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Design & Development of Biomass Gasifier Using Agro-Waste to Produce Producer Gas

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Abstract— *Biomass will play an important role in the future global energy infrastructure for the generation of power and heat, but also for the production of chemicals and fuels. Distributed generation (DG) of power has a great potential for supplying power to the remote areas. The use of gas engine integrated with biomass gasifier is a technologically and commercially viable option for the decentralized generation. However, the sustainability in the supply of biomass in remote villages is an important issue. Biomass gasification means incomplete combustion of biomass resulting in production of combustible gases consisting of Carbon monoxide (CO), Hydrogen (H_2) and traces of Methane (CH_4). This mixture is called producer gas. The production of producer gas called gasification and takes place at temperatures of about 1000ºC. The reactor is called a gasifier. Various types of waste - namely those resulting from Mediterranean farming (rice husk, olive bagasse, nut shells, etc.) - have been used for energy purposes in power plants equipped with technologies that range from well-established direct combustion systems to gasification systems that are currently being developed. This paper contains a description of processes and technologies related to direct combustion and gasification of agricultural & agro-food waste.*

Keywords— *Agro-waste, Biomass Gasifier, Gasifier Design, Cyclone, Producer gas*

I. INTRODUCTION

Gasification is a thermal process of converting dry biomass feedstock into a mixture of gases that can be burnt in internal combustion engines and gas turbines. It was referred to as 'suction gas', because the gas was sucked by the engine from the gasifier. It was also known as ‘town gas’ or ‘coal gas’. A variation of this gas (using steam or hydrogen instead of oxygen or air) is also known as ‘synthesis gas’ because a variety of chemical compounds can be made from it. The essential chemical species in all these gases are CO (Carbon monoxide) and H_2 (Hydrogen), both of which burn to release heat.

Town gas was predominantly used for street lighting in early European cities like London. It lost out to natural gas because it is highly poisonous due to the presence of carbon monoxide. Gradually the use of producer gas as a domestic fuel was taken over by cheaply available natural gas. The advent of petroleum further accelerated a decline in the need for producer gas. Gasification is the generic term to describe the technology of conversion of solid fuels into gaseous ones. Thus there can be coal gasification or biomass gasification. Although both coal and biomass can be burnt directly to get heat energy, gasification of these fuels has certain advantage which cannot be achieved by direct burning. The main advantage of biomass gasification is that the resultant gaseous fuel can be used in an engine directly. Since gas engines are readily available, through biomass gasification one can produce electricity. It is certainly possible to get electricity from directly burning biomass, but that would require, first, a boiler for making steam and then a steam turbine. Environmentally, Biomass Gasification is a clean technology free of CO_2 emissions, if well designed. Utilization of renewable energy sources makes it a sustainable energy system. The disadvantages can successfully be mitigated both by "good practices" and engineering measures. In developed countries, there is not much interest in small-scale decentralized electricity generation because of its high cost. However, co-firing that is using biomass along with other fuels to reduce fossil fuel consumption is becoming very popular and this practice is responsible for the consumption of vast quantity of biomass. Developed countries like Brazil are more interested in liquid bio-fuels, bio-ethanol and bio-diesel. India is becoming a leading user of the small- scale version of this technology and many new designs are being innovated. Thailand is also experimenting with it. Bangladesh is an agrarian country and there is easy availability of agriculture-based mass, which can be used to generate energy. Burning this biomass directly is the oldest and also the least efficient method of generating energy**.** On the other hand, gasification of this mass is technologically viable and at the same time has the potential to replace the consumption of fossil fuel to some extent. In this study, the goal is to construct a downdraft biomass gasifier at laboratory scale and to check whether the required composition of producer gas can be achieved successfully.

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The resulting producer gases have the advantage of being easy to handle. The entire gasification process is made up of various chemical and physical processes such as drying, pyrolysis and partial oxidation, reduction and condensation. Some of the processes have been described and modelled. However, gasification still requires significant research and refinement to suit higher energy demands and utilize available biomass.

