Chapter–2

Literature Review

Chapter 2

Literature review

2.1 Introduction

Biomass cook stove and its design is one of the most versatile topics of research and development, including recent works on improving combustion efficiency and performance through better design, waste heat recovery and use of computational methods. The present chapter therefore discusses the aspects on socio-economic impacts of improved cook stove implementation, impact of design improvements on performance, use of simulation and modeling in cook stove, and waste heat utilization in biomass cook stove.

2.2 Socio-economic factors influencing improved biomass cook stove design and implementation

Biomass cook stoves are one of the most commonly used cooking technology all over the world. Implementation and use of an improved version of biomass cook stoves has impacts on socio-economic factors of poverty, education, health and gender equality. These factors have also been targeted to be addressed as Sustainable Development Goals (SDG) by United Nations which involves 17 SDG in various sectors [1]. Thus biomass cook stoves have the potential to address the issues listed in SDGs 1, 3, 5, 7 and 13 i.e. poverty, good health and well-being, gender equality, affordable and clean energy, and climate action.

The use of traditional cook stove has brought upon many negative impacts in the life of its users. They are highly inefficient and create a lot of indoor air pollution. Dependency on these stoves has affected the livelihood of poor people especially rural livelihood that lacks clean cooking option. In India the effects are more adverse on women folks who spends almost one third of their working hour near these traditional stoves or its associated works. Inefficiency of these stoves has always engaged valuable working time of both women and girls who are engaged both in cooking and fuel collection, thus creating gender inequality. The necessary time for education by girls and time for income generating activities by women are both reduced, which also reduces the income potential of rural households. In addition the pollution created by traditional stoves is also responsible for various respiratory diseases in women as well as premature deaths. Illness due to such emissions involves medical expenses which add to the expenses of poor people. Thus reduction of income by the women as well as involvement of medical expenses increases the poverty of its users. Its use also affects the forest cover of an area due to high consumption rate and increases deforestation. The solution is the use and availability of clean cooking options. These devices include LPG stoves, natural gas stoves and improved cook stoves. However such devices involves higher cost of device and high operating cost except improved cook stoves, as biomass in rural areas is almost free. Thus improved cook stoves proves to be a viable clean cooking alternative which can address the issues of health improvement, poverty reduction, reduced deforestation and gender equality.

Although improved biomass cook stoves proves to be a viable option, however issues related to their adoption and implementation still remains. Literatures suggest the improved cook stoves should be designed in a way to meet local cooking habits and fuel availability which varies with geographical location as in Table 2.1 for better adoption. Some literatures showed the initial influence by government authorities has resulted in mass implementation. Keeping these in view, efforts have been made to check and analyze the effects of implementing region based improved cook stoves around the world and listed in Table 2.1.

Table 2.1: Review of literatures on effects of improved cooking stoves on socio-economic upliftment and factors affecting stove design

Literature	**Works**	**Ref.**	**Year**
Lung et al.	• Wood consumption data in Kenya • Area: 3000 km^2, Period: 7 years • Traditional 3 stone fire consumption: 9.95 kg/day per household • Upesi improved cook stove: 3.87 kg/day per household • 37.7% fuel wood savings • Predictors: Household size, Meals cooked, Distance from forest • Non-predictors: Season, stove age, stove condition and type of meal	[2]	2019
Karanja et al.	• Reviews about context, status, adoption and impacts of improved stoves in Kenya • Factors affecting adoption: market structure, consumer awareness, stove design/performance, socioeconomic status and cultural practices • Suggested six policies: enhance stakeholder collaboration, raise awareness, facilitate funding, quality	[3]	2019

Literature	Works	Ref.	Year
	assurance, behavioral change and enhance research as well as capacity		
Atanga et al.	• Performance comparison and field performance tests of four fan-assisted gasifier cook stoves and one natural draft cook stove • Fan-assisted stove: Rua (RRHS), Viet (VRHS), Paul Olivier 150 (PO150) and Paul Olivier 250 (PO250); Advantages: Safer to use, Low emissions of flue gas and particulate matter, Efficient • Natural draft stove: Mayon (MYN) • Rice husk mixed with palm kernel shell burned for longer time, no effect on flame temperature	[4]	2019
Jagger et al.	• Discussed the outcome of providing fan assisted micro-gasification on lease and supplying pellet based fuel on contract. • 30% adoption, adoption is likely if household head is married and cooks are female • Adopted households has reduced systolic blood pressure, breadth shortness, cooking time and fuel expenditures on using charcoal	[5]	2019
Lucas et al.	• Assess child mortality rate depending on achievement of Sustainable Development Goals • Develops a IMAGE 3.0 Integrated Assessment Model • Child mortality rate can be reduced by more than 25% by implementing policies on food, water and energy	[6]	2019
Gioda	• Study evaluates socioeconomic as well as environmental factors to assess the use of firewood in Brazil • 11 million households currently use firewood • Increase in LPG price, low income and unemployment leads to more fire wood use	[7]	2019
Kong'ani et al.	• Reveals low adoption rate of improved cook stoves (ICS) • 93% households receive ICS from government, amongst it 50% continue using it and out of it 14% adopted it • Factors limiting adoption: efficiency, suitability, socio-cultural practices, economic capacity, limited capacity to appreciate and government initiatives • Need: Policy and strategies to improve design and implementation	[8]	2019
Sharma et al.	• Investigates effect of Indoor air pollution with change in ICS and kitchen type in rural India • Results shown enclosed kitchen is the worst and ICS use reduced emissions of PM_{10}, $PM_{2.5}$, PM_1 and CO by 21-62%, 20-80% and 19-93%	[9]	2019
Kedir et al.	• Compares "Mirt" (cement stove) and "Gonzie" stove (mud stove) used in Ethiopia • Problems with "Mirt": High cost, lacks training and inappropriate plate size • "Gonzie" : 33.9-54.2% reduction in firewood consumption as compared to open fire, emissions similar to "Mirt" • Improved stove saves wood and reduces fire damage	[10]	2019
Ravindra et al.	• Study conducted in Punjab, India • 77.5% rural population relies on solid biomass • Factors for adoption of improved cook stove: household income and education • High cost and limited supply restricts LPG use	[11]	2019

