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Research Article

Adoption of smokeless *Chulha* (Stove) in rural of Meghalaya and its feasibility: A case study

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Abstract
The smokeless *chulha* is a kind of stove that can directly impact the health of women in rural areas who are burning firewood as cooking fuel. The present study aimed to evaluate the impact of the smokeless *chulha* and to compare the social and economic benefits associated with it. The smokeless *Chulhas* (stoves) were distributed among the villagers in Tuber Kmai village of Meghalaya, India and its impact was compared with the traditional *chulha* used by the villagers. The efficacy of the smokeless chulhas was measured and compared with traditional *chulhas* in term of cooking time, fire wood consumption, gases, volatile compounds and particulate matter emitted. To measure the amount of gases, volatile compounds and particulate matter released, multifunctional air gas and particulate matter Detector (Labart, India) was used. Compared to traditional *chulha*, smokeless *chulha* showed 68.7 % reduction in firewood consumption and 45% reduction in cooking time. In addition, smokeless chulha showed 68.9% and 98% reduction in carbon dioxide and carbon monoxide compared to traditional *chulha*. Further, a significant reduction ($p < 0.05$) was observed for particulate matter (75%-87%), formaldehyde (75%) and total volatile organic compounds (88.5%). The results indicate that smokeless *chulha* could save a huge number of natural resources by reducing the cutting of forest. Moreover, smokeless *chulha* has a positive economic impact on family income.

Keywords: Carbon dioxide, Carbon monoxide, Firewood, Smokeless *chulha*, Particulate matter

INTRODUCTION

In many parts of the world, particularly in rural areas of developing countries, traditional cooking methods involve cow dung, wood, etc., in open or rudimentary stoves with no proper ventilation. While these methods have been used for centuries to prepare meals, they come with a significant drawback: the production of smoke (Alex *et al.*, 2018; Smith, 2000; Belachew *et al.*, 2023). When these traditional *chulha*s are used, they emit large amounts of smoke that can have severe health and environmental impacts. The smoke emitted from traditional stoves contains harmful pollutants and particulate matter, including carbon monoxide, nitrogen oxides, volatile organic compounds (VOCs), and fine particulate matter (PM2.5 and PM 10) (Das *et al.*, 2009; Shrestha and Shrestha, 2013). The abovementioned pollutants and particulate matter are well-known for multiple health hazards (Lachowicz *et al.*, 2022; Sidibe *et al.*, 2023). Prolonged exposure to this smoke can lead to various health problems, including respiratory diseases, eye irritation, lung cancer, and cardiovascular issues (Witinok-Huber *et al.*, 2022; Hussain *et al.*, 2022). It is particularly concerning for women and children who spend more time near the stove while cooking or carrying out domestic activities.

Furthermore, the smoke produced by traditional stoves (*Chulahs*) contributes to environmental degradation. The inefficient combustion of biomass fuels leads to the release of greenhouse gases, including carbon dioxide

and methane, contributing to climate change (Bhattacharya and Abdul Salam, 2002; Venkataraman *et al.*, 2010) . Additionally, using biomass fuels exacerbates deforestation and strains local ecosystems as communities rely on unsustainable fuel sources. With government efforts, environment-friendly energy sources LPG (Liquid petroleum gas) cylinders have reached villages, yet they continue to be expensive for a reasonable population. To address these problems, researchers, organizations, and governments have been working to develop and promote smokeless *chulha*s (Bhojvaid *et al.*, 2014; Chandra *et al.*, 2022).

The primary objective is to improve combustion efficiency, minimize smoke production, and reduce the negative health and environmental impacts associated with traditional cooking methods (Chandra Nayak Manmatha *et al.* ;Roul 2022; Dilshad *et al.*, 2020; Panwar *et al.*, 2006). Smokeless *chulhas* incorporate various design features and technologies to achieve these goals. One important aspect is the improvement of insulation to ensure that heat is retained within the cooking chamber, resulting in better combustion (Sheikh and Bhaduri, 2020). By retaining heat, less fuel is required, reducing both the cost and the environmental impact of cooking. Insulation also helps to ensure that the outer surfaces of the stove remain cool to the touch, reducing the risk of accidental burns. Another key feature of smokeless *chulhas* is better airflow control. These stoves are designed to optimize the mixture of air and fuel, allowing for more complete combustion. Air vents or chimneys are incorporated into the design to facilitate the escape of smoke and ensure that it is directed away from the cooking area. This reduces smoke inhalation and improves indoor air quality (Chandra *et al.*, 2022). Efficient combustion chambers are another important component of smokeless *chulha*s. These chambers are designed to promote complete fuel combustion, resulting in higher energy efficiency and reduced emissions. The chambers often have a well-defined shape and size to ensure the fuel burns uniformly and efficiently. In addition to these design features, smokeless *chulha*s may incorporate other technologies to enhance their performance further. Some stoves use forced air systems, such as fans or bellows, to provide a steady oxygen supply to the combustion chamber, ensuring a more controlled and efficient burn. Others may use catalytic converters or gasification techniques to convert the fuel into a cleaner-burning gas, reducing the production of smoke and harmful pollutants.

