RICE HUSK GAS STOVE HANDBOOK

Alexis T. Belonio

With "Preface" by Paul S. Anderson

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He was awarded as “Outstanding Professional in the Field of Agricultural Engineering” by the Professional Regulation Commission of the Office of the President, Republic of the Philippines in 1993. In that same year, he was also awarded “Outstanding Agricultural Engineer in the Field of Farm Power and Machinery” by the PSAE. In 1997, the Ten Outstanding Young Men and the Gerry Roxas Foundations awarded him as “The Outstanding Young Filipino in the Field of Agricultural Engineering.”

At present, he is actively engaged in various undertakings in the fields of biomass cookstoves, gasifiers, furnaces, kilns, and ovens. He also serves as Consultant to various private manufacturers/companies, government, and non-government organizations.

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DEDICATION

This handbook is dedicated to You, Lord Jesus Christ, who is the only source of wisdom and knowledge in all of my research and development works, especially in this rice husk gas stove technology. Without Your help Lord, I could not have done anything. As what your word says, "If a man remains in me and I in him, he will bear much fruit; apart from me you can do nothing" (John 15:5). But, "I can do all things through Christ who strengthens me"(Phil. 4:13).

To you Lord, I give back all the glory, honor, thanksgiving and all the credit for this technology. May Your Name, Lord Jesus, be lifted up in all my undertakings and be made known to those who will use this Handbook.

Proverbs 3:5-6, it says "Trust in the Lord with all your heart and lean not on your own understanding; In all your ways acknowledge Him, and He shall direct thy path."

ACKNOWLEDGMENT

As an expression of my gratitude, I would like to thank above all else my God and my Savior, Jesus Christ, for enabling me develop this technology.

I am also grateful to the Almighty God for the following people whom He used and whose contributions are instrumental in the development of the rice husk gas stove and in the completion of this Handbook:

- To Dr. Juanito M. Acanto, President, Central Philippine University, for releasing blessing to us at the Appropriate Technology Center to develop technologies that will uplift the living status of the people especially those at the grass root level;
- To Dr. Randy Anthony Pabulayan, Director, University Research Center of CPU, for providing the fund to print this Handbook;
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- To Dr. Tom Reed of Biomass Energy Foundation, for encouraging me to do more developments on this technology;
- To Ms. Feri Lumampao of APPROTECH ASIA, for supporting me in the development and promotion of this stove technology nationwide and in the whole world;
- To Ms. Cristina Aristanti of the Asia Regional Cookstove Program (ARECOP), for giving me the privilege to attend the Training Seminar in Gasifier Stove at the Asian Institute of Technology, Thailand in 2003, where I saw similar stove utilizing wood as fuel, from which development of this rice husk gas stove was based;
- To Dennis and Rommel for fabricating the stove and for contributing a lot in making the unit more applicable for commercial use;
- To Professor Hope Patricio for diligently editing this manuscript;
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- To my wife, Salve, and my children for their prayers, encouragement, and inspiration to carry out this task through completion; and
- To all who bought a unit of this stove for reproduction in their respective places all over the country, and to all who signify their interest in the technology through email and cellular phones.

Thank you so much to you all! And, I give all the glory and honor to Jesus, my Lord and my Savior!!!

Alexis T. Belonio

TABLE OF CONTENTS

NOTES:

The page numbers at the bottom center of each page match the numbering of the .pdf document pages.

The page numbers in the upper left and upper right of the pages starting with Chapter I are the numbers that match the page numbers in the Table of Contents, and are the official numbers to be used in bibliographic references to this handbook.

The margins are sufficient to allow printing on either A4 paper or "Letter size" paper (8.5 x 11 inches).

LIST OF TABLES

LIST OF FIGURES

PREFACE

The importance of this “Handbook” and the work of Engr. Alexis Belonio should not be underestimated. I have been given the honor to write this Preface, and **my intent is to illustrate the importance of this work.**

The search for technology for **clean combustion of low-value dry biomass in small stoves suitable for residential cooking** has been on-going for hundreds, if not thousands, of years. One relatively new technology was identified and initiated in 1985 by Dr. Thomas B. Reed. He originally called it **“Inverted DownDraft” (IDD)** gasification, but recently we have also called it **“Top-Lit UpDraft” (T-LUD)** gasification, a name that more clearly denotes what is actually happening in this combustion technology. The terms “gasifier” and “gasification” refer to having any type of **combustible gases from dry biomass created *distinctly separate* from the combustion of those gases,** even if the separation is only a few millimeters and/or milli-seconds.

Developments and adaptations of **Dr. Reed’s IDD or T-LUD technology** during the past twenty years have been slow, mainly without commercial products, but **discussed and shown occasionally as a combustion curiosity on every inhabited continent.** At one conference/workshop in Thailand in 2003, someone from Sri Lanka gave a demonstration seen by Engr. Belonio.

Alexis Belonio is an Agricultural Engineer who **specializes in rice husks and had previously made other stoves.** For him there was only one question: Could rice husks be meaningfully combusted in one of these small gasifiers? For three years he worked in virtual isolation, but not in secrecy. He simply did not have awareness of what others were doing and writing. When I first contacted him by e-mail in October 2005, I introduced him to the specialized literature and to the terminology of IDD and T-LUD gasification, which he has readily accepted as applicable to his rice-husk stove.

By not having the prior literature, **he was unaware that what he was trying to do had been determined by Dr. Reed, myself and others as not being possible in a viable T-LUD stove.** He did not even know that he should have been highly surprised that he has succeeded where others have stopped short of success. Therein reside **the three most important aspects of his work!!!!**

A. The Belonio Rice Husk Gas Stove is the first (and currently only) T-LUD gasifier that **can utilize a small-particle fuel.** This stove will pass primary air upward through a thirty-five centimeter column of dry rice husks, allowing the pyrolysis and char-gasification processes to consistently descend through the fuel column. This means:

1. the ability to use raw unprocessed abundant rice husks as a fuel for residential cooking, and

2. the positive prospects for accomplishing similar T-LUD gasification for other small-particle fuels such as sawdust, husks from cacao and soybeans, and uniformly coarse (not powdery) by-products from other agricultural and industrial products, perhaps even sugar cane bagasse.

B. The Belonio Rice Husk Gas Stove **provides a final flame for cooking that is distinctly more blue** (with the higher quality gases of H_2, CO, and CH_4) than in the other variations of Reed's IDD technology with mainly yellow flames from burning tars and other long hydrocarbons released in pyrolysis. This means:

1. probably even cleaner combustion than what has been very favorably measured for Reed's "WoodGas CampStove" and Anderson's "Juntos B" T-LUD Gasifier, and
2. favorable prospects for replicating that blue-flame combustion in other small gasifiers using other fuels.

C. The Belonio Rice Husk Gas Stove can **operate with remote combustion** (as opposed to the "close-coupled combustion" used in all other T-LUD gasifier stoves). In other words, the top of the gasifier can be closed and the gases can be piped to remote burners, undergo cooling, and still produce a wonderful clean blue flame in traditional LPG stove burners. This means:

1. the batch-fed small-scale T-LUD technology has fully entered the world of the larger and standard-setting gasifiers, and
2. the gases could probably be cooled, filtered and stored for use-on-demand, possibly including use in high-value tasks like lighting or fueling internal combustion (IC) engines for mechanical power or electricity generation.

These three results alone are sufficient to mark Engr. Alexis Belonio as easily **one of the world's top-ten developers of stoves using the IDD / T-LUD technology.** Such stoves form a small "pond" without many "fish," but he is already a big fish in that small pond which could someday become a lake or even an ocean for improved cookstoves.

Not everything is perfect. Much work still needs to be done. Already Dr. Reed, Engr. Belonio, and myself have agreed to close collaboration for further advances, and all others who are interested are invited to join with us. The tasks include:

Fuels: greater varieties of fuels and assurance of adequate supplies,
Combustion: further work on both forced-air and natural-draft versions, plus larger and smaller versions,
Applications: appropriately designed structures for cookstoves, for space heating, for small heat-use industry, and the high-value tasks of lighting and IC engines,

Human factors: reduction of cost of the various devices, designs for specific populations, gaining acceptance by the users, relations with governments and NGOs for rapid dissemination, and more.

We will be working on these and other issues as fast as we can. But we will not be waiting for perfection before dissemination of the results. As an example of this, I have encouraged Engr. Belonio to make minor changes in the draft of this document and then proceed to **release this "Handbook" as soon as possible.** This is his work, he deserves recognition for it, and the information should not be delayed while awaiting a re-writing. His future work is likely to include co-authors with a blending of ideas, styles, and credits. Let him be recognized now for the major work he has accomplished with so little outside influence.

The year 2005 is the **Twentieth Anniversary of Dr. Tom Reed's initial revelation and experimentation about inverted downdraft (IDD) or top-lit updraft (T-LUD) combustion.** Two major causes for celebration are the Belonio Rice Husk T-LUD Gas Stove and the independent testing at the Aprovecho Research Center that reveals the higher quality (lower emissions) of the T-LUD combustion technology. Therefore, we look forward to 2006 when the innovative IDD / T-LUD technology "comes of age" (21 years old) with expressions and applications in various countries around the world.

Paul S. Anderson, Ph.D. 10 November 2005
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Note: For those wanting to accompany the developments of T-LUD gasifier technology, the best single source is to visit the Stoves website at: http://www.repp.org/discussiongroups/resources/stoves and then search "Contributions by List Members" seeking the names of the authors, or by searching for the keywords like T-LUD and IDD and gasifiers. Also, consider joining the Stoves List Serve (via the same website address) and participate in the wide-ranging discussions and developments of all types is stoves for developing societies and our resource-challenged world.

CHAPTER I

INTRODUCTION

Figure 1. The Liquefied Petroleum Gas Stove.

Liquefied petroleum gas (LPG) is one of the conventional sources of fuel for cookstoves in the Philippines (Fig. 1). The use of LPG as source of fuel is common both in the urban and in the rural areas, particularly in places where its supply is readily accessible. The main reasons why LPG is widely adopted for household use are: it is convenient to operate, easy to control, and clean to use because of the blue flame emitted during cooking. However, because of the continued increase in the price of oil in the world market, the price of LPG fuel had gone up tremendously and is continuously increasing at a fast rate. At present, an 11-kg LPG, that is commonly used by common households for cooking, costs as high as P540 per tank (US$1 = PHP55) in urban areas or even higher in some places in rural areas. For a typical household, having four children, one LPG tank can be consumed within 20 to 30 days only depending on the number and amount of food being cooked. With this problem on the price of LPG fuel, research centers and institutions are challenged to develop a technology for cooking that will utilize alternative sources other than LPG. The potential of biomass as alternative fuel source to replace LPG is a promising option. (7, 8)

For the past years, gasifier stoves using wood as fuel has been developed in countries like the US, China, India, Thailand, Sri Lanka, and other developing countries in Asia. These gasifier stoves produce a flammable gas by burning the fuel with limited amount of air. Wood gas stove was found promising to replace the conventional LPG stove. This stove has a minimal problem on carbon dioxide emission during cooking since it produces primarily carbon monoxide. However, with the problem on forest denudation facing the country combined with the need for fuel for cooking requirement, there is a need for us to look for alternative biomass fuel, other than wood, that can be used for cooking.

Rice husk biomass waste is very much abundant in the Philippines. This waste material can be found elsewhere and oftentimes we can see piles of rice husks at the back of the rice mill (Fig. 2), where they are stacked for disposal or some are thrown (Fig. 3) and burned on road sides to reduce its volume. (1, 8)

Figure 2. Disposal of Rice Husk at the Back of Rice Mill.

Voluminous amount of rice husks can be found in areas predominantly in rice producing regions, such as the Central Luzon, Western Visayas, Bicol, Cagayan Valley, and Central Mindanao. About 2 million metric tons of rice husks (Table 1) are produced annually. If this waste can be converted into fuel for domestic

Figure 3. Dumping of Rice Husk on Road.

Table 1. Rice Husks Annual Production by Region.

	Metric Tons
Philippines	1,932,846
CAR	39,064
Ilocos	168,125
Cagayan Valley	203,793
Central Luzon	341,191
Southern Tagalog	203,504
Bicol	149,098
Western Visayas	255,000
Central Visayas	38,004
Eastern Visayas	85,225
Western Mindanao	74,812
Northern Mindanao	78,019
Southern Mindanao	133,328
Central Mindanao	163,683

cooking, there will be a lot of households that can be benefited, and more dollar savings for the country can be achieved. (1, 24)

The rice husk gas stove developed at the Appropriate Technology Center of the Department of Agricultural Engineering, College of Agriculture, Central Philippine University, Iloilo City was proven to produce a luminous blue flame for cooking using rice husks as fuel. Employing the concept of burning fuel in a controlled environment can gasify rice husks to produce a fuel like LPG.

Historical Background of the Rice Husk Gas Stove Development

The rice husk gas stove development in the Philippines started way back in 1986 when the Department of Agriculture – International Rice Research Institute (DA-IRRI) Program for Small Farm Equipment, headed by Dr. Robert Stickney, developed and introduced the first downdraft rice husk gasifier stove. The potential of this technology as a replacement to the use of wood fuel and wood charcoal for domestic cookstoves led the Department of Agricultural Engineering, College of Agriculture, Central Philippine University, Iloilo City (DAE-CA-CPU) to further develop a similar technology in 1987. With some problems encountered, especially in the excessive tar produced from the gasification of rice husks, the rice husk gas stove technology was left on hold for a moment. In 2000, with the establishment of the Appropriate Technology Center (ATC) under the Department, different designs of cookstoves were developed utilizing rice husk as fuel. Through a collaborative program with The Asian Alliance of Appropriate Technology Practitioner Inc. (APROTECH ASIA) and the Asia Regional Cookstove Program (ARECOP), the Author was given an opportunity to attend the Training on Wood Gasifier Stove at the Asian Institute of Technology in Thailand in 2003. In this training, an Inverted Down-Draft (IDD) or Top-Lit Updraft (T-LUD) wood gasifier was demonstrated by a Sri Lankan participant, was found promising to be used for rice husks as fuel without experiencing the problems encountered in the previous designs of rice husk gasifier. In the late 2004, a proto-type rice husk gasifier stove following the IDD/T-LUD concept was fabricated as a student project. Performance test and evaluation which were carried out in early 2005, showed that rice husk fuel for IDD/T-LUD gasifier was proven to be a good alternative technology for the conventional LPG stoves. After six months of continued development, a commercial model of the gasifier stove was introduced in the market for utilization. Initially, 30 units of the stove had been commercially sold (See Table 7) for reproduction and for promotion all over the Philippines. (7, 10, 11, 12)

Benefits of the Technology

The rice husk gas stove technology was found to have the following advantages, not only to users but to the general public as well:

1. It is a good replacement for LPG stove, particularly in terms of fuel savings and quality of flame (i.e., luminous blue flame) produced during cooking. By direct energy

conversion, about 23 tanks of 11-kg LPG fuel can be replaced by a ton of rice husks.

2. It will significantly reduce the cost of household spending on conventional fuel sources such as electricity, kerosene, wood, and wood charcoal. Appendix 4 shows the energy conversion of rice husks to other fuel sources.

3. It will help minimize the problem on rice husk disposal which contributes a lot on environmental pollution, especially the burning of this waste on roadsides and the dumping of the same along river banks. In this single burner rice husk gas stove, one kilogram of rice husk fuel per load per cooking will be used. For a typical Filipino family, about 1.095 tons of rice husks will be consumed per year in using this gas stove. In the Western Visayas region alone, if 25% of the entire household of 1,211,734 families (See Appendix 5) will use rice husk gas stove, 32,933.5 metric tons of rice husks are estimated to be consumed in a year.

4. It will help reduce the carbon dioxide emission in the air brought about by the excessive burning of wood and other biomass fuel in the traditional cookstoves, which contributes to the ozone layer depletion and consequently in the "greenhouse effect" into the atmosphere. (27)

5. It will help preserve the forest by reducing the cutting of trees for the production of wood fuel and wood charcoal thus, minimizing problems concerning drought during summer and flood during rainy season. For every ton of rice husks utilized for cooking, about 847.45 kg of wood and 510.20 kg of wood charcoal (Appendix 4) can be preserved.

6. It will provide employment and income generating projects for Filipinos in the production and marketing of the stove, and even in the selling of rice husk fuel in the future.

6

This handbook briefly describes the IDD/T-LUD gasifier that uses rice husks as fuel. The design, performance, and the fabrication of the stove are illustrated in detail in the succeeding chapters to provide interested individuals and organizations a comprehensive guide in designing, fabricating, and operating the stove.

This is just the first release of the series of edition of this handbook. Comments and suggestions are highly solicited to further improve this handbook.

CHAPTER II

THE RICE HUSK GAS STOVE

The rice husk gas stove is a recently developed device for domestic cooking utilizing rice husks as fuel. The stove was designed to burn rice husk using limited amount of air for combustion to produce a luminous blue flame, which is almost similar to that of the LPG stove.

Figure 4 below shows the various major parts of the rice husk gas stove. Two models of the stove are shown in Figure 5.

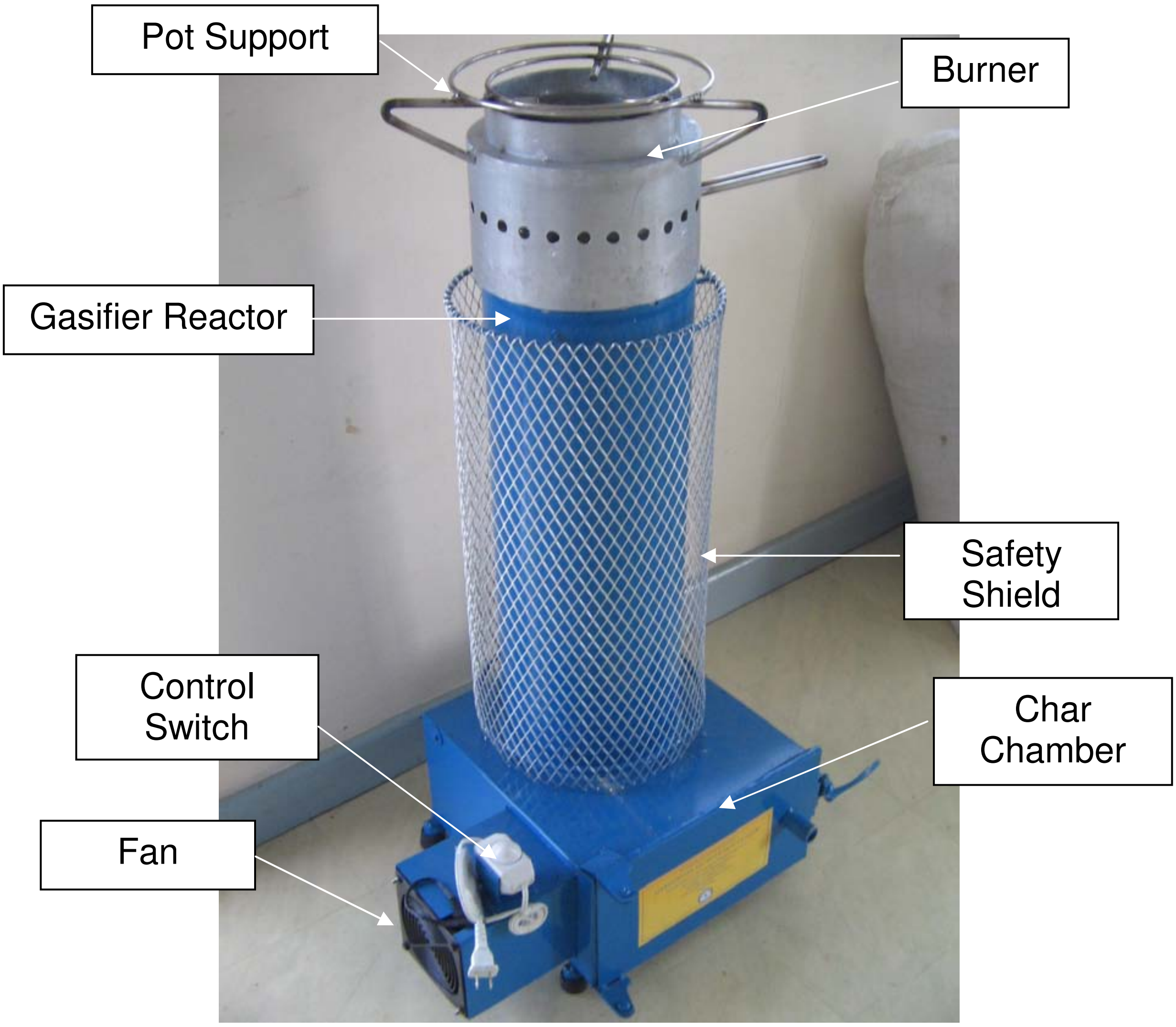

Figure 4. The Rice Husk Gas Stove Showing Its Various Parts.

8

(a)

(b)

Figure 5. Two Different Models of the Rice Husk Gas Stove: (1) Without Safety Shield, and (b) With Safety Shield.

WARNING !!!

The rice husk gas stove emits a flammable and poisonous gas. Make sure that the gas produced during operation is properly burned in the burner. DO NOT INHALE THE GAS EMITTED FROM THE STOVE BECAUSE IT IS TOXIC AND INJURIOUS TO HEALTH. The stove should only be operated in a well-ventilated place to avoid suffocation.

The Gasifier Stove Reactor

The gasifier stove reactor (Fig 6.) is the component of the stove where rice husks are placed and burned with limited amount of air. This reactor is cylindrical in shape having a diameter of 0.10 to 0.30 m, depending on the power output needed for the stove. The height of the cylinder varies from 0.4 to 1.0 m, depending on the required operating time. The cylinder is made of an ordinary galvanized iron sheet gauge no. 18 on the outside and of a stainless steel sheet gauge no. 20 in the inside. This cylinder is provided with an annular space of 2 cm, where the burned rice husks or any other materials is placed to serve as insulation in order to prevent heat loss in the gasifier. At the lower end of the reactor is a fuel grate made of stainless steel material, which is used to hold the rice husks during gasification. This grate is positioned such that it can be inclined to easily discharge char after each operation. The grate is controlled by a spring or a lock to set it in proper position during operation. At the outside of the reactor are circular rings that hold the aluminum screen to keep the hands from accidentally touching the hot reactor during operation.

Figure 6. The Gasifier Stove Reactor.

The Char Chamber


Figure 7. The Char Chamber.

The char chamber (Fig. 7) serves as the storage for char produced after each operation. It is located beneath the reactor to easily catch the char that is falling from the reactor. This chamber is provided with a door that can be opened for easy disposal of char and it must be kept always closed when operating the gasifier. The char chamber is tightly fitted in all sides to prevent the air given off by the fan from escaping the chamber hence, minimizing excessive loss of draft in the system in gasifying the fuel. Four (4) support legs with rubber caps are provided beneath for the chamber to support the entire stove.

The Fan Assembly


Figure 8. The Fan Assembly.

The fan assembly (Fig. 8) is the component of the stove that provides the air needed by the fuel during gasification. It is usually fastened on the char chamber, either at the door or at the chamber itself, to directly push the air into the column of rice husks in the reactor. The fan used for the standard model is a 3-inch diameter axial-type fan that is commonly used for computers. It has a rated power input of 16 watts using a 220 volt AC line. A manually-operated rotary switch is used to control the speed of the fan which, in turn, controls the flow of gas to the burner during operation.

The Burner

Figure 9. The Burner.

The burner (Fig. 9) converts the gas coming out from the reactor to a bluish flame. It consists of series of holes, 3/8-in. in diameter, where combustible gas is allowed to pass through. The secondary holes located at the periphery of the burner are used to supply the air necessary for the combustion of gases. On top of the burner is a pot support that holds the pot in place during cooking. The burner is removable for easy loading of fuel into the reactor and is set in place during operation.

Advantages and Limitations of the Stove

The stove has the following advantages as compared to other commercially available stoves:

1. It uses no cost rice husk fuel, which means cost savings to users.
2. It is convenient to operate since the start-up of fuel can be done by using pieces of paper, and gas is ignited using a match stick.
3. Almost no smoke can be observed during cooking.
4. It can cook rice and two viands per cooking, which is good enough for a family of 4 to 6 members.

5. The degree of burning the fuel can be controlled using a rotary switch. Hence, the amount of flame on the burner can be regulated.
6. Gasified rice husks can be converted into char which is a good material as soil conditioner due to its high water holding capacity, or ash, when the burning of char is prolonged inside the reactor, which is a good refractory material;
7. It is also adoptable for battery, in case of brown out, by using an appropriate-sized inverter; and
8. It is safe to operate with no danger of explosion since the stove operates at a normal atmospheric pressure.

Some of the limitations of the stove are:

1. It is difficult to use in areas where rice husks are not available. It cannot be used for other biomass material since the design was made for rice husks.
2. It needs hauling of fuel when the source of rice husks is from a distance. In cities or urban areas, there is a need for a separate enterprise to ensure the supply of this fuel.
3. Loading of fuel and unloading of burned rice husks are quite inconvenient. This is most especially true to households that are used to operating LPG stoves.
4. It needs electricity to run the fan which limits its adoption in areas that are far from grid, except when a 12-volt battery and an appropriate inverter are available.

Principle of Operation

The rice husk gas stove follows the principle of producing combustible gases, primarily carbon monoxide, from rice husk fuel by burning it with limited amount of air. The rice husks are burned just enough to convert the fuel into char and allow the oxygen in the air and other generated gases during the process to react with the carbon in the char at a higher temperature to produce combustible carbon monoxide (CO), hydrogen (H_2), and methane (CH_4). Other gases, like carbon dioxide (CO_2) and water vapor

(H_2O) which are not combustible, are also produced during gasification. By controlling the air supply with a small fan, the amount of air necessary to gasify rice husks is achieved.

As illustrated in Figure 10 below, rice husk fuel is burned inside the reactor in a batch mode. The fuel is ignited from the top of the reactor by introducing burning pieces of paper. The burning layer of rice husks, or the combustion zone, moves down the reactor at a rate of 1.0 to 2.0 cm per minute, depending on the amount of air supplied by the fan. The more air is introduced to the rice husks, the faster is the downward movement of the burning fuel. As the combustion zone moves downward, burned rice husks are left inside the reactor in the form of char or carbon. This carbon reacts with the air that is supplied by the fan and other converted gases thus producing combustible gases.