Literature	Works	Ref.	Year
Gould et al.	• Studies the effects of post-acquisition service for improved cook stoves in Peru • Services: Maintenance training, parts replacement and repairing services • High improved cook stove usage in region • High demand for post-acquisition services • Kitchen performance tests shows no difference in stoves with and without damages	[12]	2018
Gizachew et al.	• Study conducted in Bale Eco-region, Southeastern Ethiopia • Use of descriptive statistics and binary logistic regression • Factors for higher adoption: Higher education level of household head, larger family size and presence of separate kitchen • Traditional stove: 1.12 kg firewood per day for each Standard Adult Equivalent (SAE) • Improved cook stove: 0.79 kg firewood per day for each SAE	[13]	2018
Mamuye et al.	• Accessed the performance and adoption of improved Merchaye and Lakech charcoal stoves • About 43.7% adopted Merchaye stove and 31.3% adopted Lakech stoves • Factors influencing adoption: Household head age, sex, education level and income • Results: lowering climate change, forest degradation and household work load	[14]	2017
Peša	• Study area: Zambia and initiatives to implement micro gasification cook stoves and sawdust pellets • Charcoal and charcoal based stoves dominates the market due to competitive price • Suggests the use of efficient market chain for higher adoption rate of micro gasification cook stoves and sawdust pellets	[15]	2017
Khandelwal et al.	• Studies the reasons for failure of Improved Cook Initiatives in India • Uses applied science and social science to understand reasons of failure • As remarked Indian Chulha is a successful technology and satisfies household needs • For rural women to prioritize: high investment and adoption by powerful institution • Failure as improved cook stoves programs are cheaper, decentralized, mechanical and apolitical	[16]	2017
Bansal et al.	• Reviews developments in rural cooking sector • Income is the main determining factor for selection of fuel • Need: research to develop low cost improved model • Suggestive design modifications: Enclosed combustion chamber and enhanced contact between hot gas and pot	[17]	2013
Okello et al.	• A review on efforts by various organizations in promoting improved technologies on biomass utilization in Uganda • Estimated 72.7% population use traditional cook stoves having efficiency less than 10% • Modern biomass utilization techniques: introduced but not largely implemented	[18]	2013

Literature	Works	Ref.	Year
	• Policies to implement efficient technologies and ensure sustainable biomass supply.		
Vaccari et al.	• Studies the effect of implementing ICS in Logone Valley • Data in relation with local cooking habits estimated reduction of 25% fuel expenditure per family for cooking • Implementation of ICS helps in assessing a sustainable minimum level of energy for poor people	[19]	2012
Pine et al.	• Studied the effect of disseminating improved Patsari stoves in rural communities of Mexico • A total of 259 stoves were disseminated which reduced to 55% of usage after 8 months of operation • A bi-level model to evaluate improved stove dissemination is developed using multinomial logistic regression • Suggests the evaluation of improved stove programs in terms of stove's use with time, rather than number of stoves disseminated	[20]	2011
Venkataraman et al.	• Discussed the effects of National Biomass Cookstoves Initiatives in India • Successful implementation targets reduction in premature deaths as well lowering greenhouse emissions • Also recognizes technology development and implementation challenges	[21]	2010
Kanagawa et al.	• Focuses on impacts of change in stoves on socio-economic condition • Provided an energy-economic model for rural India to link energy, income and health impacts using opportunity cost and exposure to suspended particulate matter. Shows positive relation	[22]	2007

2.3 Impact of design improvements on performance of biomass cook stove

The biomass cook stoves unlike any other thermal conversion device are also being continuously improved in its design to enhance either its performance (efficiency, power output and time to boil), any other related heat utilizing functions or waste heat utilization. These improvements may result in either change in its shape, size, performance, additional accessories or a new improved cook stove. Thus improvements play a vital role in acceptance and achievements of improved cook stoves to eradicate negative socio-economic factors as listed in Section 2.1. In this regard various works have been carried out in improving the designs of biomass cook stoves and are listed in Table 2.2.

Table 2.2: Review of literatures on impact of design improvements on performance of biomass cook stove

Literature	Works	Ref.	Year
Paulsen et al.	• A monolith with potassium titanate as catalyst reduced carbon monoxide and particulate matter emissions by 82% and 70% respectively. • Potassium titanate also reduced carbon monoxide temperature to as low as 500°C or 300°C when doped with copper or cobalt	[23]	2019
Li et al.	• Investigated the benefits in emission reduction during household cooking by switching to carbonized solid fuels • The carcinogenic potentiality of polycyclic aromatic hydrocarbons were reduced by 95±3% • Average ratio of volatile organic compounds contained in $PM_{2.5}$ was reduced to 7.1±3.9%	[24]	2019
Chica et al.	• An improved biomass cook stove is developed with efficiency, time to boil, specific fuel consumption and specific energy consumption rate of 20.9%, 31.6 min, 122.57 g/L and 64.54 kJ/L-min • Combustion chamber is rocket type with skirts and made of steel sheet metal which makes it light and portable	[25]	2019
Sakthivadivel	• Studies the effect of different biomass as fuel on combustion process • Flame propagation rate of 0.063, 0.071 and 0.05 mm/s as well as fuel bed temperature of 700°C, 700°C and 825°C for coconut shells, *Prosopis juliflora* and tamarind seed • Particulate matter increases with decrease in fuel size • Densification increases energy density • Increase in fuel size increases specific fuel consumption	[26]	2018
Rasoulkhani et al.	• A top lit updraft stove is modified to combust apple pruning waste in a gasification mode. • Time to boil was 13 minutes with efficiency of 35%.	[27]	2018
Gandigude et al.	• Discussed five stove geometry design principles • Use light weight insulation around fire • Use insulated short chimney above stove • A fast draft is essential through primary and secondary air inlet • Use of grate • Heat transfer to pot is increased by properly sizing the gaps	[28]	2018
Tryner et al.	• Change in particle size distribution of emissions with changes in operation is examined • Gasifier cook stoves emits smaller particles than other conventional stoves • Top lit updraft gasifier shows peaks at 10 nm and 40 nm when pot is placed above stove and peak at only 10 nm when pot is removed • The concentration increased to 80 nm when secondary flame extinguished • Refueling decreases to 10 nm and increased to 100 nm once flame extinguishes	[29]	2017
O'Shaughnessy et al.	• Developed a domestic electricity generator clad clay stove for domestic electricity generation • Field tests in Malawi showed maximum power consumption of 4.5 Wh of energy per day from stove • Found that the stoves were not operated daily	[30]	2017

