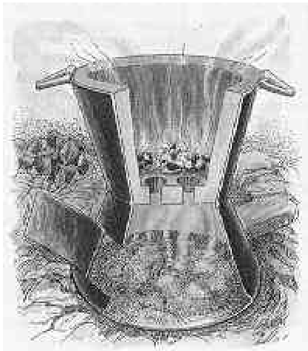
IMPROVED BIOMASS COOKSTOVE PROGRAMMES: FUNDAMENTAL CRITERIA FOR SUCCESS



MA Rural Development Dissertation

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SUMMARY

This paper examines the design of improved biomass cookstoves and the content of programmes that facilitate their effective use and dissemination. The primary aim of improved cookstove programmes is to improve the overall efficiency of the cooking process. Fundamental technical and practical methods of achieving this are discussed and consolidated in this paper. Conflicts resulting from balancing technical perfection and user needs are also explored. Finally, a number of the author's ideas are proposed as further improvements to the effectiveness of stove programmes.

This paper is primarily a technical piece of writing. It is intended to have the potential for adaptation to a guide relating to the fundamentals of stove design and programme planning.

Front Cover Pictures.
The Traditional Three Stone Fire and The Ceramic Jiko Improved Charcoal Stove. (Kammen 1995).

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LIST OF ABBREVIATIONS AND KEY TERMS

CO	Carbon Monoxide
CO_2	Carbon Dioxide
IS	Improved Stove
FAO	Food and Agriculture Organisation of the United Nations
ICP	Improved Cookstove Programme
KENGO	Kenya Energy & Environment Organisation
MJ	Megga Joules - Units of (heat) energy
PHU	Percentage Heat Utilised
RWEDP	Regional Wood Energy Development Programme
UNHCR	United Nations High Commissioner for Refugees

Key Terms

Biomass	Denotes solid biomass in raw or processed form including fuelwood, charcoal, agriresidues and briquettes. (RWEDP 1993a: 7).
Exothermic	A reaction that gives out energy (as heat).
Secondary air	Air supplied to the hot volatiles above fuel bed.
Primary air	Air supplied to the fuel-bed
Pyrolysis	The process of evaporation of the volatile components of wood.
Volatiles	Elements (esp. of wood or other biomass) that become airborne during combustion or heating.

Stove Design	The technical aspects of stove design
Stove Programme	The stove programme as a whole; including research, design, manufacture, dissmenation and education phases.

FIGURES AND TABLES

PREFACE

The purpose of this paper is to draw together the most important aspects of stove design and programme contents to optimise efficiency of the cooking process using a biomass stove.

The paper examines the design of improved biomass cookstoves and the content of programmes that facilitate their effective use. Section 1 shows how both of these objectives remain both important and inextricably linked. It explains how they may be simultaneously tackled by improving the efficiency of the cooking process. In addition to the 'obvious' environmental and human welfare objectives, further aspects are introduced by the specific needs of beneficiaries. These too are discussed in some detail in this section.

The ways in which the cooking process can be made more efficient are many, and range from technical design characteristics to cooking techniques. Section 2 outlines and discusses some of the required technical characteristics of a fuel-efficient stove. Sections 3 and 4 outline and discuss elements of a programme that will compliment the technological improvements. These comprise of energy-efficient stove operation and cooking practices respectively. Within Sections 1 and 2, based on the author's knowledge of physics and technical behaviour of stoves, certain additional suggestions are volunteered to further enhance the effectiveness of stove programmes. Section 5 briefly outlines some of the other aspects of stove programmes, namely manufacture, testing and manufacturing and dissemination phases.

It is concluded that there exist certain elements of the design of cookstoves that are generically applicable. These are shown to be capable of tackling environmental and human welfare problems associated with traditional cooking methods, and it is suggested that they should be a part of a stove programme anywhere. There are other aspects of stove and programme design which cannot be prescribed, some of which are explored in Section 1 and are determined by the beneficiaries. Other specific aspects rely, as with any project, on the local availability of resources and the specific needs of given situations.

The paper does not arrive at a design for an 'ideal' stove, but at a set of concepts which, if adhered to, are likely to optimise the effectiveness of a stove and stove project. It consolidates project lessons, guidelines and technical data.

SOURCES CONSULTED

I have drawn heavily on sources relating to past improved stove projects in rural, urban and refugee affected areas. The Regional Wood Energy Development Programme (RWEDP) has proved to be a very key organisation in having published extensive technical material, and Intermediate Publications Group have also provided me with a number of key texts - mostly practitioners' manuals. Much information pertaining to specific programmes has been drawn from the Internet. In addition I have been able to converse with a number of practitioners who have been a valuable source of first hand information and insight.

ACKNOWLEDGEMENTS

Particular thanks to Matthew Owen an Energy Expert Consultant for his insight into projects with CARE and UNHCR, to Kassie McIlvaine a fellow student and employee of CARE International for providing invaluable resources and contacts, and to Auke Koupmanns and Bert Van Der Plas of RWEDP (Regional Wood Energy Development Programme in Asia) for kindly supplying obscure papers. Finally, thanks to my supervisor, Richard Black for his advice and assistance.

1. INTRODUCTION TO IMPROVED BIOMASS COOKSTOVE PROGRAMMES

1.1 SHIFTS IN EMPHASIS OF OBJECTIVES

1.1.1 Environmental Objectives

In the 30 year history of improved stove programmes, a shift in emphasis has occurred from environmental protection to human welfare improvement. At the outset, deforestation was seen as the main issue, and domestic wood consumption seen as the major cause. Projects focused almost exclusively on tackling this. They endeavoured to reduce demand for domestic woodfuel by making stoves more fuel efficient. Fuel efficiency was achieved, but often at the high price of convenience and user-friendliness. In the course of time it was realised that domestic woodfuel collection was often not the major force behind deforestation, and that stove projects were failing to meet their objective in part due to very low uptake rates. (Crewe 1997: 63, 1998: 11-12). A new set of programme objectives emerged in the 1980s centred more around human welfare issues.

1.1.2 Human Welfare Objectives

Regardless of its cause, deforestation often makes the task of wood collection more difficult, as it becomes necessary to walk progressively long distances to find supplies. This affects mostly women and children who are the main collectors of wood in much of the developing world. For those (particularly in urban areas) who purchase their wood, scarcity tends to inflate prices. In certain areas where population density is high and resources scarce (such as around refugee camps) domestic woodfuel demand can cause deforestation. Well designed and utilised improved biomass stoves are capable of relieving wood demand, hence addressing environmental and human welfare issues.

In addition, indoor smoke pollution from cooking fires has been found to be one of the four most critical health issues facing the world (WB 1992: 2 in Barnes 1994: 6) and leads to various illnesses, most notably acute respiratory infections (ARI). (Smith 1998: 3, 7). In India, some 13% of total deaths are from ARIs. The problems of smoky combustion associated with traditional cooking methods can also be addressed by improved stoves which burn more cleanly. Reducing smoke and greenhouse gas emissions also has positive ramifications for the environment at large, as well as in the kitchen environment. (Ballard-Tremeer 1998).

Finally, cooking with woodfuel can often be dangerous, inconvenient and messy. These issues have also been tackled in more recent improved stove projects, and have in turn made their uptake more immediately attractive to beneficiaries. Woodfuel remains the main fuel for over half of the world's population. (Leach *et al* 1986, in Black 1998: 83 and Kammen 1995: 1). It is for the above reasons that the need to reduce demand for wood fuel, and to make its use more efficient and cleaner remains.

1.2 COMBINING OBJECTIVES

Thus, human welfare concerns associated with woodfuel collection, health and general convenience have moved to the top of the agenda in improved biomass stove programmes. However, environmental and human welfare objectives are inextricably linked, and can be effectively and simultaneously tackled simply by improving the efficiency of the cooking process as a whole. This can be achieved in two ways; by improving the efficiency of combustion and by minimising cooking times.

1.2.1 Improving the Efficiency of Combustion

The efficiency of combustion can be improved by a number of technical stove design features, discussed in Section 2. In efficient combustion, wood gives more heat more quickly than wood burnt inefficiently. This means that less wood is required for the same cooking tasks so demand for wood decreases. Hence, the workload of wood collectors also lessens. This has further ramifications in situations where wood fuel demand has led to deforestation, as degradation of resources may be arrested or even reversed.

1.2.2 Minimising Cooking Times

Cooking times can be minimised by adopting a series of fuel saving practices in stove operation and cooking, described in Sections 3 and 4 respectively. In addition, because wood burns hotter in efficient combustion, cooking times can be shortened, hence reducing the amount of time women spend cooking. Another aspect of efficient combustion is that it is much cleaner. Emissions are lower and less toxic, which means less macro and micro-environmental pollution, hence tackling the associated health problems of stove users as well as the wider pollution.

1.3 EXTENSIONIST AGENDAS

A dichotomy is sometimes apparent between the agenda of the extensionists, those who initiate and first perceive the needs for improved stove projects, and the agenda of the beneficiaries. As a result of the focus on practical aspects of project design, an assumption is made that human welfare and environmental objectives are universally those of the extensionists, and are at the root of the vast majority of improved cookstove programmes. This may be contentious, but is a fair assumption to make given the objectives of most programmes in reality.

The objectives, needs and demands of the beneficiaries cannot be so readily assumed however, and it is important to examine them in some detail.

1.4 BENEFICIARY AGENDAS

In addition to the environmental and human welfare agendas, there is a further, equally important, agenda; that of the potential beneficiaries. In order to design stove programmes that respond to their unique needs, it is vital to gain a detailed understanding of what the beneficiaries hope to get from what is, in fact, *their* improved cookstove programme. Only by taking into account their wishes, issues and needs will a project succeed, as success relies upon their adopting the technology. (Sakubita 1990: 32). Many projects have failed because the opinions or needs of the beneficiaries were not accounted for. Examples range from blatant design shortcomings such as in Malawi where stoves were designed for use with a pot size and shape that nobody in the ‘target community’ owned, to more subtle cultural, environmental or resource oversights such as where stove have been designed for a fuel that is unavailable. (Ligomeka 1999: Pers. comm.).

As with any project designed by persons not totally familiar with the people for whom the project is intended, it is impossible to accurately anticipate all needs. A participatory process must be a part of a stove programme design in order to include the third group of factors that determine the nature of improved stove programmes; the needs of the beneficiaries. Table 1 (overpage) summarises some of the possible factors that could be most important to prospective improved stove users. It represents an amalgamation of many pieces of literature and the author’s own thoughts. It has the potential for use as a ranking exercise wherein people could rank factors listed (plus any of their own) in order of importance. This could be a useful tool in gaining an understanding of the issues of cooking, fuel and fuel-economy as perceived by beneficiaries.

