Designing Vernacular Cooking Stoves: A Quick Summary for the Shell Foundation Discussions

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Changing paradigms

Although greatly under appreciated, the open fire has many advantages compared to high mass, older style cooking stoves. If sticks of wood are expertly fed into an open fire, the results can be almost complete, and therefore clean, combustion. Metering the fuel as it is used can create a hot fire that combusts gases before they escape as smoke. The flame and hot air naturally rise up out of the fire, touching a great deal of the surface area of the outside of the pot. No heat is absorbed and lost into the stove body. The coals radiate heat into the pot. The very hot, flame generated temperatures close to the pot assist efficient convective heat transfer. The open fire (three-stone fire) in laboratory tests can heat up food faster, often uses less fuel, and can burn cleaner than many of the first generation of wood burning cook stoves.

(In the same way, Model T automobiles smoked a lot more and were not as fuel efficient or convenient as 2001 models. A lot of people preferred horses rather than the first generation of cars.)

The above statements conflict with assumptions found in stove articles and books published twenty-five years ago. The open fire was thought to be very inefficient, and as a direct corollary almost any stove was accepted as an improvement. Open fires were often assigned efficiencies of 3 to 7%. Today, we know that efficiencies of the open fire, (the percent of the released heat that gets into the pot), can be much higher. Outdoor tests at Aprovecho Research Center in a 10MPH wind conducted by 14 college students, who were amateur fire makers, making 52 fires, resulted in an average result of 11.3%. The top of the amateur range was around 18%, showing where experts who value conservation might begin.

Faults of the open fire

1.) Most open fires are not carefully tended. People do not use dry wood. The fire smokes in practice and inhaled smoke causes serious health problems. 2.) Fires die down quickly creating the temptation to build an overly large fire. 3.) Wind can divert flame and greatly prolong cooking times. 4.) An open fire is messy. Pots and kitchen are covered in soot. 5.) One fire can cook multiple pots of food on a stove, not so over an open fire. 6.) In practice, open fires can be wasteful of firewood and other types of biomass. 7.) An open fire is very dangerous, burns are commonplace.

Earth is not insulation

Any mass around the open fire diverts heat intended to cook food. As well, mass in the stove body can absorb heat, cooling combustion temperatures, resulting in a smokier fire, and prolonging the heating of the pot. Twenty some years ago, earth was thought to be a type of insulation. Making earthen walls around the fire was a common method of stove building. The paradigm of earth as insulation lent credence to this approach. The appealing idea (since earth is free) was that the earth-insulation would help to keep the combustion temperatures high and that the walls would direct errant flames at the pot.

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Studies by Baldwin and others showed the inherent problem in these designs. Earth is not "insulation"; it is a better example of thermal mass. The insulative value of earth is low, about 1/4 R per inch of thickness. Earth is also moderately conductive. Instead of insulating around the fire, earthen walls absorb and divert useful heat resulting in stoves that, unless they are in windy conditions, can use more fuel than open fires and tend to be as smoky or worse. Designing stoves that improve on an open fire requires study, testing, analysis, and an understanding of thermodynamics. Many engineers and dedicated scientists now largely agree how improved stoves can be built. These modern stoves are, at their best, twice as fuel efficient and less smoky than the expertly operated open fire.

How is the modern stove improving over an open fire? 1.) Stoves can burn wood more cleanly creating less pollution. 2.) The stove chimney removes the remaining harmful emissions from the room. 3.) By improving how much heat enters the pot(s) of food, stoves can use less fuel. Stoves create a cleaner, safer environment. Cooking is made easier and more convenient as well.