Literature	Works	Ref.	Year
Febriansyah et al.	• Designing a biomass stove using palm kernel as fuel • Best fuel efficiency and combustion temperature of 66.63% and 682.59°C : Combustion chamber diameter of 20cm and height of 25 cm with burner opening at 75%	[31]	2015
Sutar et al.	• Reviewed design features, parameters and test protocols • Combination of forced draft and gasification mode lowers emissions, however capital and running cost is high. It requires smaller size fuel and creates problem of adoption • Complexity in cook stove process is difficult to be replicated by simulation and modeling especially for emissions • Other design features: gasifier stoves has cleaner combustion and higher efficiency, metal as constructional material, grate improves combustion quality as well as rate, near stoichiometric air supply improves combustion as well as heat transfer, chimney helps in creating draft and remove emissions, damper regulates air and can regulate burn rate, baffles improves heat transfer for multiport cook stoves and thermoelectric generators can utilize waste heat.	[32]	2015
Raman et al.	• The study evaluates the performance of three commercially available stoves using Water Boiling Test with change in fuel quality • TERI's stove has a higher burning rate irrespective of fuel • The efficiency of stoves decreased with increase in calorific value (CV) of fuels • Firepower increases with increase in fuel CV • Forced draft increase heat transfer rate, combustion efficiency and cleaner operation • Fuel processing as a constraint in adoption	[33]	2013
Kumar et al.	• Reviewed the technical aspect of improved cook stove and their development • Covered: design aspect, test protocols and health issues • Design improvements like use of grate, insulation, pot skirt, forced air flow, durable materials of constructions and dampers improves performance. Gasifier stoves provide clean combustion as well as higher efficiency. Batch feeding improves overall efficiency	[34]	2013
L'Orange et al.	• Studied the effects of variation in stove design and stove as well as pot temperature on emissions • Lower stove wall temperature has lower effects on emissions • Emissions from gasifier varied widely and has greater PM_{10} emissions • A hot pot results smaller particle size and lower PM_{10} emissions whereas cold pot resulted similar PM_{10} emissions however particle size was larger	[35]	2012
Castaner et al.	• Designed a three-chamber improved cook stove • It is made of steel and uses sand as insulator • It has provisions to ventilate the exhaust • Efficiency: 33%, Time to boil 5 liters: 19-20min, Price:$65, Operating cost: $15 per month, Fuel: Charcoal	[36]	2011

MacCarty et al.	• Studied 50 different cook stoves for their performance parameters
	• Design suggestions includes:
	  o Well-designed combustion chamber reduces fuel use
	  o Rocket type stoves reduces fuel use, CO and PM emissions by 33%, 75% and 46% respectively
	  o Pot skirt reduces both fuel use and emissions
		[37]	2010

Literature	Works	Ref.	Year
	o Gasifier stoves reduces PM emissions o Forced draft reduces fuel use and emissions by 40% and 90% respectively o Charcoal stoves uses similar energy to open fire o Use of liquid fuels lowers fuel use and emissions o Chimneys help in removing flue gas		
Kshirsagar	• Describes design steps of charcoal stove • Parameters such as air supplied, flue gas retention time, insulation and pot skirt gap improves efficiency	[38]	2009
Jetter et al.	• 14 nos. of stoves are tested for efficiency and emissions with recommendations for designing cook stoves • Stoves with a lower mass uses less time to boil, high fuel efficiency and low emissions • Ceramic materials are low cost and have high life however heat is diverted once it gets heated • Improving heat transfer efficiency reduces boiling time and burn rate whereas improving combustion efficiency reduces emissions • Use of pot skirts, optimizing gaps between stove and pot and stove height improves efficiency • Better fuel feed rate and control of fuel moisture as well as air flow through grate improves combustion efficiency	[39]	2009
Bhattacharya et al.	• Three biomass fired stoves were tested for change in moisture, fuel size, pot size and ignition method • Increase in moisture decreases stove efficiency and increases emissions of CO • Fuel size and pot size didn't affect efficiency • Emissions were low for top ignition method	[40]	2002

2.4 Use of simulation and modeling techniques in improving biomass cook stove designs

The effect of the above mentioned design improvements are either related to changes in an existing stove or development of a new prototype. Conventionally the effects of these design changes as a modification or new prototype are tested using an established lab or field based test. In case results are not satisfactory, the process of redesigning and re-development is repeated unless successful. The process of designing was therefore difficult and involved both a lot of time and money. In order to simplify the process, modern techniques of designing involves simulation and modeling techniques with the help of advanced tools like Computational Fluid Dynamics, Neural Network, ANSYS, MATLAB and other higher end software. The use of simulation tools have resulted in both analyzing and improving the designs of improved cook stoves, thus saving both time and money. However use of such tools requires pre-requisite knowledge along with higher capital investments and therefore limits their availability for application. In contrast steady state modeling techniques doesn't involve any license fee as well as costly system which could be developed and used by anyone with basic knowledge level. Degree of accuracy could be varied based on precision requirement. Thus numerous works have been reported on development of various simulation and modeling techniques as well as use of modern tools in improving as well as designing biomass cook stoves and are listed in Table 2.3. However gaps remained in availability of a dedicated simulation and modeling tool for biomass cook stove which could both access the heat transfer phenomena and evaluate the performance parameters of efficiency, time to boil and power output without the need of prototype development, especially of biomass cook stoves.

