DEVELOPMENT OF UPDRAFT GASIFIER AND PERFORMANCE ANALYSIS FOR DIFFERENT TYPES OF BIOMASS MATERIALS

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ABSTRACT

Traditional fossil fuels such as coal, gas and oil are still major candidates to fulfill the energy requirement but their depletion at sharp rate due to increase in demand is at alarming condition. High prices and environmental pollution issues associated with fossil fuels has diverted thefocus of the world to find out the new energy roots. Biomass is one of energy candidates, environment friendly, which can be utilized to generate heat and power. Biomass can be converted into useful products by thermochemical process such as gasification.

This study focuses on to design and development of pilot scale updraft gasifier with gas cleaning unit. Performance analysis in terms of producer gas composition, LHV of producer gas, A/G,G/F, gasifier efficiency and gasification efficiency for different biomass materials at different air flow with and without the packing plate was studied. Other main objective was to find out energy potential of mango pit shell as new biomass material and its comparison with coconut shell, ginisyria (*Gliricidia sepium*) and a mixture of 50%, 25%, 25% coconut shell, mango pit shell and *Gliricidia sepium* respectively as an arbitrary selection.

Bench scale updraft gasifier was designed and fabricated. Elemental analysis for each biomass was performed in laboratory to find out the properties such as moisture contents, ash contents, volatile matters etc. Reactor was operated successfully, producer gas and other useful byproducts was obtained. Producer gas was analyzed for compositional analysis as major product and reactors performance parameters was calculated.

It has been observed that biomass we utilized contains the sufficient energy potential. In case of without packing plate at ER of 0.2 LHV (MJ/Nm^3) of producer gas was 4.40, 3.35, 4.20, 3.14 for coconut shell, mango pit shell, ginisyria and mixture respectively. When air flow rate increased, ER increased up to 0.25 it was observed that LHV of producer gas has been decreased. With packing plate experiments it has been found that LHV of producer gas at ER of 0.2 is 4.02, 3.29, 3.70, and 3.21 for coconut shell, mango pit shell, ginisyria and mixture respectively. In packing plate case as well with increase of air flow decrease in LHV of producer gas was observed. Collectively without packing plate results obtained are good as compare to with packing plate case. Gasifier thermal efficiency for different biomass has been found in the range of assumed designed value which was 70%.

Bio-char and black condensate was obtained as valuable by products which can be utilized for different applications. Mango pit shell which is thrown as waste can be utilized as biomass to generate the heat and fulfill the respective industry energy demand especially juice industry. Results without packing plate were found good rather than with packing plate.

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ACRONYAMS

HHV: Higher heating value

HHV_f : Higher Heating value of fuel

LHV: Lower heating value

FCR: Fuel Consumption rate

VM: Volatile Matters

FC: Fixed Carbon

ER: Equivalence ratio

SGR: Specific Gasification rate

ft: feet (units)

mm: millimeter (units)

A/G: Air to gas ratio

G/F: Gas to fuel ratio

GHG: Green House Gases

CHAPTER-1: INTRODUCTION

1.1 Biomass Energy

The word biomass is achieving popularity in the field of energy in world,because of its characteristics to produce valuable products such as energy and biofuels which are rapidly growing to compete with fossil fuels in market. From last few years increasing trend has been observed in use of biomass especially in developed countries however now it’s getting attention in developing regions as well.Biomass is carbon material environmental friendly fuel, competitive candidate in term of price and quality with respect to traditional fossil fuels. Biomass has no commercial value due to various constraints such as lack of availability of raw material, handling and storage difficulty, technologies available and less awareness. Even though researchers are struggling in improvement of technologies to convert biomass into useful energy,it will replace fossil fuels in near future. Depletion of fossil fuels at a sharp rate and its harmful impact on environment forced the world towards new energy sources to achieve the sustainability. It is estimated that oil, gas and coal will last for 37, 45, 60 years respectively[1] and after 2030 it is expected that world will completely change their roots to biomass[2].

1.2 Role of biomass and gasification

One biomass energy based system, which has been proven reliable and had been extensively used for transportation and on farm systems during World War II, is wood or biomass gasification[3].Biomass such as wood is commonly used for heating application at domestic level since long time ago. Still in Asia and many developing countries wood is the major source of fuel for thermal general supply. In the gasification process, producer gas is generated and it can be used for high temperature thermal requirements. Emission of biomass combustion can be mitigated by this process. Biomass was found to be a considerable candidate in energy sector which can be converted by suitable techniques into solid, liquid and gaseous fuels. Current development in biomass sector is finding the maximum available roots and has been found that agricultural, domestic, commercial and industrial sectors have large potential in bioenergy sector. Asian region is very rich in agricultural sector and large quantity of agricultural waste biomass can be obtained annually which not only play a role in economic status of farmer but also will set the increasing trend in economy of country as well. A study estimated that the biomass usable in seven Asian countries namely China, India, Pakistan, Nepal, Philippines, Sri Lanka and Vietnam is 152 million tons of fuel wood and 101 million tons of agricultural residues, for the domestic cooking in early nineties. The amount of biomass that can be saved through efficiency improvement can serve as a source of additional energy and can potentially substitute for fossil fuels to reduce net GHG emission [4]. The other main challenging task is selection and development of suitable technology. One of the oldest technology is gasification.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[5]**.**Other valuable by products obtained from gasification are biochar andbio oil which can be further purified and used in many applications. Gasification has two major techniques namely fixed bed and fluidized bed. Fixed bed is however an old technology but still development is continued to achieve better results.

1.3 Energy scenario of Sri Lanka and role of biomass

Sri Lanka is one of main Asian country which is very rich in agricultural resources. It also heavily relies on fossil fuels which are imported. Due to increasing trend in prices of fossil fuels and environmental concern it has been strongly felt to enhance national energy security. The share of hydro power in total power generation was only39.3% which was 52.6% in the previous year reflecting increase of demand and the changes in rainfall in catchment areas [6]Wind and solar are two promising energy option in Sri Lanka.Solar energy is too expensive while wind energy is dependent upon the required speed of air wind. The only choice remain which can be commercialized is biomass energy. Biomass gasification is a promising renewable energy technology for supplying thermal energy as well asgenerating electric power. It is vital to use biomass for stand-alone power generation in remote areaswhere the national grid is not available. Unlike thermal applications, power generation demands low tarproducer gas which in turn need cleaning of gas.Down-draft gasifier generally produces low particulate and low-tar gas[7].

Government is sincere to commercialize renewable resources and it is in positive progress phase. In this regard Government of Sri Lanka has recently declared *Gliricidia sepium* which is also called as ginisyria as 4th crop[8]. Ginisyria is a wood fuel abundantly available in the country which can be utilized as biomass to produce valuable gas fuel. Presently many research works on gasification technology is progressing in the country to develop biomass gasification plant for industrial and domestic level (From NERDC Center).

1.4 Research Objectives

1. This study is intended to design and development of pilot scale updraft gasifier for different biomass materials.
2. To analyze the performance parameters of gasifier for different biomass,with and without packing at different equivalence ratio.
3. Potential of Mango pit shell as new biomass.

1.5.Research Scope

Research work has been successfully done by utilizing coconut shell, mango pit shell, ginisyria and mixture in developed updraft gasification. Performance parameter mainly LHV of producer gas, was in good range. This work indicates that mango pit shell which is thrown as waste and harm the environment can be used as a biomass source for useful energy production. Especially in juice industries for production of gas and its utilization in thermal applications as well as for power generation. In Sri Lanka context of view all these raw materials are abundantly available and can be utilized in the developed unit with some modifications, such as continuous feeding system at large scale.

1.6.Research Limitations

This study focuses on to find out energy potential of mango pit shell as new biomass resource and its comparative study with different biomass raw materials namely coconut shell and Ginisyria at different ER. This study also includes design and fabrication of Updraft gasification system with gas cleaning unit. The concept of packing plate provision in pyrolysis zone of reactor was new core idea to analyze the performance parameters for different feed stocks.

1.7.Research Gaps

Packing plate idea in updraft gasifier was new concept so no standard data found regarding this in literature. In fruit juice and jam industries mango pit shell is also thrown away as waste and evidence regarding its utilization as biomass gasification is not found. Gliricidia sepium is a recent entry as biomass especially in Sri Lanka and no presently evidence was found to its utilization as biomass in updraft gasification system. Utilization of a mixture of biomass with arbitrary selected values (Mixing Proportion) is also a new case in this study.

1.8.Dissertation Outline

Chapter 1: It has a brief introduction about biomass, gasification and its role while it also has a brief description about research objectives, limitations, gaps and scope of present studies.

Chapter 2: In this section, literature review is presented which is about biomass and its properties while gasification technologies, types of gasifiers and gasification reactions are also described. In addition to this, gasification design parameters are also discussed in this chapter.

Chapter 3: This chapter titled as materials and methods deals with design and development including fabrication of the gasifier unit with all relevant details of axillary components. Standard equations and step by step calculation procedure is presented for better understanding. This includes dimensions, calculation of gasifier, design parameters of unit and other miscellaneous. Pictorial view of parts is also included. It also contains feed stock preparation, analysis and operation details.

Chapter 4: it focuses on the results and mainly discuss about elemental analysis such as proximate and ultimate analysis of fuel, producer gas composition for different biomass with and without packing plate at variant air flow setting. Lower heating value and all other parameters for each trial are calculated with specimen calculation. Graphical presentation describes clearly about variation of parameters.

Chapter 6: in this section conclusion and discussion is carried out. Present study results and earlier work comparisons are presented while it also contains future work suggestions.

