

PERFORMANCE EVALUATION OF FABRICATED MICROBIAL ASSISTED FUEL REACTOR WITH SELECTIVE CONSORTIA FOR HEXAVALENT CHROMIUM REDUCTION, WASTEWATER REMEDIATION AND ENERGY GENERATION

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ABSTRACT

Use of biological microbial agents to reduce waste has been at the centre of sustainable technology for a decade now. A major type of pollutant from tannery effluents is hexavalent chromium. A ten-litre dual-chamber reactor with dual chamber was used as a microbial fuel cell for remediating synthetic sludge containing hexavalent chromium. Sulphonated polyether ether ketone as an exchange membrane for protons was used to transfer the generated ions to the cathodic chamber. Microbial consortia used in this study were isolated in our laboratory previously, which were *Bacillus australimaris* and *Bacillus albus*. It was observed that the percentage removal of biological material from the catholyte was around 95%, and for chemical compounds it was around 86%. Dissolved solids were reduced by 84%. The present consortia with the functionalized membrane used to separate the chambers in this study have never been addressed for the current working volume. The production of electricity by the consortia is related to SDG 7, while the remediation part of the Microbial fuel cell is related to SDG-6. This system can be integrated with pre-existing treatment anaerobic digesters or membrane bioreactors, as well as novel applications such as hydroponics or remote sensors that extend their viability for both centralized and decentralized sanitation solutions. This research will pave the way for many more innovative designs and alternatives in microbial fuel cells for a sustainable future for all.

Keywords: *Bacillus albus*, *Bacillus australimaris*, Microbial Fuel Cell, Sulphonated Polyether Ether Ketone, Hexavalent Chromium, Remediation.

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INTRODUCTION

Wastewater remediation is the need of the hour today.¹ Different easy-to-remediate effluents are being researched by scientists all around the world. Biological electrochemical fuel cells treat effluents with microbial colonies to generate electricity. They oxidize contaminants of organic nature in the wastewater to produce ions and electrons that produce electricity. Protons move to the cathodic chamber through the sulfonated polyether ether ketone membrane while electrons move in the external circuit. The most commonly used exchange membrane is Nafion. It has excellent conductivity towards protons. But it has cons like high economic costs and fouling on the surface during extended operations that hinder scaling up of the same. Sulphonated polyether ether ketone has aromatic groups around the backbone of the polymer, which is responsible for its rigidity, as a result reducing the production cost by half. Thus, overcoming the shortcomings of Nafion. It has reduced the oxygen transfer coefficient and has 88% superior chemical oxidation potential.² Microbial fuel cells using sulphonated polyether ether ketone have been recently used in remediating effluents and wastewater from heavy metals.³ Effluents from tanneries have a large number of heavy metals in them that are toxic to nature. Chrome tanning is an essential process in the leather industry. This makes the leather soft and available for further manufacturing protocols. This leads to the release of hexavalent chromium in the wastewater after processing. Many ailments like skin irritation, nasal irritation, perforation of the eardrum and respiratory diseases are recorded due to exposure to chromium in food, air and water.⁴ Thus, secondary processing of effluent wastes is done in microbial fuel cells to reduce them and generate electricity at the same time. The hexavalent form is converted to the trivalent form, which is less toxic and less harmful to the

environment.⁵ The hexavalent form of chromium is found to be permeable and extremely mobile through the cell wall and membrane of living things. Inside the microbial cell, the mitochondria convert this hexavalent form to the trivalent form by the electron transport chain.⁶ The present study deals with a 10 L bioreactor for a microbial fuel cell to transform toxic hexavalent chromium to the trivalent form from effluents released by tanneries. The consortia used in this study have been isolated by our team from local wastewater sources. As reported previously, this consortium produced good results in remediating chromium and generating electricity. The production of electricity by the consortia is related to SDG 7, while the remediation part of the microbial fuel cell is related to SDG-6. The use of the present consortia isolated exclusively in our laboratory in our newly designed 10 L reactor with a functionalized membrane has never been reported before. This lacuna is filled in the present study.