How to reduce the amount of biomass used for cooking

The fuel efficiency of a cooking stove depends on two factors: combustion efficiency and the efficiency of heat transfer to the pot. Even smoky open fires are turning most of the combusting wood into heat. Smoky fires are often 80 to 90% efficient. On the other hand, the upper limit of heat transfer to the pot is around 50% in cooking stoves without fans. Frequently only 20% of the released heat from biomass makes it into the pot. A common rule in engineering, that improving the least efficient part of a machine results in the greatest gain in improving system efficiency, has directed stove researchers to concentrate on better ways to capture a greater percentage of heat into the pot(s). Since the hardest thing to accomplish in a cooking stove is capturing the heat, improving the heat transfer efficiency determines to a large extent the fuel saving ability of the stove. Achieving almost complete combustion cleans up emissions but it is of secondary importance when designing a stove that burns less wood.

The important design principles that increase heat transfer to the pot(s) are:

1.) Force the heat to rub against as much of the pot(s) outer surface as possible. The heat is forced through small insulated ducts to scrape against the pot(s).

2.) Insulate everywhere around the fire except where heat touches the pot(s). Insulation is made up of small isolated layers of air in a lightweight, relatively non-conductive material. Wood ash, firebrick, dead air spaces, pumice rock, perlite, vermiculite, etc. are good insulators used in vernacular stoves.

3.) Get the pot near to the hot flames. The intense heat is much better at heating food than moderate heat.

4.) Metal pots conduct heat better than clay pots. Multiple pots capture more of the heat than single pots.

5.) Increase the speed of the heat as it hits the pots. Faster hot flue gases punch through the still air that surrounds the pot(s).

How to increase combustion efficiency

Changing all of the biomass into flame is important because fewer poisons are released into the air. If the stove is successful these poisons are burned up inside the combustion chamber. Indoor air pollution can be eliminated by directing harmful emissions up a chimney and out of the kitchen but the plan fails if smoke from the neighbor's stove wafts back in through the open window. Complete initial combustion is preferable.

The modern cooking stove will burn cleaner than the open fire because:

1.) It insulates around the fire. Insulation keeps the fire hot and fierce. Smoke (unburned fuel) cannot easily escape the hot fire.

2.) The stove does not let too much cool air into the fire. Fuel is fed into the fire through a small opening.

3.) The good stove preheats the air that feeds the fire. Swirling air mixes gases, air, and flame to achieve more complete combustion.

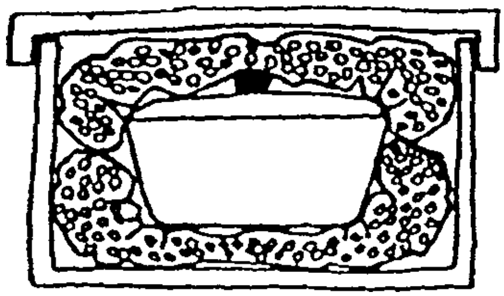
4.) Smoke, that escapes the fire, may be burned up as it passes through hot parts of the cooking stove that provide an improved region for secondary combustion. Combustion of smoke is encouraged by high temperatures and the mixing of fuel, air and spark.

5.) The stove forces the user to meter the fuel. Sticks of biomass lay side by side and burn at the tips as they are pushed into the fire as the fuel is used. Not adding too much fuel greatly assists clean burning.

6.) The cook has an easier time making small hot fires since the insulated combustion chamber and the draft of the chimney keep the fire going automatically. The open fire easily goes out which tempts cooks to make overly large fires.

These, and other design characteristics, improve the efficiency of combustion. It is quite possible to make simple, inexpensive stoves that smoke much less and use about half the fuel compared to a carefully tended open fire. Typically in good cooking stoves, between 90-99% of the fuel is changed into heat and about 40% of the heat enters the pot(s). Many modern stoves can capture approximately 35% of the total amount of released heat into the cooking food. Forcing heat to contact many pots decreases the loss of valuable heat up the chimney. Adding a chimney to any cooking stove, which usually costs less than $10, is a powerful technique that addresses the hazard of breathing the harmful pollutants in smoke.

Retained heat cookers save even more fuel!



