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DESIGN, CONSTRUCTION & PERFORMANCE ANALYSIS OF LOW COST FIXED BED BIOMASS GASIFIER

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ABSTRACT

Liquefied petroleum gas (LPG) is one of the most convenient sources of fuel for cook stoves. The main reasons why LPG is widely adopted for house hold 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. With this problem on the price of LPG fuel, research centres 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. Henceforth this project work focus on fabricating an environmental friendly, low cost, fixed bed (down draft) biomass gasifier that completely utilize producer gas and converts it into efficient energy resource.

Keywords: biomass, gasifier, gasification, renewable energy.

INTRODUCTION

Most of the population in least developed countries is located where the biomass resource is extensive. These biomass resources particularly agricultural residues, can provide a major source of raw material for biomass gasifiers which can provide an attractive energy option for these communities. However, biomass resources are non homogeneous by nature. Due to this, the fuel feedstock characteristics as well as gasifier reactor operation, performance and control vary from one fuel resource to another. Therefore there was a need to study the functional and operational characteristics that result from feeding a gasifier with several agricultural residues to ascertain these differences. Also as information on biomass gasification performance is still minimal, this project aims in determining the gasification performance parameters for different types of agricultural residues to contribute in closing this information gap. My original goals with this gasifier project, were to build a compact and simple gasifier, that uses inexpensive feedstock (like wood chips or groundnut shell that is available very inexpensively, or even free), and produced high-quality gas.

BIOMASS

Biomass is a biological material derived from living, or recently living organisms. It most often refers to plants or plant-based materials which are specifically called lingo cellulosic biomass. As an energy source, biomass can either be used directly via combustion to produce heat, or indirectly after converting it to various forms of biofuel. Conversion of biomass to biofuel can be achieved by different methods which are broadly classified into: thermal, chemical, and biochemical methods.

GASIFICATION

Gasification is a process that converts organic or fossil fuel based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide. This is achieved by reacting the material at high temperatures (>700 °C), without combustion, with a controlled amount of oxygen and/or steam. The resulting gas mixture is called syngas (from synthesis gas or synthetic gas) or producer gas and is itself a fuel. The power derived from gasification and combustion of the resultant gas is considered to be a source of renewable energy if the gasified compounds were obtained from biomass

BIOMASS GASIFICATION

Gasification is the production of gaseous fuel by the process of partial oxidation of a solid fuel. Gasification adds value to low- or negative- value feedstock by converting them to marketable fuels and products. This is supported by the fact that the gaseous fuels can be easily distributed for both domestic and industrial applications, used in devices that produce electricity such as internal combustion engines, gas turbines, and fuel cells, or for chemical synthesis of liquid fuels and chemicals.
It includes the following steps:

a) Thermal decomposition to gas, condensable vapors and char (pyrolysis)
b) Subsequent thermal cracking of vapors to gas and char
c) Gasification of char by steam or carbon dioxide
d) Partial oxidation of combustible gas, vapors and char

The devolatilisation step (pyrolysis) is slightly endothermic and for temperatures above 500 °C, 75 to 90% (wt) volatile matter is produced in the form of steam, gaseous and condensable hydrocarbons. The relative yield

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of gas, condensable vapors (including tars) and the remaining char depend mostly on the rate of heating and final temperature. A high process temperature is maintained in various ways, depending on the type of reactor.

The final product gas contains carbon monoxide, hydrogen and methane as the desired components as well as steam, carbon dioxide, nitrogen, trace Biomass resources include forestry residues, energy crops, manufacturing wood wastes, bagasse from sugarcane processing, grasses, livestock residues from cattle, pigs, poultry, etc and food processing residues. Each type of biomass has its own specific properties which determine its performance as a fuel in a gasifier reactor. Some of these important properties considered for gasification are moisture content, ash content and ash composition, elemental composition, heating value, bulk density and morphology, volatile matter content, and fuel related contaminants such as sodium, sulphur, chlorine, alkalis, heavy metals, etc. Biomass gasification is the conversion of an organically derived carbonaceous feedstock by partial oxidation into a gaseous product, synthesis gas or Syngas, consisting primarily of hydrogen (H2), nitrogen (N2) and carbon monoxide (CO), with lesser amounts of carbon dioxide (CO2), water (H2O), methane (CH4), hydrocarbons (C+). During gasification, the chemical structure of the biomass undergoes thermo chemical conversion due to the high temperatures involved in the process. The conversion to gas is facilitated by the gasification agent and various heterogeneous reactions at each level in the gasification process. It is a two stage process consisting of oxidation and reduction processes which occur under sub stoichiometric conditions of air with biomass.

