Chapter–1

Introduction

Chapter I

Introduction

1.1 Concept of cook stove and its evolution

A cook stove uses thermal energy of combustion of fuel for cooking operation and has a long history of its evolution. Some milestone developments are depicted in Fig. 1.1.

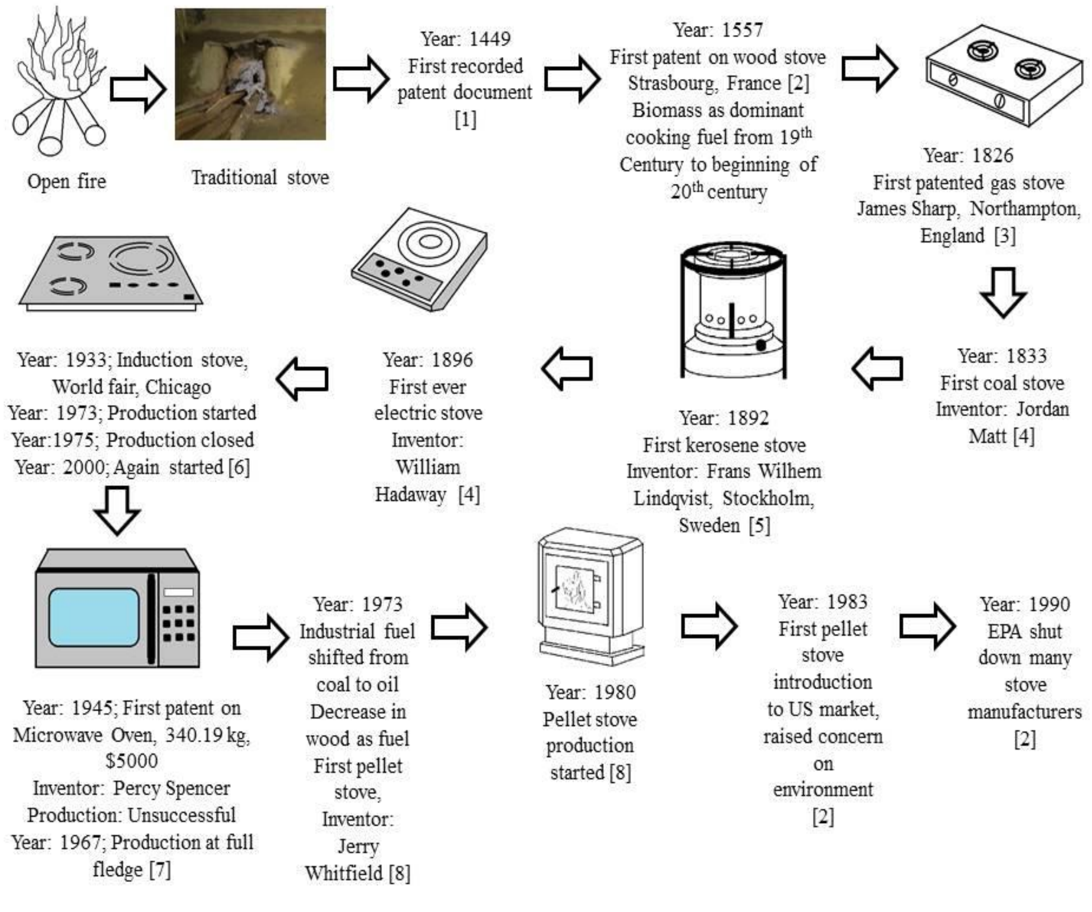

Fig. 1.1: Evolution of cook stoves

The requirement to fulfill the basic necessity of food and subsequently the cooked food dates back to primitive stage of human civilization. Therefore, history of cooking practice appears to be little newer than human history. However, the advancement of science and technology, as could be seen in all aspects of our lives, has also been appropriately reflected in the development of cooking stove as presented in Fig. 1.1.

In the present day context, cook stove can broadly be classified as (i) traditional stove, (ii) improved solid fuel stove (e.g., biomass), (iii) gaseous fuel stove (e.g., LPG), (iv) liquid fuel stove (e.g., kerosene stove), (v) electric stove (e.g., resistive and induction heating) and (vi) microwave oven. There are wide variations in the design of each type of stove. The range of variability of these stoves in terms of some standard features viz., nature of energy source, conversion efficiency, emission level, portability, durability and cost, as reported in different literatures are presented in Table 1.1.

