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Finite Element Analysis of Combustion Process in Biomass Rice Husk Gasifier

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ABSTRACT

World Health Organization reported that all over the world 4.3 million people died due to household indoor air pollution in developing and under developed countries during2012. Rural India is facing indoor air pollution due to burning of biomass like garbage, waste and agricultural waste in a crude manner which generates smoke, particulates, CO, CH and many organic compounds including carcinogens. As a result, thousands of people are dying every year in India due to asthma, lung cancer, stroke, acute lower respiratory disease, ischemic heart disease, chronic obstructive pulmonary disease. This study is aimed to design, fabricate an applicable rice husk gasifier for the production of producer gas using locally available biomass fuel rice husk and to analyze the same using finite element method. Various factors that effects design of gasifier is fuel feed rate, air flow rate, time for cooking and items used for cooking.

***Keywords**: Bio gas, Rice Husk Gasifier, FEM.*

1. INTRODUCTION

Biomass is the oldest source of energy and currently accounts for approximately 10% of total primary energy consumption. Many of the developing countries has growing their interest in bio-fuel development and providing greater access to clean liquid fuels while helping to address the issues such as increase in fuel price, energy security and global warming concerns associated with petroleum fuels. Abundant biomass is available throughout the world which can be converted into useful energy. Biomass is considered as a better source of energy because it offers energy security, rural employability and reduced GHG emission. Biomass is traditionally available in the form of solid. Solid biomass include crops residues, forest waste, animal waste, municipal waste, food waste, plant waste and vegetable seeds. This biomass can be converted into heat and power by adopting appropriate method. The biomass can be utilized to get various different outputs. [1]

The prices of conventional fuel used for domestic purpose is rising day by day at a faster rate. Biomass fuel is an alternative source which has carbon, oxygen and hydrogen as basic components. Uses of widespread local rich biomass resources are best economical options to reduce pollution, provide rural employment and save conventional energy. In India, wood, agro waste like rice husk and straws, cow dung, garbage are the different types of fuels used in rural areas for domestic purpose, while LPG, kerosene and electric stoves are extensively used in urban areas. Biomass is used for energy consumption from several centuries. Even today bio-energy provides 10% of world primary energy supply (International Energy Agency 2015). Depending upon physical structure of biomass, it can be transformed into solid, liquid and gaseous fuel. Biomass from cultivated crops and Biomass from organic matter are the two main types of biomass. Biomass resources available in India are agricultural produce and process waste, wood, shrub, tree, sawdust, bark from forest clearing, wood waste from wood mill, urban organic waste, and urban wood waste etc.

Liquefied petroleum gas (LPG) is one of the conventional sources of fuel for cook stoves in India 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 faster rate. At present, an 11-kg LPG, that is commonly used by common households for cooking, costs as high as 540 per tank 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. For the past years, gasifier stoves using wood as fuel has-been developed in countries like the US, China, 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 [2].

2. BIOMASS RICE HUSK GASSIFIER

The gasifier consists of reactor, char chamber, fan assembly and grate as shown in Fig 1. The reactor is one where rice husks are placed and burned with limited amount of air. Rice husk was used as fuel in the experiments conducted to measure the gasifier efficiency. Rice husk is located into the fuel chamber that 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 moves down the reactor 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. The combustible gases that are coming out of the reactor are directed to the burner holes which secondary air is naturally injected to the combustible gases through the secondary air holes. After each operation, char is discharged from the reactor by tilting the char grate. [3]

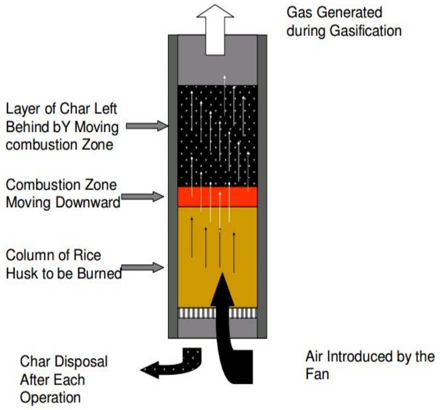

Fig .1 Principle Operation of the Rice Husk Gasifier

3. PRINCIPLE OF RICE HUSK GASIFICTION

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 as shown in Fig 2. Gasification of rice husks is accomplished in a 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 gas, which are combustible when ignited. Hence gasification is a very complicated chemical process and only empirical investigations and experience will satisfy gasifier operation. This is also true with the cleaning system.

