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Pakistan indoor air pollution: Investigation of thermal properties of cooking stove

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Abstract

For low-income homes in developing nations, an improved cooking burner is the most practical solution to minimize indoor air pollution. This research was carried out in a rural region of Khipro City in Pakistan's Sindh province. The thermal efficiency and water boiling tests were carried out on the upgraded cooking stove that was designed. The results of the experiment are equivalent to those of published research. The enhanced cooking stove is made of mud and has design parameters of 10-inch height, 16-inch width, and 32-inch length. A twin mouth cooking burner with a chimney to extrude the generated gases is the design. The designed ICS was tested using a water boiling test (WBT) and found to have a fuel consumption of 293 g with 30% efficiency, which is comparable to the claimed efficiency of ICSs. The use of comparable stoves can considerably reduce the quantity of gases produced by cooking, resulting in a healthier lifestyle.

Keywords: Improved cooking stove; Thermal efficiency; Indoor air pollution

1. Introduction

South Asia has a total population of about 1.9 billion people, accounting for 25% of the world's population, and Pakistan is listed as the region's second most concerned population for utilizing traditional solid biomass [1]. However, a large proportion of Pakistan's population lives in rural regions, where agriculture is the primary source of income. The indoor biomass burning for food has a significant impact on people's living standards. According to research, 2.5 billion people do not have access to modern fuel [2]. Similarly, about 102 million people in Pakistan do not have access to clean fuel [3]. Approximately 72 percent of Pakistan's population relies on biomass burning for home cooking and heating. The average biomass composition in the nation is 63 percent firewood, 21 percent animal manure, and 16 percent crop waste [4].

Due to weather patterns in Pakistan, the average use of wood increases as one moves from sea level to high altitude. Local biomass is used in poor nations to fulfil household energy needs, causing serious health problems owing to indoor air pollution (IAP). IAP claims the lives of 1.8 million individuals per year [5]. Because energy generation is highly reliant on conventional thermal methods, climate change is impeding the country's economic progress [6]. On the other side, one of the causes contributing to climate change is the massive influx of people into the nation who use biomass for cooking. Poverty in the global south drives people's traditional behavior toward clean cooking. Burning biomass exposes people to respiratory risks, and pneumonia is still one of the leading causes of mortality in children under the age of five worldwide [7]. Females spend many hours preparing food in kitchens with no windows and insufficient ventilation. As a result, prolonged exposure to smoke irritates the eyes and infiltrates the lungs every day [8]. Governments across the world have been searching for a long-term solution to the IAP in order to reduce death rates and gain long-term health and environmental advantages. Each year, 730 million tons of biomass are burnt in developing nations, resulting in more than 1 billion tons of CO_2 in the atmosphere [6]. Table 1 shows the contribution of several Asian countries to reducing greenhouse gas (GHG) emissions. Despite a strong awareness of climate change and different ICS initiatives, the failures to reduce indoor air pollution are responsible for three million premature deaths each year [9]. The notion of an improved cooking stove (ICS) is not new to the globe, and numerous national and international organizations have collaborated on ICS initiatives. The traditional ICS was only 5-10% energy efficient and has to be improved in terms of energy efficiency, pressure draught, and maximum heat transmission [10]. The implementation of such programmes in a variety of developing nations has resulted in a clear knowledge of how to minimize smoke inhalation, which has major health advantages, as well as GHG emissions, which slows deforestation and provides a variety of social benefits.