II. EXPERIMENTAL SETUP FOR GASIFIER SYSTEM

A. Introduction

The gasifier system developed in the project is a Downdraft fixed grate gasifier having a capacity of 5 kW as shown in Figure 1. It is developed by burning the gas, thus this mass flow rate has to be calculated. Also the time between two successive refilling, is the time for which the continues operation of the gasifier is desired is also to be taken into consideration. This factor is determined by the hopper size. It has been proved that the hopper size is the main factor that decides the cost of the gasifier. Also the size of the gasifier depends on the hopper size; we have to optimize the hopper size in such a manner considering the economic feasibility and also the size of the unit. We observed that duration of 4 to 6 hours is considered as the most efficient periods of continuous operation.

The gas coming out of the gasifier has to be cleaned & cooled before it is passed through the blower unit. The cleaning unit consists of a combined cyclone & scrubbing unit in which water is sprayed so that the carbon particles & dust present in the gas is cleaned & also the gas is cooled by the water spray.

During the testing of the gasifier system we found that the tar deposition of the system was considerably high. So a filter was designed so that all the tar particles could be collected so as to allow the gasifier operation without damage to the blower. Mass flow was controlled by a valve at the end of the blower. The final unit was a burner which consisted of a Gas-Air mixing system so that the gas would be readily combustible when exposed to a flame.

B. Reactor

Conventional downdraft gasifier has a throat or restriction in the oxidation zone. The temperature of oxidation zone is required to be maintained between, 900 to 1200^0C to achieve efficient thermal cracking of the tar and maintaining adequate temperatures in the other zones. Design and configuration of oxidation zone therefore is a critical facet of successful gasified design. In case of low ash biomass materials especially those like wood, which undergo substantial size reduction, usually a reaction cone is provided with appropriate number, size and location of air tuyers.

The temperature profile is expected under steady state conditions for optimal tar conversion. It has suggested design for a hot zone (>1000^0C) distribution in a downdraft gasifier with wall tuyers.[4] There are two drawbacks of this design:

- Cold regions are generated below the tuyers.
- A homogeneous hot cross-section is not generated below the pyrolysis zone.

It has been reported that tar generation increased when the distance between the air required value.

C. Venturi and Water pump system

It is based on Bernoulli's equation that is the velocity head increases in an accelerated flow by reducing the cross sectional area of the flow passage. The gas produced in reactor is extracted by venturi and Water pump system. As there is low pressure at the throat area and high pressure at the reactor so the gas which is produced is sucked by venturi. The gas is carried forward along with water to the cyclone; water simultaneously cools the extracted gas.

D. Orifice plate with U-Tube Manometer

Orifice meter is a device used to measure rate of flow through pipe. It consists of flat circular plate which has sharp edged hole called orifice concentric in pipe. The U-Tube manometer is used to measure pressure difference across the orifice plate. This arrangement is used to measure mass flow rate of gas.

The theoretical discharge is calculated as follows:-

$$Q = \frac{a_1 a_0 \sqrt{(2gh)}}{\sqrt{(a_1^2 - a_2^2)}} \qquad (1)$$

E. Cooling cleaning system

The temperature of gas at the gasifier outlet is about 250^oC to 400^oC. This gas contains tar and particulates. Gas suction in a downdraft gasifier is by a blower/engine depending on the application. A higher amount of tar and particulates will damage the blower/ engine. Hence it is essential to cool and clean the gas before it is taken to the blower/ engine.

The gas cooling and cleaning system consists of different units.

1) Cyclone
2) Filter

A description of the above units is given below:

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1) Cyclone

A cyclone is a dust collector without moving parts. In a cyclone the velocity of the inlet gas stream is transformed into a vertex. Dust separation from the gas takes place through centrifugal forces. The suspended particles are driven to the walls of the cyclone and are collected at the bottom of the cyclone. There are two types of coarse particles takes place in the cyclon e. There are two types of cyclones.

- High efficiency cyclone
- Medium efficiency cyclone

The collection efficiency of the cyclone depends on the gas in take velocity. It is therefore located at the exit of the gasifier where the velocity is maximum. Apart from cleaning the cyclone also cools the gas due to expansion.

2) Filter

The cooled and cleaned gas may still contain very small particles and vapors of tar, water. A filter is usually provided to clean the gas. The different types of filters used are dry packed bed filter, fabric filter. A dry packed bed of filter consists of a bed of fine material. The gas passes through this bed to a fine filter. A fabric filter is a fine filter either of cotton, wool, nylon, Teflon or fabric filter wherein the fine particles in gas are removed.

