Aprovecho Research Center
Advanced Studies in Appropriate Technology
80574 Hazelton Rd. Cottage Grove, OR 97424
541.942.8198 www.Aprovecho.net apro@efn.org

Stove Performance Report
Mayon Rice Hull Stove
June 7th, 2005
Updated July 18th, 2005

INTRODUCTION:

This report serves to provide detailed performance measures of the smaller red model of the Mayon Turbo Rice Hull cooking stove including speed, fuel use, efficiency, and emissions produced. Stove performance is also considered in comparison to a laboratory open fire and the average of four similar wood burning stoves recently tested at the Aprovecho laboratory. Comments are included describing ease of use and recommendations for possible design improvement.

The Mayon Turbo stove reduces both Carbon Monoxide and Particulate Matter when compared to a carefully operated open fire. It is especially successful at reducing Particulate Matter.

RESULTS AT A GLANCE:

The chart below includes the average results of two full emissions tests and one simmer retest of the smaller red model of the Mayon Rice Hull stove:

Results At A Glance

Mayon Rice Hull
Average of Two Full Water Boiling Tests:
2/15/05, 4/15/05,
Simmer and Boil Retest 4/26/05, 5/31/05

Time To Boil 5 Liter of Water	25.1	minutes
Approximate Thermal Efficiency	26%	
Firepower:		
Boiling Firepower	2,879	Watts
Simmering Firepower	3,065	Watts
Turn Down Ratio	1	
Fuel:		
Fuel to Boil 1 Liter of Water	85.2	g/Liter
Fuel To Simmer 1L for 45 min.	159.7	g/Liter
Fuel To Cook 1L	245.0	g/Liter
Energy:		
Energy to Boil 1 Liter of Water	1,128	kJ/Liter
Energy to Simmer 1L for 45 min.	2,055	kJ/Liter
Energy to Cook 1L	3,183	kJ/Liter
Carbon Monoxide Emissions:		
CO to Boil 1 Liter of Water	3.0	g/Liter
CO to Simmer 1 Liter for 45 min.	4.9	g/Liter
CO to Cook 1 L	7.9	g/Liter
***Particulate Matter Emissions:**		
PM to Boil 1 Liter of Water	25.8	mg/Liter
PM to Simmer 1 Liter for 45 min.	26.2	mg/Liter
PM to Cook 1L	52.0	mg/Liter

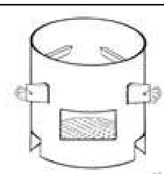
COMPARITIVE PERFORMANCE:

Since 2004, more than 23 cooking stoves sent to the ASAT laboratory have been examined for performance and emissions. Following are the averaged results of two full emissions tests of the Mayon Rice Hull Stove performed under an emissions collection hood. The 2003 revised International Testing Standard Water Boiling Test protocol was followed using rice hulls for fuel and an International Testing Standard 7 liter pot with no lid. In each test series, 5 liters of water was brought to a boil from a cold start, fresh water was added and boiled again from a hot start, and then the water was simmered for 45 minutes. This extensive test is designed to show performance for typical cooking tasks and conditions.

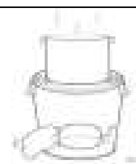
Results of the same Water Boiling Test protocol for the following wood-burning stoves are presented in comparison to the Mayon Rice Hull:


Open fire


Mud / Sawdust


VITA


World Food Program


Ghana Wood

See appendix C for stove details

Time to Boil

	Rice Hull Stove	Open Fire	Average of Four Similar Stoves
Time to Boil 5L of Water (min)	25.1	29.9	18.5

- Time to boil is corrected for a starting temperature of 25C as a means of accurate comparison.

Fuel Consumption

	Rice Hull Stove	Open Fire	Average of Four Similar Stoves
Fuel to Boil 1L of Water (g/L)	85.2	124.1	68.2
Fuel to Simmer 1L of Water (g/L)	159.7	97.5	69.1
Fuel to Cook 1L of Food (g/L)	245.0	221.6	137.4

- Fuel Consumption is corrected for beginning water temperature and reported *per Liter Boiled* in order to account for losses to steam.
- Fuel Consumption is reported in grams of fuel. In this case Rice Hulls (14,400 kJ/kg dry) are compared to Douglas Fir (20,580 kJ/kg dry), which has about a 30% more energy in each unit of mass.