Much greater fuel efficiency can be obtained by using retained heat cookers. Once a pot of food has boiled for five to ten minutes, usually all the contents are at 100 degrees C. Removing the full pot from the flame and placing it in an insulated, airtight box allows the food to finish cooking without the addition of more heat. The insulated, airtight box uses the retained heat to finish cooking food, replacing long hours of simmering over flame. (A relatively airtight fireless cooker with insulation rated at R-7 will successfully cook pinto beans after ten minutes of boiling.)

The use of a retained heat cooker (often called a Haybox) can result in savings of over two thirds of the biomass used when simmering food. Beans are often simmered for hours. Hayboxes are very easy to make. Hay or straw works well as insulation. The box can be made from many locally available materials. This simple cooking method saves time and effort for cooks. A Haybox can save more wood than using a modern cook stove, even if the food is heated by an open fire! However, the combination of a modern cook stove and Haybox results in safer, even more fuel-efficient cooking.

Responding to market desires is necessary

The outer appearance of a stove, whether it features a griddle, wok, multiple pots, single pot, a comal, added water heater, baking oven, etc., can flexibly respond to the desires of cooks in a particular region. The design principles and combustion characteristics stay the same and can accommodate any sort of cooking, including baking and water heating. For good reasons, cooks, who are mostly women, tend not to accept a stove if it does not meet their needs.

Therefore, careful and thorough market research, surveys, and analysis must precede the design and manufacturing of a stove. Involving female cooks in the design of a regional stove is a very good idea. Continuing maintenance is much more likely if cooks care for and are involved in their stoves. User groups that supply needed replacement parts may create a self-sustaining beneficial influence. Users become very effective trainers, passing on their familiarity with the new technology. The smooth transition to a new stove is greatly assisted by training from female experts who know and like the new technology.

The Aprovecho experience is that stove preferences may change from village to village. In Honduras, towns fifty miles apart required very different stoves! In one location wood was plentiful and women required clean pots, kept away from soot. The other town was experiencing a wood shortage and a stove that was as conserving as possible was requested. Teams of stove promoters who do not respond to local needs may find their stove abandoned after a short time.

Use of refractory materials

A stove will not last very long unless durable parts are used that can withstand the heat generated by burning biomass. A lot of stoves develop problems after a relatively short time period. The use of refractory materials makes stoves that will last appreciably longer. If a stove will not endure years of normal service, given regular maintenance, users may not like the stove and revert back to the traditional open fire.

The transition to modern cooking stoves

Cooking stoves are a convenience that protect the health of the family and help to conserve the supply of biomass. Obtaining a stove may be the most fundamental sign of improving conditions for a family. The research and development accomplished by many separate groups located all over the world has resulted in a beneficial evolution in stove designs. Careful testing and follow up studies pointed out the problems in the first generation of improved cook stoves. The current generation will be improved by following the same practice. Careful study of the performance of stoves over time is important as is listening to improvements suggested by users.

Shared strategies in designing fuel efficient cooking stoves

The following pages show cooking stove designs from all around the globe. The stoves share an improved strategy of convective heat transfer through small gaps around the pot(s). Many of the stoves are either insulated or low mass. A common design characteristic is sealing the stove body around the top of the pot, diverting smoke into a chimney. Multiple pot stoves also optimize heat transfer by forcing hot air to contact the sides as well as the bottoms of the pots. Stove designers seem to generally agree that how to obtain better fuel efficiency is a well explored problem.

How to increase combustion efficiency

Pellet stoves burn biomass so cleanly that chimneys can exit out of the side of the house. These stoves burn much cleaner than other types of wood burning stoves. Pellet stoves employ two major strategies to accomplish such clean burning: metering the fuel and preheating primary air for combustion. Electric motors assist both functions. A motor controls the dropping of pellets. Another motor creates a draft which forces air past heated areas before it enters the combustion chamber. Vernacular cooking stoves could be as clean burning if they used the same technology. But it seems very unlikely that such a high tech approach will be suitable for most of the people using biomass for cooking today.