The benefits of smokeless *chulha*s are numerous. They significantly reduce the amount of smoke generated during cooking. By providing better combustion conditions and directing smoke away from the cooking area, these stoves contribute to improved indoor air quality and reduce the risk of respiratory illnesses and other health issues associated with prolonged exposure to smoke. Smokeless *chulha*s also offer fuel efficiency advantages. Through their improved combustion design, they maximize the use of available fuel, resulting in reduced fuel consumption and cost savings for people using it (Chandra *et al.*, 2022, Das *et al.*, 2022).

This study aimed to investigate the smokeless *chulha's* working and compared the savings in terms of time and energy consumed while using the smokeless *chulha* vis -a-vis the traditional *chulha*. The various parameters considered during the comparative study were not limited to fuel consumption and time-saving, but also included investigation of various gases such as Carbon dioxide (CO_2), carbon monoxide (CO), Formaldehyde (HCHO), total volatile organic compounds (TVOCs), etc. and particulate matters (PM10 and PM2.5) that were released during the burning of wood while cooking.

MATERIALS AND METHODS

Description of smokeless *chulha (stove)*

Smokeless *Chulha* was procured from Shivkrupa Enterprise, Pune, India. The model used for the present study was Swastik Shegdi (Fig. 1). The smokeless stove also burns firewood like a traditional *chulha*. However, the smokeless *chulha* employed a closed system that helped to burn wood more efficiently and produce more heat.

Study area

The smokeless *Chulha* was installed in Tuber Kmai (25°25'51.97"N and 92°17'17.90"E) village of Meghalaya, India (Fig. 2). As per the latest record from Block Development Officer (Khliehriat district, Meghalaya), 460 households were there, and the population is 3195. A total of 30 households were selected. And 50% of these houses used smokeless *chulha* provided by the East Janita Hills Deputy Commissioner.

Methodology

Fuel consumption

For traditional *chulha*, villagers used locally available fuel wood collected from the nearby forest area of East Jaintia Hills . Hence, the same firewoods were used to determine the fuel consumption quantity by smokeless *chulha*. The consumption of firewood (kg) was measured daily for the same type of food cooked on traditional *chulha* and smokeless *chulha*.

Smoke analysis

Carbon Dioxide (CO_2 in ppm), Formaldehyde (HCHO in mg/m^3), Volatile Organic Compound (TVOC in mg/m^3), and Carbon monoxide (CO in ppm) were measured using Real-Time electrochemical sensors of a Multifunctional Air Gas Detector (Labart, India). In addition, particulate matter (PM10 and PM2.5) in smoke was

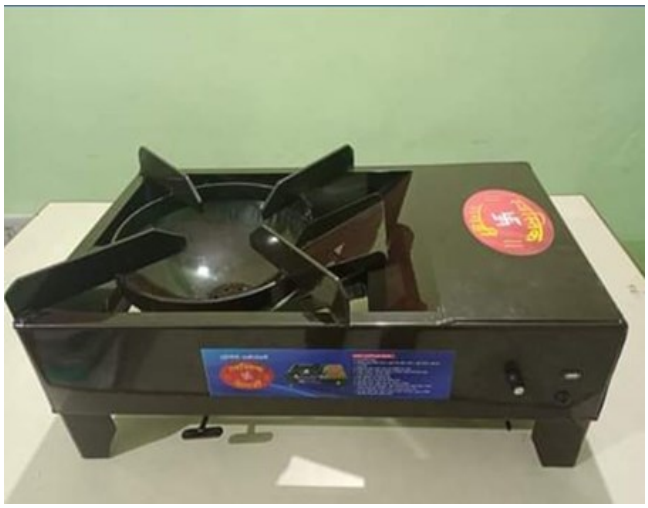

Fig. 1. *Smokeless chulha (*Swastik Shegdi*) installed in Tuber Kmai village of Meghalaya*