The combustible gases that are coming out of the reactor, as illustrated in Figure 11, are directed to the burner holes. Air is naturally injected to the combustible gas, through the secondary holes, for proper ignition thereby producing a luminous blue color flame.

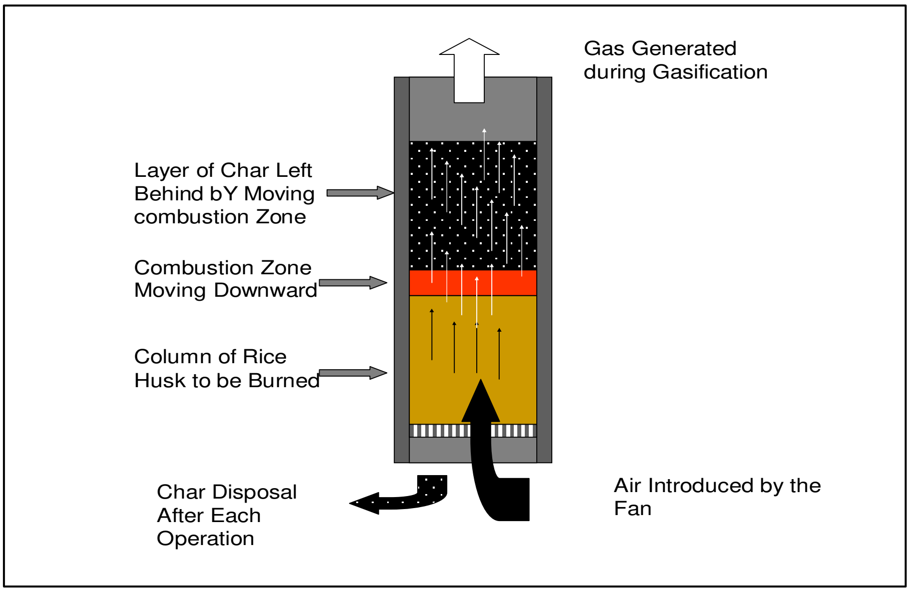

Figure 10. Schematic Drawing of the Principle of Operation of the Rice Husk Gasifier Reactor.

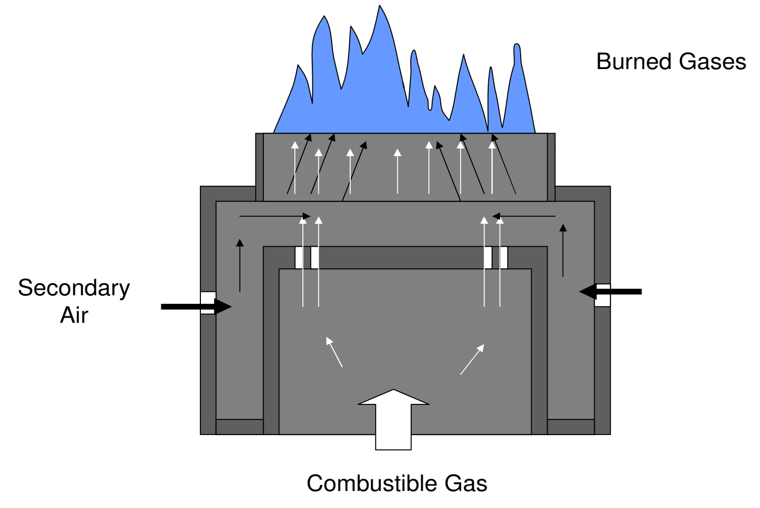

Figure 11. The Principle of the Burner Operation of the Rice Husk Gas Stove.

The amount of flame emitted by the stove is regulated using a rotary-type switch, which controls the fan. Rotating the switch counter clockwise increases the fan speed thereby delivering more air into the column of rice husks so that more fuel is burned. On the contrary, rotating the switch clockwise will gradually reduce the fan speed and the amount of air delivered to the fuel bed. It was observed that the color of the flame in the burner is also affected by the amount of air supplied to the reactor. The more air is injected into the fuel column, the bluish the color of the flame becomes.

After each operation, i.e. when rice husk fuel is completely gasified, char is discharged from the reactor by tilting the char grate with its lever. Leaving the char inside the reactor for a longer period will allow it to be completely burned, which converts char into ash.

Stove Performance in the Laboratory

Results of the performance testing of the stove in the laboratory (Table 2) showed that at full load, the reactor can accommodate 1.3 kg of rice husks. At 75% load of the reactor, the amount of rice husks that can be loaded is 0.975 kg, while at 50% load, it is 0.650 kg. Start-up time of the rice husk fuel in the stove is about 1.35 to 1.82 minutes, which was found to be lesser for the 50% load than at full load. This is due to low draft requirement of the fan which gives more air when it is half loaded than when fully loaded. After igniting the fuel, the time required for the fuel to produce flammable gas is 8 to 57 seconds, depending on the quality of the fuel and the amount of air introduced into the fuel column during firing. The total operating time obtained, from the start-up of the fuel until all the fuel is gasified, is 46.10 to 51.40 minutes when the reactor is fully loaded with fuel, while it is 28.63 to 29.70 minutes when loaded with fuel at ¾ of the reactor. At ½ load of the reactor, the total start-up time is 19.48 to 22.30 minutes.

Data in Table 3 shows the operating performance of the stove in terms of fuel consumption rate, char produced, combustion zone velocity, specific gasification rate, and electric consumption rate of the stove. The computed fuel consumption rate of the stove ranges from 1.59 to 2.0 kg per hour. The percentage amount of char produced from the reactor ranges from 16.9 to 35.0%. At 1/2 load of fuel, the rice husks in the reactor were observed to be converted into ash rather than into char. This can be attributed to the higher amount of air supplied by the blower as when the reactor is fully loaded with rice husks. The rate of downward movement of the combustion zone ranges from 1.23 to 1.53 cm per minute. The specific gasification rate was lower at full load of about 56.81 kg per hr-m^2 and higher at ¾ load of about 113.63 kg per hr-m^2. Energy consumption by the small fan ranges from 7.79 to 13.01 W-hr. The overall thermal efficiency of the stove ranges from 12.3 to 13.3 percent (Table 4). With the power input for the stove of 5.724 to 7.200 kW and the above computed thermal efficiency, the power output of the stove ranges from 0.749 to 0.909 kW.

16

Table 2. Performance Test Results of the Rice Husk Gas Stove.

Loading Capacity	Weight of Fuel (kg)	Fuel Start-Up Time (min)	Gas Ignition Time (sec)	Total Operating Time (min)
Full Load				
Trial 1	1.300	1.75	40	48.95
2	1.300	1.82	32	46.10
3	1.300	1.35	57	51.40
Average	1.300	1.64	43	48.82
¾ Load				
Trial 1	0.975	0.97	33	29.70
2	0.975	0.77	26	28.63
3	0.975	0.63	16	29.38
Average	0.975	0.79	25	29.23
½ load				
Trial 1	0.650	0.58	10	19.63
2	0.650	0.47	8	19.48
3	0.650	0.42	11	22.30
Average	0.650	0.49	9.66	20.47

Table 3. Operating Performance of the Stove.

Loading Capa-city	Fuel Consump-tion Rate (kg/hr)	Char Pro-duced (%)	Combus-tion Zone Velocity (cm/min)	Specific Gasifica-tion Rate (kg/hr-m^2)	Electric Consump-tion (W-hr)
Full Load	1.59	35.0	1.23	56.81	13.01
¾ Load	2.00	33.6	1.53	113.63	7.79
½ Load	1.90	16.9	1.46	107.95	5.45

*Average of 3 runs

Table 4. Power Output and Efficiency of the Stove.

Loading Capacity	Power Input (kW)	Thermal Efficiency (%)	Power Output (kW)
Full Load	5.724	13.1	0.749
¾ Load	7.200	12.3	0.886
½ Load	6.840	13.3	0.909

Boiling time using a liter of water, (from 29 °C to 100°C), ranges from 7.93 to 8.67 minutes while for two liters of water, it ranges from 16.20 to 25.85 minutes (Table 5).

Table 5. Test Results of Boiling Water using the Stove.

Volume of Water	Initial Temperature (ºC)	Final Temperature (ºC)	Boiling Time (min)
1 Liter			
1	29	100	7.93
2	29	100	8.33
3	29	100	8.67
Average	29	100	8.31
2 Liters			
1	29	100	25.85
2	29	100	18.42
3	30	100	16.20
Average	29.3		20.15

* Measured gas temperature ranges from 160 to 210 ºC
** Measured flame temperature ranges from 465 to 610 ºC

Cooking Tests Results

Table 6 below gives the period of time required to cook various foods in the rice husk gas stove. Boiling a liter of water (Fig. 12a) would take 8 to 9 minutes while boiling two liters of water would take 16 to 25 minutes. Frying 2 pieces of fish (Fig. 12b) would take 20 to 26 minutes. Boiling two pieces of fish, with water to 1/3 of the height of the casserole, would take 15 to 20 minutes. Cooking rice (Fig. 12c), for a standard family size of 4 to 6 members, using 3 cups of rice with 3 cups of water would take 9 to 12 minutes. With these results, using the rice husk gas stove is sufficient to provide energy for a family for cooking rice, two viands, and some excess energy can be used to heat water for bathing.

Table 6. Period of Time to Cook Various Foods in the Rice Husk Gas Stove.*

Operation	Description	Cooking Time (min)
Boiling Water		
1 liter	Tap water for coffee and milk	8 – 9
2 liters	Tap water for bathing	16 – 25
Cooking Rice	3 cups rice with 3 cups water	9 – 12
Frying	2 pcs of “Bulao” fish	20 – 26
Boiling	2 pcs of “Bulao” fish with water 1/3 height of the casserole	15 – 20

* Actual tests obtained from households who use and operate the stove.

(a)

(b)

(c)

Figure 12. Cooking Tests in the Stove: (a) Boiling, (b) Frying, and (c) Rice Cooking.

Actual Performance of the Stove

Monitoring the performance of the stove from several users in Iloilo (Figs. 13 and 14) revealed that the stove is useful as an alternative saving device for domestic cooking, to replace LPG. For an average household size of 4 to 6 members, each load of fuel can cook three types of food. First is to cook rice, second is to cook viand (either fish or vegetables), and third is to fry fish or egg. Excess fuel can be used further to heat water.

Figure 13. Actual Operation of the Stove in Dingle, Iloilo.

One sack of rice husk was found enough for 3- to 5-day supply of fuel, depending on the frequency of use. Electric consumption was observed to be very minimal.

Some suggestions for the improvement of the design of the stove are as follows:

1. Power supply must be ready as a back-up unit in case of power failure.

2. A multiple burner stove needs to be developed so that cooking can be done simultaneously.

Figure 14. Actual Operation of the Stove in Tubungan, Iloilo.

3. The stove should incorporate other kitchen functions such as provisions for tables and drawers to stock pots and other utensils or cooking equipment; and

4. The stove must be designed for continuous operation.

Listed in Table 7 are the individuals and organizations, from Iloilo and other provinces throughout the Philippines, who bought a unit of the rice husk gas stove. Individuals, organizations, US Peace Corps assigned in the Philippines, and other visitors who came to ATC also purchased a unit of the stove for promotional and for possible reproduction in their respective places.

Cost of Producing and Cost of Operating the Stove

The stove can be produced in a small fabrication shop. Six units of the stove can be fabricated by two persons in a week. The cost of materials is approximately P2,100.00 per unit while the cost for the contract for labor and consumables is P1,000 per unit. Adding the overhead cost, profit margin, and others, the selling price per unit of the stove is P5,000.00.

In order to operate the stove, the computed fixed cost is P9.18 per day while the computed variable cost is P11.39 per day. On per hour basis, the stove requires only P3.80. Payback period is 7.47 months compared to LPG. The yearly savings on fuel is P8,037.30.

Implications

The stove is a good alternative to replace LPG stove since the technology similarly produces a flammable blue flame during cooking. The cost of operation is very much cheaper compared with that of the LPG but loading of fuel and disposal of char after each operation are quite inconvenient on the part of the user. If more households will adopt this technology, more rice husks will be disposed as fuel (i.e., approximately one ton per household per year). The problem on rice husk disposal would then be minimized as well as the excessive cutting of trees for fuel. Furthermore, the importation of imported fossil fuel will be reduced.

Table 7. List of Stove Buyers (As of November 2005).

Name	Place	No. of Units Purchased
Atty. Bert Salido	Quezon City	1 unit
Mr. Gascon	Iloilo City	2 units
Mr. Sherwin Fernandez	Tacloban City	1 unit
Mr. Ricardo Rule	San Carlos City	1 unit
Mr. Rogelio Tantuico	Tacloban City	1 unit
Mr. Daniel Simon	Bohol	1 unit
Mr. Pamplona	Passi City	1 unit
Mr. Diosdado Belonio	Tubungan, Iloilo	1 unit
Mr. Ananda Weerakody	Munoz, Nueva Ecija	1 unit
Mrs. Laarni Baredo	Makati City	1 unit
Mr. Roy Joligon	Numancia, Aklan	1 unit
Mr. Juan Romallosa	Dingle, Iloilo	1 unit
Mr. Julian Juantong	Iloilo City	1 unit
Mr. Hector Babista	Lucban, Quezon	1 unit
Mr. Roberto Vicente	Iloilo City	1 unit
Ms April Belasa	Iloilo City	1 unit
Ms. Florence Ng	Canlaon City	1 unit
Engr. Albert Barzosa	Bacolod City	1 unit
Engr. Gerbe Dellava	Roxas City	1 unit
Mr. Emmanuel Ignacio	Jaro, Iloilo City	1 unit
Dr. Samuel Go	Leyte State University	1 unit
Mr. Orlando Colobong	Puerto Princesa City	1 unit
Mr. Noel Hamor	Bayawan City	1 unit
Engr. Dioscoro Maranon	West Negros College	1 unit
Mr. Arnold Go	Sultan Kudarat	1 unit
Mr. Eric Limsui	Pavia, Iloilo	1 unit
Mr. Roger Sampson	REAP Canada	1 unit
Mr. Ric Tana	Batangas	1 unit
Mr. Dem Agudo	Batangas	1 unit

CHAPTER III

EXISTING DESIGNS OF RICE HUSK AND OTHER BIOMASS FUEL GAS STOVE

So far, there are only few designs of rice husk gas stove that were developed in the Philippines and even abroad. The various stoves presented below are the designs that were developed utilizing rice husks and other biomass fuel.

Rice Husk Gasifier Stoves

1. DA-IRRI Rice Husk Gasifier Stove

This stove (Fig. 15) was developed sometime in 1986 during the DA-IRRI collaborative program on small farm equipment in the Philippines by Dr. Robert Stickney, Engr. Vic Piamonte, and the Author. The stove adopted a double-core downdraft type reactor where rice husks are burned and are gasified starting from the bottom. The gasified fuel is allowed to cool and to condense on a coil inside a water-pipe heat exchanger before it is introduced to the burners. During the process, air is sucked from the reactor and is blown to the burner using an electric blower which is positioned between the reactor and the burner. (33, 36)

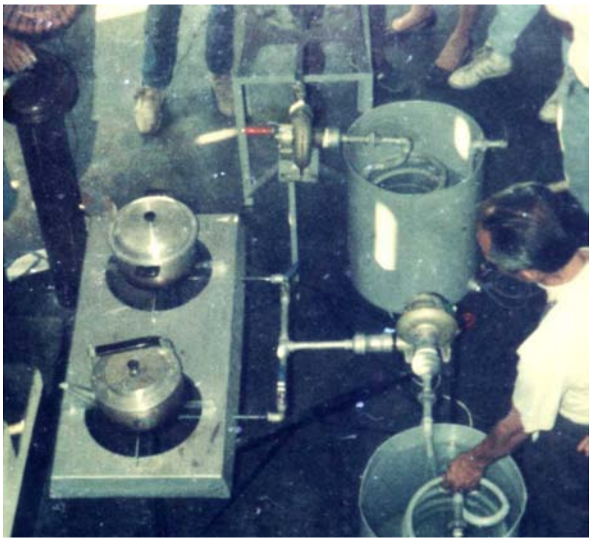

Figure 15. The DA-IRRI Rice Husk Gasifier.

The stove, as shown above, has an inner reactor diameter of 14.5 cm and an outer reactor diameter of 23 cm. The length of the inner core is 20 cm while the outer core is 30 cm. A 3-mm square wire mesh is used to hold the rice husk fuel. The stove is operated by placing first a layer of rice husk char on top of the grate and placing about 1-cm thick of rice husks on the next layer prior to its ignition. The blower is switched ON to suck the air needed for combustion of fuel. When all the fuel is completely burning, additional amount of rice husks is fed into the reactor until it is fully filled. Tests have shown that flammable bluish gas is produced from the stove. Emptying and reloading of rice husks in this stove only take less than 5 minutes. The schematic drawing of the stove is shown in Figure 16 below.

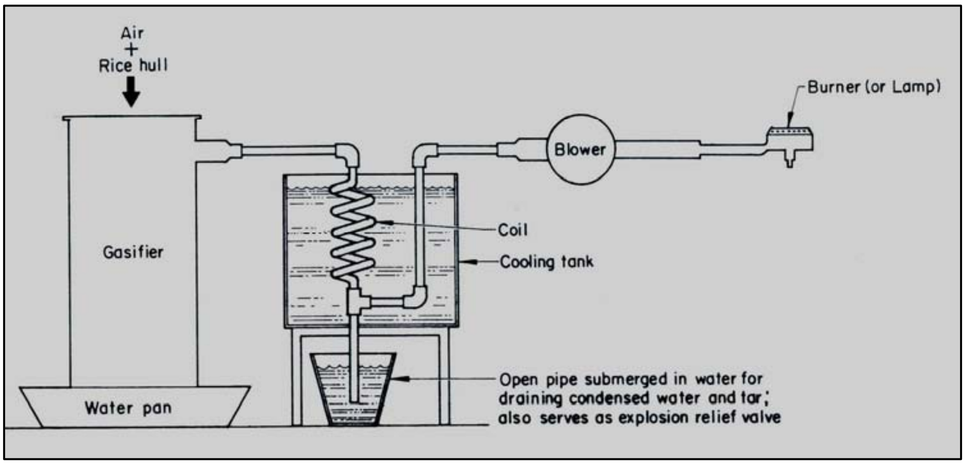

Figure 16. Schematic Drawing of the DA-IRRI Rice Husk Gasifier.

2. CPU Single-Burner Batch-Type Rice Husk Gasifier Stove

This stove (Fig. 17) was developed in 1989 at CPU basically to provide individual households a technology for domestic cooking using rice husks as fuel. It is a double-core downdraft type gasifier and is an improved version of the DA-IRRI rice husk gasifier stove. Similarly, this stove follows the principle of a double-core down-draft gasifier where burning of fuel starts from the bottom of the reactor. (10, 11)

Figure 17. The CPU Single-Burner Rice Husk Stove.

The gasifier reactor, as schematically shown in Figure 18 below, has a diameter of 15 cm and a height of 70 cm and is separated from the burner. Rice husks are burned inside the reactor starting from the bottom and the combustion zone moves upward until it reaches the top most end of the reactor. Rice husk fuel is continuously fed in the reactor until the combustion zone reaches the topmost portion of the fuel. The principle of operation of this stove is downdraft-type where air passes through the column of burning char. A 90-watt electric motor is used to suck the air and gas from the reactor. This type of stove adopts an LPG-type burner for simplicity of fabrication. The amount of gas in the stove is regulated by means of a gate valve. A chimney was also provided for the stove to discharge raw and excess gases, if desired.

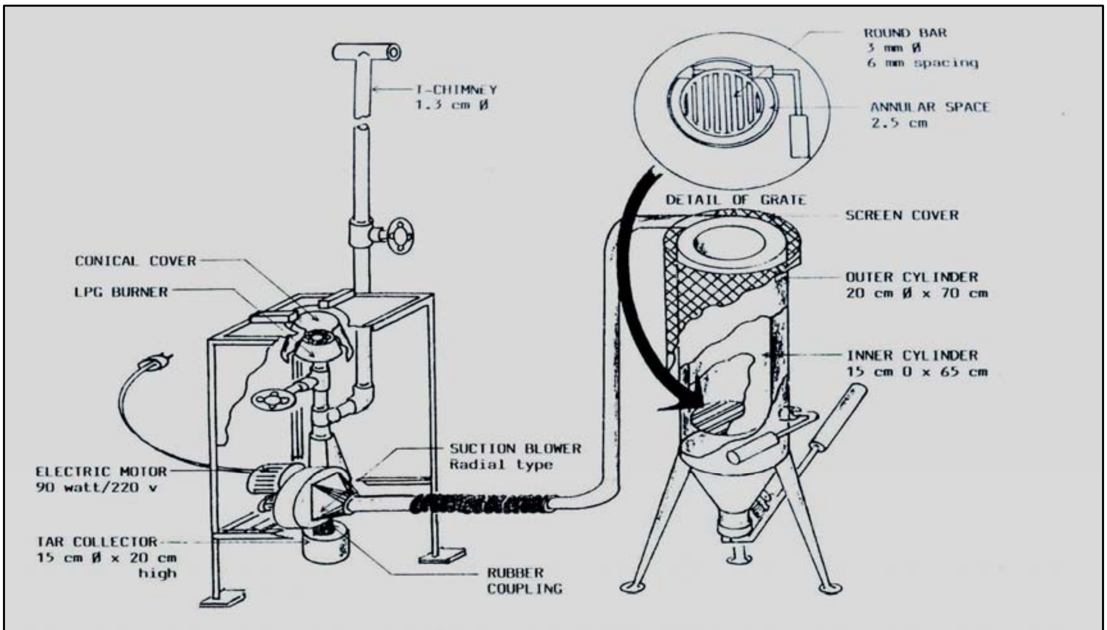

Figure 1. Technical drawing of the batch-type rice hull gasifier stove.

Figure 18. The Schematic Drawing of the CPU Single-Burner Rice Husk Stove.

Results of the performance testing on this type of stove showed that the stove operates for a total period of 0.98 to 1.25 hrs per load. The amount of fuel consumed per load is 1.96 to 2.72 kg producing from 0.53 to 1.04 by char. Boiling and cooking tests showed that 1.2 to 4.0 liters of water can be boiled in the stove within 10 to 34 minutes, and 0.7 to 1.0 kg of rice can be cooked in the stove within16 to 22 minutes.

3. CPU Proto-Type IDD/T-LUD Rice Husk Gas Stove

Figure 19. The CPU Proto-Type IDD/T-LUD Rice Husk Stove Model 1.

These models of the stove (Figs. 19 &20) were the prototype models of the commercially available IDD/T-LUD rice husk gas stove described in this handbook. These are entirely different from the Sri Lankan model in terms of the burner design, char grate, and fan speed control mechanism. The reactor has an inner diameter of 15 cm and a height of 25 cm. The ash chamber is directly beneath the reactor. The fan is attached to the door of the ash chamber, and switching it ON and OFF is done with the use of a rotary switch. The stove can accommodate 600 grams of rice husks per load. The time required to produce combustible gas at the burner of the stove is about 32 to 35 seconds. The total time required before all the rice husk fuel is consumed ranges from 15 to 20 minutes, depending on the amount of air supplied by the fan to the reactor during cooking. After all the rice husks are burned, the amount of char and ash produced range from 122 to 125 grams. (2, 12)

The computed power output of the stove ranges from 0.237 to 0.269 kW. Fuel consumption rate ranges from 0.33 to 0.43 kg of rice husk per minute. The time required for the combustion zone to travel from the top to the bottom of the reactor ranges from 1.74 to 2.27 cm per min. Thermal efficiency was found to be at the range of 12.28 to 13.83%.

Figure 20. The CPU Proto-Type IDD/T-LUD Rice Husk Gas Stove Model 2.

Boiling test also showed that a liter of water, with initial temperature of 32 °C, boils to 100 °C within 9.0 to 9.5 minutes. During the test, no smoke and fly ashes were observed coming out of the stove.

4. CPU Cross-Flow Type Rice Husk Gasifier Stove

This stove (Fig. 21) was patterned after the AIT Wood Gasifier Stove. This was designed as an attempt to gasify rice husks in a continuous mode so that operation of the stove can be done continuously, as desired. The stove uses a 3-watt DC motor to provide the needed air for gasification into a 15-cm column of rice husks inside the gasifier. The rice husks fuel flow inside the gasifier reactor in a vertical mode while the air moves into the layer of burning rice husk in a horizontal mode.

Figure 21. The CPU Cross-Flow Rice Husk Gasifier Stove.

The burner, which is located on one side of the stove, burns the gasified fuel and it is here where cooking is done. (20)

Smoke emission is quite evident in this type of stove. Water sealing is provided on the top of the fuel chamber and at the bottom of the ash chamber to properly direct the smoke to the burner. Results of performance tests have shown that the stove requires two kilos of rice husk per load. Operating time per load ranges from 37 to 47 minutes. One liter of water can be boiled in the stove within 8 to 11 minutes.

6. San San Rice Husk Gasifier Stove

As reported in the internet, this stove (Fig. 22) was developed by U. Tin Win, under the guidance of Prof D. Grov of the Indian Institute of Technology and by Dr. Graeme R. Quick. The stove burns rice husks directly by allowing the air to pass through the perforated bottom of the stove going to the top. The primary air flows directly in the producer gas burning zone at the bottom of the stove. A hinge shutter allows the removal of ash as necessary. The secondary air passes through the four zones of the stove. The stove can also be fueled with a mixture of chopped kitchen wastes, leaves and fresh biomass, and rice husks. The problem of frequent tapping the ash in the stove is minimized and the smoke emitted was found to be negligible and less polluting as reported. (39)

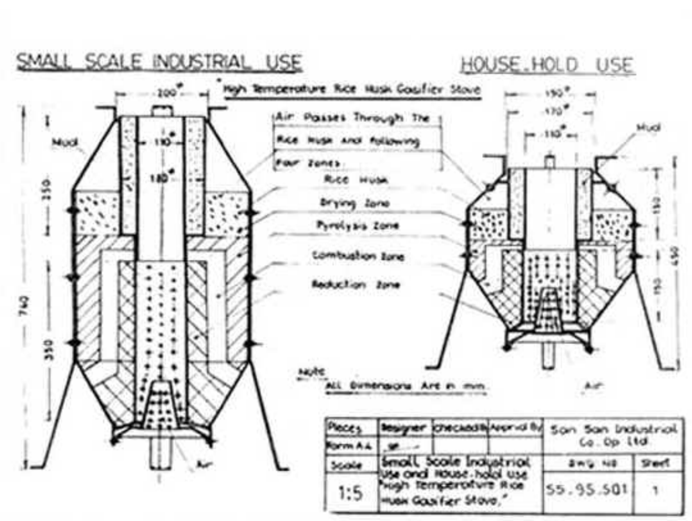

Figure 22. The San San Rice Husks Gasifier.

