

**DEVELOPMENT OF A SUSTAINABLE ENERGY SUFFICIENCY
MODEL FOR RURAL AREAS USING BIOMASS RESOURCES**

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INDIAN INSTITUTE OF TECHNOLOGY DELHI

OCTOBER 2019

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MODEL FOR RURAL AREAS USING BIOMASS RESOURCES**

by

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Submitted

in fulfilment of the requirements of the degree of Doctor of Philosophy

to the



INDIAN INSTITUTE OF TECHNOLOGY DELHI

OCTOBER 2019

CERTIFICATE

The thesis entitled "**Development of a Sustainable Energy Sufficiency Model for Rural Areas Using Biomass Resources**" being submitted by **Mr. Vandit Vijay** 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.

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ACKNOWLEDGEMENTS

First and foremost, I would like to convey my respect and gratitude towards my supervisors, Prof. P. M. V. Subbarao and Dr. Ram Chandra for their continuous guidance and encouragement during the tenure of my thesis work. I must thank them for sharing their immense knowledge and for inculcating the basics of research in me.

I express my deepest gratitude to the esteemed members of my Student Research Committee, Prof. Nomesh Bolia (External Examiner), Professor, Department of Mechanical Engineering, Prof. S. N. Naik, (Chairperson), and Prof. Hariprasad P. (Internal Examiner) for their valuable comments, reviews and support.

With a sense of gratitude and great pleasure, I acknowledge the encouragement extended by Prof. T. C. Kandpal, Professor, Centre for Energy Studies at various stages of the present investigation.

I would like to thank Mr. Joginder from IC Engine Lab for helping throughout the engine conversion process and Mr. L. D. Kala for clearing my doubts, whenever I reached out to him. I would like to specially thank Ravindra Kumar and Mahesh Verma for helping me during the course of experimental studies at various stages of work.

I must thank all my colleagues and friends of my laboratory, i.e., Mr. Bhaskar Jha, Dr. Abhinav Trivedi, Mr. Himanshu Kumar, Mr. Devarshi, Mr. Komalkant Adlak, Mr. Anil Singh Tomar, Ms. Goldy Shah, Ms. Shivali, Ms. Adya Isha, Ms. Priyanka Singh for creating a conducive work environment and helping me in the time of need. I would like to thank Dr. Rimika Kapoor and Dr. Pooja Ghosh for their guidance during

the work. I would also like to thank departmental colleagues Mr. Bhushan, Ms. Vidhi, Ms. Nidhi, Ms. Shreya and Mr. Falguni for helping me with biodiesel experiments.

I am indebted to my friends: Anu, Joyjit, Devendra, Akshay, Nalin, Gagan, Lalita, Deepak, Devashish, Rahul, Sugeet, Shabina, Amrish, Sanchayan and Manpreet for being amazing friends. They have been an essential support system that not only helped me get through difficult times, but also made each of my day special.

Last but not the least, I want to thank my Father, Mother and Sister for being the infallible foundation in my life, over which I have dared to realize my dreams. Their unconditional love, inspiration, support and blessings are the prime reasons behind my success in this endeavor.

Almighty and the divine nature.

New Delhi

October, 2019

Vandit Vijay

ABSTRACT

The dependence of our country on its rural areas can be understood from the fact that almost 70% of the population still resides in rural areas and more than 50% of the population relies on agricultural activities for their livelihoods. For true development of the country it's imperative that the rural areas must develop at the same pace as urban areas. However, energy availability which is the key driver of a nation's development is often found to be lacking particularly in the rural areas.

In the present investigation, the feasibility of making rural areas self-sufficient for their electricity needs by using biomass resources has been explored as the agrarian nature of our country offers vast pool of these resources, surplus of which can be tapped for energy generation. This idea is inspired from the concept of “**Gram Swaraj**” given by Mahatma Gandhi and we have focussed on the energy part of it, i.e., “**Gram Urja Swaraj**”. For this purpose Bhawan Bahadur Block in Bulandshahr district of the Uttar Pradesh state was selected as a case study. The biomass availability in the form of agricultural residues, livestock residues and horticultural residues was comprehensively assessed and the surplus was evaluated.

