BUILDING DIATOM BIOREFINERY: CONVERTING THERMAL POWER PLANT EFFLUENT TO SUSTAINABLE MATERIAL AND FUEL

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by

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CERTIFICATE

This is to certify that the thesis entitled **"Building Diatom Bio-refinery: converting thermal power plant effluent to sustainable materials and fuels,"** being submitted by **Mr. Rahul Jain** to the Indian Institute of Technology Delhi for the award of "**Doctor of Philosophy,**" is a record of bonafide research work carried out by him. He has worked under our guidance and supervision and has fulfilled the requirements for the submission of this thesis. To the best of our knowledge, the results contained in this thesis have not been submitted in part or whole to any other university or institute for the award of any degree or diploma.

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Abstract

Cooling tower blowdown (CTBD) water constitutes a significant amount of wastewater generation in thermal power plants, which can be sustainably treated and utilized for considerable water savings. In the present work, a microalgae-based bio-refinery approach has been utilized to treat the cooling tower blow-down water and simultaneously recover bio-crude and valuable material from the generated biomass.

Initially, the two microalgae consortia: PA6 (*Chlorella*, *Phormidium*, and *Navicula* sp.) and D (*Navicula* and *Denticula* species), were tested using a 5 L capacity bubble column reactor (BCR) and attached biofilm reactor (ABR) configuration. The isolated D consortium outperformed the PA6 in terms of pollutant removal, with 66.8% reactive silica and 83% colloidal silica reduction with total silica uptake rate of 40 mg L^{-1} d^{-1} over the first 72 hours. Compared to suspended cultivation, areal biomass yield in the D consortium biofilm system was 2.45 times higher. The ABR showed superior performance compared to the BCR in terms of both wastewater treatment and overall biomass productivity. To further improve efficiency and minimize areal footprint, the enclosed multi-plate biofilm reactor (EMPBR) was fabricated. In comparison to the ABR system, EMPBR removed approximately 12.5% higher nutrients and gave 8.3 times higher areal biomass productivity. In the life cycle assessment (LCA) study, Recipe 2016 approach showed that EMPBR has a lower environmental burden than ABR due to the high-density polyethylene resin used in ABR's water storage tank, which contributed to negative impacts.

On downstream processing of D consortium biomass, 52.4% frustules, 19.6% lipid, 11.9% protein, and 8.2% carbohydrates were recovered per gram of biomass. The recovered frustules were found to be negatively charged, symmetrical pennate-shaped, robust, mesoporous SiO_2. A comparative study was conducted to recover diatom frustules using different physicochemical techniques, focusing on both quantitative and qualitative aspects. Baking for 180 minutes removed the most organic matter (94.9%), followed by plasma exposure for 90 minutes (86.8%). However, after baking and chemical exposure, the structure was distorted. Furthermore, to simultaneously valorize both organic and inorganic fractions of the diatom biomass, hydrothermal liquefaction (HL) technology was utilized. Diatom

biomass yielded 9.5% extracted biocrude and approximately 12.5% frustule loaded fraction. According to GC-MS analysis, the bio-crude was primarily constituted of oxidized and desired functional groups such as alcohols, alkanes, alkenes, and esters, with a few unfavorable nitrogen-containing compounds (18.9%). Overall, the hydrothermal liquefaction technology was discovered to be a beneficial process for diatom bio-prospecting because it allowed for the complete valorization of intermediates.

The projection analysis of the diatom biorefinery process for a 500 MW power plant demonstrated significant water-saving of 1500 million liters, annual production of 162 tonnes of frustules, 61 tonnes of lipid, and 37 tonnes of protein. The technology promises societal benefits including improved human health, strengthened rural livelihood, and knowledge dissemination of nature-based technologies, and has the potential to revolutionize blowdown water management practices and contribute to the development of a new 'waste to wealth' industrial approach.

सार

कूलिंग टावर ब्लोडाउन (सीटीबीडी) पानी थर्मल पावर प्लांटों में अपशिष्ट जल उत्पादन की एक महत्वपूर्ण मात्रा का निर्माण करता है, जिसे काफी पानी की बचत के लिए स्थायी रूप से उपचारित और उपयोग किया जा सकता है। वर्तमान कार्य में, माइक्रोएल्गो-आधारित बायो-रिफाइनरी दृष्टिकोण का उपयोग कूलिंग टॉवर ब्लो-डाउन वॉटर के उपचार के लिए किया गया है और साथ ही उत्पन्न बायोमास से बायो-क्रूड और मूल्यवान सामग्री को पुनर्प्राप्त किया गया है।

