

**STUDIES ON ANAEROBIC DIGESTION OF DE-OILED RICE
BRAN WITH AND WITHOUT RICE STRAW**

BHASKAR JHA



**CENTRE FOR RURAL DEVELOPMENT AND TECHNOLOGY
INDIAN INSTITUTE OF TECHNOLOGY DELHI
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**STUDIES ON ANAEROBIC DIGESTION OF DE-OILED RICE
BRAN WITH AND WITHOUT RICE STRAW**

by

BHASKAR JHA

Centre for Rural Development and Technology

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CERTIFICATE

The thesis entitled "**Studies on Anaerobic Digestion of De-Oiled Rice Bran with and without Rice Straw**" being submitted by **Mr. Bhaskar Jha** to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy**, is a record of bona fide research work carried out by him. He has worked under our supervision and has fulfilled the requirements for the submission of this thesis, which has attained the standard required for a Ph. D. degree of the Institute.

The results presented in this thesis have not been submitted elsewhere for the award of any degree or diploma.

Date: August 06, 2019

(Prof. V. K. Vijay)

Professor

Centre for Rural Development & Technology

Indian Institute of Technology Delhi

Hauz Khas, New Delhi – 110 016, INDIA

(Prof. P. M. V. Subbarao)

Professor

Department of Mechanical Engineering

Indian Institute of Technology Delhi

Hauz Khas, New Delhi – 110 016, INDIA

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ABSTRACT

In the present work, de-oiled rice bran is being considered as a new primary feedstock for high specific methane production through anaerobic digestion process. The investigation focused on an efficient and sustainable utilization of de-oiled rice bran for clean fuel production. In order to solve the problem of environmental pollution created by open on-field firing of stubble of rice straw, co-digestion of rice straw and de-oiled rice bran has also been explored in detail. The main objective of the present research is to identify the most eligible candidate for the production of biogas with a high reduction in carbon footprint. Biogas production from this feed material could develop an eco-friendly and efficient life cycle, which also offers self-sufficiency in meeting rural energy needs.

The proximate and ultimate analysis of de-oiled rice bran shows its immense potential as an alternate feed material for biogas production. The analyses clearly shows the presence of high proportion of volatile solids along with the favourable carbon to nitrogen ratio, as compared to cattle dung, a most vividly material used as a substrate for biogas production all around the world. The theoretical methane potential too supports de-oiled rice bran as efficient biomass to be used as an alternate feed material for production of biogas.

As de-oiled rice bran is a non-conventional and non-excreta type of bio-material, development of an appropriate and suitable inoculum is of high importance and requirement to initiate the anaerobic digestion process to ensure a stable and stress-tolerant anaerobic digestion activity. To develop a self-sustained inoculum, a special test rig 'Secondary Inoculum Generator' was developed in a 60 L capacity

anaerobic digester that was operated at mesophilic temperature condition in the first phase of experimentation. The second phase of investigation was carried out to study the hydrolytic behaviour of the de-oiled rice bran in biodigester to find the optimal total solids loading rate. The hydrolysis experimentation using de-oiled rice bran as substrate at four different total solids (TS) concentration, i.e., 5%, 7.5%, 10%, and 15% showed that 5% loading rate is the most favourable among other loading rates in terms of digester pH and total dissolved solids (TDS) accumulation in the anaerobic digester. In the third phase of experimentation, a 60 L capacity digester was operated on semicontinuous feeding mode (using developed secondary inoculum) and at mesophilic temperature for three months duration in triplicate reactors. The value of average specific biogas and specific methane yields were found as 0.547 m³/kg VS and 0.270 m³/kg VS, respectively after 90 days of the experiment. For the same experiment, the average total volatile solids mass removal efficiency was found to be 52.1%. In the fourth and last phase of experimentation, a biodigester of gas production capacity 1.0 m³/day was operated for one year (at the ambient temperature condition), and the obtained results were analysed and compared with the third phase experimental results. The average specific biogas, average specific methane, and average total volatile solids mass removal efficiency were found as 0.475 m³/kg VS, 0.273 m³/kg VS and 44.3%, respectively.