Some special biomass resources in the form of tree seeds were identified in the selected case study which can be used for energy generation. Four species of trees were identified namely, *Acacia nilotica*, *Albizia lebbeck*, *Leucaena leucocephala* and *Prosopis juliflora*, and it was observed that they are widely present almost all across the country in large numbers. Their seeds having no other significant use have been explored for biogas production for the first time. The average methane content in biogas for all the species was found to be above 52% for the 90 days experimentation period. Average specific biogas yield was 0.409 m³/kg VS for *A. nilotica*, 0.437 m³/kg VS for *P. juliflora*, 0.429 m³/kg VS for *A. lebbeck* and 0.408 m³/kg VS for *L. leucocephala*, respectively. Thus, it was observed that they have a higher biogas production potential than cattle manure and are promising alternative feedstocks.

Biodiesel was made using non-edible *Pongamia* oil. *Pongamia* trees are available in large numbers in the selected block. Single stage base catalyzed transesterification process was adopted as the acid value of the oil was less. This method is found to be

safe and suitable for rural areas as there is no use of hazardous acidic chemicals and the cost of production is less. Few important basic characteristics of the purified biodiesel like the density, viscosity, acid value and calorific value were evaluated and found to be in the standard range. The main aim of biodiesel production experiments was making biodiesel in large quantities to run dual fuel engine along with biogas.

Diesel engine is an integral part of rural energy system. After production of biofuels i.e. biogas and biodiesel their utilization for producing electricity through converted diesel engine as standalone distributed unit was investigated. Two diesel engines were converted into 100% biogas engine and dual fuel engine respectively. Engine performance parameters tested in this study are engine speed, brake power, brake specific fuel consumption and brake thermal efficiency. Dual fuel engine was run on four fuel combinations of Diesel + Raw/Enriched Biogas, Biodiesel + Raw/Enriched Biogas. For the 100% biogas engine maximum power of 4.14 kW could be developed at a power de-rating of 45%. To demonstrate engine operation as a distributed unit in rural areas the electricity panel of our lab was connected to the engine and varying load of the lab equipment's was used to test engine's performance. Thus, engine conversion in rural area conditions simulated in our lab, is experimentally found to be a suitable option for electricity production and will help in reducing the dependency on grid based electricity which is highly intermittent and unreliable.

For the rural case study the bioenergy potential of the assessed surplus biomass was estimated based on the experiments carried out and the available literature. It was observed that the total biomass power potential (5.75 MW) is more than the power requirement (5.6 MW) of the block indicating that it can be made self-reliant for electricity by using the locally available biomass resources. The concept of self-reliance has been demonstrated practically by making our laboratory energy self-sufficient by using locally available resources from our institute's campus which are also present in the selected area of study. Thus, it is possible to make a rural area energy wise self-reliant or to substantially reduce the use of conventional energy resources by utilizing the locally available biomass resources to meet the local energy demands with the involvement of local population.

सार

ग्रामीण क्षेत्रों पर हमारे देश की निर्भरता को इस तथ्य से समझा जा सकता है कि लगभग 70% जनसंख्या अभी भी ग्रामीण क्षेत्रों में निवास करती है और 50% से अधिक आबादी अपनी आजीविका के लिए कृषि गतिविधियों पर निर्भर है। देश के सही विकास के लिए यह जरूरी है कि ग्रामीण क्षेत्रों का विकास शहरी क्षेत्रों की तरह ही हो। हालाँकि, ऊर्जा की उपलब्धता जो एक राष्ट्र के विकास का प्रमुख चालक है, अक्सर ग्रामीण क्षेत्रों में इसका अभाव पाया जाता है।

वर्तमान जांच में, बायोमास संसाधनों का उपयोग करके अपनी बिजली की जरूरतों के लिए ग्रामीण क्षेत्रों को आत्मनिर्भर बनाने की व्यवहार्यता का पता लगाया गया है क्योंकि हमारे देश की कृषि प्रकृति इन संसाधनों की विशाल उपलब्धता प्रदान करती है, जिसका अधिशेष ऊर्जा उत्पादन के लिए उपयोग में लिया जा सकता है। यह विचार महात्मा गांधी द्वारा दी गई “ग्राम स्वराज” की अवधारणा से प्रेरित है और हमने इसके ऊर्जा भाग यानी “ग्राम उर्जा स्वराज” पर ध्यान केंद्रित किया है। इस उद्देश्य के लिए उत्तर प्रदेश राज्य के बुलंदशहर जिले के भवन बहादुर ब्लॉक को एक केस स्टडी के रूप में चुना गया है। कृषि अवशेषों, पशुधन अवशेषों और बागवानी अवशेषों के रूप में बायोमास की उपलब्धता का व्यापक मूल्यांकन किया गया और अधिशेष का मूल्यांकन किया गया है।