TABLE 1. RANKING TABLE OF FACTORS IMPORTANT IN STOVE DESIGN

Factor	Detail	Rank
Fuel Efficiency	Burns less fuel: Less to collect	
	Burns less fuel: Less to buy	
Cleanliness	Chimney to directs smoke outside	
	Burns fuel with little smoke	
	Easy to clean ash from stove	
	Does not blacken pots	
Time saving	Cooks food fast	
	Easy to light and keep alight	
Fuel	Flexible. Can use wood, charcoal, dung, grass, agri-residues etc.	
	Fuel easy to prepare. Does not need to be cut very small.	
Cooking	Easy to control heat output	
	Adaptable; can cook chappati / tortilla.	
	Flexible; can use urns, pots, pans, clay or metal.	
	- Can keep second pot *warm*	
	- Can keep second pot *simmering & cooking*	
	- Can *effectively cook food / boil water* in second pot.	
	Comfortable to use	
	Can be installed at waist-height for comfort	
	Simple to use. Little / no training / new skills required	
Safety	Outside surfaces of fire cooler	
	Stable (RWEDP 1993a: 13, and Indian Standard 13152 in RWEDP 1993b Annex 2: 96)	
Cost	Low initial cost	
	Durable design. e.g. grates will not burn out fast	
Portability	Portable; can use inside and out.	
	Light; children and elderly could carry. (RWEDP 1993a: 79)	
	Comfortable handles. (RWEDP 1993a: 79)	
Space	Occupies little space (Koerhuis 1995: 49, ActionAid 1989).	
Other	Looks good; modern / status symbol (Stewart *et al* 1992: 53)	
	Produces smoke to deter insects	
	Produces smoke to seal /preserve thatch in roof. (Khamati 1987: 7)	
	Produces smoke to preserve food	
	Produces heat for drying clothes.	
	Gives out light (Khamati 1987:28, Stewart *et al* 1992: 53)	
	Space heating ability	
	Provides social focus for social groups	
	Improves division of labour in household. (Crewe 1998: 159)	
	Other factors as appropriate:	

Some factors that appear in Table 1 are not easily anticipated by an outsider to a given community, whether fellow national or otherwise, due to their cultural specificity. It has been found for example that the appearance of stoves is often an important factor in the decision as to purchase a stove. In Somalia, soapstone stoves are decorated with a pattern to make them aesthetically more pleasing (Karakezi 1987: 21), while in Kenya certain stoves have been designed to resemble traditional precursors. (Barnes 1994: 14). Other stoves have been painted colours perceived to engender modernity among user groups. (Stewart *et al* 1992: 53, 41). Other factors may be climate specific, while others still are down to user preference. In Nepal, Fiji and Guatemala space-heating ability of the stove was of paramount importance, while in other warmer climates this would be likely to be viewed as a disadvantage. In Indonesia, Sri-Lanka, Senegal and Zimbabwe cooks preferences (and possibly cooking methods) dictate that stoves must cook food fast. (Crewe 1997: 64, 1998: 127).

Sometimes, desires of user groups may be at odds with the environmental objectives of the project which may not be perceived as being as important by the individual users. One such example is that of smoke. In some areas smoke is a useful aspect to a fire for keeping insects at bay, or even for preserving and sealing thatch. (Khamati 1987: 7). In other areas, smoke is simply not perceived as being a problem. (Crewe 1997: 69). However, smoke reduction is central to improved stove projects in the interest of improving both micro and macro environments. This is where the objectives of the programme as a whole (assumed as stated to have strong environmental persuasions) must be balanced with the desires of beneficiaries. Such issues are further discussed in Section 2.4.

It is essential to both understand and include the agendas of beneficiaries in the design of stove programmes in order that they address both broader environmental concerns as well as issues directly affecting users. Without such inclusion and participation, stoves programmes have much lessened chances of success.

1.5 SUMMARY

In summary, stove projects should be designed to deal with three sets of factors; environmental, human welfare and the specific requirements of the potential users. It has been shown that it is possible to simultaneously tackle the former by improving the overall efficiency of the cooking process. The importance or careful investigation of the latter has been shown. It is essential that user preferences are included in programme and stove design in the interest of technology adoption and programme success.

Fundamental aspects of programme and stove design will encompass all three sets of factors and are discussed in the following two sections.

2. THE STOVE DESIGN

2.1 COMBUSTION THEORY

When wood burns, it undergoes a series of stages. During combustion, at temperatures of 250°C or above, 80% of the mass of the wood evaporates as a mixture of flammable gasses. These elements are referred to as the *volatiles*, and are liberated in a process called *pyrolysis*. The remaining residue consists of carbon and some minerals. When the carbon and volatiles are sufficiently hot and well mixed with oxygen they burn fully, leaving only water and carbon dioxide (CO_2) as by-products. The minerals remain as ash. However, in reality there is insufficient air and heat so combustion is not complete. As a result, by-products include carbon monoxide (CO), carbon (soot) and unburned volatiles. (Khan 1999: 1.1, RWEDP 1993a: 38). Carbon monoxide, coined ‘the silent killer’, is a highly toxic gas which claims the lives of many in the developing world (see Section 3.3.2), and many of the unburned volatiles in smoke are poisonous or carcinogenic, irritate lungs and eyes and have been shown to cause serious health problems. (Smith 1998: 3-4). Wood burns in much the same way as most biomass such as dung, grass, peat and rice husk. Charcoal is a cleaner-burning fuel as the volatiles have already been removed in the manufacturing process which involves pyrolysis, without the final oxidisation of the remaining carbon.

2.1.1 Measuring Efficiency

The efficiency of stoves can be measured in a number of ways. Standard testing methods have been documented (Stewart *et al* 1987: 17, Turyareeba 1992, RWEDP 1993a: Section 5.5) and most of them involve measuring the time taken for a given amount of water to reach a certain temperature in standardised conditions. A universally recognised measurement of stove efficiency is the PHU (percentage of heat utilised) value. This is the amount of heat usefully harnessed from the fire by the cooking pot. (Turyareeba 1992: 3). Section 5.2 describes these methods in more detail.

2.2 THREE STONE FIRES

Three stone fires consist of a simple arrangement of three stones around a fire, on which a pot is balanced for cooking. Appendix 1 shows this arrangement. Despite low fuel efficiency and smoke emissions, many prefer to use traditional cooking methods, and studies indicate that they are the methods which best address all household demands in parts of the developing world. Three stone fires are popular for the following reasons, amongst others.

- They are cheap and easy to build
- They are easy to use and require no expertise (although people can become experts at using them)
- They accept many types of fuel, and fuel does not need to be chopped into small pieces
- They can accept any shape of pot or hotplate
- It is possible to keep more than one pot warm simultaneously
- It is easy to control the heat output
- They are familiar objects

(Sakutiba 1990: 21, Barnes 1994: 14, Crewe 1997: 103-4)

An improved stove must be at least as attractive as traditional cooking methods in order to succeed, and where it has shortcomings in one area, it must have strengths in another. (Crewe 1997: 68). Therefore, the above factors need to be addressed in turn and incorporated where possible into designs, whilst adhering to technical and general programme objectives.

2.3 PRINCIPLES OF DESIGN

The ‘Lessons Learned’ publications of both the UNHCR and Care Tanzania (UNHCR 1988e: 65, McIlvaine *et al* 1997: 12) conclude that, in the context of refugee camps in Tanzania, the *principles* of stove design are more important than specific design. It is the author’s contention that this applies to all improved stove programme situations and that it is possible to consolidate a set of technical criteria for stove design that are generic. (Rouse 1999: 4). As a result, this paper does not detail dimensions or prescribe specific manufacturing methods or materials, it simply outlines principles. These technical features could be applied in an improved stove design anywhere, be it made of metal, ceramic or mud, and they would still improve combustion efficiency[1]. All aspects work toward optimising the efficiency of cooking and success of the programme.

2.3.1 Fuel Efficient Combustion in Improved Cookstoves

It is possible to facilitate efficient combustion in a stove by ensuring that

- sufficient air reaches both the burning fuel and the volatiles, and
- the system retains sufficient heat in order to facilitate complete oxidisation of charcoal and the combustion of the volatiles.

These can be achieved, respectively, by incorporating

- a small, conical, insulated firebox, and
- appropriate ventilation comprising a grate and where possible ventilation control.

2.4 TECHNICAL PERFECTION AND USER NEEDS

> It is advisable to sacrifice some efficiency at the expense of the users' convenience. Otherwise, the acceptability of the Improved Stove will be dramatically reduced.
> (Shawn *et al* in RWEDP 1993a: 46)

Technical perfection in itself does not sell stoves or cause them to be used. If stoves are not comfortable or convenient to use, and if they do not offer an obvious advantage to the user, are unlikely to be adopted. This is the lesson learnt in the 1970s when many stove projects failed because they ignored the needs of beneficiaries. (Barnes *et al* 1994: 13, 14, 24, Crewe 1997: 63). This is further confirmed by the fact that stove projects are most successful when implemented in areas where people already have to walk long distances for firewood or spend significant amounts of money on purchasing wood. In both these cases, stoves address users needs; they save their time or money. (Barnes *et al* 1994: 14).

Manufacturing factors sometimes dictate design characteristics, and necessitate a compromise between 'technical perfection' and ease of manufacture. One such example is cited by Barnes (1994: 18). It describes the inclusion of a sliding door for varying ventilation levels on a stove in Zambia. Although highly effective, manufacturing the door was time consuming and

[1] Extensive research exists on the materials science aspects of stove design and manufacture, but are not discussed in this dissertation. Certain construction materials and methods are preferable. However, these preferences are mainly based on durability as well as availability. A fuel-efficient stove can be constructed from any non-flammable material, but its durability may vary considerably.

expensive, and a hinged door, although less effective, required half the number of components to make and was adopted as being the best option.

Users' skill levels or unwillingness to be inconvenienced by technical features can also necessitate compromise. This is the case with *dampers*, an addition to a stove with a chimney that leads to improvements in efficiency of up to 20%. Incorporation of these has been found to have the opposite effect as users refuse to use them on account of their inconvenience, safety aspects and skills required for correct use. (RWEDP 1993a: 10, RWEDP 1993b: 2-3, Khamati 1987: 17)

Issues of technical perfection versus user needs and demands are re-visited, explicitly or otherwise, throughout this paper.

2.4.1 Flexibility Issues

In many parts of the developing world people live more off the land, and rely less on reliable, year-long supplies of fuel, food and other goods. As a result, particularly in rural areas, people are forced to be flexible. Flexibility must be central in the design of stoves. Stoves need to be particularly flexible in terms of what utensils can be used on the hob, and what type of fuel can be burned in the stove.

Many stove projects have fallen at the first hurdle as a result of not investigating the types of utensil used by cooks in a given region. (Crewe 1997: 63). Households may use a mixture of utensils; from flat bottomed aluminium pots to spherical ceramic bowls, or use a hotplate for making *chapattis* or *tortillas*. Before stove design begins, it is essential to investigate the types of cooking utensils used, and where possible, catering for as many of these as possible. If use of a stove necessitates buying new utensils, effectively the price is increased, and the apparatus becomes less attractive. Section 2.6 describes methods of designing pot-stove interfaces for maximising efficiency and flexibility.

Sometimes, flexibility can only be attained at the expense of fuel efficiency, but experience shows that the sacrifice is worthwhile. There are many examples of where it was beneficial to compromise technical perfection in favour of 'user friendliness'. One such example took place in East Africa, where the stove incorporated a shield which enclosed the pot. This shielded it from wind and channelled hot flue gasses up past its sides. Such measures could have increased efficiency by as much as 20%, but made the stoves totally inflexible, and as a result, the stoves were not used. (Barnes 1994: 15). This concept is further discussed in Section 2.6.2. In addition, Section 4.3 describes an author's design that incorporates this and other fuel-saving technologies whilst catering for user demands.