One key aspect that is generally acknowledged concerning biomass gasification is the fact that information on gasification performance is very minimal and databases for utilization by industry are severely needed. There was, therefore, a need to carry out a technical assessment to ascertain the differences, if any, in the functional and operational characteristics of a fixed bed gasifier when a wide range of biomass feedstock materials are fed.

GASIFICATION REACTIONS

The chemistry of biomass gasification is complex. Biomass gasification proceeds primarily via a two-step process, pyrolysis followed by gasification. Pyrolysis is the decomposition of the biomass feedstock by heat. The remaining non-volatile material, containing high carbon content is referred to as char. Combustion, occurring in the oxidation zone, is described by the following chemical equations.

$C + O_2 \rightarrow CO_2 + 393.8\text{kJ/mol}$

$C + \frac{1}{2}O_2 \rightarrow CO + 123.1\text{kJ/mol}$

$C + 2H_2 \rightarrow CH_4$

These three reactions are exothermic and provide, by auto-thermal gasification, the heat necessary for the endothermic reactions in the drying, pyrolysis and reduction zones. The water vapor introduced with the air and production by the drying and pyrolysis of the biomass reacts with the hot carbon according to the following heterogeneous reversible water gas reaction:

$C + H_2O + 118.5\text{ kJ/mol} \leftrightarrow CO + H_2$

The most important reactions are the water gas reaction and the following Boudouard reaction.

$C + CO_2 + 159.9\text{kJ/mol} \rightarrow 2CO$

These heterogeneous endothermic reactions increase the gas volume of CO and H_2 at higher temperatures and lower pressures (a high pressure suppresses the gas volume). Besides these reactions several other reduction reactions take place of which the most important ones are the water shift reaction and the methanisation reaction respectively shown below:

$CO_2 + H_2 + 40.9\text{ kJ/mol} \rightarrow CO + H_20$

$C + 2H_2 \rightarrow CH_4 + 87.5\text{kJ/mol}$

The suitability of the agricultural residue to be used as feedstock in a fixed bed gasifier depends on:

a) Volatile matter content of the feedstock
b) Ultimate analysis of the feedstock
c) Ash content and ash chemical composition
d) Size, form and size distribution of the feedstock
e) Energy content of feedstock

UPDRAFT GASIFICATION

The simplest type of gasifier is an updraft gasifier. Biomass is fed at the top of the reactor and moves downward as a result of the conversion of the biomass and the removal of ashes. The air intake is at the bottom and the gas leaves at the top. The biomass moves counter-currently to the gas flow, and passes through the drying zone, the pyrolysis zone, the reduction zone and the oxidation zone.

The advantages of updraft gasification include

a) Simple, low cost process
b) Ability to handle biomass with a high moisture and high inorganic content
c) Proven technology
d) Ability to process relatively small sized fuel particles and accepts some size variation in the fuel feedstock

The major drawbacks of updraft gasification include

a) High amounts of tar requiring extensive clean-up before producer gas applications.
b) High ash waste material difficult to gasify because of sintering problems also resulting from ash melting characteristics.

DOWNDRAFT GASIFICATION

In a downdraft reactor biomass is fed at the top and the air intake is also at the top or from the sides. The gas leaves at the bottom of the reactor, so the fuel and the gas

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move in the same direction.

