DESIGNING, LABORATORY AND FIELD STUDIES OF BIOMASS COOKSTOVE

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FEBRUARY 2021

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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

FEBRUARY 2021

Dedicated to …..

My Beloved parents

CERTIFICATE

This is to certify that the thesis entitled "**Designing, Laboratory and Field Studies of Biomass Cookstove**" being submitted by **Mr. Amit Ranjan Verma** to the Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy** is a record of 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 has attained the standard required for a Ph.D. degree of this Institute.

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

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ACKNOWLEDGEMENTS

The writing of this thesis has been one of the most significant academics challenges I have ever had to face. Without the support, patience and guidance of the following people, this study would not have been completed. I would like to express my sincere gratitude for the immense amount of encouragement. I have received from both of my research supervisors, Prof. Rajendra Prasad and Prof. Virendra Kumar Vijay. Their wisdom, knowledge and commitment to the highest standards inspired and motivated me.

I am highly obliged to the members of Student Research Committee (SRC), Prof. S. N.Naik (Chairman), Prof. K. K. Pant (External Expert) and Prof. Satyawati Sharma (Internal Expert), who gave me technical suggestions and positive way of direction to my research work.

I am grateful to Dr. Ram Chandra for his valuable suggestions, encouragement and inspiring support during this work.

My special thanks to Mr. Ratneah Tiwar, my colleague at Biomass cookstoves laboratory (CRDT) for helping me conduction laboratory and as well as field testing of biomass cookstoves.

My hearty thanks to Ms. Risha Mal, my colleague at Biomass cookstoves laboratory (CRDT) for helping me in developing of TEG cookstove. She has carried out the TEG integration work in TEG cookstove (Mal, 2017).

I express my humble thanks to my staff mates Mr. Krishna Singh, Mr. Ramesh Yadava Mr. Birender Singh and Mr. Pratap Singh for their continuous support and help to accomplish the goals.

I am also grateful, to all those who in some way or other bestowed generosity upon me regarding this study.

Last but not the least, I would like to thank my mother & father for educating me with aspects from both arts and sciences, for unconditional support and encouragement to pursue my interests, for

listening to my complaints and frustrations, and for believing in me.

Date: Amit Ranjan Verma

ABSTRACT

This research work starts with an evaluation of a general methodology for designing and development of improved biomass cookstoves. A natural draft, a forced draft, and a self–sustaining power generating Thermo-Electric Generating (TEG) biomass cookstoves have been developed by following the general methodology of designing of biomass cookstoves. The performance of these cookstoves were measured under laboratory conditions using Bureau of Indian Standards (BIS) protocol and all of them met the BIS standards.

Further field testing of two of the developed cookstoves (out of five), along with other available commercially biomass cookstoves were done in the field using Uncontrolled Cooking Test (UCT) protocol. Most of the improved stoves had significant fuel and emissions reductions relative to the traditional cookstove. Five (2 developed and 3 commercially available) of the cookstoves models saved more than 30% of fuel compared to the traditional cookstove. The best performing cookstove, in terms of fuel efficiency and emissions performance, was a model using processed fuel (pellets) and a fan, which assisted in supply of controlled amount of air for the combustion process. The Forced-Draft TEG stove performed quite well with high Modified Combustion Efficiency (MCE=Molar ratio of (CO_2/(CO_2+CO)) (95 - 96 %) and relatively low emissions of both $PM_{2.5}$ and CO, reducing particulate matter and CO by 84 % and 71 % respectively as compared to Traditional Chulha. In Madhya Pradesh the developed forced draft medium Stove performed well compared to Bihar states with relatively low emissions of both $PM_{2.5}$ and CO reducing particulate matter and CO by 62 % and 75 % respectively as compared to Traditional Chulha.

Overall, the results show that many of the cookstoves provide substantial performance improvements relative to the traditional cookstove, suggesting that user adoption should play a key role in deciding which cookstove models are ultimately promoted.

Comparisons of laboratory and field performance results indicate that the general trends in fuel efficiency were somewhat consistent between the lab and the field, but emissions were much higher in the field tests than the laboratory tests.