EXPERIMENTAL

Material and Methods

A 10 L semi-batch dual-chamber microbial batch fuel cell was designed and constructed. Acrylic was used as the base material of the reactor. The compartments were placed adjacent to each other with a synthesized sulphonated polyether ether ketone membrane in the centre, sealed by a rubber gasket. Carbon paper was kept at the anode and cathode. The dimensions were 25X25 cm². They were purchased from Synergic India Pvt. Ltd. The circuit was completed using copper wires externally. 1g per litre of sodium acetate was used as anolyte and added to wastewater, which was produced synthetically. The composition of the wastewater was as per the literature published previously in our laboratory.⁷ Potassium dichromate was purchased commercially from Sigma-Aldrich and used in synthesizing the catholyte. The microbial consortia used in this study was isolated previously from our laboratory.⁸ 1 mL of effluent sample was serially diluted and plated on nutrient agar plates. Media containing tannery effluent as the basic source of carbon along with agar was used to isolate specific colonies of choice. Further biochemical and physical screenings were performed along with DNA isolation. Confirmation of the species of bacteria was done by amplifying the 16s rRNA gene. A schematic of the fabricated microbial fuel cells has been depicted in Fig.-1. Scanning electron microscopy images were taken to visualize the anode before and after the experiment.

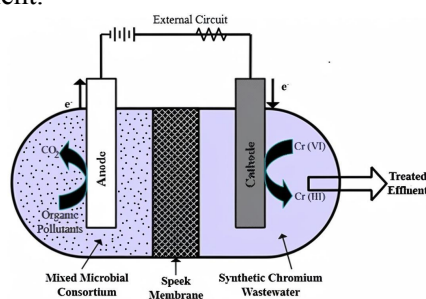


Fig.-1: Fabricated Microbial Fuel Cell with Functionalized Permeable Membrane

Power Generation

Synthetic wastewater along with dipotassium chromate was introduced into the MFC in two modes, namely the open and closed-circuit modes. Voltages were monitored by a digital multimeter. Setups were operated for 3 weeks. The voltage values for closed circuit were less than open circuit MFC setup.

RESULTS AND DISCUSSION

The treated medium at the cathode was treated to check the chromium reduction in mg/L. Figure-2 depicts the treatment effect on chromium levels in the catholyte. The microbial consortia used in the present study were able to reduce the chromium content by 85%. Hexavalent chromium can be reduced intercellularly by microbes by suitable functional groups that aid its entry into the cytoplasm. Channels like phosphate or sulfate are used to reduce these toxic heavy metals and immobilise them to form trivalent chromium. The trivalent final product is transmitted out of the cell.⁸

It was observed that the percentage removal of biological material from the catholyte was around 95%, and for chemical compounds it was around 86%. Dissolved solids were reduced by 84%.

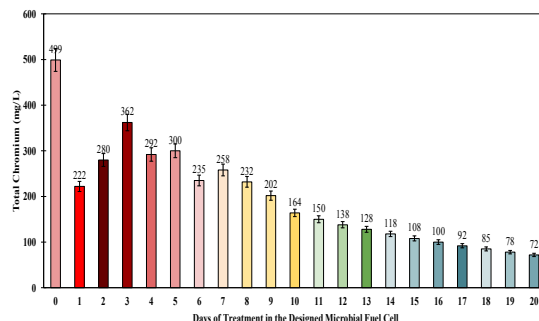


Fig.-2: (left to right) Total Chromium Analysis after 20 days of Treatment in Designed Microbial Fuel Cell

But the total solids had a negligible change, as microbial fuel cells couldn't reduce larger solid materials. Thus, tertiary treatment is essential to remove total solids and additional hues from the wastewater. Figure-3 shows the lack of total solids removal and the colour compounds from the effluent.

