

# **“DESIGN OF DOWNDRAFT GASIFIER FOR SYNGAS PRODUCTION”**

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Final Year Project Report

Presented to

**SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING**

Department of Mechanical Engineering  
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ISLAMABAD, PAKISTAN

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BY,

Muhammad Jahanzeb Hassan Shah.	242548
Saad Kamran.	246523
Muhammad Ahmed.	268534
Muhammad Faraz Masood.	264000

## EXAMINATION COMMITTEE

We hereby recommend that the final year project report prepared under our supervision by:

Muhammad Jahanzeb Hassan Shah.	242548
Saad Kamran.	246523
Muhammad Ahmed.	268534
Muhammad Faraz Masood.	264000

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Supervisor: Dr. Waqas Khalid, Assistant Professor	_____
Dated:	_____
Committee Member: Name, Title (faculty rank) Affiliation	_____
Dated:	_____
Committee Member: Name, Title (faculty rank) Affiliation	_____
Dated:	_____

\_\_\_\_\_  
(Head of Department)

\_\_\_\_\_  
(Date)

### **COUNTERSIGNED**

Dated: \_\_\_\_\_

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## ABBREVIATIONS

LHV	Lower heating value
HHV	Higher heating value
CV	Calorific value
SG	Specific gasification
SGR	Specific gasification rate
TH	Throat
DIA	diameter

## NOMENCLATURE

$T$	Temperature ( $^{\circ}\text{C}$ , otherwise units are mentioned)
$\dot{m}$	Mass flow rate (kg/s)
$P$	Absolute pressure (kPa)
$P$	Power
$d$	Diameter (m)

## ABSTRACT:

The report focuses on analyzing and identifying the working of a downdraft gasifier to produce syngas that has numerous advantages in both practical and industrial domains. The focus of this project was to study the manufactured hardware model of the gasifier and calculate the required parameters, phases, and model it for the successful production of syngas with the use of reverse engineering. The study was done for the wood pellets that are a very good source of producing energy through undesired biomass. The main operating parameters in our study were the air flow rate, equivalence ratio, specific gasification rate that helped us in predicting the performance of our downdraft gasifier. With the required modifications and addition of components, we would be able to successfully operate the gasifier, resulting in the production of quality syngas. The produced gas if properly utilized could be a great potential for generation of heat, electricity, and power and can be a real game changer in the field of biomass energy conversion and management.

## ACKNOWLEDGEMENTS:

We are really blessed and thankful to Allah Almighty for bestowing us with the courage and strength to work on this project and proceed towards its completion. The report and the project had been on its way to completion under the guidance and mentorship of our esteemed supervisor Dr. Waqas Khalid. We are thankful for his immense support and expertise that helped us a lot in this endeavor. In the end, we are thankful to our parents and family who have supported and prayed for us. Their support had been helpful and crucial.



## ORIGINALITY REPORT

We, as a team, hereby declare that all the work done for this project and report is ours and only ours, and the findings and workings have been produced originally through extensive literature review and calculations. Our project has been supervised under the guidance of Sir Dr. Waqas Khalid and has not been a support project for any of the work done towards serving the requirements of similar degree from any institute. All the work and references that we have used so far has been explicitly mentioned and cited and we take all the responsibility in case of plagiarized/copied work.

## INTRODUCTION:

### Background:

Biomass is a promising source of renewable energy. It has a lot of advantages as compared to the traditional fuel types. Biomass is a carbon neutral fuel that limits the emissions of carbon dioxide, making it an environment friendly. It can be used as a good contribution towards increase in resources available for utilizing energy through biomass conversion. The increase in use of biomass results in an additional factor of increase in economic support that are available in regions (agricultural). Moreover, the plant being a composed one doesn't require a lot of maintenance and spacing in order to work and operate successfully. Small unit capacity and good efficiency of gasifiers make it a good choice for generation of heat, gas, and electricity through use of biomass.

### Gasification:

Gasification is a process in which a particular biomass is being converted into producer gas through different phases and processes. Gasification, most simply, can be thought of incomplete or choked combustion. It is occurred when solid fuels like coal or wood are burned without complete air or oxygen that is required to complete the combustion. Therefore, the gas generated has still the potential of combusting and generating power. This unburned gas is then used to burn elsewhere.

### Processes:

The whole process is divided into five thermal processes that are discrete and play their own roles named as Drying, Pyrolysis, Cracking, Combustion, and Reduction. All the above-mentioned phases are already present in a burning match, but it is invisible to an eye because of the mixing. One can also define gasification as the isolation of these different phases that when combined can result into a producer gas that has potential to burn and generate energy. The processes are quite simple and easy to understand.

## Pyrolysis

Pyrolysis is defined as a process where heat is applied to the raw biomass. It is done in the absence of air where it is broken down into charcoal, tar gases and liquids. Pyrolysis is also known as the process of charring.

## Cracking

Cracking is the most common way of separating huge complex atoms, for example, tar into lighter gases by exposing to heat. This cycle is significant for the creation of clean gas that is viable with a IC engine since tar gases consolidate into tacky tar that will quickly foul the valves of a motor/engine.

## Reduction

Reduction is the process where oxygen atoms are stripped off combustion products of (HC) molecules. It is done so that the molecules could burn again. Reduction is also known as to be the direct or complete reversal process of combustion.

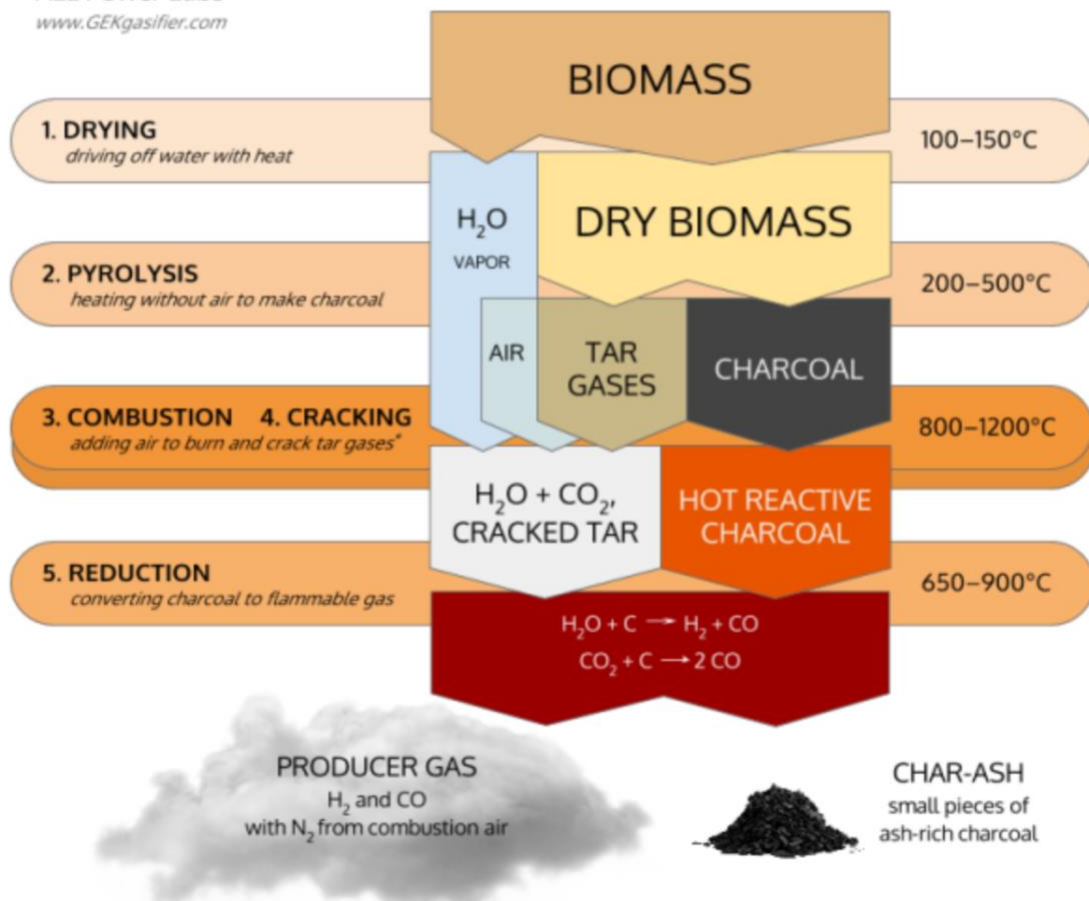
## Combustion and Drying:

Combustion is the only process in the processes of gasification that includes the net exothermic process. All the heat that is used to drive pyrolysis, drying, reduction comes either from combustion directly, or it is recovered from combustion indirectly by the processes of heat exchange in a gasifier. Combustion can be fueled by either the char or tar gasses that are produced in pyrolysis.



# The Five Processes of Gasification

ALL Power Labs  
www.GEKgasifier.com



**Fig 1- Five Processes of Gasification.**

Reference- (Biomass Gasification - Technology and Utilization (Individual Authors): Gasification History and Development, 2022)

## OBJECTIVES:

- Use of reverse engineering for finding the operational parameters of gasifier.
- Modify the gasifier by addition of several components.
- Calculation of power generated through the process.

- Production of syngas through prototype experimentation.
- 

## **LITERATURE REVIEW:**

### **History**

With the world moving towards industrialization, the need for sustainable energy arose and therefore started the efforts to obtain new energy sources. Biomass has been one of the oldest energy sources for the mankind. Now there was a need to convert it into a more useful form. This need for sustainable energy utilization of biomass led to the process of gasification which converted the biomass into a producer gas with high properties which can be used to fulfil various energy needs. (Siedlecki, De Jong and Verkooijen, 2011)

The process of gasification was developed back in 17<sup>th</sup> century. It was invented both in England and France but independently. Till now, the process of gasification has gone through numerous development phases. During the initial stages, coal gas was found. Then, a small room was lit with the help of producer gas. In 1840, first commercial gasifier was built in France. Then, siemens produced what could be said the first successful gasifier. After that, the process of gasification started being used in power generation systems and vehicles. In 1920, the gasification process reached America. They started doing extensive research on the process and its applications. The research and its applications were left in the way on the discovery of fuels that can be used relatively easily such as Natural gas and Sea oil. (Reed and Das, 2006)

### **Gasification in vehicles**

In the early 19<sup>th</sup> century, coal gasification was being used widely. It found its application in vehicles such as boats, cars, trucks, and trains. During World War 1, Gasifiers were used in vehicles but between 1919 and 1939, its applications saw a decline because gasoline was relatively cheaper. In 1939, As Germany halted the supply of gasoline to Europe, the gasifiers became widely popular to be used with vehicles. Since most of the gasoline was being used by military, therefore, the civilians resorted to the use of gasifiers in vehicles. Over 1 million vehicles were operated by gasifiers in the war years. This included Cars, buses,

trains, boats, and trucks. Over 90% vehicles in Sweden were run on gasifiers in 1943 and all the 20,000 tractors were run on gasifiers. (Reed and Das, 2006) Although the number of vehicles which operated on gasifiers were very large during the war years, but this modification was temporary as the gasoline became very inexpensive after the war. These gasifiers mainly used coal or biomass feedstock. The figure 1 shows a bus in 1943 which is being driven by wood gasifier.