Table 2.3: Review of literatures on use of simulation and modeling techniques in improving biomass cook stove designs

Literature	Works	Ref.	Year
Majumdar et al.	• Studies were conducted to test CO exposure in food vending shanties of Kolkata using charcoal stoves • Portable electrochemical CO monitors for CO concentration measurement • Blood carboxyhaemoglobin and exhaled CO were both determined using regression models • Experiments shows exposure levels crosses USEPA's limot of 9 ppm	[41]	2019
Sakthivadivel et al.	• Optimizes secondary combustion air inlet to combustion chamber • Injection angle of 45° improves gasification • WBT is used for testing which shows the stove operates at 36.7%, 37% and 38% efficiency • The flame propagation rate, burn rate and PM emissions are experimentally obtained	[42]	2019
Nadimi et al.	• Use of time use analysis and simulation model to determine the basic energy requirement by a household • Simulation model has determined that in a family of 2 members 18.3%(11.6 MJ), 39.2% (24.8 MJ), 23.6% (37.2 MJ) and 5.2% (3.3 MJ) energy is required for cooling, cooking, heating and lighting respectively	[43]	2019
Patel et al.	• Developed a simplified steady-state model to simulate combustion in a top-lit updraft cook stove • Incorporates effects of operating parameters, air fluxes and fuel composition. • Sensitivity analysis shows drastic variation with variation in cook stove parameters	[44]	2018
Gandigude et al.	• Study uses CFD analysis to simulate and determine better stove height of rocket stove • Simulation results height of 34 cm as best for the given configuration of rocket stove as heat transfer is highest at the pot end	[45]	2018
Dorvlo et al.	• Study evaluates the effect of two different configurations on stove's performance • CFS analysis is used to determine the heat transfer and air flow through the cook stove with the changes in chimneys	[46]	2018

Literature	Works	Ref.	Year
Pande et al.	• Develops a computational method for cook stoves • Studies the effect of inlet area ratio on performance • Use of both experimentation as well as CFD • The firepower and flame temperature increases up to inlet area ratio of 0.7	[47]	2018
Lombardi et al.	• Developed a Cooking Stoves Thermal Performance Simulator (Cook-STePS) based on 1D heat and mass transfer model • Performed laboratory tests	[48]	2017
Masud et al.	• Studied the improved cook stoves (ICS) available in Bangladesh for heat loss and efficiency determination • Heat loss is determined using ANSYS simulation • Most of the ICS have an efficiency of 30% • It also includes feasibility study of stoves regarding their cost, emissions and effectiveness	[49]	2017
Sowgath et al.	• CFD analysis is done for a mud stove • Analyzes gas flow behavior and heat transfer during cooking	[50]	2015
Agenbroad et al.	• A model was developed for natural draft biomass stove • Predicts flow parameters inside combustion chamber as well as mass flow rate, temperature and excess air ratio • Increased loss coefficient makes model more accurate and applicable	[51]	2011
Shah et al.	• A 4-zone thermochemical model is developed • Developed by considering steady state chemical reaction kinetics of char and volatile burning • Predicts performance parameters of thermal efficiency, combustion products and excess air • Effects of geometry, fuel characteristics, pot and ambient are also investigated	[52]	2011
Kausley et al.	• Developed steady and unsteady state combustion models for Harsha stove • Steady state involves flame temperature, suction and ignition front propagation modeling • Unsteady state involves moisture evaporation, devolatilization, pyrolysis, homogeneous and heterogeneous combustion reactions.	[53]	2010

2.5 Waste heat utilization in biomass cook stove for multifunctional activities

The use of modeling and simulation techniques has paved a new way of designing approach in the field of biomass cook stove. Apart from the determination of performance the use of these techniques has also helped in identifying the heat loss components in cook stoves. Researchers have therefore taken interest in utilizing the waste heat generated in cook stoves to improve cook stove's multi-functionality as well as performance as listed in Table 2.4. However technological gap could be observed as lack of an efficient waste heat utilizing cook stove with improved performance as well as which could perform simultaneous operations of multiple pot cooking and multi-functional activities.

Table 2.4: Review of literatures on waste heat utilization in biomass cook stove for multifunctional activities

Literature	Works	Ref.	Year
Obernberger et al.	• A micro combined heat and power based pellet stove is developed with thermal capacity of 10.5 kW • Waste heat is converted to useful electricity by a 50 W thermoelectric generation unit and electricity generated is used for own use and storage	[54]	2018
Rahbar et al.	• Study is done on a biomass stove used for space heating with Organic Rankine Cycle (ORC) • Used material is silicon-carbide however heat is lost when the temperature is between 240°C and 270°C through flue gas • ORC is used for trapping the waste heat and converting to electricity • Analysis using CFD is performed and tests shows 80% operating efficiency of the satisfied stove	[55]	2017
Najjar et al.	• Studied a biomass stove unit integrated with Thermoelectric Generator Unit (TEG) i.e. JUST multipurpose stove • JUST applications: Thermo electricity generation, space heating, cooking and water heating • Overall efficiency as high as 60% • Initial cost is high but could be reduced through mass production and useful for electricity depriving regions	[56]	2017
CN206410171U	• It is natural draft stove which uses the heat from firewood for cooking as well as heating water. • It is provided with a hood to extract the emissions out of the cooking area. • The stove is of fixed type. • It utilizes the unused heat to heat water using a heat exchanger which can be further used for drinking as well as washing clothes. • The thermal mass of the stove is high.	[57]	2017
CN206419985U	• The stove is natural draft stove which uses firewood as fuel. • Both cooking as well as heating of water could be done at the same time. • The stove is portable. • The stove is metallic. • Cooking is possible for a single pot at a time.	[58]	2017
CN206377694U	• The stove is a forced draft water heating stove. • It is useful for colder regions where there is a continuous need for hot water. • It solves the issue of regularly attending the stove by providing a fuel tank, auger feeder and an arrangement to feed the fuel continuously to the combustion chamber at regular intervals. • The heat from the combustion chamber and the flue gas passes through heat exchanger tubes which heats the water in the tank. The heat exchanger tubes requires	[59]	2017

