme, there is an equally increasing problem of preventing the heavy metal wastes from polluting public air and water supplies. The most toxic metals are nickel, chromium and cadmium. The method used

to remove the toxic heavy metals involves the usage of activated charcoal. Activated charcoal is usually good agent for removing heavy metals of colour, tastes and odours from air and water for the prevention of environmental pollution [18].

Heavy metals are metallic elements that are present in both natural and contaminated. In natural environments, they occur at low concentrations. However, at high concentrations, as is the case in contaminated environments, they result in public health impacts. The elements that are of concern include lead, mercury, cadmium, arsenic, chromium, zinc, nickel and copper. Heavy metals may be released into the environment from metal smelting and refining industries, scrap metal, plastic and rubber industries [19], various consumer products and from burning of waste containing these elements on release to the air, the elements are transported for large distances and are deposited onto the soil, vegetation and water, depending on their density. Adsorption is the method for separation of mixtures on a laboratory and industrial scale, where it is a surface phenomenon that can be defined as the increase in concentration of a particular component at the interface between two phases. Adsorption is a very important process due to its technological, environmental and biological importance [20]. It is a type of adsorption in which the adsorbate adheres to the surface only through van der Waals (Weak intermolecular) interactions. The molecules adhere to a surface through the formation of a chemical

bond, as opposed to the van der Waals forces, which cause physisorption. Chemisorption is thus highly selective since only certain types of molecules will be adsorbed by a particular solid. This depends on the chemical properties of the gas and the adsorbent [21].

2. Experimental

2.1 PREPARATION OF ACTIVATED CHARCOAL

Pigeon pea stems are collected from agricultural fields. The pigeon pea stems are cut into small pieces and dried at room temperature. The activated carbon is prepared from the above material impregnated with conc. HCl and carbonized at 450 °C. For impregnator ratio of acid volume to weight of plant material of 1:1 (w/v) was employed. Before utilization, the carbon was washed with distilled water and dried in a hot air oven.

2.2 PREPARATION OF Cr (VI) SOLUTION

Potassium dichromate is used to prepare the stock solution (1000 ppm). The stock solution is diluted with an appropriate quantity of distilled water to obtain a standard solution of Chromium (VI). The pH of the solution was adjusted using 0.1 N HCl and 0.1 N NaOH solutions. Hexavalent chromium Chromium (VI) is quantified using 1,5-diphenylcarbazide, which forms a red-violet complex, and the intensity of this complex was read at 540 nm using a colourimeter [24].

2.3 BATCH EXPERIMENTS

Batch studies were conducted with Chromium (VI) solutions prepared in the laboratory. The studies were conducted at a constant temperature of 30° C-35° C in a 250 ml conical flask. Each conical flask contains 50 ml of

Chromium (VI) solution to which the adsorbent was added. The initial pH of Chromium (VI) solution was measured to be 2 [25]. The flasks were agitated in a mechanical shaker. The liquid samples were withdrawn from the flask at regular intervals of time and centrifuged to separate the solid particles. Initially, a standard calibration curve between the percentage of removal and the concentration of Chromium (VI) solution was prepared using Chromium (VI) solution of known concentrations. The effect of the following parameters on the adsorption potential of pigeon pea stem charcoal. Initial concentration of Cr (VI) solution (10-50 mg/L), time (up to 60min) [26].

3. Results and Discussion

3.1 EFFECTS OF AGITATION TIME, TEMPERATURE, PH, DOSAGE AND INITIAL CONCENTRATION OF Cr (VI)

Adsorption isotherms are usually determined under equilibrium conditions. A series of contact time experiments for Chromium (VI) have been carried out at different initial concentrations (10-50 mg/L) and at a temperature of 35 °C, pH, and dosage. Fig. 3.3 shows the contact time of 60 minutes. However, for Chromium (VI) with higher initial concentrations (10-50mg/L) longer equilibrium time of 60 min. is needed [27].