Other Biomass Fueled Gas Stove

1. CPU IDD/T-LUD Wood Gasifier Stove

This stove (Fig. 23) was developed similar to the IDD/T-LUD rice husk gas stove. However, instead of using rice husks, chunks of wood are used as fuel. Fuel wood, cut into pieces of about an inch, is placed inside the reactor where it undergoes gasification. The reactor has a diameter of 15 cm and a height of 35 cm. A small fan is used to start the fuel. During operation, the fan is totally turned Off. Ash is collected in a chamber located beneath the reactor, where a small fan is installed for the start-up of fuel. On top of the reactor is an improved burner where gasified fuel is injected and mixed with combustion air. The flame emitted from the gasifier is yellowish orange with traces of blue color. (23)

Figure 23. The CPU IDD/T-ULD Wood Gas Stove.

Test results have shown that the stove can successfully generate gas for cooking. Two kilos of wood chunks can sustain 56 to 75 minutes operation. Boiling time of 1.5 liters of water is from 4 to 9 minutes. Thermal efficiency of this gas stove model ranges from 10 to 13 percent.

2. NERD Forced Draft Smokeless Wood Gas Stove

This stove (Fig. 24) design came from Sri Lanka and was demonstrated at AIT, Thailand during the 2003 Training Seminar on Wood Gasifier Stove sponsored by ARECOP. The stove technology follows the principle of IDD/T-LUD where wood chunks are burned inside the reactor and firing of fuel starts from the top of the reactor. Air is supplied to the wood chunks by forcing it into the fuel column using a small electric fan.

In this stove, as reported in the internet, wood is converted into gas and burn on top of the burner. Report showed that 555 grams of wood fuel, or any bio-mass chips, are burned inside the reactor for 30 min. The stove is smokeless during operation. It is handy and portable which can be easily transferred from one place to another, as desired. According to the report, the stove does not emit so much heat during operation. It is claimed that the stove's overall efficiency is 34%. Two watts D.C. micro fan is used to supply air for gas generation and combustion. The stove has AC main plugs, terminals for battery, and battery charger serving as accessories for the unit. It was also reported that the residue after each operation is only a few grams of ash. The stove has a total weight of 10 kg with a height of 50 cm. (25)

Figure 24. The Sri Lanka Wood Gas Stove.

3. CPC Turbo Wood Gas Stove

This stove (Fig. 25) is an Inverted Down Draft (IDD, and now called T-LUD) type wood gas stove originally developed by Dr. Tom Reed of the Biomass Energy

Figure 25. The Turbo Wood Gas Stove.

Foundation in the US. As reported from the internet, this stove combines especially designed gasification chamber, mixer, and burner to provide a 3-kW high- intensity heat using only 10 grams of fuel per minute. A 2-watt micro blower provides a fully variable amount of air just where and when needed to achieve the stove's very high performance level. The stove can be easily adjusted in terms of cooking intensity and time needed for frying, boiling, or simmering for up to two hours on a single charge of fuel. (29, 30, 31, 37)

The stove uses small pieces of wood and other biomass fuel such as nut shells, corn cobs, and others. As claimed, it is extremely clean stove that can be used indoors even with only minimal ventilation. It can cook fast just as modern gas or electric stove.

Report shows that the stove can boil a tea pot of water within 3 to 4 minutes. It can simmer up to 2 hours for slow cooking to save fuel and preserve food nutrients. It can be easily started and is ready for high intensity cooking in less than a minute. It has high efficiency of about 50%. It produces extremely low emissions that will virtually eliminate respiratory and eye diseases due to smoke inhalation.

4. Juntos T-LUD Gasifier Stoves

The Juntos brand of Top-Lit Updraft (T-LUD) gasifier stoves are developed by Dr. Paul Anderson of Illinois State University. Using as fuel various types of dry chunky biomass (including wastes such as yard wastes, locust tree pods, and briquettes mainly from paper pulp and sawdust, the stove operates

Figure 26. An early Juntos Gasifier Stove.

by natural convection. Early versions in 2002 were made from tin can with the top removed and covered with another metal serving as outer jacket with an annular space of 1 cm to pre-heat the air, thereby improving the combustion of burning gases. A 2-cm diameter air pipe is installed at the bottom of the stove reactor to provide primary air to the burning fuel. (3)

An improved version of this stove, the Juntos Model B, (shown in Figure 27), has two chambers: (1) the pyrolysis chamber, and (2) the combustion chamber. The pyrolysis chamber is the bottom part of the stove that is basically made of a metal container in which air enters the central fuel area from underneath a grate that supports the fuel. As reported from the internet, the pyrolysis chamber has a diameter of 10 cm to 15 cm and can be made into various heights as long as the flow of primary air is not obstructed. The fuel is ignited on top of the column of fuel, creating smoke via the process of pyrolysis. The second chamber is where the hot flammable pyrolysis gases receive the flow of secondary air. The combustion chamber acts as an internal chimney so that gases are completely combusted before reaching the cooking pot.

The Juntos Model B T-LUD gasifier (Fig 27) won an award for cleanest combustion of nine natural draft biomass stoves. Simplicity helps keep its base price below US$10.

T-LUD gasifiers are batch-fed and can yield charcoal equaling approximately 25% by weight of the load of biomass fuel. (4)

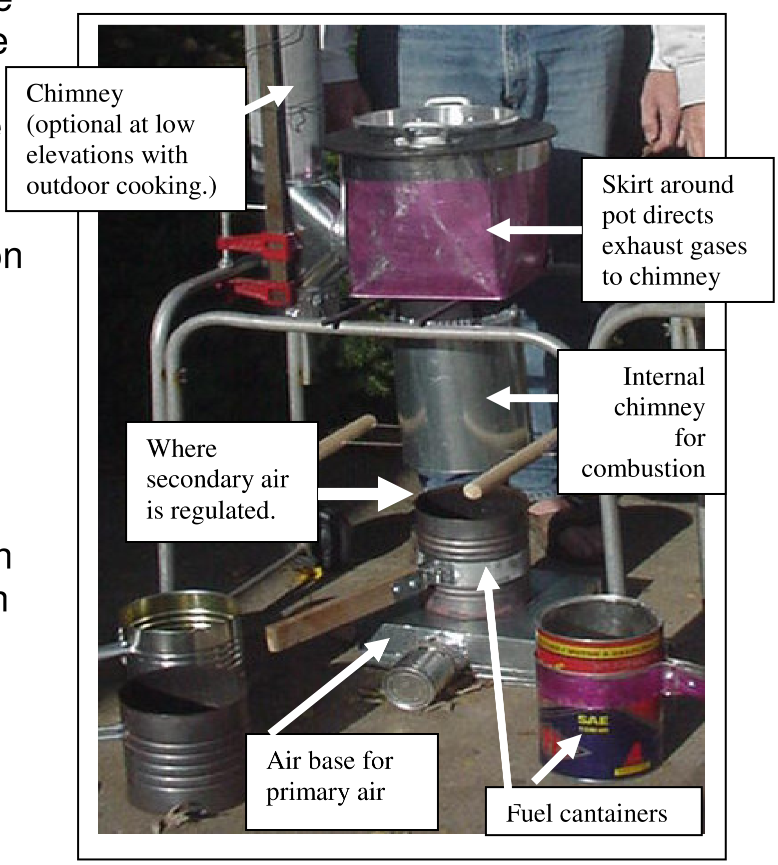

Figure 27. An improved Juntos Model B T-LUD gasifier stove, including chimney needed for altitudes above 1000 meters.

5. AIT Wood Gasifier Stove

This stove (Fig. 28) was developed at the Asian Institute of Technology, Bangkok, Thailand. This stove was demonstrated and presented during the 2003 Training on Gasfiier Stove. While rice husk briquette can be used as fuel, this stove is primarily designed for wood chunks. (13, 14, 32)

Figure 28. The AIT Gasifier.

As shown, the stove consists of a cone-shaped fuel chamber, a reaction chamber where fuel is gasified, and a combustion chamber where the gasified fuel is burned by natural convection mode. During gasification, air passes through the layer of fuel and escapes at the other end of the reaction chamber through a producer gas outlet. Flow of air and of gases in the stove is facilitated by the draft created by the combustion chamber.
Ash is discharged from the reaction chamber to the ash pit door of the stove. Reports have shown that the stove can be operated continuously for 24 hours. Operation is smokeless with average thermal efficiency of 17% when using rice husk briquettes, 27% with wood chips, and 22% with wood twigs as fuel. The stove is reported to be promising for community type cooking, particularly for institutional kitchens and traditional cottage industries.

Figure 29. The Chinese Gasifier Stove.

6. Chinese Gasifier Stove

This stove (Fig. 29) is an improved version of a center-tube type stove that uses crop residues as fuel. It consists of holes on its upper and middle portions to provide the needed air for gasification of fuel. As reported from the internet, the stove was claimed to have an efficiency of about 60%, that is 3 to 4 times higher as compared with other stoves utilizing crop residues as fuel. (16)

7. Special-Purpose Straw Gas Cooker

This stove (Fig. 30) was introduced by Kevin Chisholm of Wattpower in the internet. It is used to change agricultural and forestry wastes into fuel gas. It is claimed that the stove has the following characteristics: It is small enough for household use, it operates well, and it can be recharged with fuel material easily and conveniently. Gas can be produced in this stove in 1 to 2 minutes and can be operated continuously without the need of shutting down when adding fuel. According to the report, it can gasify materials such as corncobs, corn stover, wheat straw, rice straw, peanut husks, wood chips, and others. The stove can produce 6 to 12 m^3/hr of gas and is operated by an 80-watt, 220-volt AC blower. The gas produced contains 18% CO, 6 to 10% H_2, and 2% CH_4 with calorific value of 4,600 to 5,200 kJ/m^3. (17)

Figure 30. The Special-Purpose Straw Gas Cooker.

8. CRESSARD Gasifier Stove

This stove (Fig. 31) as reported in the internet was designed in Cambodia by CRESSARD. The stove was constructed out of materials from a junk yard. The stove runs on a downdraft mode having an inner sleeve of 30 cm. It has a rolled flange at one end and support

Figure 31. The CRESSARD Gasifier Stove.

cross pieces in the other end. The throat is constructed by cementing an ordinary fired clay cooking stove available in the local market. The bottom cover of the cooking stove is provided with holes so that ash could fall to the bottom of the 55-gallon drum during operation. The top of the drum was cut in a circle, which matched the stainless steel sleeve. (18)

9. Pellet Gasifier Stove

This stove (Fig. 32), as reported in the internet, is a gasifier type that uses pellet grass. It is claimed that this stove is capable of burning moderately high ash pellet agricultural fuels at 81 to 87% efficiency. According to the REAP's report, switch grass pellets are used like wood pellets in this stove and provide fuel combustion efficiencies and particulate emissions in the same range as modern oil furnaces. (28)

Figure 32. The Pellet Gasifier Stove.

10. Holey Briquette Gasifier Stove

This stove (Fig. 33), as reported in the internet, was designed specifically for biomass based low pressure briquette that is made manually by rural poor or urban producers. The stove is made from refractory ceramics having a height of 23 cm, a diameter of 14 cm, and a wall thickness of 25 mm. The combustion of fuel in this stove rests on a stainless steel plate. A 100-mm diameter tin can limit the primary air, which is placed on top of the grate. The stove was preliminarily tested and suggestions were solicited from the experts for future development of this stove. (34)

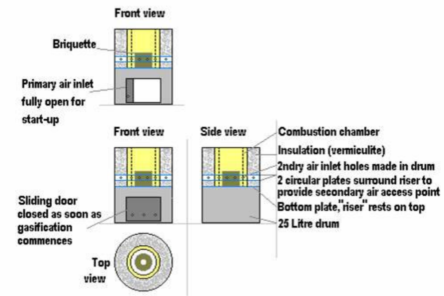

Figure. 33. The Holey Briquette Gasifier Stove.

CHAPTER IV

BASICS OF RICE HUSK GASIFICATION

Rice husk gasification can be fully understood if one has a thorough understanding of the characteristics of rice husk fuel itself as well as of the principle of gasification. The discussion below gives brief descriptions of rice husk itself, the physical, the thermal, and the engineering properties of this material particularly the combustion and gasification properties.

Rice Husk

Rice husk is a by-product of milling paddy. It is produced after the paddy passed through the husker and conveyed outside the mill through an aspirator. The amount of rice husks produced in a rice mill depends on the capacity of the milling plant. Large capacity mill usually produces a lot of rice husks per unit hour. Rice husks (Figs. 34 & 35) may either be whole or ground, depending on the type of husker used. For rice husk gasifier, whole rice husk is better to use in attaining proper gasification. In addition, ground rice husk may require a higher-pressure blower.

Figure 34. Rice Husks Produced from a Rice Mill.

Figure 35. Close Up View of Rice Husk.

A kilogram of paddy can produce about 200 grams of rice husks. This is about 20% of the weight of paddy and this may vary in few percent, depending on the variety of rice. Therefore, a 1-ton paddy per hour rice mill is capable of producing 200 kg of rice husks per hour. For a day long operation of 10 hours, a total of 2 tons of rice husks can be produced.

Several reports have shown that rice husks leaving the mill has a moisture content of 10 to 16% and this may increase to as high as 20% in humid condition. The bulk density of both compacted and non-compacted rice husks ranges from 100 to 120 kg/m^3. It has energy content of about 3000 kcal per kg and, when burned completely, produces about 15 to 21% ash which is almost 90% silica. In order to completely burn rice husks, 4.7 kg of air is needed per kg of rice husk. Burning it using 30 to 40% or an equivalence ratio of 0.3 to 0.4 only of the air needed for combustion will gasify rice husks, which produces a flammable, bluish gas. The gas produced from the gasifier has an energy content of about 3.4 to 4.8 MJ/m^3. After gasification, the percentage char leaving the reactor is about 32% of the total volume of rice husks previously loaded. (6, 21)

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Principle of Rice Husk Gasification

Rice husk gasification is the process of converting rice husks fuel into combustible carbon monoxide by thermo-chemical reaction of the oxygen in the air and the carbon available in this material husk during combustion. In complete combustion of fuel, the process takes place with excess air. In gasification process, on the other hand, it is accomplished with excess carbon. In order to gasify rice husks, about 30 to 40% of the stoichiometric air (4.7 kg of air per kg of rice husk) is needed. (22)

Gasification of rice husks is accomplished in an air sealed chamber, known as the reactor. Limited amount of air is introduced by a fan into the fuel column to convert rice husks into carbon-rich char so that by thermo-chemical reaction it would produce carbon monoxide, hydrogen, and methane gases, which are combustible when ignited.

Basically, the gas produced during gasification is composed of: (a) carbon monoxide, (b) hydrogen, (c) methane, (d) carbon dioxide, and (e) water vapor. The chemistry of gasification and the reactions of gases during the process are illustrated below.

Combustion	$C + O_2$	$= CO_2$
Water Gas	$C + H_2O$	$= CO + H_2$
Water Shift Reaction	$CO + H_2O$	$= CO_2 + H_2$
Boudouard Reaction	$C + CO_2$	$= 2\ CO$
Methane Reaction	$C + 2\ H_2$	$= CH_4$

Carbon monoxide, hydrogen, and methane are combustible gases while the carbon dioxide and vapor are not. Some reports claim that there is nitrogen gas in trace amount during gasification of rice husks.

Given in Table 8 is the percentage composition of gases as found by Dr. Albreacth Kaupp for rice husk gasifier at 1000°C gasifier temperature, 0.3 equivalence ratio, and rice husk fuel moisture content of 10 to 40%. As shown, the percentage composition of CO varies from 15 to 26.1% while that for H_2 varies from 20.6 to 21.2%. The higher the moisture content of rice husks, the lower is the percentage CO, and the higher is the percentage H_2 composition. Since the gasifier reactor operates at a very high temperature (1000°C), the percentage of methane gas available during gasification is zero.

On the other hand, increasing the equivalence ratio from 0.3 to 0.6 for rice husk moisture content of 30% and temperature of 1000 °C, the percentage of gases varies. As shown, in Table 9, the percentage CO ranges from 18.6 to 8.6% while that of H_2 ranges from 8.7 to 21.5%. Increasing the equivalence ratio during gasification decreases the percentage composition of CO and H_2 gases. It can therefore be concluded that in the design of

Table 8. Types and Percentage Composition of Gases Produced from the Gasification of Rice Husk Gasifier at 1000 °C Temperature and at 0.3 Equivalence Ratio.

Gas	% Composition *
Carbon Monoxide, CO	26.1 – 15.0
Hydrogen, H_2	20.6 – 21.2
Methane, CH_4	0
Carbon Dioxide, $C0_2$	6.6 – 10.3
Water, H_2O	8.6 – 24.0

* Rice Husk Moisture Content = 10 to 40%

Table 9. Composition of Gases Produced from Rice husk Gasifier at 1000 ºC Temperature and at Rice Husk Moisture Content of 30%.

Gas	% Composition *
Carbon Monoxide, CO	18.6 – 8.6
Hydrogen, H_2	21.5 – 8.7
Methane, CH_4	0
Carbon Dioxide, $C0_2$	9.5 – 12.6
Water, H_2O	18.0 – 21.1

* Equivalence Ratio = 0.3 to 0.6

a rice husk gasifier, the lower the equivalence ratio and the moisture content of rice husk fuel, the better will be the obtained gas quality for CO and H_2. Methane (CH_4) can only be achieved if the gasifier reactor is operated at lower temperature of about 400 to 500°C.

It should always be remembered that, like liquefied petroleum gas used as fuel for cooking, gasified rice husks is toxic in excessive amount. Hence, caution should be considered when using gasifiers.

Factors that Influence Gasification

Studies have shown that there are several factors influencing gasification of rice husks. (22) These include the following:

1. **Energy Content of Fuel** – Fuel with high energy content provides better combustion. This is most especially obtained when using rice husks that are freshly obtained from the rice mill. Deteriorated rice husks, such as those dumped on roadsides and along river banks for several months, were observed to be more difficult to gasify than the fresh ones.

2. **Fuel Moisture Content** – The moisture content of rice husks also affects gasification. Rice husks with low moisture content can be properly gasified than that with high moisture. Freshly produced rice husks are preferred to use for they usually contains only 10 to 12% moisture. Rice husks with high moisture content should be dried first before they are used as fuel for the gasifier.

3. **Size and Form of Fuel**– Rice husks obtained from steel-huller type rice mill or “kiskisan” are difficult to gasify. Over milling of rice produces powdery-form rice husks which require high-pressure fan in order to be gasified. Rice husks produced from rubber roll-type rice mill are more suitable for gasifier operation.

4. **Size Distribution of the Fuel** – Rice husks mixed with other solid fuels are not suitable for gasifier operation. Not uniform fuel size distribution will result to difficulty in getting well-carbonized rice husks, which affects fuel gasification.

5. **Temperature of the Reactor** – Temperature of the reactor during gasification also affects the production of flammable gas. There is a need to properly insulate the reactor so that during gasification, flammable gas can be produced. Rice husk ash and refractory materials are good examples of materials effective in maintaining high

temperature in the reactor for better gasification. Providing an annular space in a double core reactor is also an effective way in maintaining high temperature in the reactor. (15, 19, 22)

Types of Gasifiers for Rice Husks

There are two general types of gasifiers that are used in gasifying rice husks. These are the fixed-bed and the fluidized-bed gasifiers. For rice husk gas stove, the fixed-bed type gasifier was found to be more suitable. However, of the different types of fixed-bed gasifiers, the down draft-type and the cross-draft type gasifiers, as presented below, were found to be more effective for rice husks.

Downdraft-Type Gasifier – In this type (Fig. 36 A), the gas flows downward taking the pyrolysis "smoke" into the bottom-lit hot char-gasification zone, burning the tars, resulting in very clean combustion. The fuel decends into the zone of combustion. Reloading at the top means continuous operation.

In contrast, the Inverted Down Draft (IDD) or Top Lit Updraft (T-LUD) gasifiers light the fuel at the top of the reactor. The fuel is stationary and the zone of flaming pyrolysis decends downward. Reloading is by batches of fuel, interrupting the gasification processes.

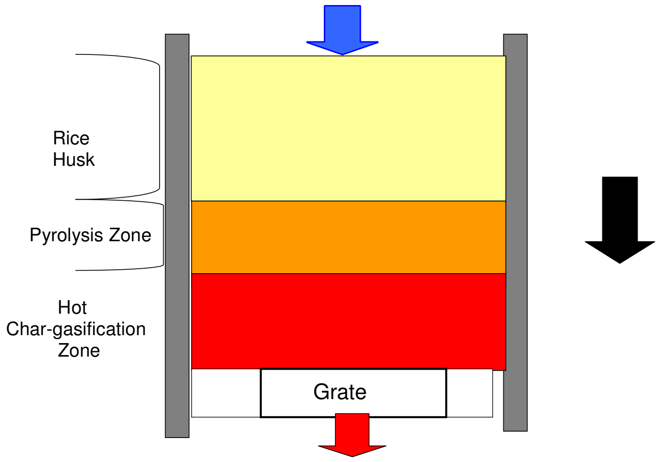


Figure 36 A. DownDraft Type Gasifier. (Bottom-Lit)

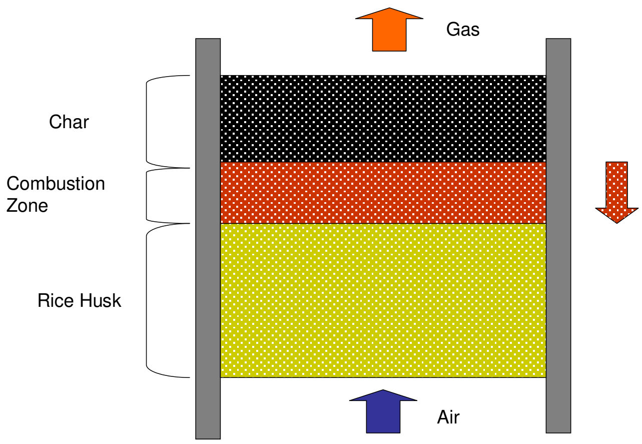
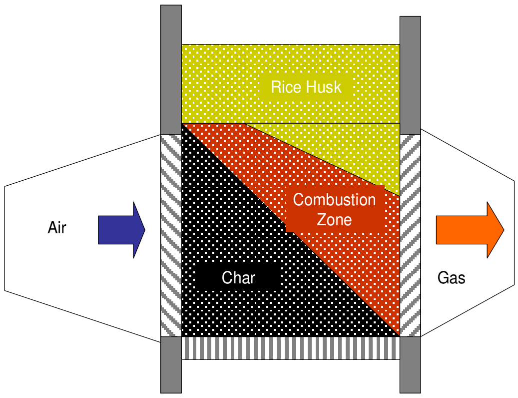


Figure 36 B. Inverted DownDraft Type Gasifier is Top-Lit with UpDraft

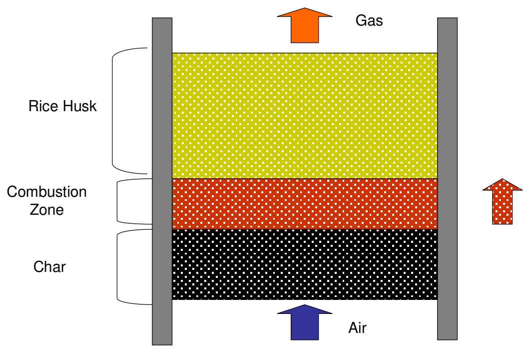
Cross-Draft Type Gasifier – In this type (Fig. 37), the gas flow crosses the fuel column in perpendicular action with respect to the direction of the combustion zone. This type of reactor allows a continuous operation of the gasifier reactor even wh char is being done. Sm However, this can be eliminated by modifying the method of ignition of fuel and by providing an outlet for the smoke (to escape from the stove during operation).



Cross Draft Type Rice Husk Gasifier

Figure 37. Cross Draft Type Rice Husk. Gasifier.

Updraft-Type Gasifier – In this type (Fig. 38), the major fire is at the bottom, the hot gases move upward and then laterally exit, while the fuel continues to fall downward as space is created. Although this type works out well with rice husks,its major disadvantage is the production of too much smoke during operation. Rice husk gas stove for this type should be designed with chimneys to divert excess gases during operation.



Up Draft Type Rice Husk Gasifier

Figure 38. Up Draft type Rice Husk Gasifier.

Fluidized Bed Gasifier – In this type, fuels (rice husks) are in motion inside the reactor. A high pressure fan is needed to cause the fuel being gasified to move. Gasifiers of this type are highly suitable for institutional or industrial stove where the cost of the system can be justified.

Air Requirement for Gasification

The amount of air needed to gasify rice husks is limited than that needed to burn by direct combustion. The stoichiometric air requirement of rice husk is normally equivalent to 4.7 kg of air per kilogram of rice husks. At an air density of 1.25 kg/m^3, the volume of air needed for combustion is 3.76 cubic meter per kilogram of rice husks. In order to gasify rice husks, the amount of air needed for gasification is about 30 to 40 % of the stoichiometric air. Therefore, the amount of air to gasify a kilo of rice husks ranges from 1.128 to 1.504 m^3.

Pressure Draft of Fuel and Char

During gasification, the column of fuel and of char inside the reactor exerts pressure to the fan in moving the air. The amount of pressure exerted depends on the thickness of the column as well as the nature of the fuel and the char. Figure 39, from Kaupp (1984), shows the pressure draft of rice husks in centimeter of water per meter depth of fuel at various superficial gas velocities. In order to overcome the resistance exerted by the char, a small percentage of about 10% should be added to the data obtained from the rice husks.

