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Thermal Analysis of Gasifier System

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Abstract —*The paper consists of performance analysis of gasifier system. The biomass gasifier converts the various bio-mass into combustible gaseous fuel by gasification process. The fuel obtained is used for thermal/heating and power development processes. The performance analysis of both applications is of main concern and peroposes to study the thermal performance of a downdraft gasifier system by taking down various observations during the experimentation and plotting the graphs which help in the evaluation of the study of the gasifier system. This in turn would be helpful in putting forward the gasifier system as an efficient source for renewable energy.The energy obtained from the gasifier can be used for power generation in rural area, absorbtion type refrigeratiuon and for cogenration.*

Keywords: *Biomass energy, biomass gasifier, gas flow rate, efficiency*

I. INTRODUCTION

The global energy consumption in last 50 years has increased rapidly and expected to continue to grow over the next 50 years. However we expect to see the significance difference between the last 50 years and the next. And the additional factors like global warming and population growth making the picture more complex for next 50 years. Thus, the need for alternative energy sources is getting urgent, hence the development of renewable energy is moving fast. Nationally and internationally various individuals and research institutes are creating new and exciting energy systems.

If we look at a pattern of the energy production coal and oil accounts 52% and 33% respectively with natural gas hydro and nuclear contributing to the balance. India presently imports 70% of its crude petroleum from OPEC and other overseas countries. Because the energy prices for crude oil are going through the roof, the small and developing countries suffer even more. These high oil prices have their effect on almost everything. The monthly electricity costs for households increase among others like transport cost and prices for basic products. Hence, these high oil prices make it harder for these small countries to grow there economies. In India problem due to uncontrollable population growth are ever increasing day by day with a view of improving quality of life of the huge population the demand for energy which is one of the basic need is increasing its manifolds.

The fossil fuels are depleting in a rapid rate and are harder to retrieve. The consequence is that we can be facing an energy crisis in the future is we are not careful today. The energy prices will sky rocket and not be available for many individuals or countries. To avoid this doom scenario we need to find alternatives and used them to their full potential.

The second problem is that the fossil fuels that are widely used today are harmful for the environment. The earth is warming up and climates are changing. There are parts in the world were there be more rain and sunshine and others parts will be come dryer then they already are. Another negative effect is that the ozone layer is getting thinner which also leads to a warming up of the earth. These two effects compliment each other and make it even more crucial to make another step in a different direction. This step will lead us to the use of renewable energy.

The solution for the above problems can be resolved by renewable energy. Our beautiful planet gives us the opportunity to make proper us of sunlight, flowing water, strong winds, Bio-mass and hot springs and convert these into energy. These energy sources are abundant and free to use. We must be sure that we convert the energy the right way, without causing other problems that can again hurt our environment. Luckily the many efforts by individuals and research institutes show that this can be done.

The efforts have been made here to use biomass energy, which can be used for various thermal applications and power generation using bio mass gasifier. A biomass gasifier converts solid fuel such as wood waste, saw dust briquettes and agro-residues converted into briquettes into a gaseous fuel through a thermo-chemical process and the resultant gas can be used for heat and power generation applications. The work is carried out by evaluating thermal performance of gasifier.

II. BIOMASS GASIFICATION SYSTEM

2.1 Bio mass

In this era of depleting energy sources, we are focusing our efforts to tap all the available renewable sources of energy like the solar, wind, wave, tidal, geothermal etc. But the biomass is the only renewable source which has been refined and concentrated by nature compared to the other renewable sources. In this chapter, it is attempted to see what is biomass, why are mankind after this source, how can we extract energy from it and at last gasification route in little detail. Biomass is a renewable energy resource derived from the carbonaceous waste of various human and natural activities. It is derived from numerous sources, including the by-products from the timber industry, agricultural crops, raw material from the forest, major parts of household waste and wood. Biomass is solar energy stored in organic matter.

As trees and plants grow, the process of photosynthesis uses energy from the sun to convert carbon dioxide into carbohydrates (sugars, starches and cellulose). Carbohydrates are the organic compounds that make up biomass. When plants die, the process of decay releases the energy stored in carbohydrates and discharges carbon dioxide back into the atmosphere. Biomass is a renewable energy source because the growth of new plants and trees replenishes the supply.

