RECONSIDERING THE STOVE DESIGN PROCESS: SOME PROPOSED SAFETY GUIDELINES

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ABSTRACT

Combustion of biomass is used as the primary form of household energy for approximately 2-3 billion people. This usage has significant impact on families in developing countries. These impacts include deforestation, respiratory infection, and fire related injuries in unnecessary expanse. In an attempt to address many of these problems, a wide variety of biomass cookstoves have been developed that generally deal with increased efficiency and decreased emissions. However, except in a very few cases has the safety of these household energy devices been considered. In this paper, the basic safety concerns of household biomass stoves used in developing countries is considered and a set of safety guidelines based on this review is proposed. These guidelines are intended for testing and evaluating in the field as well as in the design lab.

Keywords: Biomass Cookstove, Safety, Design, Household Energy

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1. INTRODUCTION

Worldwide, approximately 50% of all households and 90% of rural households utilize solid fuels for cooking or heating. This creates large amounts of pollution with particulate matter levels reaching 20 times the allowable amounts in the United States, causing nearly 3% of global diseases [Desai et al, Kammen]. Consequently, an increasingly large effort has been focused on assisting families in developing countries to reduce fuel consumption and reduce air pollution, resulting in numerous household stove designs based on the needs, capabilities, and materials available. Some typical biomass cookstoves are shown in Figure 1. A cookstove may consist solely of a combustion chamber and a fuel loading area, but typically has insulation, a cooking surface, and sometimes a chimney.

[Figure 1 Placed Here]

In the research community, significant attention has been attracted to designing cookstoves that use less fuel, are more efficient, and cost less [Bryden KM et al, McCorkle et al, Smith et al]. But little effort has been focused on the safety of biomass cookstoves. Since the safety of the public must be kept in the highest regard [ASME, 2003], more attension should be given to developing cookstoves that lessen the occurance of injury. This is primarily the responsibility of the cookstove designers and manufacturers, who may be foreign or indigenous.

Cookstoves tend to give a safer environment over that of a three-stone open fire, but they are not completely hazard free. For instance, a cookstove may enclose burning wood and most of the fire, but still allow flames to surround part of the cookpot and easily burn the user's hand. In some cases, cookstoves may even increase the potential of injury. For example, the cooking area on a stove can be high off the ground for added comfort, but this increases the likelihood that a cookpot can be spilled onto children below, resulting in burns and scars.

Much research has been conducted with smoke pollution from buring biomass and its relation to respiratory illness [Bruce et al, Desai et al, Ezzati et al]. Other hazards related to cookstove use may result in burns, scalds, cuts and even loss of property. Since air pollution has been examined in such great detail, the less publicized hazards associated with cookstove use have yet to be examined, and are presented here to provide much needed attention. It is intended that stove designers and manufacturers learn to take into account more safety concerns when designing a stove. This paper considers the risks associated with household biomass cookstoves and provides testing guidelines for stove safety. In Section 2, some common injuries caused by cookstoves are discussed. Then, in Section 3 guidelines and procedures for cookstove safety evaluation are elaborated based on the injury analysis in Section 2. Section 4 provides a summarization of completed work and findings while giving an explanation of future work in the area of cookstove safety.

2. RISK ANALYSIS AND COMMON INJURIES

Injuries associated with cookstove use are most often classified as a burn or a scald, while cuts and abrasions occur less frequently. Women in developing countries who cook using biomass stoves are highly susceptible to burn injuries. Minor burns typically occur from contact with a hot surface and can heal in a short period of time with little or no scaring. Major burns, which often result from contact with flames or boiling liquid, cause disfigurement, immobility, and may even result in death. Shown in Figure 2a is a woman whose skirt, the traditional female dress in many developing countries, caught fire and resulted in third-degree burns to the skin and muscle of the leg. Long hair can be dangerous when cooking over an open flame. The woman in Figure 2b has a diffigured face after her hair caught on fire from flames that were not sufficiently enclosed.

