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A Novel Approach for Eco-Friendly Biodiesel Production Using Fish Scale Waste as Catalyst

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Research Article

Keywords: Green catalyst, Biodiesel, Fish scale catalyst, Response surface methodology, Waste disposal, Design expert

Posted Date: June 18th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9722437/v1

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“A Novel Approach for Eco-Friendly Biodiesel Production Using Fish Scale Waste as Catalyst"

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ABSTRACT

Rising population impacts the excessive consumption of petroleum fuels leading to global warming and changes in the environment. As a result, it is important to use renewable and clean energy such as biodiesel as a source of energy to fulfil the energy requirement. It leads to complete combustion of fuel and reduces exhaust gas emissions. This study focuses on the green production of low-cost catalysts using discarded fish scale Labeo Rohita and optimised biodiesel production using design expert software. Analytical tools such as Xray diffraction (XRD), Fourier Transform Infrared spectroscopy (FTIR), and Scanning Electron Microscopy (SEM) are used to analyse synthesized catalysts. At optimal conditions, 90.21% yield of biodiesel was obtained at 1.5 wt.% catalyst concentration, at temperature of 65^0C, and 1.5-hour reaction time. Several properties of prepared biodiesel such as density, flash point, pour points, and kinetic energy were evaluated and validated as per American Society for Testing and Materials (ASTM) Standards.

Keywords*:* Green catalyst; Biodiesel; Fish scale catalyst; Response surface methodology; Waste disposal; Design expert.

HIGHLIGHTS

- Green synthesis of low-cost heterogeneous catalyst using fish scale.
- Analysis of heterogeneous catalyst using XRD, FTIR and scanning electron microscope SEM
- Application of prepared catalyst for biodiesel production.
- Optimization of biodiesel production using design expert software
- Verification of properties of prepared biodiesel as per international standard

INTRODUCTION

The growing industrialization, urbanization, lifestyle standards and increasing population have led to the huge energy requirements and is increasing day by day. (Akhmat et al. 2014)(Kazemi and Hosseinzadeh 2016). The energy consumption is 105 times faster than nature can produce. Thus, the natural (Buchori, Istadi, and Purwanto 2017)energy sources are not sufficient to satisfy future need of energy, moreover excessive uses of fossil fuel resulted into global warming and ecological unbalance(Jo et al. 2013)(Khan, Hou, and Le 2021)(Energy 2001). Therefore, it is important to give attention on nonconventional energy sources, but there stands a limitation as they are expensive and requires large portion of land and infrastructure (Kumar et al. 2020).

Hence Biodiesel emerges as an effective alternative to conventional fossil fuels. It derived from vegetable oils or animal fats by transesterification, which is renewable, biodegradable and capable of significantly reducing greenhouse gas emissions (Dewangan, Yadav, and Mallick 2018)(Kumar et al. 2020).

The biodiesel causes complete combustion of fuel due to excess amount of oxygen present and results into low carbon emission. The various methods

such as pyrolysis, microemulsion etc are used for biodiesel production but transesterification is widely used (Zahan and Kano 2019). In biodiesel production, catalyst plays significant role which reduces activation energy thereby increasing the rate of reaction(Mardhiah et al. 2017). For this purpose, homogeneous, heterogeneous and biocatalyst can be used(Goli and Sahu 2018). Heterogeneous catalysts have several advantages over homogeneous catalyst including easy separation from the reaction mixture, reusability, and reduced environmental impact (T. Tan et al. 2010). The utilization of waste materials in catalyst manufacturing not only coincides with sustainability objectives, but also addresses waste management difficulties (Yadav, Singh, and Sharma 2017). Fish scales from the Labeo rohita (Rohu) species, which are by-products of the fish processing industry, are a valuable resource. Instead of being thrown, fish scales can be recycled to create low-cost, efficient heterogeneous catalysts for biodiesel production(Sharma et al. 2012)

In this research, low cost waste fish scale is used to synthesis catalyst without chemical reagent. It resolves the issue of fish scale storage, smell and reduces catalyst cost. The fish labeo rohita has highest production in India and it produces 2-2.5 lakh eggs per kilogramme of its body weight (Chandra and Nautiyal 2012; Pakhira et al. 2015).It contains large quantity of omega-3 fatty acid which is helpful to improve health in many aspects such as heart and brain functioning(Majumder et al. 2018). Many researchers have utilized fish in different manner for the production of catalyst. Notable are highlighted below.

(Krishna Kumar Jaiswal, et.al. 2018) prepared heterogeneous catalyst by using fish scale, it resulted to 89.62% biodiesel yield. (Sulaiman et al. 2021) used fish bone as a catalyst and obtained 90% yield of biodiesel after 2 hours reaction time at 90^0 C.