There are other simpler non-electrified approaches that attempt to burn wood cleanly as well. Most of these strategies are attempting to accomplish a deceptively simple task. Wood and biomass create smoke when parts of the fuel are not burning. No smoke is made if all of the fuel is burning. The stove that burns all of the fuel without partially heating fuel and thereby making smoke will achieve almost total initial combustion.

While it is simple to state theoretically how “complete combustion” can be achieved, the strategies for achieving this goal in simple, inexpensive stoves are varied. A lot of work has been done on fuel efficiency in wood burning cooking stoves. While individuals have spent decades of work on the problem of complete combustion in vernacular cooking stoves, there seems to be less consensus regarding a successful approach. Careful study of the proposed solutions needs to be done.

The proven techniques that reduce emissions are numerous. A short list of the major approaches includes:

1.) The Rocket type stoves, invented by Dr. Larry Winiarski, have an added feature, the L shaped, insulated combustion chamber and horizontal feed magazine, that increases combustion efficiency, reducing harmful emissions. The Z stove and Tso-Tso stoves, like Rocket stoves, also use a internal short chimney for cleaner burning but they are top loading.

2.) Downfeed/downdraft patterns of burning are cleaner than the horizontal feeding of sticks into the combustion chamber. Any escaping smoke passes over the hot bed of coals and is more likely to combust. Many Rocket stoves use this approach.

3.) Batch feeding of wood allows for the top lighting of biomass. Top burning, where the fire is made on top of the fuel and burns down through it, has been used in European masonry heating stoves for hundreds of years. It is a recognized clean pattern of burning.

4.) Gasification of biomass and the subsequent burning of the gases has intrigued combustion engineers for decades. When the process is working, very clean burning can be accomplished.

5.) EPA approved heating stoves in the US make do with insulating the smaller combustion chamber, encouraging hot burns, preheating air and encouraging secondary combustion in a normal box type combustion chamber. Without careful metering of fuel, these stoves still smoke a bit and rely on the chimney to take pollutants out of the indoor spaces.

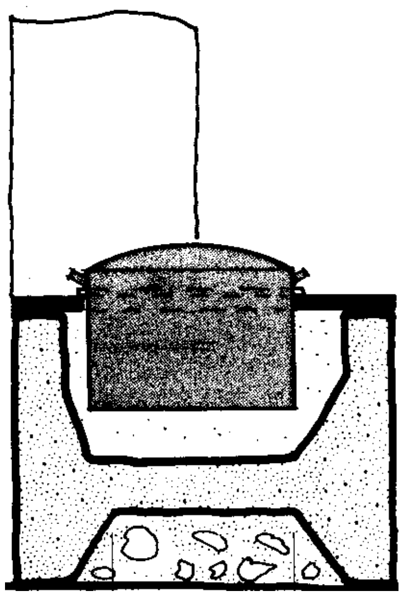
6.) A fan can clean up combustion amazingly well. Blowing on the fire makes for a hot, fierce fire. Using the fan to help preheat the air can turn the stove into a little blast furnace, which is very clean burning. Fans can be used to direct flame and hot flue gases down though the coals which is a very clean pattern of burning.