Energy Consumption

	Rice Hull Stove	Open Fire	Average of Four Similar Stoves
Energy to Boil 1L of Water (kJ/L)	1,128	2,136	1,174
Energy to Simmer 1L of Water (kJ/L)	2,055	1,679	1,189
Energy to Cook 1L of Food (kJ/L)	3,183	3,815	2,362

- Energy Consumption is corrected for beginning water temperature and moisture content of fuel.

Firepower

	Rice Hull Stove	Open Fire	Average of Four Similar Stoves
High Power Firepower (Boil)	2,897 W	6,980 W	5,854 W
Low Power Firepower (Simmer)	3,065 W	2,841 W	2,017 W

Turn-Down Ratio	1	2.6	3.2

- Turn-Down Ratio is a measure of a stove's ability to operate at a lower power, found by dividing high power firepower by low power firepower. A turn-down ratio of 1 indicates that the stove can not be turned down for simmering.
- It should be noted that charring of the fuel in the magazine during the simmer phase can lead to unexpectedly higher consumption and emissions.

Emissions per Liter of Water

	Rice Hull Stove	Open Fire	Average of Four Similar Stoves
CO to Cook (g/L)	7.9	10.2	6.6
PM to Cook (mg/L)	52.0	159.6	72.1

*Particulate readings in our emissions monitoring system have still not been deemed accurate in magnitude.

Emissions per Gram of Equivalent Dry Fuel Consumed

	Rice Hull Stove	Open Fire	Average of Four Similar Stoves
Carbon Monoxide			
To Boil (g/g)	0.0478	0.044	0.042
To Simmer (g/g)	0.0757	0.071	0.067
Carbon Dioxide			
To Boil (g/g)	1.7635	1.406	1.818
To Simmer (g/g)	2.9726	2.116	2.662
Hydrocarbons			
To Boil (g/g)	0.0062	0.003	0.004
To Simmer (g/g)	0.0168	0.009	0.013
Particulate Matter			
To Boil (mg/g)	0.3759	1.249	0.922
To Simmer (mg/g)	0.4549	0.361	0.351

Safety

	Rice Hull Stove	Open Fire	Average of Four Similar Stoves
Safety Score (40 is safest)	30/40	20/40	29/40

* Safety score is a composition of safety factors such as likelihood of tipping, burning, ember expulsion, and safety of fuel.