इस अध्ययन में पेड़ के बीजों के रूप में कुछ विशेष बायोमास संसाधनों की पहचान चयनित केस स्टडी में की गई, जिनका उपयोग ऊर्जा उत्पादन के लिए किया जा सकता है। पेड़ों की चार प्रजातियों की पहचान की गई थी, एकेसिया निलोटिका, एल्बिजिया लेबेक, ल्यूकेना ल्यूकोसेफला और प्रोसोपिस जूलीफ्लोरा, और यह देखा गया कि वे व्यापक रूप से बड़ी संख्या में देश भर में मौजूद हैं। साहित्यिक सर्वेक्षण में पाया गया कि उनके बीजों का कोई अन्य महत्वपूर्ण उपयोग नहीं है और पहले उन्हें कभी बायोगैस उत्पादन के लिए प्रयोग में नहीं लिया गया है। सभी प्रजातियों के 90 दिनों की प्रयोग अवधि में बायोगैस में औसतन मीथेन मात्रा 52% से ऊपर पाई गई। औसतन विशिष्ट बायोगैस पैदावार ए निलोटिका के लिए 0.409 घन मी/किग्रा वी.एस., पी। जूलीफ्लोरा के लिए 0.437 घन मी/ किग्रा वी.एस., एल लेबेक के लिए 0.429 घन मी/ किग्रा वी.एस. और एल ल्यूकोसेफला के लिए क्रमशः 0.408 घन मी/किग्रा

वी.एस. इस प्रकार, हैं। यह पाया गया कि उनकी बायोगैस उत्पादन क्षमता गोबर की तुलना में बेहतर है और ये सभी बीज अच्छे वैकल्पिक फीडस्टॉक्स हो सकते हैं।

इस अध्ययन में गैर-खाद्य पॉंगामिया तेल का उपयोग करके बायोडीजल बनाया गया था। अध्ययन के चयनित क्षेत्र में पॉंगामिया के पेड़ बड़ी संख्या में उपलब्ध हैं। सिंगल स्टेज बेस उत्प्रेरित ट्रांससेराइजेशन प्रक्रिया को अपनाया गया क्योंकि तेल का एसिड मूल्य कम था। यह विधि ग्रामीण क्षेत्रों के लिए सुरक्षित और उपयुक्त पाई गई है क्योंकि इसमें खतरनाक अम्लीय पदार्थों का उपयोग नहीं होता है और उत्पादन की लागत कम होती है। शुद्ध बायोडीजल के घनत्व, चिपचिपापन, एसिड मूल्य और कैलोरी मान जैसे कुछ महत्वपूर्ण बुनियादी विशेषताओं का मूल्यांकन किया गया और मानक सीमा में पाया गया। बायोडीजल उत्पादन प्रयोगों का मुख्य उद्देश्य बायोगैस के साथ दोहरी ईंधन इंजन को चलाने के लिए बड़ी मात्रा में बायोडीजल बनाना था।

डीज़ल इंजन ग्रामीण ऊर्जा प्रणाली का एक अभिन्न अंग है। जैव ईंधन यानी बायोगैस और बायोडीज़ल के उत्पादन के बाद उनकी परिवर्तित डीज़ल इंजन के माध्यम से स्टैंडअलोन वितरित इकाई के रूप में बिजली उत्पादन के लिए जांच की गई । इस प्रयोजन के लिए दो डीज़ल इंजनों को क्रमशः 100% बायोगैस इंजन और दोहरे ईंधन इंजन में परिवर्तित किया गया। इस अध्ययन में जिन इंजन प्रदर्शन मापदंडों का परीक्षण किया गया है वे इंजन की गति, ब्रेक पावर, ब्रेक विशिष्ट ईंधन खपत और ब्रेक थर्मल दक्षता हैं। डीज़ल + रॉ / एनरिचड बायोगैस, बायोडीजल + रॉ / एनरिचड बायोगैस के चार ईंधन संयोजनों पर दोहरे ईंधन इंजन को चलाया गया। 100% बायोगैस इंजन से 4.14 kW की अधिकतम पावर को विकसित किया जा सका और पाया गया की मौलिक इंजन के बनस्पत परिवर्तित इंजन की पावर में 45% की गिरावट है। ग्रामीण क्षेत्रों में एक वितरित इकाई के रूप में इंजन के संचालन को प्रदर्शित करने के लिए हमारी प्रयोगशाला का बिजली पैनल इंजन से जोड़ा गया और प्रयोगशाला के उपकरणों के अलग-अलग लोड का उपयोग इंजन के प्रदर्शन का परीक्षण करने के लिए किया गया। इस प्रकार, हमारी प्रयोगशाला में सिम्युलेटेड ग्रामीण क्षेत्र की स्थितियों में इंजन रूपांतरण, प्रयोगात्मक रूप से बिजली उत्पादन के लिए एक उपयुक्त विकल्प के रूप में पाया गया जो अत्यधिक