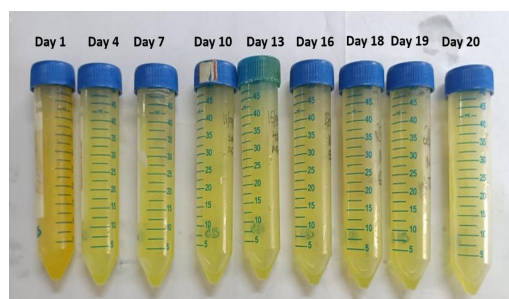


Fig.-3: Physical Parameters of Treated Effluent in the Designed Microbial Fuel Cell

The COD and BOD efficiency of the modified membrane used in this study has yielded superior results than nafion. This efficiency is 26 times higher than Nafion 112. 63.6% functionalization of the membrane with sulfate gave up to 91% efficiency previously in our laboratory.⁸ Table-1 summarizes the hexavalent chromium, sulfate, and chloride content in the catholyte and its reduction trajectory after 20 days. There was a 75% reduction seen in toxic hexavalent chromium at the end of the experiment. 99% and 98% reduction in sulfates and chlorides, respectively, for the same experimental duration. Thus, the present consortia isolated by our laboratory are very effective in remediating potential contaminants from the tannery industry with good efficiency. The functionalized membrane used in this study with our isolated consortia works synergistically in remediating wastewater with ease, which can be further processed for tertiary treatment.

Table-1: Comparative Data of Toxic Parameters of Effluent from 0 to 20 Days in the Current Designed Reactor

Part A: Untreated sample and treatment Days 0–10

S. No.	Wastewater quality parameter	Untreated Raw Effluent (mg/L)	Treated Chrome Taanning Effluent (mg/L)										
			Day 0	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
1.	BOD	1230	520	476	432	388	344	300	256	212	168	124	80
2.	COD	3200	870	803	736	669	602	535	468	401	334	267	200
3.	TDS	12730	5960	5544	5128	4712	4296	3880	3464	3048	2632	2216	1800
4.	Total Solids	17720	2530	2530	2530	2530	2530	2530	2530	2530	2530	2530	2530
5.	Volatile Solids	3800	1480	1406	1332	1258	1184	1110	1036	962	888	814	740
6.	Hexavalent Chromium	133	81	77	72	69	65	66	60.5	58	56.1	49.5	49
7.	Total Chromium	5.6	499	222	280	362	292	300	235	258	232	202	164
8.	Sulfates	1515	4849	4367	3885	3403	2921	2439	1957	1475	993	511	29
9.	Chlorides	116	1331	1206	1082	957	833	709	584	460	335	211	87

Part B: Treatment Days 11–20

S. No.	Wastewater quality parameter	Day 11	Day 12	Day 13	Day 14	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20
1.	BOD	70	62	55	48	42	37	33	29	26	23
2.	COD	185	171	158	146	134	124	114	105	96	88
3.	TDS	1650	1550	1450	1360	1280	1200	1130	1060	1000	940

S. No.	Wastewater quality parameter	Day 11	Day 12	Day 13	Day 14	Day 15	Day 16	Day 17	Day 18	Day 19	Day 20
4.	Total Solids	2530	2530	2530	2530	2530	2530	2530	2530	2530	2530
5.	Volatile Solids	690	645	602	563	526	492	460	430	402	375
6.	Hexavalent Chromium	48.3	45.1	42	38.9	35.8	32.6	29.5	26.4	23.2	20
7.	Total Chromium	150	138	128	118	108	100	92	85	78	72
8.	Sulfates	22	18	15	12	10	8	6.5	5	4	3
9.	Chlorides	75	65	58	52	46	41	36	32	28	25

Image of the electrode topography was performed using scanning electron microscopy. Organic material buildup was noticed after 20 days of remediation at the anode. Figure-4A illustrates the electrode surface before remediation and 4B after 20 days of remediation. Biofilm growth was observed on the surface of the anode after 20 days. This indicates good microbial activity using contaminants as a carbon source to grow and thrive. The positive charge of the electrode pulls the microbes towards it as the surface of the microorganisms is oppositely charged. Thus, improving the overall voltage output as degradation of the waste materials occurs in the fuel cell. This data is in sync with previously published results that support biofilm presence on electrode surfaces after 13 days of successful operations.⁹⁻¹⁰