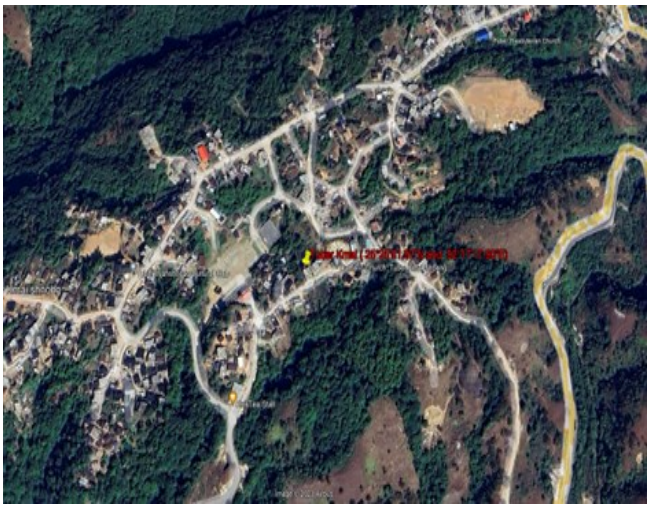

Fig. 2. *Study area : Kmai (25°25'51.97"N and 92° 17'17.90"E) village of Meghalaya*

measured using WREA HLW-100 Labart, India.

Statistical analysis

All analyses were conducted in triplicates, and the results are expressed in terms of mean ± SD (standard deviation) calculated using XLSTAT 2014.

RESULTS AND DISCUSSION

Firewood consumption and cooking time

The present study showed that, on average traditional *chulha* utilized 3.2 kg of fire wood during the cooking, whereas the smokeless *chulha* utilized only 1.0 kg of fire wood for the same kind of food . It was observed that firewood consumption reduced up to 68.7% with smokeless *chulha* (Table 1). Similar reduction in fuel consumption was observed with other smokeless *chulha* as compared to traditional *chulha* in other studies too (Chandra *et al.*, 2022). For example, up to 42.3 % decrease in fuel consumption was observed with the smokeless *chulha* (Udairaj smokeless *chulha* developed by Renewable Energy Department., (College of Technology and Engineering, Udaipur) installed in Churachandpur District, Manipur (Devi and Singh, 2018). In another study, up to 37% reduction in fuel consumption was observed with the smokeless chulha in a village (Chaukpuri, Bijnor, Uttar Pradesh) (Dilshad *et al.*, 2020). The present study and other studies indicated that smokeless *chulha*'s fuel consumption reduced significantly compared to traditional *chulha* (Chandra., 2022). The fire wood is the most common fuel used for cooking in the villages in Northeast India. Reducing fuel consumption by 68.7 % with smokeless *chulha* will directly reduce deforestation and contribute simultaneously to the environment.

In addition, the time for cooking up the food is reduced drastically with smokeless *chulha* compared to the traditional *chulha*. It was observed that on an average traditional *chulha* took up to 40 min to cook and it was reduced to 22 min with smokeless *chulha*. Up to 45% reduction in cooking time was observed with smokeless *chulha* (Table 1). Similar reduction in cooking time was observed with smokeless chulha name 'Udairaj' installed in village of Manipur and Uttar Pradesh (Devi & Singh, 2018; Dilshad *et al.*, 2020). Further, low emission of smoke was observed with smokeless *chulha* compared to traditional *chulha*. The above observation directly contributes to people's health in homes with smokeless *chulha*. Smoke from the fire wood contains large amount of CO_2, CO, carcinogenic elements, particulate matters, etc and cause various health hazards such as eye irritation, allergy, respiration issues, headache, etc. With smokeless *chulha*, a person's smoke exposure time reduces significantly compared to traditional *chulha*. Hence smokeless *chulha* directly contributes towards the health of people.

Gas analyses

Table 1 indicates the amount of carbon dioxide and carbon monoxide released by the smokeless *chulha* and traditional *chulha* while cooking. It was observed that, on an average up to 1654 ppm of carbon dioxide was released by the traditional *chulha*, whereas on the other hand, smokeless *chulha* released only 514 ppm of carbon dioxide while cooking.