[Figure 2a Placed Here] **[Figure 2b Placed Here]**

A scald is a common injury that occurs frequently to both small children and adults. Women often receive a scald to the hands when trying to move pots from a cooking surface that has raised obstructions along its edges. Improperly placed cookstove handles or a large combustion chamber encasement can create an impediment that tips a cookpot with boiling contents onto the hands of the user. These obstructions also lead to women spilling boiling water onto nearby children. More scald injuries occur when children pull cookpot contents down onto themselves, as shown in Figure 3. Scalds to children often cause great pain and disfigurement to the head or torso and may result in death. In the least, restricted movement results as skin severely constricts in the area of the injury.

[Figure 3 Placed Here]

Children often fall directly into the fire and receive major burns to the hands, arms, and head. Complete loss of hand function or visual sensory may result. Simple activities such as learning how to walk or playing can put children in danger in homes that are very small, typically 3 x 4 meters. Figure 4 shows a child whose hand is being repaired after sustaining injury from falling into a fire during his first steps. This can occur when a mother leaves the house to get more fuel and does not believe her child can walk yet. Adults also receive similar injuries when working on or around the stove, as well as burns from stepping too close to the fire.

[Figure 4 Placed Here]

Cuts and abrasions occur through contact with sharp edges or points along the cookstove. These injuries are less severe than those associated with burns or scalds, but they tend to receive less care. Infection of a cut may occur without proper medical attention and lead to fevers, amputation, or even death depending on the severity of the infection. This is probable when proper medical tools and medicine are not accessible, as is the case in many developing countries. Injuries of this kind can occur when the stove is heated or when it is not being used. Meaing an unlit stove may then appear completely safe when it is in fact not.

Loss of property or housing may result when flames or burning fuel come into contact with surrounding materials. Stoves that do not sufficiently enclose fire or have poor insulation can ignite surrounding structures of materials if placed to close. Loss of the home may result in such instances. Burning homes may not always cause physical injury to the occupants, but the loss of a home is highly undesirable. A family without shelter is at risk to the elements while they find or build a new shelter. Establishing a new home takes much time and money, which can greatly lessen the economic stability of the family and result in further harm.

Based on the risk analysis, ten factors were identified that increase the potential for injury during cookstove use. These are categorized under burns, scalds, property loss, and cuts:

Burns:

- Large amounts of flames surrounding the cookpot can produce third-degree burns on the hands and ignite clothes
- Flames exiting the fuel loading area can easily burn nearby children and adults, as well as ignite clothes
- Excessive cookstove handle temperatures cause improper use and lead to injuries such as first and second degree burns
- Excessively high surface temperatures can cause minor to moderate through with even minimal contact
- The expulsion of embers from burning fuel can result in burns to the body, particularly to the eye, and may include property damage

Scalds:

- Protrusions along the upper edges of the cooking surface create obstructions when moving heated pots from the stove and cause boiling water to be spilt
- Stoves that do not maintain a stable upright orientation result in spilling boiling contents onto persons (especially children) and cause scalds

Property loss:

- Containment of biomass and structural integrity are important so that the fire stays within the stove
- Large amounts of heat transmission to surroundings can cause combustibles and construction in the area of the cookstove to be ignited

Cuts:

- Sharp edges or points often result in cuts but may also cause the cookstove to tip over if clothes become entangled

Utilizing these factors an evaluation and rating system have been developed to examine cookstove safety levels. These procedures are simple and can be used by local or foreign designers and manufactures, giving all parties the ability to improve the safety of a stove. This enables an enhanced conception to implementation safety analysis that greatly minimizes cookstove hazards. With evaluations and metrics given for each of the identified risks, safety concerns can be pinpointed and addressed individually to improve the entire stove in a step-by-step process. An overall safety rating is also provided based upon these individual factors, which allows cookstoves to be compared against each other for their potential to lessen injury. Safety can then be used as selection criteria alongside efficiency and emissions when examining various stoves.