One of the main features of improved cookstoves is that space heating ability is effectively minimised by directing all heat upwards towards the cooking utensil, and minimising radiation from stove sides. This can be a problem for regions where space-heating is a requirement such as in regions of Nepal, Fiji and Guatemala, mentioned in Section 1.3. (Crewe 1997: 64). Appendix 3 comprises a description of an accessory capable of adapting a stove to space-heating ability.

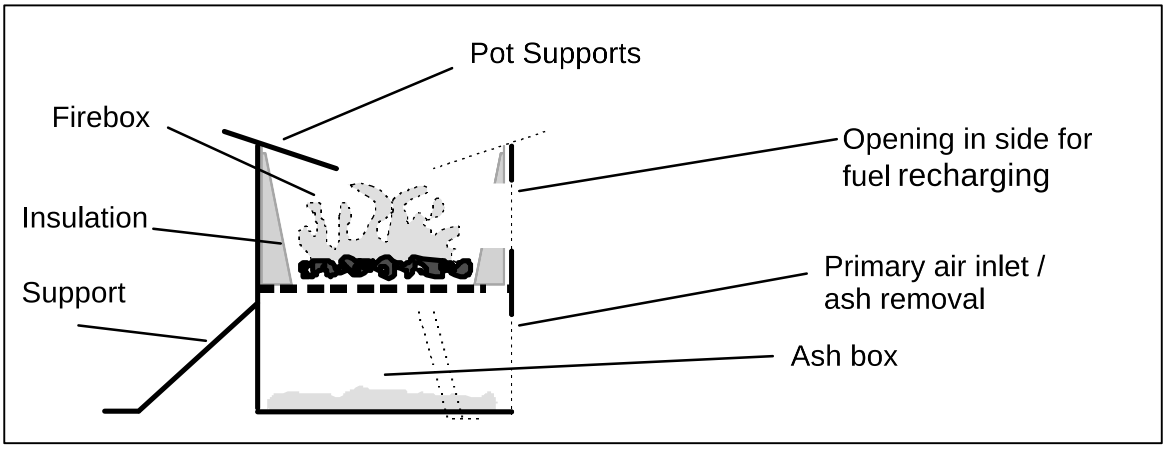
Particularly for users in rural and marginalised areas, flexibility in use of fuels is important. When wood is unavailable, a number of other fuels may be utilised including dried dung, rice husks, peat, grass and roots. Charcoal may also be used in some situations, though this may have to be purchased. Only physical dimensions of the firebox limit what fuel can be used in a given stove, though a design is likely to work best for one particular fuel. Wood is often the preferable fuel as it is renewable and capable of being burned cleanly. Cow dung is, ideally, not burned as it can be employed significantly more beneficially as manure for crops. (Anderson and Fishwick 1985 in Barnes 1994: 4). Charcoal, although burning extremely cleanly, is not always an ideal fuel as in most traditional methods of manufacture much of the woods energy is wasted. (See Appendix 2.) The subject of fuel is revisited in the next section.

2.5 THE FIREBOX

2.5.1 Size

The firebox is the part of a stove in which fuel is placed in order to burn. Figure 1 shows a stove with the firebox and other elements marked[2].

FIGURE 1. DIAGRAM OF AN IMPROVED STOVE



Many findings suggest that it is beneficial to have a small firebox for two reasons. Firstly, smaller volumes of fuel burn more efficiently than large volumes. Secondly, in many circumstances it has been found that stove users will always fully charge the firebox before lighting. (RWEDP 1993a: 39). It is always more efficient and cleaner to have a small hot fire than a large, cooler fire. Air can more easily reach all parts of a smaller volume of fuel to facilitate full combustion, whereas in larger volumes there are likely to be areas which air cannot reach. It has also been shown after extensive testing that smaller re-charges of fuel during the cooking process lead to more efficient operation than large recharges. (RWEDP 1993a: 39). If the firebox is small, only smaller re-charges are possible. (Ballard-Tremeer 1998: 3).

2.5.2 Insulation

A fire emits heat in all directions through radiation, as well as through the through convection in rising, hot gasses. An open fire or stove with no insulation around the firebox emits much of its heat outwards. Table 2 below shows the heat loss characteristics for three stove types;

the three-stone fire, a metal stove, and a ceramic Jiko as used extensively in Kenya. Appendix 1 contains diagrams of the three stoves juxtaposed in this section. The traditional three-stone fire loses around 65% of the total heat produced by the fire to the surrounding environment, and around 25% is lost with the flue gasses. Only 10% is harnessed usefully.

TABLE 2. HEAT LOSS AND FIREBOX INSULATION.

Stove type	**% of heat:**		
	radiated to environment	***lost with flue gasses***	***utilised by pot (PHU value)***
Ceramic Jiko *(with insulation)*	35%	25%	40%
Metal stove *(No insulation)*	55%	25%	20%
Three stone fire	65%	*25%	10%

*Source: Kammen 1999: 2. * - Figures approximated from text.*

The metal stove is an example of an improved stove with a grate and enclosed firebox. It is made entirely of metal, and is used extensively in Kenya. By enclosing the fire, the PHU value has doubled as 10% less heat was lost to the environment. This stove is cited here to show the contrast between it and a similar stove - the Ceramic Jiko - which is similar in size and characteristics, but which has an insulated firebox. By insulating the firebox, the PHU value doubles again (now four times better than the three-stone fire) to 40%, and the heat radiated to the environment drops to 35%. This clearly demonstrates the effectiveness of thermal insulation for redirecting heat to where it can be utilised. This results in quicker cooking times, which means less wood need be used for given tasks.

In addition to improving the PHU value of the stove, thermal insulation can improve the efficiency of the combustion process. An insulated firebox helps the fire retain heat, helping to prevent the fuel and volatiles from cooling. Complete combustion requires high temperatures which insulation helps achieve, and complete combustion results in lower toxic emissions.

Thermal insulation can consist of a ceramic liner, or a cavity between two metal sheets filled with vermiculite or just mud. It must not be too thick or it will absorb and retain too much

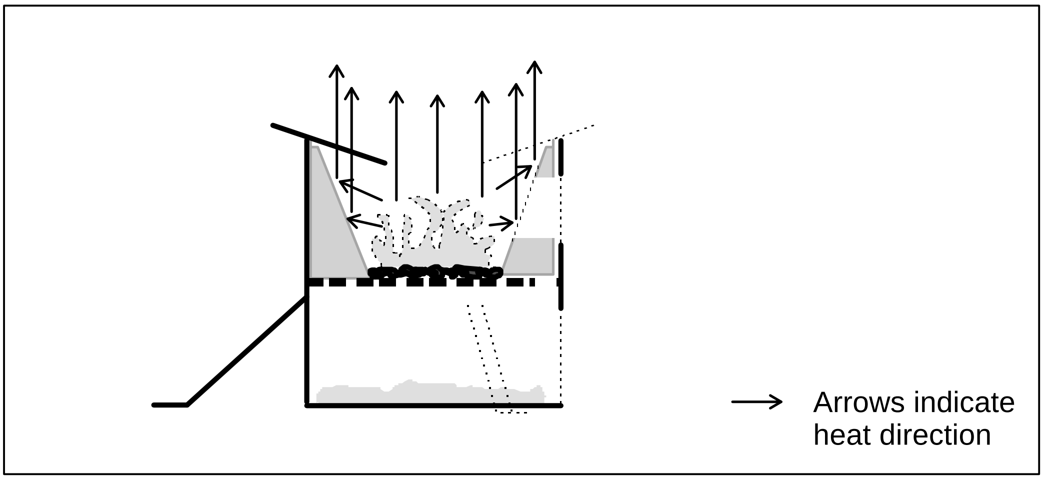
[2] It is useful to have a door into the firebox through which fuel-recharging can be carried out without inconvenient removal of the pot. Small recharges are more likely to be made using this arrangement, the benefits of which are

heat. (Kammen 1999: 3, RWEDP 1993a: 16). In addition to issues relating to fuel efficiency, an insulated firebox is cooler to the touch on the exterior and is thus safer in the kitchen environment, both for users and for children.

2.5.3 Shape

Part of the marked increase in PHU for the ceramic Jiko described in Table 2 is also likely to be due to the conical shape of the firebox. Making the sides of the firebox sloping has been found to significantly improve efficiency as heat is reflected onto the pot-bottom. (De Lepeleire in RWEDP 1993a: 48. *Section 3.5.2b).* Figure 2 demonstrates this effect. The three stone fire does nothing to direct heat to the bottom of the pot, and the upright metal sides of the traditional metal stove do equally little.

FIGURE 2. STOVE WITH INSULATED CONICAL FIREBOX

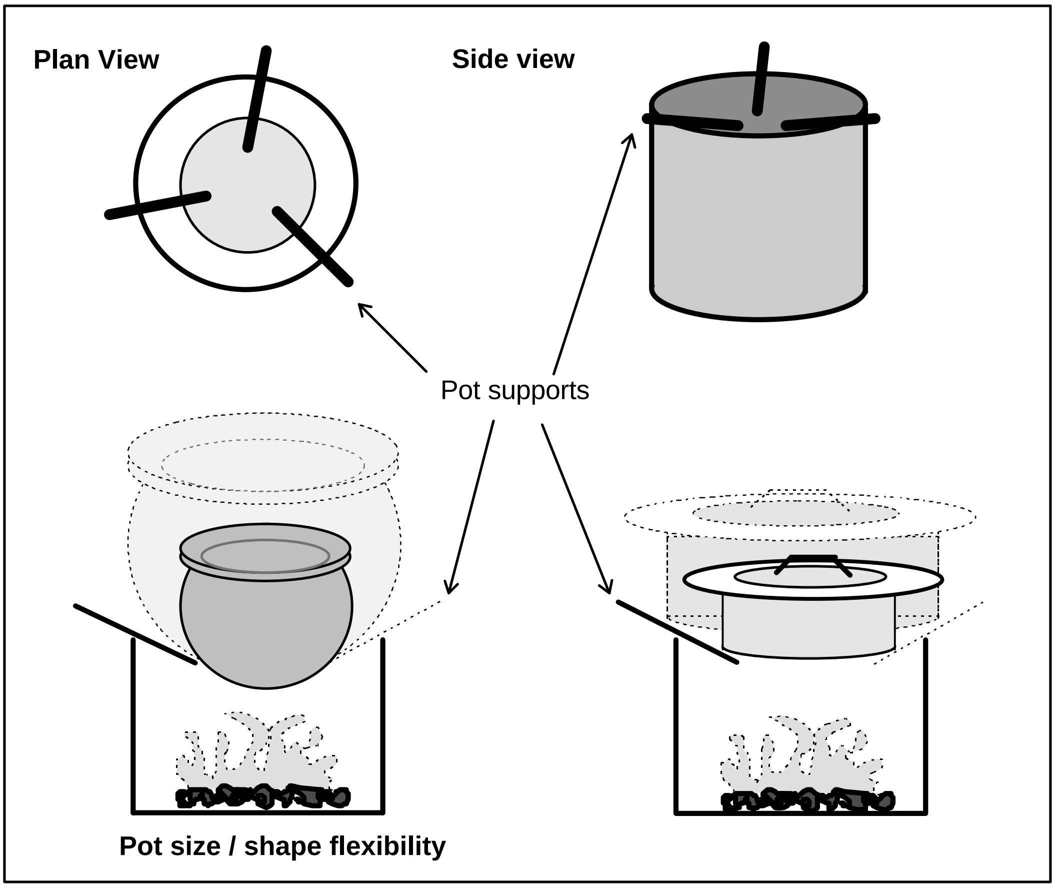


outlined in Section 3.2.3.