2.2 Types of biomass

- Wood residues
- Agricultural residues
- Energy crops
- Animal waste
- Rice husk
- straws, etc

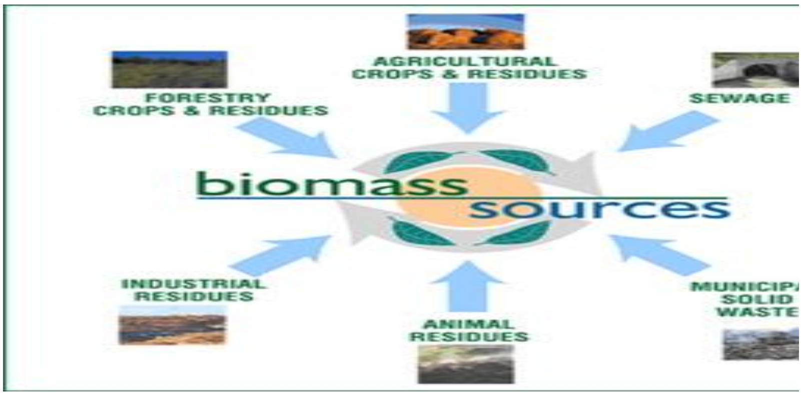

Figure 1 Biomass energy sources

2.3 Biomass is better choice.

The best reason for accepting biomass as a fuel is its eco friendliness. Even though they are not as concentrated as fossil fuels, they are distributed moderately near the usage points, reducing the overheads on transportation and storage. Many of the biomass is wastes from some other process, and so the utilization will help in making the environment clean. Biomass does not add co_2 (carbon dioxide) to the atmosphere as it absorbs the same amount of carbon in growing and releases as it consumes as fuel. Another reason is that it can be used to generate electricity with the same equipment of power plants that are now burning fossil fuels. Biomass is the most important fuel worldwide after coal and natural gas so in this way by using Biomass as a energy alternative and mainly it does not add co_2 (carbon dioxide) to the atmosphere. It will be a kind gift to the world in a way that it can be one good solution to reduce the greenhouse effect which is today's burning problem to the mankind.

2.4 What is a gasifier ?

A biomass gasifier converts solid fuel such as Wood Waste, Saw Dust briquettes and agro-residues converted into briquettes into a gaseous fuel through a thermo-chemical process and the resultant gas can be used for heat and power generation applications. The producer gas has relatively low calorific value, ranging from 1000 to 1100 $kCal.Nm^3$ (5500 MJ/Nm3). The overall thermal efficiency of this process is more than 75%.

The combustible gas mixture, known as 'producer gas', typically contains:

1 Carbon monoxide (20% - 22%)
2 Hydrogen (12% - 15%)
3 Nitrogen (50% - 54%)
4 Carbon Dioxide (9% - 11%)
5 Methane (2% - 3%)

Gasifire system consist of reactor which receives solid fuel and air and converts them to gas followed by cooling and washing train , where impurities are removed. The clean combustible gas is sent to the engine at nearly ambient temperature for power generation. In thermal application this cooling and cleaning depends upon requirement.

2.5 Environmental consideration

Accounting for the environmental impacts of biomass is perhaps more complicated than for any other energy source considered here. Although a renewable resource, biomass has a much broader effect on the environment than other renewable sources. For example, while there are no emissions from wind turbines, the combustion of biomass produces pollutants that can have effects on human health and the environment. The environmental impacts we are most familiar with are those "from the smoke stack." The combustion of biomass can produce the same air pollutants as fossil fuel combustion.

These pollutants have been shown to cause asthma and other health and environmental problems. Depending on the type of generator and emission control technology that is used, pollutants can be kept to a level much below existing fossil plants. One advantage that biomass has over fossil fuel emissions is reduced impact on global warming. Fossil fuels are the primary source of the greenhouse gas carbon dioxide. Plants take carbon dioxide out of the air as they grow, thus neutralizing the effect of releasing the carbon dioxide when the plant is burned, and thus biomass can be considered a nearly "carbon- neutral" source of energy.