Literature	Works	Ref.	Year
	frequent maintenance in order to maintain its high heat transfer capability. Therefore a blade controllable from outside is provided which cleans the heat exchanger outer cover to remove the impurities.		
CN206377698U	• Stove provided with a top plate where cooking could be done using hot water. • Uses an arrangement of fire tubes forming a parallel heat exchanger which utilizes the heat of flue gas to heat water. • An induced draft fan is used to enhance the process.	[60]	2017
Wang et al.	• In this study a Chinese traditional cook stove has been redesigned and transformed by turning it into a multifunctional biomass stove with a heat collector • Thermal efficiency was tested to be 30.79% higher than traditional biomass cook stove and reduction in energy consumption	[61]	2015
3568/MUM/2014	• A forced draft portable single pot stove consisting of an inner combustion chamber and an outer chamber. • Forced air is supplied through primary holes and secondary air holes. • The stove can attend the needs of drying, baking and cooking.	[62]	2014
5175/CHE/2014	• It is a Hybrid Ejector Reverse Downdraft biomass stove using continuous feed and low fan power. • An arrangement has been made so that continuous feed is supplied on a perforated sheet. • The perforated sheet extends to a third of the combustion chamber. • The sheet contains a char well at its lower end and an ash tray below the perforated sheet. • Forced air enters through the ejector jets placed at 10 to 30 degrees across the combustion chamber to reduce the combustion chamber size. • The system ensures a continuous operation and better char conversion.	[63]	2014
552/CHE/2013	• The present invention is a natural draft cooking stove capable of both, cooking and heating water. • It comprises of an inner and outer chamber which are made of thermally sealed material with top and bottom panel. The combustion chamber is surrounded by water. Heat is transferred to the combustion body during combustion and a part of which is transferred to the water surrounding it. • The stove has a hole at the top to accommodate the cooking pot. • The fuel is being fed through the fire hole. • As the fuel combusts the products of combustion touches the pot and moves to secondary pot or to the flue gas outlet. The flue gas outlet is surrounded by a cold water tank having a safety cum water level indicator. As the flue gas goes through the flue gas outlet it transfers heat to the cold water. Thus cold water receives heat both from the combustion chamber and the flue gas outlet. The outlet hot water is collected from the hot water outlet tap at the front i.e. near the fire hole.	[64]	2013
5556/CHE/2012	• The present stove is a natural draft wood burning stove for community use.	[65]	2012

Literature	Works	Ref.	Year
	• The stove is portable and is made of bricks, cement, coarse aggregate, fireclay, cast iron cylinder and GI sheets. • It consists of two chambers i.e. primary and secondary chambers. The top of the primary chamber has a hole above which the secondary chamber is located. The secondary chamber contains a grill and a provision to accommodate the chimney. • The fuel is fed through the front door which is rectangular in shape. • Primary air and secondary air enters through the top and bottom of the grate respectively. • The cooking pot is placed in such a way that it is half inside the secondary chamber. • The products of combustion escape the secondary combustion chamber through the chimney. • The secondary chamber collects the combustible gases and acts as a pot skirt.		
1763/CHE/2008	• The present stove is a forced draft biomass stove and uses biomass pellets as fuel. • The stove comprises of a rectangular cross-sectional combustion chamber made of ceramic blocks which can withstand very high temperature and corrosive environment. The ceramic chamber is surrounded by a metallic chamber. • The incoming combustion air from the fan is divided into primary and secondary air. Primary air flows underneath the grate to the combustion chamber through the primary air duct and valve. Whereas the secondary air flows through the secondary air duct and valve to the annular chamber located at the top of the combustion chamber. The annular chamber consists of secondary air holes through which the secondary air participates in combustion of the combustible gases. The flow rate of secondary air is greater than primary air during the operation period ensuring complete combustion of the products produced. • The system ensures a lower outer chamber temperature.	[66]	2008
US5944090	• A parallel flow heat exchange system for heat transfer from flue gas to combustion air	[67]	1999
1114/DEL/1998	• A natural draft multipurpose stove which can perform cooking, baking, space heating and drying at the same instance. • Uses an attachment along with the combustion chamber to perform additional duties.	[68]	1998
US4738241	• A jacketed space around the combustion chamber where air is pre-heated with natural draft • Flame comes in direct contact with cold air which reduces the heat retention of the combustion chamber and thus the efficiency of the system varies according to the temperature of the ambient air.	[69]	1988
US4416325	• Heat exchanger arrangement using two heat exchangers in conjunction- a high temperature one having heat exchange tubes and a low temperature one having heat pipes. • The arrangement transfers the heat from the flue gas to incoming combustion air to pre-heat.	[70]	1983

Literature	Works	Ref.	Year
	• This exchange mechanism is useful when the mass flow rate of flue gas is higher which makes it suitable only for industrial application.		
US4319556	• Stove with two stage combustion chamber where the air for the secondary combustion of flue gas is heated by auxiliary means and the primary air is not pre-heated.	[71]	1982

2.6 Summary

The review of the literatures has unveiled the necessity of simulation and modeling techniques in improving cook stove designs for better performance and multifunctional activities. The improved cook stove models thus developed will also be capable of addressing various socio-economic factors and help in solving the issues related to poverty, good health and well-being, gender equality, affordable and clean energy, and climate action. This will help in better acceptability and implementation of improved biomass cook stove. However gaps in technology were found in the fields of simulation and modeling of biomass cook stoves as well as utilization of waste heat generated during biomass cook stove operation. Review states that there is a lack in a dedicated modeling technique especially for biomass cook stove which could identify the various heat transfer components as well as determine the various performance parameters such as efficiency, time to boil and power output. Moreover there remains gap in technology for efficient utilization of waste heat released by biomass cook stoves for both multiple pot cooking and multipurpose activities. On identification of the gaps in technology the research is further continued to address these gaps through development of a simulation model, an improved cook stove design and a prototype as well as their validation and testing in subsequent chapters.