It was detected that smokeless *chulha* reduced the carbon dioxide production by 68% compared to the traditional *chulha* used by the villagers. Similar, reduction patterns were observed with the Carbon monoxide gas. Smokeless *chulha* utilization drastically reduced the amount of carbon monoxide gas by 98% (Table 1). Both carbon monoxide (CO) and carbon dioxide (CO_2) have harmful effects on human health and the environ-

ment. Carbon monoxide is a toxic gas that, when inhaled, binds to haemoglobin in the blood, reducing its oxygen-carrying capacity and potentially leading to tissue damage and even death. It can cause symptoms such as headaches, dizziness, and nausea, and prolonged exposure can result in neurological damage (Manisalidis *et al.*, 2020). On the other hand, carbon dioxide contributes to climate change and global warming. Increased CO_2 levels in the atmosphere lead to rising temperatures, altered weather patterns, and adverse effects on ecosystems (Scott *et al.*, 2019). Further, the amount of total volatile organic compounds during the firewood burning reduces to 0.78 mg/m^3 in smokeless *chulha* from 6.79 mg/m^3 (traditional *chulha*) (Table 1). It was examined that smokeless *chulha* reduces the total volatile organic compound by 88.5% compared to traditional *chulha*. TVOCs can have negative effects on human health and the environment. Prolonged exposure to high levels of TVOCs can cause irritation of the eyes, nose, and throat, as well as respiratory problems, headaches, and fatigue. Some TVOCs are known to be carcinogenic or can contribute to the formation of ground-level ozone, leading to air pollution and respiratory issues (Oh *et al.*, 2020). Additionally, TVOCs contribute to smog formation and can harmcosystems and vegetation (Wu *et al.*, 2023). In addition, the percentage of formaldehyde was also significantly reduced with smokeless *chulha*. It was observed that traditional *chulha* was emitting an average of up to 0.88 mg/m3 of formaldehyde, whereas with smokeless *chulha* its concentration reduces to 0.22 mg/m^3 (Table 1). Inhalation of formaldehyde smoke can irritate the eyes, nose, and throat, causing symptoms such as coughing, wheezing, and difficulty breathing. Prolonged exposure to formaldehyde smoke has been linked to an increased risk of respiratory problems, including asthma, bronchitis, and even lung cancer (Lee *et al.*, 2021; Naddafi *et al.*, 2019).

Particulate Matter

It was investigated that smokeless *chulha* produced significantly lesser particulate matter (PM 2.5 and PM 10) than traditional *chulha* used by the villagers. Up to 75% reduction was observed with smokeless *chulha* compared to the traditional *chulha* (Table 1). Multiple ill effects are associated with PM 2.5. Due to their small size, PM2.5 particles can penetrate deep into the respiratory system and enter the bloodstream. Prolonged exposure to PM2.5 has been linked to a range of health problems, including respiratory issues such as asthma, bronchitis, and reduced lung function (Manojkumar and Srimuruganandam, 2021). It can also exacerbate cardiovascular diseases, leading to heart attacks, strokes, and increased mortality rates. Additionally, PM2.5 particles may contain toxic substances and chemicals, posing a risk of long-term health complications, particularly for vulnerable populations such as children, older people, and individuals with pre-existing respiratory or cardiovascular conditions (Southerland *et al.*, 2022) .

Further, the concentration of PM10 reduced significantly to 228.2 µg/m^3 from 1744.6 µg/m^3 when smokeless *chulha* was used for cooking. Up to 87% reduction of PM10 was observed with smokeless *chulha* as compared to the traditional *chulha* (Table 1). Particulate Matter 10 (PM10) refers to airborne particles with a diameter of 10 micrometres or smaller. These particles can have negative effects on human health and the environment. Inhalation of PM10 can irritate the respiratory system, leading to coughing, wheezing, and shortness of breath. Prolonged exposure to PM10 has been associated with an increased risk of respiratory diseases such as asthma, bronchitis, and decreased lung function (Xu *et al.*, 2022). Additionally, PM10 can carry toxic substances, heavy metals, and organic compounds, which can pose a risk to human health when inhaled. PM10 also contributes to air pollution, reduces visibility, and can harm ecosystems, including soil and water contamination (Gao *et al.*, 2020).