(Tan et al. 2019) used fish bones catalyst and obtained 89.5% yield of biodiesel after 1.54 hours reaction time and at 60^{0C}.(Goli and Sahu 2018) prepared catalysts using chicken and eggshell, it resulted to 93% yield of biodiesel.(Hangun-Balkir 2016) synthesized biodiesel by using eggshells as a cheaper catalyst.

The objective of this research is to synthesis low cost heterogenous catalyst by using waste fish scale, its characterisation as well as optimisation by using design expert software. This research contributes to the field of sustainable energy by addressing two critical issues: waste management and renewable energy production. By converting waste fish scales into effective catalysts, the study not only provides a low-cost solution for biodiesel production but also adds value to fish processing waste, reducing its environmental footprint.

MATERIALS

Unrefined ground nut oil was used and Labeo rohita fish scales were collected from fish market, High grade methanol of purity level greater than 99% was used. A magnetic stirrer, Oven, heating mantle, a thermometer, a separating funnel and refrigerator were used.

METHODOLOGY

The collected (labeo rohita) fish scale were washed in hot water and then washed with lemon juice to get rid of its smell and then kept for sun drying. After three days of sun drying, the scales were placed in a hot oven. The sun-dried fish scales were roasted for six hours at 100°C. The dried scales were subsequently pulverized. This fish scale powder was heated in the furnace for two hours from 700 to 900°C. The synthesized catalyst was investigated using analytical tools such as FTIR, XRD, and SEM. The prepared catalyst was used for biodiesel production.

The biodiesel was prepared with unrefined ground nut oil, methanol, and the catalyst. The unrefined ground nut oil and methanol ratio of 1:6 was maintained, but the catalyst concentration and reaction temperatures were adjusted.

The prepared biodiesel consists of a number of impurities, including unreacted reactants, catalyst, and glycerol. It was kept in a funnel for 24 hours. After 24 hours in a funnel, two layers formed: a heavy layer rich in glycerol and a lighter layer with biodiesel at the top. The contaminants in biodiesel were eliminated during refinement.

Result & discussion

The catalyst was synthesized at temperatures of 700,750, and 900°C, and its peak is illustrated in Figure 2. The peak at 900°C temperature has sharp peat at 1110 cm^{-1} and 567 cm^{-1}, however the peak at 700 and 750°C is not apparent. It demonstrates that the main component of fish scale is hydroxyapatite, which after calcination at 900°C converts to B-tricalcium phosphate, which is used as a catalyst (Chakraborty, Bepari, & Banerjee 2011, Tan et al. 2019).

The peak detected at 3570 cm^{-1} represents the stretching mode of the hydroxyl group (Tan et al. 2019), while the peaks at 1041 and 945 cm^{-1} show the phosphate group.

XRD

The calcination at 900°C, the main component of fish scale is hydroxyapatite which after calcination converted to ß-calcium phosphate which works as catalyst, hence calcination at 900^0C considered for further analysis

XRD-ANALYSIS

The figure 3, shows the X ray diffraction plot at 900°C. It shows the intense peak at 26.21, 33.13, 51.59 and 53.51shows presence crystalline b-tricalcium phosphate (Chakraborty et al. 2011)(Jo et al. 2013). The main component of fish scale is hydroxyapatite which after calcination converted to ß-Ca_3-$(PO_4)_2$ that can work as catalyst(Chakraborty, Bepari, and Banerjee 2011)(Zhu et al. 2010)(Sulaiman et al. 2021).

Scanning Electron microscope

The figure 4 (a), shows the scanning electron microscope image of catalyst calcinated at 900°C.Figure a, b &c are the zoom images. It shows rough surface with uneven pores and irregular strip of catalyst. The rough surface is more effective and required more residence time for the reactant to carry out reaction and resulted to high conversion. After calcination at 900°C, surface area was found to be increased and resulted to more active rough surface which provided

more time for reaction and resulted in increment of conversion of reactants to products.

The FTIR analysis shows that calcination temperatures at 900^0C, hydroxyapatite is transformed into b-calcium phosphate, and XRD determine crystalline nature of b- calcium phosphate and SEM indicate rough, uneven shape of the particles.