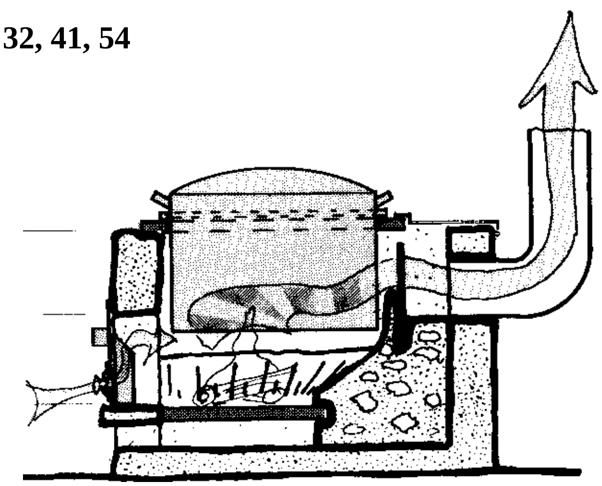
More attention is recently being paid to the reduction of indoor air pollution caused by cooking with biomass. Hopefully this interest will result in studies of the various approaches to cleaner burning.. Many well known strategies are known to reduce emissions. More work needs to be done to determine strategies suited to vernacular cooking stoves.

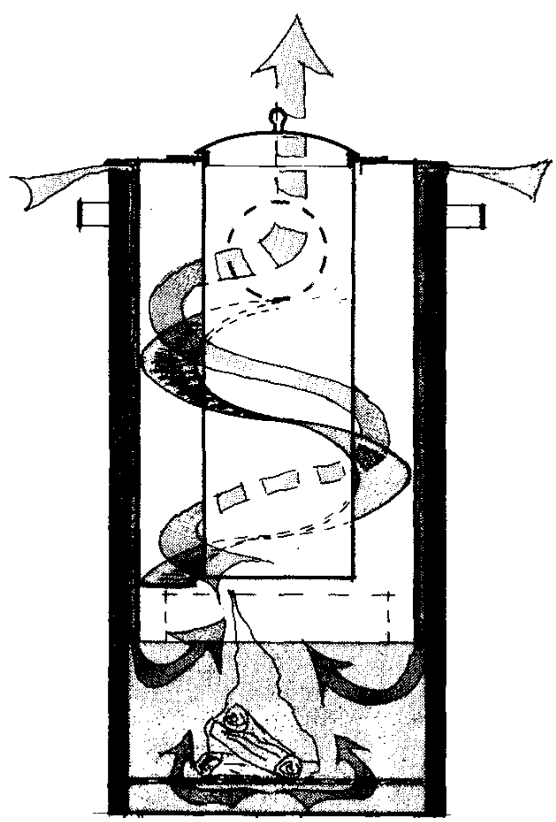
The obvious and historical solution to breathing tainted indoor air is to use a chimney. Adding chimneys to stoves is a simple, first step that is inexpensive and effective. Even the best stoves will smoke a bit now and then so a chimney is necessary to guard the health of householders. It is reassuring that while experts are learning how to burn wood, the solution to smoke in houses has been in use for hundreds of years.

Examples of efficient cooking stoves

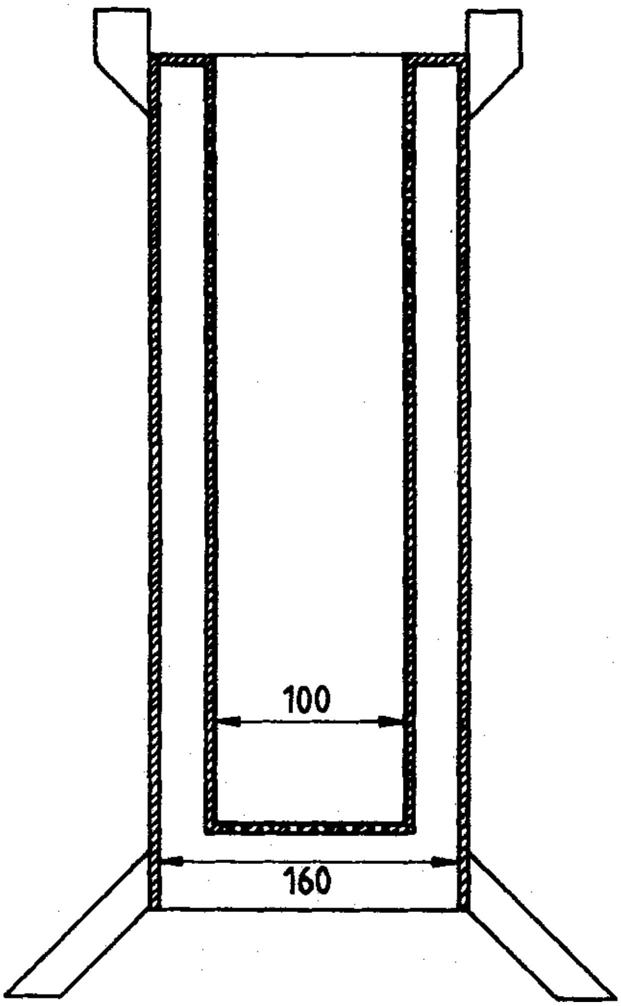
Modern Stoves For All, Micuta, 1981. Pages 32, 41, 54