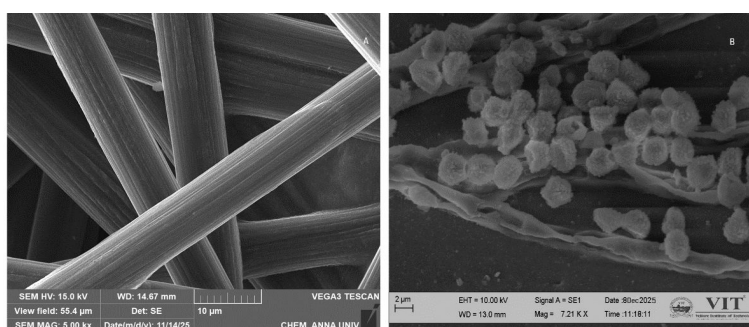


Fig.-4: (A) Scanning Electron Microscopy Image of Anode Before Commencement of the Remediation, (B) Image of the Anode After 20 Days of Operating the Microbial Fuel Cell

Overall comparison of all the parameters inside the microbial fuel cell is depicted in Fig.-5. Maximum decrease in hexavalent chromium, sulphates and chlorides has been noticed. Total solids will require further tertiary processing to make the effluent more compatible to be released in the environment. Overall performance of the reactor is very satisfactory.¹¹

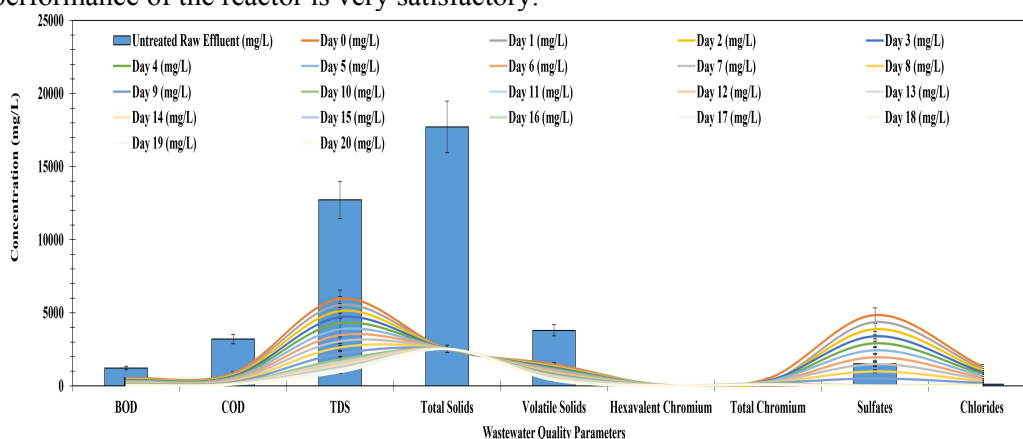


Fig.-5: Comparative Illustration of Different Parameters Analyzed For 20 Days in the Designed Microbial Fuel Cell

Toxic hexavalent chromium was reduced by 85% in the present study. This has been depicted in Fig.-6. The electrons produced at the anode move towards the cathode through the external circuit. More electron production denotes reduction of hexavalent chromium in the anodic chamber. The proposed mechanism of action for reducing hexavalent chromium by microbes is due to NADH, heme proteins and flavin proteins. After microbes internalize hexavalent chromium through channels of sulfates and phosphates and reduce it to its trivalent form and eject it out of the cell by plasmid transfer. Free radicals and reactive

oxygen species are formed during the reduction process. This could potentially harm the DNA under an oxygenated environment.¹² Thus, maintaining an optimal environment for the consortia is very important for the better performance of the microbial fuel cell.