CHAPTER-2: LITERATURE REVIEW

2.1.Biomass energy and its scenario

The energy produced from organic materials is called bio energy such as plants, crops etc. Biomass is produced by green plants converting sunlight into plant material through photosynthesis and includes all land and water based vegetation, as well as organic wastes[9]**.**Plants storesunlight energy as chemical energy having strong molecular bonds which when broken up these material are subjected to some conversion process and then heat is released. Biomass has always been a major source of energy for mankind and is presently estimated to contribute of the order 10-14% of the whole world’s energy supply[9]. However from last few years it has got major attention which might be due development in conversion technology of biomass, lower prices, surplus food generation especially in European countries, climate change due to adverse effect of fossil fuel emission on environment, increased energy demand and sustainability. We know that biomass was the main source of energy for heat from early days but with the introduction of fossil fuels in the form of coal, petroleum oil and natural gas, the world increasingly became dependent on these fossil fuel sources. Currently the main energy source in the world is fossil fuel [10].Increases in fossil fuel demand are also due to utilization of by products at very high rate in daily life. Still it has not been confirmed how much fossil fuel is remaining.With the high consumption rate it is approximated that depletion isfast. Further, these fuels have no even distribution in the globe and therefore many countries are dependent on others. This increasing consumption trend of fossil fuel with its byproducts combining with other factors was the main barrier in commercialization of biomass. Now realization in terms of non-renewable state of fossil fuel and high depletion rate give the opportunity to think seriously about other resources and biomass energy is one of them. It has been estimated that the global biomass potential is 91-675 EJ/year for the years 1960 to 2060[11].Total worldwide energy potential from biomass on sustainable basis is 104 EJ/year, of which woody biomass, energy crops and straw constitute 40.1%, 36% and 16.1 % respectively[12].Still biomass and its products need to grow in the market and it needs awareness in local communities. Currently, the total global energy demand is about 470 EJ/Year [10].In the United States, without many changes in land use and without interfering with the production of food grains, 1.3 billion tons of biomass can be harvested each year on sustainable basis for biofuel production [13].It is approximated that 1.3 billion tons of biomass is equivalent to 3.8 billion barrels of oil in energy content [10].The energy shift with time is shown in Figure 2.1.

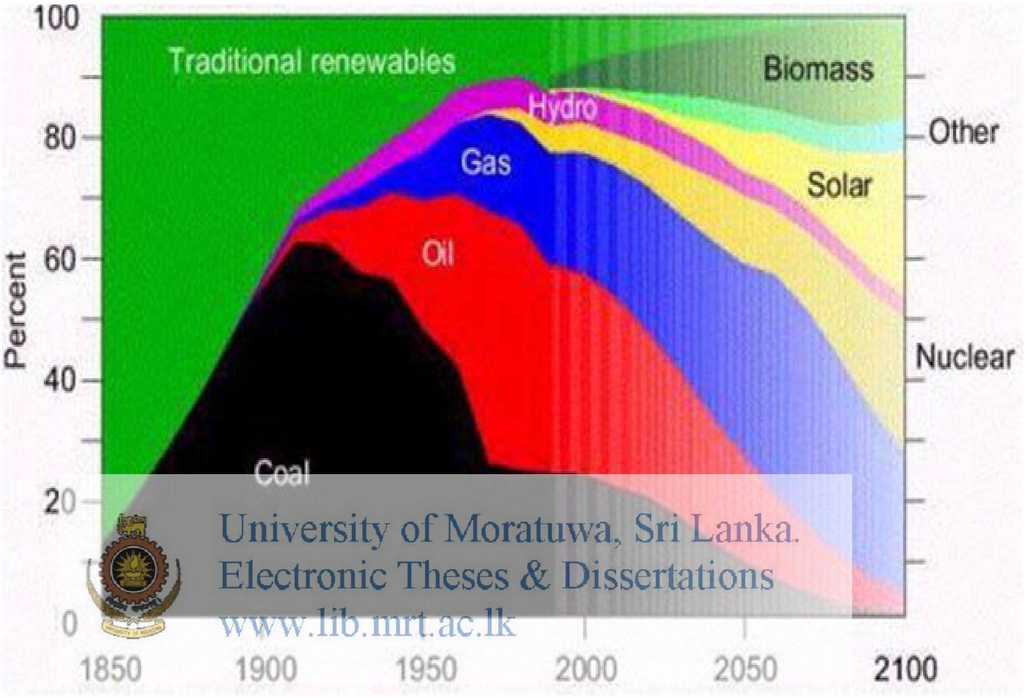


Figure 2.1: Energy shiftwith time [14]

Figure 2.1 clearly depicts that with the passage of time how energy trend will shift globally and around 2050 biomass will be tycoon of energy sector. Other renewable sources such as solar, wind will also participate but their contribution looks much less than biomass. Biomass has the advantage over traditional fossil fuels that it replenished quickly, renewable and environmentally friendly. Currently, biomass constitutes 10% of the worldwide primary energy production, as shown in Figure 2.2, equating to 1.277 Gt oil equivalent (Gtoe) (53.47 EJ) of primary energy consumption of total biomass in 2012 [15].The contribution of fossil fuels to energy production amounted to more than 80% of the primary energy production In 2011, 337 TWh of electricity has been produced from combustible renewable energy sources and waste generation.

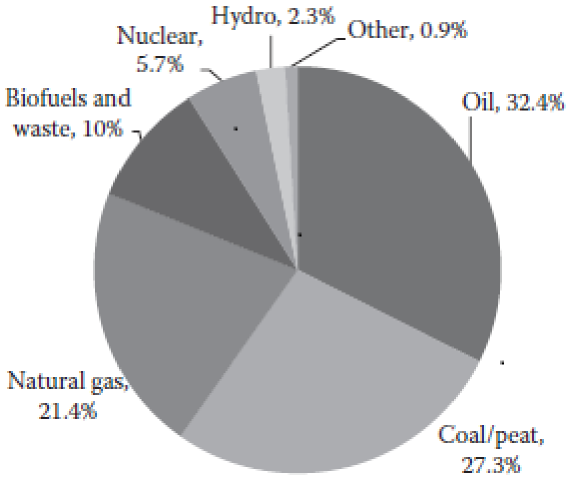


Figure 2.2: Total world primary energy source [16]

2.2.Biomass materials

Biomass materials classification has been done by many researchers and still it’s being developed and improved to find out a better new one but basically as at to date all have agreed on wood species. Peter classified it as woody plants, herbaceous plants and grasses, aquatic plants[17]While[18]have classified stating more clearly that biomass material can be wood, herbaceous, and agricultural, aquatic, human and animal wastes, contaminated and industrial waste.

2.2.1. Sources of biomass

Following are the main sources of biomass materials

- Wood species
- Agricultural wastes (e.g. cotton grit, Paddy husk/straw etc.)
- Industrial wastes (e.g. Palm oil/ Bagasse/Mango Pit etc.)
- Domestic wastes (e.g. Coconut shell etc.)

2.2.2. Biomass properties and selection

The important biomass properties include the following (a) heating value (b) proximate analysis (c) Ultimate analysis [19]. Proximate analysis includes determination of moisture contents, ash contents, volatile matters, fixed carbon by percentage while ultimate analysis is to determine the presence of percentage of carbon, nitrogen, oxygen, hydrogen and sulfur. Other characterization would include describing its compositional contents such as lignin, cellulose and hemi-celluloses, carbohydrates and fat contents[19].

2.2.2.1.Calorific value

The calorific value(CV) of material is an expression of the energy content, or heat value released when burnt in air. The CV is usually measured in terms of energy contents per unit mass or volume; hence MJ/Kg for solids, MJ/l for liquids and MJ/Nm^3 for gasses. [9].In this study calorific value is evaluated by using Dulong equation [20]and the Boie equation (Annamalai, et al., 1987) shown in equations (2.1) and (2.2).

The Dulong equation is given by the following equation

$$HV\ \left(\frac{kJ}{kg}\right) = 33{,}823 \times C + 144{,}250 \times \left(H - \frac{O}{8}\right) + 9{,}419 \times S \text{ ……………Eq. (2.1)}$$

where C, H, O, N and S are the elemental mass fractions in the material,

The Boie equation is given by the following equation

$$HV\ \left(\frac{kJ}{kg}\right) = 35{,}160 \times C + 116{,}225 \times H - 11{,}090 \times O + 6{,}280 * N + 10{,}465 \times S \text{ …Eq.(2.2)}$$

where C, H, O, N and S are the elemental mass fractions in the material[19].

2.2.2.2.Proximate analysis

- **Moisture contents**

There are two types of moisture contents associated with biomass one is called intrinsic moisture while other is known as extrinsic moisture. In first category there is no impact of weather conditions while in later one weather condition has an impact specially during harvesting and this is the additional moisture added to material. In respect of the prevailingweather conditionsat the time of harvesting, is the potential contamination of the harvested biomass by soil and other detritus, which can in turn have a significant deleterious impact on other ‘material’ properties during subsequent treatment or processing. The parameters of interest that area affected by such contamination is the ash and alkali metal content of the material.

Thermal conversionrequires low moisture content feedstock (typically<50%), while bio-conversion can utilize high moisturecontent feedstocks. Thermal conversion technologiescan also use feedstocks with high moisture content butthe overall energy balance for the conversion process isadversely impacted[9].

- **Fixed Carbon and volatile matters**

Fuel analysis has been developed based on solid fuels,such as coal, which consists of chemical energy stored intwo forms which are fixed carbon and volatiles:

- The volatiles content, or volatile matter (VM) of a solid fuel, is that portion driven-off as a gas (including moisture) by heating (to 950 ^{0}C for 7 min)
- The fixed carbon content (FC), is the mass remaining after the releases of volatiles, excluding the ash and moisture contents[9].