2.6 POT - STOVE INTERFACE

The importance of flexibility with regards what cooking utensils can be used with a stove have already been discussed in Section 2.4.1. Figure 3 below shows the most commonly used method of allowing multiple sizes and shapes of pot to fit onto a stove. In this section some of the theory behind fuel efficient heat transfer to the pot is discussed, and ways of incorporating user needs with fuel-saving designs.

FIGURE 3. FLEXIBLE POT-STOVE INTERFACE DESIGNS.



Heat is transferred to pots in two ways; through radiation, and via convection currents of hot gasses passing next to the cooking utensil. Appendices 4 and 5 describe these physical principles in more detail.

2.6.1 View Factor and Thermal Radiation

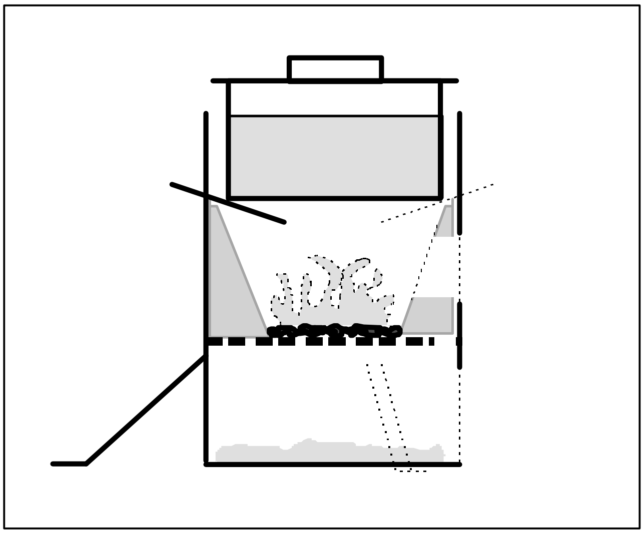
The distance between the grate (i.e. burning fuel) and pot-bottom is critical with regards to the quantity of radiated heat captured. The reason for this can be explained by a geometric principle called the 'view factor'. This indicates how much heat will be transferred by radiation given the distance from the fire to pot, and their relative diameters. It is described in more detail in Appendix 4. It has been shown that optimising this distance for a given stove can lead to significant improvements in efficiency of up to 20%. (RWEDP 1993a: 18).

Generally it is recommended that the grate to pot distance be slightly greater than the sum of the depth of fuel and height of flames. The latter obviously depends on types of fuel used. The pot should be a small distance from the flames to minimise *quenching*, where the flames are cooled against the cooler pot surface. This results in the slowing or cessation of combustion, and hence incomplete combustion and deposition of soot (i.e. carbon) on the base of pots as well as the release of toxic unburned volatiles. (RWEDP 1993a: 38). It is for this reason that pot supports (see Figure 3) should be angled gently in order that vertical positions are a similar as possible for different pots sizes.

2.6.2 Shielding and Thermal Convective Transfer

Heat is also transferred to the pot via the hot gasses through a process called convection and thermal transfer. A number of stoves have been designed in such a way that hot gasses are channelled along the sides of the cooking pot. This increases the velocity of the flue gasses and keeps them in contact with the pot for longer, hence enhancing heat-transfer. Such an enclosure would also serve to protect the pot from the cooling effects of wind. Figure 4 shows a stove with this capability.

FIGURE 4. STOVE WITH POT SHIELDING



Studies undertaken by RWEDP have shown that the width of the channel through which the gasses pass is critical. Gap width has been shown to be at an optimum when around 5mm.

This can result in efficiency improvements of up to 20% (RWEDP 1993a: 88-90). In addition, it should guide the hot gasses across as larger a surface area of the pot as possible, as heat transfer is proportional to surface area exposed. Appendix 5 describes the concepts of thermal convective heat transfer in more detail.

In practice attaining this precise channel width is difficult as the stove would have to be custom built for a particular size and type of pot. Larger pots would not fit into the shield, and if smaller pots were used, the channel width would increase. In the interest of cooking pot flexibility, the design as in Figure 4 is not feasible. The ideal design would incorporate shielding as well as an optimum flue width, *as well as* flexibility of pots. Section 4.3 describes a design that does encompass all of these factors; an author's innovation that incorporates shielding, channelling and a lid in one accessory.

2.6.3 Interface Shrinking Rings

Interface shrinking rings are energy saving devices for use when small pots are used on a given stove. When a small pot is placed onto a stove, if it is significantly smaller than the outlet of the stove, hot gasses escape without having come into contact with the pot, thus being wasted and reducing efficiency. These rings are used to close off the outer part of the top of the stove, forcing the hot exhaust gasses through a smaller, central aperture. Depending on the types of pot used these *could* be distributed with stoves themselves.

2.7 VENTILATION

As has been outlined above, ventilation is the key to efficient combustion. Ventilation is required in two parts of a stove. It is required at the fuel level as well as above the fuel, at the hot volatiles. Sufficient air for the fuel facilitates the first stage of combustion, the pyrolysis and the conversion of carbon and CO to CO_2. This can be provided from under a grate, and is referred to as *primary air*. Air at the second stage facilitates the combustion of the flammable volatiles, and should be introduced above the grate. It is referred to as *secondary air*.

2.7.1 Primary Air and The Grate

The purpose of a grate is to lift the fuel, whilst allowing ash to fall through to allow increased air circulation to the fire and easier removal of ash. (RWEDP 1993a: 48). Although some writers report that the introduction of a grate to a stove had little impact on efficiency, most find that it significantly increased the efficiency of combustion. Ballard Tremeer (1998: 1) found that the introduction of a grate increased the efficiency and lowered emissions of even a three stone fire. Karakezi (*et al* 1991: 87) found in his programmes with improved stove technology that the introduction of a grate doubled the efficiency of many stoves, from 20 to 40PHU.

The introduction of a grate under a fire enables more air to mix with the burning fuel. This means that more of the carbon (i.e., charcoal) and CO (resulting from initial combustion) can be fully converted to CO_2 leaving less toxic CO. This process in itself is *exothermic*, i.e. gives out energy, so the benefits are compounded, i.e., the hotter the temeprature of combustion, the more heat is in turn released. It is for this reason that for every 10°C hotter the burning temperature, power output increases by up to 50%. (RWEDP 1993a: 18).

The exact dimensions and materials of a grate are not discussed here at length, but can also impact burning efficiency. The 'free space : material' ratio is important (RWEDP 1993a: 18), and free space should ideally be around 25% of the grate. However, optimum values vary for different stoves and fuels and range from 16% for a Kenyan ceramic Jiko to 50% for a Thai metal charcoal stove.

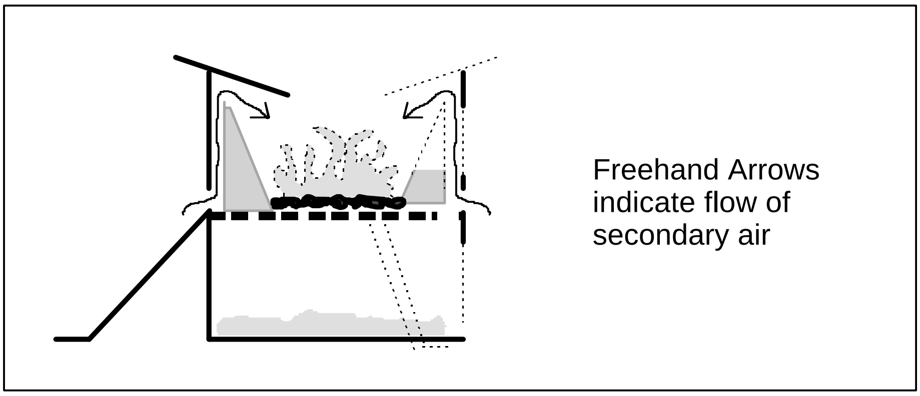
Stewart (*et al* 1987: 141) finds ceramic grates enable charcoal to burn more efficiently, confirmed by RWEDP investigations (1993a: 48). However, other authors, including Karakezi (1987: 16) argue that ceramic grates disintegrate too fast, and again in the interest of user needs, cheapness and durability, sacrificing this aspect of efficiency proves worthwhile.

2.7.2 Secondary Air

Secondary air is the key to cleaner emissions, but its supply is not entirely straightforward. Clearly, in an open three-stone fire there is no restriction to air reaching the gasses above the fire, but the fires do not burn cleanly or efficiently. This is because the air does not mix fully with the gasses, and the gasses are cooled too by the *over*-abundance of cool air, and as a result become less flammable. In an improved stove, it is important to keep the exhaust gasses hot *and* well supplied with a turbulent supply of hot air. The heat reduces cooling, and the turbulence aids mixing. If all these criteria are met (this is very difficult) then hot exhaust gasses combust fully leaving only water and CO_2. There are a number of measures that facilitate this, as follows.

Secondary air could be heated by having it pass through a cavity around the firebox before being introduced to the firebox. This could additionally produce a chimney effect; an updraft drawing a plentiful supply of air into the firebox. Figure 5 shows a stove with this design incorporated. In order to facilitate good mixing of the air with the gasses, the air can be introduced either at high speed[3] and / or in a turbulent manner that would encourage full mixing. Turbulent introduction is normally achieved by introducing the air through a number of different inlets pointing in different directions, or introducing in such a way that it spins around the firebox. Turbulence also serves to reduce flame quenching. (See Section 2.6.1).

FIGURE 5. TURBULENT INTRODUCTION OF SECONDARY AIR INTO THE FIREBOX.



2.7.3 Variable Ventilation

Variable ventilation is the key to control over the combustion rate, and this is a particularly useful feature of a cook-stove, enabling the user to control the heat output. The primary air supply is the easiest and most effective to control, and can be done by having a door in an otherwise enclosed chamber (i.e. ash-box) under the grate. The door could be opened or closed by degrees, to allow more or less air to enter the chamber respectively. This functionality is particularly useful and beneficial for simmering dishes, a common cooking operation for diets in many developing countries. If the air supply is restricted to an established fire it can still burn cleanly, particularly if most pyrolysis has already taken place and just charcoal remains. Beans, maize and lentils all require simmering, often for a number of hours. By slowing combustion for simmering, fuel savings of over 20% can be made. (Owen *et al* 1997: Appendix D).