As can be seen from Fig. 1.3, the amount of Chromium (VI) adsorbed into activated carbon increases with time and, at some point in time, reaches a constant value beyond which no more is removed from solution. At all these points, the amount of Chromium (VI) is being ad-

sorbed onto the activated carbon. The time required to attain this state of equilibrium is termed the equilibrium time, and the amount of Chromium (VI) adsorbed at the equilibrium time reflects the maximum adsorption under those operating conditions. The adsorption capacity at equilibrium increases with an increase in the initial Chromium (VI) concentration from 10 to 50 mg/L. It may be noted that at a particular Chromium (VI) concentration, adsorption by different adsorbents was dependent on the type of Chromium (VI) solution [28]. Pigeon pea stem charcoal activated carbons as an adsorbent. It was also observed that, in general, for all Chromium solutions at lower concentration adsorption process was not so effective. It was observed at 10-60 mg/L of Chromium (VI).

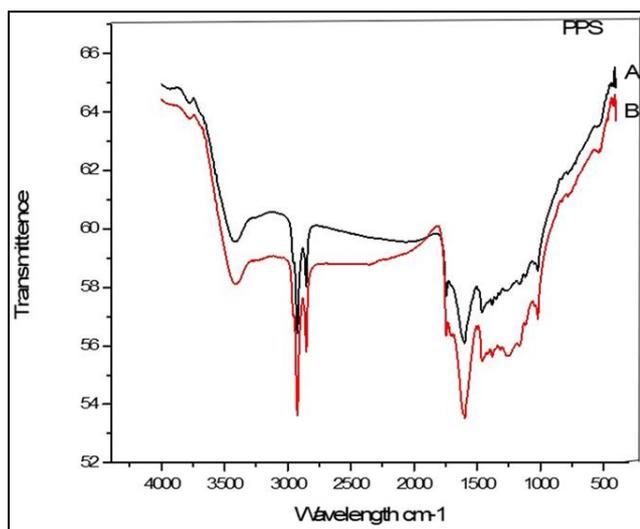


Fig. 1.1 FTIR spectra of After (A) Adsorption and before (B) Adsorption of PPS FTIR Analysis (PPS)

The FTIR spectra of raw adsorbent and chromium-loaded pigeon pea stem Activated Carbon powder are presented in Fig 1.1 before and after, respectively. The peak at 2800 cm^{-1} indicates the presence of the N-H

Stretching group, and the peak at 2924 cm^{-1} indicates the presence of alkanes C-H stretching group. The peak at 1550 cm^{-1} indicates N-H bend 1 amines [29]. In addition, the peaks at aromatics 1427 cm^{-1} C-C stretching and 1096 cm^{-1} indicate the presence of aliphatic amines C-N stretching group. The peak at 872 cm^{-1} C-Cl stretching for alkyl halides, and 674 cm^{-1} .

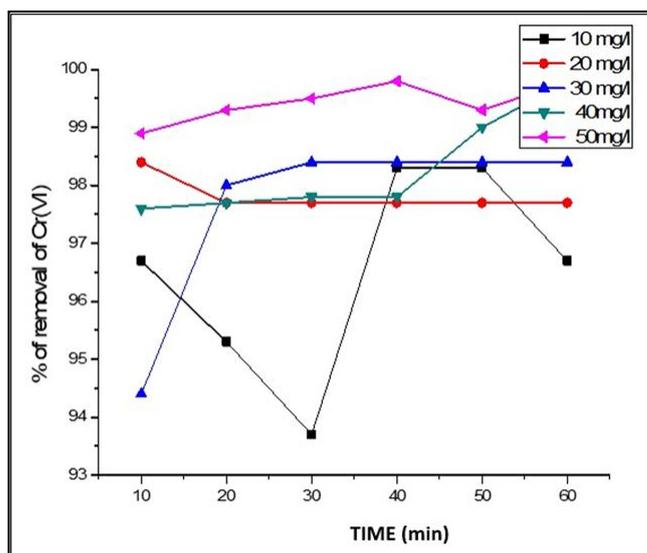


Fig. 1.2 (i) Effect of contact time (min) on chromium removal by PPS [Cr (VI) Concentration 10, 20, 30, 40, and 50 mg/L, stirring speed 400 rpm, adsorbent dosage 500 mg and pH=2]

The effect of initial concentration of Chromium (VI) and removal percentage is shown in Fig. 1.2 - 1.4 (i) variation in specific Chromium (VI) solution and % removal of Chromium (VI) (10-50 mg/L) using con.HCl-modified carbon from Pigeon pea stems as an adsorbent for different initial concentrations at volume (50 ml), time (60 min), and weight of adsorbent (500 mg) [30-33].