Table 1.1: Comparative status of some common features of different types of cook stove [9-14]

Parameters	**Energy source**		**Efficiency**	**End use emissions**	**Portability**	**Durability**	**Cost***	**Ref.**
Stove type	Type	Form	%			Years		
Open fire	Biomass	Solid	5-15%	PM: 1674 mg CO: 65g	Portable and fixed	< 1	--	[9-10]
Traditional biomass stove	Biomass	Solid	12.6%	PM: 2352 mg CO: 49g	Fixed	< 2	--	[10-11]
Improved biomass stove	Biomass	Solid	*Natural draft*: 25%≤	*Natural draft* (average) PM: 1181.5 mg CO: 15g	Portable and fixed models	≤ 3	₹789-2600	[10-13]
Improved biomass stove	Biomass	Solid	*Forced draft*: 35%≤	*Forced draft* PM: 514 mg CO: 24.5 g	Portable and fixed models	≤ 3	₹1450-7300	[10-13]
Gaseous fuel stove	LPG	Gas	53.6%	PM: 4 mg CO: 1g	Portable	10	₹1093-4299	[10, 13]
Liquid fuel stove	Kerosene	Liquid	49.5%	PM: 10 mg CO: 8 g	Portable	10	₹999	[10, 13]
Electric stove	Electricity	--	70%	Nil	Portable	13	₹2500-3990	[13]
Microwave oven	Electricity	--	73%	Nil	Portable	9	₹5699-17299	[14]
Induction stove	Electricity	---	84%	Nil	Portable	8	₹1599-2695	[13]

*Pertaining to different years of reference

The method of combustion of fuel without any enclosure i.e., “open fire” probably was the beginning of the concept of stove. Such concept was progressed and extended through a wide variety of design of traditional stove with common feature such as earthen or stone enclosure around the fire place. The use of special clay with binding materials for enclosure of the fire and support of the cooking pot was realized to ensure quicker cooking and longer life of the stove which has led to development of a variety of traditional cooking stoves depending upon the availability of local materials. The design of the traditional stove has also been driven by the nature of the fuel which are mostly variety of locally available biomasses. However, the higher emission to working space, partial combustion and excessive losses of thermal energy have remained as common undesirable features and mostly ignored in traditional stoves [11]. The higher emission resulting indoor air pollution and lower efficiency leading excessive fuel requirements are mostly ignored by users due to several reasons in favor of the traditional stove. Majority of the users are habitually accustomed to traditional stove and need not to pay additionally for owning it.

The improved solid fuel stoves are evolved while attempting to address the undesirable features through better technological intervention. The provision of chimney, selection of long lasting and thermally efficient material, arrangement of forced air flow have been some of the interventions noticed in improved variety of cook stoves [10]. The advent of liquid and gaseous petroleum fuels has extended their uses in cooking stove also. Compared to solid fuel cooking stove, the emission and thermal performances of liquid fuel and gaseous fuel stoves are better primarily due to inherent differences in fuel characteristic enabling better design and improved combustion. Controllable fuel flow, better air-fuel mixture and superior heat transfer associated with better safety features make gaseous fuelled stove the best among all types of combustion stoves. However, despite obvious advantages, gaseous fuel remains inaccessible to a large chunk of population primarily due to supply-demand gap and higher capital cost and fuel cost. Moreover, convenience of traditional biomass fuelled cook stove for preferred cooking practices and associated food habits is also strong driving force for its prevalence.

The non-combusting cooking technologies viz., electrical resistive heater, electrical inductive heater and microwave oven have mitigated the distributed emission hazard in the cooking space. Moreover, the on-spot efficiency (i.e., electrical energy to useful heat) of these electrically powered devices is also sufficiently higher than the combustion type cook stove. However, the inadequate supply of electricity, non-affordable cost and non-preferred cooking methods linked with food habits are some of the reasons preventing universal adaptability of these clean cooking technologies.

1.2 Features of improved biomass cook stoves

There have been widespread efforts and initiatives to improve the performance of biomass cook stoves which resulted in the development of several types of improved cook stoves. The comprehensive review with elaborate discussion and overview of different types of cook stoves including improved cook stoves are available in the literature [15]. Based on such review, some important features used for classification of biomass cook stove are presented in Fig. 1.2.

Traditionally, cook stoves remain as non-commercial commodity made up of locally available materials. Non-commercial stoves are mostly fixed design and promoted through Government or Non-government agencies. However, a variety of biomass fuelled improved commercial cook stoves are available in market. Some of the commercial stoves are presented in Table A.1 of Appendix A [16-17]. These are mostly metal made portable variety and preferred for special purposes such as camping etc.