The advantages of downdraft gasification include

a) Up to 99.9 percent of the tar formed is consumed requiring minimal or no tar cleanup.
b) Minerals remain with the char/ash, reducing the need for a cyclone separator.
c) Proven, simple and low cost process

The disadvantages of downdraft gasification are

a) Requires feed drying to a low moisture content (<20%)
b) Producer exiting the reactor is at high temperature.
c) Requires secondary heat recovery system.
d) 4-7 percent of carbon remains unconverted

Aim & objectives

a) To determine the physical properties and proximate analysis for each of the agricultural residues.
b) To design and construct a portable, low cost, environmental friendly fixed bed gasifier with zero effluent discharge system.
c) To determine the gasification operating conditions for each of the several agricultural residue feedstock.
d) To evaluate the operation, performance and control of the fixed bed biomass gasifier reactor.
e) To determine the gas composition of the producer gas for each agricultural residue.
f) To determine the gasification parameters for each of the agricultural feedstock.
g) To minimise the cost of disposal of bio residues.
h) To produce fire and electricity from bio residues for rural-small scale industries.
i) To minimise the emission of carbon dioxide caused by uncontrolled burning of bio residues.
j) To ensure complete utilization of carbon monoxide gas produced in the gasifier.
k) To minimise the generation of tar which behave as a major problem during cleaning operation.
l) To ensure hygienic conditions in the production of handmade food products by rural people.

Characterstics of the gasifier

Basically the gasifier what I want to make is a chemical reactor that converts wood, or other biomass substances, into a combustible gas that can be burned for heating, cooking, or for running an internal combustion engine. This is achieved by partially combusting the biomass in the reactor, and using the heat generated to pyrolyse or thermally breaks down the rest of the material into volatile gasses.

By products

This would be a well built reactor which could convert combustion byproducts like CO2 and water vapor into flammable CO and H2 by passing them over a bed of hot charcoal where they will get reduced. This gasifier converts most of the mass of the wood (or other biomass feedstock) into flammable gasses with only some ash and unburned charcoal residue. The gasifier would break down biomass into nothing but Methane (and other simple gaseous hydrocarbons), Hydrogen and Carbon Monoxide. Even a well-built gasifier produces a small amount of tar. Most real-world applications can't handle much or even any tar. This project would be a battle to reduce tar production.

Components

This system mainly comprises the following components

a) Reactor
b) Fuel feeding system
c) Air blower
d) Ash collecting system and
e) Gas sampling unit.

Process occurring in downdraft gasifier

In the down-draught gasifier, the fuel is introduced at the top, the air is normally introduced at some intermediate level and the gas is taken out at the bottom. It is possible to distinguish four separate zones in the gasifier, each of which is characterized by one important step in the process of converting the fuel to a combustible gas. The processes in these four zones are examined below and the design basis will be discussed in the following section.

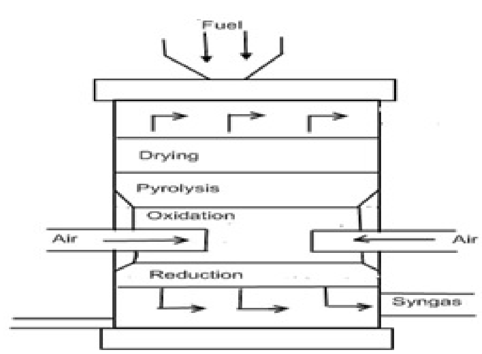

Figure-1. Downdraft Gasification (Knoef et al., 2005).

Bunker section (Drying zone)

Solid fuel is introduced into the gasifier at the top. It is not necessary to use complex fuel-feeding equipment, because a small amount of air leakage can be tolerated at this spot. As a result of heat transfer from the lower parts of the gasifier, drying of the wood or biomass

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fuel occurs in the bunker section. The water vapour will flow downwards and add to the water vapour formed in the oxidation zone. Part of it may be reduced to hydrogen and the rest will end up as moisture in the gas.