*Figure 1: A bus, powered by wood gas generated by a gasifier on a trailer, Leeds, England c.1943*

## **Power generation**

First commercially used gasifier was built in France in 1948. In 1961, Siemens built a very successful gasifier which served as a breakthrough in the industry and resulted in power and electricity generation. A lot of work was being done in this field and by 1900, gasifiers of more than 5400hp were built. Gasifiers became increasingly popular during the World War 1 and World War 2 because there was a dire need of fuel. Due to this scarcity of gasoline, gasifiers were in huge demand and were being widely used for energy generation and other purposes. After the end of second world war, the gasifier technology became almost extinct because of availability of inexpensive fuel. In 1972, first coal gasification combined power plant was built in Germany which produced 183 MW of energy. (History of Power, 2022)

After 1970, gasifiers started getting attention again because now they used feedstock other than coal and wood to produce gas. With world moving towards clean energy and waste recycling, this became a topic of interest. With continuous development, the gasifiers started producing more energy with different kinds of waste materials. Currently there are thousands of small scale and medium scale

gasifiers being run in many countries including India, Sri Lanka, Australia, South Africa etc. Approximately, 24000 MW of electricity is being produced worldwide along with other useful products through gasifiers with an annual growth percentage of 10%. (Domestic and Global Usage of Gasification Technology | Wastes | US EPA, 2022)

The major feedstocks that are being used nowadays for gasification are rice husk, cotton stalk, wood, municipal waste and organic waste of industries.

## Gasification

Gasification is a process that converts organic or fossil-based carbonaceous materials such as wood, coal, biomass at high temperatures ( $>700^{\circ}\text{C}$ ) and low pressure (1-20bar), without combustion, with a controlled amount of oxygen and/or steam into carbon monoxide, hydrogen, and carbon dioxide. It is basically controlled burning of fuel in very controlled quantity of air. This produces a gas which has very useful properties. This gas is called producer gas, syngas, wood gas, and generator gas. The process of gasification is done in a heating chamber which is called a gasifier. The detail of gasifier, its types and working will be explained later in the report.

## Syngas

Syngas is a mixture of gases and is the product of gasification. The mixture of gases which make up syngas are hydrogen, carbon monoxide, and very small quantities of carbon dioxide and methane. Lower heat value of syngas does not exceed  $6\text{MJ}/\text{Nm}^3$ . The composition of syngas is as follow:

Hydrogen 15-20%

Carbon Monoxide 15-20%

Methane 0.5-2%

Carbon dioxide 10-15%

The byproducts of gasification process are tar and charcoal. Syngas can be converted into many useful products such as synthetic natural gas, ammonia, methane, ethanol (El-Nagar and Ghanem, 2022).

## Processes

Gasification is completed in several steps having different operating conditions. Gasification will not take place if these steps are not performed correctly according to their defined conditions and the syngas will not be produced. The details of these processes are as follows:

## **1     Drying**

For gasification to be effective and increasing the efficiency of gasification, the feedstock must have very low moisture content. Therefore, the feedstock is heated to remove the moisture content before it enters the pyrolysis zone. As it is explained in the Figure 2, the process of drying takes place between 100-150 degree centigrade and it is the first step that takes place in a gasifier.

## **2     Pyrolysis**

Pyrolysis is the breaking down of the feedstock by the application of heat into charcoal, gases (CO, CO<sub>2</sub>, H<sub>2</sub>, H<sub>2</sub>O, CH<sub>4</sub>) and tar vapors. This is the major step in gasification as these products of pyrolysis will be going to form syngas later on during burning.

The equation of pyrolysis is as follow:

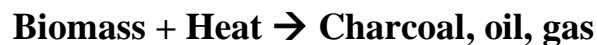


Figure 3 explains all the process and their parameters of the combustion, gasification, pyrolysis.

## **3     Cracking**

Cracking is the process of breaking down of larger molecules into smaller, more combustible molecules. This is important because if we don't do this, then the tar after combustion will take the form of soot and will stick to the walls of internal combustion engine which will reduce its efficiency.

## **4     Combustion**

Combustion is the only net exothermic reaction in the gasification process. It is more complex than pyrolysis or gasification since the biomass must first pyrolyze and then be partially combusted (gasified) before it is fully combusted.





## 5 Reduction

Reduction is the process where the actual syngas is formed by the reaction of the products of pyrolysis and combustion.

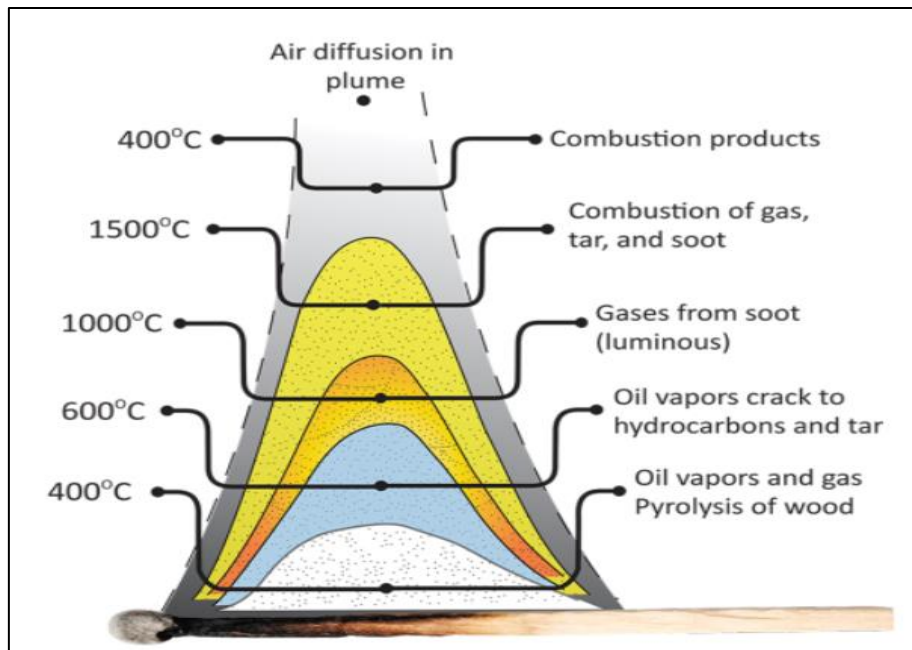
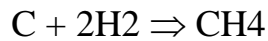
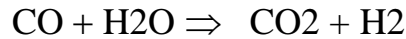
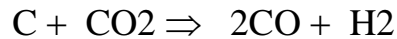
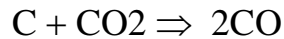


Figure 2: Description of pyrolysis, combustion and gasification (The Five Processes of Gasification – ALL Power Labs, 2022)

### Parameters:

Gasification depends on a number of factors which if not taken into account can spoil our process and results. These parameters are:

### Temperature

Gasification is performed at constant temperature. The temperature zones are defined in Figure 2 and these temperatures are kept constant until the feedstock is completely burnt. Drying takes place between 100-150°C, Pyrolysis take place between 200-500°C, Cracking and combustion takes place between 800-1200°C and Reduction takes place between 650-900°C. (Ramírez Rubio, Sierra and Guerrero, 2022)

## **Process time**

The more the feedstock is kept in the gasification chamber and is allowed to react, more will be the effectiveness and lesser will be the unburnt products.

## **Feedstock**

Feedstock plays a major role in determining the efficiency and effectiveness of gasification process. The factors such as ash content, moisture content, volatile matter, LHV, HHV and fixed carbon determine which feedstock is more suitable for a specific type of gasifier.

## **Reactivity**

The carbonized products' reactivity is influenced by their chemical structure determining the number of active sites, the internal surface area and porosity controlling diffusion speed and the inorganic compounds which might have a catalyst or inhibitor effect.

## **Chemical kinetics**

The physicochemical process occurring during gasification consists of transition from feedstock until being carbonized and its subsequent reduction.

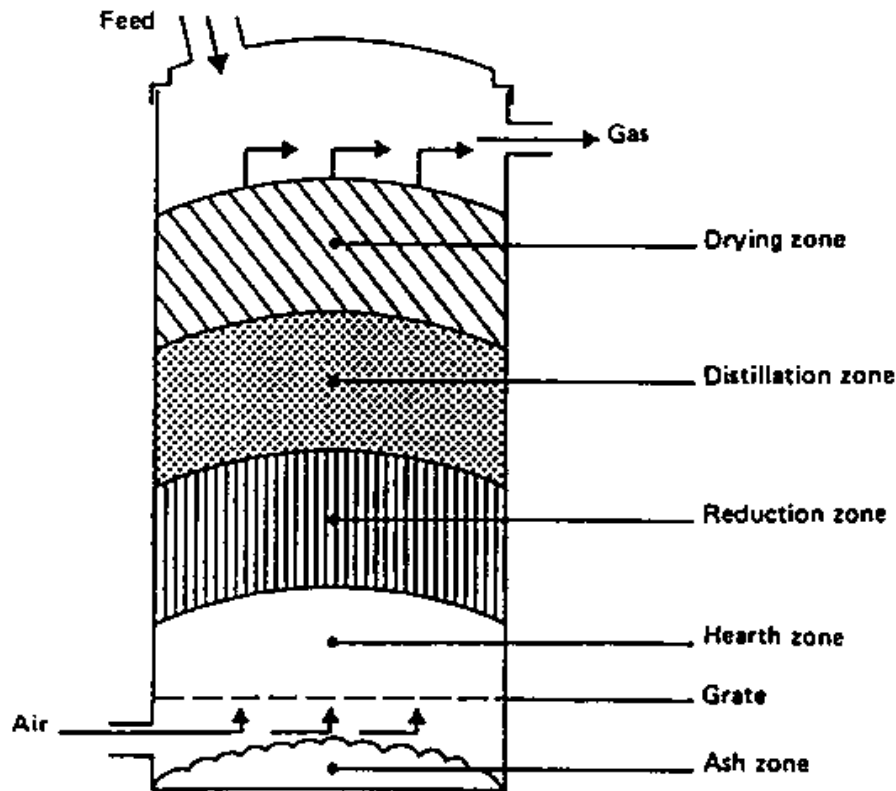
Carbonized product and volatile production are important in a fixed-bed gasifier due to the low heat rate ( $<100^{\circ}\text{C}/\text{min}$ ) and the solids' long residence time. The organic matter's thermal behavior is frequently studied by thermogravimetric analysis (TGA) measuring a sample's weight loss rate regarding time and temperature.