- **Ash contents**

The chemical breakdown of a biomass fuel, by either thermo-chemical or bio-chemical processes, produces a solid residue. When produced by combustion in air, this solid residue is called ‘ash’ and forms a standard measurementparameter for solid and liquid fuels. The ashContent of biomass affects both the handling and processing costs of the overall, biomass energy conversion cost. During biochemical conversion, the percentage of solid residue will be greater than the ash content formed during combustion of the same material. For a biochemical conversion process, the solid residue represents the quantity of non-biodegradable carbon present in the biomass. This residue will be greater than the ash content because it represents the recalcitrant carbon which cannot be degraded further biologically but which could be burnt during thermo-chemical conversion [9]

- **Cellulose / lignin ratio**

The proportions of cellulose and lignin in biomass areimportant only in biochemical conversion processes. The biodegradability of cellulose is greater than that of lignin;

hence the overall conversion of the carbon-containedinplant material present as cellulose is greater thanfor plants with a higher proportion of lignin, a determiningfactor when selecting biomass plant species forbiochemical processing. Table 2.1 gives the proportions ofcellulose, hemicellulose, and lignin for softwoods and hardwoodsand for comparison, wheat straw and switch grass.

Table 2.1: Cellulose/lignin contents of selected biomass wt.% [9]

Biomass	**Lignin %**	**Cellulose %**	**Hemicellulose**
Softwood	27-30	35-40	25-30
Hardwood	20-25	45-50	20-25
Wheat Straw	15-20	33-40	20-25
Switch Grass	5-20	30-50	10-40

2.2.3. Coconut shell

Coconut shell belongs to crop and domestic or industrial waste family.They were abundant in tropical countries in Latin America, Africa and Asia, occurring as biomass wastes from different agro-industrial processes[21].Presently coconut shells are used to produce activated carbon, which has more commercial value as well as thisbiomass represents a grand potential as renewable energy source for power generation for different end uses, especially for household rural energy, in the developing countries where they occur[21].Much study has been done on this material especially in India as biomass material. Properties of this material were determined by different researchers and properties depend on treatment, samples taken for analysis, geographical condition from where material is obtained. One studied that it contains 4.09%, 71.95%, and 23.96% by percent ash, volatile matters and fixed carbon respectively while carbon, Hydrogen, Nitrogen and Oxygen contents are 54.52%, 6.05%, 0.69% and 38.74% by percent respectively[22]. Moisture content, Volatile matters,Fixed carbon and Ash content by percentage are 10.1% ,64.6%, 11.2%& 14.2% respectively while carbon , Hydrogen, Nitrogen and Oxygen contents are 64.23%,4.89%, 4.77%& 22.64% by percent respectively

[23].Another study says that the proximate and ultimate analysisof biomass as follows: moisture 10.53%, fixed carbon13.10%, volatile matter 57.96% and ash 18.4%.Ultimate analysis was C 50.2 %, H 5.30%, N 0.0% and $O_2$43.4% [24].

2.2.4. Mango pit shell

Mango pit shell also belongs to family of crop waste mainly but it also obtained as fruit industry waste. Mango is king of fruits which is mostly cultivated in Asian regions. Mango pit shell after getting pulp is thrown as waste material,without gettingmuch attention as a useful biomass material. However there are expectations that energy can be extracted from it. Mango (Mangifera indica) stone residues, if not harnessed, constitute a waste disposal problem in the environment during peak production period. The heating value and carbon, hydrogen, nitrogen, ash, moisture content, volatile matter and fixed carbon contents of the raw mango stone shell were found to be 21.74 MJ/kg, 44.63%, 4.2%, 0.35%, 1.89%, 1.86%, 65.28%, 18.4% wt. %,respectively. The main composition values were 34.68%, 16.63% and 20.17% wt. % for cellulose, hemicellulose and lignin contents respectively[25].Utilization of mango pit shell as energy candidate is a new entry in to the field which can play a significant role in fruit juice industries to fulfill the energy demand.

2.3. Gasification Process

Gasification is the conversion of biomass into a combustible gas mixture by the partial oxidation of biomass at high temperatures, typically in the range 800–900 °C. The low calorific value (CV) gas produced (about 4–6 MJ/N m^3) can be burnt directly or used as a fuel for gas engines and gas turbines [17]. The product gas can be used as a feedstock (syngas) in the production of chemicals (e.g. methanol) [9].Gasification is a chemical process that converts carbonaceous materials like biomass into useful convenient gaseous fuels or chemical feedstock[26].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. Producer gas can be used to run internal combustion engines (dual fuel), can be used as substitute for furnace oil in direct heat applications and can be used to produce, in an economically viable way, methanol – an extremely attractive chemical which is useful both as fuel for heat engines as well as chemical feedstock for industries . Since any biomass material can undergo gasification, this process is much more attractive than ethanol production or biogas where only selected biomass materials can produce the fuel [5].

2.3.1. Chemistry of Gasification Process

The following major reactions take place in combustion and reduction zone of the gasifier.

- **Combustion zone.**

The combustible substance 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 assteam. The combustion reaction is exothermic and a theoretical oxidation temperature is 1450 °C therefore the main reactions are:[27].

$C + O_2 = CO_2$……………………………………………………………...Eq.(2.3)

$2H_2 + O_2 = 2H_2 O$…………………………………………………………......Eq.(2.4)

- **Reaction zone**

The products of partial combustion, water, carbon dioxide and uncombusted partially cracked pyrolysis products now pass through a red-hot charcoal bed where the following reduction reactions take place[3, 5]

$C + CO_2 \rightarrow 2CO$ ……………………………………………………………...Eq.(2.5)

$C + H_2O \rightarrow CO + H_2$………………………………………………………...Eq.(2.6)

$CO + H_2O \rightarrow CO + H_2$………………………………………………………….Eq.(2.7)

$C + 2H_2 \rightarrow CH_4$…………………………………………………………….Eq.(2.8)

$CO_2 + H_2 \rightarrow CO + H_2O$………………………………………………………….Eq.(2.9)

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 800-1000 ^{0}C. Lower the reduction zone temperature (~ 700-800C), lower is the calorific value of gas.

- **Pyrolysis zone**

Wood pyrolysis is an intricate process that is still not completely understood[27].The products depend upon temperature, pressure, residence time and heat losses. However followinggeneral remarks can be made about them.Upto the temperature of 200 °C only water is driven off. Between 200 to 280 °C carbon dioxide, acetic acid and water are given off. The real pyrolysis, which takes place between 280 to 500 °C, produces large quantities of tar and gases containing carbon dioxide. Besides light tars, some methyl alcohol is also formed. Between 500 to 700 °C the gas production is small and contains hydrogen. Thus it is easy to see that updraft gasifier will produce much more tar than downdraft one. In downdraft gasifier the tars have to go through combustion and reduction zone. Since majority of fuels like wood and biomass residue do have large quantities of tar, downdraft gasifier is preferred over others. Indeed majority of gasifiers, both in World War II and presently are of downdraft type [5].

- **Drying zone**

Finally in the drying zone the main process is drying of wood. Wood entering the gasifier has moisture content of 10-30%. Various experiments on different gasifiers in different conditions have shown that on an average the condensate formed is 6-10% of the weight of gasified wood. Some organic acids also come out during the drying process. These acids give rise to corrosion of gasifiers [5].

2.4. Gasification reactors

In this study the focus is on fixed bed gasifiers. Therefore thediscussion below will be related accordingly.

2.4.1. Fixed bed gasifiers

Fixed bed reactors are those in which solids move either countercurrent or concurrent to the flow of a gas as reaction takes place, and the solids are converted to gases. Fixed beds are particularly suited to solid fuel contacting operations that require close temperature control (especially if the temperature is variable along the flow path), carryover of particles away from the reaction zone, simple operation and minimum erosion of the body of the reactor[28].

2.4.1.1.Updraft gasifier

Figure 2.3 illustrates an updraft gasifier where the flow of the fuel and gases are countercurrent to each other. This is the earliest and simplest type of gasifier reactor known. The high temperature oxidation zone is located at the bottom of the gasifier where part of the fuel is burned. The gasifying agent is injected at the bottom of the reactor and ascends from the bottom to the top while the feedstock is introduced at the top of the reactor and descends from the top to the bottom. The fuel descends through three zones (drying, pyrolysis and oxidation) of progressively increasing temperatures. Temperatures in the oxidation zone can exceed 1500^{o}C. The heat dissipated from the oxidation zone and the gasification zone is transferred by forced convection and radiation upwards to the pyrolysis and drying zones, thus providing the heat required for drying, pyrolysis and endothermic char gasification processes. The oxidation zone lies at the bottom of the gasifier and the combustion gas passes through this zone reacting with the char, thereby releasing the required process heat. The produced gases, tar and other volatiles disperse at the top while ashes are removed at the bottom of the reactor. Part of the fuel is burned in the oxidation zone. The gas produced by an updraft gasifier usually exits at low temperatures (approximately 400 ^{o}C) and thus is rich in hydrocarbons and has high tar content. The tar contains as much as 30% of the energy in the original crop biomass. The high tar content is not a major problem if the producer gas is used for direct heat applications. However, it requires thorough cleaning for internal combustion engine applications. The product gas from an updraft gasifier contains more CO, but less CH_4, ethane and acetylene than gas from other gasifiers. Updraft gasification of biomass using particulate fuels has been used widely in agricultural and industrial applications. The use of an endothermic agent (usually steam) has been the traditional approach for controlling the oxidation zone temperature of updraft gasifiers. Exhaust gas re-circulation is another approach to control the temperature of an updraft gasifier. Updraft gasifiers have several advantages, including simple design and construction, low gas exit temperature, high charcoal burnout and high thermal efficiency. However, slagging can be very severe in updraft gasifiers, especially with high ash-content fuels like cereal straws and corn cobs. [28].