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[3] Some manufacturers have experimented with hand operated or solar powered motors to force secondary air into the firebox. These have been found to significantly improve efficiency and combustion cleanliness, but their suitability for use in the developing world is questionable.(Community Power Organisation 1998)

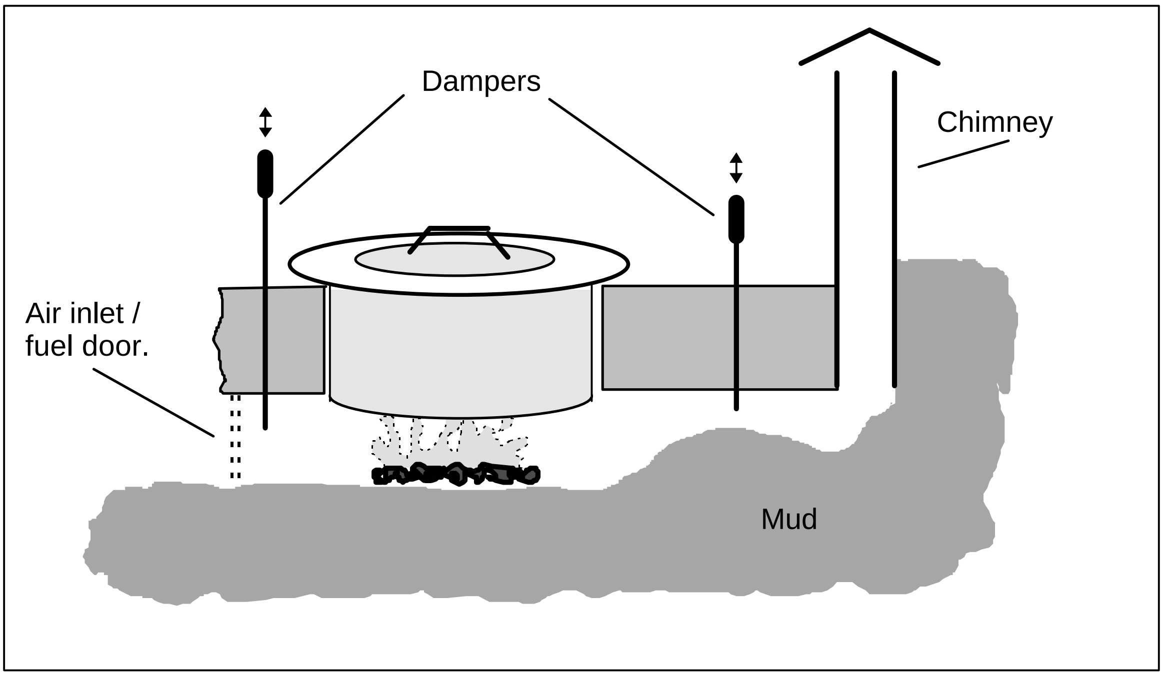
2.8 CHIMNEYS

The decision as to whether or not to incorporate a chimney into the design of a stove is not a simple one. The function of chimneys is obviously to channel smoke from the fire to the outside. This results in lower levels of indoor pollution which is beneficial to users. Chimneys also draw air into the firebox which can result in cleaner, fuller combustion. However, studies suggest that the addition of a chimney to stoves in itself does not result in an improvement of the efficiency of the stove.(RWEDP 1993a: 13). Chimneys do not therefore tackle the broader pollution problems, and this is an important issue on village, camp and global scales. (Ballard-Tremeer 1998: 1). Furthermore, it could be reasoned that chimneys could lead to a *lower* efficiency of the stove as follows. A good indication of efficiency of a stove is the level of smoky emissions; the lower the emissions, the higher the efficiency and burning completeness. If there is a chimney, the stove user is not aware of - and indeed may not be so concerned about - the level of emissions as they are not immediately affecting him or her. There is much a stove user can do to improve the efficiency of a stove (discussed in the final section) but the incentive to use the stove in an efficient manner may diminish with the introduction of a chimney as the *disadvantages* of using the stove *inefficiently* become less apparent. To a stove user, emissions have an immediate impact if there is no chimney, and so they may be more likely to endeavour to adopt efficient habits.

2.8.1 Dampers

In order to make chimneys work more efficiently, it is useful to include dampers in the section between the fire and the chimney itself, as shown on Figure 6. These enable a degree of control over the flow of air up the chimney, and, when used correctly, can improve the efficiency of a stove by as much as 20%. Despite being capable of significantly improving the efficiency of stoves, they reportedly often have the opposite effect and reduce the efficiency. This is due to a number of factors which all result in dampers not being used as intended. Disincentives to use dampers include their becoming very hot during stove operation, causing burns, and becoming coated in creosote - a sticky, viscous substance that is difficult to remove from hands and clothes. In addition, some degree of skill is required to use dampers effectively, and people are frequently not prepared to learn. If dampers are incorporated but not used, the stove will burn less efficiently than if it had been designed *without* them. On balance therefore, they are often considered best avoided. (RWEDP 1993a: 10, RWEDP 1993b: 1-2, Khamati 1987: 17).

FIGURE 6. MUD STOVE WITH CHIMNEY AND DAMPER SYSTEM.



Overall, chimneys are complex constructions and are difficult to make operate correctly. They need to be built according to stringent technical specifications (e.g. height and diameter) in order to operate correctly. (Gitonga 1997: 49, Gulland Associates[4]). If made of ceramic or metal they will add to the cost of stoves, and if constructed from mud or dung and grass mixes, deteriorate fast and require frequent repair. (RWEDP 1993a: 13). As discussed, it is possible that they may even lead to less efficient use of stoves, resulting in higher pollution levels and higher use of wood. It is concluded that they are not an essential part of a stove project, and that their inclusion should be preceded by detailed surveys and analyses of the situations and circumstances of users.

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[4] Internet Source. Gulland Associates Inc. *No date* Chimney Physics Workshop - Tegueiigalpa. Internet Address: http://www.gulland.ca/prowork.htm

3. FUEL-SAVING STOVE OPERATION TECHNIQUES

Crewe (*et al* 1998: 107) asserts that 'in wood burning stove use, the user is a more influential variable on fuel consumption than the equipment.' Indeed, it has been found that in certain situations the use of three-stone-fires in conjunction with good user practice has been more efficient than the use of improved stove technologies. (Howarth 1992: 24, Karakezi 1991: 7, Bennett: 1990: 20 in Crewe *et al* 1998: 107). Thus, user education is as important to fuel economy as the technology itself. (UNHCR 1998e: 62).

The key to fuel economy in cooking is minimising cooking times, and maximising the efficiency of combustion. This section brings together techniques used in conjunction with the use of an improved stove to further enhance efficiency and smoke reduction.

3.1 AIR VENTS

The technical aspects of these have already been outlined in Section 2.7. Users who have only ever cooked on open fires are likely to require instruction as to the effective use the use of air vents on the stove. Careful use of air vents can lead to fuel savings of more than 20% by slowing the burning of wood, particularly during simmering. (Owen *et al* 1997: Appendix D).

3.2 FUEL USE

3.2.1 Moisture Content

A common problem in areas with resource shortages is that people resort to using freshly cut wood. To burn efficiently, wood must be very dry or combustion does not take place at such high temperatures, and is therefore less complete. Freshly cut wood can liberate a total energy of just 8MJ/Kg, whereas oven-dried wood (i.e., moisture content approaching 0%) up to 18.8MJ/Kg. In terms of efficiency, the optimum water content has been found to be around 5%, and it is possible to reach this by sun drying wood. (RWEDP 1993a: 27, 36). It has been found that drying wood instead of using it freshly cut can lead to fuel savings of more than 20%. (Owen 1997: Appendix D). Such practice requires small-scaling stockpiling of wood to allow for drying.

3.2.2 Size

In addition to speeding up the speeding of the drying process, chopping wood small has been shown to be beneficial to the combustion of the wood. This is to do with surface area to volume ratios, and is a result of increased air flow to burning wood. In order to fully convert carbon to CO_2 and not just partially to CO, much oxygen is required at the surface where it is liberated. Small pieces of wood have larger surface area to volume ratios. (RWEDP 1993a: 38, Owen 1999: *Pers comm*).

This measure has its disadvantages. It requires more work to split or chop wood into small pieces than would be required for an open, three stone fire for which no chopping is necessary. It is possible that this would negate time-saving aspects of improved stoves, as women have to spend the time saved from having to collect less wood, in chopping that wood. (Barnes 1994: 16). In addition, expensive tools may be necessary for chopping. However, fuel savings can be considerable, and, by virtue of the preferable small-size of the firebox in improved stoves (see Section 2.5.1) is an essential part of the use of the stoves.

3.2.3 Re-charging

During cooking, ideally, small charges of fuel should be made. Small amounts of fuel burn more efficiently than larger amounts as air is more easily able to reach all the wood. When wood is added to a burning fire to top-up the firebox, the new wood cools the existing fire, and can serve to smother it, and reduce oxygen flow. The larger volume of wood added, the more this happens, so it is preferable to just add small amounts. This is one of the reasons that a small firebox is preferable in the design of an improved stove - it forces the user to build a small fire at the outset, and to make small recharges. (RWEDP 1993a: 39, Ballard-Tremeer 1998:3).

3.2.4 Extinguishing

After cooking has finished, it is normal to simply leave the fire burning until it naturally dies. This means that fuel is burning without the heat being harnessed usefully (assuming it is not just heating a room or area), and it is therefore beneficial to extinguish fires immediately at the end of cooking. This need not be done with water (which would create a mess and again negate one of the benefits of improved stoves – i.e. their cleanliness) but with sand, which smothers the fire, saving up to 15% fuel. (Owen 1997: Appendix D). The sand is shaken off the wood and charcoal when cool, and both are re-used.

3.2.5 Ash

The ash box should be cleared out regularly in order to keep air vents clear, and in order to allow free flow of air under the grate. (Stewart *et al* 1992: 97).[5]

3.3.6 Safety Issues

Most safety education relating to general stove use relates to hot components, and the care that should be exercised (particularly with regard to children) to avoid burns. However, the issue of carbon monoxide poisoning is worthy of explanation, and worthy of being a part of an improved stove programme.

If used in an unventilated area, combustion is less efficient and likely to result in the release of Carbon Monoxide (CO). This is a highly toxic gas that can kill and which must be known about by users. It is important that kitchen areas (if indoors) are well-ventilated and that exhaust gasses can escape through holes in the wall or roof.

[5] In the case of fires without a grate, leaving a small quantity of ash can aid efficiency because it serves to insulate the firebox and this retain some heat. (Ballard-Tremeer 1998:2).

4. FUEL-SAVING COOKING PRACTICES

In 1991, a conference was held in Udaipur, India for stove experts from across the continent. They concluded that:

> Improved cook stove programmes should follow a wider systems approach. Programmes should look at not only the introduction improved cookstoves but also at improved kitchens, cooking practices, utensils and foods. (RWEDP 1993a: 6).

This section brings together the cooking practices that can lead to fuel savings, mostly by minimising cooking times and the amount of time for which the fire is lit. There are two categories of fuel efficient cooking processes relating to cooking techniques and cooking utensils. These are examined in Sections 4.1 and 4.2 respectively.

4.1 COOKING TECHNIQUES

Cooking techniques are based around minimising actual cooking time. If cooking time is decreased, clearly, so too is the amount of fuel used. The following are simple, cost-free practical methods of attaining this end.

4.1.1 Pre-soaking / Milling Foods

Pre-soaking beans and lentils can reduce cooking time by many hours, and can reduce fuel consumption by more than 30%. (Owen 1998: 5, 1997: Appendix D). There is sometimes cultural opposition to this practice, associated with suspicion that food will taste different if pre-soaked as opposed to long-cooked. However, CARE International did some 'taste-tests' in a refugee camp in Tanzania, and succeeded in demonstrating to Rwandan refugees that in contrast to what they expected, pre-soaked beans did not taste any different. (McIlvaine 1999: Pers. Comm.).

Milling or grinding of grains before cooking reduces cooking times resulting in energy savings of up to 70%. (Owen *et al* 1997: Appendix D, 1996: 22).