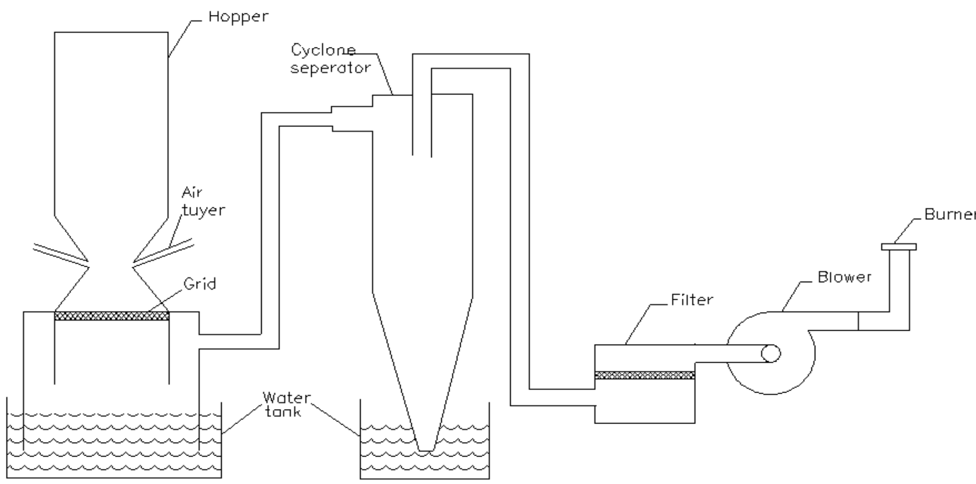

Figure 1. Experimental setup

III. DESIGN OF GASIFIER COMPONENT

A. Hopper

The hopper is the storage unit of the Biomass in a gasifier. The size of the hopper decides the interval between the two feeds to the gasifier. Normally this time is 4 to 6 hours. Bigger hoppers though convenient from point of view of having continuous and nonstop long duration operations become expensive and make the equipment too bulky.

The hopper for the project is designed on the basis of the bulk density of the biomass and the biomass consumption per hour. Literature provides these details and the volume of the hopper is so determined so as to allow the non-stop operation of the gasifier for about 5 to 6 hours. The hopper is a frustum of a cone with Φ 200 mm with a height of 650 mm.

1) Mass Flow Rate

The mass flow rate of the gas plays on important role in the residence time that is the time for which the gas remains in the oxidation zone. The calculation for the mass flow rate for a 5 KW engine based on the following assumptions [10].

1) Diesel replacement = 60%
2) Efficiency of engine = 35%
3) Gas calorific value = 4000KJ/m^3
4) Gas produced per Kg of biomass = 1.8 m^3/Kg of biomass

From the formula:

$$\text{Energy supplied by gas} = \frac{(\text{Power x \% Replacement})}{\text{Efficiency}}$$

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$$= \frac{(5 \times 0.6)}{0.35}$$

$= 8.57\ KJ/m^3$

Volume of gas to be replaced $= \frac{\text{Energy supplied}}{\text{Calorific value}}$

$$= \frac{(8.57 \times 3600)}{4000}$$

$= 7.71\ m^3/hr$

Consumption rate $= \frac{\text{volume of gas supplied}}{\text{Gas per Kg}}$

$$= \frac{7.71}{1.8}$$

$= 4.285$ kg/hr

Let 'D' be the diameter of reactor.

Specific gasification rate x area of reactor = consumption rate

150 x (pi/4) D2 = 4.285

D=19.07 cm= 20 cm= 200mm

2) Density of pallets

Average mass of pallets= 7 gm

Average volume of pallets= 5293.79 mm^3

Density $= \frac{\text{Average mass}}{\text{Average volume}}$

$$= \frac{7}{5293.79}$$

Density = 1322.3 kg/m^3

B. Reactor

Reactor or Reaction cone is the part where oxidation reaction takes place. Air tuyers are therefore also located in there. It being the highest temperature zone of the equipment is usually made of mild steel and is coated with refractory material. The last portion of air tuyers are also made of mild steel for the same reason.

The temperature of the oxidation zone is required to be maintained between 900°C to 1200°C to achieve efficient thermal cracking of the tar and maintaining adequate temperature in the other zones. Also depending upon the properties of biomass certain amount of ash is always formed. This ash amount is about 0.2 % in case of certain of certain wood and depending upon the properties of ash like its melting point etc. Provision must be made for the continuous removal of ash.

