DEVELOPMENT OF THERMOCHEMICAL GASIFICATION PROCESS FOR PEARL MILLET AND CORN COBS: TESTING OF POWER GENERATION SYSTEM USING MIXTURE OF PRODUCER GAS AND BIOGAS

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D E D I C A T E D

to my parents, teachers, my wife and Son

CERTIFICATE

This is certify that the thesis entitled **Development of Thermochemical gasification process for Pearl Millet and Corn Cobs: Testing of power generation system using mixture of Producer gas and Biogas** being submitted by Mr. Praveen Kumar to the Indian Institute of Technology Delhi, India, for award of degree of **Doctor of Philosophy** is a record of the 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, which to our knowledge has reached the requisite standard.

The results contained in the thesis have not been submitted, in part or full, to any other university or institute for the award of any degree or diploma.

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ABSTRACT

The present work focuses on use of agriculture residue as energy feedstock. Agricultural residues as gasification feedstock require pre-processing before it can be used in a gasifier. Corncob (CC) and Eucalyptus wood (EU) are generally sliced into pieces, whereas pearl millet cob (PMC) required densification through palletization. A scientific approach is followed in this work for thermal characterisation of the selected biomasses for gasification. Thermochemical gasification is carried out and Performance Analysis and Optimization of gasification performed. Lastly, the producer gas singularly and together with biodiesel and biogas are utilized in IC engines for power generation.

The quantification of various characteristics included carrying out proximate analysis (moisture, volatile matter, fixed carbon, and ash), ultimate analysis (CHNS test), thermal degradation studies, heating value measurement, TGA and estimation of activation energy, etc. All of these confirmed the suitability of the biomasses as good gasification candidates. The average apparent activation energy of the chosen biomasses using FWO methods follows the trend, EU > PMC > CC. The activation energies for EU, PMC, and CC are 201, 150, and 68 $kJ.mol^{-1}$. The biomass gasifier require feedstock having bulk density higher than about $200 kg.m^{-3}$.As a bulk density of agriculture residue (PMC) is low, densification can achived through the process of pelletization. Densification improves the physical and conversion charteristics of low density biomass or agriculture residue.

A open top downdraft was used for generation of producer gas from the three biomasses and the it was evaluated by carrying out Performance Analysis besides conducting Optimization of gasification. It is found that the producer gas has average calorific value for PMC, CC and EU as 3.80, 3.43, 4.08 $MJ.Nm^{-3}$ respectively. Eucalyptus is considered an appropriate energy source amongst the residues for gasification in the study with a stable gas composition (EU being a conventional feedstock). The thermal conversion coefficient of PMC, CC and EU is 0.673, 0.671 and 0.730 respectively and energy release per kg of fuel is 13.58, 13.55 and 14.75 $MJ.kg^{-1}$ respectively.

Power generation from producer gas using a spark ignition converted I.C. engine was studied. Generation of electric power with blends of producer gas with biogas was also studied using a dual fuel compression ignition engine. Biodiesel was used as the pilot fuel and its substitution was achieved in the dual fuel engine with an acceptable efficiency. The converted engine was found to run smooth and stable on 100 % producer gas smoothly, and found the optimum power by three biomass EU, PMC and CC as 2.5, 2.0 and 1.7 kW respectively at 20ºbTDC with a constant speed of 1500 rpm. The performance of engine operation in dual mode with fuels biodiesel and producer gas - biogas mix was found satisfactory. The flow rates were 0.53, 9.5 and 0.63g.s^{-1} for biodiesel, producer gas and biogas respectively. The optimum power is found by mixing of biodiesel - producer gas-biogas was 6.3kW. This work has huge application in the rural sector and its implementation was highlighted.