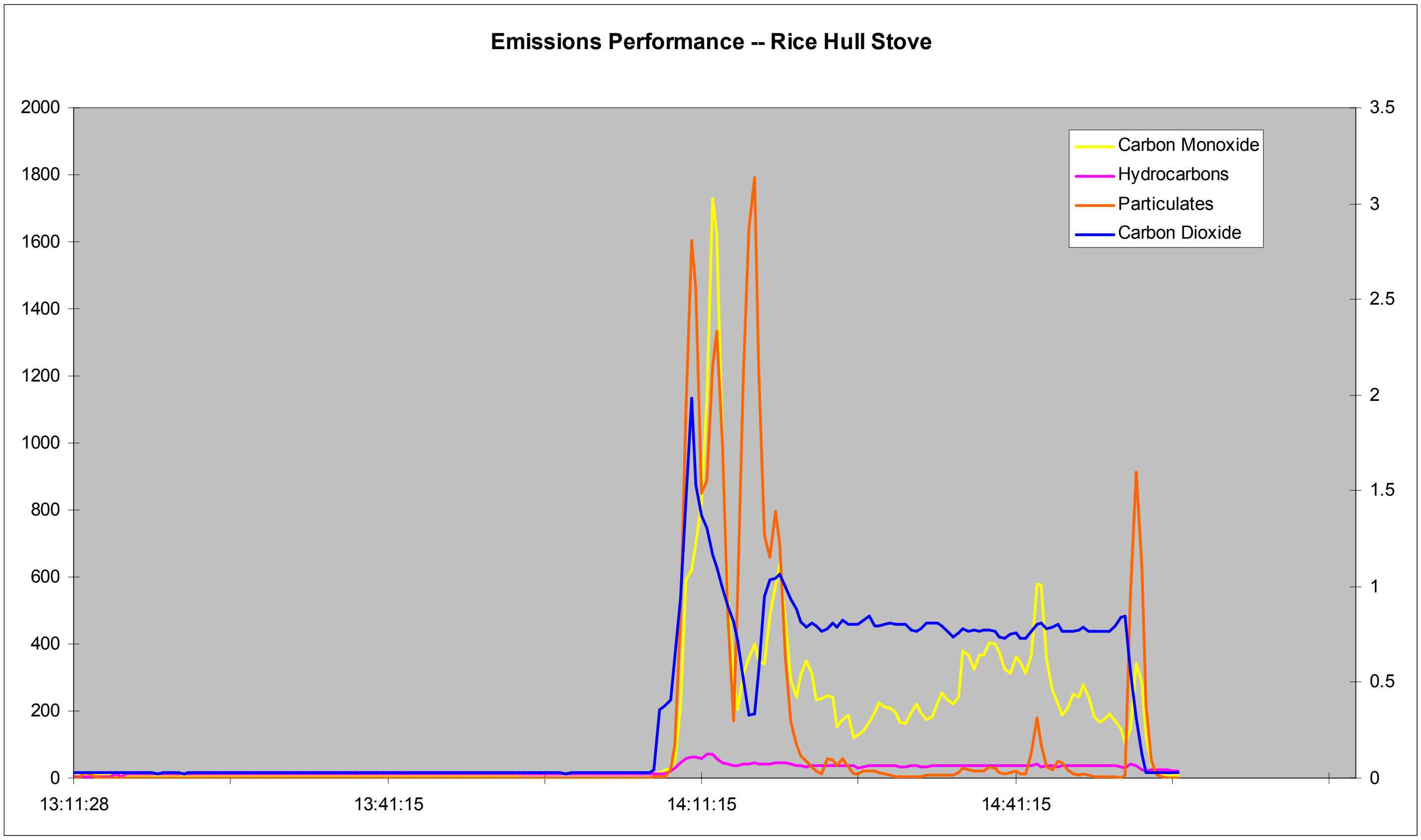
Ease of Use

It was necessary to hit the leg of the stove with a piece of iron every 2 to 3 minutes to keep the fuel feeding and to prevent the fire from going out. Experience was required to operate the stove. Hitting it too hard would cause the rice hulls to spill out the bottom and disrupt the cone of coals. Hitting the stove too infrequently allowed the fire to go out.

DETAILS OF TEST RESULTS:

A detailed procedure of the revised International Testing Standard Water Boiling Test may be found in Appendix A.

While performing the water boiling test, the amounts of Carbon Monoxide, Carbon Dioxide, Hydrocarbons, and Particulate matter are measured. The stove is tested under an emission collection hood which determines the levels of pollutants being produced each second. Below is the real-time Emissions output record of the Rice Hull for a cold-start to boiling test performed on May 31st, 2005.



The graph of a cold stove brought to boiling shows that when the fire is started using kerosene a good deal of smoke is produced, and then the pollutants drop down and level out as the fire is established, rising again slightly each time new fuel is added. These data points are then used to calculate the totals of each substance emitted for each testing phase, and then calculated per liter of water boiled or simmered.

OBSERVATIONS:

- During the hot start phase the rice hulls waiting in the magazine began to smolder. The smoke from the rice hulls smoldering in the fuel hamper raised the levels of recorded emissions.
- It will be important for users to properly operate the stove, including hitting it to help the fuel to feed.
- The fuel magazine should be kept full of rice hulls to discourage smoldering of fuel.
- Since the fire is fairly enclosed, it is difficult to see whether or not the fire is going in daylight.

RECOMMENDATIONS:

A more effective heat shield between the combustion chamber and fuel magazine is recommended.