Basically, the gas produced during gasification is composed of: (a) carbon monoxide, (b) hydrogen, (c) methane, (d) carbon dioxide, and (e) water vapor. The types and percentage composition of gases produced is given in Table.1. 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 $C + 2\,H_2 = CH_4$

Table1. Types and Percentage Composition of Gases Produced from the Gasification of Rice Husk Gasifier at 1000 °C, Temperature and at 0.3 Equivalence Ratios

Gas	% Composition
Carbon Monoxide, CO	26.1 – 15.0
Hydrogen, H_2	20.6– 21.2
Methane, CH_4	1.3 – 1.8
Carbon Dioxide, CO_2	6.6 – 10.3
Water, H_2O	8.6 – 24.0
Rice Husk Moisture	Content = 10 to 20%

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.

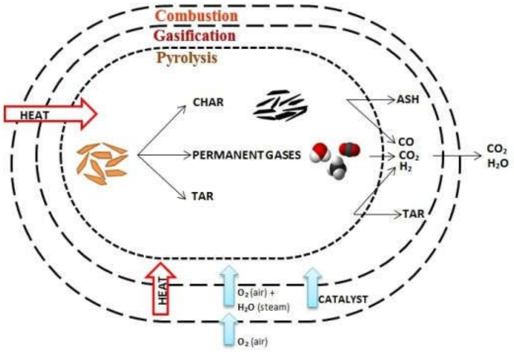

Fig.2. Rice Husk Gasification Process

4. FACTORS THAT INFLUENCE GASIFICATION

Studies have shown that there are several factors influencing gasification of rice husks. 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 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.

5. REACTION OF GASIFICATION

The combustible substance of a solid fuel is usually composed of elements carbon, hydrogen and oxygen. The producer gas is formed by the partial combustion of solid biomass in a vertical flow packed bed reactor. In the conventional theory of producer gas, gasification reaction takes place in four zones. They are oxidation, reduction, pyrolysis and distillation zones.

1 Oxidation zone

In the oxidation zone, the oxygen in the air-stream reacts with the carbon and hydrogen in the fuel to reduce carbon and hydrogen to form carbon dioxide and water. Carbon dioxide is obtained from carbon and water is obtained from the hydrogen in the fuel.

$C + O_2 = CO_2$ (+393 MJ/kg mole) -----------------------1

$2H_2 + O_2 = 2H_2O$ (-242 MJ/kg mole) -----------------2

Reaction (1) is known as combustion reaction. The oxidation reaction (2) is exothermic and this heat is supplied to the neighboring zones i.e. reduction zone.

2 Reduction zone

The partial combustion products CO_2, H_2O obtained from oxidation zone are now passed through reduction zone. Here CO_2 and H_2O are reduced to form carbon monoxide (CO) and hydrogen (H_2) by absorbing heat from the oxidation zone. Oxidation zone raise the temperature of reduction zone to promote the carbon/steam gasification reaction which has higher activation energy. This reaction requires temperature of 9000C and above. Over 90% of CO_2 is reduced to CO at temperatures above 9000C. It is an endothermic reaction.

$C + CO_2 = 2CO$ (- 164.9 MJ/kg mole) ----------------3

$C + H_2O = CO + H_2$ (- 122.6 MJ/kg mole) -------------4

Reaction (3) is known as Boudouard reaction. Reaction (4) is the water gas reaction and it is very important in gasification as it can enrich the gas manufactured with hydrogen, thus enhancing its calorific value. The other reaction with carbon/steam gasification occurs at lower temperature between500-6000C.

$C + 2H_2O = CO_2 + 2H_2$ (-88 MJ/kg mole) ------------------5

A further steam reaction in gas producer with excess of steam is water gas shift reaction. This should be avoided as it reduces the cold gas efficiency, though it reduces the carbon monoxide which is highly toxic in fuel gas distribution for public use.

