COMPARATIVE ASSESSMENT OF TRADITIONAL AND IMPROVED BIOMASS COOKSTOVES IN LABORATORY AND FIELD- PROTOCOLS AND STANDARDS

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by

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Dedicated to …..

My Grandfather

CERTIFICATE

This is to certify that the thesis entitled **"Comparative Assessment of Traditional and Improved Biomass Cookstoves in Laboratory and Field- Protocols and Standards"** being submitted by **Mr. Ratnesh Tiwari** 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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ABSTRACT

Performance evaluation is an extremely important aspect to be dealt with for the success of Improved cookstoves (ICS). It can play key role by providing required information to the decision-makers and can also help in selection of the appropriate technology as per the requirement. A well-documented data on the performance evaluation of ICSs can also serve as very important input for global climate prediction models. The present study deals with performance evaluation of biomass cookstoves. The aim of this research work was to identify the main criticalities related to the testing and evaluation of biomass cookstoves and provide indications for a better testing approach.

The results of laboratory based comparative study of two protocols BIS and WBT shows that the thermal performance and emission performance results were found to be different between the two test methods. During testing with WBT, higher uncertainty in performance results were observed. Hence BIS protocol was selected for further testing of stoves in laboratory. Uncontrolled Cooking Test protocol was selected for field testing.

The study on impact of different parameters on performance of cookstoves shows that there is a significant impact of different operating parameters on cookstoves performance.

There were differences in performance across the locations in field, likely due to differences in cooking demands and fuel conditions. The suggested baseline from testing of traditional stoves in field in terms of specific fuel consumption (per kg of food cooked) is around 7.5 MJ. In simple word, we can say that, around half kg of fuelwood being consumed for cooking of 1 kg of food in traditional stoves. This led to emissions of around 95 g CO and around 9.5 mg PM2.5. A good correlation was established between the laboratory and the field testing in terms of specific fuel consumption. One unit of food cooked in the field appeared to be equivalent to on an average 7 units of water boiled in the laboratory.

The emissions were much higher in the field than in laboratory. The CO and PM2.5 emissions rates were on an average 3-4 times and 8-10 time higher in the field respectively.

शोध- सार

उन्नत चूल्हे (कुकस्टोव) की सफलता के लिए प्रदर्शन मूल्यांकन एक अत्यंत महत्वपूर्ण पहलू है। यह निर्णय लेने वालों को आवश्यक जानकारी प्रदान करके मुख्य भूमिका निभा सकता है और आवश्यकता के अनुसार उपयुक्त प्रौद्योगिकी के चयन में भी मदद कर सकता है। उन्नत चूल्हे के प्रदर्शन मूल्यांकन पर एक अच्छी तरह से प्रलेखित डेटा भी वैश्विक जलवायु भविष्यवाणी मॉडल के लिए बहुत महत्वपूर्ण इनपुट के रूप में काम कर सकता है। यह शोध कार्य चूल्हे के प्रदर्शन मूल्यांकन से संबंधित है। इस शोध कार्य का उद्देश्य बायोमास चूल्हे के परीक्षण और मूल्यांकन से संबंधित मुख्य जटिलताओं की पहचान करना और बेहतर परीक्षण दृष्टिकोण के लिए संकेत प्रदान करना था।

दो प्रोटोकॉल भारतीय मानक ब्यूरो (बीआईएस) और पानी उबलने का परीक्षण (डब्ल्यूबीटी) के प्रयोगशाला आधारित तुलनात्मक अध्ययन के परिणाम बताते हैं कि थर्मल परीक्षण और उत्सर्जन प्रदर्शन परिणाम दो परीक्षण विधियों के बीच भिन्न पाए गए थे। डब्ल्यूबीटी के साथ परीक्षण के दौरान, प्रदर्शन के परिणामों में उच्च अनिश्चितता देखी गई। इसलिए प्रयोगशाला में स्टोव के मूल्यांकन के लिए बीआईएस के प्रोटोकॉल का चयन किया गया था। क्षेत्र परीक्षण के लिए अनियंत्रित खाना पकाने के टेस्ट (यूसीटी) प्रोटोकॉल का चयन किया गया था।

चूल्हे के प्रदर्शन पर विभिन्न मापदंडों के प्रभाव पर अध्ययन से पता चलता है कि चूल्हे के प्रदर्शन पर विभिन्न ऑपरेटिंग मापदंडों का एक महत्वपूर्ण प्रभाव है।

खाना पकाने की मांगों और ईंधन की स्थिति में अंतर के कारण, क्षेत्र में प्रदर्शन के स्थानों में अंतर थे। विशिष्ट ईंधन खपत (पकाया भोजन प्रति किलो) के संदर्भ में पारंपरिक स्टोव के परीक्षण से सुझाई गई आधार रेखा लगभग 7.5 MJ है। सरल शब्दों में, हम कह सकते हैं कि, पारंपरिक चूल्हे में 1 किलो भोजन पकाने के लिए लगभग आधा किलो ईंधन की खपत होती है। इससे लगभग 95 ग्राम सीओ और लगभग 9.5 मिलीग्राम पीएम 2.5 का उत्सर्जन हुआ। विशिष्ट ईंधन खपत के संदर्भ में प्रयोगशाला और क्षेत्र परीक्षण के बीच एक अच्छा संबंध

स्थापित किया गया था। घरों में पकाए गए भोजन की एक इकाई प्रयोगशाला में उबलाए गए औसतन 7 यूनिट पानी के बराबर दिखाई देती है।

प्रयोगशाला की तुलना में इस क्षेत्र में उत्सर्जन बहुत अधिक था। सीओ और पीएम 2.5 की उत्सर्जन दर क्रमशः क्षेत्र में औसतन 3-4 और 8-10 गुना अधिक थी।

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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	=	Combustion value of 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	=	Giga joule
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	=	Kilo gram
kJ	=	Kilo joule
KPT	=	Kitchen Performance Test
kW	=	Kilo watt
kW-h	=	Kilo watt hour
L	=	Litre
LPG	=	Liquefied Petroleum Gas
M	=	Mass of volatiles produced
m	=	Fuel burning rate (kg/h)
m	=	Meter
M Pa	=	Mega pascal
m^3	=	Cubic metre
mc	=	Moisture content
MCE	=	Modified Combustion Efficiency
mg	=	Milli gram
MJ	=	Mega joule
MJ_d	=	Megajoule of energy delivered
mm	=	Milli metre
MNES	=	Ministry of Non-Conventional Energy Sources
MNRE	=	Ministry of New and Renewable Energy
MP	=	Madhya Pradesh
MW	=	Mega watt
ND-D	=	Natural Draft -Domestic
NPIC	=	National Program on Improved Chulha
O_2	=	Oxygen
OD	=	Odisha
P	=	Power
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
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 (m)
α	=	Fraction of mass
δ	=	Gap between the pan and the shield
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)

Subscripts

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