Table 1. Improved cooking stove program in various countries

Country	**Programs and contribution to ICS development**
Pakistan [4][11][12]	Economic Cook Stove • The Design developed by NWFP University and Appropriate Technology Organization • 70,000 ICS installed during 1994-1999 Coal Cake Manufacturing Project • Funded by Empower New Zealand • Greatly endorse by local people in northern areas Fuel-Efficient Cooking Technology by GTZ • GTZ spearheaded the program during 1988-1992 Aga Khan Planning & Building Services • New stove design launched in 1985, and around 10,000 ICS installed in Northern areas • AKPBS started a program, Building & Construction Improvement Program • BACIP installed 10,500 ICS during 1999-2009
Bangladesh [4][13][14][15][16]	Bangladesh Council for Scientific & Industrial Research • Distribution of 300,000 ICS between 1980 and 2001 • The following organization installed smokeless stoves around 133,841 ICS (1988-1991) • Swanirvar, Aid Bangladesh, Village Education Resource Center, Bangladesh Association of Community Education, Bandhujan Parishad • Stage II (1994-1997) & stage III (1998-2001), approximately 166, 159 ICS were installed USAID project (2005-2007) • ICS project by USAID was implemented by Winrock International and Concern Worldwide Bangladesh • 580 ICS were distributed in two different districts Grameen Shakti • GS has successfully established a market of 2 million ICS • The program has equipped more than 600 people with the concept of ICS technology • It has installed 2,000 ICS by 2009 GTZ • The project has launched 150,000 ICS by 2009 • By the project, GTZ has trained 8,000 local people
Bhutan [4][17]	National Women Association of Bhutan, NWAB • Installed pilot ICS in Thimphu Dzongkhag National Stove Program, 1985 • 4,000 ICS were installed in the first phase Bhutan Youth Development Association, BYDA

Country	Programs and contribution to ICS development
	• In 1999 United Nations Development Program, under a small grant program, started smokeless stove installation in rural areas • UNDP provided 25,670 USD for North Trashigang and 44,440 USD for Tsirang
India [18][19][20][21][22]	National Program on Improved Chulhas, NPIC • The program was funded by the Ministry of Non-Conventional Energy Sources, India • The program started in 1984 and had gone through many changes in policy and implementation • NPIC has successfully reached 32.77 million households by 2001 • Technical Back-up Unit covered the R&D section of the program • NPIC has developed more than 30 models of stoves over 17 years, and 34 million stoves were installed between 2001-2002 • NPIC was the second biggest program on ICS after the Chinese National Program Appropriate Rural Technology Institute, ARTI • ARTI is based in Maharashtra and supported by Shell Foundation under UK Breathing Space Program • ARTI has successfully reached 15,00,000 in Maharashtra and 50,000 in Gujarat Technical Informatics Design Endeavors, TIDE • The organization developed a program in South India, initially in Kerala and Karnataka. It started working in Tamil Nadu and Andhra Pradesh • 1050 installed up to the end of 2007 Gram Vikas in Orissa • 5072 smokeless stoves designed and installed by the organization in 2007-2008
Nepal [23]	Department of Agriculture (1960-1970) • The first ICS was installed in 1950 • Designed a stove model known as Lorena Stove • 57,000 ICS were installed in different parts of the country ICS Development in 1990 • 40,000 ICS were installed until 1998 National ICS Program • The program was supported by Energy Sector Analysis Program (ESAP) • Alternative Energy Promotion Centre strengthens the network activities later on • Phase I 2000-2006: 15 districts with 2,13,059 ICS installed • Phase II 2007-2011: 4,34,000 ICS installed in Mid Hills and Terai, 5,000 ICS installed in a different institution, and 50,000 ICS installed in High Hills
Sri Lanka[4][24]	The ICS program was divided into 3 phases • The program implementing agencies were Sri Lankan government, several donor agencies, DGIS, Ceylon Electrical Board • Design and testing phase 1970-1985 • Promotion and dissemination 1985-1991

Country	Programs and contribution to ICS development
	• Commercialization phase 1991-2005 • 300,000 distributed between 1985-1990 • Over 200 potters and 2,000 stove installers were trained • Sarvodya, NGO, designed the ICS for local people IDEA 1991 • Integrated Development Association specifically launched to spearhead the campaign for ICS • IDEA had successfully collaborated with Practical Action, ARCOP, and INFORCE • Every year, 300,000 produced by local potters to serve 14 districts