Optimum flow of air is essential for efficient combustion and hence for better performance of cook stove [18]. The flow of air is maintained either by natural draft created due to combustion process or by forced draft created by external power source. Forced draft biomass cook stoves are costly compared to natural draft cook stove, but reported to exhibit better performance [10]. Besides natural draft and forced draft biomass cook stove, there is third type of cook stove that are known as gasifier stove which requires secondary air for combustion of gas generated due to partial combustion of fuel [11]. List of some prevailing models of biomass cook stove of each type are provided in Appendix A.

In India, the Ministry of New and Renewable Energy (MNRE), Govt. of India has also approved 27 natural draft stoves and 26 forced draft stoves with set standards for both efficiency and emissions [12] as presented in Table 1.2.

Table 1.2: MNRE standards for performance of improved cook stove

Parameters	**Natural draft**	**Forced draft**
Thermal efficiency	≥ 25%	≥ 35%
CO emission	≤ 5g/MJd	≤ 5 g/MJd
PM	≤ 350 mg/MJd	≤150 mg/MJd

MJd: Mega Joules of energy delivered to the pot [12]

Nature of fuel (biomass) also affects the performance of cook stove. Some stoves are designed to work only on processed i.e., compressed homogenous fuel whereas some other stoves operate on naturally available fuels including crop residues. Composition, density, calorific value, moisture content and particle size are identified to influence performance of stove [19-21].