DESIGN EXPERT

The design expert software is used to optimise process parameters. The parameters were optimized by design software-13. Traditional methods optimize one parameter at a time, however this method optimizes a number of parameters, therefore it reduces experimentations (Chakraborty, Bepari, and Banerjee 2011). It develops the empirical model that have valuable statistically relation with all variables. The experimental data was analysed by composite design expert software to produce a regression model. The design expert software recommended two-factor interaction regression models. The two-factor interaction model was used to calculate predicated value and equation for same is eqn -1 given below.

$$\boldsymbol{Biodiesel\ Yield} = +90.21 + 0.0345A - 0.0159\,B + 0.0130\,C - 0.0012\,AB - 0.0137\,AC + 0.0188\,BC \quad -- [1]$$

Where, A, B and C are variable parameters

Table 1 Shows analysis of Variance (ANOVA)

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0264	6	0.0044	28.82	< 0.0001	significant
A Catalyst conc	0.0163	1	0.0163	106.77	< 0.0001	
B-Temp	0.0035	1	0.0035	22.64	0.0004	
C-Time	0.0023	1	0.0023	15.07	0.0019	
AB	0.0000	1	0.0000	0.0819	0.7793	
AC	0.0015	1	0.0015	9.91	0.0077	
BC	0.0028	1	0.0028	18.42	0.0009	
Residual	0.0020	13	0.0002			
Lack of Fit	0.0003	8	0.0000	0.1118	0.9961	not significant
Pure Error	0.0017	5	0.0003			
Cor Total	0.0284	19				

AB, AC and BC are the interaction between variable parameters.

Table 1 illustrates that the ANOVA result can predict favourable findings from experiments. Model p value is less than 0.0001, shows model is statistically significant. R^2 value is 0.99, shows that the model is highly significant(Tan et al. 2019).

Table 2 Comparison of statistical models(Tan et al. 2019)(Xu, Gao, and Xiao 2015)

Source	**Sequential p-value**	**Lack of Fit p-value**	**Adjusted R^2**	**Predicted R^2**	
Linear	< 0.0001	0.4268	0.7355	0.6282	
2FI	0.0014	0.9961	0.8978	0.8748	Suggested

Quadratic	0.9994	0.9598	0.8674	0.8287	
Cubic	0.8938	0.9004	0.8115	0.8694	Aliased

Figures 6 a&b to 8 a&b show 3D and contour graphs of all process variables. Figures 6 a and b show a 3D and contour plot of catalyst concentration and temperature. It was demonstrated that an increase in catalyst concentration up to 1.5 w/v% and temperature up to 65°C led to a higher biodiesel yield. However, further increases in concentration and temperature resulted in a decline in biodiesel yield. The increase in catalyst concentration promoted glycerol formation, which led to catalyst saturation and reduced mass transfer(Yadav, Singh, and Sharma 2017). Additionally, at temperatures above 65°C, biodiesel yield decreased due to methanol evaporation (García-moreno et al. 2014; Leduc et al. 2009)Figures 7a and b show response and contour plots of catalyst concentration and time, which are irrelevant because temperature is the most important factor influencing biodiesel yield.

The regression model was used to determine the optimum condition (Ayyalusamy and Mishra 2018) and the results are displayed in Figure 9. At optimum condition, 90.21% biodiesel yield was obtained experimentally. The validation of experimental data and predicted data were compared and verified.

Figure 10, depicts the FTIR spectra of biodiesel production using derived fish scale and solid heterogeneous catalyst, the peak situated at 2923 cm^{-1} and 2856 cm^{-1} showing the symmetric and asymmetric stretching vibration of CH in the CH_2 and CH_3 groups (Shi et al. 2020)(Y. H. Tan et al. 2019a)(Chakraborty, Bepari, and Banerjee 2011a). The prominent peak at 1745 cm^{-1} is the stretching vibration of C=O in ester. Peak at 1235 cm^{-1} indicates the existence of C-O ester stretching vibration (Sulaiman et al. 2021)(Y. H. Tan et al. 2019a). The bending vibration of HCH and CH_2 produces a peak at 1367 cm^{-1} and 1456 cm^{-1}(Zhu et al. 2010)(Hangun-Balkir 2016) (Yang et al. 2020).All functional

groups of biodiesels is present. The properties of prepared biodiesel were evaluated and compared with international standard of biodiesel. It observed that prepared biodiesel achieved all the properties of biodiesel as per American standards of testing machine expert the pour point with slightly increased.

Biodiesel Characterization

Table 3 Shows properties of biodiesel derived from fish scale catalyst.

Sl. No	properties	Unit	Observations	ASTM Standards Biodiesel
1.	Kinematic Viscosity at 40˚C	mm2 /s	4.5	1.9 – 6.0
2.	Pour Point	^{0}C	–13ºC	−5 - 10
3	Flash Point	^{0}C	141ºC	100 - 150
4	Density (15 ^{0}C)	^{0}C	872	860-890

Conclusion

The low-cost catalyst was successfully synthesized without the use of chemical reagents. It was used in the manufacturing of biodiesel and process was optimized using design expert software. Analytical tools such as FTIR, SEM, and XRD were used for analysis, at the optimum conditions, 90.21% biodiesel yield obtained at 1.5 wt.% catalyst concentration, 65^{0}C, 1.5-hour reaction time. Several physical parameters of biodiesel, including density, flash point, pour points, and kinetic energy, were tested and validated using an American Standards Testing Machine.