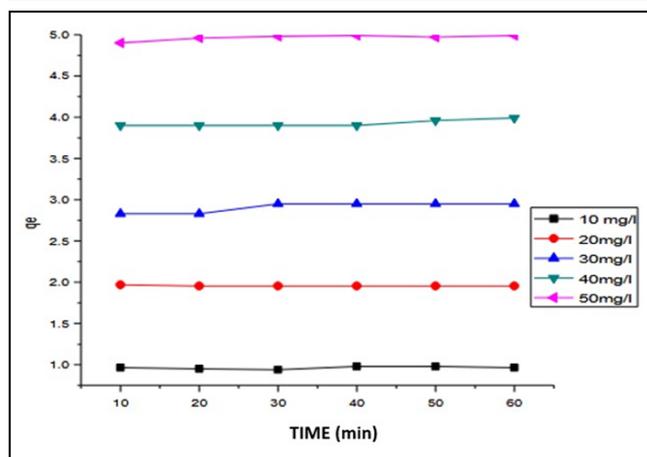


Fig. 1.3 (ii) Effect of contact time (min) on chromium removal by PPS [Cr (VI), Concentration 10,20,30,40 and 50 mg/L, stirring speed=400 rpm, adsorbent dosage=500 mg and pH=2].

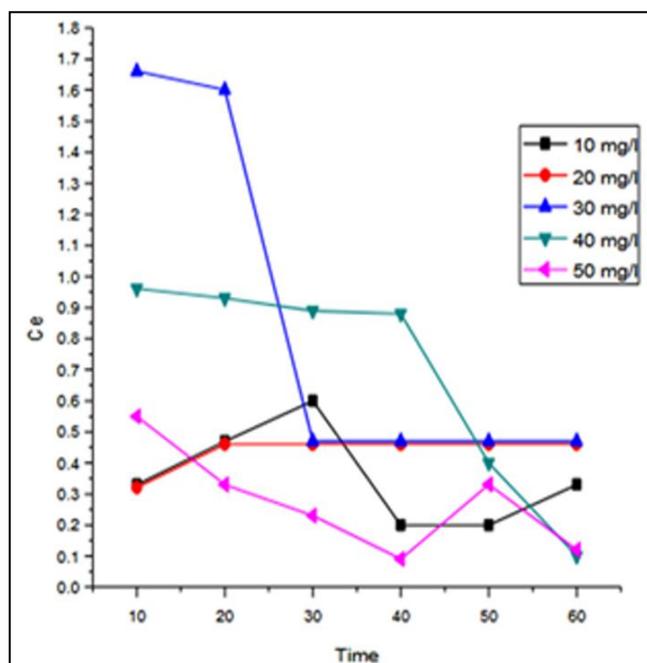


Fig. 1.4 (iii) Effect of contact time (min) on chromium removal by PPS [Cr (VI) Concentration 10,20,30,40 and 50 mg/L, stirring speed=400 rpm, adsorbent dosage 500 mg and pH=2]