REFERENCES

[1] *Envision2030: 17 goals to transform the world for persons with disabilities, United Nations – Disability, Department of Economic and Social Affairs.* Retrieved on 15 Jun. 2019 from https://www.un.org/development/desa/disabilities/envision2030.html, 2019.

[2] Lung, M. A., and Espira, A. A large-scale, village-level test of wood consumption patterns in a modified traditional cook stove in Kenya. *Energy for Sustainable Development*, 49: 11-20, 2019.

[3] Karanja, A., and Gasparatos, A. Adoption and impacts of clean bioenergy cookstoves in Kenya. *Renewable and Sustainable Energy Reviews*, 102: 285-306, 2019.

[4] Atanga, N. S., Marco, W., Sidi, S., and Koichi, F. Evaluation of fan-assisted rice husk fuelled gasifier cookstoves for application in sub-Sahara Africa. *Renewable Energy*, 2019.

[5] Jagger, P., Das, I., Handa, S., Nylander-French, L. A., and Yeatts, K. B. Early adoption of an improved household energy system in urban Rwanda. *EcoHealth*, 1-14, 2019.

[6] Lucas, P. L., Hilderink, H. B., Janssen, P. H., Samir, K. C., van Vuuren, D. P., and Niessen, L. Future impacts of environmental factors on achieving the SDG target on child mortality—A synergistic assessment. *Global Environmental Change*, 57: 101925, 2019.

[7] Gioda, A. Residential fuelwood consumption in Brazil: Environmental and social implications. *Biomass and Bioenergy, 120*: 367-375, 2019.

[8] Kong'ani, L. N., Ang'u, C., and Muthama, N. J. Adoption of improved cookstoves in the peri-urban areas of Nairobi: Case of Magina area, Kiambu county, Kenya. *Journal of Sustainability, Environment and Peace*, 1: 19-24, 2019.

[9] Sharma, D., and Jain, S. Impact of intervention of biomass cookstove technologies and kitchen characteristics on indoor air quality and human exposure in rural settings of India. *Environment international*, 123: 240-255, 2019.

[10] Kedir, M. F., Bekele, T., and Feleke, S. Problems of Mirt, and potentials of improved Gonzie and traditional open cook stoves in biomass consumption and end use

emission in rural wooden houses of Southern Ethiopia. *Scientific African*, 3: e00064, 2019.

[11] Ravindra, K., Kaur-Sidhu, M., Mor, S., and John, S. Trend in household energy consumption pattern in India: A case study on the influence of socio-cultural factors for the choice of clean fuel use. *Journal of Cleaner Production*, 213: 1024-1034, 2019.

[12] Gould, C. F., Jagoe, K., Moreno, A. I., Verastegui, A., Pilco, V., García, J., Fort, A., and Johnson, M. Prevalent degradation and patterns of use, maintenance, repair, and access to post-acquisition services for biomass stoves in Peru. *Energy for sustainable development*, 45: 79-87, 2018.

[13] Gizachew, B., and Tolera, M. Adoption and kitchen performance test of improved cook stove in the Bale Eco-Region of Ethiopia. *Energy for sustainable development*, 45: 186-189., 2018.

[14] Mamuye, F., Lemma, B., and Woldeamanuel, T. Emissions and fuel use performance of two improved stoves and determinants of their adoption in Dodola, southeastern Ethiopia. *Sustainable Environment Research*, 28(1): 32-38, 2018.

[15] Peša, I. Sawdust pellets, micro gasifying cook stoves and charcoal in urban Zambia: Understanding the value chain dynamics of improved cook stove initiatives. *Sustainable Energy Technologies and Assessments*, 22: 171-176, 2017.

[16] Khandelwal, M., Hill Jr, M. E., Greenough, P., Anthony, J., Quill, M., Linderman, M., and Udaykumar, H. S. Why have improved cook-stove initiatives in India failed?. *World Development*, 92: 13-27, 2017.

[17] Bansal, M., Saini, R. P., and Khatod, D. K. Development of cooking sector in rural areas in India—A review. *Renewable and Sustainable Energy Reviews*, 17: 44-53, 2013.

[18] Okello, C., Pindozzi, S., Faugno, S., and Boccia, L. Development of bioenergy technologies in Uganda: A review of progress. *Renewable and Sustainable Energy Reviews*, 18: 55-63, 2013.

[19] Vaccari, M., Vitali, F., and Mazzù, A. Improved cookstove as an appropriate technology for the Logone Valley (Chad–Cameroon): analysis of fuel and cost savings. *Renewable Energy*, 47: 45-54, 2012.

[20] Pine, K., Edwards, R., Masera, O., Schilmann, A., Marrón-Mares, A., and Riojas-Rodríguez, H. Adoption and use of improved biomass stoves in Rural Mexico. *Energy for sustainable development*, 15(2): 176-183, 2011.

[21] Venkataraman, C., Sagar, A. D., Habib, G., Lam, N., and Smith, K. R. The Indian national initiative for advanced biomass cookstoves: the benefits of clean combustion. *Energy for Sustainable Development*, 14(2): 63-72, 2010.

[22] Kanagawa, M., and Nakata, T. Analysis of the energy access improvement and its socio-economic impacts in rural areas of developing countries. *Ecological economics*, 62(2): 319-329, 2007.