4.1.2 Tenderisers

Chemical (natural or otherwise) 'tenderisers' can be used to help speed cooking of most foods. These chemicals occur naturally in the fruit papaya ('paw paw'), and are often used on meat before cooking. Sodium bicarbonate ('baking powder' or 'soda') is also said to be an effective tenderiser. These are used by many groups of people, and their use has been encouraged in certain refugee settings. (Owen 1999: Pers. Comm.)

4.1.3 Food Preparation

In order to minimise the amount of time for which a fire is burning, it is recommended that all ingredients be prepared in advance of lighting the fire, in order that the fire is never burning without the heat being used. (Owen 1999: Pers. Comm.)

4.1.4 Topping Up Water

When simmering foods, it becomes necessary to top up the water as it is absorbed or evaporates. It has been found that it is better to add small charges of water than one large amount at the outset, as the food remains near-boiling and hence continues to cook. (Owen *et al* 1997: Appendix D).

4.1.5 Simmering

Dishes should be simmered as gently as possible. Water cannot rise above boiling point, and so there is no advantage in violent boiling over gentle simmering. (UNHCR 1998e).

4.1.6 'Hayboxes' and Pressure Cookers

It has been found that once boiling, a pot can even be left away from the heat and continue to cook in its own heat. RWEDP (1993a: 54) and CARE (1997: 3) describe the use of 'hayboxes' for this manner of cooking. They encourage users to dig holes in the ground, line them with straw or dried leaves and place hot pots into them. In this way, pots stay hot and continue cooking.

One final measure that can be taken to reduce cooking times is to use pressure cookers. The pressure in these pots builds up enabling the water temperature to rise, resulting in faster cooking times.

Both of these accessories can meet with considerable cultural reluctance, as they can require significant changes in cooking habits and traditions. In addition, pressure cookers are frequently expensive. (Ballard-Tremeer 1998: 1).

4.2 COOKING UTENSILS

4.2.1 Pot Cleaning

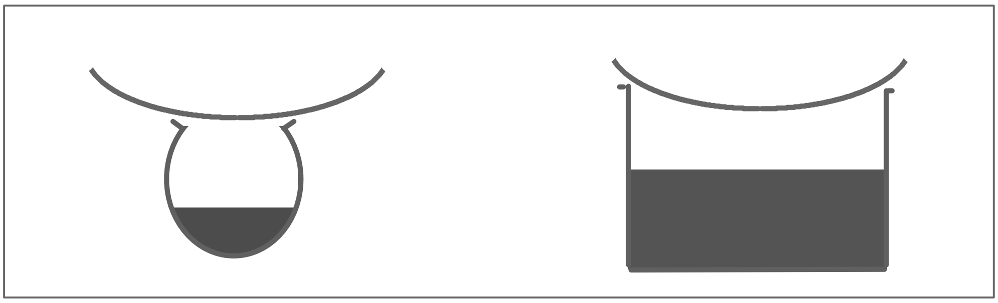
Pots should be kept relatively clean on the outside, and thick layers of soot should not be allowed to accumulate. (Owen 1997: Appendix D and 1999 *Pers comm.*, RWEDP 1993a: 38). Owen (1999: Pers. comm.) also suggests that it may be beneficial to have a *thin* layer of soot on the outside of the pan. Black soot absorbs heat but if the layer becomes too thick however, it begins to act as an insulator.

4.2.2 Lids

Lids should be used at all times where possible. The use of lids results in reduction of heat loss through evaporation from a simmering pot, and significantly reduces the amount of heat required to keep a dish hot. Owen (1997: Appendix D) found that the use of a lid saved some 7% of fuel, while weighing the lid down led to further savings of 5 - 12%, due to the increased seal around the top of the pot. Ballard-Tremeer (1998: 2) reports fuel savings of up to 65% when used during simmering.

One of the reasons that lids are not used widely is because they are an added expense.[6] In addition, in order to have well-fitting lids for different pots, individual lids may be required. A solution to this latter problem could be to have a lid that fitted (and would seal around) many different shapes and sizes of pot and pan. One such design could be a convex lid, that would fit any round-topped pot. Figure 7 below demonstrates this concept.

FIGURE 7. THE CONVEX LID ON DIFFERENT POT SHAPES / SIZES



This idea is pursued in Section 4.3, with a variation that could further enhance fuel efficiency.

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[6] For example, 20% of refugees in Kagera, Tanzania did not use lids. (Owen 1996: 20).

When using a lid, it is possible to place a second pot onto the lid. This would serve to harness the heat lost through the lid. This practice is referred to as *multi-cooking*. This can be done with conventional or convex lids.

4.2.3 Wind Cooling

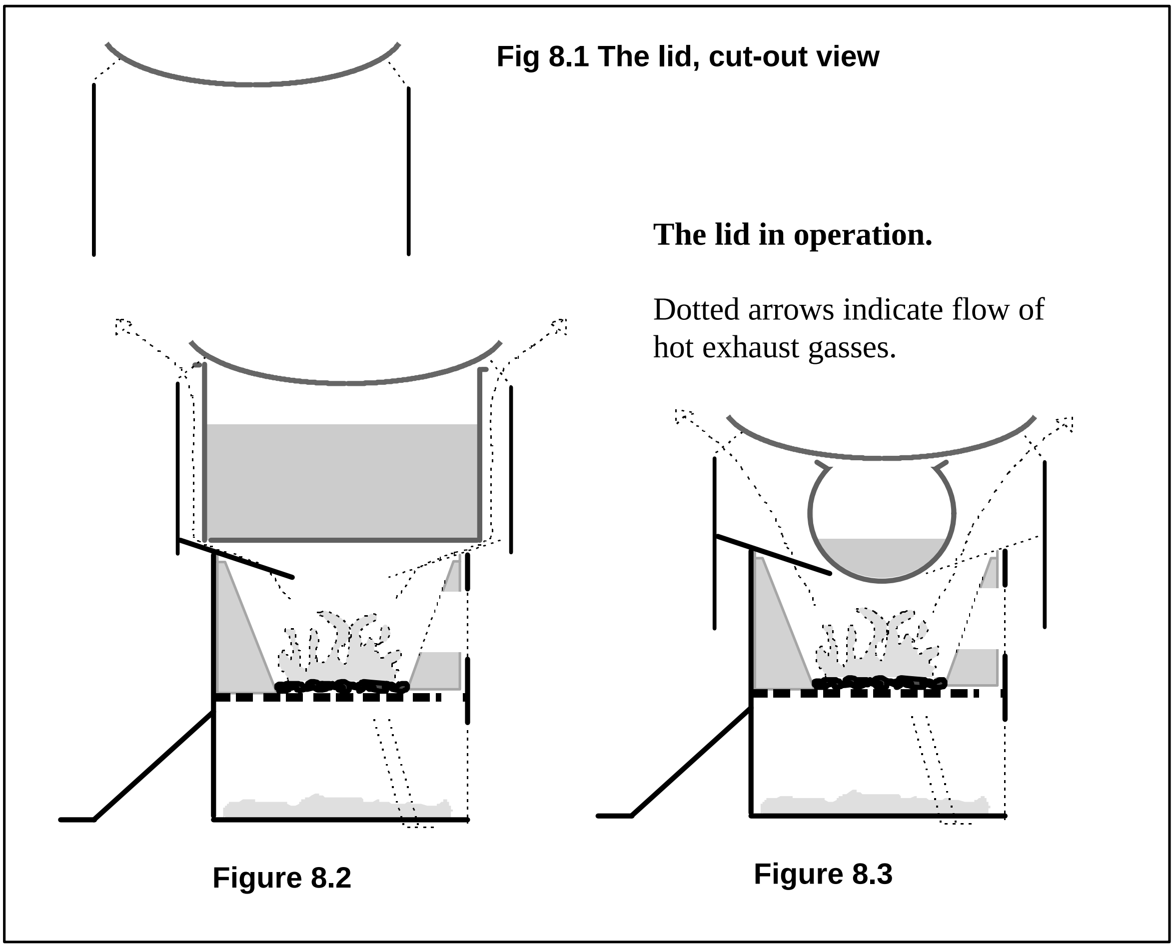
The stove and cooking pots should be kept out of the wind as much as possible to minimise heat loss through the sides of pots, and prevent wind from blowing flames / hot gasses away from the bottom of the pot.

4.3 Combining Ideas. The 'Shielded Multi-Lid'

This piece of equipment has the potential to save fuel by providing a weighted lid, wind shielding and exhaust channelling for improved heat-exchange. It is designed by the author as an accessory that improves efficiency whilst maintaining user flexibility. It should be capable of being manufactured easily and cheaply in developing countries.

The lid-design is based on the convex-lid (described in Section 4.2.2), with the addition of a cylinder of metal attached to the rim. There is a gap between the lid and cylinder to allow flue gasses to escape. When in place on a pot, the lid would effectively seal the top of pot, and the cylinder of metal would hang down as far as the stove top, effectively enclosing the pot. Figure 8 shows the lid in place over a stove.

Figure 8. The Shielded Multi-Lid.



Appendix 5 describes the criticality of the channel through which the gasses flow in terms of optimising heat transfer. Clearly, because the size of cylinder in this design is set for a large cooking pot size (Figure 8.2), it is not possible to keep the channel width constant and hence at the optimum value when using smaller pots (Figure 8.3). However, it has been shown in this paper that much of stove design involves compromise; between user demands and technical perfection. This innovation is just such a compromise, and while its use may not result in the improvements in efficiency of up to 20% when a 5mm channel width is used, it is likely to result in significant fuel savings.

This design may be considered rather cumbersome by the user, as it is a large accessory and would need to be removed each time water was added or food required stirring.[7] However, the greatest potential for fuel saving is during simmering., and during simmering food does not require so much attention. Possible savings during simmering could be broken down as follows in Table 3.

TABLE 3. POTENTIAL FUEL SAVINGS: SHIELDED MULTI LID

Factor	Maximum possible saving	Realistic Estimate
Use of lid	7%	5%
Use of weight on lid	Further 5-12%	5%
Channelling	Optimum = 20%,	5%

(RWEDP 1993a: 88-90, Owen 1997: Appendix D)

According to these estimates, use of the shielded multi-lid could result in savings of up to 15%. Field testing would be required to verify this.

This design is flexible and will fit over any pot size or shape; could be made cheaply from old food cans and it is still possible to practice multi-cooking when it is in use. It is an example of a design - albeit hypothetical - that embraces and balances both technical improvements and user needs.

[7] It may be that an opening section could be incorporated into the lid for water charging and stirring.

5. OTHER PROGRAMME PHASES

5.1 TESTING

Testing is an essential part of every phase of stove programme. It should be part of the ongoing participatory processes within the programme. It enables optimisation of improved stove technologies and essential comparisons with existing cooking technologies.(Stewart *et al* 1987: 17). In addition, testing in development phases of programmes can serve to highlight aspects of design, usage and context that had not been highlighted up to that point. (Barnes 1994: 13).

5.1.1 Who tests?

The actual efficiency of a stove can only be found out under actual field conditions. (Barnes 1994: 13). It is essential that stoves are tested not only in the controlled conditions of a laboratory, but also in the field, by those who are actually going to use them. Karakezi (1991: 7) states that ‘a three stone fire in skilful hands can be more efficient than an ‘improved’ charcoal stove’[8], which suggests that there is a good degree of skill and individual practice in the use of cooking equipment. Crewe (1997: 68, 1998: 108) asks who tests; women or men, cooks or scientists? They would most likely use a given stove quite differently, and, as a result, attain different efficiencies. Clearly, it is the results of the *cooks* that are important and relevant to projects. Laboratory results, no matter how impressive, can do nothing to impact the environment or peoples’ lives and livelihoods. (Stewart *et al* 1997: 53).