2.6 Types of gasifiers

Basically gasifier system is classified in four categories:

- Fixed bed gasifier system
- Downdraft gasifier system
- Updraft gasifier system
- Fluidized bed gasifier system

2.6.1Fixed bed gasifier system

It can be classified primarily as updraft and downdraft. Fixed bed gasifier uses a bed of solid fuel particle trough which gas is passes either up or down. They are simplest kind of gasifier and suitable for small scale application. Biomass is fed at the top and moves downward as a result of its conversion and removal of its ashes. Air is taken at the bottom and leaves at the top and vise versa.

2.6.2 Fluidized bed gasifier

Fluidizid bed gasifier features a bed of sand, or inert solid grandular paricles which is kept on suspension by high pressure air admitted at the bottam of the bed through a perforated grid plate. It processes high moistured (more than 30%) bio mass but efficiency of the energy conversion is very low. The term “updraft gasifier” and “downdraft gasifier” may seem like trival mechanical discription of gas flow patterns. In practise, however updraft gasifier can tolerate high moisture content and thus have advantages for producing gas for combusion in a burner. Up draft gasifier produces 5-20% volatiles like tar and oil, hence not suitable for operation of engines, downdraft gasifier produces typically less than 1% volatiles and hence more suitable for rngine operation. The choice of the system is dependent on no parameter so here the advantages and disadvantages are present.

2.6.3 Downdraft gasifier system

In this type of the system biomass is fed from the top of the gasifier and also air is taken at the top side and gases leaves from the base of the gasifier system.. The biomass is dried in the drying zone and pyrolizes in the distillation zone. This zones are mainly heated due to radiation (heat coming from the hearth zone where part of the charcoal is burned) pyrolysis gases also pass through this zones and burned as well. The extent to which the pyrolysis gases are burned depends upon design of the gasifier, biomass feed stock and skill of the operator. Downdraft gasifiers are specifically designed to minimize tar and oil production. After the oxidation zone remaining char and combustion products pass through the reduction zone (CO_2 and water vapor) where CO and H_2 formed. Most of the biomass is converted in to the gas in the combustion zone.

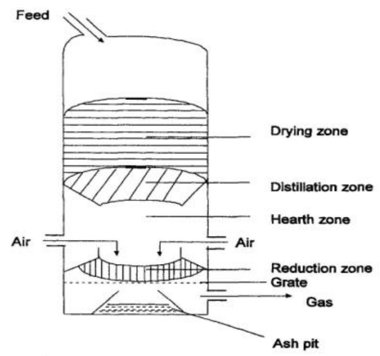

Figure 2 Downdraft gasifier system

2.6.4 Updraft gasifier system

During the operation biomass is fed from the top and air is taken from the base of the gasifier body. Zones are similar compared to downdraft gasifer system but the orders are different. In the pyrolysis section hot gases pyrolyzes the biomass to tar oil charcoal and some gases. And in the reduction zone it reacts with CO_2 and H_2O and form CO and H_2. Finally below of the reduction zone air burns to charcoal and producer CO_2 .

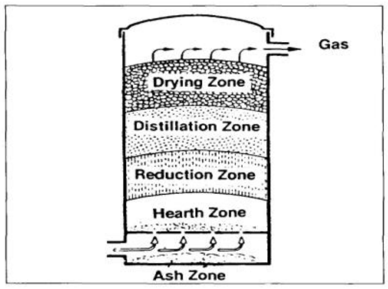

Figure 3 Updraft gasifier system

No.	Gasifier Type	Advantages	Disadvantages
1.	Updraft	- Small pressure drop - Good thermal efficiency - Little tendency towards slag formation	- Great sensitivity to tar and moisture and moisture content of fuel - Relatively long time required for start up of IC engine - poor reaction capability with heavy gas load

2.	Downdraft	- Flexible adaptation of gasproduction to load - Low sensitivity to charcoal dust and tar content of fuel	- Design tends to be tall - Not feasible for very small particle size of fuel
3.	Fixed bed	- Short design height - Very fast response time to load - Flexible gas production	- Very high sensitivity to slag formation - High pressure drop

2.7 Gasification process

Biomass fuels such as firewood and agro-residues essentially contain carbon, hydrogen, and oxygen along with some moisture. Under controlled conditions, characterized by low oxygen supply and high temperatures, most biomass materials can be converted into a gaseous fuel known as producer gas, which consists of carbon monoxide, hydrogen, carbon dioxide, methane and nitrogen. This thermo-chemical conversion of solid biomass into gaseous fuel is called biomass gasification. Basically this process involves reaction of carbon and hydrogen. This conversion process is being complete in few stages. Basically four different processes take place across the gasifier to convert biomass in to combustible producer gas. The below shown colorful figure will give more idea about the process stages in the gasifier during the conversion process.