In the second set of experiments, co-digestion of rice straw with de-oiled rice bran was studied in detail. Several materials such as cattle dung, food waste, kitchen waste etc. have been used by researchers in the past for the co-digestion of rice straw. Some of the common issues associated with these feed materials are the lack of continuous on-site availability and the additional cost of their storage and transportation, which all together making co-digestion of rice straw considerable expensive and tedious.

Since the major limiting factor in the anaerobic digestion of rice straw is the high carbon to nitrogen ratio, the favourable range was maintained by mixing nitrogen-rich de-oiled rice bran with rice straw in determined ratio to provide an ideal environment for the anaerobic digestion. At 5% TS concentration of the substrate while maintaining the ratio of 3:2 (de-oiled rice bran: rice straw). At ambient temperature condition, the average specific biogas production in terms of total and volatile solids during 241 days of experimentation was found as 0.282 m³/kg TS and 0.332 m³/kg VS. Again the average specific methane yield was found as 0.138 m³/kg TS and 0.162 m³/kg VS. The total volatile solid mass removal efficiency was found 41.2%.

At last, the techno-economics of de-oiled rice bran based biogas system for its commercial viability was studied, where efforts were made to theoretically design a system for power generation of 635 kW capacity using biogas generator. The results of techno-economic analysis showed the payback period of less than three years, which shows de-oiled rice bran based biogas power generation system is a significant, profitable venture for industries involved in rice milling industries.

सार

वर्तमान कार्य में, डी-ऑइल राइस ब्रान को एनारोबिक पाचन प्रक्रिया के माध्यम से उच्च विशिष्ट मीथेन उत्पादन के लिए एक नया प्राथमिक फीडस्टॉक माना जा रहा है। स्वच्छ ईंधन उत्पादन के लिए डी-ऑइल राइस ब्रान के कुशल और स्थायी उपयोग पर ध्यान केंद्रित किया गया। चावल के भूसे के डंठल की खुली ऑन-फील्ड फायरिंग द्वारा निर्मित पर्यावरण प्रदूषण की समस्या को हल करने के लिए, डिटिल में चावल के भूसे और डी-ऑइल वाले चावल की भूसी के सह-पाचन का भी पता लगाया गया है। वर्तमान अनुसंधान का मुख्य उद्देश्य बायोगैस के उत्पादन के लिए सबसे योग्य उम्मीदवार की पहचान करना है, जिसमें कार्बन फुटप्रिंट की उच्च कमी है। इस फ़ीड सामग्री से बायोगैस उत्पादन एक पर्यावरण के अनुकूल और कुशल जीवन चक्र विकसित कर सकता है, जो ग्रामीण ऊर्जा की जरूरतों को पूरा करने में आत्मनिर्भरता प्रदान करता है।

डी-ऑइल राइस ब्रान का अनुमानित और अंतिम विश्लेषण बायोगैस उत्पादन के लिए वैकल्पिक फ़ीड सामग्री के रूप में इसकी अपार क्षमता को दर्शाता है। विश्लेषण स्पष्ट रूप से नाइट्रोजन के अनुपात के अनुकूल कार्बन के साथ-साथ अस्थिर ठोस पदार्थों के उच्च अनुपात की उपस्थिति को दर्शाता है, मवेशियों के गोबर की तुलना में, दुनिया भर में बायोगैस उत्पादन के लिए एक सबस्ट्रेट के रूप में उपयोग किए जाने वाले सबसे ज्वलंत सामग्री है। सैद्धांतिक मीथेन क्षमता भी बायोगैस के उत्पादन के लिए वैकल्पिक चारा सामग्री के रूप में उपयोग किए जाने वाले कुशल बायोमास के रूप में डी-ऑइल राइस ब्रान का समर्थन करती है।