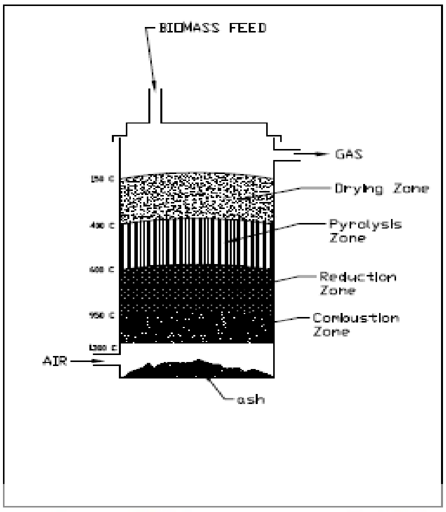


Figure 2.3: Updraft Gasifier

2.4.1.2.Downdraft gasifier

Reaction zones in a downdraft gasifier are similar to those in the updraft unit, except the locations of the oxidation and reduction zones are interchanged. The most important difference is that the pyrolysis products in the downdraft type (Figure 2.4) are allowed to pass through the high temperature oxidation zone. Hence, they undergo further decomposition. Also, the moisture vaporized from the biomass enters the gasification zone and serves as a gasifying agent. The final product gases, which leave the gasifier from the bottom at a fairly high temperature (700°C), contain substantially less tar than the updraft gasifiers. In a downdraft gasifier, feedstock is introduced at the top and the gasifying agent is introduced through a set of nozzles located on the sides of the reactor.

The benefit of the downdraft gasifier lies in its ability to produce gas with low oil and tar contents, which means less cleaning before use in internal combustion engines. The gas can, therefore, be used with minimal filtering as a fuel for spark ignition and diesel engines. However, due to slag and clinker formation problems, this type of gasifier has been found unsuitable for fuels with high ash content and low ash fusion temperatures, such as crop residues. A major drawback is its inability to handle fine and fluffy (low density) crop residue materials [28].

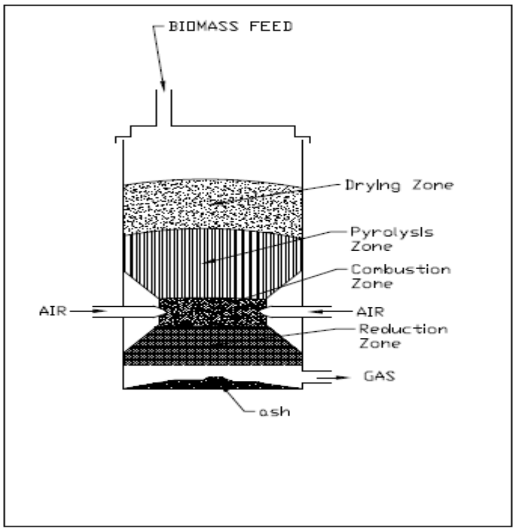


Figure 2.4: Downdraft Gasifier

2.4.1.3. Cross-draft gasifier

Cross-draft gasifiers exhibit many operating characteristics of the down draft units. Air or air and steam mixtures are introduced in the side of the gasifier near the bottom while the product gas is drawn off on the opposite side. Normally an inlet nozzle is used to bring the air into the center of the combustion zone as shown in Figure 2.5. The velocity of the air as it enters the combustion zone is considerably higher in this design, which creates a hot combustion zone. The combustion (oxidation) and reduction zones are both concentrated to a small volume around the sides of the unit. Cross-draft gasifiers respond rapidly to load changes. They are normally simpler to construct and more suitable for running engines than the other types of fixed bed gasifiers. However, they are sensitive to changes in biomass composition and moisture content [28].

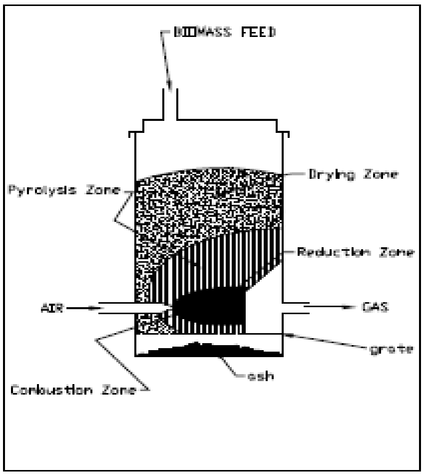


Figure 2.5: Cross -Draft Gasifier

2.5.Gasification medium

Gasifying agents react with solid carbon and heavier hydrocarbons to convertthem into low-molecular-weight gases like CO and H_2. The main gasifying agents used for gasification are

- Oxygen
- Steam
- Air

Oxygen is a popular gasifying agent, though it is primarily used for the combustion step. It may be supplied to a gasifier either in pure form or through air. The heating value and the composition of the gas produced in a gasifier are strong functions of the nature and amount of the gasifying agent used [26]. Selection of gasification media has strong effect on product gas quality. If air is used as media which is commonly available then product gas LHV will be in range of 4-6 MJ/Nm^3 due to dilution of nitrogen. Steam gasification gives 10-18MJ/Nm^3 while oxygen gasification has highest rate among all which is 18-28 MJ/Nm^3.

2.6. Factors influence the gasification process.

The main factors which influence the gasification process are equivalence ratio, feed temperature, bed height, bed temperature, pressure moisture contents of feed stock etc. These all parameters are briefly discussed here.

I .*Equivalence ratio*

Equivalence ratio is ratio between operating air fuel ratio and stoichiometric air fuel ratio has the strong effect on performance of gasifier and process. The high equivalence ratios increase the gas production rate in air gasification. The gasifier temperature was found to increase with increase in the equivalence ratio because of increases in the exothermic reactions. On the other hand, a very low equivalence ratio results in very low bed temperatures, thus producing a lower gas and higher tar yields[29].The combustible components and the heating value of the produced gas decrease with decrease in the equivalence ratio [30]. The equivalence ratio (ER), dictates the performance of the gasifier. For example, pyrolysis takes place in the absence of air and hence the ER is zero; for gasification of biomass, it lies between 0.2 and 0.3[26].

II.*Feed temperature*The moisture content of feed material affects reaction temperature due to the energy required to evaporate water in the fuel. Therefore, the gasification process takes place at a lower temperature. [31] reported on the conversion of lignin (of less than 10%wt basis moisture content at 350^{o}C and about 50% wt. moisture content at 450^{o}C. They found a direct correlation between high moisture content and high volumes of produced char. They reported a decrease in gasifier temperature with increases in fuel moisture content.It is major parameter which has very strong influence on performance. All gasification reactions are normally reversible and the equilibrium point of any of the reactions can be shifted by changing the temperature[28].Conversion of corncobs to increase from 94% at 500°C to 99% at 900°C in air gasification[32]. Product gas yield from maple sawdust (1.4% M.C.) increased as the reactor temperature increased whereas the liquid and solid products decreased with increases in temperature [33]. Tar production at low temperatures below 500^{o}C was found to increase initially with increase in temperature and then drop with further increase in temperature [34]. The yield of higher hydrocarbons (C_3-C_8) decreased with increases in temperature above 650^{o}C, which indicated the onset of cracking or reforming reactions. Other gas components, H_2 and CO, also increased with increases in temperature [35].

III.Bed height:Higher bed height resulted in greater conversion efficiency as well as a lower bed temperature due to the fly-wheel effect of the bed material [28]. [36]Showed that the fly-wheel effect is significantly reduced when the amount of bed material is reduced thereby resulting in higher bed temperature. Their results also reported that increasing the bed height increases the bed pressure drop in the dense bed but resulted in no significant changes in the freeboard region [28].Increases in H_2, CO, CO_2, CH_4 and C_2H_4have also been observed when the residence time was increased as a result of increased bed height[35].

2.7.Cleaning of gas

Cleaning of producer gas is necessary if it is used for internal combustion engine power generation because it contains tar especially in updraft gasification system which can turn down the performance of downstream equipment's of process. Scrubbers, filters, cyclone separators are mostly used for this kind of cleaning purpose.

2.8.Selection of gasifier unit for this case study and justification

For this study, we selected updraft gasifier reactor scheme with cyclone separator. The main theme behind the selection of this was

- Good thermal efficiency
- Ease in fabrication at bench scale
- Nominal cost and good operability
- Because currently in Sri Lanka downdraft is popular this was another purpose to introduce this concept for different available biomass.
- Cyclone separator was just selected to remove particles to get good quality gas for thermal purpose still and at large scale for power generation in future.

2.9.Review of gasifier design

Major design parameters of gasifier are feed flow rate, air flow rate, client requirement for power output either thermal or electrical and ER. The gasifier required power output, Q (MW_{th}), is an important input parameter specified by the client. Based on this, the designer makes a preliminary estimation of the amount of fuel to be fed into the gasifier and the amount of gasifying medium[26].Lower heating value of gas is a major concern in any gasifier output. It can be calculated from gas composition of the output or some time in design case a guessed value can be used. In the absence of lower heating value (LHV) data, reasonable guess canbe made, either from published data on similar fuels in similar gasification conditions or from the designer's experience.For air-blown fluidized-bed biomass gasifier, the LHV is in the range 3.5 to 6 MJ/Nm^3[37].For oxygen gasification,it is in the range 10 to 15 MJ/Nm^3[26]. So, to start with air blown gasifier, a value of 5 MJ/Nm^3 is a reasonable guess [38].

S.Rowland (2010) describes the experience of design of updraft gasifier, expressed that basic design of the gasifier was inspired by the work of Bowser et al (2005).The gasifier design of Bowser et al, is an updraft, batch gasifier with the basic design inspired by the work of Patil and Rao Bowser et al made improvements to the Patil and Rao's gasifier including a motorized scraper blade, improved sensors, off-the shelf pipe and pipe fittings for body components, portability and quick disassembly. The gasifier has three basic components: gasifier body, scraper and scraper drive, and support frame. The machine was fabricated in the Bio Systems and Agricultural Engineering machine shop at Oklahoma State University[39].

P.Yadav et.al.(2013) gives his experience indicated that basic structure of the gasifier is built around 13 inches inside diameter, 2.5 mm thickness, and 21 inches long air tank of trucks, and a steel tube 5 inches in inside diameter, 3mm thickness, and 22 inches long. These dimensions are not really critical. The tube could be a little longer or shorter, and a little wider or narrower in diameter. The air tank and steel tube were bought from a scrap market. The purpose of the drum is to be the main body of the gasifier unit. It contains all internal parts and collects all the gas, ash and char the unit will produce. The steel tube serves as a flame tube where the gasification process takes place[40].