It should be noted that improving safety can easily be accomplish and does not need to induce extra cost or impair cookstove performance. Modifications such as rounding a sharp edge to lessen cuts, widening the base to prevent tipping, or forming the outer edge of the cooking surface to protect children from hot substances can all be accomplished without difficulty. Additionally, each of these improvements increases safety though not adversely effecting efficiency or emissions. This realization is helpful towards developing safer cookstoves while maintaining their unique ability to reduce deforestation, pollution, and disease in developing countries.

3. GUIDELINES FOR STOVE SAFETY EVALUATION

A logical starting place for considering stove safety is to review existing standards used in the United States for rating the safety of indoor and outdoor gas cooking appliances [ANSI Z21.1, 2000; ANSI Z21.58, 1993]. These standards closely paralleled the intended safety measures against the risks of cookstove use, such as cuts, burns, scalds, and the ignition of surrounding materials. This provided a useful reference composed of established testing procedures and standards that are the strictest in the world. Simply using the standards was not possible because the tests were far too complex, require expensive equipment, and use guidelines that are too rigid. Testing procedures often call for sophisticated force gauges and thermocouples with high accuracy and precision. Since these advanced equipment would not be present in developing countries, tests were modified when suitable replacement equipment could not be found. Electric or gas stoves used in developed countries also have a general design pattern that is seldom present among biomass cookstove designs. Safety evaluation was modified to allow for design diversity in the cookstoves undergoing the testing procedure. Levels of safety are included for the ability of a biomass stove to lessen the probability for injury found in the risk analysis. These increments allow for a progression of safety that encourages improvement. Four safety levels have been identified:

1. Poor – major injuries could easily occur;
2. Fair – minor injuries are likely to occur, and a reduced risk of major injuries;
3. Good – minor injuries occur but major injuries are typically avoided;
4. Best – significantly reduced risk that any injury will result.

For the evaluation, a rating of Best has been chosen to model the safety guidelines modified from the ANSI standards. Ratings below that of Best have been created to provide increased sensitivity and allow for progress to be documented more accurately, providing stove designers and manufacturers a way to consider tradeoffs between efficiency, emissions, cost, and safety.

A few criteria express a hazard as being present or not present and do not give an incremented safety rating. For example, the potential for contact with sharp edges and points will be given a rating of Best if no sharp edges or points are present and a rating of Fair if they are present. Other tests may yield a rating of Best if a certain risk cannot be associated with the cookstove. This is the case for the risk of tipping with cookstoves that are secured to the floor or wall. Since these stoves are immobile, they will not be able to tip and automatically receive a Best rating. However, multiple levels of safety ratings are given whenever possible in order to create greater diversity in the safety evaluation to display improvement.

Results from the risk analysis showed ten hazards associated with cookstove use. Each of the risks was researched against existing standards for stoves used in the United States and how the standards may adapt to cookstoves from developing countries. This enabled testing procedures and ratings to be developed for each risk, giving a total of ten safety guidelines.

Test 1: Sharp Edges / Points

Sharp edges and points can cause cuts or result in clothes becoming snagged and the cookstove tipped over. A cookstove without such construction is a safer cookstove, meaning *exterior surfaces of a cookstove should not catch or tear any article of clothing or cut hands that may come into contact during normal use* [ANSI Z21.1, 1.2.4; ANSI Z21.58, 1.2.5]. Testing for this risk is conducted with a piece of cloth, rag, or loose clothing. The cloth is used to rub the entire exterior surface of the cookstove. Areas are noted where the cloth becomes caught or torn. Stone or clay stoves may produce some resistance to material being ran over the surface, but this should not be counted against the stove unless it produces movement or tipping of the biomass stove. The cookstove is given a rating of Best if the cloth does not get entangled or cut, and a rating of Fair is given if the cloth becomes caught or torn. These two are the only ratings for this criterion.