## **TYPES OF GASIFIERS**

### **Updraught or counter current gasifier**

The most established and easiest sort of gasifier is the counter current, or updraught gasifier shown in the figure below. The air admission is at the base and the gas leaves at the top. Close to the mesh at the base the ignition responses happen, which are trailed by decrease responses higher up in the gasifier. In the upper piece of the gasifier, warming and pyrolysis of the feedstock happen

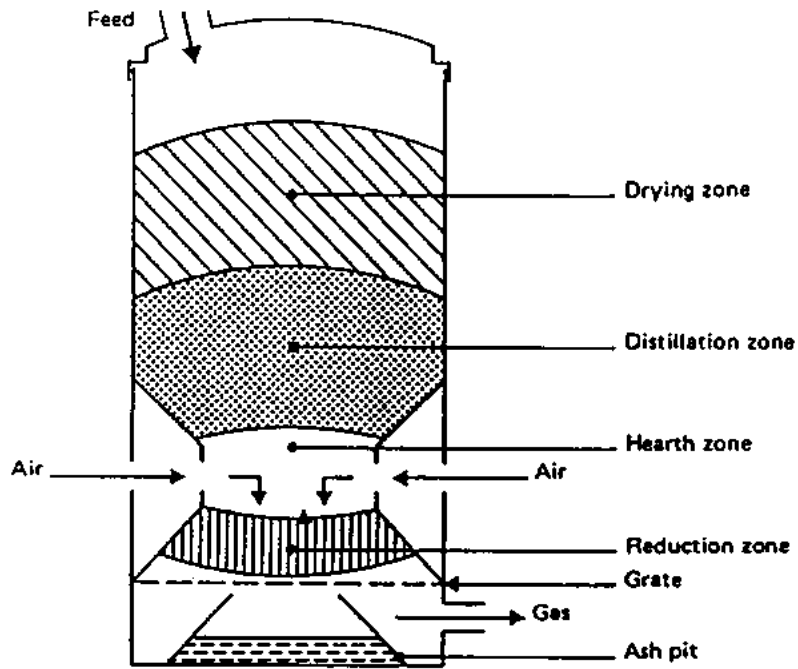
because of hotness move by constrained convection and radiation from the lower zones. The tar and volatiles delivered during this cycle will be conveyed in the gas stream. Remains are taken out from the lower part of the gasifier.



*Fig 4 – Updraft Gasifier:*

### **Downdraught or co-current gasifiers**

An answer to the issue of tar entrainment in the gas stream has been found by planning co-current or downdraught gasifiers, in which essential gasification air is presented at or over the oxidation zone in the gasifier. The maker gas is eliminated at the lower part of the device, so that fuel and gas move in a similar course. On their way down the corrosive and falter refining items from the fuel should go through a shining bed of charcoal and hence are changed over into super durable gases hydrogen, carbon dioxide, carbon monoxide and methane. Contingent upon the temperature of the hot zone and the home season of the hesitate fumes, a complete breakdown of the tar is accomplished.

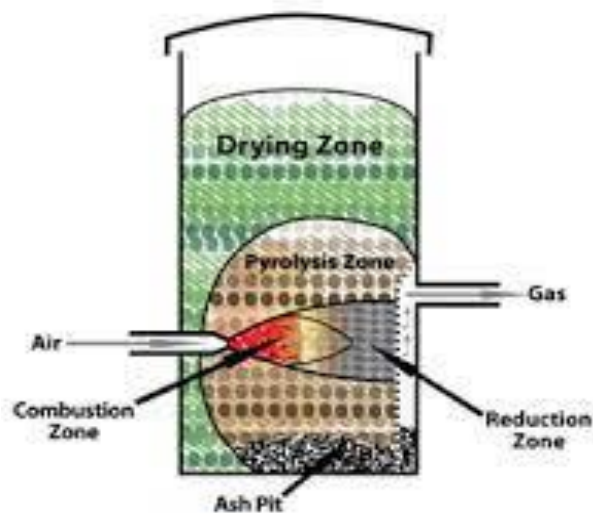


*Fig 5 – Downdraft Gasifier:*

### **Cross-draft gasifier**

Cross-draft gasifiers, schematically delineated in Figure 2.9 are a transformation for the utilization of charcoal. Charcoal gasification brings about extremely elevated temperatures (1500 °C and higher) in the oxidation zone which can prompt material issues. In cross draft gasifiers protection against these elevated temperatures is given by the fuel (charcoal) itself.

## Crossdraft Gasifier

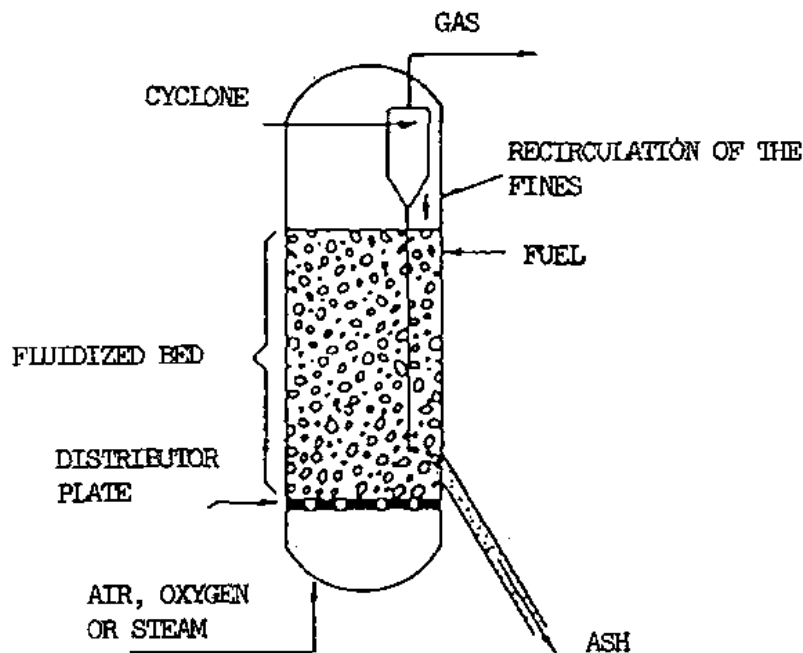


*Fig 6 – Crossdraft Gasifier:*

## Fluidized bed gasifier

The activity of both up and downdraught gasifiers is affected by the morphological, physical, and synthetic properties of the fuel. Issues ordinarily experienced are absence of bunker flow, slagging and outrageous strain drop over the gasifier. A plan approach focusing on the expulsion of the above hardships is the fluidized bed gasifier represented schematically in figure 7.

Air is blown through a bed of strong particles at an adequate speed to keep these in a condition of suspension.



*Fig 7 – Fluidized Bed Gasifier*

## Other types of gasifiers

Various other biomass gasifier frameworks (twofold terminated, entrained bed, liquid shower), which are incompletely side projects from coal gasification innovation, are as of now being worked on. Now and again these frameworks join superfluous refinements and entanglements, in others both the size and complexity of the hardware make close to term application in non-industrial nations far-fetched. Therefore, they are overlooked from this record.

## Processes happening in the down-draft gasifier

In the down-draft gasifier the fuel is presented at the top, the air is typically presented at a few middle levels and the gas is taken out at the base. It is feasible to recognize four separate zones in the gasifier, every one of which is described by one significant stage during the time spent changing the fuel over to an ignitable gas. The cycles in these four zones are analyzed underneath and the plan premise will be talked about in the accompanying segment.

## **Bunker Section (drying zone)**

Solid fuel is brought into the gasifier at the top. It isn't important to utilize complex fuel taking care of gear, because a modest quantity of air seepage can be endured at this spot.

## **Pyrolysis Zone**

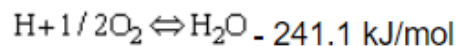
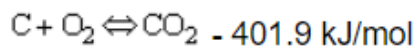
At temperatures above 250°C, the biomass fuel begins pyrolyzing. The subtleties of these pyrolysis responses are not notable, yet one can derive that enormous atom, (for example, cellulose, hemi-cellulose, and lignin) separate into medium size atoms and carbon (scorch) during the warming of the feedstock.

The solids that remain we commonly call charcoal. The gasses and liquids that are released we collectively call tars.

## **Oxidation Zone**

### **Combustion and Cracking**

- 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.



Eq (1,2)

- Cracking is the process of breaking down large complex molecules such as tar into lighter gases by exposure to heat.
- Crucial for the production of clean gas because tar gases condense into tar that will rapidly foul the valves of an engine.

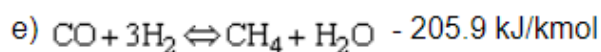
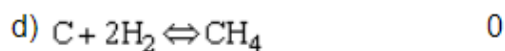
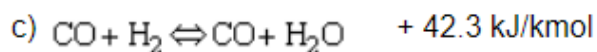
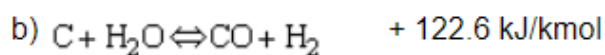
- Cracking is also necessary to ensure proper combustion because complete combustion only occurs when combustible gases thoroughly mix with oxygen.
- During combustion, the high temperatures produced decompose the large tar molecules that pass through the combustion zone.

For the most part two strategies are utilized to acquire an even temperature appropriation:

1. decreasing the cross-sectional region at a specific tallness of the reactor ("throat" idea),
2. spreading the air gulf spouts over the boundary of the decreased cross-sectional region,
3. or then again on the other hand utilizing a focal air gulf with an appropriate showering gadget

### Reduction zone

- Reduction is the process of stripping oxygen atoms off combustion products of hydrocarbon molecules
- Reduction in a gasifier is accomplished by CO<sub>2</sub> or H<sub>2</sub>O across a bed of red-hot charcoal (C).
- The oxygen atoms in CO<sub>2</sub>, H<sub>2</sub>O and O<sub>2</sub> is more attracted to the bond site on the C due to electron affinity, thus no free oxygen can survive.