Design and configuration of oxidation zone is therefore critical faces of successful gasifier design. In addition to the residence time of the gas in high temperature zone which depends upon the flow velocities and geometry of the zone is also an important parameter. The reaction cone in the gasifier has been constructed by 3mm M.S. Sheet. This cone is then coated by a refractory, lining having a thickness of about 8 to 10 mm.

C. Reduction Zone

The reduction zone is a packed bed of charcoal. This charcoal is initially supplied from external sources. Later it is in the continuous process of being consumed by the reduction reactions & being simultaneously replenished by the char produced in the pyrolysis zone. Reduction reactions that take place in this zone are all highly temperature sensitive, it is therefore necessary that this temperature limits of 900°C to 600°C. The highest temperature being nearest to the oxidation zone. The dimension of the reduction zone is taken as the diameter of oxidation chamber or combustion chamber as shown in Figure 2. The reduction zone is made of a 3mm M.S. sheet which is cylindrical & filled with charcoal. The height of this reduction

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zone is 150 mm.

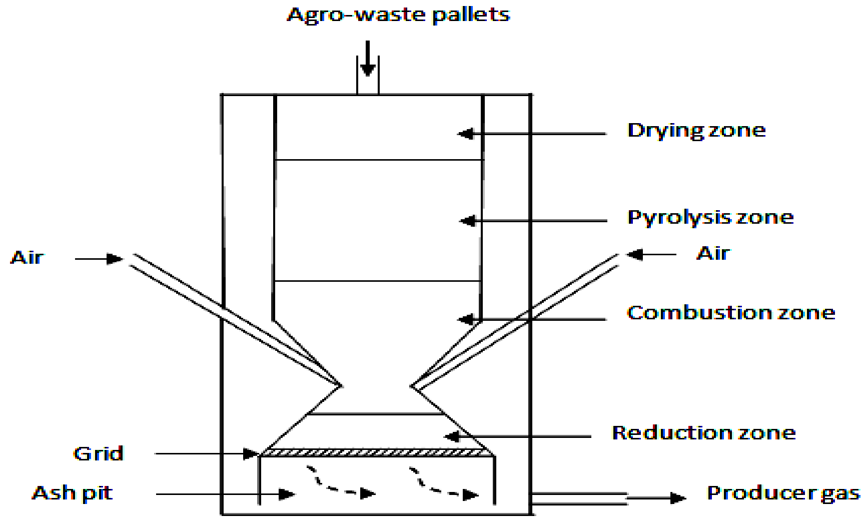

Figure 2. Zones in downdraft gasifier

1) Grate & Concentric Cylinder Arrangement

The lower part of the reduction zone is fitted with a grate which is welded so as to form a square mesh. The mesh size is 1 inch x 1 inch. The size of the grate should be so designed so that it allows the easy passage of char & ash from the reduction zone to the ash cone. The gas while traveling downwards through the reduction zone carries the char, dust, particulates tar etc. The gas is then drawn upwards through a concentric cylinder. This sudden upward motion of the gas causes the ash to be dropped downwards to the ash-cone.

The ash cone is fitted with a ash door at the button from where the ash is removed after every operation. The grate also allows the provision for the charcoal in the reduction zone to be stirred so as to allow removal of all the ash.

2) Refractory material

We chose fireclay cement as refractory material which can sustain temperature about 1600^0C & thermal conductivity in the range 0.6 to 1.8 W/mk.

D. Cooling & Cleaning System

The temperature of the gasifier outlet is about 250 to 400°C. Gas suction in the down draft gasifier is by a blower/engine depending upon the application. A higher amount of tar & particulates will damage the blower/engine. Hence it is essential to cool and clean the gas before it is taken to the blower / engine.

The gas cooling & cleaning system consists of

1) Cyclone
2) Filter

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A cyclone is a dust collection without moving parts. In a cyclone the velocity of the inlet gas stream is transformed into a vortex. Dust separation-from the gas takes place through centrifugal forces. The suspended particles are driven to the walls of the cyclone and are collected at the bottom of the cyclone. Separation of coarse particles takes place in the cyclone. There arc two types of cyclones,

- High efficiency cyclone
- Medium efficiency cyclone

The collection efficiency of the cyclone depends on the gas intake velocity. It is therefore located at the exit of the gasifier where the velocity is maximum.