Pyrolysis zone

At temperatures above 250°C, the biomass fuel starts pyrolysing. The details of these pyrolysis reactions are not well known, but one can surmise that large molecules (such as cellulose, hemi-cellulose and lignin) break down into medium size molecules and carbon (char) during the heating of the feedstock. The pyrolysis products flow downwards into the hotter zones of the gasifier. Some will be burned in the oxidation zone, and the rest will break down to even smaller molecules of hydrogen, methane, carbon monoxide, ethane, ethylene, etc. if they remain in the hot zone long enough. If the residence time in the hot zone is too short or the temperature too low, then medium sized molecules can escape and will condense as tars and oils, in the low temperature parts of the system.

Oxidation zone

A burning (oxidation) zone is formed at the level where oxygen (air) is introduced. Reactions with oxygen are highly exothermic and result in a sharp rise of the temperature up to 1200 - 1500 °C. As mentioned above, an important function of the oxidation zone, apart from heat generation, is to convert and oxidize virtually all condensable products from the pyrolysis zone. In order to avoid cold spots in the oxidation zone, air inlet velocities and the reactor geometry must be well chosen.

Reduction zone

The reaction product of the oxidation zone (hot gases and glowing charcoal) move towards reduction zone. In this zone the sensible heat of the gases and charcoal is converted as much as possible into chemical energy of the producer gas The end product of the chemical reactions that take place in the reduction zone is a combustible gas which can be used as fuel gas in burners and after dust removal and cooling is suitable for internal combustion engines. The ashes which result from gasification of the biomass should occasionally be removed from the gasifier. Usually a moveable grate in the bottom of the equipment is considered necessary. This makes it possible to stir the charcoal bed in the reduction zone, and thus helps to prevent blockages which can lead to obstruction of the gas flow.

Designs considered

Simple gasifiers don't produce good gas, and inexpensive fuel is the most difficult to work with. Only after working away with the previous project reviews for a while, and going through several major redesigns I concluded a perfect design.

Open core design

I started out designing a simple open core design. But by the time I had a reasonably well working gasifier, the design had morphed into something that looks a lot more like the complex J-Tube design on the far right of the middle row. Fortunately I was able to incrementally modify the original design to get to the final design. I choose the open core stratified downdraft gasifier design because it was by far the simplest of all the designs I could find. Everything I read about it (at the time) said it should work great. I saw vague references to people in India having great success with this design. So I thought I couldn't fail.

After several discussions with experts I found that this setup is really good at producing tar, but not so great at making high quality gas. Fortunately I figured it out before building it. So the above figure is my original design for a stratified downdraft gasifier. It would never work well, but it provided a good base to build my design. After reviewing several literatures I understood that I would face certain problems during my work. So I made a list of the problems I would have with the gasifier, in order of their severity.

a) Low temperature operation
b) Excessive tar production
c) Shaker grate not working well
d) Weak air pump

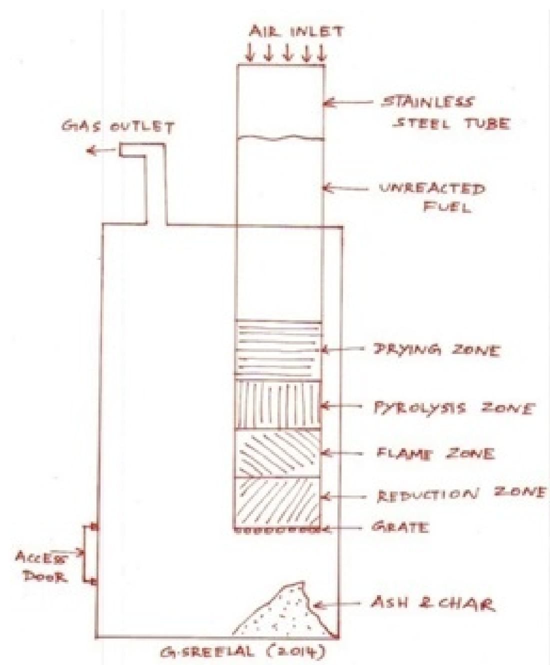

Figure-2. Open core design.