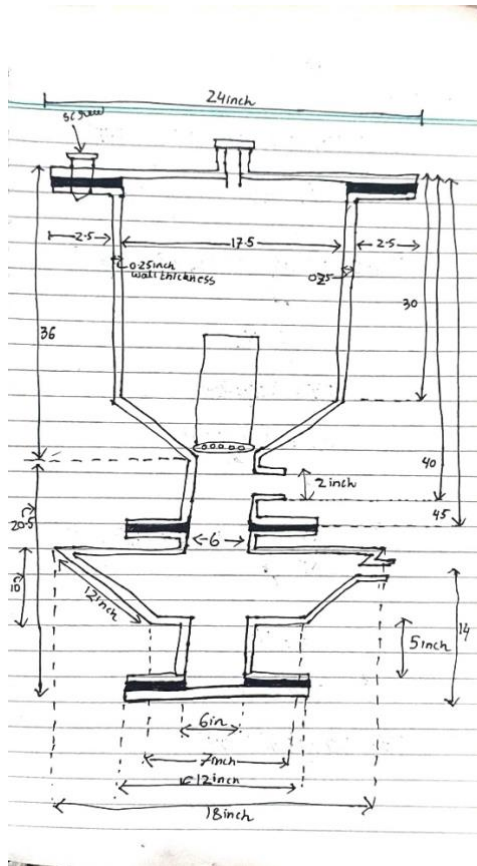


Eq (3,4,5,6,7)

- Through this process, CO<sub>2</sub> is reduced by carbon to produce two CO molecules, and H<sub>2</sub>O is reduced by carbon to produce H<sub>2</sub> and CO.
- Both H<sub>2</sub> and CO are combustible fuel gases, and those fuel gasses can then be piped off to do desired work elsewhere.



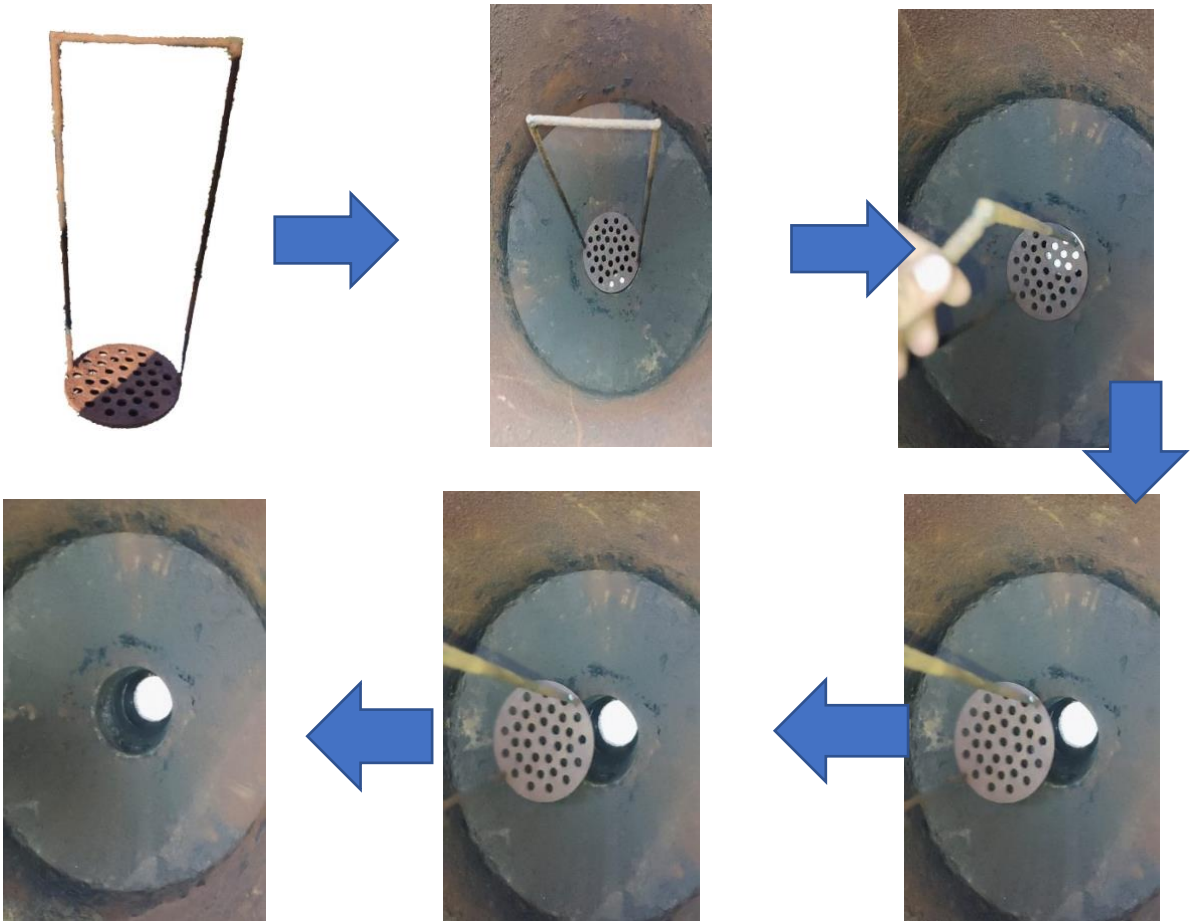
## Construction of the existent model of Gasifier:



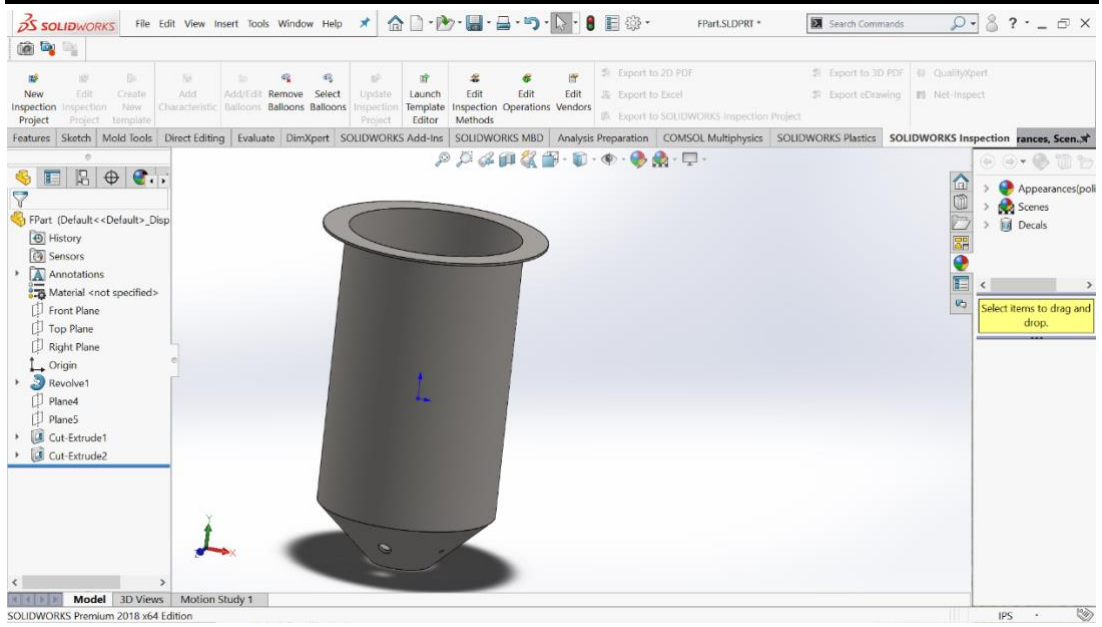
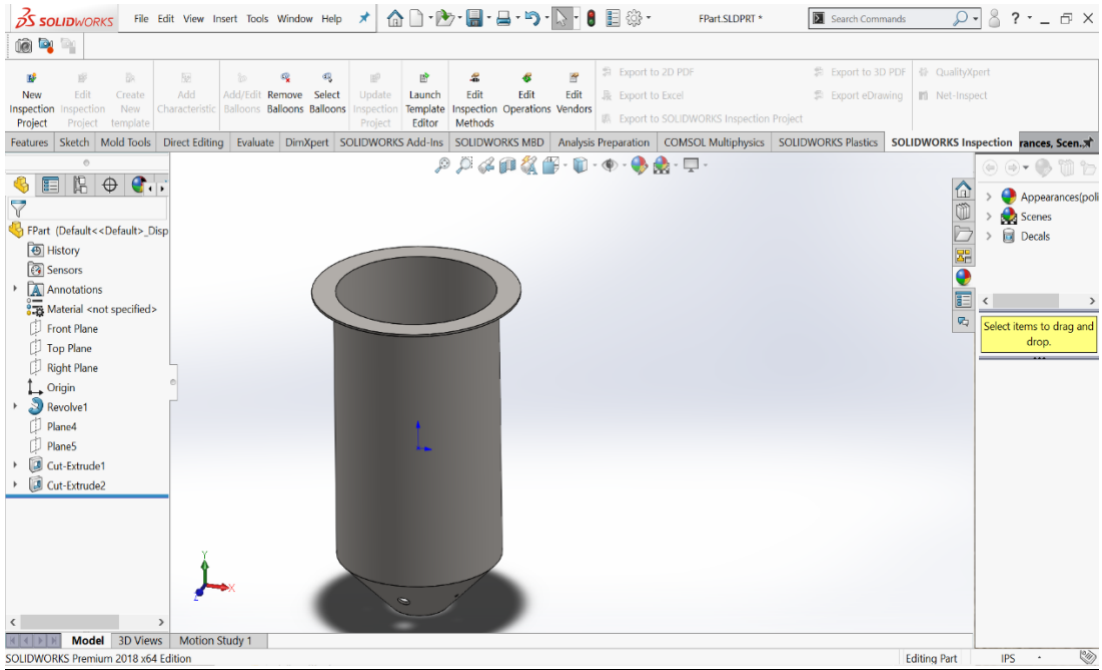
*Detailed Dimensions along with the reactor of gasifier*



*Top lid containing high temperature rubber seal (top view and bottom view)*



*Position of the removable grate in the reactor.*



*Solid Work Model of the reactor*

## Feedstock

The term feedstock is defined as *renewable or biological substances which are either used as a fuel or energy source directly or are converted to some other products to be used as energy source* (Kataki et al., 2015).

For gasifiers, the feedstock can either be coal or a lot of agricultural and forest residues (biomass). Biomass is the general term that can be used for all the organic as well as biological materials. The biomass is rich in elements like oxygen, carbon, hydrogen etc. The human body also converts the energy from the food for sustainability. The use of biological materials as an energy source in the form of heat, food, lighting, and cooking by humans has been used for 400,000 years now. In the beginning the use of biomass was only for cooking and heating purposes but eventually the humans started to process the biomass to make different materials and for building purposes (Susastriawan, Saptoadi and Purnomo, 2017).