S.Ojolo et.al(2010) published their research indicated thata laboratory scale downdraft biomass gasifier was designed by to deliver a mechanical power of 4 kW and thermal power of about 15 kW. Their gasifier was manufactured as a single piece having a water seal and cover. The gasifier was tested in natural downdraft and forced downdraft mode. Ignition of the fuel was done beneath the grate, using natural downdraft mode, with wood shavings as fuel. The produced gas had burnt with a blue flame for 15 minutes. When using either palm kernel shells or wood shavings, during the natural downdraft mode, the gasifier has not produce syngas and ignition at the throat has not been observed. During the forced downdraft mode, fuel was ignited at the throat. Gasification was successful with the palm kernel shells, during forced downdraft, which produced gas which burned steadily with luminous flame for 15 minutes per kilogram of biomass fed. However, wood shavings experienced some bridging problems during the forced downdraft mode of operation. The fuel conversion rate of the gasifier, when using palm kernel shells as fuel in forced downdraft mode, was 4 kg/h. Forced downdraft mode of operation yielded better results and is the preferred operation of the gasifier[41].

S.J.Ojolo et.al(2012)studied presented a designed and fabricated 11.19 kW laboratory scale updraft gasifier tested on saw dust and palm kernel shell as feed stock. The samples were analyzed for properties. The performance test conducted on both and indicated that heat energy input of 28,125 and 31633 kJ for saw dust and palm kernel respectively. Power input was 7.812 and 8.79 kW while power output obtained had been 5.47 and 6.15 kW. Gasifier efficiency was calculated as 93 and 67.4 %. FCR was 3.00 kg/ hr while diameter and height of gasifier are 0.2 m and 0.96 m respectively. The time taken to consume the fuel was 2.2 hour[42].

Chapter 3-MATERIALS AND METHODS

3.1.Design and development of updraft gasifier

Design of gasifier is a very critical task in initial stages because of desired output power and other parameters such as FCR etc. play key role in specifying the dimensions; selection of construction material depends on maximum possible temperature; grate geometry and ash chamber shape. Design power is the most important parameter demanded in gasifier designing [26].Required power can be termed either thermal or mechanical. If the gas produced is used for direct heating purpose then it is termed as thermal power on the other hand if it is utilized in power generation then it is called as mechanical power. In present study a 25 kW power output witha thermal efficiency value of 70%[42]is assumed for the unit.

3.1.1. Fuel consumption rate

This refers to the amount of energy needed in terms of fuel to be fed into the gasifier. This can be computed using the formula,

$$FCR = \frac{Q}{HVf \times \xi_g} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq.(3.1)[26, 42]}$$

Where:

FCR – Fuel consumption rate, kg/hr

Q – Rated thermal energy, kW

HV_f - heating value of fuel, MJ/kg (Ref: Section 4)

ξ_g - gasifier efficiency (Taken as 70% [42])

Hence Fuel consumption rate isequal to, $\frac{25\times10^3}{18.5\times10^6\times0.7}$=6.9 Kg/ hr

3.1.2. Reactor dimensions calculation

3.1.2.1.Diameter of reactor

This is the size of reactor in terms of cross sectional area of cylinder where biomass is fed and burned. This parameter is a function of fuel consumption rate and specific gasification rate. Specific gasification rate normally lies in the range of 110-210 kg /m^2.hr.[42].In this study we selected specific gasification rate 110 kg /m^2.hr as an arbitrary value for the design. Diameter of reactor is calculated by following equation

$$\mathrm{D} = \left(4 \times \frac{\mathrm{FCR}}{\mathrm{SGR} \times 3.14}\right)^{0.5} \quad \text{..Eq.(3.2)} \quad [42]$$

Where

D=diameter of cylinder, m

FCR= Fuel consumption rate, kg/hr

SGR=Specific gasification rate= kg /m^2.hr

Therefore, $D = \left(4\,x\,\frac{6.9}{110x3.14}\right)^{0.5} = 0.28$ m

3.1.2.2.Height of reactor

This refers to the total distance from the top and the bottom end of the reactor. This determines how long would the gasifier be operated in one loading of fuel. Basically, it is a function of a number of variables such as the required time to operate the gasifier (T), the specific gasification rate (SGR), and the density of biomass. The time required to operate the gasifier and complete a batch is taken as 4 hours. As shown below, the height of the reactor can be computed using the formula (3.3).

$$H = SGR \times T \; / \, \rho \text{...Eq.(3.3)[42]}$$

Where

H= Height of reactor

SGR= Specific gasification rate

ρ =Density of fuel= 350 kg/m^3 (Ref: Section 4)

T= Required time to operate (Which was selected as 4 hours because we have already fixed two parameters(SGR and Density) so to get desired height for this pilot scale reactor (around 1.25 m) the only variable parameters at this condition was operational time and the period 4 hours satisfies that condition.

So the height of reactor is= $\frac{110 \text{ x } 4}{350}$= 1.257 m

3.1.2.3.Volume of the reactor

Volume of the reactor is given by equation (3.4)

$\boldsymbol{V} = \pi r^2 \times H$……………………………………………………Eq.(3.4)[42]

V=volume of reactor (m^3)

R=radius of reactor (m)

H=height of reactor (m)

$V = 3.14 \times 0.142 \times 1.25$ =0.076 m^3

3.1.2.4.Total working height of reactor

Total working height of gasifier means to make provision for grate , ash chamber, plugs and socket accommodation. This height value is taken as 37. 75%. So the total height calculated is given below.[42].

$Height \times Fixed\ Value$ =1.25 × 0.37 =0.46 m

$Total\ Height = 0.46 + 1.25$ = 1.71 m

3.1.3. Time required to consume fuel :

This is the total maximum time required for gasification of biomass inside the reactor[42]. This time is a combination of startup time and operational time. This is calculated by formula given below.

$Time \; = \; \rho \, of \, Fuel \; \times \; V \, / FCR$ ……………………… ………………Eq.(3.5)

$T \;\; = \; 350 \times 0.076/7.0$ = 3.8 hr

This value is almost near to 4 hr which is the value considered in section 3.1.2.2 to complete a batch in the gasifier.

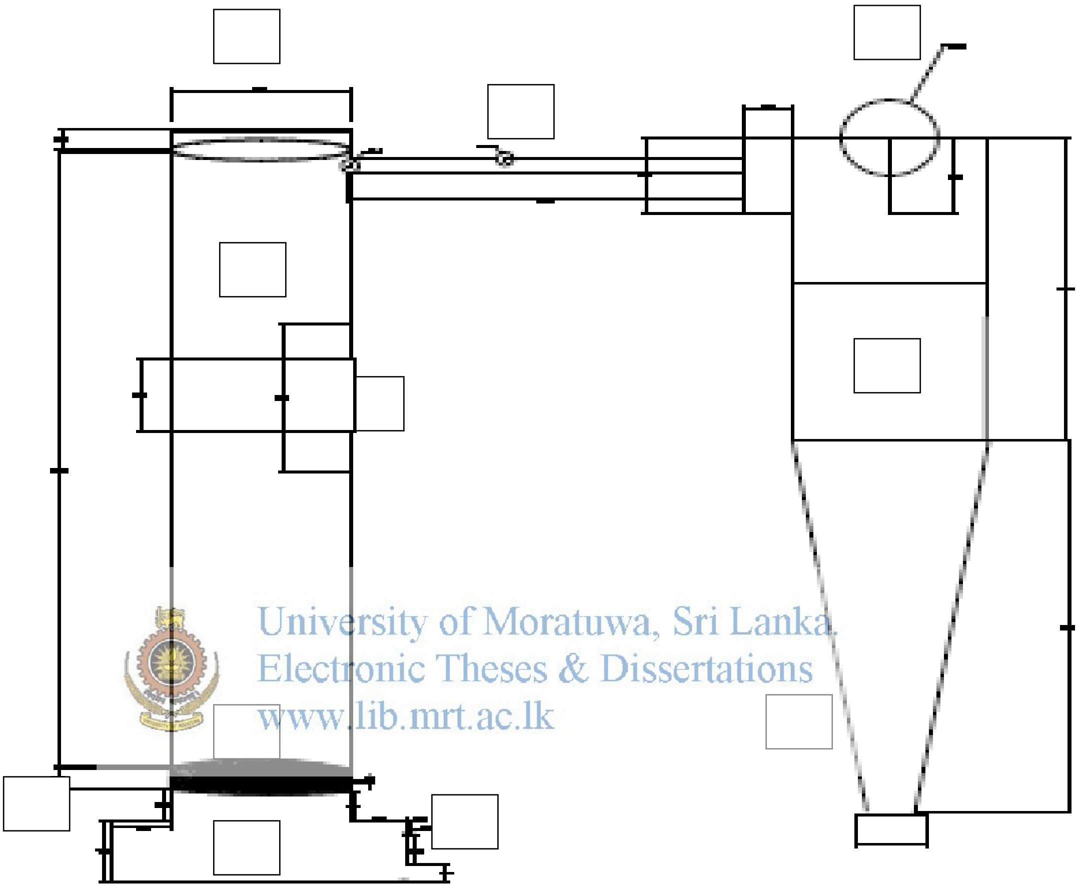


Figure 3.1: Model of Updraft Gasifier with Cyclone separator. (A) Feeding Provision ; (B) Reactor Main Body; (C) Packing plate Provision; (D) Grate; (E) Ash Window; (F) Ash Chamber;(G) Air blowing line;(H) Gas Exit pipe ; (I) Gas exit pipe with sampling port; (J) Cyclone separator; (K) solid particles and Condensate collector

3.1.4. Selection of material and unit fabrication

The designed unit described above and presented in Figure 3.1 was fabricated at Mechanical Engineering Department workshop of university of Moratuwa, Sri Lanka. Material of construction and fabrication detail of each part of unit is given below.