Test 2: Cookstove Tipping

It is important that a cookstove be stable enough to maintain an upright orientation when in operation so that burning or boiling contents do not spill onto persons or surrounding combustibles. This provides the guideline that *cookstoves should come back to rest upright after being slightly tipped* [ANSI Z21.58, 1.3.5]. This test is performed only if the cookstove is not secured to the ground or wall. Immobile stoves receive a rating of Best in this category because tipping cannot occur. All cookstove covers and/or utensils should be left in their normal positions during the test. The tests are performed with fuel in the loading chamber, but not ignited. Several runs are conducted for this test, with an amount equal to the number of legs or corners on the base of the cookstove. That is, the number of trialss corresponds to the amount of directions in which tipping most easily occurs. If the cookstove base is circular, four runs are conducted, with equal separations between each of the tipping directions (approximately one-quarter turn).

A pictorial explanation of the test is shown in Figure 5. The cookstove is tilted in directions that are facing outward and are perpendicular to adjacent legs. On the side being tipped towards, the highest point on the cookstove (which may be the cooking surface) is chosen and its height above the ground is measured and recorded as the starting height. The cookstove is then tipped to that side until the stove can tip on its own. At this point, the new height of the previously chosen point is measured and recorded as the tipped height. With these two measurements, the ratio of the tipped height to that of the starting height is evalutated using a calculator and the following equation:

$$R = \frac{h}{H}$$

R = ratio of heights H = starting height h = tipped height

The user can reference Table 1 to find the safety rating [ANSI Z21.58, 1993]. A cookpot would have been used in this test to more accurately model a higher center of gravity, but it was removed to make testing easier. This was accounted for by slightly lessening the tipping ratios. Accurate and precise measurements should be taken with care because the change in height may be small. The worst result of all the trials is taken to rate the stove for its ability to counteract tipping.

[Figure 5 Placed Here]

[Table 1 Placed Here]

Test 3: Containment

Structural integrity and the containment of biomass is important so that burning biomass does not fall from the stove and cause the surroundings to catch fire if the cookstove does tip over. Unless cookstoves are heavy or mounted they will have at least some potential to tip, and this test provides a way to gauge the safety of the cookstove on how it handles having been overturned. *Flaming embers should seldom fall from the cookstove if it is overturned* [ANSI Z21.1, 1.2.6; ANSI Z21.58, 1.2.13]. This test is performed only if the cookstove is movable, immobile stoves receive a rating of Best because they will not tip. The cookstove should still be loaded with fuel from the last test, but not ignited. Also, small pieces of biomass with sizes of approximately 1 to 3 cm^3 (about the size of a marble) should be placed in the fuel chamber to simulate embers. A ruler or a tape measure is used to find the approximate sizes of the biomass.

This test will be conducted four times in each of the tipping directions found in Test 2. As previously stated, tipping directions are perpendicular to adjacent legs, or in the case of a circular base, approximately one-quarter turn apart. Leaving all natural operating equipment in place, the cookstove is tipped and allowed to fall. Visual inspection of the fallen cookstove shows if any fuel has been expelled. The tip/inspection process is conducted until all runs have been completed, while counting the number of times biomass is released. A summation of the number of times wood fell from the cookstove is caculated. If this total is two or less the cookstove receives a Best rating, three to five instances give a Good rating, Fair describes six to eight, and a rating of Poor is given for cookstoves that allow embers to fall out nine or more times.

Test 4: Expulsion of Ember

The expulsion of embe from burning fuel can result in burns to the body and may include property damage. From this it follows that *embers should have little chance of being expelled from the cookstove*. Large embers have the greatest chance of starting a fire while small embers are hazardous to the eyes. The cookstove is fully loaded for this test, but not ignited. In order to simulate the worst possible scenario, a small pot or pan should be placed in the normal cooking position to yield the largest area from which popping (crackling) wood may be expelled. Then, approximate distance measurements are taken across each gap in the cookstove that fuel can be seen through. Table 2 shows the relation between these measurements and the safety ratings. The larger gap the more likely it is for embers to pass through it when cooking. After the test, the pot is removed.