COMPLEX J-TUBE DESIGN

I also realized looking at the list that solving the poor air flow problem would probably improve or even

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eliminate other problems on the list like low temperature and tar production. So I decided to tackle the top two problems first and others as opportunities presented themselves. I found out that the easiest way to solve the zone migration problem was to cap the top of the flame tube. In the previous setup the flame will simply move up-wind towards the source of oxygen. Looking at the list, it was obvious to me that the zone migration problem would be the biggest problem I would face. The fuel might be mostly converted into charcoal, rather than being properly gasified. Solving that problem would make a big improvement in the operation of the gasifier. Since the original design requires air to move through the whole fuel column, the flame might simply go up the column towards the source of air and would create zone migration problem. Capping the tube means I had to find a new way to get the air into the gasifier.

I studied various gasifier designs and got cleared with the task that I should install air inlet tubes near the bottom of the flame tube. It looked like the easiest way to do it, and still allow the core section to be removable was to install J-Tubes. The J-Tubes would also have the added benefit of pre-heating the air, since they would pass through the hot gas in the drum before entering the flame tube. I also noticed that almost all gasifier designs have a constriction or throat where the unit narrows below the flame zone. Further research explained that the constriction helped reduce tar production by forcing the volatiles produced in the pyrolysis zone to pass near or through the hot flame zone where the tar gets cracked into gas. After anchoring the above research on mind, I decided that I had to add a constrictor plate.

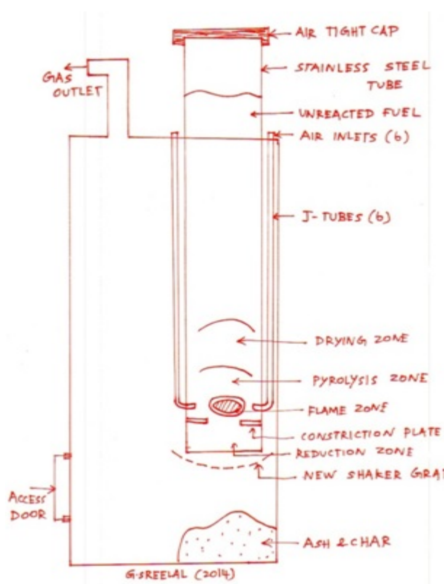

Figure-3. Complex J-Tube design.

MODERNIZING THE GASIFIER DESIGN

My ultimate aim was to make the gasifier look's simpler and convenient. Using J-tube designs made it to look complex, so I changed my mind by going on with mechanical air blowers instead of J –tubes. Then I screwed my design stipulations by keeping the ash collector at the bottom rather at the side. I kept in mind that I have to burn atleast about 3 kg of bio residue in a single move. Then I formulated my design that my gasifier should work on a continuous basis and so I planned to fix a feeder system in my gasifier. After several research I identified that lock hopper feeder system would be great. Here this lock hopper system operates on the principle of intermittent charging or feeding across the pressure boundary, typically by the staged opening and closing of valves on the top and bottom of the charged pressure vessel. For this system, the top valve is opened to receive material into the lock hopper while the bottom valve is maintained in a closed position. After the top valve is closed, the lock hopper is brought to or above system pressure, typically with an inert gas. Following pressurization, the bottom valve is opened, and the material is allowed to discharge to the process. Following emptying of the lock hopper, the bottom valve is closed and the vessel depressurized to allow another cycle. Dual or parallel lock hoppers may be employed to allow one lock hopper to be on-line, that is, discharging at pressure to the process, and allow the other lock hopper to be in the filling and pressurizing modes. I kept in mind that during fabrication no segments should be wasted and so I made every component with coupler technology so that it could be easy for checks in future

DESIGN RESULTS

After considering the previous downdraft types, their characterstics, their merits as well as demerits the following designs are resulted.