Apart from cleaning the cyclone also cools the gas due to expansion. The cyclone in this project is also provided uses a liquid stream to recover small water or oil. Oil is efficient in removing particles but not used because of high cost, hence water is commonly used.

The gas entry is at the bottom. In another type, the gas passes through a sieve plate on which water is flowing. The gas bubbles through the water, in a baffle scrubber the gas changes direction and skips over the surface of water.

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A packed bed filter consists of a column of packing. Water is sprayed on the top and passes through the packed bed. The purpose of providing packing material to break down the liquid flow into film with high surface area thereby ensuring contact between gas & water. In a centrifugal scrubber or wet cyclone, water is sprayed from the top or a thin water film is provided on the walls of the cyclone for gas cooling and cleaning. Thus the gas can be cooled and cleaned for engine applications. The cyclone used here is shown in Figure 3.

1.1) Calculations for Cyclone Design

From the literature [9], all the dimensions of the cyclone have been based on the major diameter 'Dc' of the cyclone.

Assume value of Dc = 300mm

The other cyclone dimensions are

De = Dc/2 = 150mm

Lc = 2Dc = 600mm

Zc = 2Dc = 600mm

Jc = Dc/4 = 75mm

Hc = Dc/2 = 150mm

The water spray required for scrubbing is passed through a pipe from the cyclone outer pipe which is fitted with a spray nozzle at its end.

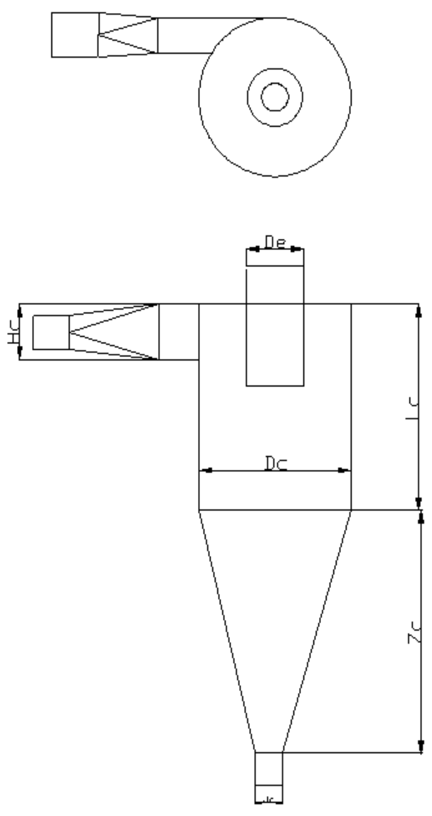

Figure 3. Cyclone Separator

2) Filter

The cooled and cleaned gas may still contain very small particles and vapors of tar and water. A filter is usually provided to clean the gas.

The filter used in the project consists of a single layer coir pad which has area 300mm*300mm*300mm. The large area of the filter also helps in the dampening the fluctuations in air suction and also helps in maintaining a consistent composition of the gas.

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IV. EXPERIMENTAL WORK

As we performed various tests on the existing set-up we have done some improvements on the system.

1) Previously the Gasifier was run using blower having following specifications:-

- Phase- 3 Phase
- RPM- 2880
- HP- 2
- Flow rate-50 m^3/hr

There were following problems of using blower

a) Dilution of producer gas due to suction of excess atmospheric air.

b) Due to excess suction, retention time was very less.

2) For controlling the excess suction we have used dimmerstat which has range of voltage from o to 480V.

3) We have put up a burner system which has a pipe of 2" diameter and length of 300 mm. This helps in providing residence time to gas at outlet and also the velocity is reduced properly. Figure 4, 5, and 6 show experimental setup and ignition of producer gas for biomass gasifier respectively.

