SYNTHESIS OF CARBON BY CO-PYROLYSIS OF END-OF-LIFE TYRES & JACKFRUIT PEELS AND ITS APPLICATION IN WASTEWATER TREATMENT

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by

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Submitted
In fulfilment of the requirements of the degree of Doctor of Philosophy

to the

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Dedicated to

My parents, husband, and son.

CERTIFICATE

This is to certify that the thesis entitled **"Synthesis of carbon by co-pyrolysis of end-of-life tyres & jackfruit peels and its application in wastewater treatment"** being submitted by **Ms. Devika Venu** to the Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy** is a bonafide record of the research work carried out by her under my supervision and guidance. The thesis work, in my opinion, has reached the requisite standard, fulfilling the requirements for the degree of Doctor of Philosophy.

The contents of this thesis, in full or in parts, have not been submitted to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

The management of End-of-Life Tyres (ELTs) and jackfruit peel (JP) represents a critical global challenge due to their resistance to biological degradation and large-scale generation respectively. ELTs, with an annual global production exceeding 1.5 billion tons, and the vast quantities of discarded JP in jackfruit-producing countries highlight the need for sustainable and eco-friendly solutions for their disposal. This study investigates the co-pyrolysis of ELTs and JP to produce multifunctional materials for environmental remediation, specifically focusing on wastewater treatment.

The presence of zinc (Zn) in ELTs, known to enhance catalytic activity, was utilized in the preparation of a heterogeneous Fenton catalyst. The iron-loaded ELT-JP char exhibited high degradation efficiencies for both dyes (Methylene Blue and Acid Red 1) and micropollutants (Caffeine and Tetracycline) through Fenton oxidation. The degradation efficiency was significantly influenced by parameters such as pH, catalyst dosage, and H_2O_2 concentration. Using Response Surface Methodology (RSM), these parameters were systematically optimized to achieve over 90% degradation under optimal conditions.

In parallel, activated carbon was produced from the co-pyrolyzed ELT-JP char with a specific focus on reducing KOH usage to enhance cost efficiency while maintaining high adsorption performance. The production process was studied using both microwave pyrolysis and conventional heating methods, with microwave pyrolysis demonstrating superior outcomes in terms of yield, BET specific surface area, and energy efficiency. The activated carbon was applied for the adsorption of dyes and micropollutants, with key parameters such as pH, initial pollutant concentration, adsorbent dosage, and temperature being optimized using RSM. Adsorption studies indicated that the activated carbon prepared using microwave pyrolysis was

highly effective, achieving removal efficiencies comparable to those prepared via conventional methods but with reduced energy and material costs.

The synergistic combination of ELTs and JP in the co-pyrolysis process resulted in materials with enhanced properties. The catalytic role of Zn in ELTs improved the activity of the heterogeneous Fenton catalyst, while the high BET specific surface area of the activated carbon ensured efficient adsorption. A comparative cost analysis of the preparation methods further underscored the feasibility of microwave pyrolysis for large-scale applications.

This work demonstrates a novel approach to valorising ELTs and JP, converting these waste materials into value-added products for wastewater treatment. The dual application of the synthesized materials—heterogeneous Fenton catalysts for degradation and activated carbon for adsorption—provides a comprehensive solution for the removal of dyes and micropollutants. By integrating sustainable production techniques, systematic optimization using RSM, and cost-effectiveness analysis, the study offers a scalable and eco-friendly model for addressing global waste and wastewater management challenges. The findings align with circular economy principles, promoting the reuse of waste materials while addressing critical environmental concerns.

अमूर्त

एंड-ऑफ-लाइफ टायर्स (ईएलटी) और कटहल के छिलके (जेपी) का प्रबंधन क्रमशः जैविक क्षरण और बड़े पैमाने पर उत्पादन के प्रतिरोध के कारण एक महत्वपूर्ण वैश्विक चुनौती का प्रतिनिधित्व करता है। ईएलटी, जिसका वार्षिक वैश्विक उत्पादन 1.5 बिलियन टन से अधिक है, और कटहल उत्पादक देशों में बड़ी मात्रा में छोड़े गए जेपी उनके निपटान के लिए टिकाऊ और पर्यावरण-अनुकूल समाधान की आवश्यकता पर प्रकाश डालते हैं। यह अध्ययन विशेष रूप से अपशिष्ट जल उपचार पर ध्यान केंद्रित करते हुए पर्यावरणीय सुधार के लिए बहुक्रियाशील सामग्री का उत्पादन करने के लिए ईएलटी और जेपी के सह-पाइरोलिसिस की जांच करता है।