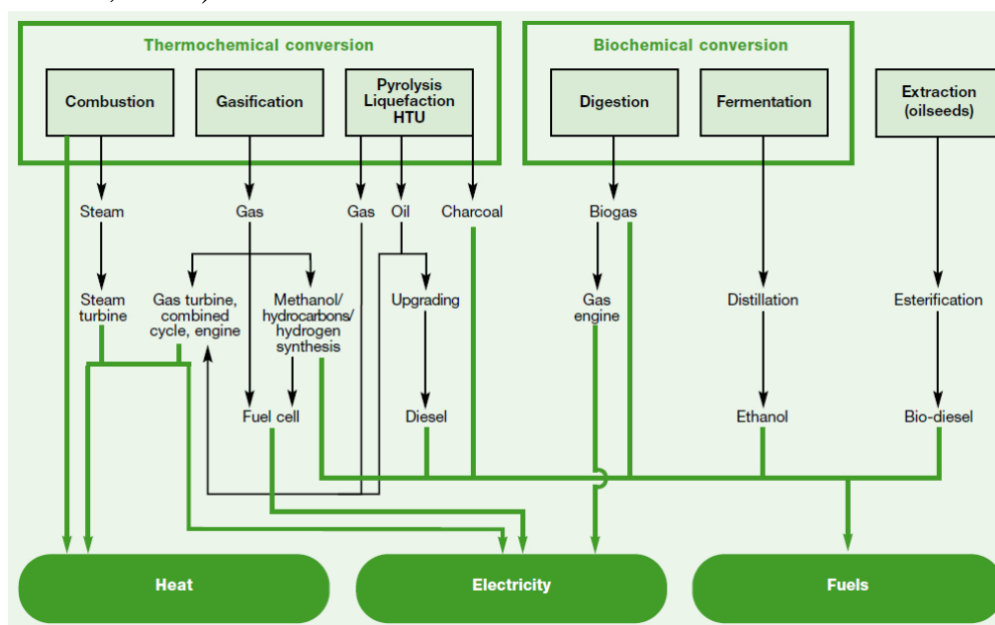


Figure 8: Biomass Energy Harness Methods

. The Figure 8 above, shows some of such methods and the products obtained from them (Roesch, 2011).

There is no doubt that biomass is the most widely available energy source. The projections of 2050 show that, there is an annual potential of 1500 EJ/year of energy from biomass feedstocks. At present, roughly 10% of world's energy i.e., 45EJ/year is provided by the biomass. A detailed breakdown with percentages is being given in the Figure 9.

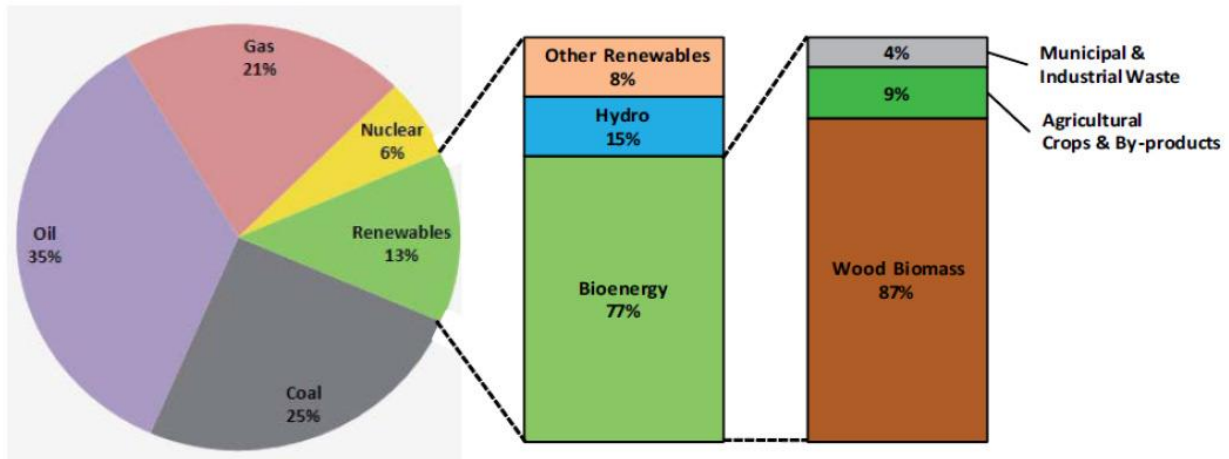


Figure 9: Biomass Source by percentage

### Characteristics of Feedstock:

The quality and properties of synthetic gas produced during gasification depends on the feedstock used. There are several parameters on which the gasification efficiency depends. These parameters include biomass characteristics, the design of gasifier and process parameters. The important biomass characteristics include size, density, composition of biomass, the volatility, fixed carbon, the ash content, and the moisture content. At the same time, the operational parameters include the equivalence ration, the gasification temperatures, and the fuel consumption rate (Ai, Chen and Fu, 2022). The characteristics of the biomass are determined through the different analysis, the major two of which are as follows:

### Ultimate Analysis:

The composition of the biomass is determined through the ultimate analysis. It gives the elemental composition of the sample of biomass as the percent by mass of hydrogen, oxygen, carbon, sulfur, and other key elements. This analysis is done to find out the amount of energy that can be produced from the biomass as compared to the harmful pollutants.

### Carbon, Hydrogen, and Oxygen Composition:

The main elements in a fuel that determine its heating value are carbon, oxygen, and hydrogen. The biomass being organic has greater carbon content (approx. 45%) as compared to hydrogen (approx. 6%) but the heating value of hydrogen is about 7 times higher than that of carbon. Thus, higher hydrogen to carbon ratio is desirable. This will result in lower oxidation state and more release of energy during the oxidation(Onochie, Obanor, Aliu and Igbodaro, 2017).

Similarly, carbon too is very important for methane (CH<sub>4</sub>) production as well as it is main component of sync gas produced as a result of gasification. Lastly, greater oxygen levels in biomass means help in gasification process by reducing the requirement of air or oxygen from outside for gasification.

### **Proximate Analysis:**

The moisture content, volatility, ash content, and the fixed carbon are determined through the proximate analysis.

#### *Moisture Content*

The biomass with high moisture content directly decreases the efficiency of the gasification process as it yields synthetic gas with low calorific value. As a thumb rule, lesser moisture content is desirable because water does not produce energy at all. Typically, biomass with moisture content less than 30% is used in a down draft gasifier. The calorific value of the produce gas decreases due to incomplete pyrolysis during gasification. Actually, some of the heat during pyrolysis is wasted to evaporate the extra water in the biomass. Further, the producer gas from the feedstock with lesser moisture content has more CO and hydrogen content as compared to the one from a feedstock with much higher moisture content. The moisture content can also be reduced by pre-treatment of the fuel (Umesh, Sarsavadiya, Vaja and Mahadeo, 2015).

We can determine the moisture on dry as well as wet basis. The moisture content on dry basis is calculated as:

$$\text{Moisture Content}_{dry} = \frac{x - y}{y} * 100\%$$

The moisture content on wet basis is calculated as:

$$\text{Moisture Content}_{wet} = \frac{x - y}{x} * 100\%$$

Here,

**x:** wet weight and **y:** dry weight

#### *Ash Content:*

Ash content is that mineral content which after combustion of biomass remains oxidized. In addition to that ash also comprises of the unburnt feedstock fuel. The ash content affects the working of the gasifier. The main problem due to



melting of ash is the clinker formation and slagging in the reaction chamber. Excessive ash formation if not attended leads to slagging on high levels which ultimately blocks the reaction chamber completely (Sukarta, Sastrawidana, Ayuni and I, 2018).

The downdraught and updraught gasifiers can be unlisted with high ash content biomass by modifying the grates and using continuously moving or shaking grates. For high ash content feedstocks, the fluidized beds serve the purpose. The ash content can be calculated using the muffle furnace as:

$$\% \text{ Ash Content} = \frac{X}{g} * 100\%$$

Here, X: weight of ash and g: weight of sample

#### *Fixed Carbon and Volatile Matter:*

The non-volatile incendiary parts of the fuel are termed as the fixed carbon content of the fuel. If the carbon in feedstock is volatile, then it is called as volatile matter content of fuel. If the volatile matter is more than it means that the carbon can easily break its bonds and form new ones to make the synthetic gas. On the other hand, the higher fixed carbon content will make it difficult to break the carbon bonds and eventually higher temperatures, more retention time, and some other complex processes.

#### *Calorific Value:*

The heating value of the biomass feedstock also plays an important role in their selection for gasification. The two parameters; higher heating value (HHV) and lower heating value (LLV) are used to measure the overall energy content of the feedstock. The higher heating value is the measure of the amount of energy released when the fuel is burnt or combusted and is called as the gross calorific value. The lower heating value is obtained the heat of vaporization of water from the higher heating value or simply the LHV differs from HHV by an amount equal to heat of vaporization of water. Thus, greater HHV is desired as it will produce more energy.

#### *Feedstocks in Pakistan*

The true potential of the resources of Pakistan for energy production has not been explored all at. The energy demand in Pakistan is continuously on the rise with 5-7% increase per year. In Pakistan only 3.1% of the total energy needs are met through renewable energy sources and no work is being done in the field of gasification (Mahmood et al., 2021).

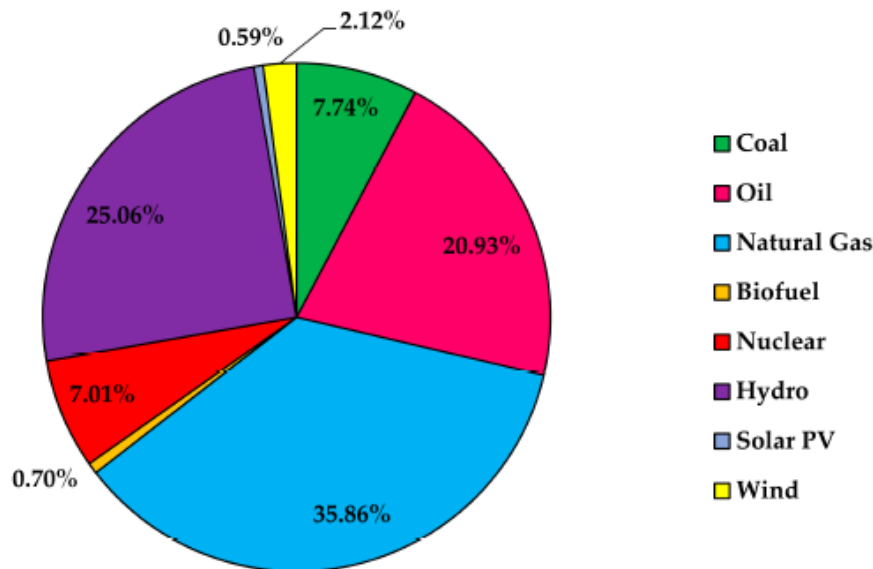


Figure 10: Energy Production from different sources in Pakistan (NEPRA 2020)