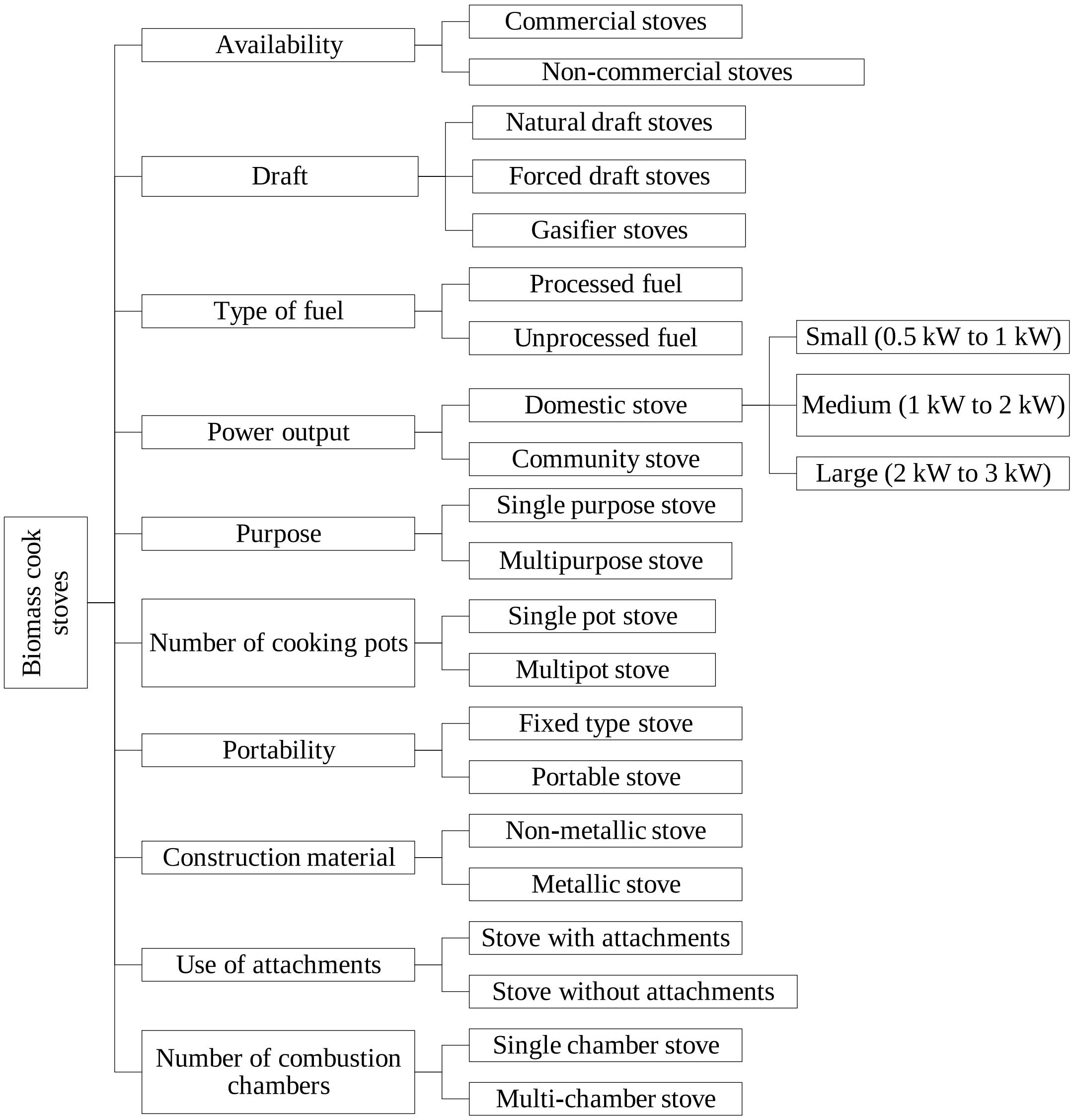

Fig. 1.2: Classification of improved biomass stoves

Thermal power output which is a function of fuel feed rate and hence the physical size of the stove, is another important aspect of stove classification. Bigger size community cook stoves are designed to deliver up to 10 kW of power. Power output of domestic cook stove ranges between 0.5 and 3 kW. The domestic cook stoves are further classified into small (0.5-1 kW), medium (1-2 kW) and large (2-3 kW) based on the maximum capacity of thermal power output [22].

Concept of utilizing excess thermal energy available in cook stove is evolved with the motivation for energy conservation. Accordingly, the multi-purpose cook stove are provided with options for space heating, drying and boiling water in addition to the primary work of cooking [23-27]. Habitants of cold regions including Europe prefer biomass stove for space heating only [28-29]. However, for South-East Asia and African people a multi-purpose cook stove could be a better choice [30].

Improved cook stoves are also available with provision for more than one cooking pot to capture roll over heat through flowing flue gas from the combustion chamber [10, 31]. Further, there are portable design, mostly with single pot type, made up of metallic body [10], whereas fixed type improved cook stoves, either single pot or multi-pot, are generally non-metallic [15]. There are also designs with more than one combustion chamber for some special purpose [32] whereas commonly available designs have a single combustion chamber.

Improved cook stoves are also available with special attachment besides the normal components, for improving performance and also for some specific function. Provision of a pot skirt and chimney are two such examples. The former improves the heat transfer to the pot whereas the later helps in removing the flue gas from chimney to ambient [33].

Energy conservation to reduce deforestation and prevention of indoor air pollution are two primary motives behind the evolution of improved cook stoves all over the world. The indiscriminate cutting down of forest for fuel wood has been almost a universal serious concern which is linked with avoidable wood consumption in traditional cook stove [9]. Therefore, Governments of many countries are concerned to introduce and popularize improved cook stoves. Coupled with the above, serious health hazard due to indoor air pollution caused mostly by traditional cook stove has alerted the Governments to introduce high performance and low emission improved cook stoves [34]. However, the Governments initiatives have mixed degree of success due to several region specific reasons. In line with the efforts of Governments, there are also efforts to introduce several commercial improved cook stoves [12] in the market. Realizing the need for transparent and healthy completion, the standard procedure for assessment and reporting of performances are also introduced through a series of test protocols. For the present research work aiming at the development of a new variant of improved cook stove, a comprehensive review concerning (i) initiatives of national Governments for introduction of improved cook stove and (ii) available test protocols used for assessment of performance of improved cook stove have been done. Some details of both of these aspects are provided below.

1.3 Initiatives for promotion of improved biomass cook stoves

It is seen from the above discussion that multiple options are now available for cooking devices vis-à-vis cooking stoves. Further, the extent of users has also been widened to commercial sectors from the traditional domestic sector. However, cooking is still a dominant family affair in most parts of the world. The prevalence of solid fuel (mostly biomass) cook stove with or without improvement is common in rural areas across the world. The choices for the option are driven by several factors comprising of capital cost, fuel cost, food habit, cooking practices, access to clean energy, abundance of non-commercial fuel in the locality, affordability, awareness about the consequences of indoor air pollution and awareness about energy conservation which have been adequately addressed through a series of studies [35-36]. It is conclusively evidenced that despite obvious advantages of non-combustive cooking devices and cleaner gaseous fuelled stoves, biomass fuelled stove will remain as preferred choice for major chunk of population at least for a reasonable period of time which may be period of transition. Therefore, effort to popularize and disseminate improved cook stove has been continuing since for a long time.

Replacement of traditional biomass cook stove by improved biomass cook stove has not been natural despite serious environmental and health related issues as discussed in the previous section. Some highlights of 25 specific programs on improved cook stoves completed in recent time covering 33 different countries (Africa, Asia, Australia, USA and Canada) are found relevant for the present research work and presented below [38-47].