[Table 2 Placed Here]

Test 5: Obstructions near Cooking Surface

Handles or protrusions along the upper edges of the cooking surface create obstructions that pots collide with when being moved. This often results in heated contents being poured onto hands or nearby children. Consequently, the *area surrounding the cooking surface should be flat*. This test is conducted on stoves that have a flat surface for cooking and do not use a skirt to surround the cookpot. A stove is considered to have a skirt when the lower part of the cookpot rests within an enclosed space that allows the heat of combustion to have further contact with the pot before being released into the air. Biomass stoves with skirts automatically receive a rating of Best because by design there is negligible chance to collide with other components on the stove when lifting the pot from the skirt. However, small obstructions near the edges of a flat cooking surface are hazards and should be judged for their potential to cause injury based upon a difference in height from the flat cooking surface. A ruler is used to measure the difference in height of the cooking surface to the height of any protrusions closely surrounding it. Typically these protrusions are handles along the sides of the stove or the combustion chamber encasement. The largest difference in height is used to rate the cookstove, with a rating of Best being less than 1 cm, a Good rating 1 to 2.5 cm, Fair with 2.5 to 4 cm, and Poor with a difference in height greater than 4 cm.

Test 6: Surface Temperature

Excessively high surface temperatures can cause minor to moderate burns with even minimal contact, such as brushing a leg alongside the stove, or within the small time it takes for the body to react after touching something hot. This lends that *burns should not occur if the cookstove surface is touched briefly* [ANSI Z21.1, 2.18, ANSI Z21.58, 2.15]. Cooking surfaces are not included in this test because they need to be hot in order to cook food. The importance of this test is prevalent seeing that children have a tendency to touch cookstoves [Street et al., 2002]. Since children are more sensitive to heat than adults, lower surface temperatures are suggested for heights that are within the reach of a child (0.9 m or less). Adults can come into contact with any height but heights above 1.5 m, which are considered out of reach of most women and are not tested.

Temperature measurements are taken at various points on the external surface of the cookstove, excluding any horizontal cooking surfaces such as burners or griddles. The first step consists of drawing a grid of chalk in approximately 8 x 8 cm squares along the external surface of the cookstove, creating an identification system that allows easy reference of the intersections of crossing lines. One example of an identification system could be writing numbers onto the cookstove near line intersections, but the cookstove configuration will determine what method is easiest, so user discretion is suggested. Extra thick chalk lines are marked at heights of 0.9 m and 1.5 m on the cookstove (if the cookstove is that tall) to provide useful indicators of what areas are below and above the child line but also below the maximum testing height.

Differences in temperature between the body and cookstove cause heat transfer. When the difference in temperature is large, heat is transferred at a faster rate and burns occur more quickly and severely. The temperature of the skin can vary from person to person, so the ambient air temperature is used to approximate exterior body temp, which is a reasonable assumption in many circumstances. In addition, material composition also affects heat transfer by differences in thermal properties, causing heat transfer to occur at different rates even though the difference in temperature may be similar. Therefore, materials are grouped according to metallic or nonmetallic for the test to provide more accurate results.

The cookstove should be loaded with fuel and can be ignited. More fuel is added when necessary until the cookstove reaches a regular working state. Afterwards, surface temperature measurements are taken using a hand-held thermocouple with the following information being recorded: data point, temperature, above or below the 0.9 m child-line, metallic or nonmetallic material. The maximum values are determined above and below the child-line and on both metallic and nonmetallic materials where applicable. The most deficient rating based on material, temperature, and location will be used to determine the likelihood of a person to avoid harm when coming into contact with the cookstove. Temperature differences between the ambient air and cookstove correspond to the safety ratings given in Table 3 [ANSI Z21.1, 2.18; ANSI Z21.58, 2.15]. The temperature of the ambient air should be measured using a thermometer. Then, the projected ranges for safe cookstove temperatures can be calculated. This is the most efficient method because it requires calculating the acceptable surface temperatures only a few times instead of calculating the difference between the air and surface temperatures at every data point. For instance, if the measured room temperature is 31.5 °C, then a Good rating for metallic components would be $69.5 < T < 75.5$.