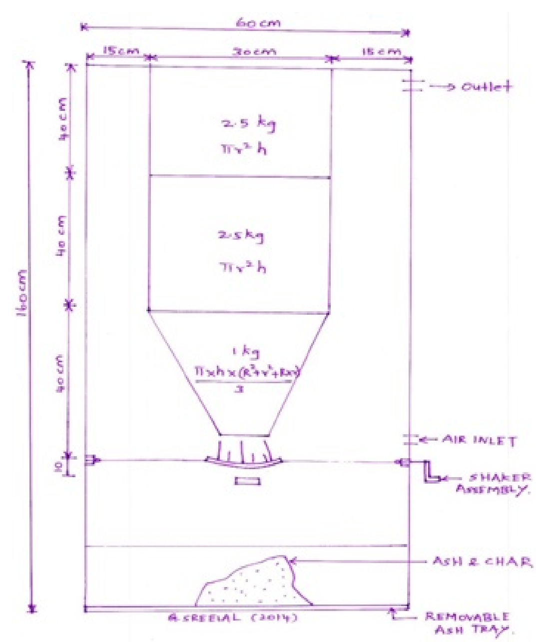

Figure-4. 1.6m Height gasifier.

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Outer segment

The reactor is so far planned to be a cylinder with internal diameter 50-60 cm and height of about 160-175 cm from the fuel feeding point.

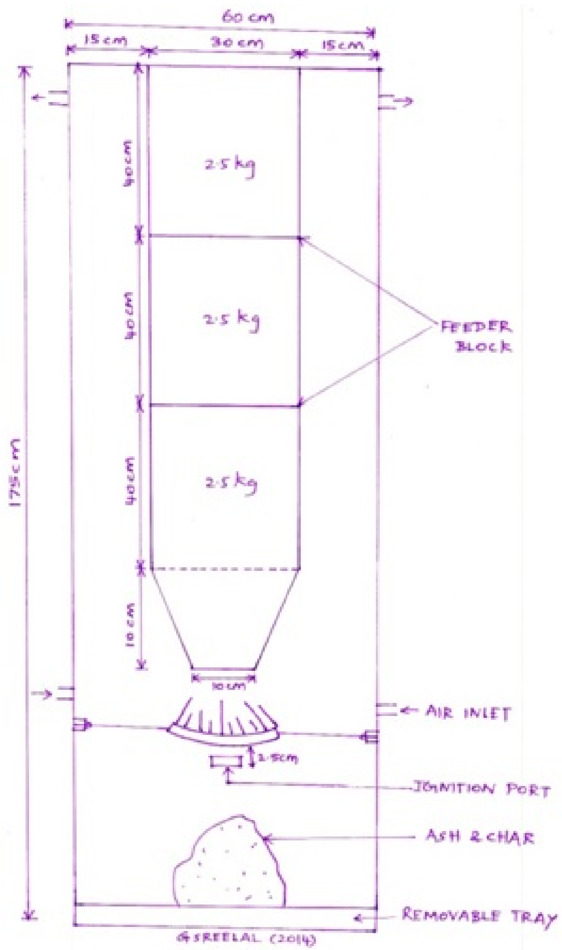

Figure-5. 1.75m Height gasifier.

INTERNAL SEGMENT

It is provided up inside with a ceramic cylinder of 30cm outer dia & ending up with 10cm at the bottom at a height of about 130cm.The void created by this cylinder presents a region where the producer gas circulates before exit. The ash collection point could have an internal diameter of 35cm and a height of 45cm from the grate to the bottom of the ash collection point. The smaller of the two bungs on the drum will be the gas outlet.

The bottom of the tube will be the reactor where the gasification takes place. The remainder of the tube is a hopper for holding un-reacted fuel. The tube will be subjected to very high temperatures and corrosive gasses. Stainless steel is the obvious choice here. In this down-draught gasifier, the fuel is introduced at the top, the air is normally introduced at some intermediate level and the gas is taken out at the top.

The thickness of the reactor vessel wall is approximately 4mm and the wall structure has to be made of mild steel. The purpose of the drum is to be the main body of the gasifier unit. It contains everything and collects all the gas, ash and char the unit will produce.

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