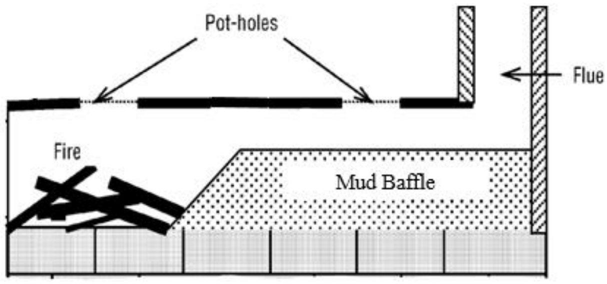
The goal of this research is to develop energy-efficient stoves that assure complete biomass combustion while reducing fuel usage. The purpose of this study is to compare the efficiency of the ICS to that of an open fire. Water boiling tests and thermal efficiency were used to evaluate the ICS's performance. The goal of this research is to develop energy-efficient stoves that assure complete biomass combustion while reducing fuel usage. The purpose of this study is to compare the efficiency of the ICS to that of an open fire. Water boiling tests and thermal efficiency were used to evaluate the ICS's performance.

Table 2. Design parameters for the ICS

Material	Parameter	Units	Values	References
Wood	Calorific value	KJ/g	17.39	[25]
Air	Thermal conductivity	W/m.K	0.029	[26]
Water	Specific heat capacity	J/g.K	4.186	[27]
Water	Density	g/liter	1000	[28]
Flame	Temperature	K	1011	[29]
Smokeless stove	Thermal efficiency	%	0.35	NA
Smokeless stove	Energy loss	%	0.65	NA

2. Methodology

The proposed model was constructed using mud, dimensions of the ICS areas shown in Figure 1. The stove is double mouthed to minimize combustion of wood. A baffle is installed to develop nature draft of air across the stove to achieve complete combustion. This design is helpful to minimize the carbon mono-oxide generation during combustion. The height of first compartment is 10 inches and second compartment is 5 inches high to develop natural air flow across the ICS with 4 inches diameter of the chimney.



Dimensions: Length 32 inches, width 16 inches, Height 10 inches
Baffle height 5 inches, Chimney diameter 4 inches

Figure 1. Improved cooking stove

The model has unique qualities and features that allow it to be used for thermal efficiency experiments. The ICS can be improved by including heat-insulating material within the stove, which will reduce the amount of biomass consumed. The technique is therefore eventually contributing to the reduction of greenhouse gas emissions. It is possible to produce the suggested design out of a variety of materials, including carbon steel, refractory material, and even mud. Following public health guidelines, industrial complexes should be fuel-efficient in a variety of ways [30]. The thermal efficiency is determined on the basis of the data from the experimentation.

According to the Shell Foundation, the Water Boiling Test (WBT) is divided into three steps that must be completed in succession and are referred to as the Controlled Cooking Test (CCT) [31]. The WBT is divided into three phases: the first phase is known as the cold-start high power test, the second phase is known as the hot-start high power test, and the third phase is known as the simmering or lower point of WBT, which occurs immediately after the second phase.

To determine the thermal efficiency, burning rate, and specific fuel consumption using equations, only a cold-start high power test is carried out in the suggested research. The pot has a capacity of 5,000 grams which is sufficient for most cooking tasks. An electronic scale with a capacity of ten kilograms (ten kg), a digital thermometer, a wood moisture gauge, a stop watch, and an ordinary saucepan to boil water are all utilized in the WBT. First and foremost, the weight of the wood is determined using an electronic scale. We kept the diameter of the wood we utilized for WBT at or below 2 cm. For a long time, the moisture content of wood was assessed only by weighing it. In order to determine the moisture content of woods, the equation (1) was employed. It was determined that the wood used for WBT had a moisture level of around 10% and was thus properly dry. The data acquired during the WBT are shown in Table 3.