चूंकि डी-ऑइल राइस ब्रान एक गैर-पारंपरिक और गैर-उत्सर्जित प्रकार की जैव-सामग्री है, एक उचित और उपयुक्त इनोकुलम का विकास उच्च महत्व का है और एक स्थिर और तनाव-सहिष्णु एनारोबिक पाचन सुनिश्चित करने के लिए अवायवीय पाचन प्रक्रिया शुरू करने की आवश्यकता है। गतिविधि। आत्मनिर्भर इनोकुलम को विकसित करने के लिए, एक विशेष परीक्षण रिग सेकेंडरी इनोकुलम जेनरेटर विकसित किया गया था जो 60 एल क्षमता वाले एनारोबिक डाइजेस्टर में प्रयोग के पहले चरण में मेसोफिलिक तापमान स्थिति में संचालित किया गया था। इष्टतम कुल ठोस लोडिंग दर का पता लगाने के लिए बायोडीजेस्टर में डी-ऑइल राइस ब्रान के हाइड्रोलाइटिक व्यवहार का अध्ययन करने के लिए दूसरे चरण की जांच की गई। चार अलग-अलग कुल ठोसों (टीएस) पर सबस्ट्रेट के रूप में डी-तेल वाले चावल की

भूसी का उपयोग करके हाइड्रोलिसिस प्रयोग, यानी, 5%, 7.5%, 10%, और 15% ने दिखाया कि 5% लोडिंग दर अन्य लोडिंग दरों के बीच सबसे अनुकूल है डाइजेस्टर पीएच और एनारोबिक डाइजेस्टर में कुल घुलित ठोस (टीडीएस) संचय की शर्तें। प्रयोग के तीसरे चरण में, ट्रिपलेटिक रिएक्टरों में तीन महीने की अवधि के लिए अर्ध-फीडिंग मोड (विकसित माध्यमिक इनोकुलम का उपयोग करके) और मेसोफिलिक तापमान पर एक 60 एल क्षमता डाइजेस्टर संचालित किया गया था। औसत विशिष्ट बायोगैस और विशिष्ट मीथेन पैदावार का मूल्य प्रयोग के 90 दिनों के बाद क्रमशः $0.547 \text{ m}^3 / \text{kg VS}$ और $0.270 \text{ m}^3 / \text{kg VS}$ पाया गया। इसी प्रयोग के लिए, औसत कुल वाष्पशील ठोस द्रव्यमान हटाने की क्षमता 52.1% पाई गई। प्रयोग के चौथे और आखिरी चरण में, गैस उत्पादन क्षमता $1.0 \text{ m}^3 / \text{दिन}$ का एक बायोडीजेस्टर एक वर्ष (परिवेश समशीतोष्ण स्थिति में) के लिए संचालित किया गया था, और प्राप्त परिणामों का विश्लेषण किया गया था और तीसरे चरण के प्रयोगात्मक परिणामों की तुलना में। औसत विशिष्ट बायोगैस, औसत विशिष्ट मीथेन और औसत कुल वाष्पशील ठोस द्रव्यमान हटाने की क्षमता $0.475 \text{ m}^3 / \text{kg VS}$, $0.273 \text{ m}^3 / \text{kg VS}$ और $44.3\% \text{ VS}$, क्रमशः के रूप में पाए गए।

योगों के दूसरे सेट में, डी-ऑइल राइस ब्रान के साथ चावल के भूसे के सह-पाचन का विस्तार से अध्ययन किया गया। चावल के भूसे के सह-पाचन के लिए कई सामग्री जैसे कि गोबर, खाद्य अपशिष्ट, रसोई अपशिष्ट आदि का उपयोग शोधकर्ताओं द्वारा अतीत में किया गया है। इन फ़ीड सामग्रियों से जुड़े कुछ सामान्य मुद्दे निरंतर साइट पर उपलब्धता और उनके भंडारण और परिवहन की अतिरिक्त लागत की कमी है, जो सभी चावल के भूसे के सह-पाचन को काफी महंगा और थकाऊ बनाते हैं।