[Table 3 Placed Here]

Test 7: Heat Transmission to Surroundings

Large amounts of heat transmission to surroundings may ignite combustibles or construction in the area of the cookstove. This provides the guideline that *cookstoves should not cause extremely elevated temperatures on surrounding surfaces in the environment* [ANSI Z21.1, 2.20; ANSI Z21.58, 2.16]. This test is performed only on cookstoves that will be placed within 10 cm of a combustible or have combustion chambers less than 5 cm in height from the ground. Procedures for this test are similar to that of Test 6, allowing for both tests to be done concurrently if chalk drawings are done before the start of the test. Differences between the temperatures of the wall or floor with that of the ambient air are used to create ranges of temperatures for each safety rating from values in Table 4 [ANSI Z21.58, 1993].

[Table 4 Placed Here]

The cookstove is placed in its normal operating location and orientation (if the test is not performed in the field with the usual location of the stove, find a suitable location for a supplement). Chalk is used to sketch a silhouette of the cookstove on the ground when looking from above and a silhouette on the wall when looking towards the wall. The stove is then pulled away and approximately 8 x 8 cm squares are chalked inside the silhouettes on the floor and wall, with additional squares chalked two high (16 cm) above the silhouette on the wall. Intersections of lines are again given a form of reference chosen by the user. The cookstove is returned back to its normal operating location and orientation and the fuel ignited. Fuel should be added until the cookstove reaches a stable, and regular, working state. Then, the temperature is measured using a hand-held thermocouple at each intersection of lines, while recording the following: data point, temperature, floor or wall.

If measurements cannot be taken without removing the stove, the cookstove can be pulled away for a short period of time, allowing for no more than one minute to transpire when taking data. The cookstove is then placed in its original position for a period of no less than five minutes before taking more data, giving time for the surfaces to warm back up. This process of moving, taking data, and replacing the cookstove occurs until all data points along the floor and wall have been checked. The maximum temperature found on the floor and wall is recorded in the worksheet and the most deficient rating is taken to describe the cookstove. For cookstoves that are designed to be attached to the floor or wall, omit the procedures of this test and use the highest surface temperatures found in Test 6 and subtract 15 centigrade to give approximated wall or floor temperature to account for loss of heat through the air, floor, or wall.

Test 8: Cookstove Handle Temperature

Excessive cookstove handle temperatures tend to cause improper use and lead to injuries such as first and second degree burns as well as scalds. Consequently, *cookstove handle temperatures should not reach a level where use can cause harm either directly or indirectly* [ANSI Z21.1, 2.19; ANSI Z21.58, 2.15]. This test is performed on stoves that have components that may be handled during use, such as doors for the combustion chamber or handles that can be used to move the stove. Stoves that do not have parts that need to be touched during use receive a rating of Best in this category. The test is performed when the cookstove is at its regular working heat production, and can easily be completed along with Tests 6 and 7. Differences between the handle temperatures and ambient air temperatures are given in Table 5. The projected values for both metallic and nonmetallic handles can be computed in the same manner as done in Tests 6 and 7. Temperature readings are taken using a hand-held thermocouple for any and all handles, noting the highest temperature found. This temperature is then referenced against values in Table 5 to describe the safety of the stove, using the lowest rating found.

[Table 5 Placed Here]

Test 9: Flames Surrounding Cookpot

Large amounts of flames around the cookpot can ignite clothes or produce severe burns on the hands and other parts of the body. This shows that *flames touching the cookpot should be concealed and not able to come into contact with hands or clothing*. If the cookstove has a flat cooking surface, such as a griddle, the cookstove receives a rating of Best because all flames are concealed and none can come into contact with a person. The stove should still be loaded and fully ablaze from the last few tests. The typical cookpot used with the particular stove is placed in its normal operating position to simulate how the stove is most often used. The amount of uncovered flames surrounding the cookpot is observed and applied to the metric given in Table 7, which lists the approximate amount of unconcealed flames. After completion of the test, the cookpot can be removed.