Table 3. Data obtained for water boiling test of the improved smokeless stove

Parameters	Units	First test	Second test	Average
Time required to boil the water	min	42	44	43
Water boiled	g	4850	4875	4862.5
Water vaporized	g	150	125	137.5
Latent heat of vaporization	J/g	2260	2260	2260
Fuel burnt	g	295	291	293
Mass of water in kettle	g	5000	50000	5000
Specific heat capacity of water	J/g.K	4.186	4.186	4.186
Boiling point of water	K	398.7	397.2	397.95
Initial temperature of water	K	299.75	299.05	299.4
Lower heating value	J/g	17370	17390	17380

3. Results and discussion

3.1. Fuel for the experiment

Wood was the most readily available fuel in Khipro City. The amount of energy required to achieve boiling point of 5 kg of water is 2,093,000 J. For this the following equation was utilized:

$$Q = mCp\Delta T \quad (1)$$

“Q” is the heat required to increase the temperaturefor 5000 g of water from 273.15 K to 373.15 K, which is calculated to be using equation (1):

Q = 5000 g * 4.186 J/kg.K * (273.15-373.15)K

Q = 2,093,000 J

Assuming the system is 100% efficient, the amount of wood required if the lower heating value of wood is around 17.390 kg/J [32]

2,093,000/17390 = 120.35 g

Since the combustion process in our ICS is not 100% efficient, we assumed that losses are 65% with 35% combustion efficiency[33][34], we get:

120.35/0.35 = 343.85 g of wood

4. Thermal feat ofICS

4.1. Thermal efficiency

Special features of ICS are characterized by the experimental data obtained from WBT in Table 3. The overall efficiency of can be determined by Equation 2.

$$Overall\ efficiency = \frac{Heat\ absorbed\ by\ water}{Total\ heat\ produced} * 100 \quad (2)$$

$$hc = \frac{Heat\ energy\ required\ to\ boil\ water + Energy\ of\ vaporisation}{Heat\ energy\ released\ by\ a\ given\ quantity\ of\ wood} * 100$$

$$hc = \frac{MwCw\Delta T + Mwvh}{Fcm\ LHV} * 100$$

where,

M_w= mass of water in the kettle
C_w = specific heat capacity of water
ΔT = temperature difference
M_{wv} = mass of water vaporized
LHV = lower heating value
h = the specific enthalpy of vaporization

$$hc = \frac{4990 * 4.186\ (98.5 - 24.5) + \ 100 * 2260}{295 * 17390}$$
$$hc = 30.17\%$$

From the above calculations, it was determined that the overall efficiency of the ICS was approximately 30%.

4.2. Water boiling rate

The water boiling rate (WBR) was obtained by following Equation 3.

$$WBR \ = \frac{Time\ to\ boil\ water}{Effective\ mass\ of\ water\ boiled} * 1000 \qquad (3)$$

4.3. Specific fuel consumption

The specific fuel consumption (SFC) is obtained by Equation 4.

$$SFC \ = \frac{Fuel\ consumed}{Effective\ mass\ of\ water\ boiled} * 1000 \qquad (4)$$

4.4. Fire power

Fire power (FP) was calculated using Equation 5.

$$FP \ = \frac{Fuel\ consumed * LHV}{Time\ to\ boil\ water * 60} \qquad (5)$$

The equations 3,4, and 5 were taken from the literature [35]. Based on the data obtained from carrying out the WBT experiment, the performance indicators of ICS provided in Table 4 are promising.

Table 4. Key performance indicators for ICS obtained from WBT analysis

Performance indicators	Units	First test	Second test
Overall efficiency	%	33.7	35.4
Water boiling rate	min/lit	11.1	10.46
Specific fuel consumption	g/liter water boiled	60.5	59.69
Fire power	KW	1.58	1.65

5. Conclusions

In this study, an improved cooking stove was constructed using mud in a small village near Khipro City based in the Sindh province of Pakistan. The purpose of this effort was to construct an ICS with a concept of natural draft of flow across the stove to achieve complete wood combustion leading to less biomass consumption and the mitigation of indoor air pollution (IAP). The overall structure of the stove was kept very simple so that it may replicate by non-technical people. The overall efficiency of the constructed ICS was investigated using the water boiling test (WBT) and was found to be around 30% having a fuel consumption of 293 g which is similar to efficiency of ICS's reported in literature. Other thermal properties of ICS like water boiling rate, specific fuel consumption and fire power are shown in Table 4. The design of the ICS was completed by engaging various engineering aspects so that it may serve as a baseline for further improvement in less developed countries.

Declaration of competing interest

The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

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