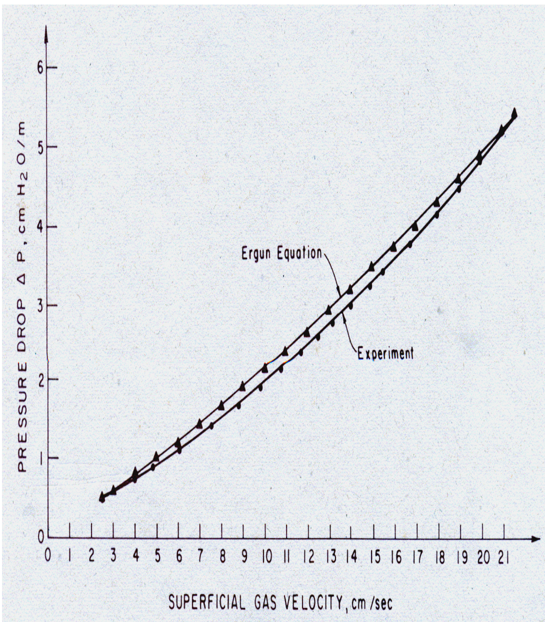


Figure 39. Pressure Draft of Rice Husk at Different Superficial Velocity of Gas.

Basic Information on Rice Husk Gasification

The information given in Table 10 is helpful in the design of rice husk gas stove. Note that an optimum amount of air is needed for gasification of rice husks to maximize the amount of combustible gases. The velocity of the gas in the column of fuel will cause problem during gasification, especially the channel formation if allowed to pass through the column in excessive amount. The temperature during gasification is limited to a certain level in order to minimize the formation of clinkers, which are difficult to remove after operation. There is a need to have provision in the removal of char from the reactor since slugging and caking are always a problem. Since tar is a common problem in rice husk gasification, there is a need to eradicate this by-product by cooling or by burning as demonstrated in the IDD/T-LUD type gasifier. Rice husk gasifier efficiency should be taken into account when sizing up a gasifier. (22)

Table 10. Summary of Information on Rice Husk Gasification.

1	The optimum equivalence ratio for a rice husk gasifier is 0.32.
2	Channel formation occurs in the rice husk bed inside the reactor at a superficial gas velocity of 8.5 to 9 cm/sec and 20-23 cm/sec for rice husk char.
3	Normal operating temperature for gasifier ranges from 900 to 1000°C.
4	Slugging and caking are the common problems in 15 to 30 cm gasifier reactor.
5	The residue obtained from the reactor after gasification is about 30 to 40% of the initial volume or 25 to 35% of the initial weight.
6	Rice husk gasifier efficiency ranges from 55.8 to 66.5%
7	Cooling gas during gasification will cause the tar to condense.
8	Fuel of up to 30% moisture can be handled in rice husk gasifier.
9	Gasification rate of rice husk varies from 110 to 210 kg/m^2-hr.

CHAPTER V

RICE HUSK GAS STOVE DESIGN

Designing a rice husk gas stove is quite a difficult job for beginners. This is because the rice husk fuel that is being gasified has different characteristics and properties than wood fuel, which is more commonly used fuel for gasification. It is therefore suggested that those who wish to design a rice husk gas stove should copy exactly the commercial model of the stove presented in this Handbook before starting an exploratory work. This is more so in designing the burner and in determining the diameter and the height of the reactor, in combination with the size of the fan.

Below are the information needed to guide anybody who wants to design a rice husk gas stove. All these information were obtained from literatures and studies in the past including the experiences gained during the course of designing the different models of the stove.

Factors to Consider

There are several factors to consider in designing a rice husk gas stove. Proper consideration of these different factors will be of great help in order to come up with the desired design of the stove and its desired performance. As given below, the different factors that need to be considered in designing a gasifier stove using rice husks as fuel are:

1. **Type of Reactor** – The operating performance of the rice husk gas stove basically depends on the type of the reactor used. Although there are several types of combustor that can be used for rice husks, the T-LUD or IDD under the down-draft type gasifier was proven to work well with this waste material as compared with the traditional bottom-lit downdraft type, cross-draft type, or updraft-type reactors. Of the different types of reactor, the T-LUD/IDD has better operating characteristics in terms of ease of starting the fuel, least smoke emitted, and tar produced during operation.

Also, it was observed that in this type of reactor, smooth operation of producing gas can be achieved. However, it has one disadvantage: it is difficult to operate in a continuous mode. A cross-draft type reactor is more fitted for a continuous operation except that smoke emission and erratic burning of gas are experienced in this type. Combining these two types in one reactor would be a new approach in the design development of a rice husk gas stove in the future.

2. **Cross-sectional Area of the Reactor** – This is the area (Fig. 40) in which rice husks are burned and this is where the fuel is gasified. The wider the cross-sectional area of the reactor, the stronger the power output of the stove. Uniform gasification can be achieved when the reactor is designed in circular rather than in square or in rectangular cross-section.

3. **Height of the Reactor** – The height of the reactor (Fig. 40) determines the time the gasifier can be operated continuously and the amount of gas that can be produced for a fixed column reactor. Usually, the combustion zone

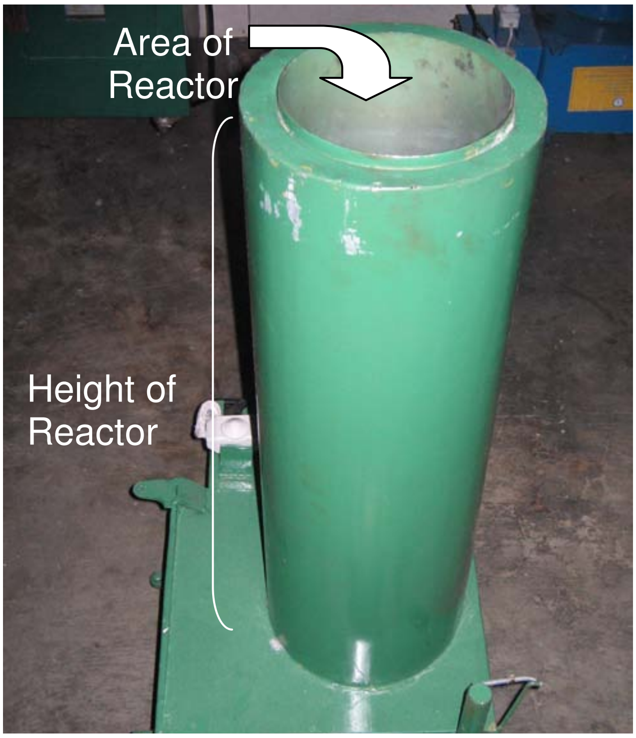


Figure 40. The Cross-Sectional Area and the Height of the Reactor.

moves down the entire height of the gasifier reactor at a speed of 1 to 2 cm/min. The higher the reactor, however, the more pressure draft is needed to overcome the resistance exerted by the fan or by the blower.

4. **Thickness of Fuel Bed** – The thickness of the fuel bed is only considered when designing a cross-draft gasifier. It is the same as that of the height of the reactor in the down-draft gasifier. Similarly, the thicker the layer of fuel in the reactor, the greater is the resistance required for the air to pass through the fuel column. The only advantage in using a thicker column of rice husks is that it slows down the downward movement of the combustion zone in the reactor, which can help in minimizing the erratic production of flammable gas during gasification.

5. **Fan Airflow and Pressure** – The fan provides the necessary airflow that is needed for the gasification of rice husks. They are available in AC (Fig. 41) or DC (Fig. 42). The fan to be used should be capable enough to overcome the pressure exerted by the rice husks and, subsequently, by the char. A high-pressure fan is usually ideal for down-draft type gasifier reactor, while low-pressure fan is used for cross-draft type reactor. The amount of airflow per unit mass of rice husk is about 0.3 to 0.4 of the

Figure 41. AC 220V-16 W Fan.

Figure 42. DC 12V-3W Fan.

stoichiometric air requirement of the fuel. A kilogram of rice husks usually requires about 4.7 kg of air to completely burn the fuel. In case of unavailability of suitable longer fan size needed, two fans can be used which are positioned either in parallel or in series which each other. Multi-staging of fan was proven to be effective in increasing the available pressure for the same airflow. Using blowers (Fig. 43) can overcome pressure in long reactors or those with thicker fuel column. However, the noise produced by its impeller can be destructive to the users.

Figure 43. AC 220 Volt-1 Amp Centrifugal Blower.

Figure 44. The Conventional LPG Burner.

6. **Burner Type** - The commonly used LPG-type burner (Fig. 44) can be utilized for a rice husk gasifier stove. However, there is a need to retrofit the burner design to allow proper combustion of fuel gas. Retrofitting includes enlarging of the inlet pipe of the burner and the provisions of a cone to induce secondary air, thereby making the gas properly ignited and burned. If the burner is to be designed and be fabricated for the rice husk gasifier

(Fig. 45), burner holes of about 3/16 to 1/4 of an inch spaced at 1/8-in. apart were proven to work well with gasified rice husks. The air for combustion should be introduced at the exhaust port of the burner rather than at the inlet port.

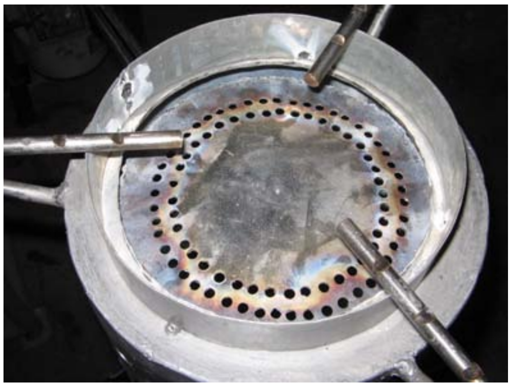


Figure 45. The Fabricated Gas Burner.

7. **Insulation for the Reactor** - The gasifier reactor needs to be properly insulated for two reasons: First, this will provide better conversion of rice husk fuel into gas. Second, this will prevent burning of skin when they accidentally touch the reactor's surface. Rice husk ash (Fig. 46) was found to be the cheapest and the most effective insulation material for rice husk gas stove. Concrete mixed with rice husk, at a proportion of 1:1, can also be used as an insulator. However, the reactor will become heavier and freight cost would be more expensive.

Figure 46. The Rice Husk Ash.

8. **Location of Firing the Fuel** - Rice husk fuel can be fired in the stove in different ways. For fixed bed gasifiers, like the down-draft reactor, rice husk fuel can be fired starting from the top (Top Lit) (Fig.47) or from the bottom (Bottom Lit) of the reactor. So far, for an inverted down-draft type gasifier, firing the fuel on top is the best and easiest way. Firing the fuel in this manner minimizes smoke emission.

Figure 47. Firing Fuel on Top of the Reactor .

However, reloading of fuel in between operation is not possible. Experience on the previous stove design revealed that reloading of fuel during operation is only possible when burning of fuel starts from the bottom of the reactor. The other advantage of firing from the bottom is that the total start-up time for the same height of the reactor can be extended, which cannot be done when firing the fuel from the top of the reactor.

9. **Size and Location of the Char Chamber** – The size of the chamber for carbonized rice husks (Fig. 48) determines the frequency of unloading the char or the ash. Bigger chamber can accommodate larger amount of char and can allow longer time before the char is removed. In addition, designing a shorter chamber will give sufficient height for the stove reactor and the burner. If the desired by-product of gasification is char, the size of the chamber should not be too big so that it will only require a shorter time before it is discharged. The hot char discharged from the reactor undergoes further

Figure 48. The Char Chamber.

burning which will consequently convert the char into ash. To properly discharge the ash or the char from the reactor, the angle of friction at the bottom of the chamber hopper should be at 45 degrees. In the case of limited angle, scraper or scoop will be needed to properly discharge the ash or the char.

10. **Safety Considerations** - Operating the stove requires safety. Therefore, safety considerations should be part of the stove design. In this regard, a safety shield is incorporated in the design of the stove to prevent the cook or the children from getting in direct contact with the hot
reactor. Pot support, such as a ring holder or protruded bars, is welded to the burner and to the pot support assembly to prevent the pot from accidentally sliding.

Design Procedure

In coming up with the desired design of the rice husk gas stove, the designer must have full understanding of the basic principles of gasification, material selection, manufacturing, as well as the economics of manufacturing and using the stove. Designers with limited knowledge on these areas can still design a rice husk gas stove. But it will take them longer time and higher costs in coming up with a workable model because of the “cut and try” process.

The step-by-step procedure below is the simple procedure followed in designing this rice husk gas stove:

1. Prepare the conceptual design of the stove. Making several concepts is better so that there will be more alternatives of design to choose from during the development stage. Make a careful study of the functions of the components and how it will optimize your design. Make a list of the advantages and limitations of every concept before coming up with a decision for the final design. Starting the design from the existing workable units is far better than starting from “scratch”.

2. Identify all components that need to be quantified starting from the most important one to the least. This may include the fuel hopper, combustion chamber, burner, fan, and switches.

3. Gather the data needed in the calculation from literatures. If no data are available, conduct experiments to generate the needed information in the design.

4. Determine the amount of power needed by the stove. This can be estimated from the energy requirement to cook food or to heat certain amount of water.

5. Determine the amount of fuel to be supplied to the stove needed to meet the energy required for cooking or boiling.

6. Compute for the size of the combustion chamber of the stove in terms of diameter and height of the reactor. Note that for rice husk gas stove, the diameter of the reactor determines the power output of the stove while the height of the cylinder dictates the time of operation. The bigger the diameter, the stronger is the power output of the stove. Increasing the diameter twice will result to a four fold increase in the power output of the stove. On the other hand, the time to operate the stove is affected by the height of the reactor. The higher the reactor, the longer is the operation of the rice husk gas stove. As mentioned in the previous section of this Handbook, the combustion zone moves about 1 to 2 cm per minute inside the reactor. Therefore, for a 60-cm long reactor, the stove can be expected to operate for 30 to 60 minutes. Other parameters like thickness of insulation and sizes of materials can also be computed although these are not very important for small stoves like this.

7. Compute the amount of air and the amount of draft needed to gasify rice husks. These are important information in the selection of the fan or blower needed for the reactor. The draft of rice husk fuel can be

determined from a chart (Fig. 39) after knowing the superficial velocity of the gas in the reactor.

8. Make a fabrication drawing of the stove indicating the computed dimension. Use standard dimension, as much as possible, to minimize wastage of materials as well as to prevent additional labor cost for "do and redo." Example, if the computed length is 1.12 m, use 1.2 m standard length.

9. Fabricate the stove according to the specifications in the design. Ask the fabricator for his suggestions in the improvement of the design, especially in the construction of the stove.

10. Test the stove and solicit comments from other people especially on the operation. This will help a lot in making the stove commercially attractive.

Design Calculations

Below are some important parameters that need to be considered in determining the appropriate size of the rice husk gas stove, taking into consideration the power output desired. The size of the stove can be easily estimated by computing these parameters.

The following parameters and their formula are presented here and their formula to calculate the basic requirement in the design of a rice husk gas stove:

1. **Energy Needed** - This refers to the amount of heat that needs to be supplied by the stove. This can be determined based on the amount of food to be cooked and/or water to be boiled and their corresponding specific heat energy as shown in Table 11 below.

Table 11. Energy Requirement for Cooking Food and for Boiling Water.

Food	Specific Heat (Kcal/kg-ºC)	Total Energy Needed (Kcal/kg)*
Rice	0.42 – 0.44	79.3
Meat	0.48 – 0.93	56.5
Vegetables	0.93	74.5
Water	1.0	72

*At 72ºC temperature difference

The amount of energy needed to cook food can be computed using the formula,

$$Qn = \frac{Mf \times Es}{T}$$

where:

Qn - energy needed, Kcal/hr
Mf - mass of food, kg
Es - specific energy, KCal/kg
T - cooking time, hr

Example. A kilogram of rice has to be cooked within 15 minutes, what is the energy needed to cook the rice?

Qn = (1 kg x 79.3 Kcal per kg x 60 min/hr) / 15 minutes

= 317.2 Kcal/hr

2. **Energy Input** – This refers to the amount of energy needed in terms of fuel to be fed into the stove. This can be computed using the formula,

$$FCR = Qn / (HVf\ \xi g)$$

where:

FCR	- fuel consumption rate, kg/hr
Qn	- heat energy needed, Kcal/hr
HVf	- heating value of fuel, Kcal/kg
ξg	- gasifier stove efficiency, %

Example. What is the amount of fuel needed per hour for a rice husk gas stove to be used to cook rice in the example given above? Assume a stove efficiency of 17%.

FCR = 317.2 Kcal/hr / (3000 kcal/kg x 0.17)

= 0.62 kg rice husk per hour

3. **Reactor Diameter** – This refers to the size of the reactor in terms of the diameter of the cross-section of the cylinder where rice husks are being burned. This is a function of the amount of the fuel consumed per unit time (FCR) to the specific gasification rate (SGR) of rice husks, which is in the range of 110 to 210 kg/m^2-hr or 56 to 130 as revealed by the results of several test on rice husk gas stoves. As shown below, the reactor diameter can be computed using the formula,

$$D = \left(\frac{1.27 \, FCR}{SGR} \right)^{0.5}$$

where:

D	- diameter of reactor, m
FCR	- fuel consumption rate, kg/hr
SGR	- specific gasification rate of rice husk, 110-210 kg/m^2-hr

Example. For a rice husk gas stove with a required fuel consumption rate of 2 kg per hour, the computed diameter for the fuel reactor using specific gasification rate of 100 kg/m^2-hr will be,

$$D = [\ 1.27\ (2 \text{ kg per hour}) / 100 \text{ kg/m}^2\text{-hr}\ ]^{0.5}$$

$$= 0.15 \text{ m}$$

4. **Height of the Reactor** - This refers to the total distance from the top and the bottom end of the reactor. This determines how long would the stove be operated in one loading of fuel. Basically, it is a function of a number of variables such as the required time to operate the gasifier (T), the specific gasification rate (SGR), and the density of rice husks (ρ_{rh}). As shown below, the height of the reactor can be computed using the formula,

$$H = \frac{SGR \times T}{\rho_{rh}}$$

where:

- H - length of the reactor, m
- SGR - specific gasification rate of rice husk, kg/m^2-hr
- T - time required to consume rice husk, hr
- ρ_{rh} - rice husk density, kg/m^3

Example. If the desired operating time for the gasifier stove above is 1 hour, assuming a rice husk density of 100 kg/ m^3 for the gasifier, the height of the reactor will be,

$$H = [\ (100 \text{ kg/m}^2\text{-hr} \times 1 \text{ hour}) / 100 \text{ kg/ m}^3\ ]$$

$$= 1 \text{ m}$$

4. **Time to Consume Rice Husk** - This refers to the total time required to completely gasify the rice husks inside the reactor. This includes the time to ignite the fuel and the time to generate gas, plus the time to completely burn all the fuel in the reactor. The density of the rice husk (ρ_{rh}), the volume of the reactor (Vr), and the fuel consumption rate (FCR) are the factors used in determining the total time to consume the rice husk fuel in the reactor. As shown below, this can be computed using the formula,

$$T = \frac{\rho_{rh} \times Vr}{FCR}$$

where:

T - time required to consume the rice husk, hr
Vr - volume of the reactor, m^3
ρ_{rh} - rice husk density, kg/m^3
FCR - rate of consumption of rice husk, kg/hr

Example. A 20-cm diameter rice husk gas stove with a 1.2-m high reactor is to be operated at a fuel consumption rate of 2.5 kg/hr. The time required to operate the stove will be,

$$T = [100\ kg/m^3 \times \pi\ (0.20\ m)^2\ (1.2\ m) / 4\ ] / 2.5\ kg/hr$$

$$= 1.5\ hours$$

6. **Amount of Air Needed for Gasification** – This refers to the rate of flow of air needed to gasify rice husks. This is very important in determining the size of the fan or of the blower needed for the reactor in gasifying rice husks. As shown, this can be simply determined using the rate of consumption of rice husk fuel (FCR), the stoichiometric air of rice husk (SA), and the recommended equivalence ratio (ε) for gasifying rice husk of 0.3 to 0.4. As shown, this can be computed using the formula,

$$AFR = \frac{\varepsilon \times FCR \times SA}{\rho_a}$$

where:

AFR - air flow rate, m^3/hr
ε - equivalence ratio, 0.3 to 0.4
FCR - rate of consumption of rice husk, kg/hr
SA - stoichiometric air of rice husk, 4.5 kg air per kg rice husk
ρ_a - air density, 1.25 kg/m^3

Example. The fuel consumption rate required for the rice husk gas stove is 2.5 kg per hour. The amount of air needed in order to gasify the fuel would be,

AFR = [0.3 (2.5 kg/hr) (4.5 kga / kg rh) /(1.25 kga/m^3)]

= 2.7 m^3/hr

7. **Superficial Air Velocity** - This refers to the speed of the air flow in the fuel bed. The velocity of air in the bed of rice husks will cause channel formation, which may greatly affect gasification. The diameter of the reactor (D) and the airflow rate (AFR) determine the superficial velocity of air in the gasifier. As shown, this can be computed using the formula,

$$Vs = \frac{4\ AFR}{\pi (D)^2}$$

where:

Vs - superficial gas velocity, m/s
AFR - air flow rate, m^3/hr
D - diameter of reactor, m

Example. For the stove in the example above with computed air flow rate of 2.7 m^3 per hour and a reactor diameter of 20 cm, the superficial velocity of air will be,

Vs = [4 (2.7 m^3/hr) / 3.14 (0.2 $m)^2$]

= 85.9 m/hr x 100 cm/m x hr/3600 sec

= 2.38 cm/sec

6. **Resistance to Airflow** – This refers to the amount of resistance exerted by the fuel and by the char inside the reactor during gasification. This is important in determining whether a fan or a blower is needed for the reactor. The thickness of the fuel column (Tf) and the specific resistance (Sr) of rice husk, which can be determined in Figure 39, will give enough information for the total resistance needed for the fan or the blower. As shown, this can be computed using the formula,

Rf = Tf x Sr

where:

Rf - resistance of fuel, cm of H_2O
Tf - thickness of fuel column, m
Sr - specific resistance, cm of water/m of fuel

Example. A 1-meter fuel column reactor with superficial air velocity of 2.38 cm/sec will have a specific pressure resistance of 0.5 cm water per m depth of fuel (See Fig. 39). Therefore, the calculated resistance needed by the fan or by the blower will be,

Rf = [1 meter x 0.5 cm water per m depth of fuel)

= 0.5 cm of water

Sample Design Computation

A rice husk gas stove (Fig. 49) is to be designed with the following requirements: fuel consumption rate - 1.5 kg of rice husk per hour and operating time - 45 minute operation. Compute the following: (1) required diameter and height of the reactor, and (2) airflow rate and pressure draft for the fan. Assume a rice husk density of 100 kg/m^3, specific gasification rate of 90 kg/m^2-hr, stoichiometric air of 4.7 kg air per kg rice husk, and equivalence ratio of 0.3.

Figure 49. The Rice Husk Gas Stove.

Given:

FCR	- 1.5 kg/hr
To	- 45 minutes
ρ_{rh}	- 100 kg.m^3
SGR	- 90 kg/m^2-hr
ε	- 0.3

Required:

Diameter of reactor
Height of reactor
Fan airflow rate
Fan pressure draft

Solution:

Calculating for the diameter of the reactor using the required rice husk consumption rate of 1.5 kg per hour and the specific gasification rate of 90 kg/m^2-hr, will give a diameter of

$$D = \left(\frac{1.27 \times 1.5 \text{ kg rice husk / hr}}{90 \text{ kg/m}^2\text{-hr}} \right)^{0.5}$$

= 0.145 m or use a 0.15 m reactor

Assuming a density of rice husk of 100 kg/m^3, the height of the reactor for the desired running time of 45 minutes would be

$$H = \frac{90 \text{ kg/m}^2\text{-hr} \times 0.75 \text{ hr}}{100 \text{ kg/m}^3}$$

= 0.675 m or use a 0.70 m high reactor

On the other hand, the amount of air needed by the fan for gasification using the rate of fuel consumed is

AFR = 0.30 x 1.5 kg rh/hr x 4.7 kg air/kg rh
= 2.115 kg air/hr

At an air density of 1.25 kg air /m^3, the volume of air needed is

= 2.644 m^3 of air per hour

In order to get the specific draft of rice husks from the graph in Figure 39, there is a need to compute for the superficial velocity of air inside the reactor. Computing for the superficial air velocity,

Vs = [2.644 m^3 / hr] / [3.14 (0.15 m)^2] / 4
= 150 m/hr or 4.17 cm/sec

Using Figure 39, the pressure draft of rice husk, at a superficial velocity of 4.17 cm/sec, is 0.9 cm of water per meter depth of fuel. Calculating the draft will give,

Pd = 0.70 m x 0.9 cm / m fuel
= 0.63 cm of water

In summary, the rice husk gas stove requires a reactor diameter of 0.15 m and a height of 0.70 m. The fan should be capable of supplying 2.644 m^3 of air per hour to the fuel column and of overcoming draft resistance for the fuel column of 0.63 cm of water.

Design Tips

Designing a rice husk gas stove, as earlier mentioned, is quite difficult and requires several modifications before arriving at a workable model. The design tips presented below will help beginners to minimize complicated problems and will help him or her narrow down his or her design options. Based on experience, the following were observed during the process of designing and developing the rice husk gas stove.

1. The power output of the stove is highly dependent on the diameter of the reactor. The bigger the diameter of the reactor, the more energy that can be released by the stove. This also means more fuel is expected to be burned per unit time since gas production is a function of the gasification rate in kg of fuel burned per unit time per unit area of the reactor.

2. The total operating time to produce gas is affected by the height of the reactor. The higher the reactor, the longer is the operating time. However, the height of the reactor is limited by the height at which the stove is to be installed in the kitchen. For the stove that is fired on top and where the burner is directly placed on it, the reactor is usually limited to about 65 cm. On the other hand, for the stove fired at the bottom and the burner is separately installed at the side of the reactor, the height can go as high as 1 to 2 meters as long as the fan can still deliver the required airflow and pressure to the fuel column.

3. The design considerations for the fan should be based on the pressure required to overcome the resistance to be released by the char instead of that by the rice husks. It

was observed that in a continuous operation, the resistance available in the reactor gradually increases as the combustion zone reaches the bottom end of the reactor. During gasification, the rice husk's lower resistance to airflow is gradually converted into a high-resistance material which is char.