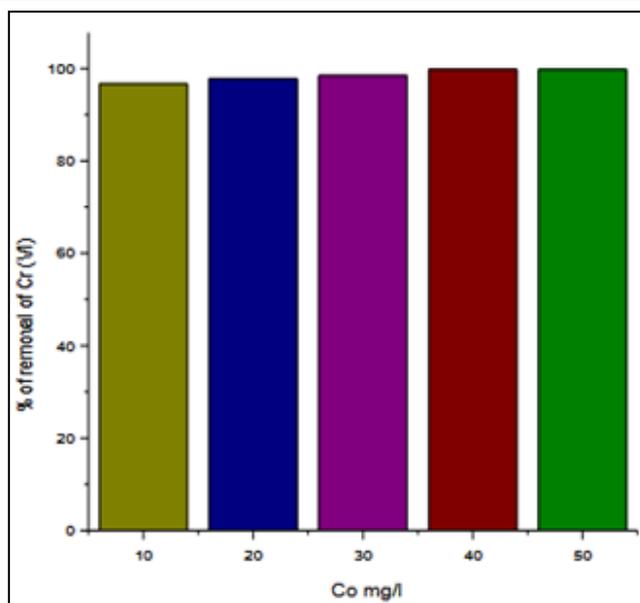


Fig. 1.5 Removal of Cr (VI) using different initial concentrations in PPS

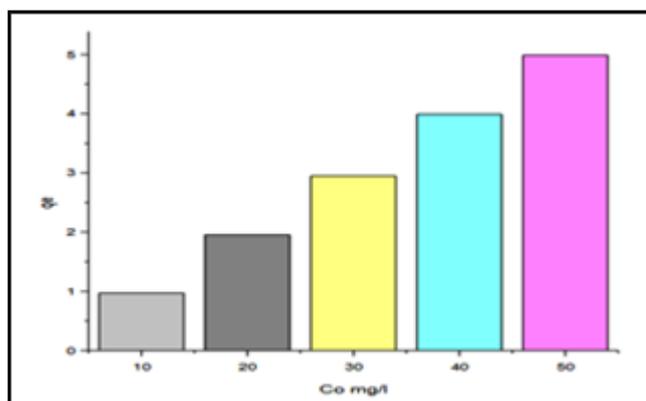


Fig. 1.6 Removal of Cr (VI) using different initial concentrations in PPS

Table. 1 (i) PPS Effect of initial concentration of Cr (VI) at constant pH (2), weight of adsorbent (500 mg) and time (60 min).

Co (mg/L)	Ce (mg/L)	% Removal of Cr(VI) $\frac{Co-Ce}{Co} \times 100$	Amount of Cr (VI) adsorbed $q_e = \frac{Co-Ce}{m} \times V$
10	0.33	96.7	0.967
20	0.46	97.7	1.954
30	0.47	98.4	2.95
40	0.1	99.8	3.99
50	0.12	99.8	4.99

4. Conclusions

The study indicated that activated carbon prepared from pigeon pea stem could be used as effective adsorbent materials for treatment of Chromium (VI) bearing aqueous waste waters. The adsorption of Chromium (VI) onto activated carbon is found to be different time, concentration, and constant dosage, pH. The adsorbent selected from pigeon pea stem in the present study proved to be good adsorbent which was evident with the adsorption data. The use of pigeon pea charcoals as an adsorbent seems to be an economical and promising alternative over conventional methods. Percentage Chromium (VI) removal at equilibrium increased with increasing adsorbent with initial concentration with different time whereas the adsorption decreased with increase of initial metal ion concentrations in PPS.

Acknowledgements

The financial support from the Don Bosco Research Grant, (SHC/DB Grant/2024/06 Sacred Heart College, Tirupattur TN 635 601, Affiliated to Thiruvalluvar University, Serkkadu, Vellore, TN 632 115, India. is gratefully acknowledged.