सार

वर्तमान कार्य कृषि अवशेषों के ऊर्जा फीडस्टॉक के रूप में उपयोग पर केंद्रित है। गैसीकरण फीडस्टॉक के रूप में कृषि अवशेषों को गैसीफायर में इस्तेमाल करने से पहले पूर्व-प्रसंस्करण की आवश्यकता होती है। कॉर्नकोब (सीसी) और नीलगिरी की लकड़ी (ईयू) को आम तौर पर टुकड़ों में काटा जाता है, जबकि बाजरा कोब (पीएमसी) को पैलेटाइजेशन के माध्यम से घनत्व की आवश्यकता होती है। गैसीकरण के लिए चयनित बायोमास के तापीय लक्षण वर्णन के लिए इस कार्य में एक वैज्ञानिक दृष्टिकोण का पालन किया जाता है। थर्मोकेमिकल गैसीकरण किया जाता है और प्रदर्शन विश्लेषण और गैसीकरण का अनुकूलन किया जाता है। अंत में, बिजली उत्पादन के लिए आईसी इंजनों में अकेले और बायोडीजल और बायोगैस के साथ उत्पादक गैस का उपयोग किया जाता है।

विभिन्न विशेषताओं के परिमाणीकरण में निकटस्थ विश्लेषण (नमी, वाष्पशील पदार्थ, निश्चित कार्बन और राख), अंतिम विश्लेषण (सीएचएनएस परीक्षण), थर्मल क्षरण अध्ययन, ताप मान माप, टीजीए और सक्रियण ऊर्जा का अनुमान आदि शामिल हैं। ये सभी अच्छे गैसीकरण उम्मीदवारों के रूप में बायोमास की उपयुक्तता की पुष्टि की। FWO विधियों का उपयोग करके चुने गए बायोमास की औसत स्पष्ट सक्रियण ऊर्जा प्रवृत्ति, EU > PMC > CC का अनुसरण करती है। ईयू, पीएमसी और सीसी के लिए सक्रियता ऊर्जा 201, 150 और 68 $kJ.mol^{-1}$ हैं। बायोमास गैसीफायर के लिए लगभग $200 kg.m^{-3}$ से अधिक बल्क घनत्व वाले फीडस्टॉक की आवश्यकता होती है। चूंकि कृषि अवशेषों (PMC) का थोक घनत्व कम होता है, घनत्व को पेलेटाइजेशन की प्रक्रिया के माध्यम से प्राप्त किया जा सकता है। घनत्व कम घनत्व वाले बायोमास या कृषि अवशेषों के भौतिक और रूपांतरण चार्टरिस्टिक्स में सुधार करता है।

तीन बायोमास से उत्पादक गैस के उत्पादन के लिए एक ओपन टॉप डाउनड्राफ्ट का उपयोग किया गया था और इसका मूल्यांकन गैसीकरण के अनुकूलन के अलावा प्रदर्शन विश्लेषण करके किया गया था। यह पाया गया है कि उत्पादक गैस का पीएमसी, सीसी और ईयू के लिए औसत कैलोरी मान क्रमशः 3.80, 3.43, 4.08 $MJ.Nm^{-3}$ है। एक स्थिर गैस संरचना (यूरोपीय संघ एक पारंपरिक फीडस्टॉक है) के साथ अध्ययन में गैसीकरण के अवशेषों के बीच नीलगिरी को एक उपयुक्त ऊर्जा स्रोत माना जाता है। पीएमसी, सीसी और ईयू का थर्मल रूपांतरण गुणांक क्रमशः 0.673, 0.671 और 0.730 है और प्रति किलो ईंधन में ऊर्जा रिलीज क्रमशः 13.58, 13.55 और 14.75 $MJ.kg^{-1}$ है।