As shown in the fig the four stages are,
1. Drying zone
2. Pyrolysis zone
3. Combustion zone
4. Reduction zone

(1) Drying Zone basically dries the biomass and reduces moisture content from the biomass by radiation using heat coming from the combustion zone. **(2) Pyrolysis Zone**, In this section hot gas pyrolyzes biomass to tar, oil charcoal and some gases. **(3) Combustion Zone**, the combustible material of a solid fuel is usually composed of elements carbon, hydrogen and oxygen. In complete combustion carbon dioxide is obtained from carbon in fuel and water is obtained from the hydrogen, usually as steam. The combustion reaction is exothermic and yields a theoretical oxidation temperature of 1450^0 C. The main reactions, therefore, are:

1. $C + O_2 = CO_2$
2. $2H_2 + O_2 = 2H_2O$

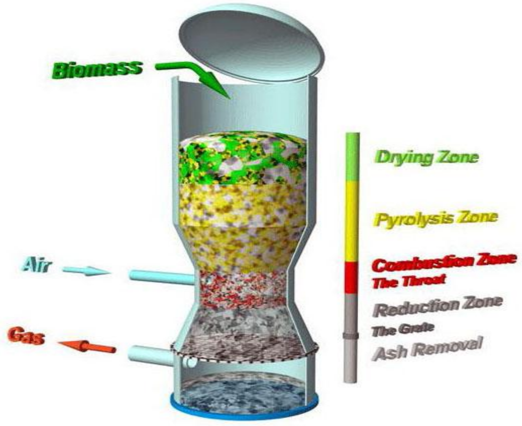

Figure 4 Zones of the gasifier

(4) Reduction Zone, the products of partial combustion (water, carbon dioxide and uncombustible partially crackedpyrolysis products) now pass through a red-hot charcoal bed where the following reduction reactions take place.

[1] $C + CO_2 = 2CO$
[2] $C + H_2O = CO + H_2$
[3] $CO + H_2O = CO + H_2$
[4] $C + 2H_2 = CH_4$
[5] $CO_2 + H_2 = CO + H_2O$

Reactions (3) and (4) are main reduction reactions and being endothermic have the capability of reducing gas temperature. Consequently the temperatures in the reduction zone are normally 800-10000C. Lower the reduction zone temperature (~ 700-8000C), lower is the calorific value of gas. The gas produced from the gasifier generally contain contaminants that are required to be removed. The principle contaminants encountered are particulates, alkali compound, tars, nitrogen-content compound, sulphur and low molecular weight hydrocarbons. Tar is one of the most unpleasant constituents of the gas as it tends to deposit in the carburetor and intake valves causing sticking and troublesome operations . It is a product of highly irreversible process taking place in the pyrolysis zone. The physical property of tar depends upon temperature and heat rate and the appearance ranges from brown and watery (60% water) to black and highly viscous (7% water). There are approximately 200 chemical constituents that have been identified in tar so far. And if this all particulate matters reach to the engine where power is being generated, may deposit on the piston and cylinder that may lead to inefficient working of engine. That may also damage the piston and may lead to knocking of the engine. But again need of the remove this particulate from the gas is depends upon the application.

2.8 Applications

Gasifiers find their application almost everywhere in human life. Given below is a list of potential applications:

-Heat Treatment furnaces
-Captive power generation
-Textile dyeing
-Gasifier can be used in any application where LPG, Diesel or any other Petro-fuel is used

-Rural Electrification
-Decentralized Rural power generation
-Institutional cooking
-Restaurants/Hotels
-Hot water generation
-Steel re-rolling mills and many more.

III. EXPERIMENTAL PROCEDURE

3.1 System discription

the system consists of the open core drawndraft gasifier of 55-kg/ hr capacity with blower-burner setup both for starting mode and normal running mode along with a hot cyclone to trap the coarser dust particles. Gasifier is provided with thermal insulation to prevent thermal leakage and to achieve the desired thermo chemical reactions at the desired temperature inside the reactor. it is also provided with a inspection cum clinker removal window to remove clinkers when high ash content biomass with low ash fusion temperature is as used as feed stock for the gasifier.