चूंकि चावल के भूसे के अवायवीय पाचन में प्रमुख सीमित कारक नाइट्रोजन अनुपात के लिए उच्च कार्बन है, अवायवीय पाचन के लिए एक आदर्श वातावरण प्रदान करने के लिए निर्धारित अनुपात में चावल के भूसे के साथ नाइट्रोजन युक्त डी-ऑइल राइस ब्रान को मिलाकर अनुकूल रेंज बनाए रखी गई थी। 1:3:2 (डी-ऑइल राइस ब्रान: राइस स्ट्रॉ) के अनुपात को बनाए रखते हुए सबस्ट्रेट की 5% टीएस सांद्रता पर। परिवेश के तापमान की स्थिति में, प्रयोग के 241 दिनों के दौरान कुल और वाष्पशील ठोस पदार्थों के संदर्भ में औसत विशिष्ट बायोगैस उत्पादन $0.282 \text{ m}^3 / \text{kg TS}$ और $0.15 \text{ m}^3 / \text{kg VS}$ के रूप में पाया गया। फिर से औसत विशिष्ट

मीथेन उपज $0.138 \text{ m}^3 / \text{किग्रा टीएस}$ और $0.162 \text{ m}^3 / \text{किग्रा वी.एस.}$ कुल वाष्पशील ठोस द्रव्यमान हटाने की क्षमता 41.2% पाई गई।

अंत में, इसकी व्यावसायिक व्यवहार्यता के लिए डी-ऑइल राइस ब्रान आधारित बायोगैस प्रणाली के तकनीकी-अर्थशास्त्र का अध्ययन किया गया था, जहां सैद्धांतिक रूप से बायोगैस जनरेटर का उपयोग करके 635 किलोवाट क्षमता की बिजली उत्पादन के लिए एक प्रणाली डिजाइन करने का प्रयास किया गया था। टेक्नो-इकोनॉमिक एनालिसिस के नतीजों में तीन साल से कम समय की पेबैक अवधि दिखाई गई, जो दर्शाता है कि डी-ऑइलड राइस ब्रान आधारित बायोगैस बिजली उत्पादन प्रणाली चावल मिलिंग उद्योगों में शामिल उद्योगों के लिए एक महत्वपूर्ण, लाभदायक उद्यम है।

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SYMBOLS AND ABBREVIATIONS

%	=	percent
&	=	and
/	=	per
<	=	lower than
>	=	greater than
°	=	degree
ρ	=	density
η	=	efficiency
°C	=	degree celsius
C/N	=	carbon - nitrogen ratio
d	=	day
db	=	dry basis
FFA	=	free fatty acid
g	=	gram
GDP	=	gross domestic product
h	=	hour
HRT	=	hydraulic retention time
kg	=	kilo gram
kJ	=	kilo joule
kW	=	kilo watt
kWh	=	kilo watt hour
L	=	litre
m ³	=	cubic metre
mL	=	milli litre
mm	=	milli metre
MMT	=	million metric tonne
MNRE	=	Ministry of New and Renewable Energy
MoPNG	=	Ministry of Petroleum and Natural Gas
MPa	=	mega pascal
MW	=	mega watt
N	=	nitrogen

NH ₃	=	ammonia
NH ₄	=	ammonium ion
NO _x	=	nitrogen oxides
NVS	=	non-volatile solids
OLR	=	organic loading rate
ppm	=	part per million
STP	=	standard temperature and pressure
T	=	temperature
TMP	=	theoretical methane potential
TS	=	total solids
TVSMRE	=	total volatile solids mass removal efficiency
V	=	volume
VFA	=	volatile fatty acids
VS	=	volatile solids
yr	=	year