References

Akhmat, Ghulam, Khalid Zaman, Tan Shukui, Faiza Sajjad, Muhammad Azhar Khan, and Muhammad Zahir Khan (2014) 'The Challenges of Reducing Greenhouse Gas Emissions and Air Pollution through Energy Sources: Evidence from a Panel of Developed Countries'. *Environmental Science and Pollution Research* 21(12): 7425–35. doi:10.1007/s11356-014-2693-2.

Ayyalusamy, Sureshkumar, and Susmita Mishra. (2018) 'Optimization of Preparation Conditions for Activated Carbons from Polyethylene Terephthalate Using Response Surface Methodology'. *Brazilian Journal of Chemical Engineering* 35(3): 1105–16. doi:10.1590/0104-6632.20180353s20160724.

Buchori, Luqman, Istadi Istadi, and Purwanto Purwanto. (2017) 'Synthesis of Biodiesel on a Hybrid Catalytic-Plasma Reactor over K2O/CaO-ZnO Catalyst'. *Scientific Study and Research: Chemistry and Chemical Engineering, Biotechnology, Food Industry* 18(3): 303–18.

Chakraborty, R., S. Bepari, and A. Banerjee (2011). 'Application of Calcined Waste Fish (Labeo Rohita) Scale as Low-Cost Heterogeneous Catalyst for Biodiesel Synthesis'. *Bioresource Technology* 102(3): 3610–18. doi:10.1016/j.biortech.2010.10.123.

Chakraborty, R., S. Bepari, and A. Banerjee (2011) 'Application of Calcined Waste Fish (Labeo Rohita) Scale as Low-Cost Heterogeneous Catalyst for Biodiesel Synthesis'. *Bioresource Technology* 102(3): 3610–18. doi:10.1016/j.biortech.2010.10.123.

Chandra, Amitabh, and Prakash Nautiyal (2012). 'Stock Assessment of Fish Species Labeo Rohita, Tor Tor and Labeo Calbasu in the Rivers of Vindhyan Region, India'. *Journal of Environmental Biology* 33(2): 261–64.

Dewangan, Ashish, Ashok Kumar Yadav, and Ashis Mallick.(2018). 'Current Scenario of Biodiesel Development in India: Prospects and Challenges'. *Energy Sources, Part A: Recovery, Utilization and Environmental Effects* 40(20): 2494–2501. doi:10.1080/15567036.2018.1502849.

Energy, Secondary. (2001). '1. Energy Scenario'. *Energy*: 1–36.

García-moreno, Pedro J, Mohriam Khanum, Antonio Guadix, and Emilia M Guadix. (2014)'Optimization of Biodiesel Production from Waste Fi Sh Oil'. *Renewable Energy* 68: 618–24. doi:10.1016/j.renene.2014.03.014.

Goli, Jibril, and Omprakash Sahu (2018). 'Development of Heterogeneous Alkali Catalyst from Waste Chicken Eggshell for Biodiesel Production'. *Renewable Energy* 128(1): 142–54. doi:10.1016/j.renene.2018.05.048.

Hangun-Balkir, Yelda (2016). 'Green Biodiesel Synthesis Using Waste Shells as Sustainable Catalysts with Camelina Sativa Oil'. *Journal of Chemistry* 2016(1): 1–10. doi:10.1155/2016/6715232.

Jo, Yong Beom, Sung Hoon Park, Jong Ki Jeon, Chang Hyun Ko, Changkook Ryu, and Young Kwon Park (2013). 'Biodiesel Production via the Transesterification of Soybean Oil Using Waste Starfish (Asterina Pectinifera)'. *Applied Biochemistry and Biotechnology* 170(6): 1426–36. doi:10.1007/s12010-013-0279-y.

Kazemi, Aliyeh, and Mahnaz Hosseinzadeh (2016) 'Environmental Progress & Sustainable Energy'. *Environmental Progress & Sustainable Energy* 00(00): 1–10. doi:10.1002/ep.

Khan, Irfan, Fujun Hou, and Hoang Phong Le (2021) 'The Impact of Natural Resources, Energy Consumption, and Population Growth on Environmental Quality: Fresh Evidence from the United States of America'. *Science of the Total Environment* 754: 142222. doi:10.1016/j.scitotenv.2020.142222.

Krishna Kumar Jaiswal, Laboratory for Energy Materials and Sustainability, Department of Green Energy, and India 5 Technology, Pondicherry University, Puducherry (2018). 'Waste Fish Scale Derived Ferromagnetic Heterogeneous Biocatalyst (α-Fe2O3-β-Ca3(PO4)2) for Efficient Transesterification of Waste Silkworm Pupal Lipids into Biodiesel'. *Grou* 23529(2): 1–45.