आंतरायिक और अविश्वसनीय ग्रिड आधारित बिजली पर निर्भरता को कम करने में मदद करेगा।

ग्रामीण केस स्टडी में अधिशेष बायोमास का मूल्यांकन एवम् इसकी बायोएनेर्जी क्षमता का अनुमान किए गए प्रयोगों और उपलब्ध साहित्य के आधार पर लगाया गया। यह देखा गया कि कुल बायोमास बिजली क्षमता (5.75 मेगावाट) ब्लॉक की बिजली आवश्यकता (5.6 मेगावाट) से अधिक है, यह दर्शाता है कि स्थानीय स्तर पर उपलब्ध बायोमास संसाधनों का उपयोग करके इसे बिजली के लिए आत्मनिर्भर बनाया जा सकता है। हमारे संस्थान के परिसर से स्थानीय स्तर पर उपलब्ध संसाधनों का उपयोग करके आत्मनिर्भरता की अवधारणा को व्यावहारिक - रूप से आत्मनिर्भर बनाया गया है, जो अध्ययन के चयनित क्षेत्र में भी मौजूद हैं। इस प्रकार, स्थानीय आबादी की भागीदारी के साथ स्थानीय ऊर्जा मांगों को पूरा करने के लिए स्थानीय रूप से उपलब्ध बायोमास संसाधनों का उपयोग करके ग्रामीण क्षेत्र ऊर्जा को आत्मनिर्भर बनाना या पारंपरिक ऊर्जा संसाधनों के उपयोग को काफी कम करना संभव है।

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SYMBOLS AND ABBREVIATIONS

%	=	percent
&	=	and
/	=	per
<	=	lower than
>	=	greater than
°	=	degree
ρ	=	density
η	=	efficiency
μ	=	viscosity
°C	=	degree celsius
BB Nagar	=	Bhawan Bahadur Nagar
BD-EB	=	biodiesel + enriched biogas
BD-RB	=	biodiesel + raw biogas
bhp	=	brake horse power
BP	=	brake power
BSFC	=	brake specific fuel consumption
BTDC	=	before top dead centre
BTE	=	brake thermal efficiency
C	=	carbon
C.I.	=	compression ignition
C/N	=	carbon - nitrogen ratio
CH ₃ OH	=	methanol
CH ₄	=	methane
cm	=	centi metre
CNG	=	compressed natural gas
CO	=	carbon monoxide
CO ₂	=	carbon dioxide
Conc.	=	concentration
CV	=	calorific value
d	=	day
D-EB	=	diesel + enriched biogas

D–RB	=	diesel + raw biogas
db	=	dry basis
DM	=	dry matter
FFA	=	free fatty acid
g	=	gram
GDP	=	gross domestic product
GJ	=	giga joule
h	=	hour
H	=	hydrogen
HDI	=	human development index
H ₂ O	=	water
H ₂ S	=	hydrogen sulphide
ha	=	hectare
HC	=	hydro carbon
HRT	=	hydraulic retention time
H ₂ SO ₄	=	sulphuric acid
I	=	current
IA	=	ignition advance
IC	=	internal combustion
IISc	=	Indian Institute of Science
kg	=	kilo gram
kJ	=	kilo joule
km	=	kilo metre
kT	=	Kilo ton
kW	=	kilo watt
kW-h	=	kilo watt hour
L	=	litre
LCFA	=	long-chain fatty acids
LPG	=	liquefied petroleum gas
m ³	=	cubic metre
\dot{m}_f	=	mass flow rate
mg	=	milli gram
MJ	=	mega joule

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
Mt	=	million tonne
MW	=	mega watt
N	=	nitrogen
NaOH	=	sodium hydroxide
NH ₃	=	ammonia
NH ₄	=	ammonium ion
NO _x	=	nitrogen oxides
NSS	=	national sample survey
NVS	=	non-volatile solids
O ₂	=	oxygen
OLR	=	organic loading rate
ppm	=	part per million
rpm	=	revolutions per minute
SI	=	spark ignition
SO _x	=	sulphur dioxides
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