<u>शोध- सार</u>

यह शोध कार्य बेहतर चूल्हे (कुकस्टोव) के डिजाइन और विकास के लिए एक सामान्य पद्धति के मूल्यांकन के साथ शुरू होता है। एक नेचुरल ड्राफ्ट , एक फोर्स्ड ड्राफ्ट, , और एक आत्मनिर्भर शक्ति उत्पन्न करने वाले थर्मोइलेक्ट्रिक जनरेटिंग (टीईजी) चूल्हों को चूल्हे के डिजाइन की सामान्य पद्धति का पालन करके विकसित किया गया है। इन चूल्हों का मूल्यांकन भारतीय मानक ब्यूरो (बीआईएस) के प्रोटोकॉल का उपयोग कर प्रयोगशाला की स्थितियों के तहत मापा गया था और वे सभी बीआईएस मानकों पर खरे उतरे।

इसके बाद अनियंत्रित खाना पकाने के टेस्ट (यूसीटी) प्रोटोकॉल का उपयोग करके दो विकसित चूल्हों (पांच में से दो) के साथ-साथ अन्य व्यावसायिक रूप से उपलब्ध चूल्हों का मूल्यांकन क्षेत्र में कया गया था। अधिकांश उन्नत स्टोवों में पारंपरिक चूल्हों के सापेक्ष ईंधन और उत्सर्जन में कमी महत्वपूर्ण आई थी। पांच चूल्हों के मॉडल (2 विकसित और 3 वाणिज्यिक रूप से उपलब्ध) पारंपरिक चूल्हे की तुलना में 30% से अधिक ईंधन बचाया। ईंधन दक्षता और उत्सर्जन प्रदर्शन के मामले में सबसे अच्छा प्रदर्शन करने वाला चूल्हा, संसाधित ईंधन (पेलेट) का उपयोग करने वाला मॉडल था, जो दहन प्रक्रिया के लिए नियंत्रित मात्रा में हवा की आपूर्ति में सहायता करता था।

फोर्सड-ड्राफ्ट टीईजी चूल्हे की उच्च संशोधित दहन क्षमता 95 - 9 6 % थी, और पारंपरिक चुला की तुलना में पीएम 2.5 और सीओ क्रमशः 84% और 71% अपेक्षाकृत कम उत्सर्जन थे । मध्य प्रदेश में फोर्स्ड ड्राफ्ट माध्यम स्टोव ने बिहार राज्यों की तुलना में अच्छा प्रदर्शन किया, जिसमें पीएम 2.5 और सीओ दोनों पारंपरिक चुल्हा की तुलना में अपेक्षाकृत 62% और 75% क्रमशः कम उत्सर्जन थे ।
कुल मिलाकर, परिणाम दिखाते हैं कि कई चूल्हे पारंपरिक चूल्हे की तुलना में अच्छा प्रदर्शन करते हैं, यह निर्णय लेने में महत्वपूर्ण भूमिका निभानी चाहिए कि कि उपयोगकर्ता आखिरकार कौन से चूल्हे को ले।

प्रयोगशाला और क्षेत्र के प्रदर्शन के परिणामों की तुलना से संकेत मिलता है कि प्रयोगशाला परीक्षण के मुकाबले ईंधन दक्षता में सामान्य रुझान कुछ हद तक संगत थे, लेकिन प्रयोगशाला परीक्षणों के मुकाबले क्षेत्र परीक्षण में उत्सर्जन बहुत अधिक था।

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Nomenclature

Symbols and abbreviations

%	=	Percent
/	=	Per
<	=	Lower than
>	=	Greater than
^{0}	=	Degree
^{0}C	=	Degree celsius
A	=	Pre-exponential factor
A	=	Area
A/F	=	Air-to-fuel ratio
A_{cc}	=	The cross sectional area of the combustion chamber
ASTRA	=	Application of Science and Technology for Rural Areas
B	=	Heat of Combustion (heating value) of wood fuel
BIS	=	Bureau of Indian Standards
BR	=	Bihar
C	=	Carbon
CAD	=	Computer Aided Design
CCT	=	Controlled Cooking Test
CH_4	=	Methane
cm	=	Centimetre
CNG	=	Compressed Natural Gas
CO	=	Carbon monoxide
CO_2	=	Carbon dioxide
Conc.	=	Concentration
Cp	=	Heat capacity at constant pressure
d	=	Gap between the pan bottom and the top plate
db	=	Dry basis
DC	=	Direct Current
E	=	Activation energy
FD-D	=	Forced Draft -Domestic
FD-I	=	Forced Draft -Institution
FDM	=	Forced Draft Metal
FD-M	=	Forced Draft- Medium
FDP	=	Forced Draft Pellet
FD-TEG	=	Forced Draft -Thermo Electric Genetor
g	=	Gram
GACC	=	Global Alliance for Clean Cookstoves
GIZ	=	Deutsche Gesellschaft fur Internationale Zusammenarbeit
GJ	=	Gigajoule
h	=	Hour
H	=	Hydrogen
H_2O	=	Water
H_{cc1}	=	Height of combustion chamber occupied by the fuelbed where charcoal burns and the pyrolysis take place
H_{cc2}	=	Height of combustion chamber occupied by the flames