Gasifier consists of a hopper which holds feedstock for around 2 hours of operation, which needs to be filled up as and when the biomass level goes down during operation. a stair case is also provided to climb up and feed the gasifier manually. large scale system can be mechanized with conveyors to feed the biomass. in the combustion zone also known as oxidation zone there are 4 air tuyers provided to supply air during operation of gasifier, which otherwise will be closed by plugging the end caps provided with it. there is also a cast iron grate with a shaking mechanism provided at the bottom of the gasifier to remove deposits of ash collected at the bottom of the gasifier reactor. shaking of the grate sometimes also helps in achieving the compact bed of fuel in the gasifier, which inturn promotes the proper gasification and prevents bridging of fuel and creation of void spaces, mainly in the reduction and oxidation zone. too vigouros shaking of the grate is not desirable as the gasifier zones gets affected seriously and the gasifier is very senstitive for any such sudden changes. at the bottom of the gasifier a water seal is provided to prevent air leakage into the system which otherwise affects the performance of the gasifier and makes it to behave like a combustor. the water level in the seal has to be monitored and maintained within the limits. there is also a water seal and top cover provided at the top of the gasifier to prevent air infusion into the system during shutdown of the gasifier.

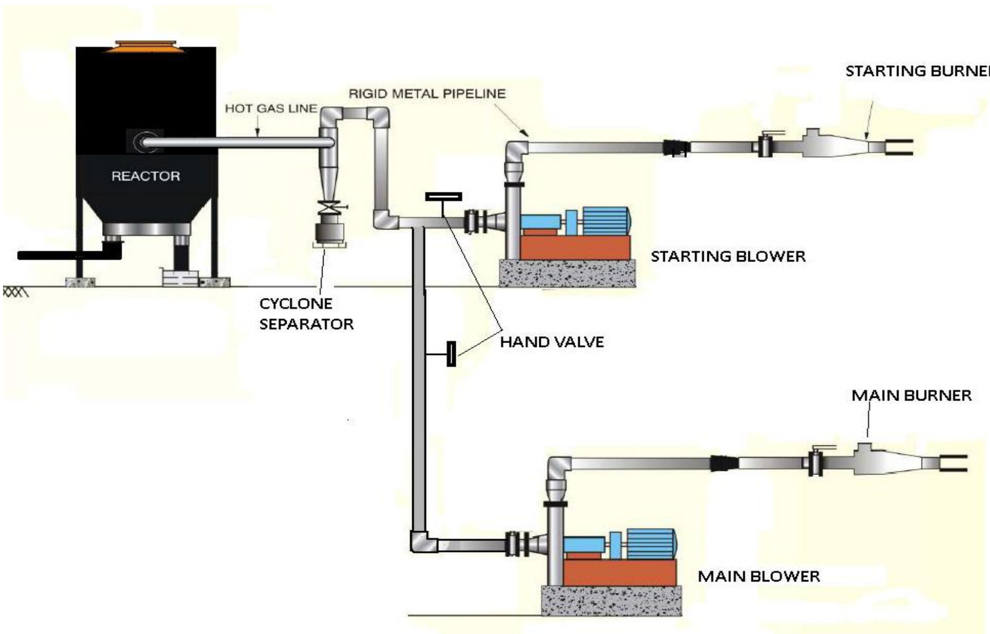

Figure 5 Schematic diagram of gasifier system for thermal application

The producer gas from the gasifier is drawn to the starting burner and main burner through blowers. Before the gas makes entry in to the blowers, gate valves are provided to isolate the gas flow in each direction after passing through the hot cyclone. Hot cyclone is provided at the exit of the gasifier to trap the coarser dust particles before the gas makes an entry to the blowers. Figure 3.1 shows the general schematic arrangement of the gasifier system for thermal application.