Kumar, Naveen, Ankit Sonthalia, Harveer S. Pali, and Sidharth.(2020) Green Energy and Technology *Next-Generation Biofuels—Opportunities and Challenges*. Springer Singapore. doi:10.1007/978-981-13-9012-8_8.

Leduc, Sylvain, Karthikeyan Natarajan, Erik Dotzauer, Ian McCallum, and Michael Obersteiner. (2009). 'Optimizing Biodiesel Production in India'. *Applied Energy* 86(SUPPL. 1). doi:10.1016/j.apenergy.2009.05.024.

Majumder, Sandip, Neha Majumdar, Pinki Ghosh, Surjya Kumar Saikia, and Samar Kumar Saha.(2018). 'Rohu Labeo Rohita Changes Feeding Strategy throughout Its Ontogeny An Explanation from Feeding Ecology'. *International Journal of Scientific Research in Biological Sciences* 5(4): 92–96. doi:10.26438/ijsrbs/v5i4.9296.

Mardhiah, H. Haziratul, Hwai Chyuan Ong, H. H. Masjuki, Steven Lim, and H. V. Lee. (2017). 'A Review on Latest Developments and Future Prospects of Heterogeneous Catalyst in Biodiesel Production from Non-Edible Oils'. *Renewable and Sustainable Energy Reviews* 67: 1225–36. doi:10.1016/j.rser.2016.09.036.

Pakhira, Chitra, T. S. Nagesh, T. J. Abraham, G. Dash, and S. Behera. (2015) 'Stress Responses in Rohu, Labeo Rohita Transported at Different Densities'. *Aquaculture Reports* 2: 39–45. doi:10.1016/j.aqrep.2015.06.002.

Sharma, Meeta, Arif Ali, S K Puri, and D K Tuli (2012) 'Wood Ash as a Potential Heterogeneous Catalyst for Biodiesel Synthesis'. *Biomass and Bioenergy* 41: 94–106. doi:10.1016/j.biombioe.2012.02.017.

Shi, Wenying, Hongbin Li, Bin Yu, Haixia Zhang, and Yuheng Su. (2020)'Biodiesel Production Catalyzed by Polyvinyl Guanidineacetic Membrane'. *Catalysis Letters* (0123456789). doi:10.1007/s10562-020-03279-9.

Sulaiman, S., Syakirah, N. Khairudin, P. Jamal, and M.Z. Alam (2021) 'Fish Bone Waste as Catalyst for Biodiesel Production'. *Journal of Tropical*

Resources and Sustainable Science (JTRSS) 3(1): 180–84. doi:10.47253/jtrss.v3i1.554.

Tan, Tianwei, Jike Lu, Kaili Nie, Li Deng, and Fang Wang (2010) 'Biodiesel Production with Immobilized Lipase: A Review'. *Biotechnology Advances* 28(5): 628–34. doi:10.1016/j.biotechadv.2010.05.012.

Tan, Yie Hua, Mohammad Omar Abdullah, Jibrail Kansedo, Nabisab Mujawar Mubarak, Yen San Chan, and Cirilo Nolasco-Hipolito(2019) 'Biodiesel Production from Used Cooking Oil Using Green Solid Catalyst Derived from Calcined Fusion Waste Chicken and Fish Bones'. *Renewable Energy* 139(June 2011): 696–706. doi: 10.1016/j.renene.2019.02.110.

Xu, Wei, Lijing Gao, and Guomin Xiao (2015) 'Biodiesel Production Optimization Using Monolithic Catalyst in a Fixed-Bed Membrane Reactor'. *Fuel* 159(1): 484–90. doi:10.1016/j.fuel.2015.07.017.

Yadav, Meena, Veena Singh, and Yogesh C Sharma (2017)'Methyl Transesterification of Waste Cooking Oil Using a Laboratory Synthesized Reusable Heterogeneous Base Catalyst : Process Optimization and Homogeneity Study of Catalyst'. *Energy Conversion and Management* 148: 1438–52. doi: 10.1016/j.enconman.2017.06.024.

Yang, Jie, Peter Havard, Quan Sophia He, and Xingyu Peng. (2020) 'Ultrasound - Assisted Biodiesel Production from Waste Cooking Oil at Room Temperature'. 5(1). doi:10.12103/j.issn.2096-2355.2020.01.003.

Zahan, Khairul Azly, and Manabu Kano. (2019). 'Technological Progress in Biodiesel Production: An Overview on Different Types of Reactors'. *Energy Procedia* 156(September 2018): 452–57. doi:10.1016/j.egypro.2018.11.086.

Zhu, Mulan, Benqiao He, Wenying Shi, Yaohui Feng, Jincheng Ding, Jianxin Li, and Fandi Zeng. (2010). 'Preparation and Characterization of PSSA/PVA Catalytic Membrane for Biodiesel Production'. *Fuel* 89(9): 2299–2304. doi:10.1016/j.fuel.2010.02.001.