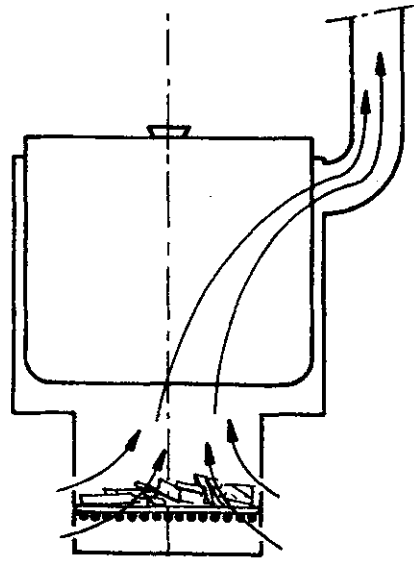


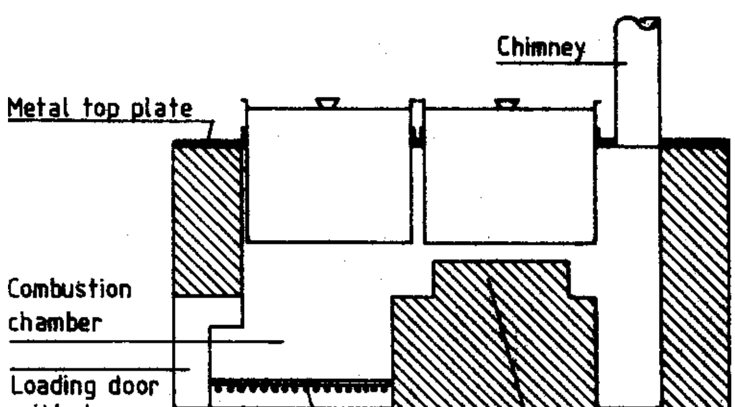




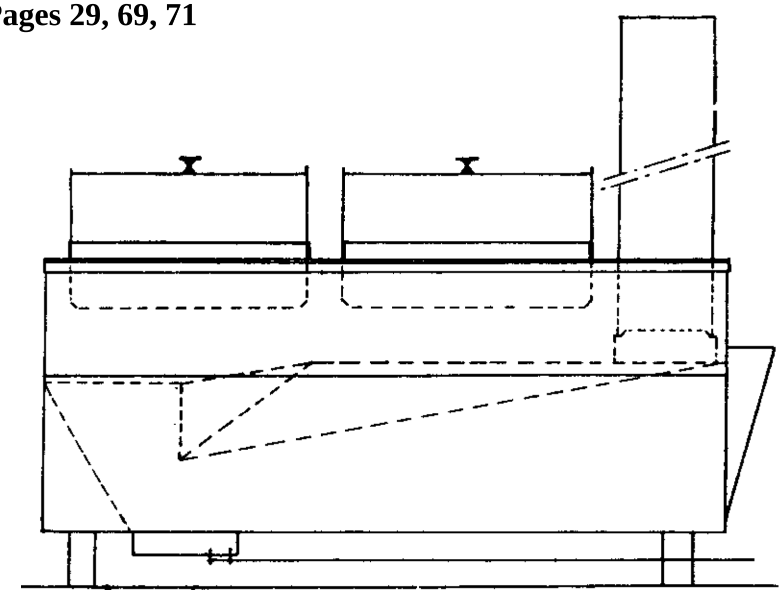
Woodburning Cookstoves, Prassad, Sanger, Visser, 1984. Pages 215, 222, 226