प्रारंभ में, दो माइक्रोएल्गे कंसोर्टिया: PA6 (क्लोरेला, फोर्मिडियम, और नेविकुला प्रजातियां) और डी (नेविकुला और डेंटिकुला प्रजातियां), 5 एल क्षमता बबल कॉलम रिएक्टर (बीसीआर) और संलग्न बायोफिल्म रिएक्टर (एबीआर) कॉन्फ़िगरेशन का उपयोग करके परीक्षण किया गया था। पहले 72 घंटों में 40 मिलीग्राम / लीटर / दिन की कुल सिलिका अपटेक दर के साथ 66.8% प्रतिक्रियाशील सिलिका और 83% कोलाइडयन सिलिका की कमी के साथ पृथक डी कंसोर्टियम ने प्रदूषक हटाने के मामले में पीए 6 से बेहतर प्रदर्शन किया। निलंबित वृद्धि की तुलना में, डी कंसोर्टियम बायोफिल्म सिस्टम में क्षेत्रीय बायोमास उपज 2.45 गुना अधिक थी। अपशिष्ट जल उपचार और समग्र बायोमास उत्पादकता दोनों के मामले में एबीआर ने बीसीआर की तुलना में बेहतर प्रदर्शन किया। दक्षता में और सुधार करने और क्षेत्र के पदचिह्न को कम करने के लिए, संलग्न मल्टी-प्लेट बायोफिल्म रिएक्टर (EMPBR) का निर्माण किया गया था। एबीआर प्रणाली की तुलना में, ईएमपीबीआर ने लगभग 12.5% अधिक प्रदूषकों को हटा दिया और 8.3 गुना अधिक क्षेत्रीय बायोमास उत्पादकता प्रदान की। जीवन चक्र मूल्यांकन (LCA) अध्ययन में, रेसिपी 2016 के दृष्टिकोण ने दिखाया कि ABR के जल भंडारण टैंक में उपयोग किए जाने वाले उच्च घनत्व वाले पॉलीथीन राल के कारण EMPBR का पर्यावरणीय बोझ ABR से कम है, जिसने नकारात्मक प्रभावों में योगदान दिया।

डी कंसोर्टियम बायोमास के डाउनस्ट्रीम प्रसंस्करण पर बायोमास के प्रति ग्राम 52.4% फ्रस्ट्यूल, 19.6% लिपिड, 11.9% प्रोटीन और 8.2% कार्बोहाइड्रेट बरामद किए गए। बरामद कुंठाओं को नकारात्मक रूप से आवेशित, सममित पेनेट के आकार का, मजबूत, मेसोपोरस SiO2 पाया गया। मात्रात्मक और गुणात्मक दोनों पहलुओं पर ध्यान केंद्रित करते हुए, विभिन्न भौतिक-रासायनिक तकनीकों का उपयोग करके डायटम फ्रस्ट्यूल को पुनर्प्राप्त करने के लिए एक तुलनात्मक अध्ययन किया गया था। 180 मिनट के लिए बेक करने से अधिकांश कार्बनिक पदार्थ (94.9%) निकल जाते हैं, इसके बाद 90 मिनट (86.8%) के लिए प्लाज्मा एक्सपोजर होता है। हालांकि, बेकिंग और रासायनिक एक्सपोजर के बाद, संरचना विकृत हो गई थी। इसके अलावा, डायटम बायोमास के कार्बनिक और अकार्बनिक दोनों अंशों को एक साथ मान्य करने के लिए, हाइड्रोथर्मल द्रवीकरण (एचएल) तकनीक का उपयोग किया गया था। डायटम बायोमास से 9.5% निकाले गए बायोक्रूड और लगभग 12.5% फ्रस्टूल लोड अंश प्राप्त हुए। जीसी-एमएस विश्लेषण के अनुसार, बायो-क्रूड मुख्य रूप से कुछ प्रतिकूल नाइट्रोजन युक्त यौगिकों (18.9%) के साथ अल्कोहल, अल्केन्स, अल्केन्स और एस्टर जैसे ऑक्सीकरण और वांछित कार्यात्मक समूहों का गठन किया गया था। कुल मिलाकर, हाइड्रोथर्मल द्रवीकरण तकनीक को डायटम जैव-पूर्वेक्षण के लिए एक लाभकारी प्रक्रिया के रूप में खोजा गया था क्योंकि इससे मध्यवर्ती का पूर्ण मूल्यांकन हुआ।

500 मेगावाट बिजली संयंत्र के लिए डायटम बायोरिफाइनरी प्रक्रिया के प्रक्षेपण विश्लेषण ने 1500 मिलियन लीटर की महत्वपूर्ण जल बचत, 162 टन फ्रस्ट्यूल, 61 टन लिपिड और 37 टन प्रोटीन का वार्षिक उत्पादन प्रदर्शित किया। प्रौद्योगिकी मानव स्वास्थ्य में सुधार, ग्रामीण आजीविका को मजबूत करने, और प्रकृति-आधारित प्रौद्योगिकियों के ज्ञान प्रसार सहित सामाजिक लाभों का वादा करती है, और इसमें जल प्रबंधन प्रथाओं में क्रांति लाने की क्षमता है और एक नए 'अपशिष्ट से धन' औद्योगिक दृष्टिकोण के विकास में योगदान करती है।

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