ईएलटी में जिंक (जेडएन) की उपस्थिति, जो उत्प्रेरक गतिविधि को बढ़ाने के लिए जानी जाती है, का उपयोग एक विषम फेंटन उत्प्रेरक की तैयारी में किया गया था। आयरन-लोडेड ईएलटी-जेपी चार ने फेंटन ऑक्सीकरण के माध्यम से दोनों रंगों (मिथाइलीन ब्लू और एसिड रेड 1) और सूक्ष्म प्रदूषकों (कैफीन और टेट्रासाइक्लिन) के लिए उच्च गिरावट क्षमता प्रदर्शित की। क्षरण दक्षता पीएच, उत्प्रेरक खुराक और H2O2 एकाग्रता जैसे मापदंडों से काफी प्रभावित थी। रिस्पांस सरफेस मेथडोलॉजी (आरएसएम) का उपयोग करते हुए, इन मापदंडों को इष्टतम परिस्थितियों में 90% से अधिक गिरावट प्राप्त करने के लिए व्यवस्थित रूप से अनुकूलित किया गया था।

समानांतर में, उच्च सोखना प्रदर्शन को बनाए रखते हुए लागत दक्षता बढ़ाने के लिए केओएच उपयोग को कम करने पर विशेष ध्यान देने के साथ सह-पाइरोलाइज्ड ईएलटी-जेपी चार से सक्रिय कार्बन का उत्पादन किया गया था। उत्पादन प्रक्रिया का अध्ययन माइक्रोवेव पायरोलिसिस और पारंपरिक हीटिंग विधियों दोनों का उपयोग करके किया गया था, जिसमें माइक्रोवेव पायरोलिसिस ने उपज, बीईटी विशिष्ट सतह क्षेत्र और ऊर्जा दक्षता के संदर्भ में बेहतर परिणाम प्रदर्शित किए। सक्रिय कार्बन का उपयोग रंगों और सूक्ष्म प्रदूषकों के सोखने के लिए किया गया था, जिसमें पीएच, प्रारंभिक प्रदूषक सांद्रता, सोखने की मात्रा

और तापमान जैसे प्रमुख मापदंडों को आरएसएम का उपयोग करके अनुकूलित किया गया था। सोखने के अध्ययन से संकेत मिलता है कि माइक्रोवेव पायरोलिसिस का उपयोग करके तैयार किया गया सक्रिय कार्बन अत्यधिक प्रभावी था, जो पारंपरिक तरीकों के माध्यम से तैयार की गई निष्कासन क्षमता को प्राप्त करता है, लेकिन कम ऊर्जा और सामग्री लागत के साथ।

सह-पाइरोलिसिस प्रक्रिया में ईएलटी और जेपी के सहक्रियात्मक संयोजन के परिणामस्वरूप उन्नत गुणों वाली सामग्री प्राप्त हुई। ईएलटी में जेएन की उत्प्रेरक भूमिका ने विषम फेंटन उत्प्रेरक की गतिविधि में सुधार किया, जबकि सक्रिय कार्बन के उच्च बीईटी विशिष्ट सतह क्षेत्र ने कुशल सोखना सुनिश्चित किया। तैयारी के तरीकों के तुलनात्मक लागत विश्लेषण ने बड़े पैमाने पर अनुप्रयोगों के लिए माइक्रोवेव पायरोलिसिस की व्यवहार्यता को और अधिक रेखांकित किया।

यह कार्य ईएलटी और जेपी को महत्व देने के लिए एक उपन्यास दृष्टिकोण प्रदर्शित करता है, जो इन अपशिष्ट पदार्थों को अपशिष्ट जल उपचार के लिए मूल्य वर्धित उत्पादों में परिवर्तित करता है। संश्लेषित सामग्रियों का दोहरा अनुप्रयोग - क्षरण के लिए विषम फेंटन उत्प्रेरक और सोखने के लिए सक्रिय कार्बन - रंगों और सूक्ष्म प्रदूषकों को हटाने के लिए एक व्यापक समाधान प्रदान करता है। टिकाऊ उत्पादन तकनीकों, आरएसएम का उपयोग करके व्यवस्थित अनुकूलन और लागत-प्रभावशीलता विश्लेषण को एकीकृत करके, अध्ययन वैश्विक अपशिष्ट और अपशिष्ट जल प्रबंधन चुनौतियों के समाधान के लिए एक स्केलेबल और पर्यावरण-अनुकूल मॉडल प्रदान करता है। निष्कर्ष चक्रीय अर्थव्यवस्था सिद्धांतों के अनुरूप हैं, महत्वपूर्ण पर्यावरणीय चिंताओं को संबोधित करते हुए अपशिष्ट पदार्थों के पुन: उपयोग को बढ़ावा देते हैं।

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ELT	End-of-Life Tyres
JP	Jackfruit peels
MB	Methylene Blue
AR1	Acid Red 1
CFN	Caffeine
TC	Tetracycline
Fe-ELTJP	Iron loaded End-of-Life Tyre and Jackfruit peel catalyst
Fe-JP	Iron loaded jackfruit peel catalyst
Fe-ELT	Iron loaded End-of-life tyre catalyst
ELTJP-KOH	KOH activated End-of-Life Tyre and Jackfruit Peel carbon