3.1.4.1.Main reactor body

It is made of mild steel and stainless steel top and bottom portions respectively which can be seen in Figure 3.1.Gauge of both materials selected were 3 mm in order to withstand high temperatures. Welding rods ofSS having 12 gauge and MS 10 gauge were used to join both sections. Welding was done carefully to prevent leakages. In the reactor body four holes were provided with diameter 10 mm for fixingthermocouple sensors.The holes were allocated at equal distance of 0.312m from top to bottom of reactor (above grate). From top of the reactor at a distance of 0.312 m , 0.1524m provision for packing plate was made for packing plate insertion. For packing plate support, two flanges were welded inside the reactor body. In outer side nut and bolts allocations were given for easy opening and closing, that is for removal and insertion of plate . This packing plate is a cage which was made of mild steel having 30 mm cut bars at top and bottom. Mild steel round rings of 3.175 cm were used as packing material.

Figure: 3.2. Stainless Steel and Mild steel cylinders for Main Reactor Body

3.1.4.2.Grate

Thegrate was placed at the bottom of the reactor body. It is a round circular plate made of stainless steel having the same diameter as the reactor body. The main purpose of grate is to support the biomass and provision of ash passage down while passing the blown air to top. It contains 10 mm circular holes at surface which was selected according to average feed size.

3.1.4.3.Ash chamber

Just below grate ash chamber provision was made. It is square box made of mild steel having the ash collection window at one side while air blow supply line at the other side. Air blow supply line of 3.175cm diameter was introduced just below the grate.

3.1.4.4.Thermocouples

K-type thermocouples were used to measure the temperature at different sections. Four thermocouples were installed in reactor body as mentioned in section 3.4.1 to measure the temperature of zones, Drying, Pyrolysis, Reduction and Combustion. One thermocouple was installed at exit line to measure the gas temperature.

Figure 3.3. Welding of reactor body, Ash Chamber and Provision for Thermocouples

3.1.4.5.Cyclone

Cyclone separator was actually designed and fabricated to remove solid particles and tar with condensate to get the best quality of producer gas. Conventional cyclone dimensions were selected as design values. Cyclone is made of mild steel low gauge sheet having gas exit pipe at top.

Figure 3.4: Cyclone body Preparation at Workshop

3.1.4.6. Gas sampling port

A gas sampling port allocation was made at gas exit pipe of cyclone separator. A polythenehose was connected at main nozzle of the valve in this port and then the pipe was passed through a cool water bath to lower the temperature of gas and then other side was connected to a gas collecting bag. Gas bag valve was fully opened and then closed after sufficient collection for analysis as shown in Figure 3.5.

a

b

Figure 3.5. (a) Gas sampling port : (b) Gas collecting

3.1.4.7.Panel and other auxiliaries.

Panel consists of two digital meters for temperature reading. Small digital meter is used for exit gas temperature reading while another is used for multizone temperature measurement. For multizone a regulator was installed and four thermocouples connections were made via this regulator to the digital meter. The regulator numbers 1, 2, 3 and 4 are for drying, combustion, reduction and pyrolysis zone temperature readings respectively.

Figure 3.6: Panel of unit

3.1.4.8.Insulation

Reactor body was insulated with rock wool insulation of sufficient thickness to minimize the heat losses.

3.1.5. Air supply and velocity measuring

A3 inch 220/110 V blower having 3000/3600 rpm was used. The air blowerhas a supply line of 3.175cm diameter and a gate valve to control the air supply while small section in pipe was made to measure the air velocity by using a digital anemometer. By measuring the velocity and with the known diameter of the pipe we can calculate air flow rate.Specifications of instrument are given below in Table 3.1.

Table 3.1: Specification of Instrument

Anemometer [Hot wire with temperature sensing probe]	
Type	Digital RS-232
Model	AVM 714
Circuit	Custom one-chip of microprocessor LSI circuit
Display	13 mm (0.5") super large LCD display (dual function meter's display)
Sampling Time	approx. 0.8 sec.
Operating Temperature	0°C to +50°C
Power supply	1.5V AAA (UM-4) battery x 6 pcs. (alkaline or heavy duty type)
Range	0.2 to 20 m/s
Main Instrument and Telescope probe Dimension	180 x 72 x 32 mm& round 72 mm dia., L = 250 to 940 mm

Figure 3.7. Digital Anemometer

Figure 3.8: Blower and supply line with control valve

Figure 3.9: Complete overview of fabricated unit

3.2.FEED STOCK PREPERATION, ANALYSIS AND OPERATION

3.2.1. Biomass feed stock

Following raw materials shown in Figure 3.10 were used for this study as the biomass feed stock.

- Coconut shell
- Mango pit
- *Gliricidia sepium* (Ginisyria)
- Mixture (50%,25%,25% Coconut shell, Mango pit & Ginisyria Respectively). Mixing proportions were taken as arbitrary values.

3.2.2. Feed stock collection

- Coconut shell was collected from local market (Colombo)
- Mango Pit was collected from juice factory in Jaffna
- Ginisyria was collected from local Market (Moratuwa)

a b c

Figure: 3.10:Biomass Feed Stock (a) Mango Pit (b) Coconut shell(c) Ginisyria

3.2.3. Feed stock sizing and preparation

In the present study the biomass particles havingan average size 25 mm were selected from each feedstock. The sizing was done according to requirement by following methods.

- For coconut shells hammer mill was used to reduce the size as required.

- For mango pit, first seed of material was removed from shell then shell (Pit) was sized for specific requirement manually using cutter and hammer.
- Ginisyria as it was collected in large pieces, desired particles were obtained by using a wood cutting machine in wood workshop of the University of Moratuwa.
- All raw materials were sun dried to reduce moisture as much as possible for number of days and then packed to prevent it from environmental impacts.
- Mixture sample was prepared as described in section 3.2.1 from all these above prepared materials and then packed and stored until it is used in the gasification process.

Figure 3.11: Sized Material (a) Coconut Shell (b) Ginisyria

3.2.4. Elemental analysis of biomass feed stock

Fuel properties of materials were tested in energy laboratory of Department of Chemical and Process Engineering, University of Moratuwa as per Labstandard method. From the laboratory analysis the average density of biomass was calculated as 350 kg/m^3 and this value was used for design of the gasifier.

3.2.4.1. Proximate analysis

In proximate analysis, moisture contents, ash contents, volatile matters and fixed carbon contents were determined from lab analysis results. Below given procedure was adopted for mentioned analysis. Equations and formulas used for this calculation and tabulated results of all analysis are presented in Appendix B.

3.2.4.1.1. Determination of moisture contents.

Samples were weighted accurately in a petrydish spreadingevenly over the dish surface. These samples were then introduced into an oven for 1 hour at 100 °C. After removing samples from oven they were placed in a desiccator for 10 minutes to cool and then weighted.

3.2.4.1.2. Determination of ash contents

Samples were weighted accurately in crucibles. It was then kept in the muffle furnace for one hour where the temperature was maintained at about 700 °C . It is then cooled in desiccator & weighted. The color of ash was noted, as generally observed red ashes contain iron contents and readily tend to form clinker while white ashes are Anorc refractory and form clinker only at very high temperatures.

3.2.4.1.3. Determination of volatile matters (VM)

Samples were weighted accurately after moisture determination in crucibles. It was then introduced in to the muffle furnace and kept there for about 7 minutes. The temperature of furnace was maintained at about 700 °C during thistime . It is then cooled in desiccator & weighted. Crucibles were covered with lid as per standard method directions.

3.2.4.1.4. Coke residue

The residue determined after removal of Volatile matter was investigated as soft.

3.2.4.1.5. Determination of fixed carbon

It was calculated by subtracting weight of ash from the weight of residue obtained after volatile matters determination.

3.2.4.2.Ultimate analysis

The analysis used for determination of percentage of carbon, hydrogen, nitrogen, oxygen etc. is called ultimate analysis. Percentage of respective components was calculated by using equations presented in Appendix B.

3.2.4.3. Calorific value of biomass

Calorific value was measured by using bomb calorimeter. The calculated value from this analysis was 18.5 MJ/kg. This average heating value was selected for all kinds of biomass design of the gasifier.