Acknowledgements
I would like to express my deepest gratitude to Department of Chemical Engineering, Sinhgad College of Engineering Pune for their valuable support, and encouragement throughout this research.

Funding

Not applicable

Authors Contributions

Manuscript title: "A Novel Approach for Eco-Friendly Biodiesel Production Using Fish Scale Waste as Catalyst**".** All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication. Please indicate the specific contributions made by each author (list the authors' initials followed by their surnames, e.g., Y.L. Cheung). The name of each author must appear at least once in each of the three categories below.

Category 1

Conception and design of study: P.G. Bansod, Y.V. Thakare

Acquisition of data: P.G. Bansod, Y.V. Thakare, S. D. Doke

Analysis and/or interpretation of data: P.G. Bansod, Y.V. Thakare, S. D. Doke

Category 2

Drafting the manuscript: P.G. Bansod,

Revising the manuscript critically for important intellectual content: P.G. Bansod, Y. V. Thakare., S.D. Doke

Category 3

Approval of the version of the manuscript to be published (the names of all authors must be listed): P.G. Bansod, Y. V. Thakare, S.D. Doke

Ethical Approval

Hereby, I Dr. Praful G Bansod consciously assures that for the manuscript A Novel Approach for Eco-Friendly Biodiesel Production Using Fish Scale Waste as Catalyst the following is fulfilled:

1] The manuscript is not submitted to more than one journal for simultaneous consideration.

2] The submitted work is original and has not been published elsewhere in any form or language.

3] A single study is not be spited up into several parts to increase the quality of submission and submitted to various journals or to the journal over time.

4] Result is presented clearly, honestly and without fabrication, falsification or inappropriate data manipulation. Authors are adhere to discipline –specific rules for acquiring, selecting and processing data.

6] All sources used are properly disclosed (correct citation). Literally copying of text is indicated as such by using quotation marks and giving proper reference.

7] Authors ensure that they have permission to use software, questionnaires/(web) surveys, and scales in their studies

8] Both research and non-research articles are cited appropriate and relevant literature to back up their claims. Excessive and inappropriate self-citation, as well as coordinated efforts among several authors to collectively self-cite, is strongly discouraged.

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I agree with the above statements and declare that this submission follows the policies of Solid-State Ionics as outlined in the Guide for Authors and in the Ethical Statement.

Date:19/5/2026



Corresponding author's signature

Consent to Participate
All authors voluntarily participated in this study and have given their consent to participate. All authors have read and approved the final manuscript.

Consent to Publish

The participant consent for publication of their identifiable details in relation to: Title of manuscript: A Novel Approach for Eco-Friendly Biodiesel Production Using Fish Scale Waste as Catalyst. Journal: Environmental Science and Pollution Research. I, Dr. Praful G Bansod the undersigned, give my consent for the publication of identifiable details, which can include images, graphs and details within the text materials to be published in the above Journal. I confirm that I have seen and been given the opportunity to read both the Material and the Article to be published by springer. I have discussed this consent form with Yash V Thakare and Suhas D Doke who are an author of this paper.
I understand that springer's journals may be available on the internet, and will be available to a broader audience through marketing channels and other third parties. Therefore, anyone can read material published in the Journal. I understand that readers may include not only medical professionals and scholarly researchers but also journalists and general members of the public.

Date 19/05/2026

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Conflicts of Interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us. We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property. We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). He is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address which is accessible by the Corresponding Author. Signed by all authors as follows:

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Date 19/5/2026



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Data Availability

The data generated during the current study has already been included in manuscript.

List of Figure

.

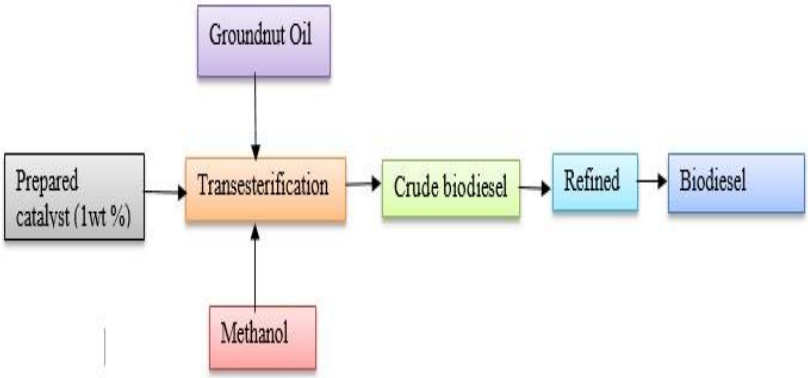
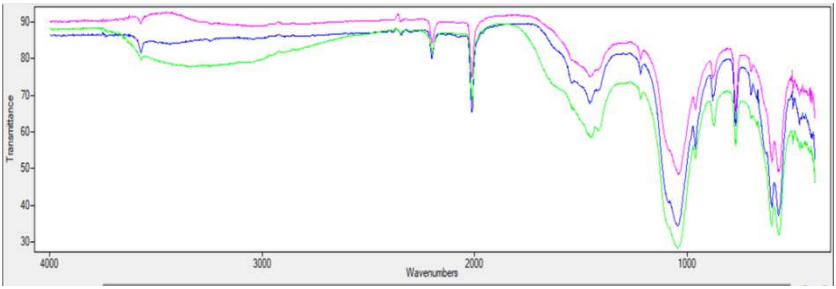