5.1.2 Testing Manuals

There are a variety of detailed testing manuals in print, produced by organisation such as RWEDP, KENGO (Kenya Energy and Environment Organisation) and VITA (Volunteers in Technical Assistance). Appendix 6 outlines some of the testing standards and methodologies most commonly used for stoves.

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[8] It is not clear from the text by Karakezi whether this could be due in part to the inefficiency of the charcoal producing process (see Appendix 2). The point would, however, still stand.

5.2 MANUFACTURE.

This is not discussed or explored further in this paper as materials have not, by design, been discussed in any detail, and, like materials, labour supply and skills availability vary regionally.

5.3 MARKETING / DISSEMINATION

Marketing programmes are a further important element of a successful programme. Stoves are consumer items that are sold as a result of what they, and most consumer products promise; a better life. For a stove, this can mean less fuel to collect or buy and a cleaner, more convenient *and more modern* cooking environment. (Stewart *et al* 1987: Ch 11).

Awareness of stoves is major factor in adoption. (Stewart *et al* 1987: 52). It can be raised by neighbours, in the market place, by village organisation, visiting government or NGO representatives or through demos in village meetings. In addition, the mass media has also been used extensively in stove promotion. However, detailed marketing methods cannot be generically prescribed, except with regard to pricing.

5.2.1 Pricing

The cost of stoves is not examined in this paper, though the fundamental criteria is cheapness. Prices should be kept as low as possible to enable as many people as possible to be able to afford stoves. Experience shows that it can be beneficial to the ongoing success of projects if stoves are sold at a sufficiently high price to allow for good profit margins for manufacturers. In addition, most successful projects were characterised by people buying their stoves, not being given them, and receiving little or no subsidy. (Barnes 1994: 14, UNHCR 1998e: 64).

CONCLUSION

In combining the technical dimension and the accounts of expressed user preferences, this paper has shown how the process of stove programme planning and stove design involves compromise. Clearly, numerous technical improvements can be made to stoves to make them more efficient and cleaner burning. However, other factors dictate how (or whether) these improvements can be made. Stove design has been shown to be a process of balancing user needs with technological improvements; making stoves more efficient whilst maintaining their attraction for users. The ‘shielded multi lid’ innovation described in Section 4.3 is an example of how technological principles can be employed, and compromised, in the interest of meeting user demands. The notion of technical perfection in a stove is tempered by user demands for *appropriateness*.

The importance of people’s participation in planning and implementation of programmes has been stressed and explained. Participation is vital for facilitating a detailed understanding of user needs and demands, shown to be paramount to programme success. Programme content has been discussed at length and some of the practical measures that can be adopted to compliment the technology have been described. These are clearly numerous, and given the statistics are both effective and an essential accompaniment to improved stoves themselves. User practice is as important as the technology; the effectiveness of the latter relies entirely on the former for adoption and correct utilisation.

The paper has not arrived at a set of criteria for an ‘ideal global stove’. It has attempted to avoid prescription of ideas, and has thus tried to relate to *principles* of design. It has highlighted a set of principles that can be applied, where possible, *alongside* criteria as defined by specific cultural and environmental contexts.

There is considerable scope for further innovation and research into stoves and into nurturing the symbiosis between user needs and technological improvement. It is vital that research and ideas are shared to enable transferable lessons learned in one place to be embraced elsewhere. ‘Fundamental criteria for success’ is a bold concept. However, the indication is that there exist a number of generic elements of improved stove programmes that can result in cleaner burning, fuel efficient cookstoves that meet user demands.

APPENDICES

APPENDIX 1. TYPES OF STOVE - DIAGRAMS

FIGURE 9. THE THREE STONE FIRE

FIGURE 10. THE TRADITIONAL METAL STOVE

FIGURE 11. THE KENYAN CERAMIC JIKO (CUT-OUT VIEW)

Figures 9, 10 and 11 reproduced from Kammen 1995 by kind permission of Professor D. Kammen, co-chairperson of the Science, Technology & Public Policy Program of the Woodrow Wilson School of Public and International Affairs at Princeton University.

Appendix 2. The Charcoal Making Process

The process of manufacturing charcoal involves a long gentle burning of wood with insufficient oxygen for complete combustion. This results in total pyrolysis; the liberation of volatiles, leaving (depending on the effectiveness of the process) pure carbon, i.e. charcoal.

A pile of wood is covered in straw, leaves and sometimes mud, and a fire is lit below to heat the wood. In order to keep the wood hot and burning slowly during manufacture, much wood is required to feed the lower fire. It is in this way that much energy is expended and lost.

Efficiency of Improved Charcoal Stoves

The process of making charcoal is only 30% efficient. (Stewart *et al* 1987: 141). The average efficiency of a charcoal burning improved stove is around 30%. (Kammen 1992: 2). 'T', the *overall* efficiency of a charcoal stove from the wood stage can be approximated as follows;

$$
\begin{aligned}
T &= 30\% * 30\% \\
&= (0.3)^2 \\
&= 0.09 \\
T &= 9\%.
\end{aligned}
$$

The efficiency of a three stone fire with no fuel-saving alterations or techniques employed has been calculated to be approximately 10% (Kammen 1992: 2, Karakezi 1991: 7). Hence, the charcoal stove, in terms of total wood use is less efficient and can have a more significant impact on forestry than the three stone fire. However, in terms of smoke pollution and wood-collection work, the charcoal stove is preferable, as the final burning stage is considerably cleaner, and gives more heat per Kg.

Improved Charcoal Making Techniques

There are techniques being developed to make charcoal production more efficient. The National Improved Charcoal Programme (NICP) in Kenya is one organisation engaged in this research.

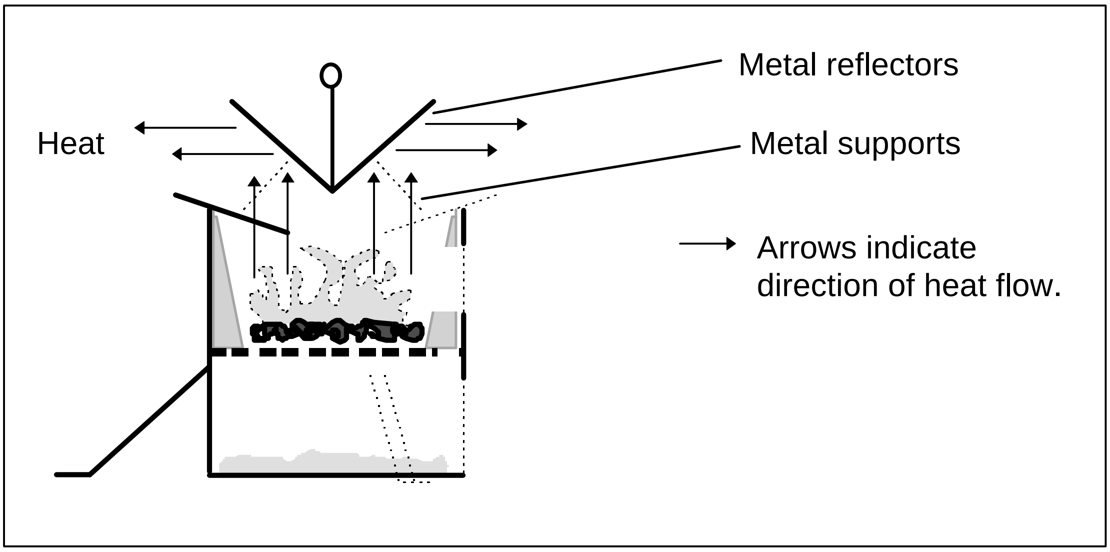
Other organisations are looking at *stove* designs which make charcoal *during cooking*. One such example is the ‘New Turbo Wood Gas Stove’ developed by the Community Power Organisation in the United States. It has a lower chamber which houses the wood where pyrolysis takes place, and an upper chamber where the volatiles are burned. The latter combustion phase provides most of the heat for the cooking process. (Community Power Organisation 1999).

APPENDIX 3. SPACE-HEATER ADAPTER

This design could be used to convert a cook stove to a space heater, whilst retaining the design characteristics that facilitate efficient cooking. One of the main features of improved cookstoves is that space heating ability is effectively minimised by directing all heat upwards towards the cooking utensil, and minimising radiation from stove sides. This design simply reflects the upward-directed heat radially, off a cone of metal that is placed over the top of the stove. Figure 12 shows the arrangment.

The design is very simple, is a stove *accessory* and hence does not add to the cost of just purchasing the stove. There would also be advantages in using this set-up compared to using an open fire as the stove could still operate cleanly, safely and with little smoke.

FIGURE 12. SPACE HEATER ADAPTER



APPENDIX 4. VIEW FACTOR AND HEAT RADIATION

The following text and figures have been drawn directly from the RWEDP 1993a 'Improved Solid Biomass Cookstoves: A Development Manual' Section 3.5.2, pages 18-19. NB: There appears to be a printing error in Figure 3.5. I believe the x-axis should read 'Height to pot (cm)' not 'r_2/r_1'.

'The View factor is the fraction of energy emitted by one surface that is intercepted by the second surface. It is determined by the relative geometry of the two surfaces.

The total power radiated by a black body as a function of temperature and the View Factor versus the distance between fire bed and pot/radius of fire are presented in figures 3.4 and 3.5 (Baldwin 1986). The energy emitted by the fire bed corresponding to its temperature is calculated from figure 3.4, while the View Factor is determined from figure 3.5. These graphs are extremely useful for designing the fire box of a cookstove.

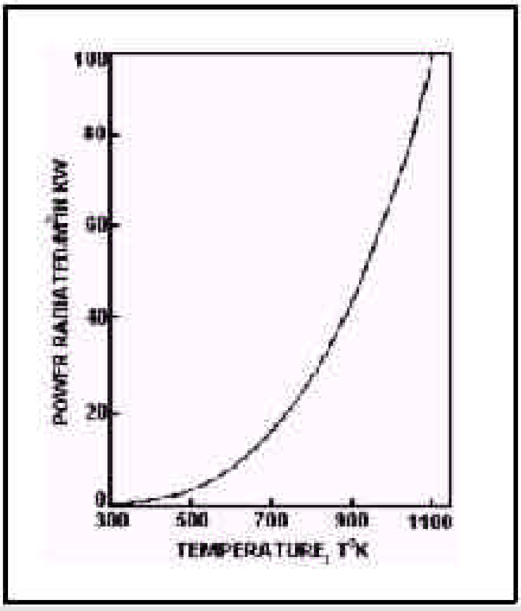


Figure 3.4 Total power radiated by a black body as a function of the temperature

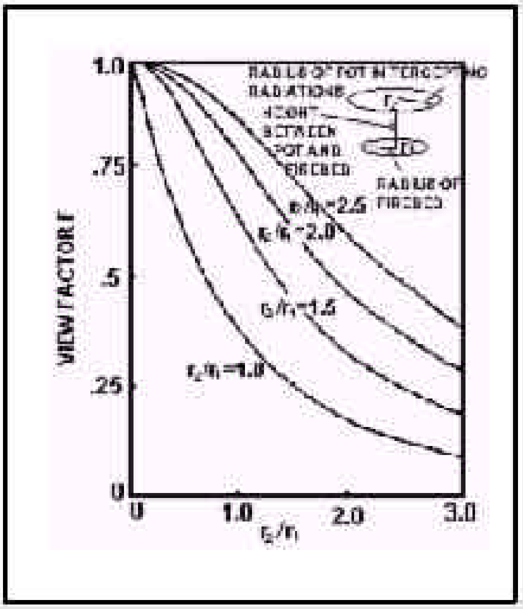


Figure 3.5 View Factor versus the height to the pot

The energy intercepted by the cooking pot from the fire bed can be calculated from the following equation if the View Factor is known.