IV. OBSERVATIONS AND RESULTS

4.1 Calibration of orifice meter

The gas flow rate to the engine was measured using a calibrated orifice meter. The reading of the same and the calibration curve was provided to calculate the gas flow rate for the corresponding pressure drop across the orifice plate. The velocity of air was measured using an anemometer at different discharge conditions by controlling the flow by a control value. Knowing the cross-section area of the pipe and the velocity of the air flow, the discharge of air was

calculated and the corresponding pressure drop across the orifice meter was recorded. A best fit curve and an equation was developed to find the flow rate at various intermediate pressure drops across the orifice meter.
The diameter of the pipe before and after orifice plate = 50.8 mm
The diameter of the orifice plate = 25.4mm
The cross-sectional area of the pipe = 0.002027m^2

Table 1 Observation for calibration of orifice meter

Sr. No.	Differential Pressure(mm)	Velocity (m/s)	Flow rate(m3/s)
1	5	5	0.010135
2	10	5.7	0.011554
3	15	6.5	0.013176
4	20	7.1	0.014392
5	25	8	0.016216
6	30	8.8	0.017838
7	35	9.6	0.019459
8	40	10.2	0.020675
9	45	11.2	0.022702
10	50	11.6	0.023513
11	55	12.1	0.024527
12	60	13.3	0.026959
13	130	17.5	0.035473

Table 2 Observations for the thermal analysis

Time (hr:min)	Dp across gasifier (mm of water)	Dp across orifice (mm of water)	Gas flow rate (m^3/hr)	Temp. gas outlet T (^{0}C)
11:37	05	-	-	135
11:45	07	-	-	313
12:00	20	28	145.68	400
12:20	18	23	131.47	482
12:40	15	22	125.76	446
1:00	25	22	125.76	420
1:20	28	20	127.56	545
2:50*	20	28	145.68	487
3:10	13	22	125.76	529
3:30	15	22	125.76	524
3:50	16	23	131.47	540

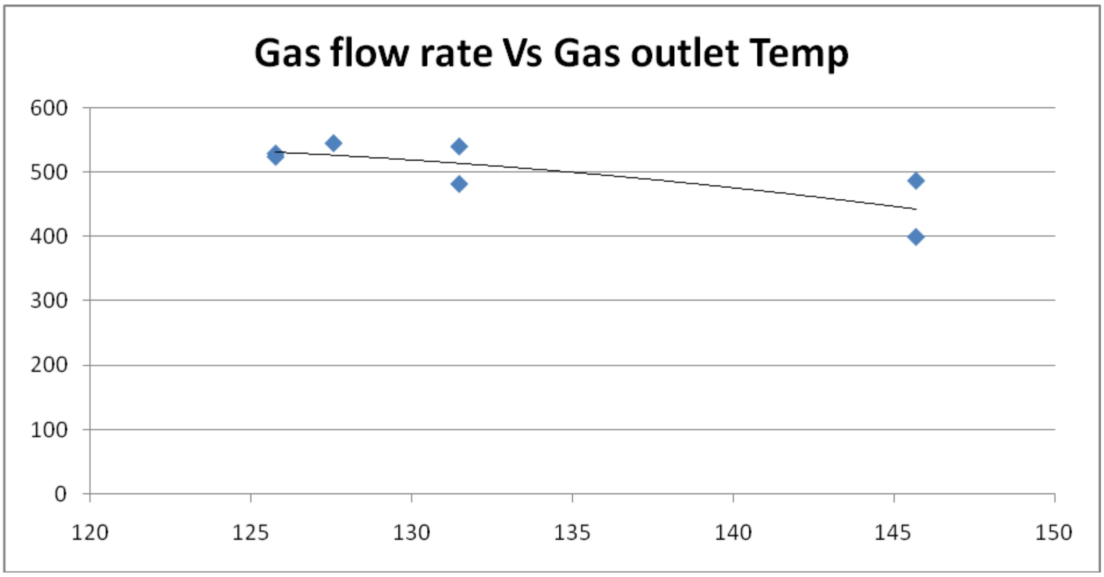

Figure 6 Graph for Gas flow rate v/s Gas outlet temp

Avg. c.v of the wood/bricket= 4000 kcal/kg
Avg. c.v of the producer gas= 1250 kcal/m^3
Fuel consumption of gasifire= 50kg/hr

4.2 Observations for thermal analysis

The performance of the Thermal analysis is evaluated in terms of the energy conversion efficiency of the system, which is calculated as below.