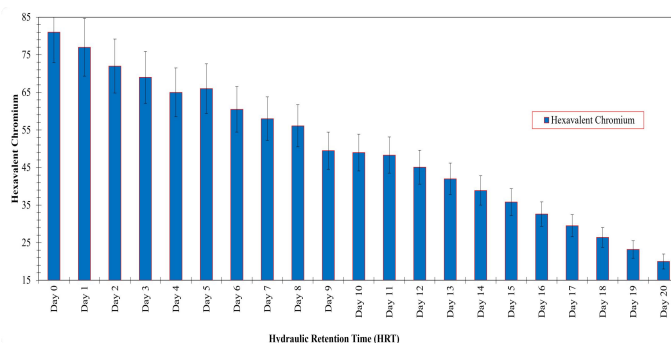


Fig.-6: Hexavalent Chromium Reduction in the Designed Microbial Fuel Cell

A decline in the cell voltage is noticed as current density increases from 0.3 mA/m^2 to 2.6 mA/m^2 . High voltages are observed at low current densities. This has been observed near open-circuit setups. The activation losses are found to be quite low in these setups. As current density increases, the drop in voltages becomes predominant due to ohmic resistance, limited mass transfer and activation losses. This behaviour is seen to be characteristic for carbon-based electrodes. As voltage decreases, the current density goes beyond 2.2 mA/m^2 . This indicates depletion of substrate and gradual ion transport limiting across the membrane. Thus, depicting onset concentration polarization. In polarization curves, current density increases to a maximum value, then tends to decrease as current density is increased further. This has been depicted in Fig.-7. A steady increase can be obtained if the current and voltage are increased simultaneously. When current density was maintained at 2.2 mA/m^2 , maximum power density was generated. Thus, creating optimal balance between the two parameters. Resistance in the MFC, both internal and external, matches each other as reported in the literature. Due to internal loss, power density decreases with an increase in current beyond the maximum density of current.

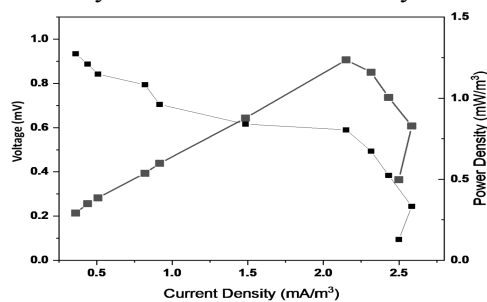


Fig.-7: Polarisation and Power Curves for the MFC

Unlike previous studies that primarily focused on electricity generation, the present work demonstrates the effectiveness of the SPEEK membrane in a scaled-up 10 L dual-chambered semi-batch microbial fuel cell reactor in treating wastewater, reducing the hexavalent chromium, while simultaneously enhancing power generation. This expands the potential application of SPEEK-based microbial fuel cells in practical wastewater treatment systems. This improvement can be attributed to the lower oxygen crossover of SPEEK, which minimizes oxygen diffusion into the anode chamber and enhances electron recovery. These findings suggest that SPEEK is not only a low-cost alternative to Nafion but also offers superior electrochemical performance, making it a promising membrane for future large-scale microbial fuel cell applications in wastewater treatment plants.

Limitations And Future Scope

Biofilm formed at the anode could obstruct electricity after a certain time if used continuously for extended durations. Maintenance of the electrodes would be required as fouling at membranes could also occur. The duration of remediation is longer when biological consortia are used instead of chemical

counterparts. Electricity generated is also not at a sufficient scale when compared to a chemical fuel cell.¹³ As a future agenda, nanoparticles can be incorporated alongside the microbial consortia to enhance the reduction efficiency by reducing the time and inhibiting biofilm formation. Nanocarrier-based consortia can be synthesised to remediate pigments in the effluents to avoid further tertiary treatments after microbial fuel cell operations.⁴ But toxicity parameters need to be considered when working with nanomaterials, as they have their own pros and cons.¹⁴ Different phenolic wastes that have potential for remediation can also be used along with microbial consortia to gain better results in terms of sustainability and recyclability of wastes from different sources used to remediate each other.⁴ Wastes generated from wood industries can be used to season the microbial fuel cells to generate innovative by-products that might have some commercial value alongside remediated qualities.⁵

CONCLUSION

A 10 L bioreactor microbial fuel cell was designed to transform toxic hexavalent chromium to the trivalent form from synthetic wastewater mimicking the effluents released by tanneries. The consortia used in this study were isolated by our team from local wastewater sources. Microbial consortia used in the present study were able to reduce the chromium content by 85%. There was a 75% reduction seen in toxic hexavalent chromium at the end of the experiment. 99% and 98% reductions in sulfates and chlorides, respectively, for the same experimental duration. Thus, the present consortia isolated by our laboratory are very effective in remediating potential contaminants from the tannery industry with good efficiency. The current study is closely related to SDG 6 for the removal of organic pollutants in anolyte and reduction of Hexavalent Chromium in catholyte, and SDG 7 for electricity generation in the reactor due to biocatalytic activity.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