The potential biomass sources in Pakistan include crop residues, animal wastes, municipal wastes, forest waste etc. All of these sources collectively make about 230 billion tons of biomass on annual basis (Mahmood et al., 2021). Therefore, there a high potential of energy production from biomass in Pakistan which is also shown in the figure below:

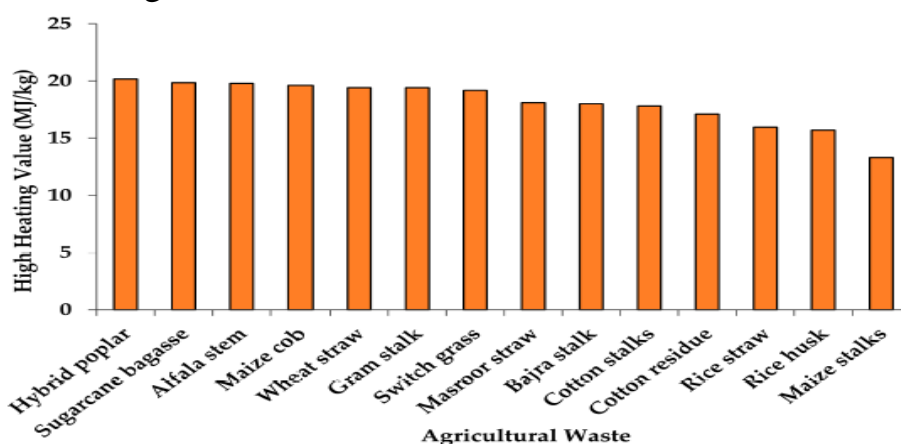


Figure 11: Thermal Energy Potential from Agricultural Waste of Pakistan

Pakistan has favorable weather and conditions for production of energy from the energy crops, such as maze, sunflowers, rice husk, alfalfa, cotton stalk and wood pellets etc (Saghir et al., 2019).



Feedstock	Biogas Yield (m <sup>3</sup> /ha)	Biogas Potential (L/kg VS)
Maize	12,000–15,830	520–602
Sorghum bicolor	5300–8200	563–586
Sweet Sorghum	9478	721
Jerusalem Artichoke	5105	463
Amaranth	3641	441
Sugar beet	5823	649
Sorghum sudanense	5835	415
Potato	2280	280
Sunflower	5750	495
Alfalfa	3965	410
Barley	2030	360

*Table 1: Biogas yield Potential*

Biomass	Proximate Analysis (wt %, dry basis)			Ultimate Analysis (wt %, dry basis)					
	Ash	Volatile Matter	Fixed Carbon	C	H	N	O	Cl	S
Hazelnut shells	0.77	62.70	24.08	46.76	5.76	0.22	45.83	0.76	0.67
Olive pruning	3.67	82.35	13.98	47.50	6.00	1.06	43.66	1.74	0.04
Vine pruning	2.62	80.84	16.54	50.84	5.82	0.88	40.08	1.87	0.05
Hazelnut pruning	3.20	79.60	17.20	47.40	5.23	0.70	43.50	3.14	0.03
Olive pomace	4	77	19	51	6	0.30	38	0.02	0.02
Corn	7	69.5	15	47.30	5.50	0.90	45.3	0.5	0.5
Wheat	11	66.3	21.4	48.86	6.80	0.59	43.4	0.15	0.2

*Table 2: Proximate and Ultimate Analysis of Biomass*

## METHODOLOGY:

Our methodology has been divided into five different phases that are described below:

1. Extensive Literature Review.
2. Use of existent, non-functional and Prototype.
3. Addition of Components to Modify and Operate the Gasifier.
4. Calculations of Operational parameters of Gasifier.
5. Experimentation analysis with the use of selected feedstock.

### Extensive Literature Review:

One of the most crucial and important part of our project was to go through the literature review to understand and contemplate the working of a general gasifier, its types, mechanism, and its operational parameters. A comprehensive yet detailed analysis of this part has been done and presented in the upper section of report.

### Existent Prototype:

The existent prototype (hardware) shown in the Fig 8 consists of combination of different parts that when assembled makes a downdraft gasifier.

### Hopper:

The cylindrical part on the top is known as hopper. Hopper is the part where all the biomass is fed and stored that is further used and utilized to burn the biomass. Hopper is the home for three of the gasification phases: Drying, Pyrolysis, and Combustion. The hopper in our case has dimensions that can store and operate with a large quantity of biomass, therefore increasing the batch time for each cycle and generating more power as compared to the small ones. The biomass is fed from the lid of hopper and is closed when the hopper is full.

**Throat:**

At the bottom of hopper comes the throat of gasifier which can also be termed as the “heart of gasifier”. All the gasification is initiated in this region, making it the most crucial part of the process. The combustion zone that is responsible for initiating and carrying out this process is formed inside throat. When the biomass is heated initially, the biomass starts burning in the presence of limited air/oxygen, thus resulting in syngas.

**Reduction Chamber:**

The bottom chamber of the model is the reduction chamber where the reduction zone of gasifier is established. The charcoal from the pyrolysis reacts with the combustion gases ( $\text{CO}_2$  &  $\text{H}_2\text{O}$ ) from the combustion zone and form  $\text{CO}$  and  $\text{H}_2$ .

**Gas Exit:**

The port at the bottom is the exit port for the gas produced. It is the point where the produced gas is extracted out of the system and fed for further cleaning phases.

**Structure:**

The structure in blue metal is made to support and mobilize the gasifier for ease in mobility and working of the process. Tires are used for transportation purposes.



*Fig 11 - Existent Model/Hardware of Downdraft Gasifier:*

### Additional Components/Modifications:

The existent prototype that we planned to utilize and modify in our project wasn't operational and required a lot of modifications in terms of component and operation. Therefore, a list of devices was selected to be added to the design of overall gasifier that would help it in making it functional and would result in syngas production. Following are the components/ devices added to our system.

### **Suction Blower:**

Suction blower is used to suck the gas once it is produced. It is continuously operating so that the gas doesn't go in upward direction rather it moves downwards towards the lower exit of gasifier. As the name suggests, it serves the sole purpose of gas suction as shown in the Fig 9.



*Fig 12 – Suction Blower:*

### **Gas Filter:**

Gas Filter is added after the exit gas port that serves the cleaning purpose for the produced gas. When the gas is produced, impurities like char and solid tar accompany them while it is being sucked. To tackle this issue, a gas filter with dry corn and coal inside is used. The gas enters the filter from beneath and exit from the top. During this time, the impurities get trapped inside making the gas at the exit a clean and safe gas. The syngas then is sucked and stored for further uses.

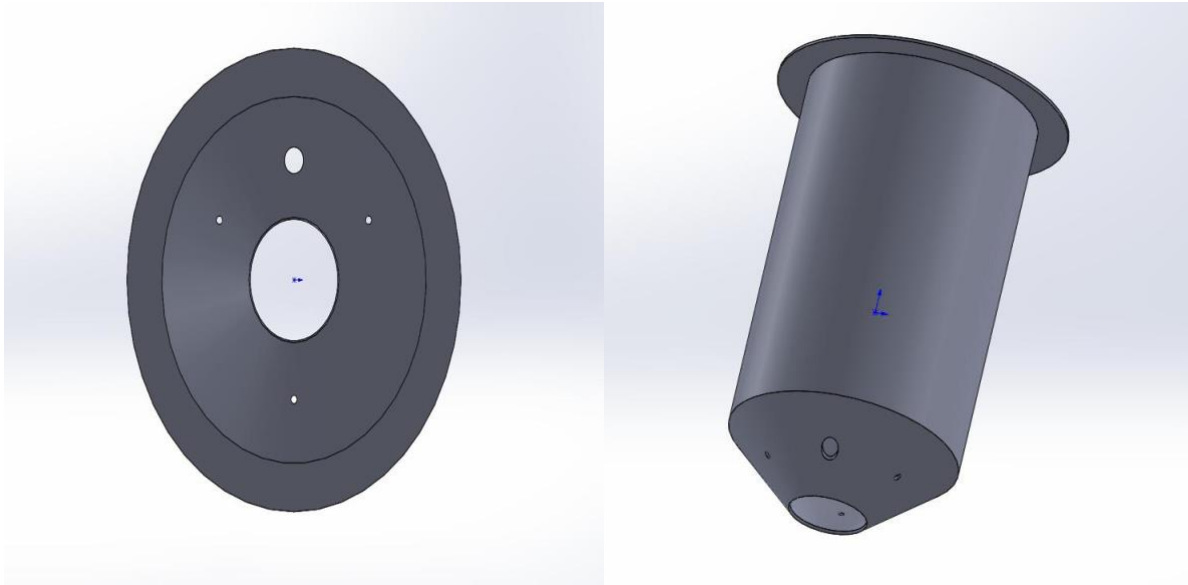


*Fig 13 – Gas Filter:*

### **Air Nozzle/Ignition Port:**

One of the most important additions to the design was to add the nozzles for air intake. As the process is carried out with incomplete combustion for which the amount of air must be regulated/controlled. Therefore, three air nozzles are added to the design along with the ignition port. The required calculations were done, and nozzle sizes and their position were then finalized.

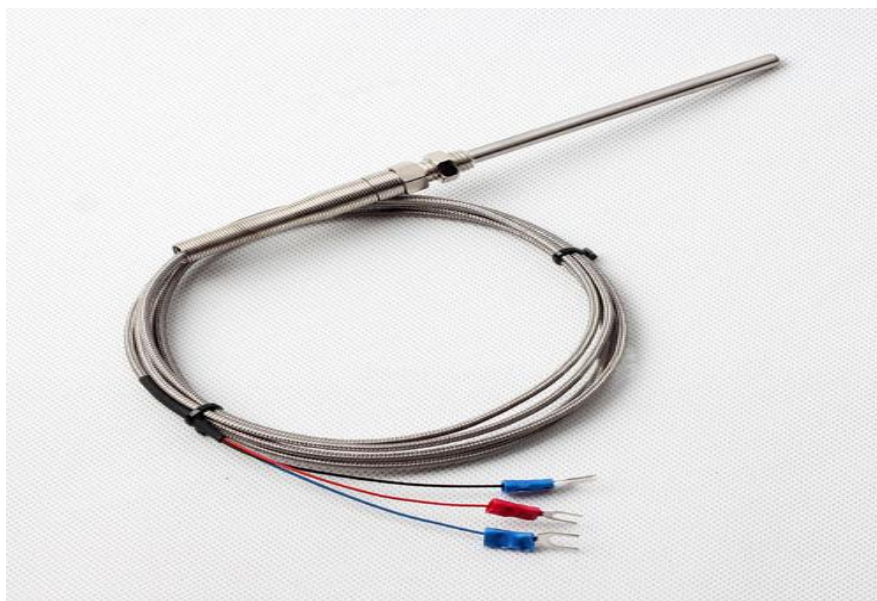




*Fig 14 – Air Nozzles/Ignition Port:*

### **Thermocouple:**

K-Type thermocouple is added to the combustion chamber of gasifier. The range of these type of thermocouple is extremely wide and can measure temperature up to 1200 °C . When the temperature of combustion zone reaches 600 °C, the production of gas gets started and the blower starts sucking the syngas.