The economically backward regions are the most severely affected by the predominance of traditional stoves and therefore, maximum number of programs has been reported from such regions. For example, 8 different programs in 23 different African countries with duration ranging from 1 to 12 years were reported. Zimbabwe's *Tso Tso Stove Program* launched in 1980 encouraged for mass production of the improved cook stove named *Tso Tso stove*. Later the promotion of *Tso Tso Stove*, with some modification, was also done in Namibia. It is also reported that during the 1998-2010, about 250,000 improved cook stoves (Legacy biomass and coal chimney stoves, basic efficient charcoal stoves and basic efficient wood stove) were distributed under GIZ (Gesellschaft für Internationale Zusammenarbeit) sponsored ProBEC (Programme for Basic Energy and Conservation) in Botswana, Democratic Republic of the Congo, Lesotho, Malawi, Mozambique, Tanzania, South Africa, Swaziland and Zambia. Similarly, UNEP-AREED (United Nations Environment Programme - Africa Rural Energy Enterprise Development) launched improved cook stove program in Ghana, Mali, Senegal, Tanzania and Zambia during 2000-2012 creating about 24 sustainable rural enterprises for promotion of improved cook stoves. GVEP-DEEP (Global Village Energy Partnership -Developing Energy Enterprises Program) reported creation of more than 400 cook stove enterprises distributing about 200000 improved cook stoves annually during the period 2008-2012 in the countries of Kenya, Tanzania and Uganda. Biomass Energy Initiative for Africa (BEIA) has been another similar initiative in Benin, Democratic Republic of the Congo, Ethiopia, Gambia, Kenya, Rwanda, South Africa, Tanzania and Uganda with nine pilot projects during the 2010-2015 to address the issues concerning related to cooking stove. GACC (Global Alliance for Clean Cookstoves) operated in Ghana, Kenya, Nigeria and Uganda targeting distribution of more than 20 million clean cook stoves and market development [42]. Development of customized improved cook stove to suit the habits of the local people and development of market eco-system for its promotion have been the common features of all the above mentioned African initiatives.

Similarly, 16 different improved cook stove programs operated during 1982 to 2017 in seven different South East Asian countries could also be reviewed. Chinese National Improved Stove Programme (CNISP) launched in the year 1982 reporting successful dissemination of 129 million improved cook stoves during 10 years perhaps is one of the successful cook stove programme [38]. Efforts were also continued in Bangladesh to popularize improved cook stoves by several Government and Non-governmental organizations (Bangladesh Council of Scientific and Industrial Research (BCSIR), Bangladesh Rural Development Board, Ansar-Village Defense, Grameen Shakti, GTZ, USAID and Winrock) during 1994 to 2014 claiming development of prototypes suiting the local needs, replacement of traditional stove by improved cook stoves, training of people to sustain the dissemination. Similar initiatives on improved cook stoves have also been reported from Nepal during 2000 to 2017. The National ICS programme (Energy Sector Assistance Programme of DANIDA) during 2000-2011 and SNV

Netherlands Development Organization's improved cookstove programmes during 2012-2017 have been two major initiatives to popularize and to support market development for clean cooking technologies. Similar initiatives on improved cook stoves are also reported from India, Bhutan, Pakistan, Indonesia and Sri Lanka during 1985 to 2012. The provision of foreign aids, involvement of local governments, development of customized improved cook stoves, training of manpower for entrepreneurship development have been the general features of all the improved cook stove initiatives undertaken in African and Asian countries. However, the woodstove replacement programmes of developed countries (Australia, Canada and USA) have been aimed to address mitigation of indoor air pollution *i.e.*, reduction of PM_{10}. The details of major programs on improve cook stoves are provided in Appendix B [22-30].

As discussed above, despite the decade long effort as discussed above, the relevance of cook stove initiatives are still continuing as evident from the six current programs operated in different countries (Table 1.3).

Table 1.3: Ongoing cook stove initiatives in various countries

Country	**Initiatives**	**Year**	**Objective / Outcome**	**Ref.**
India	National Biomass Cookstoves Initiatives	2009	• 4 test centers were developed • About 23000 improved cook stoves were distributed nation wide	[12]
African Countries	World Bank Africa Clean Cooking Energy Solutions (ACCES) (Sub Saharan Africa)	2012 (ongoing)	• Support for project design, increased grants and arrangements to implement ideas	
	Energizing Development Program (EnDev), (Benin, Burkina Faso, Burundi, Ethiopia, Ghana, Kenya, Mozambique, Rwanda, Senegal, Uganda)	2005-19	• Improved stoves distributed to more than 1.5 million African households	[42]
	West African Clean Cooking Alliance (WACCA), (Benin, Burkina Faso, Cabo Verde, Côte D'Ivoire, The Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, Togo)	2012(ongoing)	• Launch of 2 national pilots • Targets to provide clean and efficient cooking to 2.6 million households under Economic Community of West African States	
	Global LPG Partnership (GLPGP),	2014	• Targets transformation	