[23] Paulsen, A. D., Kunsa, T. A., Carpenter, A. L., Amundsen, T. J., Schwartz, N. R., Harrington, J., Reed, J., Alcorn, B., Gattoni, J., and Yelvington, P. E. Gaseous and particulate emissions from a chimneyless biomass cookstove equipped with a potassium catalyst. *Applied Energy*, 235: 369-378, 2019.

[24] Li, Q., Qi, J., Jiang, J., Wu, J., Duan, L., Wang, S., and Hao, J. Significant reduction in air pollutant emissions from household cooking stoves by replacing raw solid fuels with their carbonized products. *Science of the Total Environment*, 650: 653-660, 2019.

[25] Chica, E., and Pérez, J. F. Development and performance evaluation of an improved biomass cookstove for isolated communities from developing countries. *Case Studies in Thermal Engineering*, 100435, 2019.

[26] Sakthivadivel, D., and Iniyan, S. Characterization, density and size effects of fuels in an advanced micro-gasifier stove. *Biofuels*, 1-13, 2018.

[27] Rasoulkhani, M., Ebrahimi-Nik, M., Abbaspour-Fard, M. H., and Rohani, A. Comparative evaluation of the performance of an improved biomass cook stove and the traditional stoves of Iran. *Sustainable Environment Research*, 28(6): 438-443, 2018.

[28] Gandigude, A., and Nagarhalli, M. Review of Rocket Cook-Stove Geometrical Aspects for its Performance Improvement. *Materials Today: Proceedings*, 5(2): 4743-4747, 2018.

[29] Tryner, J., Volckens, J., and Marchese, A. J. Effects of operational mode on particle size and number emissions from a biomass gasifier cookstove. *Aerosol Science and Technology*, 52(1): 87-97, 2018.

[30] O'Shaughnessy, S. M., Deasy, M. J., Doyle, J. V., and Robinson, A. J. Adaptive design of a prototype electricity-producing biomass cooking stove. *Energy for sustainable development*, 28: 41-51, 2015.

[31] Febriansyah, H., Setiawan, A.A., Suryopratomo, K., and Setiawan, A. Gama stove: Biomass stove for palm kernel shells in Indonesia. *Energy Procedia*, 47: 123-132, 2014.

[32] Sutar, K. B., Kohli, S., Ravi, M. R., and Ray, A. Biomass cookstoves: A review of technical aspects. *Renewable and Sustainable Energy Reviews*, 41: 1128-1166, 2015.

[33] Raman, P., Murali, J., Sakthivadivel, D., and Vigneswaran, V.S. Performance evaluation of three types of forced draft cook stoves using fuel wood and coconut shell. *Biomass and Bioenergy*, 49: 333-340, 2013.

[34] Kumar, M., Kumar, S., and Tyagi, S. K. Design, development and technological advancement in the biomass cookstoves: A review. *Renewable and Sustainable Energy Reviews*, *26*: 265-285, 2013.

[35] L'Orange, C., Volckens, J., and DeFoort, M. Influence of stove type and cooking pot temperature on particulate matter emissions from biomass cook stoves. *Energy for Sustainable Development*, 16(4): 448-455, 2012.

[36] Castaner, M., Li, D., and Minor, N. An Efficient and Safe Cooking Stove for Las Delicias, El Salvador. 2017.

[37] MacCarty, N., Still, D., and Ogle, D. Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks of performance. *Energy for Sustainable Development*, 14(3): 161-171, 2010.

[38] Kshirsagar, M. P. Experimental stydy for improving energy efficiency of charcoal stove. *Journal of Scientific & Industrial Research,* 68: 412-416, 2009.

[39] Jetter, J. J. and Kariher, P. Solid-fuel household cook stoves: characterization of performance and emissions. *Biomass and Bioenergy,* 33(2): 294-305, 2009.

[40] Bhattacharya, S. C., Albina, D. O., and Khaing, A.M. Effects of selected parameters on performance and emission of biomass-fired cookstoves. *Biomass and Bioenergy*, 23(5): 387-395, 2002.

[41] Majumdar, D., and Sharma, S. Assessment of carbon monoxide exposure in roadside food-vending shanties using coal cookstoves in Kolkata, India. *Environmental Pollution*, 247: 431-437, 2019.

[42] Sakthivadivel, D., Ganesh Kumar, P., and Iniyan, S. Computational modeling and performance evaluation of an advanced micro-gasifier cookstove with optimum air injection. *Biofuels*, 1-11, 2019.

[43] Nadimi, R. and Tokimatsu, K. Fundamental energy needs quantification across poor households through simulation model. *Energy Procedia*, 158: 3795-3801, 2019.

[44] Patel, S., and Biswas, P. A simplified combustion model integrated with a particle growth dynamic model for top-lit updraft cookstoves. *Energy*, 157: 658-668, 2018.

[45] Gandigude, A., and Nagarhalli, M. Simulation of Rocket Cook-Stove Geometrical Aspect for its Performance Improvement. *Materials Today: Proceedings,* 5: 3903-3908, 2017.

[46] Dorvlo, Y. S., Addo, A., Kemausuor, F., Abenney-Mickson, S., Ahrenfeldt, J., and Henriksen, U. Evaluating the Effect of Two Chimney Configurations on the Overall Airflow and Heat Transfer of A Biomass Cook Stove. *Journal of Clean Energy Technology,* 6(5): 353-356, 2018.

[47] Pande, R. R., Kshirsagar, M. P. and Kalamkar, V. R. Experimental and CFD analysis to study the effect of inlet area ratio in a natural draft biomass cookstove. *Environment, Development and Sustainability*, 1-15, 2018.

[48] Lombardi, F., Colombo, L., and Colombo, E. Design and validation of a Cooking Stoves Thermal Performance Simulator (Cook-STePS) to simulate water heating procedures in selected conditions. *Energy*, 141: 1384-1392., 2017.

[49] Masud, M. H., Ahamed, R., Joardder, M. U. and Hasan, M. Mathematical model of heat transfer and feasibility test of improved cooking stoves in Bangladesh. *International Journal of Ambient Energy*, 40(3): 317-328, 2019.