$CO + H_2O = CO_2 + H_2$ (+42 MJ/kg mole) ------------------6

Other reaction occurs in char at temperature about 5000C are

$C + 2H_2 = CH_4$ (+75 MJ/kg mole) ---------------------------7

Reaction (7) is known as methane reaction and it is an exothermic reaction.

3 Pyrolysis zone

In pyrolysis zone, up to the temperature of 2000C only water is driven off and between the temperature 200 to 2800C carbon dioxide, acetic acid and water are given off. The real pyrolysis, starts between 280 to 5000C, produces large quantities of tar and gases containing carbon dioxide. Besides light tars, some methyl alcohol is also formed. Between 500 to 7000C the gas production is small and contains hydrogen. From the reason mentioned above, updraft gasifier produces much more tar than downdraft one because in downdraft gasifier the tars have to go through combustion and reduction zone and are partially broken down.

4 Distillation zone

In the distillation zone, raw fuel like tar is preheated and carbonized giving of condensable and non-condensable gases

6. FACTORS TO CONSIDER IN DESIGN

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 [4]:

1. 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, under the down-draft type gasifier was proven to work well with this waste material as compared with the traditional top-lit updraft type, cross-draft type, or up draft-type reactors. Of the different types of reactor, the updraft has better operating characteristics in terms of ease of starting the fuel, least smoke emitted, and tar produced during operation. In this type of reactor, smooth operation of producing gas can be achieved. However, it has one disadvantage: it operates in a batch mode. A updraft type reactor is more fitted for a batch operation except that smoke emission. 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.3) in which rice husks are burned and this is where the fuel is gasified. The wider the cross-sectional area of the reactor, 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.

Fig .3. Cross-Sectional Area and Height of the Reactor.

3. Height of the Reactor – The height of the reactor (Fig.3) 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 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. The thicker 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. Airflow and Pressure – The fan provides the necessary airflow that is needed for the gasification of rice husks. 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 up-draft type gasifier reactor. The amount of airflow per unit mass of rice husk is about 0.3 to0.4 of the 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 fan (Fig.4) can overcome pressure in long reactors or those with thicker fuel column. However, the noise produced by its impeller cans be destructive to the users.

Fig 4. 12V DC Fan.

6. Burner Type – The commonly used LPG type burner (Fig.5) 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. The air for combustion should be introduced at the exhaust port of the burner rather than at the inlet port.

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.6) 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.

Fig .5. Fabricated Gas Burner.

Fig .6. Rice husk ash

8. Location of Firing the Fuel - Rice husk fuel can be fired in the stove in different ways. In fixed bed gasifiers, like the down-draft reactor, rice husk fuel can be fired starting from the top (Top Lit) of the reactor. So far, for an up-draft type gasifier, firing the fuel on top is the best and easiest way. Firing the fuel in this manner minimizes smoke emission. However, reloading of fuel in between operation is possible. The other advantage of firing from the up 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 [6].

9. Size and Location of the Char Chamber – The size of the chamber for carbonized rice husks (Fig.7) 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 burning which will consequently convert the char into ash to properly discharge the ash or the char from the reactor. In the case scraper or spout will be needed to properly discharge the ash or the char.

Fig .7. Ash collector

10. **Safety Considerations** - Operating the stove requires safety. Therefore, safety considerations should be part of the stove design. In this regard, a safety shields 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.

7. FINITE ELEMENT ANALYSIS COMBUSTION PROCESS OF BIOMASS RICE HUSK GASSIFIER

The ANSYS FLOTRAN derived product and the FLOTRAN CFD (Computational Fluid Dynamics) option to the other ANSYS products offer you comprehensive tools for analyzing 2-D and 3-D fluid flow fields. Using either product or the FLOTRAN CFD elements FLUID141 and FLUID142, you can achieve solutions for the following:

- Lift and drag on an airfoil
- The flow in supersonic nozzles
- Complex, 3-D flow patterns in a pipe bend

In addition, you can use the features of ANSYS and ANSYS FLOTRAN to perform tasks including:

- Calculating the gas pressure and temperature distributions in an engine exhaust manifold
- Studying the thermal stratification and breakup in piping systems
- Using flow mixing studies to evaluate potential for thermal shock
- Doing natural convection analyses to evaluate the thermal performance in electronic.
- Conducting heat exchanger studies involving different fluids separated by solid regions

The following graph is the main results obtained Velocity in X & Y Direction along with Variation of Pressure.