स्पार्क इग्निशन परिवर्तित आई.सी. का उपयोग कर उत्पादक गैस से बिजली उत्पादन। इंजन का अध्ययन किया गया। दोहरी ईंधन संपीड़न प्रज्वलन इंजन का उपयोग करके बायोगैस के साथ उत्पादक गैस के मिश्रण के साथ विद्युत शक्ति का उत्पादन भी अध्ययन किया गया था। बायोडीजल को पायलट ईंधन के रूप में इस्तेमाल किया गया था और इसका प्रतिस्थापन एक स्वीकार्य दक्षता के साथ दोहरे ईंधन इंजन में हासिल किया गया था। परिवर्तित इंजन को 100% प्रोड्यूसर गैस पर सुचारू रूप से और स्थिर रूप से चलाने के लिए पाया गया, और तीन बायोमास EU, PMC और CC द्वारा क्रमशः 2.5, 2.0 और 1.7 kW के रूप में इष्टतम शक्ति को 1500 rpm की निरंतर गति के साथ 20^{o}bTDC पर पाया गया। ईंधन बायोडीजल और उत्पादक गैस - बायोगैस मिश्रण के साथ दोहरे मोड में इंजन संचालन का प्रदर्शन संतोषजनक पाया गया। बायोडीजल, उत्पादक गैस और बायोगैस के लिए प्रवाह दर क्रमशः 0.53, 9.5 और 0.63g.s^{-1} थी। बायोडीजल के मिश्रण से इष्टतम शक्ति पाई जाती है - उत्पादक गैस-बायोगैस 6.3kW थी। इस कार्य का ग्रामीण क्षेत्र में व्यापक अनुप्रयोग है और इसके कार्यान्वयन पर प्रकाश डाला गया।

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SYMBOLE AND ABBREVIATIONS

Common Notations

k	Heat conductivity of particles
C_P	Specific heat capacity
ºC	Degree centigrade
Ea	Energy of activation
m_0	Initial mass
m_t	Mass at temperature
m_∞	Final mass at final temperature
A	Pre exponential factor
R	Universal gas constant
ρ_w	Specific density
D_u	durability
I	Impact resistence
$\dot{m}_g$	Mixture gas Flow Rate
(A/F)m	Air/Fuel ratio
QCVg	Calorific value of producer gas
mg	Mass of producer gas per kg of Fuel
MWg	Molecular weight of producer gas
ρg	Density of producer gas
Eg	Energy released per kilogram of biomass
Cth	Coefficient of thermal conversion of fuel
ΔH	Heat of reaction
V	Instantaneous volume
V_C	Clearance volume
rc	Compression ratio
l	Connecting rod length
a	Cranck radius
Q	Heat realease rate
Qht	Heat transfer to cylinder wall
T	

T_W	Mean cylinder wall temperature
CD	Combustion duration
ηv	Volumetric efficiency
ηbth	Break thermal efficiancy
h	Convective heart transfer rate

Abbreviations

PMC	Pearl millet cob
CC	corncob
EU	euaclyptus
BD	biodiesel
BG	Bio gas
PG	Producer gas
EGT	Exhaust gas temperature
C.I.	Compression ignition
S.I.	Spark ignition
CGE	Cold gas efficiency
CCE	Carbon conversion efficiency
FTIR	Fourier infrared spectroscopy
TG	Thermogravimetry
BTE	Break thermal efficiancy
TGA	Thermogravimetric analysis
DTG	Dravativel Thermogravimetric
DTA	Differential thermal analysis
TR	Temperature Range
PT	Peak Temperature
FWO	Flynn-Wall-Ozawa
DAEM,	Distribution activation energy model
KAS	Kissinger-Akahira-Sunose method
BMEP	Brake Mean Effective Pressure, kN/m2
BSFC	Brake Specific Fuel Consumption
bTDC	Before Top Dead Centre
TDC	Top Dead Centre

Patm	Atmospheric pressure =101325 N/m2
Rg	Producer Gas Constant

Greek Letters

ρ_p	Density of particles
β	Heating rate
α	Thermal diffusivity
γ	Ratio of specific heat
σ	Axial compressive strength
σ_d	Diametric compressive strength
ϕ	Mole multiplier