3.2.4.4. Biomass formulas determination based on elemental analysis.

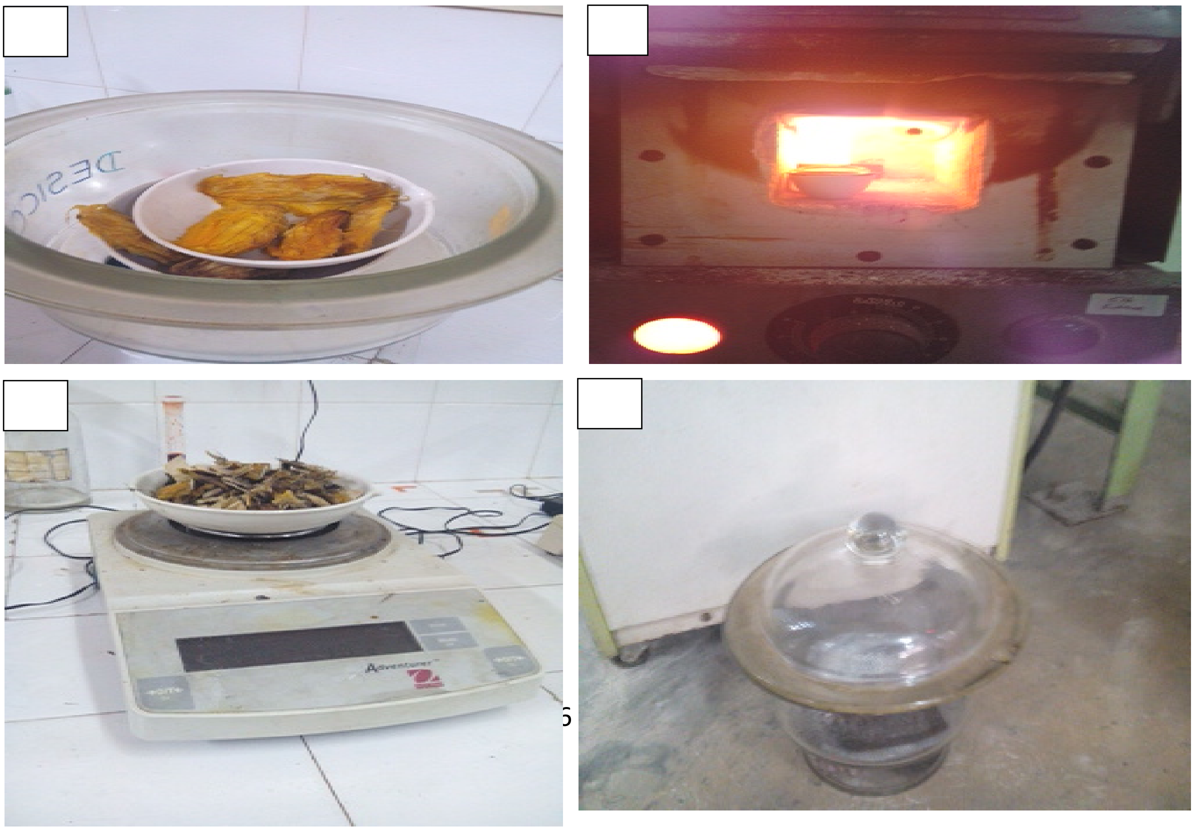
In the determination of formula only C, H and O components were considered while it was assumed that sulfur contents are not present or in very low quantity and were neglected.

Development of formulas is significant because air used for gasification calculation is highly dependent on this. Therefore in this study A/F $_{stoic}$ ratio used was based on the developed formulas presented below for each feed stock biomass.

- Coconut Shell : $C_{3.39}H_{4.47}O$
- Mango Shell: $C_{2.40}H_{3.22}O$
- Ginisyria: $C_{2.85}H_{3.69}O$
- Mixture: $C_{2.59}H_{5.42}O$

3.2.5. Laboratory equipment's used for feed Stock analysis.

Major Laboratory equipment used in feed stock analysis is petry dish, crucibles, weight balance, muffle furnace, oven, and desiccator. Pictorial view of those is given below in Figure 3.12.



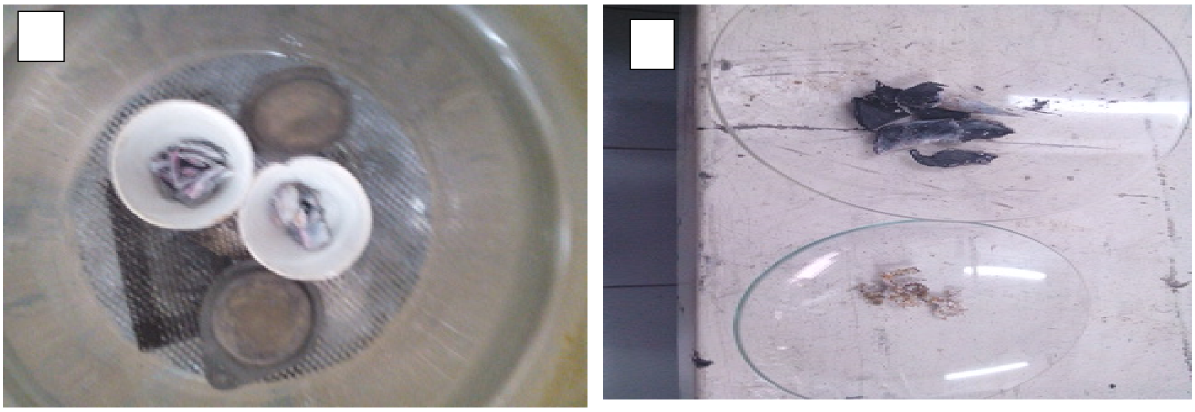


Figure 3.12:Pictorial View of Laboratory Equipment used for Biomass Elemental Analysis. **(a)** Jar ,**(b)** Muffle Furnace,**(c)** Weighing Balance **(D)** Desiccator**, (E)** Crucibles **(F)** Petry Dish

3.2.6. Operational procedure

Gasifier operation requires critical control and attention. Operational procedure for each batch was the same.In case of operation with packing plate the only difference wasto place the packing plate at allocated provision and packing material on it. Operational procedure was carried out as follows.

- Biomass material was weighted by using weight balance. Top cover plate was unbolted from reactor while ash window was unbolted and opened as well.
- Panel and blower were set in ready mode by plugging switches in socket.
- Panel switch was turned ON and initial temperature was noted which was ambient air temperature.
- Burning coke particles were placed on grate for ease in burning startup.
- Biomass weighting 28 kg was introduced carefully intothe reactor chamber. Because it is batch operation this quantity was assumed sufficient for smooth operation at maximum design value.
- Top cover plate with seal was fixed after filling with biomass and bolted tightly to prevent it from leakage.
- Gas exit valve and air supply pipe valve was fully opened.
- After that fire was introduced from ash window. Assuring sufficient burning has been started by noticing increase in temperature of combustion

zone,blower was turned on.Then ash window was closed and tightened by fixing bolts.

- Air velocity was measured by using anemometer at allocated point and adjusted by using gate valve.
- Gas collecting bags were connected to the sampling plastic pipe at one end which was connected to sampling port at the other end. The plastic pipe was passed through cold water bath to reduce the gas temperature.
- Immediately after starting, white smoke was observed coming out. A few minutes later the gas coming out started to burn.
- Flare last for long time.However during a small interval of time it disappears.This inconsistency might be due to presence of moisture or changes in reaction timing occurring in chambers.
- Flare was reddish; however blue color was also observed which is an indication of presence of methane.
- During gas burning, valve of gas bags was opened immediately and collected sufficient amount of gas for analysis. After that sample collecting valve was closed.
- During operation, temperature of each zone was noted at every 15 minutes interval.
- Highest temperature recorded was 1020 degree °C in combustion zone during in all batches while operation.
- A bucket was placed at the bottom of cyclone separator for collection of solid particles, and condensate which was of black color.
- When gas stops coming out of gas exit, the air supply valve was closed and blower was turned off.
- Unit was let for cooling by observing decrease in temperature at different locations of reactor. After taking all the reading panel was switched off.
- In case of trials with packing plate, the only change in procedure was to open the packing plate provision window and by inserting the plate with packing material. While all other procedure was carried out in same manner.
- All trials without packing and with packing for each biomass were carried out at variant air velocity (Variation in A/F and ER).

- Before starting each batch, ash, coke and condensate of previous batch were removed manually observed and weighted.
- Thermocouples were removed for cleaning and reinstalled before starting again for the next batch.
- After cleaning the unit is verified to see whether it is ready for another batch operation.

Trials were performed and total 16 samples were collected for gas analysis. Solid residue and condensate were obtained as by product. Pictorial view of operation is presented below in figure 3.13.

Figure 3.13: Pictorial view of operation (a) white smoke at start (b) Temperature Reading (c,d,e,f,h) Flames, (g) Char (i) Packing plate provision (J) Black Condensate

3.2.7. Gas analysis

Gas analysis was performed at renewable energy department of NERDC, Sri Lanka. GC-2014 Analyzer was used for determination of composition with column capable for tracing hydrocarbon contents as well. GC analyzer was connected to a PC and a printer.

3.2.8. Balances work

In this section equation 3.6-3.24[7] are used for calculation of different parameters which are described below.

I. Specific gas production: Gas to Fuel ratio

Carbon balance is used to determine the G/F which is given as following

$C_f = C_g + C_{c-a} + C_t$……… ……………...Eq.(3.6)

Where

C_f= Rate of carbon entering the gasifier with fuel (kg/hr)

C_g= Rate of carbon leaving with Producer gas

C_{c-a}= Rate of carbon leaving with char-ash

C_t= Rate of carbon leaving with tar

Assuming carbon in char-ash and tar is negligible compared to carbon in the producer gas then equation 3.6 becomes

$C_f = C_g$……………………………………Eq.(3.7)

C_f is carbon in fuel;

$C_f = C\ wt\ \%\ in\ fuel \times FCR$……………...Eq.(3.8)

Where F is fuel consumption rate (FCR in kg/hr), calculations for other biomasses are in similar manner. So by putting the values of Eq. 3.8 into 3.7 we get the following resultant equation.