Conflict of Interest: Nil

References

- [1] P. Miretzky and A. F. Cirelli, Cr (VI) and Cr(III) removal from aqueous solution by raw and modified lignocellulosic materials: a review, *J. Hazard. Mater.*, 2010, 180, 1–19, DOI:10.1016/j.jhazmat.2010.04.060.
- [2] D. Pradhan, L. B. Sukla, M. Sawyer and P. K. S. M. Rahman, Recent bioreduction of hexavalent chromium in wastewater treatment: a review, *J. Ind. Eng. Chem.*, 2017, 55, 1–20, DOI:10.1016/j.jiec.2017.06.040.
- [3] M. N. Sahmoune, K. Louhab and A. Boukhiar, Advanced biosorbents materials for removal of chromium from water and wastewaters, *Environ. Prog. Sustainable Energy*, 2010, 3, 284–293, DOI:10.1002/ep.
- [4] C. Raji and T. S. Anirudhan, Batch Cr (VI) removal by polyacrylamide-grafted sawdust: kinetics and thermodynamics, *Water Res.*, 1998, 32, 3772–3780, DOI:10.1016/s0043-1354(98)00150-x.
- [5] C. H. Weng, J. H. Wang and C. P. Huang, Adsorption of Cr (VI) onto TiO₂ from dilute aqueous solutions, *Water Sci. Technol.*, 1997, 35, 55–62, DOI:10.1016/s0273-1223(97)00114-5.
- [6] D. E. Kimbrough, Y. Cohen, A. M. Winer, L. Creelman and C. Mabuni, A critical assessment of chromium in the environment, *Crit. Rev. Environ. Sci. Technol.*, 1999, 29, 1–46, DOI:10.1080/10643389991259164.
- [7] M. K. Aroua, F. M. Zuki and N. M. Sulaiman, Removal of chromium ions from aqueous solutions by polymer-enhanced ultrafiltration, *J. Hazard. Mater.*, 2007, 147, 752–758, DOI:10.1016/j.jhazmat.2007.01.120.
- [8] M. Costa, Potential hazards of hexavalent chromate in our drinking water, *Toxicol. Appl. Pharmacol.*, 2003, 188, 1–5, DOI:10.1016/0041-008x(03)00011-5.
- [9] A. Zhitkovich, Importance of chromium-DNA adducts in mutagenicity and toxicity of chromium (VI), *Chem. Res. Toxicol.*, 2005, 18, 3–11, DOI:10.1021/tx049774+.
- [10] J. Wang, K. Zhang and L. Zhao, Sono-assisted synthesis of nanostructured polyaniline for adsorption

of aqueous Cr (VI): effect of protonic acids, *Chem. Eng. J.*, 2014, 239, 123–131, DOI:10.1016/j.cej.2013.11.006.

[11] J. Preethi, S. M. Prabhu and S. Meenakshi, Effective adsorption of hexavalent chromium using biopolymer assisted oxyhydroxide materials from aqueous solution, *React. Funct. Polym.*, 2017, 117, 1624, DOI:10.1016/j.reactfunctpolym.2017.05.006.

[12] S. S. Kahu, A. Shekhawat, D. Saravanan and R. M. Jugade, Two-fold modified chitosan for enhanced adsorption of hexavalent chromium from simulated wastewater and industrial effluents, *Carbohydr. Polym.*, 2016, 146, 264–273, DOI:10.1016/j.carbpol.2016.03.041.

[13] L. Lin, X. Xu, C. Papelis, T. Y. Cath and P. Xu, Sorption of metals and metalloids from reverse osmosis concentrate on drinking water treatment solids, *Sep. Purif. Technol.*, 2014, 134, 37–45, DOI:10.1016/j.seppur.2014.07.008.

[14] G. Qin, M. J. McGuire, N. K. Blute, C. Seidel and L. Fong, Hexavalent chromium removal by reduction with ferrous sulfate, coagulation, and filtration: a pilot-scale study, *Environ. Sci. Technol.*, 2005, 39, DOI:10.1021/es050486p.

[15] E. Rodrigues, O. Almeida, H. Brasil, D. Moraes and M. A. L. Reis, Adsorption of chromium (VI) on hydroxalite-hydroxyapatite material doped with carbon nanotubes: equilibrium, kinetic and thermodynamic study, *Appl. Clay Sci.*, 2019, 172, 64, DOI:10.1016/j.clay.2019.02.018.

[16] A. Mittal, L. Krishnan and V. K. Gupta, Removal and recovery of malachite green from wastewater using an agricultural waste material, de-oiled soya, *Sep. Purif. Technol.*, 2005, 43, 125–133, DOI:10.1016/j.seppur.2004.10.010.

[17] J. Wei, C. Tu, G. Yuan, D. Bi, L. Xiao, B. K. G. Theng, H. Wang and Y. Sik, Carbon-coated montmorillonite nanocomposite for the removal of chromium (VI) from aqueous solutions, *J. Hazard. Mater.*, 2019, 368, 541–549, DOI:10.1016/j.jhazmat.2019.01.080.

[18] B. Saha and C. Orvig, Biosorbents for hexavalent chromium elimination from industrial and municipal effluents, *Coord. Chem. Rev.*, 2010, 254, 2959–2972, DOI:10.1016/j.ccr.2010.06.005.