[Table 6 Placed Here]

Test 10: Flames Exiting the Fuel Chamber

Flames that exit the fuel loading area can easily ignite clothes and burn nearby children and adults, yielding that *flames should not protrude from the fuel loading area*. Testing the cookstove with this guideline occurs while the cookstove continues to be fully ablaze from previous procedures. Evaluation of the safety rating is done by observing the loading area to discover if flames exit. The cookstove is given a rating of Poor if any flames exit and a rating of Best if flames do not. This test concludes the evaluation procedure and the fire in the cookstove can be extinguished.

Upon calculating safety ratings for each criterion, an overall cookstove safety rating can be determined. The quality of each rating type is transformed into point scores based on the following: Poor-1, Fair-2, Good-3, Best-4, and the results are summed for the overall safety rating. The maximum possible score for a stove is 40 points. Cookstoves with 35 points or greater receive a rating of Best, those with 26 to 34 points are considered as Good, 17 to 25 points give a rating of Fair, and 16 or less points give a stove a Poor safety rating. This overall rating can be referenced with ease and allow for various cookstove designs to be compared against their safety, along with other useful qualities such as efficiency, cost, and fuel consumption.

Equipment used to conduct the tests is kept as simple as possible in order to allow for testing to occur in the field as well as in design laboratories. One or two items may need to be borrowed or bought, but the cost is not large. The following items are required for the safety evaluation process:

- A cookstove
- One cookpot of the size most often used with the cookstove
- The typical biomass fuel used for the stove
- A tape measure or ruler, (SI units) that can measure the height of the cookstove
- Cloth, rag, or some form of loose clothing
- Chalk used to make drawings upon the stove and floor
- A thermometer to measure the air temperature
- A hand-held thermocouple to measure cookstove surface temperature

4. SUMMARY

In this paper, we proposed a set of guidelines and testing procedures for evaluating the safety of biomass cookstoves used in developing countries. The simplicity of the evaluation process allows for designers, manufacturers, and users in the field to test the safety of many stoves. For designers, the rating system provides an effective measure of cookstove safety and can easily be used as added selection criteria when comparing different designs. For local manufacturers and users, the ratings allow individual cookstoves to be examined for areas that could benefit from extra attention. Most importantly, the evaluation shows clearly what can be improved and how much improvement is needed to raise cookstoves to higher levels of safety. For the reasons outlined, use of this safety evaluation and consideration of the guidelines will decrease the likelihood of cookstove injury. The proposed guidelines and testing procedures cover many of the issues with biomass cookstoves, but future work will be conducted in these directions to further lessen the occurrence of injury:

- Further investigate cookstove related injuries and introduce more guidelines. Other safety issues may include fuel safety, ash disposal, and solar cookers;
- Specific aspects of the cooking environment (house orientation/size, social interaction, floor elevation variability) will be researched to give information on how stoves work in varying environments;

- Develop simplified testing procedures for those areas of the world with minimal literacy and equipment;
- Further test the guidelines and procedures on a larger variety of stoves.

Many cookstove related injuries can be avoided if the stoves are properly maintained and operated. Thus, we believe that educational programs should be implemented to highlight the hazards of cookstove use to teach local people proper care. However, it is the obligation of the design and research community to minimize these hazards throughout the development of biomass cookstoves.