*Fig 15 – Thermocouple:*

### **Pressure Gauge /Safety Valve:**

A pressure gauge and a safety valve are also added to make sure that the pressure doesn't exceed to concerning height and is controlled in time. For this purpose, a safety valve is used that serves as a savior when the pressure inside exceeds the desired pressure limits.



*Fig 16 – Safety Valve/Pressure Gauge:*

### **Blower Injector:**

The air through the nozzles is supplied through the blower. As the amount of air has to be strictly monitored, a variable speed blower of cfm 15 is used. The speed of the blower can be adjusted according to our desired air flow rate. The air flow rate calculated lies inside the range that this blower offers.



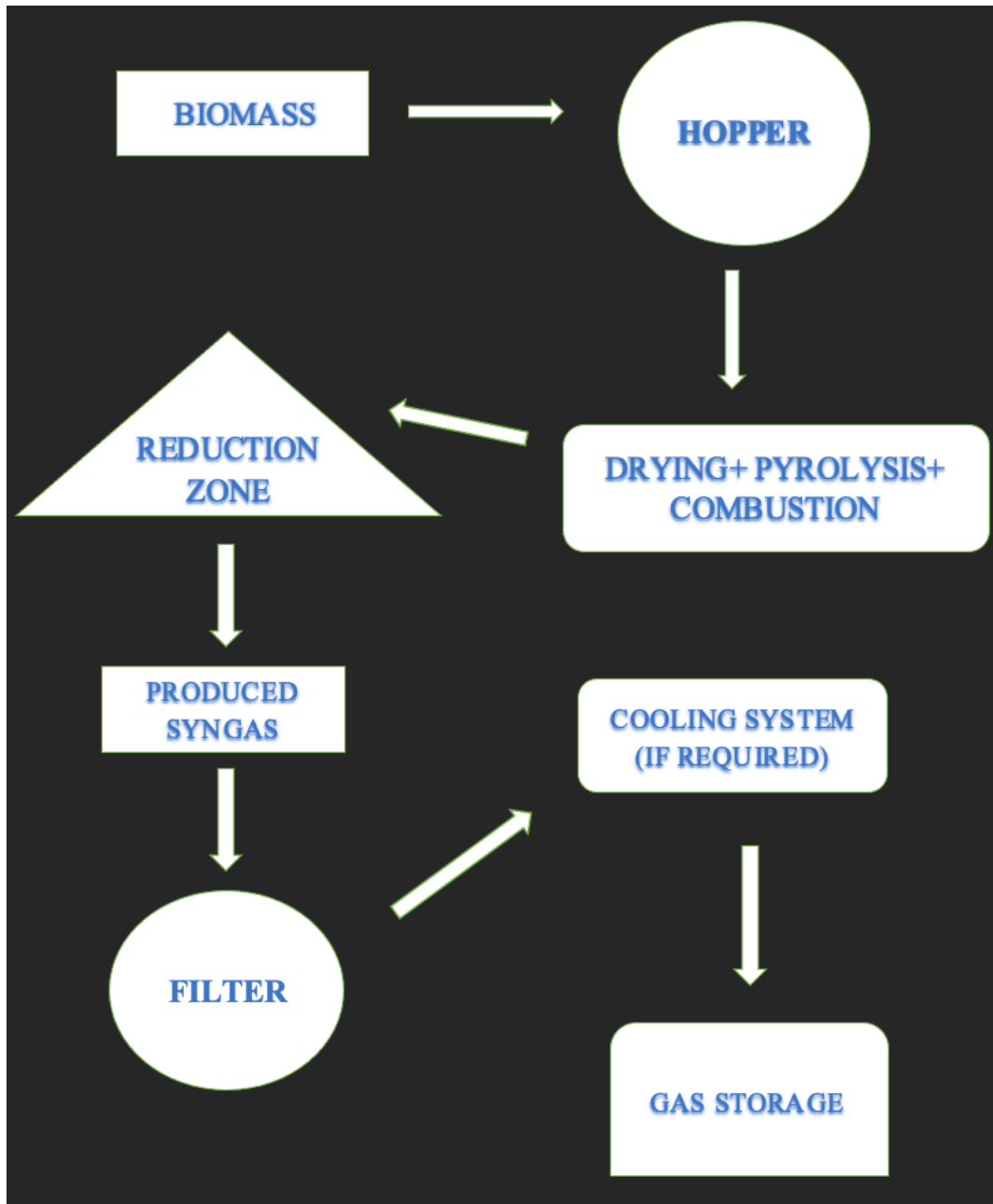


*Fig 17 – Blower Injector:*

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### DESIRED PROCESS:

The chosen biomass will be used as feedstock and fed into the hopper. After being fed, it will go through the processes of gasification i.e drying, pyrolysis, reduction and combustion. The produced gas will be collected from beneath the chamber and made to flow through a gas filter that will eliminate all the entrapped particles and impurities from it. The cooling system would cool down the gas and it would be stored for analysis via a gas bag.



## CALCULATIONS:

Table 3 – Parameters Used in Calculations:

Gasifier Type	Downdraft
Biomass Type	Wood Pellets
Calorific Value	19.85 MJ/Kg
Density	225kg/M <sup>3</sup>
Efficiency	60%
Specific Gasification Rate	2000kg/hrm <sup>2</sup>
Relative Tube Capacity	250kg/m <sup>2</sup> hr
Equivalence Ratio	0.4
Power Output	?
Lower Heating Value of Syngas	4 MJ/Nm <sup>3</sup>

### Specific Gasification Rate:

$$SGR = 2000 \text{ kg/hrm}^2$$

$$SGR = \frac{SG}{A_{th}} \quad 1$$

SG = Specific Gasification, A<sub>th</sub> = Area of throat, D<sub>th</sub> = Diameter of Throat = 0.1524 m

### Specification Gasification:

$$SG = 2000 \times \frac{\pi}{4} \times 0.1524 \quad 2$$

$$SG = 36.46 \frac{m^3}{hr}$$

### Power Generated:

$$SG = \frac{Power}{LHV} \quad 3$$

$$Power = \frac{36.46 \times 4 \times 10^3}{3600}$$

$$Power = 40.52 \text{ KW}$$

Fuel Consumption Rate:

$$FCR = \frac{P}{CV \times \eta} \quad 4$$

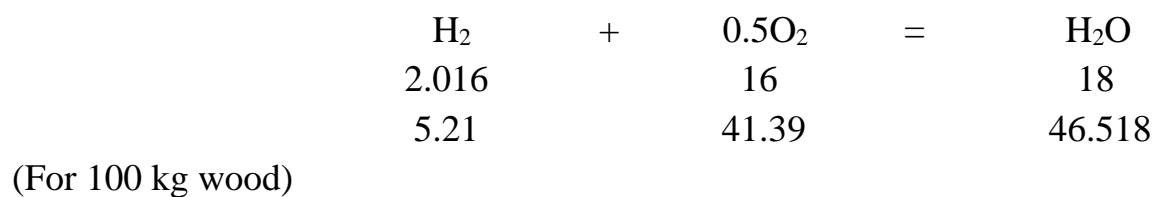
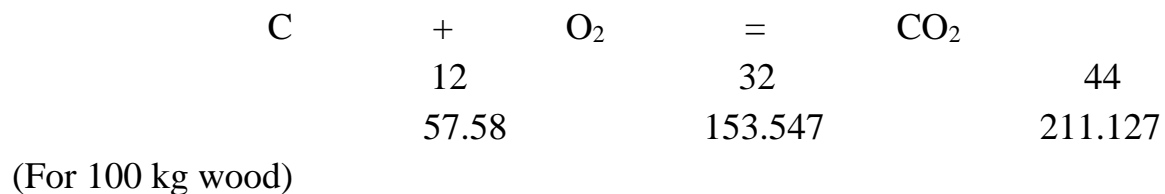
$$FCR = \frac{40 \times 3600}{19.85 \times 0.6 \times 1000}$$

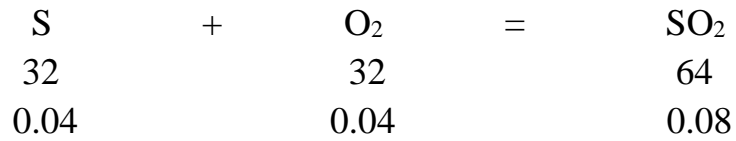
$$FCR = 12.09 \frac{kg}{hr}$$

Air Flow Rate:

Constituents	% By Weight
Carbon	57.54
Hydrogen	5.21
Oxygen	37.10
Nitrogen	0.11
Sulphur	0.04

Stoichiometric Air Requirement:





(For 100 kg wood)

Total theoretical O<sub>2</sub> required,

$$\text{Theoretical O}_2 = 153.386 + 41.349 + 0.04 - 37.10$$

$$(\text{O}_2)_{\text{theoretical}} = 157.836 \text{ kg} \quad (\text{For } 100\text{kg of wood})$$

$$(\text{O}_2)_{\text{theoretical}} = 15.7836 \text{ kg} \quad (\text{For } 1\text{kg of wood})$$

Amount of air required,

$$(\mathbf{m_a})_{\text{theoretical}} = \mathbf{6.861 \text{ kg}}$$

$$\text{Stoichiometric A/F ratio} = 6.861$$

Actual A/F Ratio:

$$\text{Equivalence Ratio} = \frac{\text{Actual A/F}}{\text{Stoichiometric } \frac{A}{F}}$$

$$\text{Actual } \frac{A}{F} = 6.861 \times 0.4$$

$$\text{Actual } \frac{A}{F} = 2.7444$$

Actual mass of air,

$$\mathbf{m_a/m_f = 2.74444}$$

$$m_a = 2.7444 \times 12.09$$

$$(\mathbf{m_a})_{\text{actual}} = \mathbf{33.179 \text{ kg/hr}}$$

Volume Flow Rate (Air):

$$V/t = \frac{m/t \times R \times T}{P}$$

$$V/t = \frac{33.179 \times 287 \times 273}{101325}$$

$$\frac{V}{t} = 0.427 \text{ cbm}$$

$$\frac{V}{t} = 15.09 \text{ cfm}$$

Height of Air Nozzle:

$$\mathbf{h/d_t = 0.9} \quad (\text{FAO 1986,}$$

Accepted Ratio)

$$h = 0.9 \times 0.15$$

$$h = 0.135 \text{ m}$$

(above throat)

Diameter of Nozzle:

**Total Nozzle Area(A) × Vb = Air Flow Rate**

$$\text{Total Nozzle Area} = \frac{7.125 \times 10^{-3}}{25}$$

$$A = 2.85 \times 10^{-4} \text{ m}^2$$

$$\text{Diameter of Nozzle} = d_n = \sqrt{\frac{A \times 4}{N \times \pi}}$$

$$d_n = 0.0109 \text{ m}$$

$$d_n = 0.429 \text{ in}$$


---

## RESULTS AND DISCUSSION:

Syngas, or synthesis gas, is a fuel gas mixture consisting primarily of hydrogen, carbon monoxide, and very often some carbon dioxide. The name comes from its use as intermediates in creating synthetic natural gas (SNG) and for producing ammonia or methanol. Syngas is combustible and can be used as a fuel of internal combustion engines. The chemical composition of syngas varies based on the raw materials and the processes. Syngas produced by coal gasification generally is a mixture of 30 to 60% carbon monoxide, 25 to 30% hydrogen, 5 to 15% carbon dioxide, and 0 to 5% methane. It also contains lesser amount of other gases.