Figure 1 Shows the biodiesel production with derived catalyst



700ºC	750ºC	900ºC

Figure 2 FTIR spectra of fish scale of sample at temperature 700,750 and 900˚C temperature.

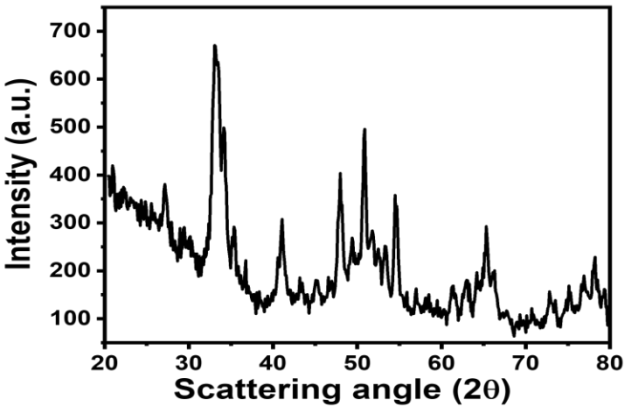


Figure 3 XRD patterns of waste fish scale catalyst at 900^0C

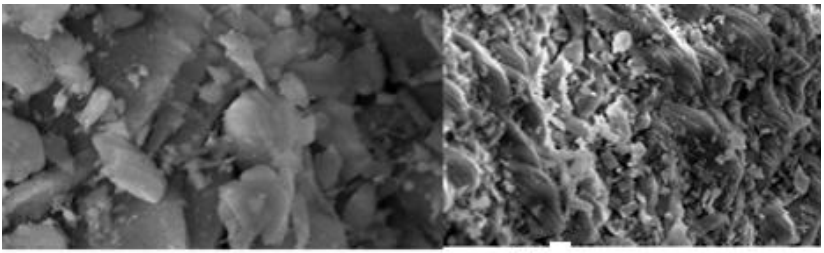


Figure 4 (a): 10 µm zoomed about ×1000 Voids

Figure 4 b. 5 µm zoomed about ×5000

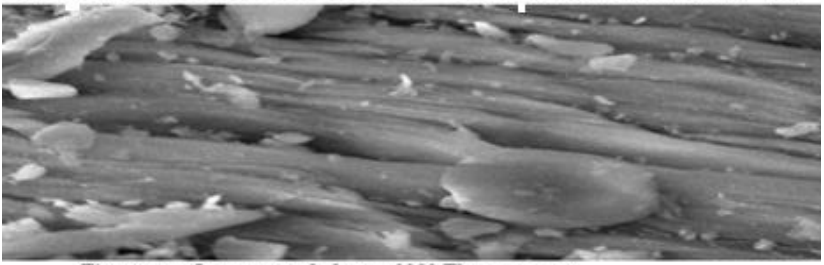


Figure 4c: 5 µm zoomed about ×3000 Flat structure

Figure 4 SEM of waste fish scale catalyst at 900˚C

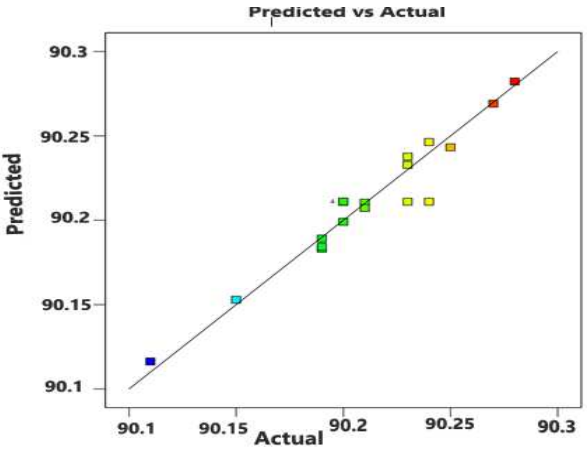


Figure 5 Graph Actual data Vs. Predicated data

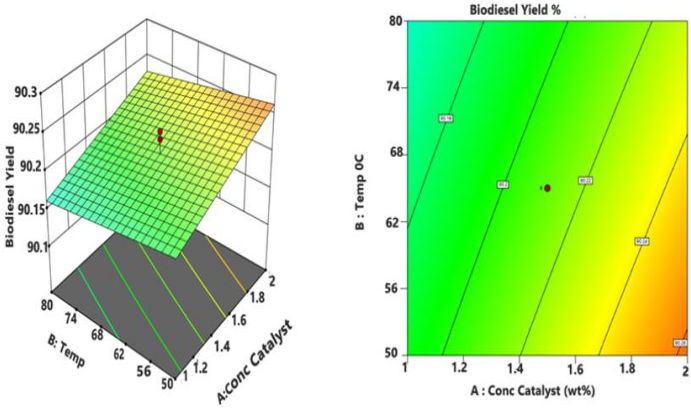