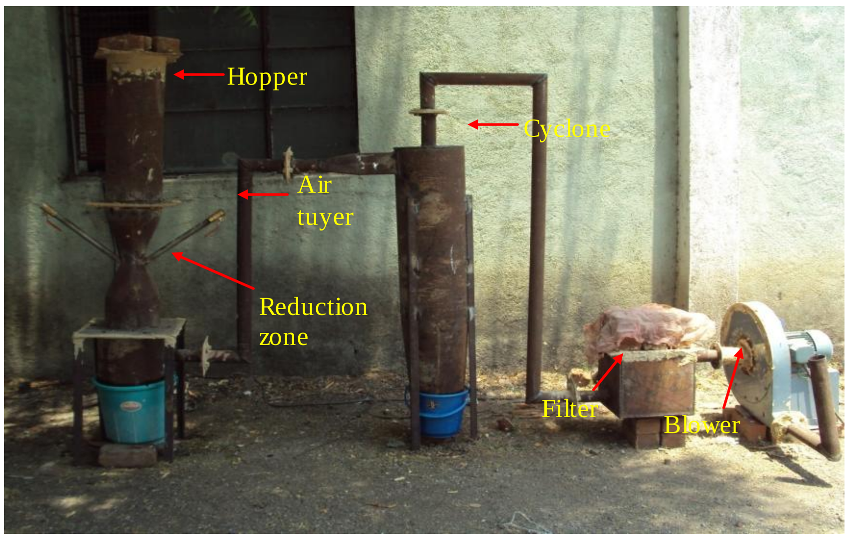

Figure 4. The complete Biomass gasifier setup

Figure 5. The producer gas is ignited through air tuyers

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Figure 6. The producer gas is ignited through outlet

V. PROPERTIES OF PRODUCER GAS

The producer gas is affected by various processes as outlined above hence one can expect variations in the gas produced from various biomass sources. The gas composition is also a function of gasifier design and thus, the same fuel may give different calorific value as when used in two different gasifiers. Thus it may be beneficial to use oxygen instead of air for gasification. However the cost and availability of oxygen may be a limiting factor in this regard. Nevertheless where the end product is methanol – a high energy quality item, then the cost and use of oxygen can be justified. On an average 1 kg of biomass produces about 2.5m^3 of producer gas at S.T.P. In this process it consumes about 1.5 m^3 of air for combustion. For complete combustion of wood about 4.5 m^3 of air is required. Thus biomass gasification consumes about 33% of theoretical stoichiometric ratio for wood burning. The average energy conversion efficiency of wood gasifiers is about 60 to 70% and is defined as

$$\text{Efficiency of gas} = \frac{\text{Calorific value of gas/kg of fuel}}{\text{Avg. calorific value of 1 kg of fuel}}$$

Example:
Table 1. shows typical % volumetric composition of biomass based producer gas,
1 kg of Agro-waste (Pallets) produces 2.5 m^3 of gas with average calorific value of 4 MJ/m^3. Average calorific value of Agro-waste (Pallets) is 15.6 MJ/kg.
Hence,

$$\text{Efficiency of Gas} = \frac{2.5\ (m^3) \times 4\ (MJ/m^3)}{15.6\ (MJ/kg) \times 1\ (kg)} = 64\%$$

Table 1. Typical % volumetric composition of Biomass based producer gas

CO	20-22
H_2	15-18
CH_4	02-04
CO_2	09-11
N_2	50-53

(1)

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VI. RESULTS

The producer gas analysis is done on Gas Chromatograph using TCD (thermal conductivity detector). The gas sample on porapack-Q column by using following gas chromatograph conditions.

1) Oven temperature = 50˚C
2) Injection temperature = 100˚C
3) Detector temperature = 100˚C

Result table 2. of producer gas analysis using gas chromatograph

Table 2. Producer gas analysis results

Sr. No.	Gas	% volume
1	CH_4	1.9
2	CO_2	32.7
3	Other	12.40

VII. APPLICATIONS

1) Shaft power systems
2) Irrigation pumping
3) Direct heat applications
4) Fluidized bed systems

VIII. CONCLUSION

On performing various trials on the set-up of gasifier, we have came to the following conclusions:

1) To avoid accumulation of tar inside the components of system and for proper filtration of gas, good quality of filter should be used.
2) For initializing the combustion small quantity of combustible liquid fuel should be used.
3) The problem faced by the gasifier was mainly of the char disposal and continuous flow of biomass in the oxidation zone.
4) The cooling & cleaning system was inadequate which is justified by the tar deposition inside the components.

We got % volume of CH_4 & CO_2 nearer to theoretical value.

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