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FIGURES

Figure 1. Biomass Cookstoves

Photo Courteously of [O'Neal, 2004]

Figure 2a. Third Degree Burns from Skirt Fire

Photo Courteously of [O'Neal, 2004]

Figure 2b. Facial Disfigurement from Hair Fire

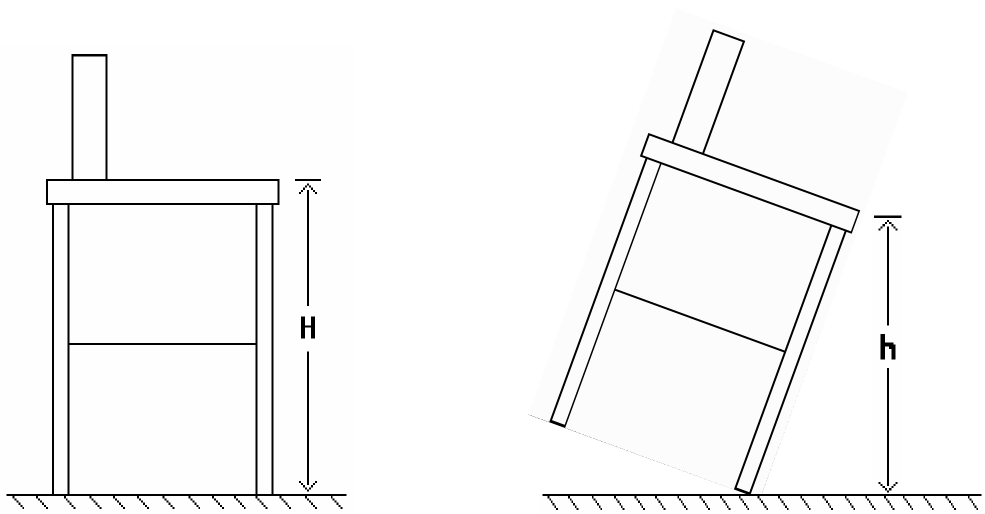
Photo Courteously of [O'Neal, 2004]

Figure 3. Severe Scald from Boiling Water

Photo Courteously of [O'Neal, 2004]

Figure 4. Burn to Hand from Falling into Fire

Photo Courteously of [O'Neal, 2004]



Height H measured prior to tilt.

Height h measured after tilt.

Figure 5. Schematic of Height Measurements for Tipping Test

TABLES

Table 1. Metric for Tipping Test.

Rating	Ratio
Poor	R > 0.978
Fair	0.961 < R < 0.978
Good	0.940 < R < 0.961
Best	R < 0.940

Table 2. Metric for Ember Expulsion Test.

Rating	Hole size (cm)
Poor	d > 5
Fair	3 < d < 5
Good	1 < d < 3
Best	d < 1

Table 3. Metric for Cookstove Surface Temperature Test.

	Below child-line (< 0.9 m)		Above child-line (> 0.9 m)	
Rating	Metallic	Nonmetallic	Metallic	Nonmetallic
Poor	T > 50	T > 58	T > 66	T > 74
Fair	44 < T < 50	52 < T < 58	60 < T < 66	68 < T < 74
Good	38 < T < 44	46 < T < 52	54 < T < 60	62 < T < 68
Best	T < 38	T < 46	T < 54	T < 62

Note: Values Represent Difference Between Cookstove Surface Temperature and Ambient Air Temperature (°C)

Table 4. Metric for Environment Surface Temperature.

Rating	Floor	Wall
Poor	T > 65	T > 80
Fair	55 < T < 65	70 < T < 80
Good	45 < T < 55	60 < T < 70
Best	T < 45	T < 60

Note: Values Represent Difference between Environment Surface Temperature and Ambient Air Temperature (°C)

Table 5. Metric for Handle Surface Temperature.

Rating	Metallic	Nonmetallic
Poor	T > 32	T > 44
Fair	26 < T < 32	38 < T < 44
Good	20 < T < 26	32 < T < 38
Best	T < 20	T < 32

Note: Values represent the difference between cookstove handle temperature and ambient air temperature (°C)

Table 6. Metric for Surrounding Cookpot.

Rating	Amount of Uncovered Flames Touching Cookpot
Poor	entire cookpot and/or handles
Fair	most of cookpot, not handles
Good	less than 4 cm up the sides, not handles
Best	none