HH	=	Household
I	=	Current
ICS	=	Improved Cookstove Stove
IIT	=	Indian Institute of Technology
IMPMUD	=	Improved Mud
IQR	=	Interquartile range
ISO	=	International Organization for Standardization
ITDG	=	Intermediate Technology Development Group
IWA	=	International Workshop Agreement
K	=	Kelvin temperature
kg	=	Kilogram
kJ	=	Kilojoule
KPT	=	Kitchen Performance Test
kW	=	Kilowatt
kW-h	=	Kilowatt hour
L	=	Litre
LPG	=	Liquefied Petroleum Gas
M	=	Mass of volatiles produced
m	=	Fuel burning rate (kg/h)
m	=	Meter
n	=	Numbers of air holes
M Pa	=	Megapascal
m^3	=	Cubic metre
MC	=	Moisture Content
MCE	=	Modified Combustion Efficiency
mg	=	Milligram
MJ	=	Megajoule
MJ_d	=	Megajoules of energy delivered to the pot
mm	=	Millimetre
MNES	=	Ministry of Non-Conventional Energy Sources
MNRE	=	Ministry of New and Renewable Energy
MP	=	Madhya Pradesh
MW	=	Megawatt
ND-D	=	Natural Draft -Domestic
NPIC	=	National Program on Improved Chulha
O_2	=	Oxygen
OD	=	Odisha
P	=	Power
PEMS	=	Portable Emissions Measurement System
PIC	=	Products of Incomplete Combustion
$PM_{2.5}$	=	Particulate matter less than 2.5 microns in diameter
ppm	=	Parts per million
R	=	Ideal gas constant
R1	=	Rocket 1
R2	=	Rocket 2
rpm	=	Revolution per minute
$R_{specific}$	=	Specific gas constant for dry air
s	=	Second
SA	=	Standard Adult
SOx	=	Sulphur dioxides

STP	=	Standard Temperature and Pressure
St. Dev	=	Standard Deviation
CoV	=	Coefficient of Variation
CE	=	Combustion Efficiency
t	=	Time
T	=	Absolute temperature
TC	=	Traditional Chulha
TERI		The Energy and Resources Institute
TLUD	=	Top Lit Up Draft
TPM	=	Total Particulate Matter
TPM stove	=	Two-Pot Mud Stove
UCT	=	Uncontrolled Cooking Test
UN	=	United Nations
UP	=	Uttar Pradesh
V	=	Volume
v		Velocity
V	=	Voltage
VITA	=	Volunteers in Technical Assistance
W	=	Fan power
W	=	Watt
WB	=	West Bengal
WBT	=	Water Boiling Test
WSG	=	Woodburning Stove Group
yr	=	Year

Greek symbols

ø	=	Diameter (cm)
α	=	Fraction of mass
α	=	Sharp edges
δ	=	Gap between the pan and the shield (cm)
ε	=	Emissivity
η	=	Efficiency (%)
λ	=	Excess air factor
μ	=	Viscosity (Pa-s)
ρ	=	Density (kg/m^3)
σ	=	Stephan- Boltzman constant (W/m^2K^4)
υ	=	Volatile fraction
φ	=	Equivalence ratio
χ	=	Packing density
ω	=	Fire penetration rate (kJ/h)
ψ	=	Stoichiometric air required for complete combustion of fuel (m^3 STP)

Subscripts

c	=	Charcoal
cc	=	Combustion chamber
des	=	Design
max	=	Maximum
n	=	Normal
d	=	Deliver