Efficiency (ή) = $\dfrac{\text{Energy available at outlet of the gasifier per unit time } (\mathbf{E_O})}{\text{Energy input in form of biomass to the gasifier } (\mathbf{E_I})}$

$\mathbf{E_I}$ = fuel consumption rate * cv of fuel = 50 kg/hr* 4000 kcal/kg = 200000 kcal/hr
$\mathbf{E_O}$ = avg gas flow rate * cv of gas =145.68m^3/hr* 1250 kcal/m^3 = 182100 kcal/hr
Efficiency(ή)= $\mathbf{E_O / E_I}$ = [182100 (kcal/hr)/ 200000(kcal/hr)] *100 = 91.05 %

Table 3 Computation table for thermal analysis

Time (hr:min)	Gas flow rate (m^3/hr)	E_O	Efficiency (%)
12:00	145.68	182100	91.05
12:20	131.47	164337.5	82.16
12:40	125.76	157200	78.6
1:00	125.76	157200	78.6
1:20	127.56	159450	79.73
2:50*	145.68	182100	91.05
3:10	125.76	157200	78.6
3:30	125.76	157200	78.6
3:50	131.47	164337.5	82.16

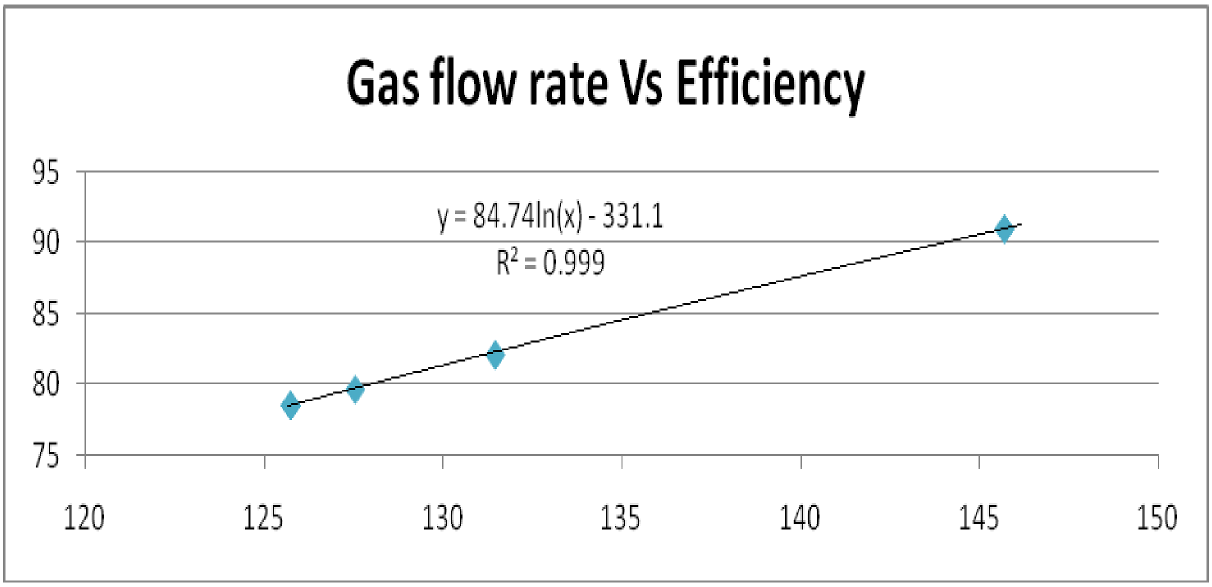

Figure 7 Graph for Gas flow rate v/s Efficiency

CONCLUSION

Biomass gasification offers the most attractive alternative energy system for agricultural purposes..The produce gas obtained from gasifier when chedked in gas chrmatographer contains expected percentage composition of Carbon monooxide, Hydrogen, Methane etcMaximum usage of producer gas has been in driving internal combustion engine, both for agricultural as well as for automotive uses. However direct heat applications like grain drying etc. are very attractive for agricultural systems. Energy conversion efficiency is found in the range of 75% to 90%, Which is satisfactory. On an average the temperature of gas leaving the gasifier is about 300 to 400C 16. If the temperature is higher than this (~ 500^0C) it is an indication that partial combustion of gas is taking place. This generally happens when the air flow rate through the gasifier is higher than the design value.

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