Energy intercepted by the pot ' Power emitted by the firebed × A × VF (3.9)

For example: Consider a pot with a diameter of 20 cm (*r*2) placed 9.5 cm (*h*) above the fire bed having diameter (*r*1) and cylindrical single pot stove having height above fire bed equal to 9.5 cm (*h*). The value of the View Factor for values of *h*/*r*2 (0.95) and *r*2 /*r*1 from fig. 3.5 is 0.8. This means that 80% of the radiation emitted by the fire bed strikes the pot bottom. From fig. 3.4, if the temperature of the fire bed is equal to 900EK, it will emit 0.40 kW/m 2 . Using equation 3.7, the energy intercepted by the pot is 1.0 kW.

Radiative heat transfer from the fire bed in a cookstove can be increased, either by increasing the fire bed temperature (by controlling the air supply to the fire bed) or by increasing the View Factor. The latter can be increased by either decreasing the distance between the pot and the fire bed or by increasing the diameter of the pot. However, too small a distance between the pot and the fire bed will result in quenching of the fire resulting in incomplete combustion and increased emission of CO and hydrocarbons.

RWEDP 1993a: 18-19.

APPENDIX 5. CONVECTIVE THERMAL TRANSFER

In addition to thermal radiation, heat can be transferred to the pot via the hot gasses by convection and thermal transfer. To maximise thermal transfer, the gasses must be in contact with as large an area as possible of the cooking pot surface, for as long as possible. Many stoves have been designed in such a way that the hot gasses are channelled along the sides of the cooking pot. See Section 2.6.2.

The equation for rate of thermal transfer (q) is as follows.

$$q = k \times A \times \Delta T$$

where q rate of heat transferred
k thermal conductivity of surface
A total area across which the gasses pass
ΔT Difference in temperature between hot gasses and pot.

(RWEDP 1993a: 20)

The larger the surface area exposed to the hot gasses, the higher the rate of heat transfer. Equally, the higher the thermal conductivity of the pot, the higher the rate of heat transfer. Obviously, the higher the temperature of the gasses passing the surface, the higher the rate of heat transfer.

It has been found that the channel width is critical in terms of efficiency acheived. This is summarised in the following excerpt from the RWEDP Improved Biomass Cookstove Development Manual (1993a: 88-90).

8.2 Channel/Shielded Fire Stoves

In channel type or shield-fire stoves, hot combustion gas is forced to pass through a small annulus between the cylindrical fire-box and the cylindrical side of the pot. This increases the velocity of flue gases and enhances the heat transfer coefficient. However, fraction of the total thermal energy of the gas entering the channel that is transferred to the pot (defined as channel efficiency) is critically dependent on the channel gap. Modeling studies (Baldwin 1986) showed that for a 10 cm long channel (L), the channel efficiency drops from 46% for an 8 mm gap (G) to 26% for a 10 mm gap (see figure 8.3). It was also concluded from this study that the length of the channel is also dependent on the channel gap. From figure 8.3, it shows also that, for a 4 mm gap, nearly all energy can be recuperated in the first 2-3 cm length of the channel. Thus in this particular configuration, channel length more than 5cm is of no use. When the channel gap is increased to 6 mm, the first 5 cm channel length recuperates 57% of the energy in the gas, the next 5 cm length recuperates additional 16%, while in the next 5 cm length, an additional 8%, and so on. Although narrow gap is useful from the heat transfer point of view, it severely limits the thermal power of the stove due to high resistance created by the small gap to the flow of gases. Effective heat transfer area also increases in channel stoves as hot gases flow around the pot in the channel gap. It can be concluded from this discussion that the selection of material of construction and fabrication facilities for channel ICSs must be selected with care, otherwise thermal efficiency will be adversely affected due to the faulty construction of the gap. In addition this type of stove can accommodate pots with only limited variation in size in which it puts severe restrictions on the part of users.

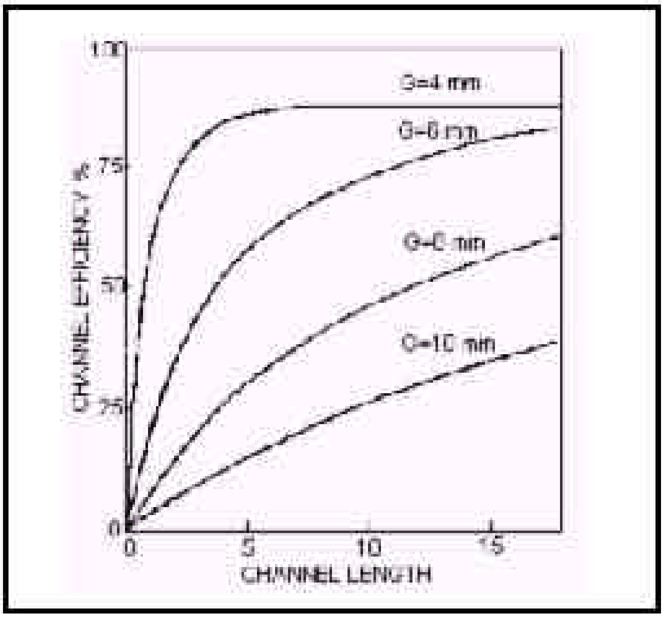


Figure 8.3: Channel efficiency as a function of channel length for various channel widths (Baldwin 1986b)

A fuel efficient design, Mai Sauki stove was developed by Bussman (1988) is shown in figure 8.4. Stove was designed for an average family in Niamey, consisting of 6 persons and using a pan diameter of 30 cm. Power density of 200 kw/m^2 ($20w/cm^2$) was chosen for the design. This is a value at which Visser's shielded-fire gave maximum efficiency. The shield height, combustion chamber height, and the stove body height were optimised on the basis of in-depth studies on combustion, heat transfer, and fluid flow. Efficiency of the stove remained constant at nearly 35% even when the grate to pan distance was varied from 8.5 cm to 12.5 cm and the grate hole area varied from 5% to 50% With the increase in the channel gap from 5 mm to 12 mm, the efficiency dropped from 35% to 30%. A shield pan gap (G) of 5 mm and a shield height (L) of 50 mm was found to be optimum. It was observed from the detailed optimisation studies that the area of the primary air holes should be equal to the secondary holes, including fuel loading opening for better performance. As a result of these optimisation studies, not only thermal efficiency increased substantially, but a material saving of around 15% was also achieved. Cost of production in informal sector, at the prevailing prices, was calculated at 615 FCFA as of early 1987, nearly 40,000 stoves were sold.

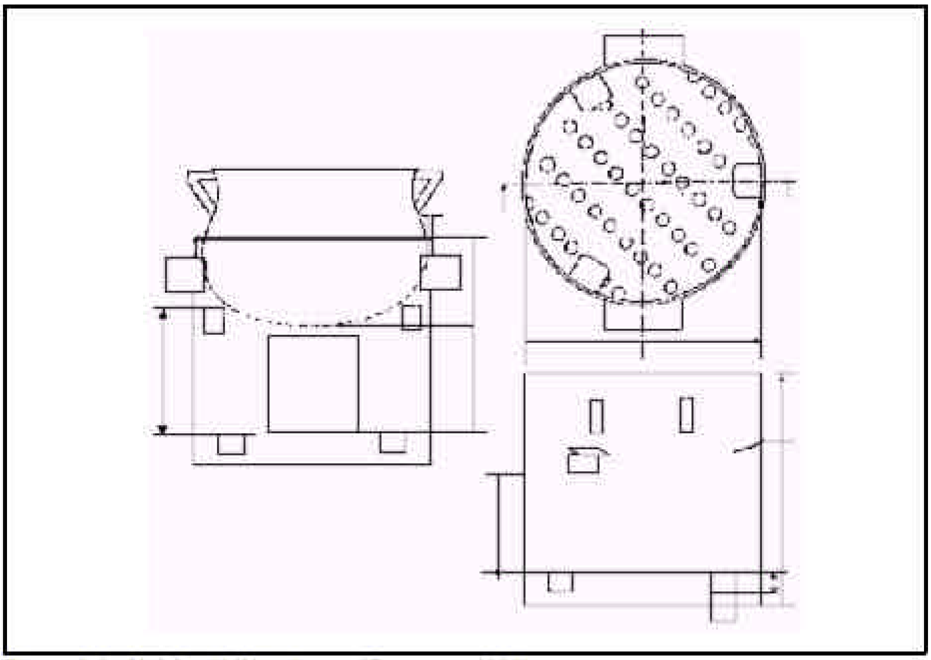


Figure 8.4: Mai Sauki Woodstove (Bussman 1988)

RWEDP 1993a: 88-90

APPENDIX 6. TESTING STANDARDS AND METHODOLOGIES.

Methodologies

Ideally all testing must be comparative, as the improved stove should live up to its name and indeed be an improvement on previous stoves.

- The laboratory water boiling test is the most basic and common test. It comprises measuring the time taken for a given volume of water to reach a certain temperature. This is good as a comparative test, as volumes and ambient conditions can easily be made uniform and constant.
- Kitchen performance test. While the above may take place in a laboratory, it is essential that comparative tests are carried out in the kitchen environment, by cooks. This is often found to give very different results to those from the laboratory. (Turyareeba 1992: 2). Often, a given dish is cooked simultaneously by two village cooks, one using the new technology, the other traditional cooking methods. Wood and water used would be measured, as would the time and effort taken. Finally, there may be tasting sessions after the cooking. This method is often used in the marketing stage of projects, and such exercises will take place in target areas.

Testing Criteria

The following are various aspects of stoves and their use that should be tested in the above manners. (Turyareeba 1992: 3).

- Speed of lighting
- Speed of cooking
- Specific fuel consumption
- Safety
- Pollution

International Standards

It is essential that everything is standardised in testing exercises in the interest of uniformity. This includes pots, pans, balances, air temp, emissions conditions and burning times. (Turyareeba 1992: 5). Turyareeba encourages the sharing of information on testing standards and methodologies (and test *results*), and there exist various national and international standards for stove testing. One such set is the ‘Indian Standard on Solid Biomass Chulha-

Specification CIS 1315 Z: 1991'[9]. This defines all standards and testing conditions. (Published in RWEDP 1993b). RWEDP (1993a: Section 5.5) also describes testing methods in some detail, as does the Intermediate Technology Development Group in its manual by Stewart (*et al* 1987: Ch 3). The organisation VITA (Volunteers in Technical Assistance) published a set of International Standards for testing the efficiency of cookstoves and KENGO / RWEDP published a guide based on this for Africa in 1992.

[9] Chulha is the Hindi word for Cookstove

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