4. The burner design affects the quality of burning gas in the stove. The size and the number of holes in the burner affect the amount of gas generated by the stove. A hole diameter of 3/16 to 1/4 in. works well for the rice husk gas stove. The holes should be closer as possible, at about 1/8 in. distance, to allow proper burning of gas in the burner. Secondary air should also be provided for the combustible gas to improve the combustion of the fuel. Moreover, the gap between the pot hole and the burner should not be too narrow in order to avoid quenching of the combustion of fuel neither should it be too wide in order to limit the heat released from the stove.

5. The size of the fan is dependent on the size of the reactor. The bigger the diameter of the reactor, the more airflow is needed. The higher the reactor, the more pressure is needed in order to overcome the resistance exerted by the fuel. An axial flow fan usually provides greater airflow than centrifugal blower. However, a centrifugal blower can produce higher pressure than an axial fan. Multi-staging of axial fan in series can increase the pressure at the same airflow. Putting them in parallel, on the other hand, can provide double airflow at the same pressure.

6. The fan is in better position if it is installed before the reactor to prevent hot gases from passing through it and eventually destroying it. Putting the fan in this position protects it from the damage that can be caused by the tar emitted by the burning rice husks. Based on experience, installing the fan after the reactor can cause a lot of maintenance problems. Also, the fan motor will be damaged by the hot gases and by the tar.

7. The fan should be installed away from any possible passage of hot gases or from the heat radiated by the burning char in the reactor for safe design installation. When the burning fuel reaches the bottom end of the reactor, it can cause damage to the fan especially if the fan is directly facing the reactor. Putting the fan at the side of the reactor or in offset position with the reactor was found workable in the stove.

8. Openings or any possible leakage of air in the gasifier fuel or char doors should be eliminated. Sometimes it is difficult to diagnose the problem in the operation of the stove when there is air leaking in the system. Air leakages basically lower the pressure needed in the reactor, which also reduces the performance of the reactor in gasifying rice husk. Gas can still be generated in such a case, but it is of poor quality and is usually incombustible.

9. There is a wide variation in the quality of rice husk fuel. The design of the stove should conform with the quality of fuel to be used. Rice husks obtained from a rubber-roll huller multipass rice mill are better than that obtained from a single-pass rubber-roll rice mill or steel-huller rice mill. The former has bigger particle size than the latter. Rice husks that are larger in size require less resistance to the flow of air than the ones that are smaller in size. Always remember that more pressure and lesser air are supplied into the fuel when small particle rice husks are used for the stove.

10. Materials for the reactor should be carefully chosen. The inner cylinder, which is directly in contact with the burning fuel, should be made of a heat resistant material. Stainless steel or refractory material is suitable for the inner cylindrical core of the reactor. However, the cost and the weight of the materials should be considered in the design of the stove. Low cost refractory material using rice husk ash with cement mixture, at a ratio of 1:1 up to 1:2, works very well for the stove reactor. GI sheet

material can also do the job but extra care must be observed in using this material because when the zinc coating oxidizes at high temperature, it emits poisonous gases.

11. The size and especially the thickness of the materials need also to be considered in the design. The cost and the life span of the stove unit are basically affected by the size of the material. Thin metal sheets are difficult to weld using an electric arc welding and require the use of oxy acetylene gas welding in order to fix them.

CHAPTER VI

STOVE FABRICATION

Generally, the discussion below is applicable only when fabricating the rice husk gas stove in a small metal craft on a batch-method, producing six units of the stove per batch. Because of the limited availability of equipment in most small fabrication shops, a simple procedure was followed by the fabricator in fabricating the stove and is presented in this Handbook. Note that mass production in a large-scale manufacturing shop is quite different than in a small shop.

Construction Materials

The rice husk gas stove, similar with other metal stoves, generally requires the following materials for its fabrication:

- Galvanized iron sheet, no. 20 or 18
- Stainless steel sheet no. 20 or GI sheet no. 16
- Stainless steel rod, 1/4-in. diameter
- Stainless steel screen mesh, 1/4 in.
- Hinges
- Door Lock
- Rice husk ash
- Fan or blower
- Switch
- Rubber Shoe Cap

The galvanized iron (GI) sheet is used for the construction of the outer cylinder of the reactor and of the char chamber. Either GI sheet gauge 20 or 18 can be used, depending on the desired durability and on the estimated cost to produce the stove. The material usually utilized for the inner cylinder of the reactor is stainless steel sheet, either gauge 20 or 22. In order to reduce the cost of producing the stove, stainless steel sheet gauge 22 can be used without sacrificing the expected durability of the stove. Thicker GI sheet, i.e. gauge no. 16, can be another alternative in case the stainless steel is hardly available or is very expensive. The cost of the stove can be further reduced by minimizing the use of stainless steel for the inner reactor.

For the burner assembly, the outer cylinder is usually made of GI sheet material with the same gauge as that of the reactor. The inner cylinder, the part of the burner which is directly in contact with the flammable gases, generally requires the use of stainless steel because of its good resistance to heat. The pot support and the handle of the burner assembly including the frame for the char grate and the lever are also made of stainless steel material for better durability. On the other hand, the insulation of the stove is made of rice husk ash which is a good insulating material due to its high silica content. Rice husk ash is also very cheap since it can be obtained from the burned rice husks found either on road sides or in the field. Mixing the cement with rice husk ash, at a ratio of 1 part cement to 1 or 2 parts of rice husk ash, can effectively keep the insulation intact.

A fan or a blower is used to provide the air needed for gasification. Fan and blower can be readily purchased from any electrical suppliers. A switch is used to regulate the amount of air delivered by the fan. It is connected with the electrical wirings of the fan for the latter to be easily switched OFF and ON during operation.

Hinges and door locks are usually obtained from hardware suppliers. They are the type of hinges and locks commonly used for steel windows of houses.

Manpower Requirement

Fabricating six units of the rice husk gas stove will require two persons to finish the job within a week. This is considering all the needed materials for the fabrication are already purchased and delivered to the Shop. Also, the tools and equipment needed for fabrication are already available.

In fabricating the stove, at least one of the two laborers must be skilled in fabrication job particularly in the welding of metal sheets. The other worker will serve as a helper to do the cutting of metal sheets and bars. If both of the welders are unskilled, this may have an effect on the quality of the finished product which may appear unattractive to the prospective buyers.

Based on experience, fabricating the stove for the first time even with someone who can guide the step-by-step procedure would take a much longer time than when they have already produced several batches of the stove. It was experienced that during the first batch of producing the stove, the two persons can finish the entire batch of the stove unit within two weeks. During the later part of the production of the stove, the two workers can finish the same batch of the stove within one week only.

Tools and Equipment

The following are the basic tools and equipment needed in the construction of the rice husk gas stove:

1. **Tin Snip** – This is a tool (Fig. 50) used for cutting metal sheets, especially for gauges 18 and above. For the rice husk gas stove, this is usually suited for cutting the materials for the inner and the outer reactors, as well as the ash or char chamber.

Figure 50. The Tin Snip.

2. **Shear Cutter** – This tool is used for cutting thicker sheets of metal, especially gauge no. 16.

3. **Bench Drill** – This tool (Fig 51) is used for drilling holes,

Figure 51. The Bench Drill.

especially in the fabrication of the burner assembly, for the primary and secondary air. A bench drill provides a better accuracy when drilling several burners at a time or drilling thicker materials. Power hand drill can also be used for drilling holes. However, drilling of holes can only be done for one to two sheets at a time when using power hand drill.

4. **Hammer** – This is used in folding metal sheets to form them into a desired shape. The use of hammer is minimized when the materials are bent using a bar folding machine.

5. **Arc and Oxy-Acetylene Welding Machines** – These equipment (Fig. 52) are used for fixing thick metal sheets together. Since a galvanized iron sheet no. 18 is used for the stove, the arc welding machine is used with the oxy acetylene welding, for welding metal parts together.

(a) (b)

Figure 52. The Welding Equipment: (a) Arc, and (b) Oxyacetylene.

6. **Roller** – This tool (Fig. 53) is a locally made device used to roll metal sheets into a cylinder, particularly in making the inner and

Figure 53. The Roller.

the outer reactors as well as all cylindrical parts of the stove burner. Although this is not as accurate as with the roller press, this device was found to serve the purpose of bending some materials in the production of the stove in small shops.

7. **Pliers** – This is used in holding pieces of the material, especially during welding, as well as in folding parts of the metal sheet to be provided with stiffeners.

8. **Jigs** – This is used to keep the parts firmly in place during the fabrication of the stove flange for the inner and the outer cylinder of the reactor.

There are still other assembly tools such as screw drivers, wrenches, and pliers needed in the production of the stove.

In large-scale production, the use of bar folding machine, roller bender, and bench shear can provide a more accurate and faster production of the stove. Producing in a large-scale manufacturing is believed to further reduce the cost of the stove per unit.

General Guidelines

The general guidelines in fabricating the rice husk gas stove are enumerated below. The succeeding section gives the specific step-by-sep procedure for finishing one unit of the stove.

1. Review the design drawing of the rice husk gas stove. Determine the various assemblies of the stove such as the fuel reactor, char chamber, and burner. Take note of the materials and the dimension of the various assemblies. Carefully study how these assemblies will be fabricated considering your own facilities and equipment. Always remember that parts of the stove should be made at a least possible cost for labor and electricity.

2. Prepare all the materials needed for the construction of the stove. Example of a list of materials is given in Table 12.

Table 12. List of Materials Needed for Fabricating Six Units of Rice Husk Gas Stove.

Qty	Unit	Description
3	Shts	GI Sheet gauge 18
1	Pc	S/S Plate gauge 22
2	Lgth	GI Pipe 1/2 in. S20
2	Lgth	S/S Rod 5/16
2	Pcs	S/S Rod 3/16
2	Ft	S/S Rod ¼
2	Pcs	Ordinary Rod ¼
6	Pcs	Blower Fan 4" – 16 watt/220 V
6	Pcs	Switch
6	Pairs	Hinges
6	Pcs	Lock
1	Li	Enamel Paint
24	Pcs	Rubber shoe
6	Pcs	Hook
2	Sacks	Rice husk ash

As shown, the list of materials may include fabricated materials such as metal sheets and bars, and standard materials such as hinges, door lock, fan, switches, and others.

3. Make a layout (Fig. 54) of each of the different components of the stove on a metal sheet. For six units of the stove, two GI sheets and a sheet of stainless steel are needed. Make sure the use of the materials is maximized when making a layout for the stove parts. In other words, wastage of materials should be minimized during fabrication.

Figure 54. Layouting of Stove Parts.

4. Cut the metal sheet (Fig. 55) according to the dimension specified in the layout using a tin snip. For thicker materials, use bench snip cutter to facilitate cutting of the metal sheet. Bend and cut bars as specified in the drawing. Note that cutting time during the production of the stove must be kept as short as possible. Based on our experience, six units of the stove can be finished in a small shop by two workers within one week.

Figure 55. Cutting Metal Sheet with Bench Snip.

5. Roll metal sheets with a pipe bender (Fig. 56) in forming the inner and the outer cylinders of the reactor, as well as the cylindrical parts of the burner assembly. When forming metal sheets, be careful not to abruptly bend the sheets so that the rolled cylinder would be uniform. You will fully gain confidence in making cylinders using these two pipes as more sheets are rolled into cylinders.

Figure 56. Forming Cylinders on Pipe Bender.

6. Fold metal sheet in making the char chamber. This can be done by placing the sheet on a straight angular bar and then hammering it on the straight edge of the bar to fold. In order to make accurate folding of the sheet, a bar folding machine can be used, if

available. Hammering the sheet for bending is the simplest way of folding metal sheet, however, finished product does not look attractive.

Figure 57. Welding of Stove Parts.

7. Weld (Fig. 57) all parts that need to be joined together. Oxyacetylene welding machine is advisable for welding thinner metal sheets, particularly in forming the inner reactor and the burner assembly where proper sealing is required. The outer reactor, char chamber, pot holder, support legs, char frame, and grate lever can be welded using the arc welding machine. After all the different parts are properly welded and constructed to the desired form, the surface of the welded parts should be smoothened using a power sander. See to it that the surfaces and edges are evenly smoothened before applying paint on them.

Figure 58. Filling Up of Rice Husk Insulation.

8. Fill the reactor with insulation using rice husk ash (Fig. 58). A mixture of cement and rice husk ash, at a proportion of 1:2, is also found effective as an insulation material. Allow the insulation to temper for at least a week before using the stove in actual cooking..

9. Apply paint on the stove to protect its surface and to make the unit more attractive. Spraying is the best way of applying paint on the stove. Using a roller brush is another way of applying paint on the stove. Note that applying paint using spray is not advisable to do when it is raining.

Figure 59. Completely Fabricated Six Units Rice Husk Gas Stoves.

Figure 60. Painted Rice Husk Gas Stoves with the Author (left photo).

10. Install the fan and the electrical switches (Fig. 61) and check whether or not they are functioning properly. Make sure that the fan is properly bolted to the housing assembly. It should be carefully fixed into the housing without damaging the impeller so that it will minimize power loss during operation. The switch for the fan must be connected in series with the wire.

Figure 61. The Fan and the Switch Installed in the Stove.

11. Wrap the stove with thick paper (Fig. 62) or place the unit inside a box container ready for handling and for transport. Usual shipment of the stove is done by just wrapping the stove with paper for ease of shipment. A packaging tape is used to hold the carton in place. Also remember that the cost of shipment of the stove is based on the weight of the unit, including the packaging materials.

Figure 62. The Stove Wrapped with Thick Paper Ready for Shipment.

Detailed Procedure in Fabricating the Rice Husk Gas Stove

The procedure below gives the specific steps being followed at present in fabricating the rice husk gas stove. All the metal sheet works is the first phase of work that must be done followed by metal bars work. In terms of parts, the char chamber and the fan housing are the first work to be done followed by the installation of the fuel reactor. The burner assembly comes next which is to be followed by the door assembly and char grate assembly. All metal bars activities are the last activities before painting the stove and installing the fan and switches.

Below is the step-by-step procedure in fabricating the stove:

1. Make a lay out of the char chamber, fuel reactor outer cylinder, fuel reactor inner cylinder, fuel reactor flange, and fan housing assembly on the steel sheet. Then, cut these various components as required. Allow at least 1/4 of an inch as overlap.

2. Fold the sheets into the various forms as required. For the char chamber, fold the sheet to make it into box as illustrated in Appendix 6. The same process should be done for the fan housing. Roll the inner and outer cylinders of the reactor according to the diameter of the cylinder required.

3. Weld all connecting parts of the char chamber box, fan housing, and the cylinders' longitudinal length. Welding should be done with overlap to prevent possible occurrence of gap that would cause spillage of the rice husk ash insulator.

4. Weld the fan housing and the reactor cylinders into the char chamber. The fan housing is positioned at one side of the reactor while the fuel reactor is on top. As shown in the drawing, the cylindrical hole at the topmost end of the char chamber is intended for the installation of the inner reactor cylinder. The outer cylinder, on the other hand, is

to be placed enclosing the inner reactor. The clearance between the inner and the outer cylinder must be the same throughout the circumference.

5. Fill the reactor with rice husk ash to the top. Press the ash so that all spaces will be filled with insulation.

6. Close the space between the inner and the outer reactor with flange and weld it.

7. Make a layout of the burner cylinder assembly. This includes the top plate, flanges, inner cylinder, and outer cylinder. Cut these components according to the required sizes.

8. Drill holes on the top plate and at the outer cylinder. The series of holes at the topmost portion of the plate, which serves as gas exhaust, should be drilled first followed by the holes in the outer cylinder, which serve as entrance for the secondary air.

9. Roll the inner and the outer sheets of the burner cylinders as required. Weld them together with oxyacetylene welding to make sure that no gas escapes during operation. Attach the flanges and weld them to form a burner. Make sure that the burner properly fit to the reactor, without possible leakage of gases during operation.

10. Make a layout of the door assembly for the char chamber. The door must be well fitted and can be easily opened or closed during operation. All edges of the door should be bent inward to properly secure it in place during operation and to provide better stiffening job to the material. Properly attach the door hinges and locks.

11. Cut all steel bars as specified in the design. This will include the support leg, frame for the char grate and the lever, pot support and handle, and the frame support for the safety shield.

12. Weld all the bars as required. Starting from the support legs, char grate frame and lever, burner pot support and handle, to safety shield frame.

13. Apply metal putty on some depressions on metal surfaces and smoothen it with sand paper.

14. Apply paint on the surface of the metal by spraying it with enamel paint. Allow the paint to dry overnight.

15. Assemble the fan and switch.

CHAPTER VII

PERFORMANCE TESTING AND EVALUATION

In testing and evaluating the performance of the rice husk gas stove, two series of tests were conducted. These are: (a) the laboratory tests, and (b) the actual cooking tests.

1. **Laboratory Test** - In the laboratory test (Fig. 63), operating parameters for the stove were determined. Series of test runs were conducted to determine the various operational performance of the stove including boiling tests to determine the efficiency and the power output of the stove. Test equipment, such as thermometer, weighing scale, volumetric flasks, and timer, were used during the testing of the stove in the laboratory.

Figure 63. Laboratory Testing of the Stove.

2. **Actual Cooking Test** – In this test, the stove was used in households (Fig. 64). Data were taken as the stove was being used. Data on the cooking performance of the stove, operational kitchen management (i.e., loading the rice husk fuel and unloading the char), operation, and economics of using the stove were

Figure 64. Actual Testing of the Stove.

gathered from households who actually used the stove. Feedbacks on the operation of the stove were also solicited from the users for further improvement in its design and operation. The economics of using the stove was also determined and compared with the traditional methods of cooking being practiced by households.

There are different methods that can be used to test the performance of a stove. These include the water boiling test, the water simmering test, and the combination of these two tests which is called water boiling-simmering test. The most commonly used method in testing the performance of the rice husk gas stove, however, is the combination of the water boiling and simmering tests which allows a certain volume of water to boil and simmer until all the fuel is consumed in the reactor. During the test, the operating performance of the stove in terms of start-up time to ignite rice husk fuel, ignition time to generate gas, total operating time, time to boil a certain volume of water, amount of fuel used, and amount of char produced after each operation were determined. Temperature profile of water during boiling is determined in this test from the time the pot is placed on the burner until all the fuel is completely gasified. Other data such as the temperature of gas and the pressure draft are also taken during the tests.

The time to cook different types of food was also recorded to determine the actual time required to cook food in the gas stove and to evaluate other operational characteristics, such as the required attendance, possible emission of fly ashes, quality of food cooked, control of stove during operation, and others.

During the tests, it was noted whether operating the stove employed a cold-start or a hot-start condition. In cold-start, the testing of the stove is done in a condition where the stove temperature is in equilibrium with the ambient air. In hot-start, on the other hand, testing is done at a temperature where the stove is still in hot condition or has been recently used. It was further noted whether the pot is with or without lid during the tests.

The following are the basic steps in testing the rice husk gas stove:

1. Ready the stove to be tested. Make sure that the stove is operational before conducting the test.

2. Prepare the rice husk fuel. Rice husk fuel should be dry and freshly obtained from a rice mill. Decomposed rice husks taken from road sides or from dumpsites are not fitted for use in this stove for it will not yield a better cooking result.

3. Prepare the test equipment such as weighing scale, thermometer, volumetric cylinder, and electric power meter.

4. Measure the weight of fuel to be loaded in the stove. This can be done by gradually loading the stove with rice husk fuel, which was previously weighed, until the reactor is full.

5. Prepare the water to be boiled. Record its weight or volume. A liter of water is usually utilized for the water boiling test in a small stove while five liters is usually boiled in a larger stove. Also record the initial temperature of water.

6. Ignite the fuel in the stove and record the start-up time as well as the amount of paper used.

7. Ignite the gas emitted from the burner and record the time until spontaneous combustion is attained.

8. Fill the casserole or pot with the prescribe amount of water. Cover the casserole and put it on top of the burner. Record the time the pot is placed on the burner.

9. Wait until the water boils. Record the time when the water in the casserole starts to boil. Also, record the temperature of water at one minute interval until the boiling point is reached.

10. Continue boiling the water until all the fuel in the reactor is totally consumed and no more combustible gas is produced. Record the operating time of the stove from the start of firing until no combustible gas is produced. Also, record the weight or the volume of the remaining water in the casserole after the test.

11. Discharge the char from the reactor and measure its weight.

12. Tabulate results of the test (See Appendixes 8 & 9 for sample test data sheets) and compute for the different parameters needed for the analysis.

Materials and Instruments

The following are the materials and instruments needed in testing the performance of the stove:

1. **Fresh, Dried Rice Husk** – This is used as fuel in testing the performance of the stove. This must be freshly obtained from the rice mill and must be dried.

2. **Spring-Scale Balance** - This device (Fig. 65) is used to measure the weight of rice husk fuel as well as the weight of food to be cooked and the weight of water to be boiled.

Figure 65. The Spring-Scale Balance

3. **Volumetric Flasks and beaker** - These glasswares (Fig. 66) are used to measure the volume of water before and after the boiling test. The change in the volume of water after the test indicates the power output of the stove per load.

Figure 66. Volumetric Flask.

4. **Bimetallic Thermometer** – This is used to measure the temperature of water. Operating range must be between 0 to 100°C.

5. **Thermocouple Wire Thermometer** - This equipment (Fig. 67) is used in measuring the gas temperature leaving the combustion chamber.

6. **AC Clamp-On Meter** - This is used to measure the current and voltage input into the fan or blower in order to determine the amount of power consumed as well as to estimate the cost of electricity incurred in operating the stove.

Figure 67. The Thermo-couple Wire Thermometer.

7. **Stop Watch** – This is used to record the time of each of the
different activities (i.e. cooking and boiling) during the tests.

Test Parameters

The following parameters are used in evaluating the performance of the rice husk gas stove:

1. **Start-Up Time** – This is the time required to ignite the rice husks and consequently to produce combustible gas. This parameter is measured from the time the burning pieces of paper are introduced to the fuel in the reactor until combustible gas is produced at the burner.

2. **Operating Time** – This is the duration from the time the gasifier produces a combustible gas until no more gas is obtained from the burning rice husks.

3. **Total Operating Time** – This is the duration from the time rice husks are ignited until no more combustible gas is produced in the stove. Basically, it is the sum of the start-up time and the operating time of the stove.

4. **Fuel Consumption Rate** (FCR) – This is the amount of rice husk fuel used in operating the stove divided by the operating time. This is computed using the formula,

$$FCR = \frac{\text{Weight of Rice Husk Fuel Used (kg)}}{\text{Operating Time (hr)}}$$

5. **Specific Gasification Rate** (SGR) – This is the amount of rice husk fuel used per unit time per unit area of the reactor. This is computed using the formula,

$$SGR = \frac{\text{Weight of Rice Husk Fuel Used (kg)}}{\text{Reactor area (m}^2\text{) x Operating Time (hr)}}$$

6. **Combustion Zone Rate** (CZR) – This is the time required for the combustion zone to move down the reactor. This is computed using the formula,

$$CZR = \frac{\text{Length of the Reactor (m)}}{\text{Operating Time (hr)}}$$

7. **Boiling Time** – This is the time required for the water to boil starting from the moment the pot is placed on the burner until the temperature of water reaches 100ºC.

8. **Sensible Heat** – This is the amount of heat energy required to raise the temperature of water. This is measured before and after the water reaches the boiling temperature. This is computed using the formula,

$$SH = Mw \times Cp \times (Tf - Ti)$$

where:

SH - sensible heat, Kcal
Mw – mass of water, kg (1kg/liter)
Cp – specific heat of water, 1 Kcal/kg-°C
Tf – temperature of water at boiling, Approx. 100°C
Ti – temperature of water before boiling, 27-30°C

9. **Latent Heat** – This is the amount of heat energy used in evaporating water. This is computed using the formula,

$$LH = We \times Hfg$$

where:

LH - latent Heat, Kcal
We – weight of water evaporated, kg

Hfg – latent heat of water, 540 Kcal/kg

10. **Heat Energy Input** – This is the amount of heat energy available in the fuel. This is computed using the formula,

$$QF = WFU \times HVF$$

where:

QF – heat energy available in the fuel, Kcal
WFU – weight of fuel used in the stove, kg
HVF – heating value of fuel, Kcal/kg

11. **Thermal Efficiency** – This is the ratio of the energy used in
boiling and in evaporating water to the heat energy available in the fuel. This is computed using the formula,

$$TE = \frac{SH + LH}{HF \times WF} \times 100$$

where:

TE - thermal efficiency, %
Sh - sensible heat, Kcal
LH - latent heat, Kcal
HF - heating value of fuel, Kcal/kg
WF - weight of fuel used, kg

12. **Power Input** – This is the amount of energy supplied to the stove based on the amount of fuel consumed. This is computed using the formula,

$$Pi = 0.0012 \times FCR \times HVF$$

where:

Pi - power input, kW
FCR - fuel consumption rate, kg/hr
HVF - heating value of fuel, Kcal/kg

13. **Power Output** - This is the amount of energy released by the stove for cooking. This is computed using the formula,

$$Po = FCR \times HVF \times TE$$

where:

Po - power output, kW
FCR - fuel consumption rate, kg/hr
HVF - heating value of fuel, Kcal/kg
TE - thermal efficiency, %

14. **% Char Produced** - This is the ratio of the amount of char produced to the amount of rice husks used. This can be computed using the formula,

$$\% \text{ Char} = \frac{\text{Weight of Char (kg)}}{\text{Weight of Rice Hull Used (kg)}} \times 100$$

Other information that needs to be determined during the test includes the following:

- Frequency of attendance
- Smoke emission
- Heat emission
- Portability
- Maintenance
- Cleaning
- Presence of fly ash
- Others

CHAPTER VIII

OPERATION OF THE STOVE

General Guidelines in the Use of the Stove

The stove is designed only for rice husks (Fig. 68). Other kinds of biomass fuel such as sawdust, sugarcane bagasse, corn cob, etc. are not appropriate for use in this particular design of the gas stove.

Figure 68. The Rice Husk Fuel.

The stove should be kept away from any combustible fuel. The area in which to operate the stove should be clean and dry. Electrical power source must be available and a back-up unit must be ready, in case of power failure.

Basically, firing of the stove begins from the top of the reactor. Firing automatically stops when the combustion zone reaches the bottom end of the reactor. Never start ignition at the bottom of the reactor, for in doing so, too much smoke and incombustible gases will be produced.