Appendix A: Water Boiling Test Procedure

The full text, data sheets, and calculation spreadsheet for the revised International Testing Standard Water Boiling Test Procedure can be found at http://ehs.sph.berkeley.edu/hem/page.asp?id=42.

Appendix B: Cookstove Safety Rating Details

Stove safety is an important consideration in any stove program. There are many factors that contribute to the level of safety of a cookstove:

	Rice Hull	Open Fire	Average of Four Similar Stoves
Sharp Edges	3	4	3
Tipping	2	4	3.25
Integrity & Containment	2	2	3.75
Ember Expulsion	4	1	2
Surface Temperature	2	1	2.75
Air Temperature	3	1	3.75
Handle Temperature	3	1	3.5
Flame Around Pot	3	1	3.25
Flame Out Magazine	3	1	1
Fuel Safety	4	4	4
Total	30/40	20/40	30/40

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.

Sharp Edges – 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

Tipping -- cookstoves should come back to rest upright after being slightly tipped

Integrity & Containment -- Flaming embers should seldom fall from the cookstove if it is overturned

Ember Expulsion -- embers should have little chance of being expelled from the cookstove

Surface Temperature -- burns should not occur if the cookstove surface is touched briefly

Air Temperature -- cookstoves should not cause extremely elevated temperatures on surrounding surfaces in the environment

Cookstove Handle Temperature -- cookstove handle temperatures should not reach a level where use can cause harm either directly or indirectly

Flame Around Pot – flames touching the cookpot should be concealed and not able to come into contact with hands or clothing.

Flame Out Magazine -- flames should not protrude from the fuel loading area.

Fuel Safety is a rating of inherent fuel safety, with wood being the safest and methanol being the least safe.

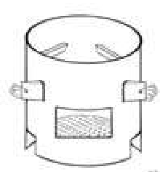
This safety criterion was developed and written by researchers at Iowa State University.

"RECONSIDERING THE STOVE DESIGN PROCESS: SOME PROPOSED SAFETY GUIDELINES", Nathan G. Johnson, Kenneth Mark Bryden*, Angran Xiao Virtual Reality Applications Center, Iowa State University, Ames, IA 50011

Appendix C: Stoves Used in Comparison

Aprovecho has performed extensive testing on 4 cooking stoves without chimneys in addition to the Bangladesh stove. Each table includes test results of the Mud/Sawdust stove, a close relative to the Bangladesh stove with slightly different design. Photos and descriptions of these stoves are found below:

Mud / Sawdust Stove	
	The earthen wall was made using 60% sand and 40% clay. Sawdust was added to help lighten the wall and to create a better insulation. 12mm of newspaper and cardboard was wrapped around the pot. The earthen mixture was then formed around the pot. Leaving a 12mm gap for the hot flue gasses to scrape against the sides of the pot.

VITA Stove	
	The VITA stove is easily made from sheet metal. The air inlets and size of the opening into the fire are scientifically designed. The VITA stove demonstrates how a narrow channel works, forcing more of the heat into the sides of the pot. The grate in the VITA stove allows air to pass up through the burning wood, which helps to maintain the fire.

<table>
<tr><th colspan="2">World Food Program Stove</th></tr>
<tr><td></td><td>The stove contains an L shaped combustion chamber surrounded by wood ash, a natural insulation. The insulation around the fire makes it burn hotter which helps to reduce smoke. A sheet metal wall around the pot increases heat transfer which reduces the amount of fuel used for cooking</td></tr>
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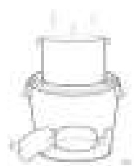
<table>
<tr><th colspan="2">Ghana Wood Stove</th></tr>
<tr><td></td><td>The Ghana stove is bucket shaped with a thick ceramic liner inside a black sheet metal body. The pot sits on top of the stove. Unlike the Mud / Sawdust and VITA stoves the heat only touches the bottom of the pot.</td></tr>
</table>

Appendix D: Design Principles

The attached .pdf file is taken from the Shell / PCIA book, “Design Principles for Wood Burning Cook Stoves” by Dr. Mark Bryden, Dr. Tami Bond, Dean Still, Damon Ogle, Nordica Hudelson.