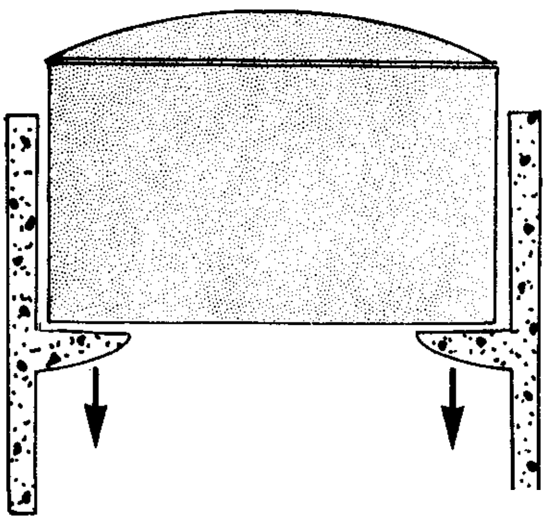


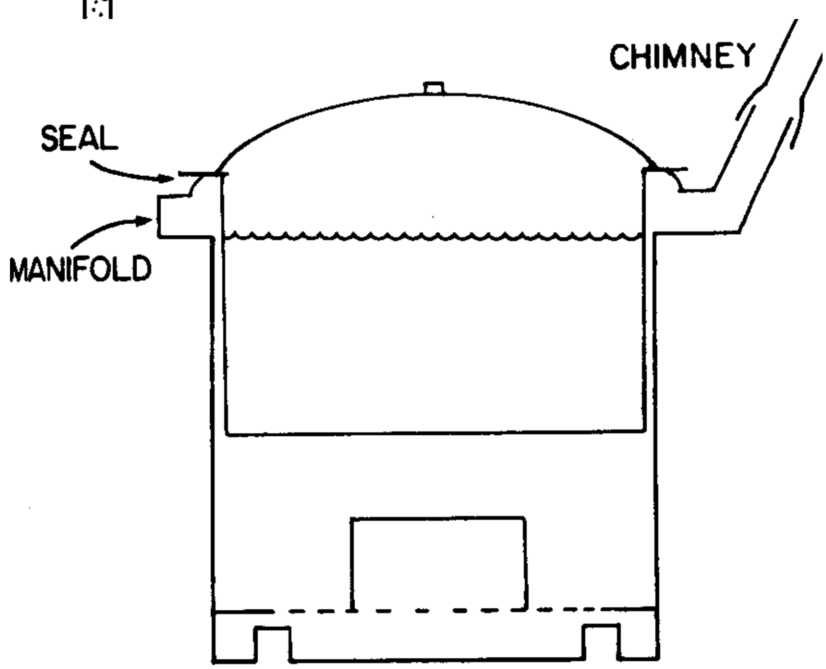




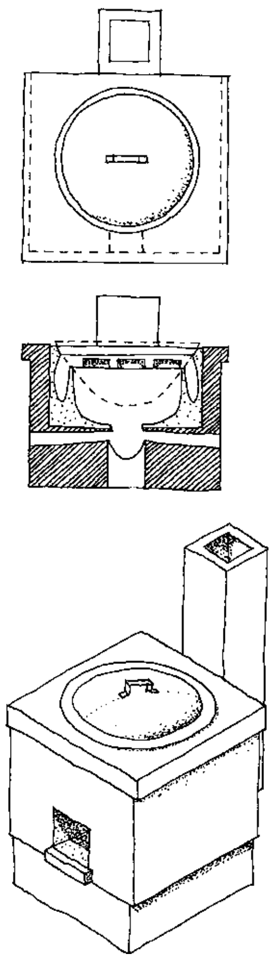
Biomass Stoves, Baldwin, 1987. Pages 29, 69, 71