Stove Installation

It is required that the stove should be installed in a **Dirty Kitchen** where there is proper air ventilation. It is not advisable to place the stove inside the Main Kitchen because of the inconvenience in loading fuel and in removing burned rice husks. Moreover, gas emitted from the stove can cause unfavorable odor inside the enclosed kitchen, especially during the start-up.

Stove Operation Procedure

The following are the guidelines and procedures in operating the stove:

1. Properly check the stove (Fig. 69). Make sure that the burner, grate, and ash chamber door are set in their proper position. Plug IN the fan to a convenience outlet and check whether or not it is functioning when the switch is in ON or in OFF position.

2. Check the rice husk fuel (Fig. 70). Rice husks should be dry and freshly obtained from a rice mill. Wet rice husks will not gasify, if used. It will produce a lot of smoke and will result to inconveniences during operation. Old stocked rice husks thrown on roadsides or along river banks will also cause problem during firing of the stove. If ever possible, use newly produced dry rice husks.

Figure 69. Checking the Different Parts of the Stove.

Figure 70. Checking Rice Husks Fuel.

3. In starting the operation of the stove, remove the burner seated on top of the reactor. The burner is made removable and the removal is made easy using a handle, which is provided at one side of the burner.

Figure 71. Loading of Rice Husks Fuel.

4. Load rice husk fuel (Fig. 71) into the reactor by using a scoop or by directly pouring the fuel from the container. One full load of fuel requires about a kilo of rice husks which is good for 50 to 60 minutes operation.

Figure 72. Placing Small Pieces of Paper on the Fuel Column.

5. Tear papers into small pieces and place them on top of the rice husk fuel (Fig. 72) to facilitate start-up. Used oil or kerosene can be used for easy start-up by pouring drops of it on the fuel column, if desired.

6. Lit the paper (Fig. 73) using a match stick and switch ON the fan to provide the air needed for proper combustion of fuel. Allow the surface of the fuel column to totally burn.

Figure 73. Lighting the Paper.

7. Close the reactor (Fig. 74) by placing the burner on top of it when ¾ of the entire area of the fuel in the reactor is observed to be burning. Make sure that the burner is well-fitted to the top end of the reactor so that no gasified fuel can escape.

Figure 74. Placing the Burner Assembly to Close the Reactor.

8. Allow the fuel to burn for about a minute, then lit or ignite the gas at the burner. Premature ignition will not produce luminous blue flame. While waiting for the flammable gas, do not inhale the gas coming out of the stove, for just like any other kind of gaseous fuel, it is injurious to health.

9. Use a match stick or a piece of paper to ignite the gas. Proper burning of gas is achieved when all the holes in the burner (Fig. 75) are fully filled by the burning gas. Adjust fan setting until proper burning of fuel is attained.

Figure 75. Burning of Gas in the Burner.

10. In cooking, place a casserole or a pot (Fig. 76) on top of the burner. For a single load of rice husk, 0.5 kg of rice plus two viands can be normally cooked. Note that this stove is designed only for a typical Filipino household

Figure 76. With a Pot on the Burner.

having 2 to 3 children. Cooking greater amount of food will require the use of a larger stove.

11. Adjust the speed of the fan during operation using the switch (Fig. 77). As the stove operates, increase the speed of the fan. It requires ample air to gasify rice husk fuel as it burns inside the reactor during operation. When all the fuel is completely burned or when the stove stops producing gas, it means that the operation is completely finished. Shut OFF the fan to keep the smoke from coming out of the stove. The burned rice husks can now either be immediately discharged or be allowed to stay in the char chamber until the next operation.

Figure 77. The Switch.

12. Remove burned fuel from the reactor by tilting the ash lever to facilitate the discharge of char or ash into the ash chamber. Removing the burned rice husks from the reactor right after operation will produce carbonized rice husks, which is called char. Allowing the burned rice husks to stay inside the reactor for half a day, at least, will produce ash as by-product.

Figure 78. Removal of Char Using a Scoop.

13. Remove the char/ash (Figs. 78 & 79) using a scoop and place them in a metal container or can. Spread the material after disposal to prevent continued burning of the char.

Figure 79. Placing the Char in a Metal Container.

Stove Storage

After each use, the stove must be properly cleaned and thoroughly dried. Remove spilled rice husks or keep any combustible materials away from the stove. Unplug the unit from the convenience outlet and make sure that the electrical wirings are properly kept secure. Ash or char must be removed from the reactor before placing the stove in storage.

Trouble Shooting Guide

The problems that are commonly encountered in the operation of the rice husk gas stove are listed in Table 13. Possible causes are identified and their corresponding remedies are given.

Table 13. Trouble Shooting Guide.

Trouble	Possible Cause	Remedy
Fan fails to operate	Not plugged to a convenience outlet	Plug to a convenience outlet
	Faulty circuit	Check circuit
	Low Voltage	Check voltage; use 220 V line
Rice husk fails to burn or it produces lots of smoke	Wet rice husk	Use dry rice husks
	Deteriorated rice husk	Use newly produced rice husks
	Small rice husk particle size	Use rice husks obtained from rubber roll multi-pass rice mill
	Adulterated rice husk fuel (with impurities)	Use better rice husk fuel with no impurities
	Compacted rice husks in the reactor	Remove rice husks from the reactor and fill again. Do not compact
	Insufficient air supply	Check fan speed; check for possible air leakage
Gas not burning properly	Too much air	Reduce fan speed
	Clogged burner (with paper or char)	Clean burner and remove clogged
Smoke coming out of the burner	Loosely fitted burner assembly	Check burner position
	Too much air supply	Reduce fan speed
	Burned paint	Allow paint to be burned
	Spilled over rice husk burns	Remove spilled fuel on the reactor before firing

CHAPTER IX

ECONOMICS

The economics of the rice husk gas stove is determined from two points of view. First is the economics of producing the stove and the second is the economics of utilizing it. The first presentation is for the producers' side while the second is for the users or adaptors' of the stove.

Cost of Producing the Stove

The rice husk gas stove, in this analysis, is basically produced in a small shop with limited equipment used in the fabrication and production process is done by batch. In order to maximize the use of materials, six units of the stove are produced in one batch. All the needed fabrication materials for the stove are bought from the nearest supplier at one time and are delivered to the fabrication shop.

To determine the cost of producing the stove, the sum of the costs of the materials consumed for the six units, contingency, and fabrication cost was determined (Table 14). The selling price per unit of the stove was determined by providing overhead cost (based on the production cost), margin, and tax.

The following are the step-by-step procedure in determining the production cost and the selling price per unit of the stove:

<u>Step 1</u> – Make a list of all the materials needed in the fabrication of the six stoves. This includes metal sheets, bars, fan, switches, and other components of the stove.

<u>Step 2</u> – Determine the cost of materials in fabricating the stove by multiplying the number of units and the price per unit of the materials used.

Table 14. Bill of Materials for Manufacturing Six Units of Rice Husk Gas Stove Model S15 and Selling Price per Unit.

Qty	Unit	Description	Unit Price (P)	Total Amount (P)
3	shts	GI Sheet gauge 18	1,085.00	3,255.00
1	pc	S/S Plate gauge 22	3800.00	3,800.00
2	lgth	GI Pipe 1/2 in. S20	259.50	519.00
2	lgth	S/S Rod 5/16	520.00	1,040.00
2	pcs	S/S Rod 3/16	230.00	460.00
2	ft	S/S Rod ¼	350.00	700.00
2	pcs	Ordinary Rod ¼	45.00	90.00
6	pcs	Blower Fan 4" – 16 watt/220 V	190.00	1,180.00
6	pcs	Switch	170.00	1020.00
6	pairs	Hinges	15.00	90.00
6	pcs	Lock	25.00	150.00
1	li	Enamel Paint	125.00	125.00
24	pcs	Rubber shoe	9.00	216.00
6	pcs	Hook	4.00	24.00
2	sack	Rice husk ash	10.00	20.00
		Total		12,649.00
		Contingency (10%)		1,264.90
		Total Material Cost		13,913.90
		Fabrication Cost*	1,000.00	6,000.00
		Production Cost		19,913.90
		Overhead Cost (20%)		3,982.78
		Sub-Total		23,896.68
		Margin (15%)		3,584.50
		Manufacturing Cost		27,481.18
		Tax (10%)		2,748.12
		Total Selling Price		30,229.30
		Selling Price per Unit		P5,038.22

* Includes labor cost, consumables, and power consumption

US$1 = 55 PHP

Material Costs = (Unit $Cost_1$ x No. of $Units_1$) + (Unit $Cost_2$ x No. of $Units_2$) + . . . + (Unit $Cost_n$ x No. of $Units_n$)

where:

Unit Cost	- is the individual cost of the different materials used in the stove
No. of Units	- is the quantity of each material used

Step 3 – Add contingency (i.e., 10% of the material cost) to the material cost derived in Step 2 to get the total material cost. This is to provide allowance for price increases and for other incidental expenses that might be needed during the fabrication of the stove.

Total Material Cost = MC + Contingency

Step 4 – Add the fabrication cost to total material costs to determine the production cost of the stove. In this rice husk gas stove, production of the stove is being sub-contracted. So, fabrication cost already includes the costs of consumables and of electricity.

Production Cost = Fabrication Cost + Total Material Cost

Step 5 – Add overhead cost and margin to get the manufacturing costs. In this project, 20% of the production cost was allotted as the overhead cost while 15% of the sum of production cost and overhead was allotted as the margin.

Manufacturing Cost = Production Cost + Overhead + Profit Margin

Step 6 – Add tax to the manufacturing cost in order to determine the total selling price of the six stoves. All taxes that need to be paid are incorporated in this calculation. In this endeavor, only 10% of the manufacturing cost was added.

Total Selling Price = Manufacturing Cost + Tax.

Step 7 – Divide the total selling price by the number of units of stove fabricated in order to determine the selling price per unit.

Selling Price per Unit = Total Selling Price / No. of Units of Stove

As shown in Table 14, total cost for the materials in producing six units of the stove is P12,649.00. This includes the costs of metal sheets, bars, fan, switch, and other basic parts. With the additional 10% contingency, the material cost for the stove is P13,913.90. Since fabrication of the stove is P1,000.00 per unit, the cost to produce the six stoves now is P19,913.90. With 20% overhead cost of P3,982.78, a 15% profit margin of P3,584.50, and a 10% tax of 2,748.12, the total selling price for the six units of stove is P30,229.30. Since there are six units of the stove produced per batch, the cost per unit of the stove is P5,038.22 or P5,000.00.

Cost of Utilizing the Stove (or Operating Cost)

Operating cost represents the total expenses incurred by the users in operating the stove. Basically, this includes the fixed cost, which is the cost of owning the stove, and the variable cost, which is the cost incurred in operating the stove.

The fixed costs basically include depreciation, interest on investment, repair and maintenance, and insurance. On the other hand, the variable costs include the cost of hauling rice husk fuel and the cost of electricity consumed in running the fan or the blower. The sum of the fixed and variable costs divided by the operating time is the cost of operating the stove per unit time. Comparative operating cost analysis of using the rice husk gasifier stove and the LPG stove is shown in Table 15.

Table 15. Comparative Operating Cost Analysis of Using the Rice Husk Gas Stove and the LPG Stove.

	Stove	
	Rice Husk Gasifier *	LPG Stove *
Investment Cost		
Stove	P5,000.00	P1,000.00
Tank		2,500.00
Total	P5,000.00	P3,500.00
Fixed Cost	P/day	P/day
Depreciation 1/	4.11	2.88
Interest on Investment 2/	3.29	2.30
Repair and Maintenance 3/	1.37	0.96
Insurance 4/	0.41	0.29
Total	9.12	6.43
Variable Cost	P/day	P/day
Fuel Consumption 5/	1.95	27.00
Electricity 6/	0.26	
Total	2.21	27.00
Total Cost	P11.39/day**	P33.43/day***
Operating Time 7/	3 hours/day	3 hours/day
Operating Cost per hour	P3.80/hr	P11.14/hr
Payback Period	7.47 months	
Yearly Saving on Fuel	P8,037.30	

1/ Straight line method with 10% salvage value and 3 years life span
2/ 24% of IC
3/ 10% of IC
4/ 3% of IC
5/ 3 kg rice husk per day at P0.5/kg hauling cost; 1 tank LPG/20 days at P540.00/tank
6/ 16 Watt at 3 hours per day and P5.50/kw-hr
7/ 3 hours per day

* US$1 = 55 PHP
** US$ 0.21
*** US$ 0.61

To determine the operating cost of the stove, the following are the basic steps:

Step 1 - Determine the investment cost for the stove. Basically, this is the purchase cost of the stove or the price of the unit when it was bought from the supplier.

Step 2 – Compute for the depreciation of the stove by getting the difference between the investment cost and the salvage value, which is 10% of the original cost of the stove, and divide by the life span of the stove expressed in days.

Depreciation = (Investment Cost – Salvage Value) / Life Span

Step 3 – Compute for the interest on investment by multiplying the investment cost with the interest rate charged by banks on loans divided by 365 days.

Interest on Investment = (Investment Cost x Interest Rate) / 365

Step 4 – Compute for the repair and maintenance cost by multiplying the investment cost with the percentage repair and maintenance of about 10% and divide by 365 days.

Repair and Maintenance = (Investment Cost x 10% of IC) / 365

Step 5 – Compute for the insurance cost by multiplying the investment cost by 3% and dividing the product by 365 days.

Insurance = (Investment Cost x 3%) / 365

Step 6 – Determine the total fixed costs by adding the depreciation, interest on investment, repair and maintenance, and insurance.

Fixed Costs = Depreciation + Interest on Investment
+ Repair and Maintenance + Insurance

Step 7 – Compute for the cost of fuel per day of operation. This can be determined based on the fuel consumption rate of the stove multiplied by the operating time per day and the cost of hauling rice husks, which is about P5.00 per sack (10 kg/sack).

Fuel Cost = Fuel Consumption Rate x Operating Time
x Hauling Cost

Step 8 – Compute for the electrical power cost per day of operation. This can be determined based on the power rating of the 16-watt fan. Multiply the electrical power cost per day by the operating time. The operating time is 3 hours per day and the cost of electricity is P5.5 per KW-hour.

Electrical Cost = Power Rating x Operating Time x Power Cost

Step 9 - Determine the variable costs by adding fuel cost and electrical cost.

Variable Costs = Fuel Cost + Electrical Cost

Step 10 – Determine the total cost of operating the stove by adding the total fixed costs and the total variable costs.

Total Cost = Total Fixed Costs + Total Variable Costs

Step 11 – Determine the operating cost of the stove per hour of operation by dividing the total cost with the number of hours the stove is operated in one day.

Operating Cost = Total Cost / Operating Time

Step 12 - Do the same computation for the use of the conventional LPG stove and compare the results with that of using the rice husk gas stove.

Step 13 – Get the difference of the cost of using LPG stove and of using the rice husk gas stove then, multiply with the total operating time in one year to determine the savings per year.

Savings = (Operating cost of RHGS – Operating Cost of LPGS) x Operating Time

Step 14 – Divide the investment cost for the stove with the savings per year to get the payback period of the stove.

Payback Period = Investment Cost / Savings per year

The procedure given above can be clearly understood by following the comparative operating cost analysis of using the rice husk gas stove and of using the LPG stove presented in Table 15.

As shown, one unit of rice husk gasifier stove needs an investment of about P5,000.00, while the LPG stove needs an investment of only P3,500.00 (i.e., stove and tank). It is clear that investment for the LPG stove is lower by P1,500 compared with that of the rice husk gas stove. However, since the gasifier stove uses rice husks as fuel and a very minimal amount of electricity, the stove is more economical to use in the long run.

Cost analysis of operating the rice husk gasifier stove, as shown in the table, revealed an economic advantage over the use of LPG stove. Computing the fixed cost, for a salvage value of 10% and a life span of 3 years, the depreciation is P4.11/day for the gasifier stove and P2.88/day for the LPG stove. Considering the interest on investment, repair and maintenance and insurance, the total fixed costs for the gasifier stove is P9.12/day while for the LPG stove, it is P6.43/day. The variable costs, on the other hand, which include the cost of hauling rice husks and the cost of electrical power in driving the fan, is P2.21 per hour for the gasifier stove and P27.00 per hour for the LPG stove. The variable cost for the LPG stove is determined by dividing the cost of an 11-kg tank of LPG, which is P540.00, by the average number of days the content of one tank is consumed, which is 20 days per month. In one hour operation, the operating cost for the rice husk gasifier stove is about P3.80 while for the LPG stove, it is P11.14. Getting the difference in the operating cost of the two stoves, a yearly savings of P8,037.30 on fuel is derived, which can be realized when gasifier stove is used instead of LPG stove.

CHAPTER X

RECENT DEVELOPMENT ON THE RICE HUSK GASIFIER STOVE

This chapter discusses the recent development on the design of the rice husk gas stove, both for domestic and institutional cooking.

This recent development on the rice husk gas stove is about the design of a multiple "remote" burner assembly that are now available in two models – the table-type and the table-top burner.

Table-Type "Remote Burner" RHGS

The table-type remote burner model, with two-burner stove (Fig. 80), was a recently developed rice husk gas stove for households who desire to cook rice and viand at a time. As shown in Figure 80, the stove has a fuel reactor that is separated from the burner. Since the stove in this model supplies gaseous fuel to the two burners, the fuel reactor is a little larger than that of the single burner stove. Similar design configuration of the burner used in the single burner gas stove was adopted in

Figure 80. The Table-Type Multiple "Remote Burner" Rice Husk Gas Stove.

this stove, except that in the “remote-burner” stove there is an additional gas control device coupled to the system. The gas control device used is a ball valve which is coupled into the pipe line between the supply gas pipe and the burner. A T- chimney is attached at the end of the gas supply pipe to discharge unwanted gases, especially at the start of the operation.

Figure 81. The Bluish Flame Produced in the Stove.

Preliminary tests have shown that the table-type multiple “remote burner,” rice husk gas stove can satisfactorily supply the heat energy needed for cooking for a typical Filipino household size. The flame can be better controlled during operation with the use of the valve and the use of a rotary switch. Flame (Fig. 81) is observed to be more bluish as compared with that in the single burner gas stove.

Figure 82. The Stove During Testing.

The stove consumes 2.5 kg of rice husks per load at 40 to 45 minutes continuous operation. The energy input for the blower is 44 watts at 220 volt line. The specific gasification rate is 126.2 kg/hr-m^2 while the combustion zone rate is 1.75 cm/min. The ignition time for rice husks is two minutes and the start-up time for the generated gas also takes 2 minutes. The advantage features of this stove model are as follows: (1) easy to start, with almost no smoke at all; (2) convenient to operate, by using ball valves and switch knob to control the flame; (3) clean to operate, with no fly ashes; (4) low operating cost, since it uses rice husks as fuel and minimal amount of electricity; and (5) affordable.

The investment cost for the stove is P8,500.00 per unit and a savings of P4,887.91 on the cost of fuel can be derived within a year of operation as compared with that of using the LPG stove.

Table-Top Multiple "Remote Burner" RHGS

This model of the stove (Fig. 83) was designed upon request of clients to further reduce the investment cost requirement for the stove. Instead of having a heavy device which occupies a large space, a stove design where the burner can be placed on top of a table was built and tested.

Figure 83. The Table-Top Multiple "Remote Burner" RHGS

The stove, as shown in Figure 83, is similar to that of the Table-Type model except that the burner adopted for this design is similar to that of an LPG burner with conical cover or cap on top to provide better combustion of fuel.

Figure 84. The stove During Operation.

Tests have shown that the stove performs satisfactorily using the same size of the reactor for the table-type stove. The same quality of flame (Figs. 84 & 85) was obtained from this stove during operation, except that an increase in power for the blower was observed. This increase in the observed power for the stove is attributed to the smaller diameter pipe used for the burner.

Figure 85. The Close-Up View of the Flame in the Stove.

The production cost for this model is only P7,000.00 per unit.

Remote Burner Institutional Size RHGS

This stove (Fig. 86) is a larger version of the multiple “remote burner” rice husk gas stove which is designed for cooking in restaurants, hotels, schools, and for other larger operation. The reactor has a diameter of 30 cm and a length of 120 cm. Similarly, the stove burner is separated from the reactor and has a chimney for exhaust of unwanted gases.

Instead of ball valves that were used to control the flow of gas for the table-type, gate valves were utilized for economic reason. In this stove, the burner has a diameter of 30 cm combining the designs of burners used in the previous models.

Figure 86. The Institutional Size “Remote Burner” Rice Husk Gas Stove.

CHAPTER XI

FUTURE RESEARCH AND DEVELOPMENT

The potential of mass utilization of rice husks as an alternative for the high-cost LPG fuel has inspired the Appropriate Technology Center of CPU to further develop rice husk gas stove for various applications such as cooking, boiling, grilling, baking, water heating, and others. Various sizes of the stove, to cater individual household, restaurant, institutional, and large-scale operation, are now in the pipeline and are considered for the next research and development. Future focus on the fuel reactor design will be on the following:

1. Rice husk gas stove operating in a natural draft mode - This will be a rice husk gasifier that will operate without the use of a fan or a blower. This R&D design comes to mind to address the need of clients who have no access to electricity or those whose houses are out of the grid. A center-tube type and inclined grate rice husk stove seems a promising technology to gasify rice husks by natural mode.

2. Rice husk gas stove for continuous operation – This technology will be developed so that cooking can be done continuously, if ever longer cooking time will be needed. The stove will have a provision for loading of rice husks and unloading of char without interrupting the operation. Modifying the existing conical grate rice husk stove will be a promising design in achieving this objective. Studies conducted on this kind of stove found out that only limited amount of air needs to be provided in producing a luminous blue flame.

3. Rice husk gas stove fuel with rice husk on a canister - There is a good suggestion from people with inventive mind to design a rice husk gas stove using fuel inside a canister. The problem in hauling rice husk fuel will be addressed in this particular design of the rice husk gas stove. With this design, the rice husk gas stove technology will become

more acceptable, especially in urban areas, if rice husk fuel placed in a canister is delivered right at the doorstep of the clients' residence. One canister good enough for one hour cooking will be most likely acceptable to mothers.

4. Rice husk gas stove with storage tank for generated gases – This technology will adopt a principle similar to biogas system where the gases produced are temporarily stored in a plastic, rubber, or metal drum. With gas storage tank, cooking can be done anytime of the day with only single firing of fuel in the reactor. Gas generation can be done separately from the burner or away from the main house thus making kitchen operation more convenient and cleaner.

5. Rice husk gas stove operating on AC/DC power – This is a technology that will allow the operation of the stove either on grid or on 12-volt battery. Several clients desire to have this gas stove operate on two power sources for more mobility in case of power failure from AC.

6. Rice husk gas stove made from locally-available low-cost or indigenous material – The desire of other prospective clients to have a rice husk gas stove at the lowest possible cost had inspired us to undertake research and development on this technology using low cost material, such as a petrol drum with locally mixed refractory cement as an alternative. In the past, the use of locally mixed refractory materials from rice husk ash was proven to have good resistance to high temperature without making cracks or any damage on the material. If ever this research will be pushed through, stove of this design will be more applicable for stationary operation.

7. Rice husk gas stove for baking and grilling – This technology will adopt the principle of burners used in the conventional LPG, with slight revision. Since gas generated in the rice husk gas stove can be conveyed to a remote burner and can be controlled smoothly, a stove design using the rice husk gasifier reactor will be a promising one.

Any organization who would like to work with us in any of these future endeavors, i. e., to develop cookstoves using rice husks as fuel in a gasified form, is highly welcomed.

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Appendix 1

ACRONYMS

AIT	- Asian Institute of Technology
APPROTECH ASIA	- Asian Alliance of Appropriate Technology Practitioners, Inc
ARECOP	- Asia Regional Cookstove Program
BEF	- Biomass Energy Foundation
BLDD	- Bottom Lit Down Draft Gasifier
CLSU	- Central Luzon State University
CPC	- Community Power Corporation
CPU	- Central Philippine University
CPU-ATC	- Central Philippine University – Appropriate Technology Center
CPUCA	- Central Philippine University – College of Agriculture
CREST	- Center for Renewable Energy and Sustainable Technology
CRESARD	- Cambodia Renewable Energy and Sustainable Agriculture for Rural Development
DA-BAR	- Department of Agriculture – Bureau of Agricultural Research
DA-IRRI	- Department of Agriculture – International Rice Research Institute
DOST	- Department of Science and Technology
GATE	- German Appropriate Technology Exchange
IDD	- Inverted Down Draft Gasifier
ILSTU	- Illinois State University
LPG	- Liquefied Petroleum Gas
NERDC	- National Energy Research and Development Centre
PCARRD	- Philippine Council for Agriculture, Forestry, and Natural Resources Research and Development
PSAE	- Philippine Society of Agricultural Engineers
REAP	- Resource Efficient Agricultural Production
REPP	- Renewable Energy Policy Project
RHGS	- Rice Husk Gas Stove
T-LUD	- Top Lit Updraft Gasifier
UK-IT	- United Kingdom – Intermediate Technology
USA	- United State of America

Appendix 2
GLOSSARY

Char Chamber – It is the place in the stove where rice husks after gasification, is discharge prior to removal from the stove.

Down-Draft Gasifier – It is a fixed bed type of gasifier where the gasification zone is at the bottom, the air enters through lateral air inlets and moves downward, with the hot gases exiting at the bottom. The fuel supply is above and keeps dropping down into the gasification zone.

Equivalence Ratio - It is the percentage ratio of the air needed for gasification to the stoichiometric air requirement of rice husks.

Fan – It is an air moving device that provides the needed amount of air for the gasification of fuel in the stove. It is characterized by high airflow but low pressure air.

Fixed Bed Gasifier - It is a major type of gasifier where the fuel is gasified while it is held in place inside the reactor.

Gasification – It is the process of converting rice husks fuel into combustible gases by using limited amount of air during combustion process.

Gasifier Reactor – It is a component of the gasifier system where the fuel is burned and the air is to be converted to a flammable gas.

Inverted Down Draft Gasifier – It is a method of gasifying fuel by starting the ignition on top of the reactor as the air is introduced at the bottom of the reactor, either naturally or with forced air.

Paddy – It is the product after rice is harvested and the mature grains are separated from rice straw.

Rice Husk – It is the by-product of milling rice after the brown rice is separated from paddy.

Specific Gasification Rate – It is the amount of rice husk fuel consumed per unit area of the reactor.

Stoichiometric Air - It is the air needed to completely burn rice husks and convert it to ash.