Fig. 6 a &b Response and contour plots of temp and catalyst concentration for biodiesel synthesis

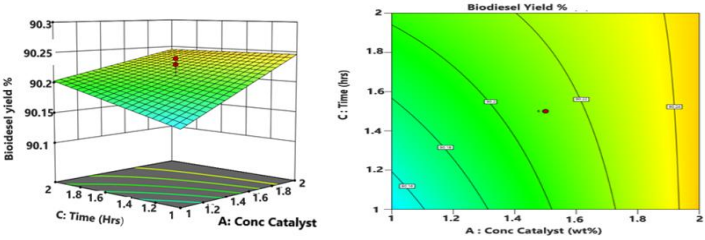


Fig. 7 a &b Response and contour plots of time and catalyst concentration for biodiesel synthesis

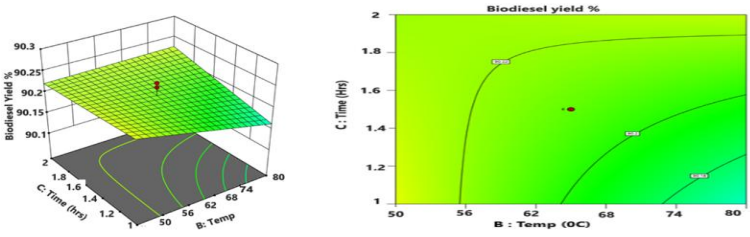


Figure 8a &b Response and contour plots of time and temperature for biodiesel synthesis

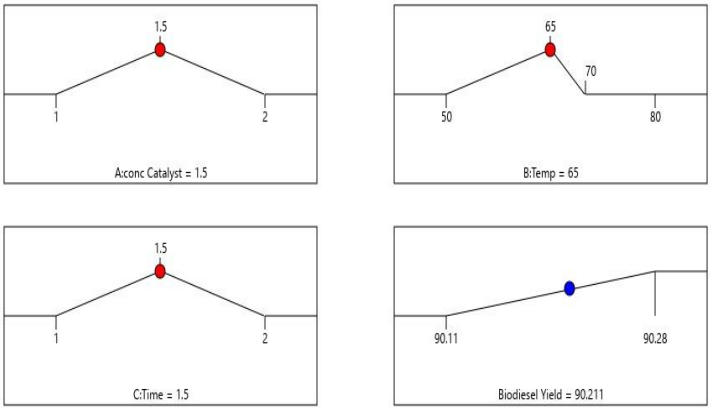


Figure 9 Optimization of operating condition of biodiesel production

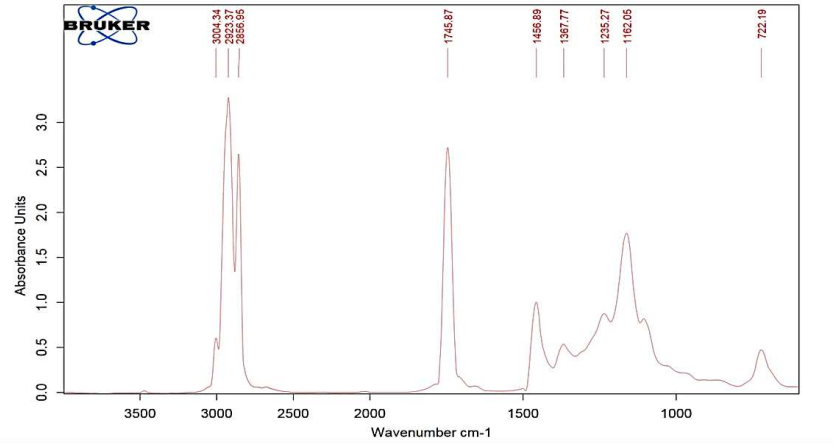


Figure 10 FTIR of biodiesel

List of Abbreviations

XRD: Xray diffraction

FTIR: Fourier Transform Infrared spectroscopy

SEM: Scanning Electron Microscopy

ASTM: American Society for Testing and Materials