The present work is related to *SDG-6: Clean water and Sanitation*. All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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REFERENCES

1. S. Das, S. Kumar, K. Mehta, M.M. Ghangrekar, *Bioresource Technology*, **406**, 131038(2024), <https://doi.org/10.1016/j.biortech.2024.131038>
2. P. Gangadharan, I.M. Nambi, *Water Science Technology*, **71**, 353(2015), <https://doi.org/10.2166/wst.2014.524>
3. V.S. Gnanarathinam, A. Balakrishnan, G. Rajendran, A. Arivarasu, S. Dharmalingam, T. S. Balasundaram, P. N. Venkatesan, E. P. U. Perumal., *Environmental Progress and Sustainable Energy*, **42**, 14158(2023), <https://doi.org/10.1002/ep.14158>
4. S. Revathi, N. Dey, A. Thomas, P.K. Issac, S. Shaik, S. A. Hussain, A. Guru., *Chemistry & Biodiversity*, **2**, 202402150(2025), <https://doi.org/10.1002/cbdv.202402150>
5. S. Revathi, N. Dey, S. Thangaleela, S. Vinayagam, L. Gnanasekaran, T. Sundaram, A. Malik, A. A. Khan, A. Roy, A. Kumar, *International Journal of Biological Macromolecules*, **274**, 133316(2024), <https://doi.org/10.1016/j.ijbiomac.2024.133316>
6. M.P. Shah, S. Rodriguez-Couto, *Microbial Ecology of Wastewater Treatment Plants*, Elsevier, (2021), <https://doi.org/10.1016/C2019-0-04695-X>

7. M.A. Shabur, N. Jahan, M.A. Mottalib, *Scientific Reports*, **15**, 41115(2025), <https://doi.org/10.1038/s41598-025-24856-1>.
8. Y. Song, Z. Guo, J. Yin, M. Liu, I. Tolj, S.A. Grigoriev, M. Ge., C. Sun, *Polymers (Basel)*, **17(16)**, 2181(2025), <https://doi.org/10.3390/polym17162181>
9. H. Sun, Y. Li, S. Gao, G. Shi, L. Cao, X. Li, Li. Tong, T. Li, M. Wang, E. Li, J. Liu, H. Ni, Y. Chen, Y. Liu, *Ecotoxicology and Environmental Safety*, **291**, 117843(2025), <https://doi.org/10.1016/j.ecoenv.2025.117843>
10. F.C. Teixeira., A.P.S. Teixeira, C.M. Rangel, *Polymers (Basel)*, **17(12)**, 1646(2025), <https://doi.org/10.3390/polym17121646>
11. S. Thanigaivel, S. Vickram, N. Dey, P. Jeyanthi, R. Subbaiya, W. Kim, M. Govarathanan, N. Karmegam, *Chemosphere*, **313**, 137475(2023), <https://doi.org/10.1016/j.chemosphere.2022.137475>
12. H. Zhou, K. Wang, L. He, Z. Liu, D. Kong, Q. Zhang, S. Jin, Y. Han, Q. Guan, G. Sheng. *Water Research*, **288**, 124581(2026), <https://doi.org/10.1016/j.watres.2025.124581>
13. M. Eyvaz and E. Yüksel(Eds), *Desalination and Water Treatment*, InTech(2018), <https://doi.org/10.5772/intechopen.72352>
14. S. Suji, A.V. Harikrishnan, N. Dey, S. Vinayagam, S. Thanigaivel, C. Kamaraj, L. Gnanasekaran, K. Goyal, H. Ali, G. Gupta, M.S. Hussain, V. Subramanian, *Journal of Nanoparticle Research*, **27**, 4(2025), <https://doi.org/10.1007/s11051-025-06306-1>

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