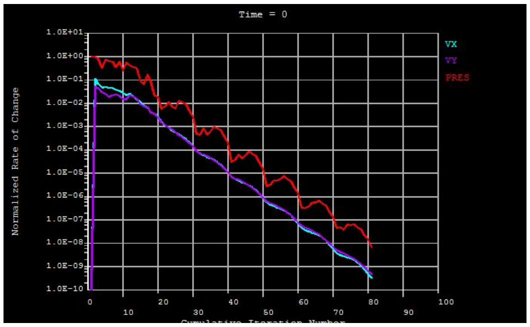

Fig .8. Velocity in X & Y Direction with Variation of Pressure.

The resulting Velocity vector plot show below is the recirculation region that occurs in the upper region of the duct. Resulting contour plot shown below is the total static and dynamic pressures occur in duct.

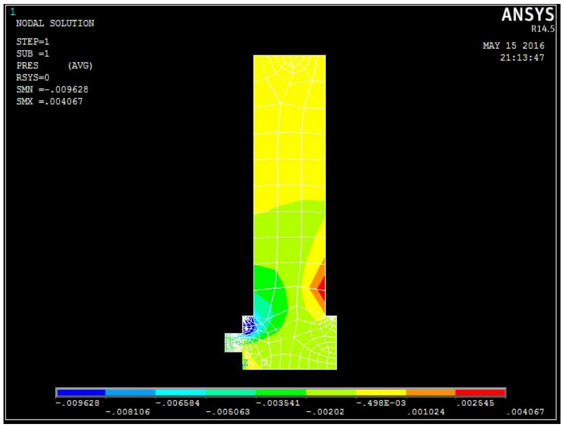

Fig .9. Velocity vector plot

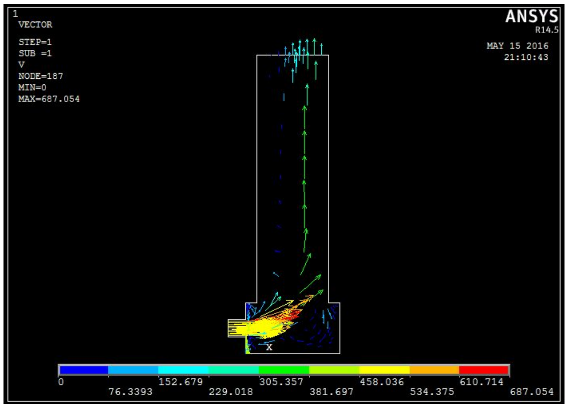

Fig .10.Static and dynamic pressures occur in duct.

The resulting path plot shows the curve has a bias towards one edge of the outlet. This indicates that the flow Velocity has fully developed. The resulting path plot shows the flow has an almost fully developed laminar profile. The curve looks relatively uniform and has a parabolic shape and velocity is well sufficient. Laminar CFD Flotran analysis in our design is sufficient for the air flow in terms of velocity and pressure.

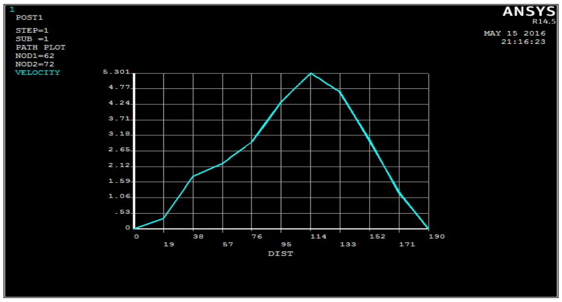

Fig .11. Velocity curve

8. CONCLUSION

The objective to meet electricity demand of village can be achieved by making proper utilization of biomass resources. The two major problem of managing the residue left after harvesting and inconvenient electricity supply of villages could be well overcome by utilizing the existing resource of village and making itself sustainable in its energy requirements. In this paper discuss the utilization of biomass sources to integrate concluded that this stove will fulfill domestic cooking energy requirements of the rural people of India for whom LPG stove is not affordable and where indoor air pollution is common due to traditional cooking methods.

In this paper efforts are made to exploit biomass resources in the region and suggest some of the cost effective and environment friendly ways to meet the demand.

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