The main reaction that produces syngas, steam reforming, is an endothermic reaction with 206 kJ/mol methane needed for conversion. The first reaction, between incandescent coke and steam, is strongly endothermic, producing carbon monoxide (CO), and hydrogen H. When the coke bed has cooled to a temperature at which the endothermic reaction can no longer proceed, the steam is then replaced by a blast of air. The second and third reactions then take place, producing an exothermic reaction—forming initially carbon dioxide and raising the temperature of the coke bed—followed by the second endothermic reaction, in which the latter is converted to carbon monoxide, CO.

The overall reaction is exothermic, forming "producer gas" (older terminology). Steam can then be re-injected, then air etc., to give an endless series of cycles until the coke is finally consumed. Producer gas has a much lower energy value, relative to water gas, due primarily to dilution with atmospheric nitrogen. Pure oxygen can be substituted for air to avoid the dilution effect, producing gas of much higher calorific value. When used as an intermediate in the large-scale, industrial synthesis of hydrogen (principally used in the production of ammonia), it is also produced from natural gas.

The sample of produced gas was taken and stored after 3 hours of start of gasifier via a gas bag and sent for Gas Chromatography. Gas chromatography is a term used to describe the group of analytical separation techniques used to analyze volatile substances in the gas phase. In gas chromatography, the components of a sample are dissolved in a solvent and vaporized in order to separate the analytes by distributing the sample between two phases: a stationary phase and a mobile phase. The mobile phase is a chemically inert gas

that serves to carry the molecules of the analyte through the heated column. Gas chromatography is one of the sole forms of chromatography that does not utilize the mobile phase for interacting with the analyte. The stationary phase is either a solid adsorbant, termed gas-solid chromatography (GSC), or a liquid on an inert support, termed gas-liquid chromatography (GLC).

A sample port is necessary for introducing the sample at the head of the column. Modern injection techniques often employ the use of heated sample ports through which the sample can be injected and vaporized in a near simultaneous fashion. A calibrated microsyringe is used to deliver a sample volume in the range of a few microliters through a rubber septum and into the vaporization chamber. Most separations require only a small fraction of the initial sample volume and a sample splitter is used to direct excess sample to waste. Commercial gas chromatographs often allow for both split and splitless injections when alternating between packed columns and capillary columns.

The vaporization chamber is typically heated 50 °C above the lowest boiling point of the sample and subsequently mixed with the carrier gas to transport the sample into the column. The carrier gas plays an important role, and varies in the GC used. Carrier gas must be dry, free of oxygen and chemically inert mobile-phase employed in gas chromatography. Helium is most commonly used because it is safer than, but comparable to hydrogen in efficiency, has a larger range of flow rates and is compatible with many detectors. Nitrogen, argon, and hydrogen are also used depending upon the desired performance and the detector being used. Both hydrogen and helium, which are commonly used on most traditional detectors such as Flame Ionization(FID), thermal conductivity (TCD) and Electron capture (ECD), provide a shorter analysis time and lower elution temperatures of the sample due to higher flow rates and low molecular weight.

For instance, hydrogen or helium as the carrier gas gives the highest sensitivity with TCD because the difference in thermal conductivity between the organic vapor and hydrogen/helium is greater than other carrier gas. Other detectors such as mass spectroscopy, uses nitrogen or argon which has a much better advantage than hydrogen or helium due to their higher molecular weights, in which improve vacuum pump efficiency.

The results of Gas Chromatography are shown below in Fig 18:



## Sample Information

Sample Name : SMME-Gasifier-24-May Sample ID : SMME-Gasifier-24-May

Injection Volume : 1  
Data File : 24-May-2022.gcd

## Chromatogram

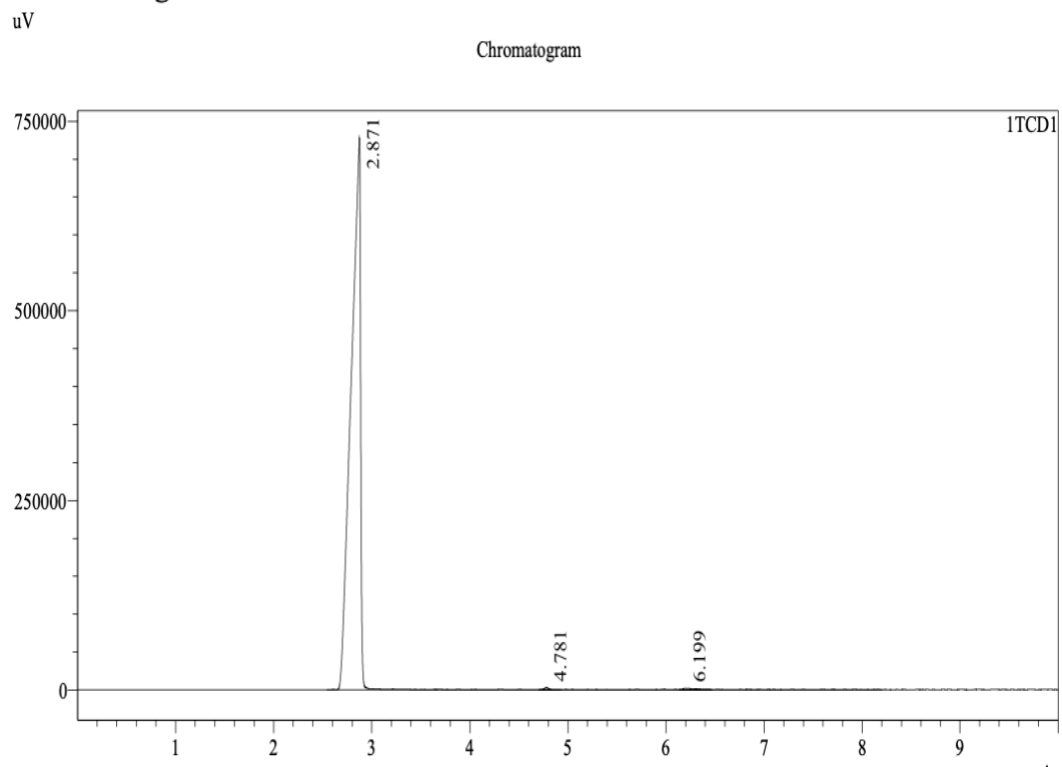


Fig 18- Results of Gas Chromatography on collected sample

# Peak Table

## Peak Table

TCD1

Peak#	Ret. Time	Area	Height	Conc.	Unit	Name
1	2.871	4827902	712356	56.805	%	Hydrogen
2	4.781	9061	2567	1.339	%	Methane
3	6.199	18345	1862	27.280	%	Carbon Monoxide
Total		4855308	716785			

---

## CONCLUSION AND RECOMMENDATIONS:

Biomass is considered to be a promising source of renewable energy. It has a lot of advantages as compared to the traditional fuel types. Biomass is a carbon neutral fuel that limits the emissions of carbon dioxide, making it an environment friendly. Gasification, most simply, can be thought of incomplete or choked combustion. It is occurred when solid fuels like coal or wood are burned without complete air or oxygen that is required to complete the combustion.

The whole process is divided into five thermal processes that are discrete and play their own roles named as Drying, Pyrolysis, Cracking, Combustion, and Reduction. All of these processes are specific in nature and need to be performed in order to produce syngas. Gasification is a process that converts organic or fossil-based carbonaceous materials such as wood, coal, biomass at high temperatures ( $>700^{\circ}\text{C}$ ) and low pressure (1-20bar), without combustion, with a controlled amount of oxygen and/or steam into carbon monoxide, hydrogen, and carbon dioxide.

It is basically controlled burning of fuel in very controlled quantity of air. This produces a gas which has very useful properties. This gas is called producer gas, syngas, wood gas, and generator gas. The process of gasification is done in a heating chamber which is called a gasifier. The choice of gasifier was the downdraft gasifier that helped us in getting syngas on a smaller scale that is both environment friendly and effective.

The maker gas is eliminated at the lower part of the device, so that fuel and gas move in a similar course. On their way down the corrosive and falter refining items from the fuel should go through a shining bed of charcoal and hence are changed over into super durable gases hydrogen, carbon dioxide, carbon monoxide and methane. Contingent upon the temperature of the hot zone and the home season of the hesitate fumes, a complete breakdown of the tar is accomplished.

The existent prototype that we planned to utilize and modify in our project wasn't operational and required a lot of modifications in terms of component

and operation. Therefore, a list of devices was selected to be added to the design of overall gasifier that would help it in making it functional and would result in syngas production. Following are the components/ devices added to our system. These components included blowers to suck and give inlet air to the system, thermocouple for the temperature measurement, a pressure gauge, and a gas filter before it was started. These components helped us in extracting syngas properly. Syngas after getting produced was collected in gas bags for further evaluation and use for household gas as well as industrial production of energy and electricity.

There were certain limitations in our project that could be tackled and replaced with more efficient techniques and processes. There should be a conveyor type mechanism for feeding the biomass into the hopper. The lid of the hopper is quite heavy and is difficult to open once the process gets started, it could be replaced by some simpler and lighter alternative. The mechanism doesn't include auto-ignition that could be a great addition in the process for igniting the biomass initially. Moreover, the system should be efficient for variety of biomass or atleast for a combination of two to three different types of biomass.

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