Country	Initiatives	Year	Objective / Outcome	Ref.
	(Ghana, Cameroon, Kenya, Nigeria, Tanzania, Uganda)	(ongoing)	of 50 million African people to LPG	
Missoula, USA	Missoula's Air Quality Program	1992 (ongoing)	• PM_{10} reduced to 45%	[44,47]

1.4 Test protocols for biomass cook stoves

Understanding of the details of test protocols of cook stove is considered as one of the important aspects of the current research. A total of 13 test protocols developed by various standard agencies to assess performances covering different aspects including safety and durability have been reviewed (Table 1.4). In general, it is mandatory to test improve cook stove for commercialization like other items. Laboratory based test protocols are performed under controlled laboratory conditions whereas the field based tests are conducted on fields according to selection of food based on local food habits and involves a local cook for the same [37]. Some of the laboratory based tests are (i) Water Boiling Tests, (ii) Controlled cooking test, (iii) Adapted water boiling test, (iv) Heterogeneous testing procedure, (v) Indian standard on solid biomass *chulha*, (vi) Indonesian clean stove initiative water boiling test, (vii) Quality and Technical Supervision Bureau of Beijing Municipality- Thermal performance test for biomass cooking and heating stoves and (viii) Uncontrolled cooking test and Stove Manufacturers Emissions and Performance Test Protocol. Kitchen Performance test is a field based test.

Table 1.4: Test protocols and their salient features [37]

Sl. No.	Test protocol	Features
1	Water boiling test	• Medium: water, Three phases of tests: cold start, hot start and simmering phase • Water quantity: 5 or 2.5 liters • Both single and multiple pot stoves could be tested
2	Cook stove field study resources	• Provides resources for developing and implementing field studies • Compares design and determines sample size, methods for sampling and data collection means
3	Biomass stove safety protocol	• Divided into ten parts to check the safety while operating the stove and ease in operation
4	Controlled cooking test	• Test is done by cooking a meal by a local cook, with repetitions of three times and measurements of amount of food cooked, charcoal formed, equivalent dry wood consumed, specific fuel consumption and total cooking time are noted

Sl. No.	Test protocol	Features
5	Cook stove durability protocol	• Provides methods to check the durability of cook stoves • Identifies the factors affecting life and quality of a cook stove
6	Kitchen performance test	Two ways of testing: • Paired sample: Same household for comparison of old and new stove fuel consumption with no control and cross-sectional study • Cross-sectional study: Different household comparison of fuel consumption between old stove and new improved stove
7	Adapted water boiling test	• Both traditional and improved cook stoves are tested simultaneously for same fuel quantity and cold start only • Performance metrics: time to boil, total time of test, useful energy and potential fuel differences
8	Heterogeneous testing procedure	• Three tests: Highest, Mid and lowest power output • Weight of pot with water and stove with fuel is taken at intermediate points
9	Indian standard on solid biomass chulha	• Test duration: one hour • Measurements of number of pots boiled in one hour is taken to determine efficiency and output power
10	Indonesian clean stove initiative water boiling test	• Labels stoves with star ratings based on performance • Five stage test is done: (i)evaluation of typical cooking cycles and selection of cooking tests (ii) heat flow rate determination (iii) technical test construction (iv) validation of technical test, and (v) testing water boiling appliances
11	Quality and Technical Supervision Bureau of Beijing Municipality- Thermal performance test for biomass cooking and heating stoves	• Different tests for cook stoves, heating stoves and cooking as well as heating stoves to measure efficiency, power and emissions • Additional features of chimney, surface temperature and lifetime should also be implemented along with benchmarks fulfilled
12	Uncontrolled cooking test	• Readings on fuel consumption during test, energy consumption per unit mass, charcoal produced and burn rate is measured
13	Stove Manufacturers Emissions and Performance Test Protocol	• Category of test: < 5 kW and >5 kW • Three stages: cold start, hot start and simmering phase • Measurements of test duration, charcoal produced, dry fuel consumed, burn rate, thermal efficiency, overall firepower, useful firepower, mass of carbon monoxide emitted and mass of particulate emitted are done

Selection of test protocol for a newly developed stove generally depends upon the nature of use. Water boiling test, which has evolved through a series of modification and up gradation comprehensively cover testing of most of the required features from user perspectives *viz.*, time to boil, burn rate, thermal efficiency, specific fuel consumption, firepower and turn down ratio. In India, Government recognized test centers conduct and certify improved cook stove through a rigorous test procedure (BIS test procedure for portable solid biomass cook stove) [22].