Top Lit Up Draft (T-LUD) Gasifier – It is similar to the inverted down draft gasifier where the ignition of fuel is started on top of the fuel bed while the air is introduced at the bottom of the bed.

Up-Draft Gasifier – It is a fixed bed type gasifier where the fire zone is at the bottom and the air moves upward through the hot char and usually exits laterally. The fuel supply, which is above the pyrolysis and char-gasification zone, continually drops into the gasification zone.

Appendix 3
CONVERSION CONSTANTS

Length	1 ft	=	12 in.
	1 cm	=	0.3937 in.
	1 in.	=	2.54 cm
	1 m	=	3.28 feet
Area	1 ft^2	=	144 $in.^2$
	1 m^2	=	10.76 ft^2
	1 ft^2	=	929 cm^2
	1 $in.^2$	=	6.452 cm^2
Volume	1 liter	=	1000 cm^3
		=	0.2642 gal
		=	61.025 $in.^3$
	1 ft^3	=	144 $in.^3$
		=	7.482 gal
		=	28.317 liter
		=	28,317 cm^3
	1 gal	=	3.7854 liter
Density	1 $lb/in.^3$	=	1728 lb/ft^3
	1 lb/ ft^3	=	16.018 kg/m^3
	1 gm/cm^3	=	1000 kg/m^3
Time	1 min	=	60 seconds
	1 hour	=	3600 seconds
		=	60 min
	1 day	=	24 hours
Speed	1 fps	=	0.3048 m/s
Force, Mass			
	1 lb	=	4.4482 N
		=	453.6 g
	1 kg	=	2.205 lb
		=	9.80665 N
	1 metric ton	=	1000 kg

Pressure	1 atm	= 1.033 bar
		= 14.7 psi
		= 101,325 N/m^2
		= 29.921 in. Hg (0°C)
		= 760 mm Hg (O°C)
		= 1.0332 kg/cm^2
	1 psi	= 27.684 in. of water
		= 2.036 in. of mercury
		= 51.715 mm Hg (0°C)
		= 0.0731 kg/cm^2
	1 in. $H_2$0	= 0.0361 psi
		= 0.0736 in. of mercury
Energy	1 Btu	= 251.98 cal
		= 1.055 kJ
	1 kw-hr	= 3412.2 Btu
		= 3600 kJ
	1 kJ	= 1 kw-s
	1 kw-min	= 56.87 Btu
	1 kcal	= 4.1668 kJ
	1 wt-hr	= 860 cal
Heat Capacity		
	1 BTU/hr-F	= 0.5274 W/°C
	1 W/C	= 1.8961 BTU/hr-F
Heat Flow	1 BTU/hr	= 0.2931 W
	1 watt	= 3.411 BTU/hr
Power	1 BTU/hr	= 0.2931 W
	1 BTU/sec	= 1.0551 kW
Specific Heat		
	1 BTU/lb-F	= 4.1868 kJ/kg-K
	1 Kcal/kg-K	= 1 cal/g-°C
Temperature		
	°F	= 1.8°C + 32
	°C	= [°F – 32] / 1.8

Appendix 4
ENERGY CONVERSION OF RICE HUSK TO OTHER FUELS

Fuel	Heating Value (Kcal/kg)	Conversion Ratio* Kg Fuel / Kg rice husk	Equivalent Amount per Ton of rice husk
LPG	11,767	3.92	23.19 Tank
Wood	3,355	1.18	847.45 kg
Wood Charcoal	5,893	1.96	510.20 kg
Kerosene	11,000	3.66	314.85 liters
Gasoline	11,528	3.84	350.59 liters
Diesel	10,917	3.64	325.19 liters
Electricity	-	-	3.49 MW-HR

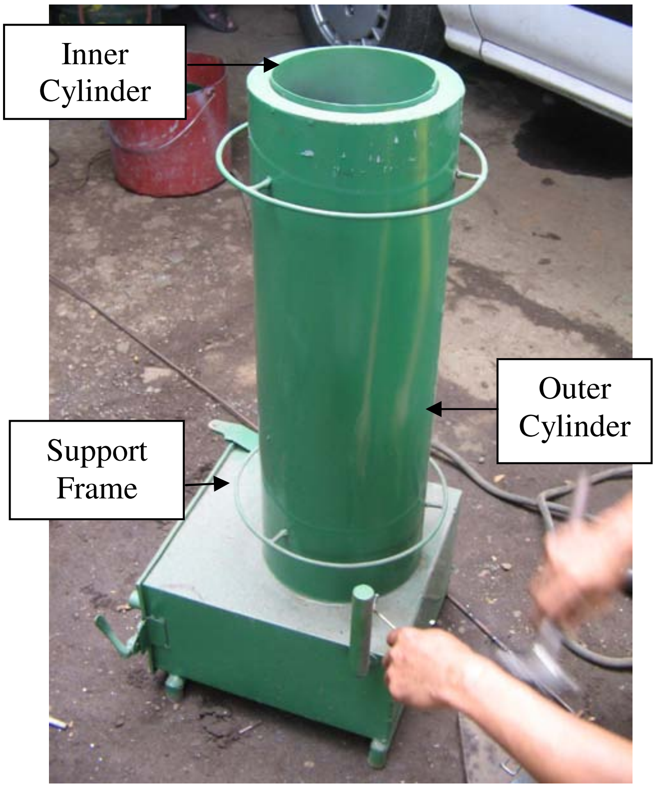
* Direct conversion using rice husk heating value of 3,000 Kcal per kg

Appendix 5
Number of Households per Region in the Philippines (During Year 2000)

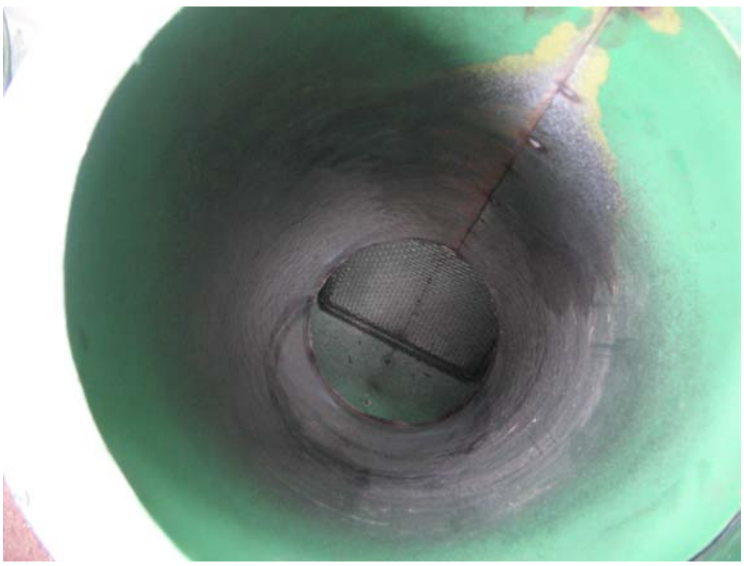
Region	Number of Households
National Capital Region	2,188,675
Cordillera Administrative Region	275,075
Ilocos Region	807,528
Cagayan Valley	566,692
Central Luzon	1,517,069
Southern Tagalog	2,274,664
Bicol Region	1,096,921
Western Visayas	1,211,734
Central Visayas	1,104,989
Eastern Visayas	734,809
Western Mindanao	603,728
Northern Mindanao	535,735
Southern Mindanao	1,032,587
Central Mindanao	514,406
CARAGA	409,790
ARMM	394,255

Appendix 6

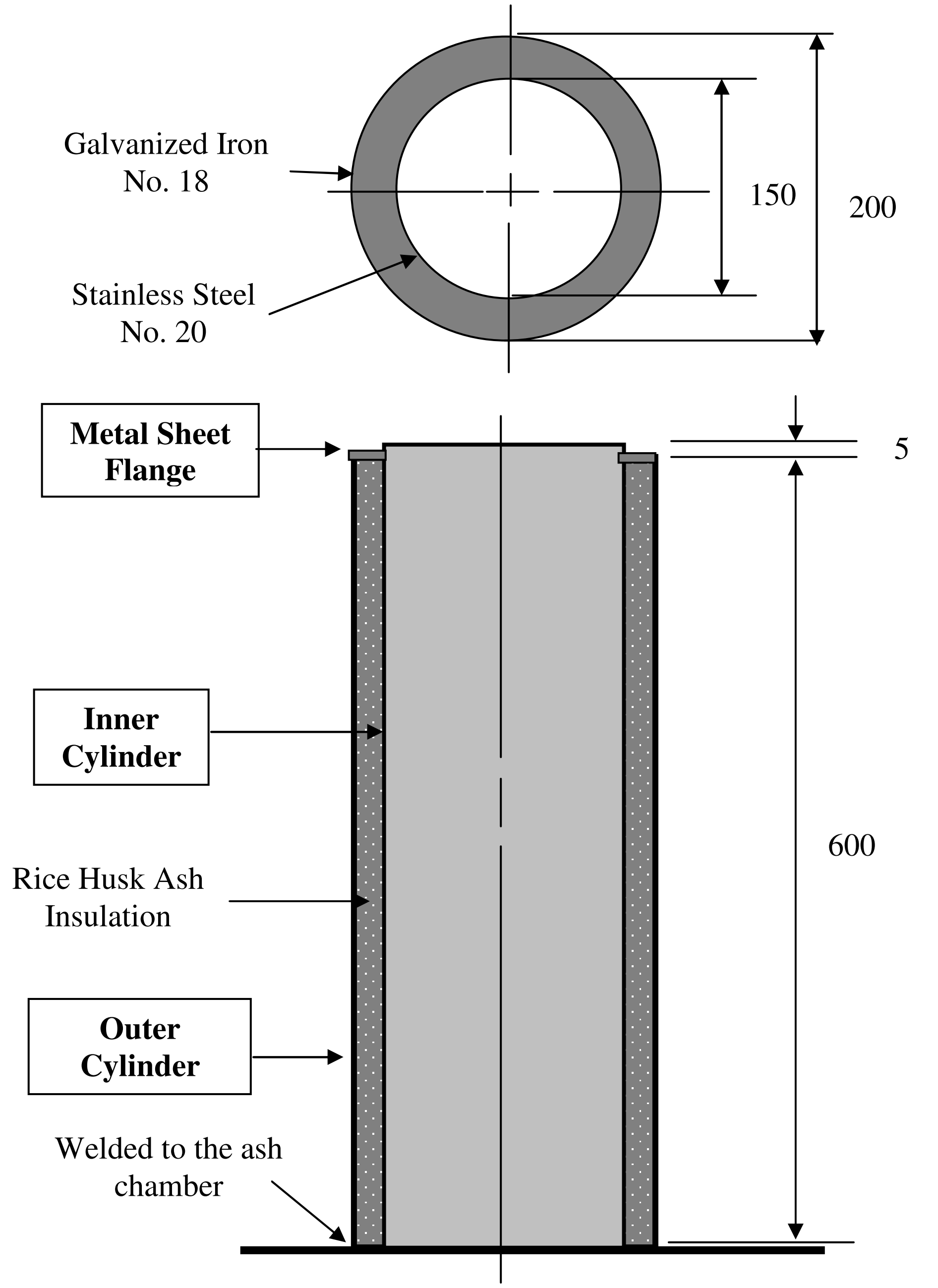
DESIGN DRAWING OF THE COMMERCIALLY-PRODUCED RICE HUSK GAS STOVE MODEL – S150



Pictorial View of the Stove Reactor



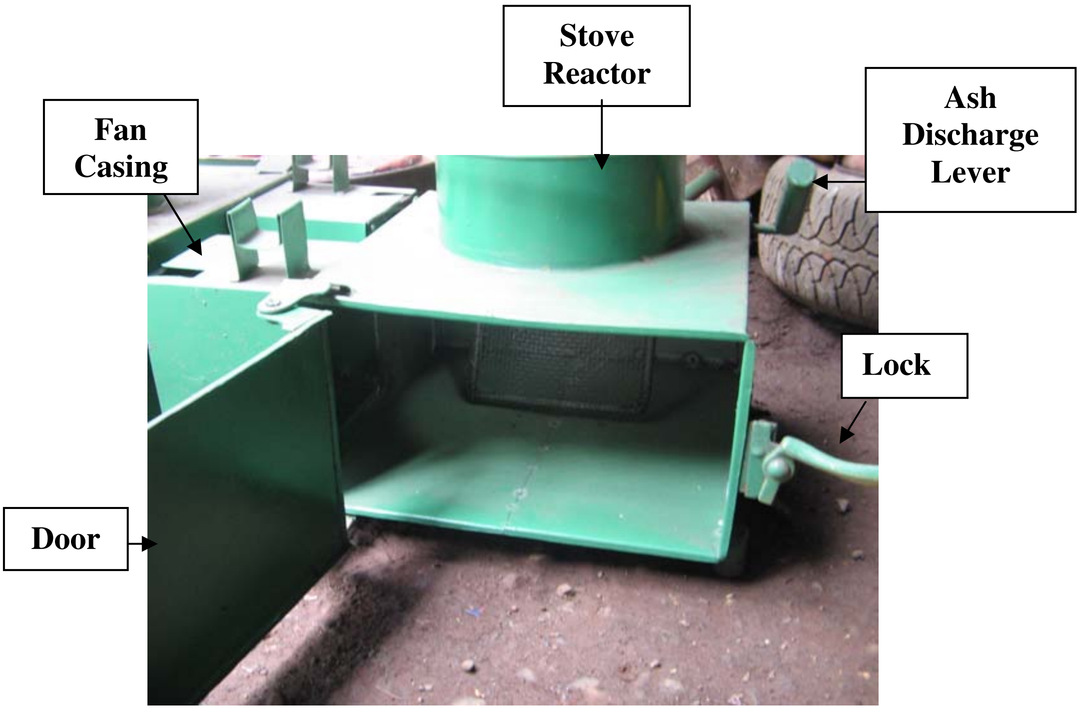
Close Up View of the Inner Core



DETAIL OF THE GASIFIER REACTOR

Not drawn to scale

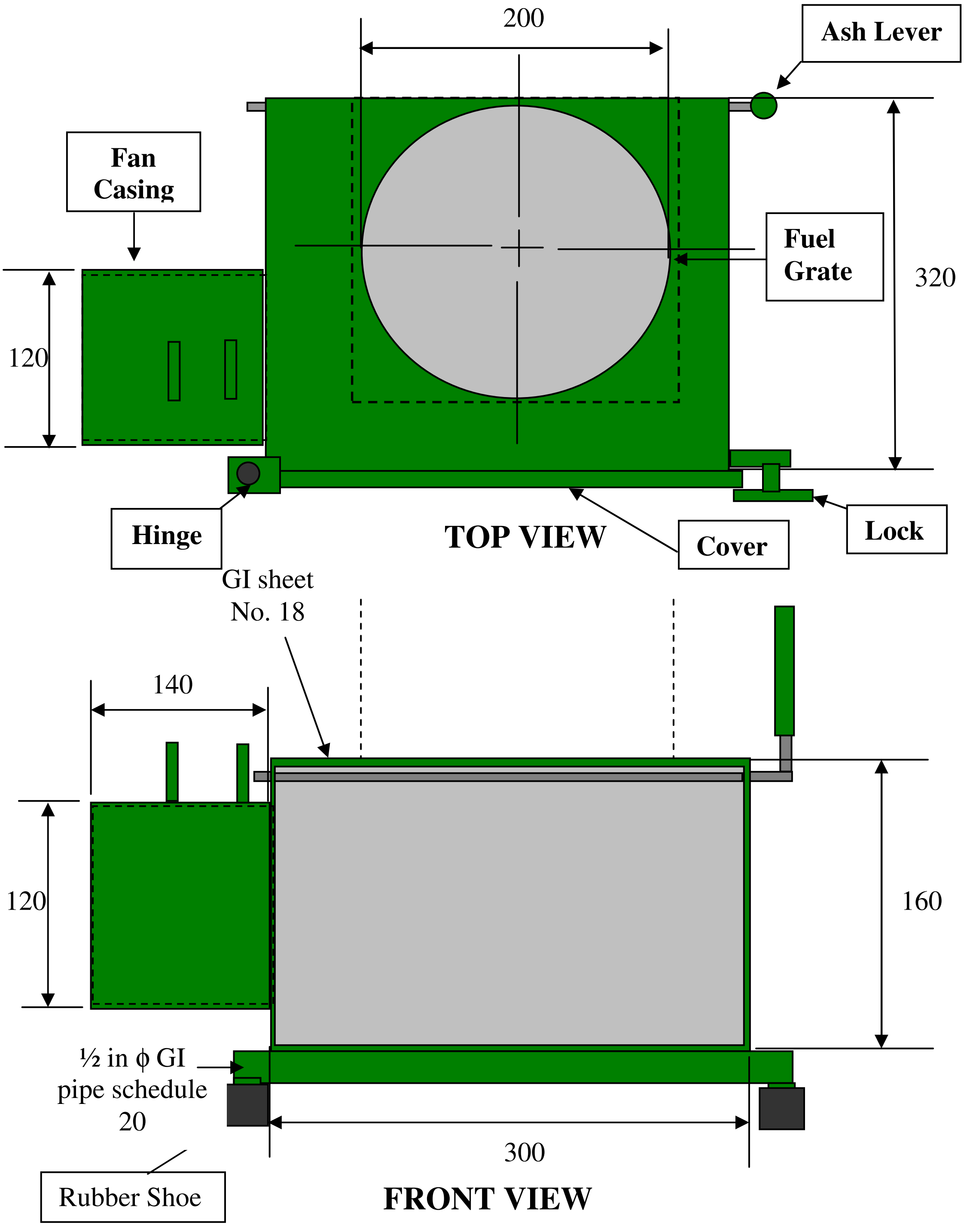
All dimensions are in mm unless specified



Close Up View of the Ash Chamber

Close Up View of Door Lock

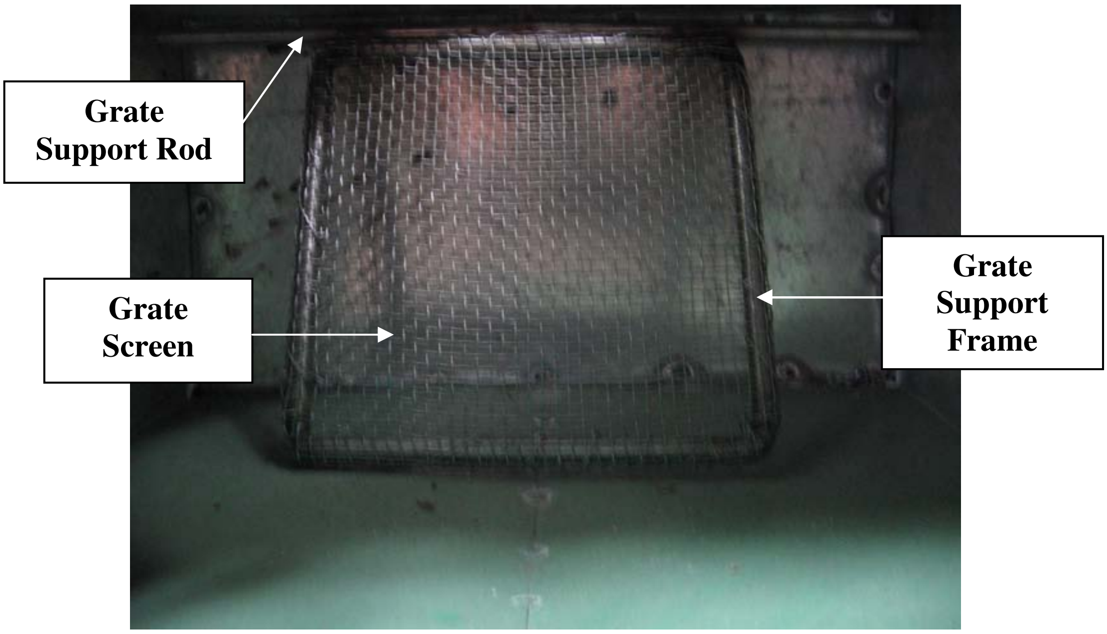
Close Up View of Hinge Assembly



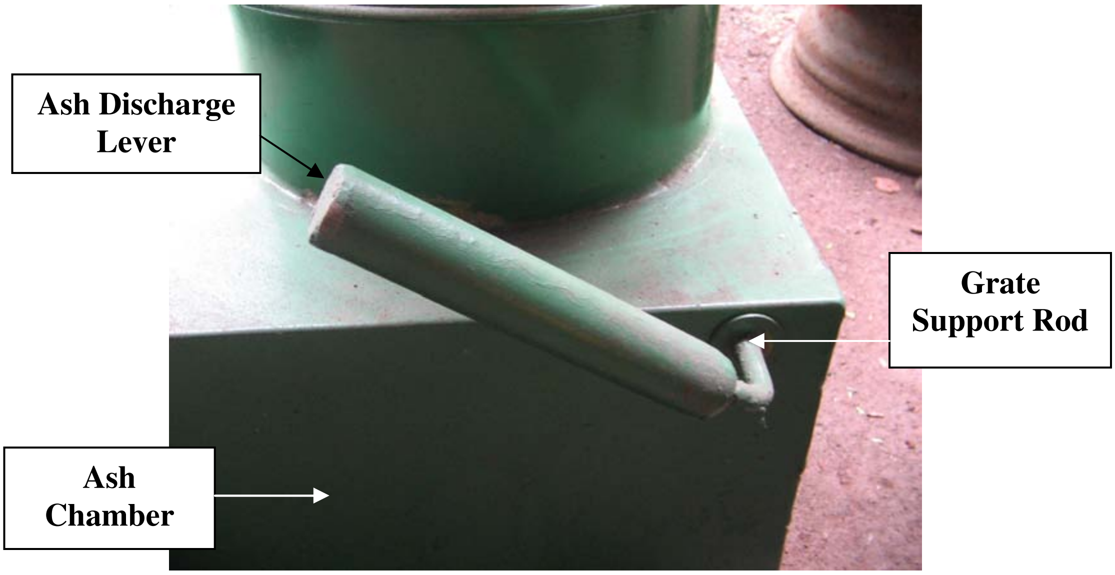
DETAIL OF THE CHAR CHAMBER

Not drawn to scale

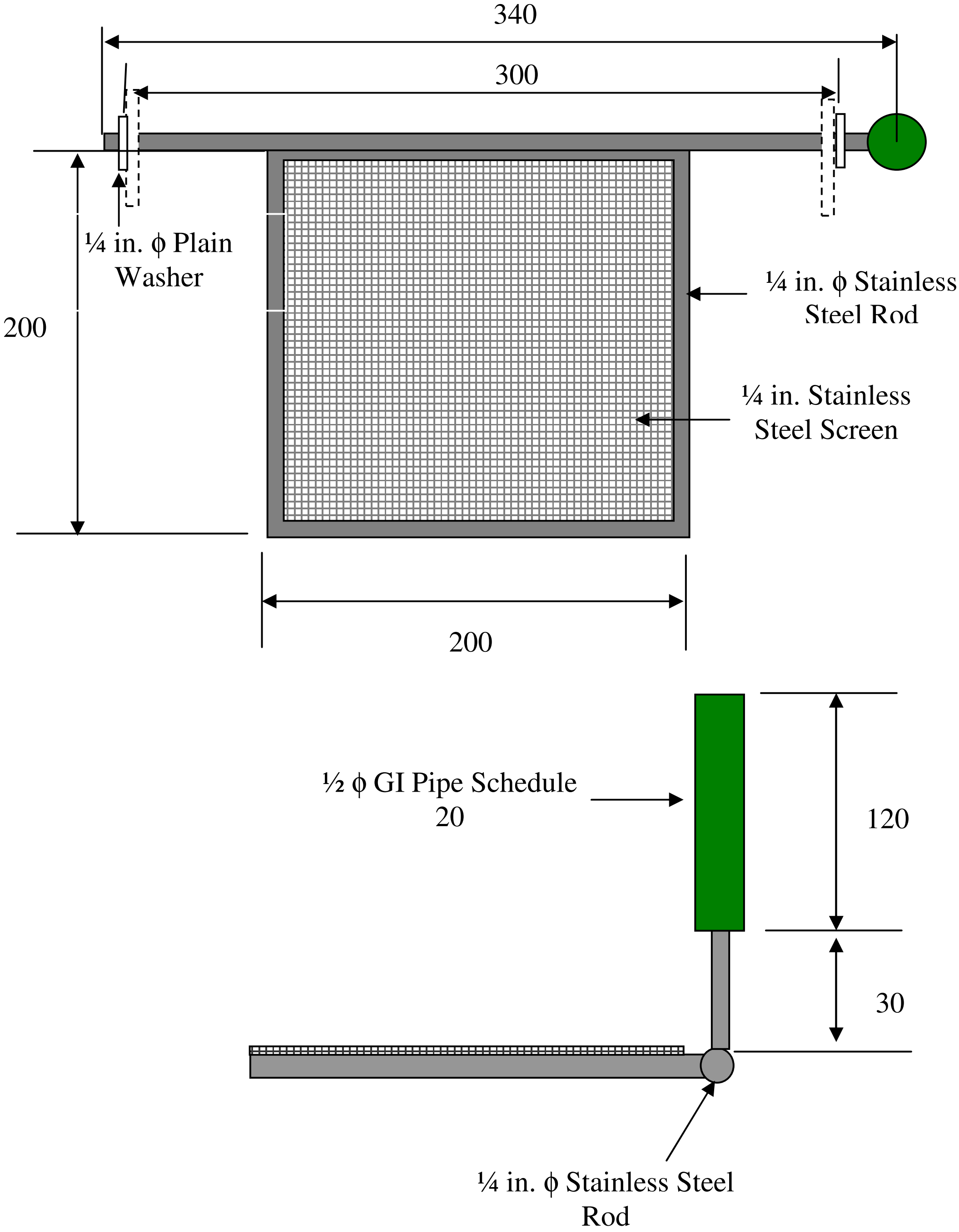
All dimensions are in mm unless specified