[50] Sowgath, M. T., Rahman, M. M., Nomany, S. A., Sakib, M. N., and Junayed, M. CFD Study of Biomass Cooking Stove using Autodesk Simulation CFD to Improve Energy Efficiency and Emission Characteristics. *Chemical Engineering Transactions*, 45: 1255-1260, 2015.

[51] Agenbroad, J., DeFoort, M., Kirkpatrick, A., and Kreutzer, C. A simplified model for understanding natural convection driven biomass cooking stoves—Part 2: With cook piece operation and the dimensionless form. *Energy for Sustainable Development*, 15(2): 169-175, 2011.

[52] Shah, R., and Date, A. W. Steady-state thermochemical model of a wood-burning cook-stove. *Combustion Science and Technology*, 183(4): 321-346, 2011.

[53] Kausley, S. B., and Pandit, A. B. Modelling of solid fuel stoves. *Fuel*, *89*(3): 782-791, 2010.

[54] Obernberger, I., Weiß, G., and Kössl, M. Development of a new micro CHP pellet stove technology. *Biomass and bioenergy*, 116: 198-204, 2018.

[55] Rahbar, K., Mahmoud, S., Al-Dadah, R. K., Moazami, N. and Ashmore, D. Feasibility study of power generation through waste heat recovery of wood burning stove using the ORC technology. *Sustainable cities and society*, 35: 594-614, 2017.

[56] Najjar, Y. S., and Kseibi, M. M. Thermoelectric stoves for poor deprived regions–A review. *Renewable and Sustainable Energy Reviews*, 80: 597-602, 2017.

[57] Yu, C. Energy -concerving and environment -protective oil absorption cigarette heating top of a kitchen range. CN206410171U, CN grant, 2017. Retrieved on 15 Mar. 2019 from https://patents.google.com/patent/CN206410171U/en?oq=+CN206410171U, 2017.

[58] Huiyun, Z. *Multi-functional energy-conserving firewood stove of movable.* CN206419985U, CN grant, 2017. Retrieved on 15 Mar. 2019 from https://patents.google.com/patent/CN206419985U/en?oq=CN206419985U, 2017.

[59] Haoyang, L., Jingquan, L., and Jinggang, L. Automatic go up energy -concerving and environment -protective kitchen range of fuel. CN206377694(U), CN grant, 2017. Retrieved on 15 Mar. 2019 from https://patents.google.com/patent/CN206377694U/en?oq=Automatic+fuel+energy-saving+stoves%2c+2017%2c+CN206377694+U, 2017.

[60] Biao, S. *Dual purpose heating stove of cooking and hydrologic cycle*. CN206377698(U), CN Grant, 2017. Retrieved on 15 Mar. 2019 from https://patents.google.com/patent/CN206377698U/en?oq=CN206377698+U, 2017.

[61] Wang, Z., Duanmu, L., Yuan, P., Ning, M., and Liu, Y. Experimental study of thermal performance comparison based on the traditional and multifunctional biomass stoves in China. *Procedia Engineering*, 121: 845-853, 2015.

[62] Bharatbhai, P., *Portable stove*. 3568/MUM/2014. Retrieved on 12 May 2019 from http://ipindiaservices.gov.in/PatentSearch/PatentSearch//ViewApplicationStatus, 2016.

[63] University, J., *Enhanced hybrid ejector reverse-downdraft stove (EHERS) - n kg/hour*. 5175/CHE/2014. Retrieved on 12 May 2019 from http://ipindiaservices.gov.in/PatentSearch/PatentSearch//ViewApplicationStatus, 2016.

[64] Sasidharan, K., *Energy Efficient Stoves, Heating Applications*. 552/CHE/2013. Retrieved on 10 Feb. 2019 from http://ipindiaservices.gov.in/PatentSearch/PatentSearch/ /ViewApplicationStatus, 2013.

[65] Jayaprakash, V. *High Efficiency Wood Burning Stove.* 5556/CHE/2012. Retrieved on 15 Mar. 2018 from https://www.quickcompany.in/patents/high-efficiency-wood-burning-stove, 2015.

[66] Mukunda, H. S., Dasappa, S., Paul, P. J., and Rajan, N. K. *Biomass stove apparatus and method for its use*. 1763/CHE/2008. Retrieved on 14 Mar. 2018 from https://patents.google.com/patent/EP2318766A2, 2009.

[67] Teal, W. J. *Heat exchanger for furnace flue*. US5944090, US grant, 1998. Retrieved on 14 Mar. 2019 from https://patents.google.com/patent/US5944090A/en?oq=Heat+exchanger+for+furnace+flue%2c1999%2c+US5944090, 1998.

[68] Murty, J. S., Khuntia, S., and Ray, H. *A multi-purpose stove useful for cooking, baking, space heating and drying*. 1114/DEL/1998. Retrieved on 14 Mar. 2018 from http://www.allindianpatents.com/patents/215495-a-multi-purpose-stove-useful-for-cooking-baking-space-heating-and-drying, 2008.

[69] Bernelov, J. H., and Bernelov, E. I. *Wood burning stove with economizer*. US4738241A, US grant, 1986. Retrieved on 15 Mar. 2019 from https://patents.google.com/patent/US4738241A/en?oq=Wood+burning+stove+with+economizer%2c1988%2c+US4738241, 1986.

[70] Barratt, R. O., and Franklin, H. N. *Heat exchanger.* US4416325A, US grant, 1980. Retrieved on 15 Mar. 2019 from https://patents.google.com/patent/US4416325A/en?oq= Heat+exchanger%2c+1983%2c+US4416325, 1980.

[71] Schwartz, L. A., Geiter, R., and Albertsen, P. S. *Catalytic stove*. US4319556A, US grant, 1981. Retrieved on 15 Mar. 2019 from https://patents.google.com/patent/US4319556A/en?oq= Catalytic+stove%2c1982%2c+US4319556, 1981.