Results of test protocols as discussed above are useful for comparison of performances of stove tested under identical conditions. Test results provide a comprehensive understanding about the working of the device. Further, results are also useful for improvement of cook stove. There are examples to use test results to design geometrical parameters (flame to pot distance, pot to flame ratio, skirt gap, pot rest height and pot size) and also to recommend operating parameters (fuel feeding interval and fuel characteristics) resulting reduction of emissions and enhancement of efficiencies [10, 33, 48]. The uses of simulation tools for improvement of design and hence performances are also increasing for many devices. The present research also explores the prospect of using simulation for design and evaluation of the improved cook stove.

1.5 Prediction of performance using Simulation

A stove consists of several components each with intended function to contribute to the overall task of thermal energy conversion. Understanding about the working of the individual components of many mechanical and thermal systems has been proved as helpful for better working as well as for optimizing the design [23-24, 48]. In case of thermal system like cook stove, the understanding of the thermal energy flow within individual component boundaries has been very limited. However, in many similar systems like, IC engine, turbine etc. information pertaining to energy balance vis-à-vis working of individual components is available. Based on the comprehensive review of component modeling of thermal systems, the present research considers development of thermal energy modeling of individual components of cook stove using the fundamental principles of energy conservation and natural laws of Physics and Chemistry. Integration of model components to build up the thermal energy model of cook stove is expected to complement the test results and predict the performances under probable user conditions. The design of stove aiming to reduce loss of thermal energy is also being focused through the application of such realistic model [24].

1.6 Relevance of multi-functional biomass cook stove under changing techno-socio-economic scenario

There has been continuous effort by the national Government to introduce LPG as a source of cooking fuel to every household in India. There is provision of financial assistance in different forms of subsidies on LPG to families of all tiers of economic disadvantages [50]. However, the co-existence of both LPG and biomass stove has been very common, particularly in rural setup. Almost all the LPG users in rural areas owning fuelwood prefer biomass cook stove, because homestead fuelwood production is common and bears no cost apparently. Further, space heating during winter is possible only with biomass cook stove. Biomass cook stoves are also preferred for liberal uses extending longer period of cooking and more number of dishes. Considering these factors, there is more affinity towards biomass cook stove even of the people living in semi-urban regions. The biomass stove is opted for space heating during cold season instead of electrical heating even by affordable section in both rural and urban areas. The use of biomass cook stoves is expected to continue for reasonable period of time even with 100% LPG penetration in domestic sectors in India. But, the performances of existing stoves both traditional and improved types are still low due to that fact that excessive amount of heat as lost as waste to environment. The assessment of performance of existing stoves opens up the prospect of design improvement. Considering the above, a rationally designed improved biomass cook stove should have certain features including (i) multi-functionality so that user's needs could be catered for maximum period of time, (ii) higher conversion efficiency and (iii) waste heat recovery so as to conserve energy. The affordability and food habit of users along with supportive entrepreneurship activities linked with manufacturing and marketing of the new stoves should be some of the considerations.

Prevailing multipurpose cooking stoves [23-27] aimed to cater for additional uses along with cooking. However, all of these patented designs have limitations including (i) lower thermal efficiency due to lack of provisions for air supply, (ii) fuel specific design, (iii) bulky and lack of portability and (iv) inconvenient fuel feeding provision. It is expected that a forced draft long duration metallic multipurpose improve cook stove incorporating the desired features such as (i) provisions of fuel feeding as per user's choice, (ii) power back up, (iii) safe, stable and portable, (iv) multiple pot cooking, (v) provision of waste heat recovery and pot skirt and (vi) air preheating would fulfill the needs of a larger section of population.

1.7 Need for present research

The detailed heat transfer analysis of a thermal device provides opportunity for efficiency improvement and is available for many thermal energy conversion devices. However such analysis has remained limited for biomass cook stove. Therefore the present investigation is aimed to perform heat transfer analysis based on fundamental theory of energy conservation and incorporating system parameters of working, of cook stove.

The effort of waste heat recovery has also remained limited. There is scope of heat recovery from exhaust gas resulted from fuel combustion and skin heat loss. Such recovery is expected to improve efficiency. However evidence of performance improvement through exhaust gas recovery has remained limited. Therefore this research aims to investigate the potential of efficiency improvement through waste heat recovery.

Finally functions of the prevailing biomass cook stoves are mostly limited to cooking, whereas users has different variety of needs such as space heating, drying and baking. A compact and robust design of improved biomass cook stove with multi-utility features has been another aspect of current research.