[19] D. Park, C. K. Ahn, Y. M. Kim, Y. S. Yun and J. M. Park, Enhanced abiotic reduction of Cr (VI) in a soil slurry system by natural biomaterial addition, *J. Hazard. Mater.*, 2008, 160, 422–427, DOI:10.1016/j.jhazmat.2008.03.044.

[20] H. Panda, N. Tiadi, M. Mohanty and C. R. Mohanty, Studies on adsorption behavior of an industrial waste for removal of chromium from aq.sulS.Afr.J.Chem.Eng., 2017, 23, 132138, DOI:10.1016/j.sajce.2017.05.002.

[21] L. Hlungwane, E. L. Viljoen and V. E. Pakade, Macadamia nutshells-derived activated carbon and attapulgite clay combination for synergistic removal of Cr (VI) and Cr (III), *Adsorpt. Sci. Technol.*, 2018, 731, DOI:10.1177/0263617417719552.

- [22] A. Mohamed, W. S. Nasser, T. A. Osman, M. S. Toprak, M. Muhammed and A. Uheida, Removal of chromium (VI) from aqueous solutions using surface modified composite nanofibers, *J. Colloid Interface Sci.*, 2017, 505, 682–691, DOI:10.1016/j.jcis.2017.06.066.
- [23] Nakajima and Y. Baba, Mechanism of hexavalent chromium adsorption by persimmon tannin gel, *Water Res.*, 2004, 38, 2859–2864, DOI:10.1080/00344893.2014.911772.
- [24] M. Gheju, Hexavalent chromium reduction with zero-valent iron (ZVI) in aquatic systems, 2011, DOI:10.1007/s11270-011-0812-y.
- [25] A. Bhatti, N. Ahmad, N. Iqbal, M. Zahid and M. Iqbal, Chromium adsorption using waste tire and conditions optimization by response surface methodology, *J. Environ. Chem. Eng.*, 2017, 5, 2740–2751, DOI:10.1016/j.jece.2017.04.051.
- [26] S. Periyasamy, V. Gopalakannan and N. Viswanathan, Fabrication of magnetic particles imprinted cellulose based biocomposites for chromium (VI) removal, *Carbohydr. Polym.*, 2017, 174, DOI: 10.1016/j.carbpol.2017.06.029.
- [27] M. K. Dinker and P. S. Kulkarni, Recent advances in silica-based materials for the removal of hexavalent chromium: a review, *J. Chem. Eng. Data*, 2015, 60, 2521–2540, DOI:10.1021/acs.jced.5b00292.
- [28] H. N. M. Ekramul Mahmud, A. K. Obidul Huq and R. B. Yahya, The removal of heavy metal ions from wastewater/aqueous solution using polypyrrole-based adsorbents: a review, *RSC Adv.*, 2016, 14791, 10.1039/c5ra24358k.
- [29] M. K. Uddin, A review on the adsorption of heavy metals by clay minerals, with special focus on the past decade, *Chem. Eng. J.*, 2017, 462, DOI:10.1016/j.cej.2016.09.029.
- [30] C. Almeida, C. E. D. Cardoso, D. S. Tavares, R. Freitas, T. Trindade, C. Vale and E. Pereira, Chromium removal from contaminated waters using nanomaterials – a review, *Trends Anal. Chem.*, 2019, 118, 277–291, DOI:10.1016/j.trac.2019.05.005.
- [31] P. Janik, B. Zawisza, E. Talik and R. Sitko, Selective adsorption and determination of hexavalent chromium ions using graphene oxide modified with amino silanes, *Microchim. Acta*, 2018, 185, 1–8, DOI:10.1007/s00604-017-2640-2.
- [32] N. K. Mondal, B. Sambrita and B. Das, Decontamination and optimization study of hexavalent chromium on modified chicken feather using response surface methodology, *Appl. Water Sci.*, 2019, 9, 1–15, DOI:10.1007/s13201-019-0930-z.
- [33] S. Mousavi, F. Shahraki, M. Aliabadi, A. Haji, F. Deuber and C. Adlhart, Surface-enriched nano fiber mats for efficient adsorption of Cr (VI) inspired by nature, *J. Environ. Chem. Eng.*, 2019, 7, 102817, DOI:10.1016/j.jece.2018.102817.