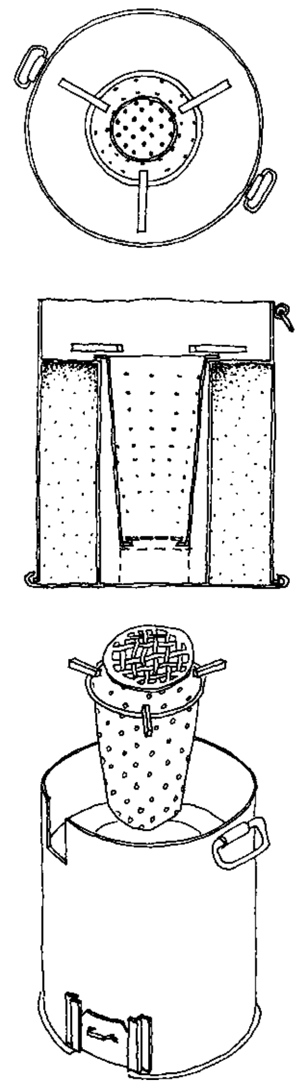




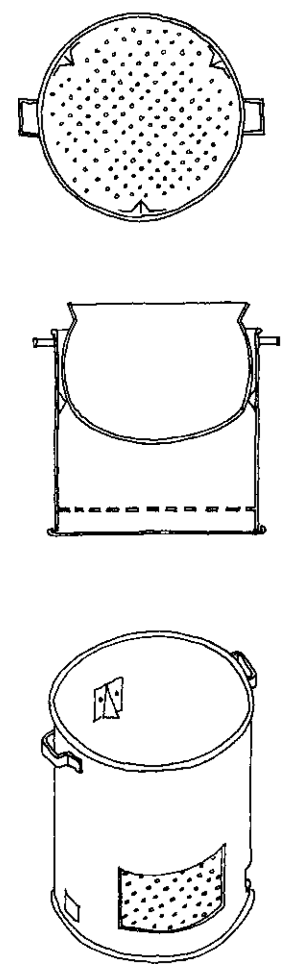
Stove Images, Westhoff, Germann, 1995. Pages 87, 119, 123



Improved Chinese Stove

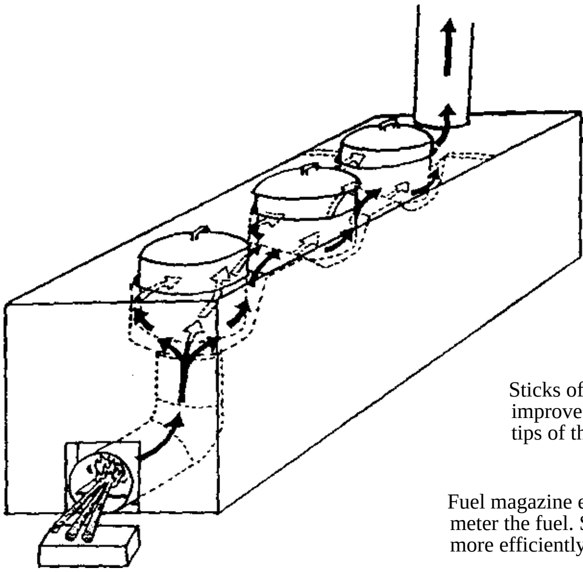


Tso-Tso Stove, Zimbabwe



Mai Sauki Stove, Nigeria

Cooking Food Safely and Efficiently With Fire, Still, 2000. Pages, 11, 12, 13, 9



Rocket Stoves