Close Up View of the Rice Hull Grate



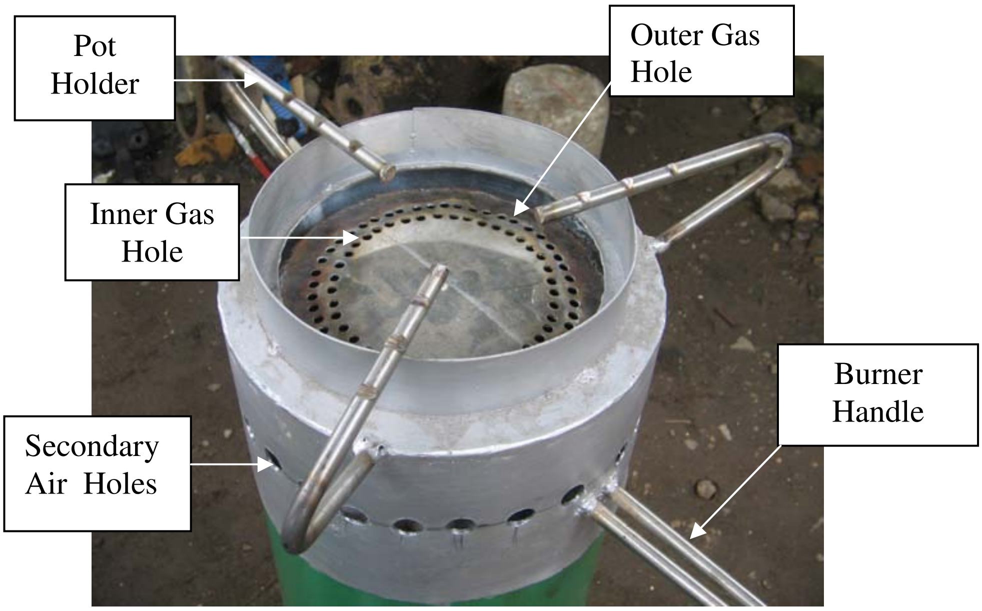
Close Up View of the Ash Discharge Lever



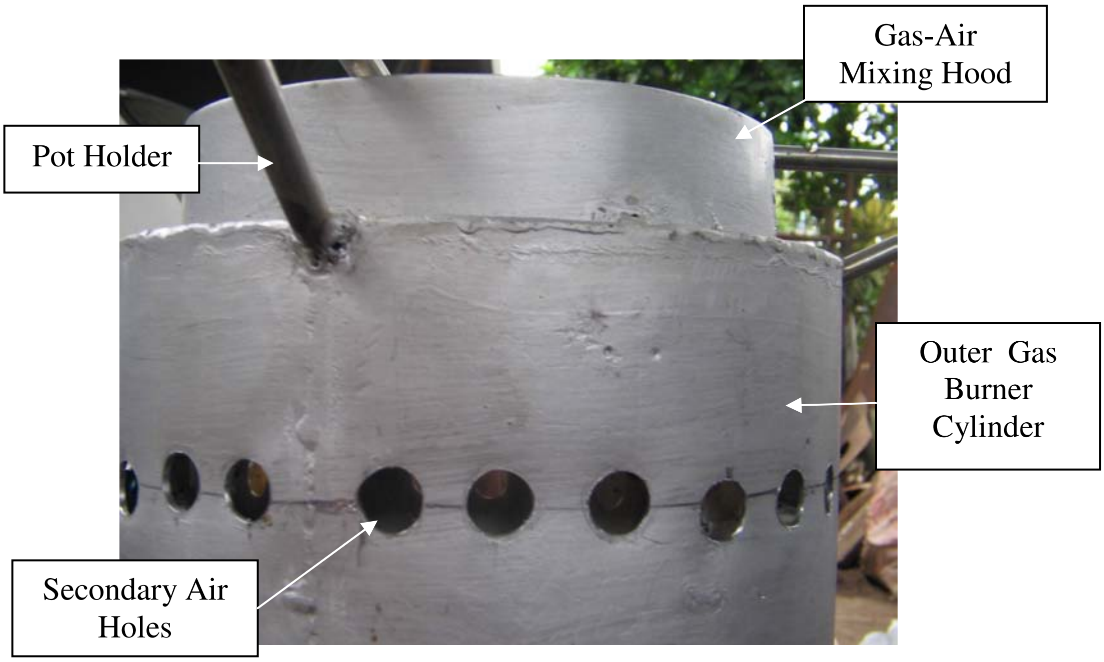
DETAIL OF THE FUEL GRATE ASSEMBLY

Not drawn to scale

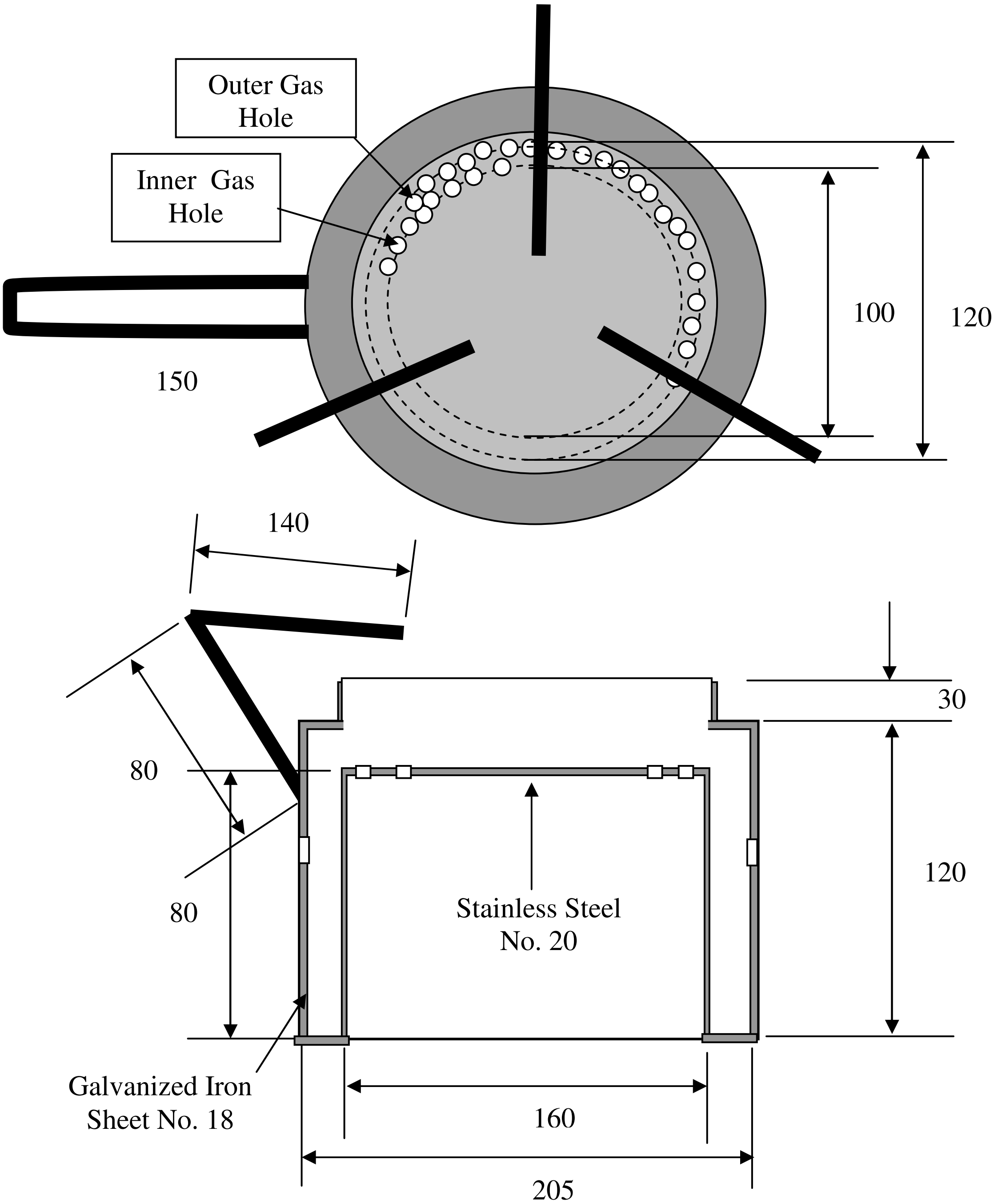
All dimensions are in mm unless specified



Close Up View of the Gas Burner



Close Up View of the Secondary Air Inlet Holes



DETAIL OF THE BURNER ASSEMBLY

Not drawn to scale

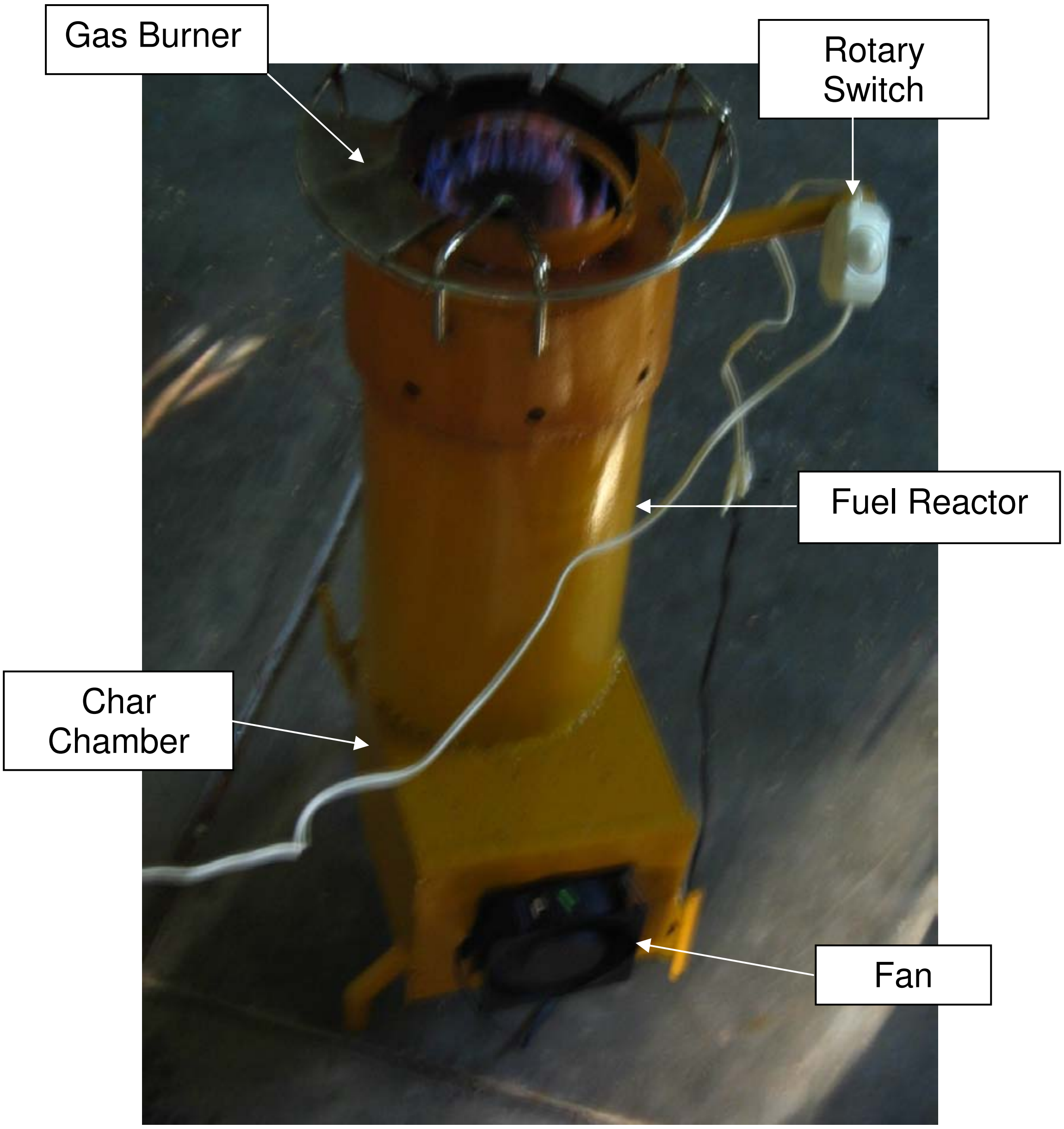
All dimensions are in mm unless specified

Appendix 7

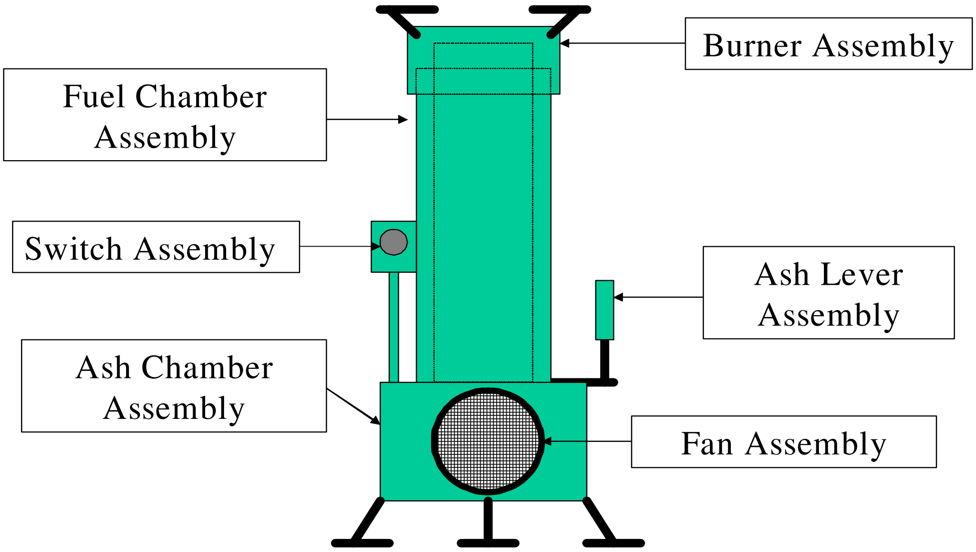
DESIGN DRAWING OF THE RICE HUSK GAS STOVE

by

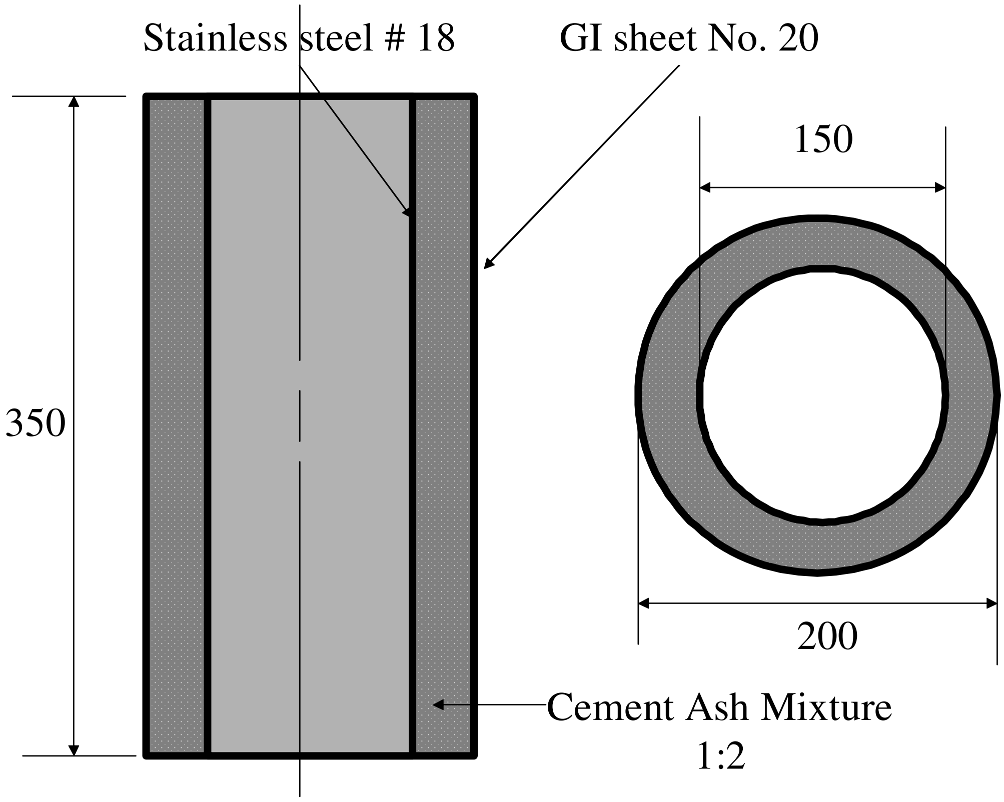
Engr. Alexis T. Belonio
Department of Agricultural Engineering and Environmental Management
College of Agriculture
Central Philippine University
Iloilo City



Pictorial View of the Proto-Type Model of The Rice Husk Gas Stove

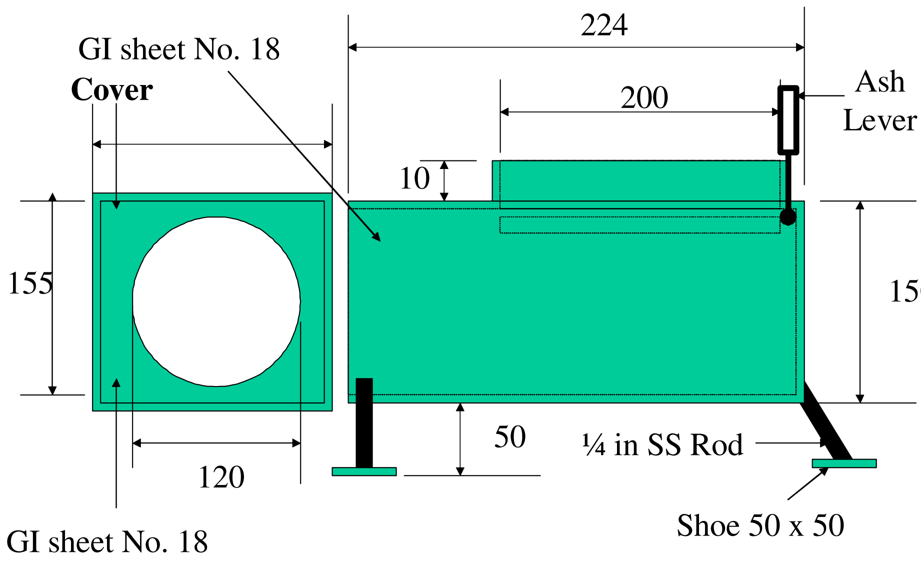


Schematic Drawing of Rice Husk Gas Stove

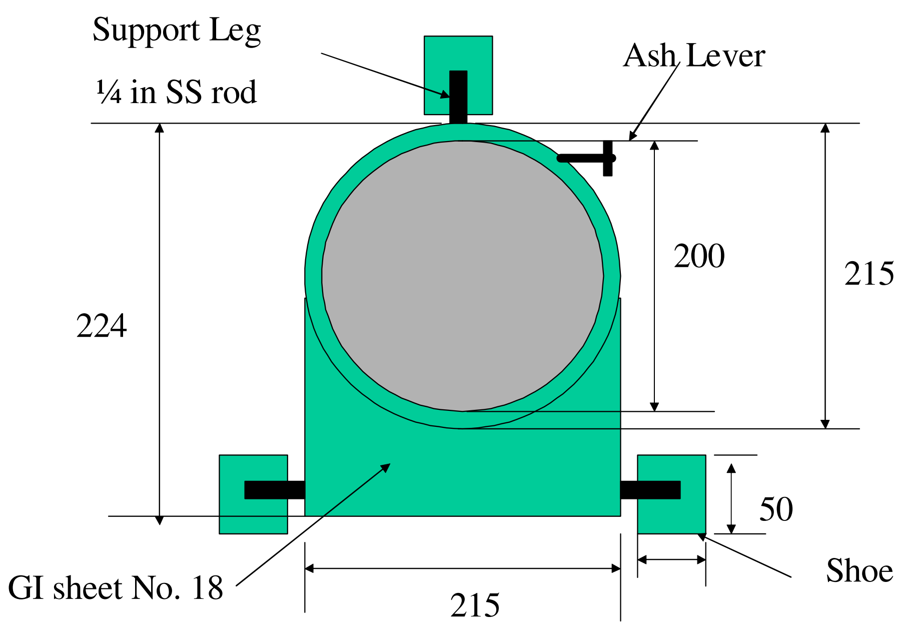


Detail of Fuel Cylinder Assembly

All dimensions are in millimeter unless specified

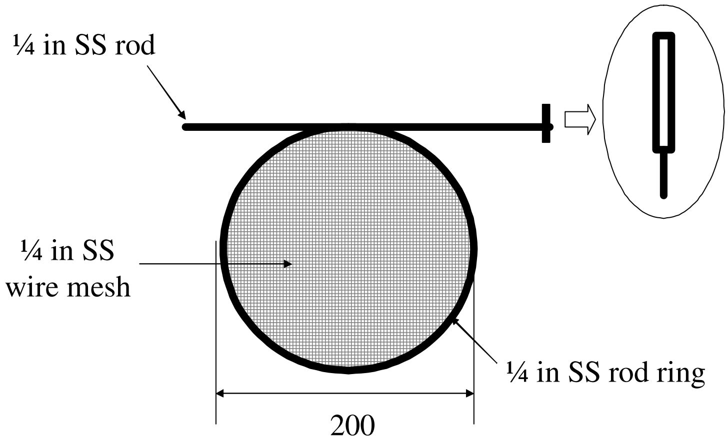


Longitudinal View of the Ash Chamber



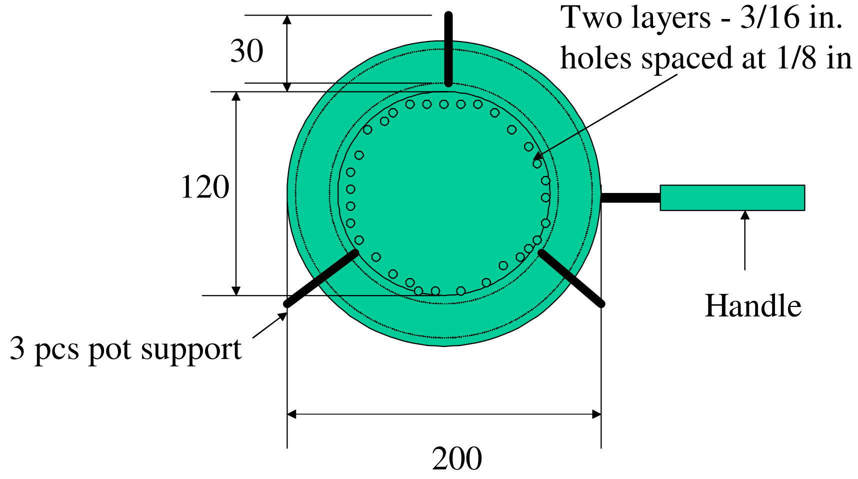
Top View of the Ash Chamber

(Cover not shown)

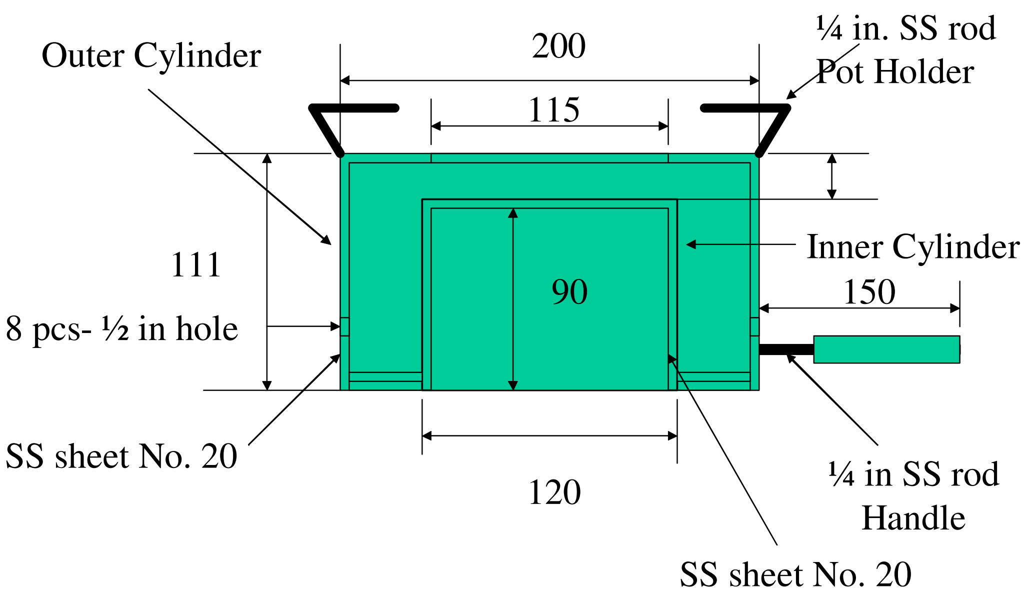


Detail of Ash/Char Grate

Pictorial View of the Gas Burner



Top View of the Burner



Detail of Gas Burner

Appendix 8

SAMPLE TEST DATA SHEET
Water Boiling and Simmering Test

Date :
Place :
Test Engineer :

A. Design

Stove Model	
Fuel Reactor Diameter, cm	
Fuel Reactor Height, cm	
Kind and Thickness of Insulation	
Fan Specifications	
Switch Specifications	

B. Operation

	Run # 1	Run # 2	Run # 3	Average
Type of Test				
Ambient Condition				
Temp, C				
RH, %				
Fuel Weight				
Initial, kg				
Final, kg				
Time Operated				
Started				
Finished				
Start-Up Time, sec				
Number of Papers Used				
Gas Ignition Time, Sec				
Volume of Water				
Initial, liters				
Final, liters				
Water Temp				
Initial, C				
Final, C				
Boiling Time, min				
Simmering Time, min				
Power Input				
Current, amp				
Voltage, volt				
Gas Temperature				
CO Level				
Before Ignition, ppm				
During Operation, ppm				
Weight of Char Produced				

Appendix 9
SAMPLE TEST DATA SHEET
Actual Cooking Test

Date :
Name of Stove Owner :
Place :
Stove Model :

Performance

Start-Up Time, min	
Gas Ignition Time,	
Rice	
Weight of Rice	
Weight of Water	
Cooking Time	
Viand # 1	
Weight of Food	
Ingredients	
Weight of Water	
Cooking Time	
Viand # 2	
Weight of Food	
Ingredients	
Weight of Water/Oil	
Cooking Time	
Weight of Water	
Fuel Consumption	
No .of Sacks of Rice Husk	
No. of Days Consumed	
Comments and Feedback	
Recommendations	