Investigation of prospect of transfer of technology is another aspect governed by economic, technical and social parameters. The present research also aims to make a thorough investigation on this respect.

1.8 Objectives of research

Keeping in view of the above the present research work is undertaken with the following objectives:

(i) To identify parameters of biomass cook stove for desired improvement of performance using heat transfer analysis

(ii) To develop a multifunctional biomass cook stove addressing desired versatility and waste heat recovery

(iii) To investigate prospect of technological transfer of newly developed multifunctional biomass cook stove comparing its performance with existing commercial stoves

1.9 Organization of the thesis

The thesis is organized into the following chapters covering the objectives of the research as mentioned above.

Chapter I: Introduction

The present Chapter initially provides a brief introduction of the evolution pattern of cook stoves followed by the selection for a suitable cooking technology for economically backward households. Selection criteria shows the need for a multipurpose improved biomass technology which lies in the category of high performing stoves as well as has low or no operating costs. Further the need for test protocols is discussed along with different government initiatives undertaken worldwide for improved cook stove technology implementation. It is followed by gaps in technology and design criteria for a new improved cook stove technology. Lastly depending on the gaps and criteria objectives are being set which is followed by the organization of the thesis.

Chapter II: Literature review

This Chapter contains a detailed literature review covering the various prospects of improved cook stoves related to socio economic factors, impact of design improvements, use of simulation in biomass cook stoves and waste heat utilization in biomass cook stoves. Initial review focuses on the various socio-economic factors which influences the design and implementation of improved cook stoves. It is followed by the impacts that the various design improvements have on performance of a cook stove. The role of simulation and modeling is undeniable in the field of cook stoves and therefore various simulation and modeling techniques used in cook stove development are reviewed. Finally review is focused on the developed multifunctional biomass cook stove technologies to have a clear vision of the objectives and define the design criteria.

Chapter III: Heat transfer for modeling of improved biomass cook stove

This Chapter focuses on developing a steady state heat transfer model. It is used to analyze the heat transfer processes inside a natural draft biomass improved cook stove. The model uses the process of initial identification of heat transfer components, modeling the components using heat transfer principles and finally validating the results. For validation of the model standard WBT test is conducted for the stove and is matched with the performance parameters thus obtained from the model analysis. Successful resemblance has validated the model and results. The steady state model thus developed has successfully identified the various heat transfer components inside the stove as well as the predominant heat loss components. The identified components proved to be useful for performance determination of a biomass stove. The model could therefore be used by stove designers to design new improved stoves or analyze the performance of existing stoves for individual study or for comparative assessment. The model can also be used to determine the best operating parameters of a biomass cook stove.

Chapter IV: Multifunctional biomass fuelled stove with provision of waste heat recovery

This Chapter discusses the design, heat transfer modeling, development and testing of an innovative multifunctional stove. The design principle and working is discussed with elaborations on each design features. A steady state heat transfer model depending on the layout and working of the designed stove is further developed. The heat transfer model provides the performance of the stove in terms of energy prior to development and saves useful time and money. On successful determination of dimensions and materials the designed stove is developed and tested in laboratory. Validation using comparative analysis between the stove's performances obtained from heat transfer analysis and laboratory is performed. The research work performed in this chapter has therefore resulted in a multifunctional multiple pot biomass cook stove with novelties which has the potential to be an intellectual property. The developed multifunctional multiple pot biomass cook stove has better efficiency, lower cooking time, multiple pot cooking options and multi-functionality. The stove due to its novel design has the potential to be scaled up by possible entrepreneurial activities.

Chapter V: Plan for MBFS technology transfer

This Chapter initially provides an introduction on the various processes involved in technology transfer followed by a methodology to determine the prospect of technology transfer. Further the present stage of technology transfer is determined with needs of a prospect manufacturer for technology transfer. Finally the techno-economic assessment of the stove is performed followed by a summary. The study on prospect for technology transfer has therefore identified the stage of the present research work and steps to be followed for its commercialization. Technical analysis identified that the fuel use pattern, rise in cooking energy and performance with respect to other stoves plays vital role in cook stove selection. The economic analysis has used standard Net Present Value method to identify the various costs, benefits and profit analysis pertaining to manufacturing facility and product development. The cost of material followed by manpower has been identified as the key parameters affecting the technology transfer process. It has identified that manpower involved affects the scaling of products whereas cost of manpower in combination with material cost affects the selling price of the product.

Chapter VI: Summary and conclusions

This chapter summarizes and presents conclusions of the present research work.

The text ends with Appendix and list of publications

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