Socio-economic and environmental impact of smokeless *chulha*

Smokeless *chulha*s are designed to be more fuel-efficient compared to traditional cooking methods. They burn fuel more efficiently and generate more heat, which means less fuel is required to cook meals. This reduction in fuel consumption can lead to significant cost savings over time, especially in areas where fuel costs represent a substantial portion of household expenses. With traditional *chulha*, on an average, a family spends approximately up to Rs. 15000/annually (183$/ Year) on firewood (including collection and transportation). In addition, a single-family utilises up to 21 trees annually for traditional *chulha*. It was concluded that smokeless *chulha* saves up to around 68% of fire wood, which would save around 14.28 trees/family on average. Hence 68% reduction in firewood consumption means an annual savings of almost Rs 10200/family (123$). Also, considering an average tree density of 600 trees per hectare, 500 smokeless stoves would save 7140 trees from felling and 11.9 hectares of forest from being cleared. Trees play a crucial role in carbon sequestration by absorbing and storing carbon dioxide from the atmosphere. Preserving trees through smokeless *chulha* helps maintain this important ecosystem service, contributing to climate change mitigation efforts (Das *et al.*, 2022; Patil *et al.*, 2021). By reducing deforestation and associated emissions, smokeless *chulha*s indirectly help mitigate the impacts of climate change.

Further, traditional cooking methods often require significant time and effort in fuel collection, preparation, and cooking (Khandelwal *et al.*, 2022; Das *et al.* 2022). With smokeless *chulha*s, the cooking process becomes

Table 1. Reduction of various pollutant in Smokeless *Chulha* as compared to traditional *Chulha* ($p < 0.05$)

Parameters Types of *Chulha*	Fuel Consumption (Kg)	Cooking Time (min)	Carbon Dioxide (ppm)	Carbon Monoxide (ppm)	TVOC (mg/ m^3)	HCHO (mg/ m^3)	PM 2.5 (µg/m^3)	PM 10 (µg/m^3)
Smokeless *Chulha*	1.0 kg± 0.12	22 ± 0.15	514.2 ± 2.3	14.4 ± 0.7	0.78 ± 0.1	0.22 ± 0.1	250.8 ± 1.3	228.26 ± 2.1
Traditional *Chulha*	3.2 kg± 0.25	40 ± 0.45	1654.2 ± 3.4	756.8 ± 5.6	6.79 ± 0.2	0.88 ± 0.2	1000.0 ± 5.7	1744.66 ± 4.3
Reduction % in comparison to Traditional *Chulha*	68.7%	45%	68.9%	98.0%	88.5%	75%	75%	87%

more efficient, requiring less time and effort. This can free up time for household members, particularly women and children, to engage in income-generating activities or pursue education and skills development, potentially leading to increased earning opportunities in the long run. Moreover, traditional cooking methods often produce harmful smoke emissions, leading to respiratory illnesses and other health issues. By using smokeless *chulha*s and minimizing indoor air pollution (Table 1), households can reduce their healthcare expenses. Fewer medical expenses mean more disposable income that can be allocated to other essential needs or saved for future investments.

The present smokeless *chulhas* showed significant reduction in cooking time and fuel consumption compared to other smokeless chulhas, for example Udairaj used by the villager of Manipur (Devi and Singh, 2018). Available literature indicates that studies pertaining to particulate matter and volatile organic compounds are lacking in smokeless chulhas installed at other places to replace traditional chulhas. The present study clearly indicates that the usage of smokeless chulhas can reduce particulate matter and volatile organic compounds drastically.

Conclusion

In conclusion, smokeless *chulha* (Swastik Shegdi) had significant advantages over traditional *chulha* regarding health, environmental, and socioeconomic factors. Smokeless *chulha* showed a reduction in the emission of harmful pollutants such as particulate matter (75-87%), carbon monoxide(98%), and volatile organic compounds (88.5%). As a result, they contributed to improved indoor air quality, reducing the risk of respiratory diseases and other health issues associated with indoor air pollution. Further, smokeless *chulha* was more fuel-efficient, reducing the amount of biomass fuel by 68.7% needed for cooking. This may lead to a decrease in deforestation and pressure on natural resources. Moreover, using smokeless *chulha* can also save households time and cost, as less time and money are required for fuel collection or purchase. Adopting smokeless *chulha* represents a sustainable and healthier cooking solution, addressing both the health and environmental challenges associated with traditional *chulha*.

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Conflict of interest

The authors declare that they have no conflict of interest.

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