$C\ wt\ \%\ in\ fuel \times FCR = Cg$ ……………………………………...Eq.(3.9)

Volumetric fraction of carbon in the producer gas is computed as follows:

$$C_{gv} = \sum \frac{(\%\ \text{of C comp} \times \rho\ \text{of C comp} \times \text{C wt.per mole})}{\text{Molecular weight of component}}$$ …………………Eq.(3.10)

However $C_g = C_{gv} \times G$ ………………………………Eq.(3.11)

Where G = Producer gas flow rate (m^3/h), from Eq. 3.9 and 3.11 we get the following

C in fuel×FCR= $C_{gv} \times G$ …… ………………………...Eq.(3.12)

$$\frac{G}{F} = \frac{0.506C \text{ wt \% in fuel}}{C_{gv}} \quad \text{…….Eq.(3.13)}$$

II. Air to Gas ratio (Specific air consumption)

Nitrogen balance is used for calculation of this parameter

$$N_f + N_a = N_g \quad \text{…….Eq.(3.14)}$$

Where

N_f= Nitrogen in fuel (kg/hr)

N_a = Nitrogen in air

N_g= Nitrogen in producer gas

As nitrogen in fuel is very low compare to nitrogen in air so we assume to neglect N_f , then equation becomes

$$N_a = N_g \quad \text{…….Eq.(3.15)}$$

By taking volumetric fraction of nitrogen in air as 0.79;

$$N_a = 0.79A \quad \text{…….Eq.(3.16)}$$

Where A = air flow rate ($m^{3/}h$)

By combining Eq. 3.15 and 3.16 the resultant equation becomes as

$$0.79A = N_g \quad \text{…….Eq.(3.17)}$$

Volumetric fraction of nitrogen in producer gas can be found from composition so

$$N_g = N_{gv} \times G \quad \text{…….Eq.(3.18)}$$

From Eq. 3.17 and 3.18 we get the following resultant equation

$$\frac{\mathrm{A}}{\mathrm{G}} = \frac{N_{gv}}{0.79} \text{ ………………………………….Eq.(3.19)}$$

III. Equivalence ratio

Equivalent Ratio reflects the combined effect of air flow rate and fuel flow rate. This is defined as the ratio of operating air-fuel ratio to Stoichiometric air-fuel ratio.

$$ER = \frac{\left(\frac{A}{F}\right)o}{\left(\frac{A}{F}\right)s} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{Eq. (3.20)}$$

Where

$(A/F)_o$ = Operational Air- Fuel ratio

$(A/F)_s$ = Stoichiometric Air- Fuel ratio

Operational Air-fuel ratiocan be determined from following equation

$$\left(\frac{\mathrm{A}}{\mathrm{F}}\right)\mathrm{o} = \frac{\text{Mass flow rate of air}}{\text{FCR}} = \left(\frac{\mathrm{A}}{\mathrm{G}}\right) \times \left(\frac{\mathrm{G}}{\mathrm{F}}\right) \times \rho \text{ of air ……..Eq.(3.21)}$$

In this study we used calculated stoichiometric values (Appendix B) based on biomass formulas (3.2.2.4). Each biomass taken in this study have different developed formulas so stoichiometric air-fuel ratio is different for each biomass as well.

IV. Lower heating value of the producer gas

Lower Heating value (LHV) of producer gas is determined from the chemical composition of the gas and LHV of individual components.

$$LHV = \sum Vol.\%\ of\ Combustible\ components \times\ LHV\ of\ Comp \text{ ……..Eq.(3.22)}$$

V. Gasification efficiency

$$\eta_g = \frac{\text{LHV of Gas}}{\text{Heating value of fuel}} \times \left(\frac{\mathrm{G}}{\mathrm{F}}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{Eq. (3.23)}$$

VI. Gasifier efficiency

$$\eta_{th} = \frac{(LHV\ of\ Gas + \rho_g \times C_{p.g} \times \Delta T)}{Heating\ value\ of\ fuel} \times \left(\frac{G}{F}\right) \text{.......................................Eq.(3.24)}$$

Where

η_{th} = Thermal efficiency of gasifier

ρ_g= Density of producer gas (1.3 kg/Nm^3) [43]

$C_{p.g}$= Specific heat of producer gas (1.45 kJ/kg K [43]

ΔT= Temperature difference between fuel inlet and producer gas outlet

LHV of gas = Lower heating value of producer gas MJ/Nm^3

3.2.9. Stoichiometric air and air velocity calculation

Required air flow rate calculation was done according to biomass formulas developed, presented in section 3.2.4.4. We assume that nitrogen is leaving without reaction. Balanced Stoichiometric equations for all biomass materials are as following

Coconut shell

$C_{3.39}H_{4.47}O + 4(O_2 + 3.76N_2) \rightarrow 3.39CO_2 + 2.23H_2O + 15.41N_2$.........Eq. (3.25)

Mango pit

$C_{2.40}H_{3.22}O + 2.71(O_2 + 3.76N_2) \rightarrow 2.40CO_2 + 1.61H_2O + 10.18N_2$......Eq.(3.26)

Ginisyria

$C_{2.85}H_{3.69}O + 4.19(O_2 + 3.76N_2) \rightarrow 2.85CO_2 + 3.69H_2O + N_2$..............Eq.(3.27)

Mixture

$C_{2.59}H_{5.42}O + 4.8(O_2 + 3.76N_2 \rightarrow 2.59CO_2 + 5.42H_2O + 15.41N_2$.........Eq.(3.28)

Stoichiometric air required is calculated as for coconut shell.

Molecular weight of coconut shell biomass = 61.18 kg

Oxygen-Fuel mass ratio= $\frac{4\times32}{1\times61.18}$ = 2.09 kg of oxygen /kg of fuel

Oxygen in air by mass percent is 23.2 so we need

$2.09\times\frac{100}{23.2}=9.01$ kg of air /kg of feed

In similar fashion stoichiometric air for other biomasses is given in Table 3.2

Table 3.2: Stoichiometric air for biomass feed stock

Sr. No	Biomass	Stoichiometric air
1	Mango pit	7.75
2	Ginisyria	10.69
3	Mixture	12.5

In our experimental setup as per objective for equivalence ratio 0.2 and 0.25 we have to know air flow rate. From this calculated air flow rate and by known diameter of pipe we have calculated air velocity for respective equivalence ratio. This air velocity was measured by using anemometer and maintained at desired value by control valve. Air flow rate is calculated by using following equation[42]

$$Air\ flow\ rate=\frac{ER\times FCR\times Stoichiometric\ air\ fuel\ ratio}{\rho\ of\ air}$$

$$air\ flow\ rate=\frac{0.2\times7.0\times9.01}{1.225}$$

Air flow rate = 10.29 m^3/h

To measure the velocity which we have to measure and control we know the pipe diameter (0.03175 m) and volumetric air flow rate. First we have to calculate the area of pipe.

$$Area\ of\ pipe = \frac{\pi D^2}{4} = \pi \times \frac{0.03175^2}{4}$$

Area of pipe = $7.91 \times 10^{-4} m^2$

Now from above described data we can find velocity

$$Velocity = \frac{volumetric\ flow}{area\ of\ pipe}$$

$$Velocity = \frac{10.29}{7.91 \times 10^{-4}} = 3.61\ m/s$$

In similar fashion velocity was calculated for different biomasses for equivalences ratio 0.2 and 0.25 which can be seen in Table 3.3 below.

Table 3.3: Air velocity at different ER

For Equivalence ratio 0.2			
Sr.No	Biomass	Volumetric Flow (m^3/h)	Velocity (m/s)
1	Coconut shell	10.29	3.6
2	Mango Pit	8.85	3.1
3	Ginisyria	14.96	5.2
4	Mixture	14.28	5.0
For Equivalence ratio 0.25			
1	Coconut shell	12.87	4.5
2	Mango Pit	11.07	3.8
3	Ginisyria	15.27	5.3
4	Mixture	17.8	6.2

Chapter 4- Results and Discussion

4.1. Elemental analysis of biomass

4.1.1. Proximate analysis

Figure 4.1 shows the fuel properties of different biomass.

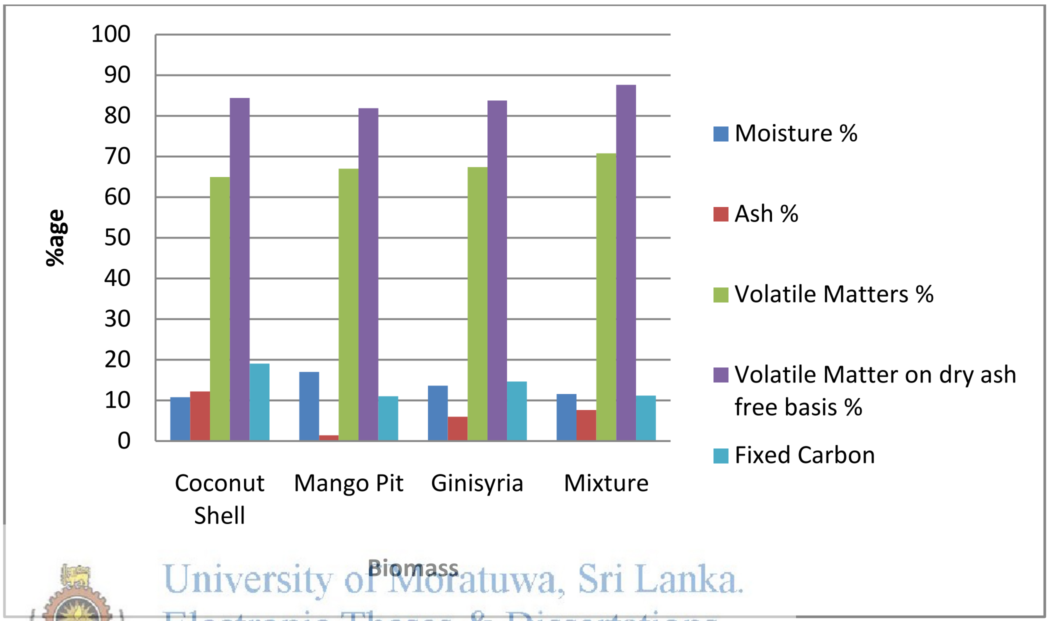


Figure 4.1: Determination of fuel properties of different biomass

It is observed that mango pit shell has highest moisture contents among all while it has low ash contents. Mixture has high volatile contents.

4.1.2. Ultimate analysis

The ultimate analysis results of biomass having C, N_2, H_2 and O_2 contentsby weight are shown in Table 4.1. A high O_2 content is shown in mango pit shell compared to that in other biomass.

Table 4.1: Ultimate Analysis of biomass fuel (Appendix B)

Sr.No	**Component**	**Mango shell**	**Coconut Shell**	**Gliricidia**	**Mixture**
1	C %	48.1	50.6	50.4	53.52
2	N_2%	0.98	0.83	0.911	0.87
3	H_2%	5.41	5.6	5.48	5.52
4	O_2%	26.7	19.87	23.5	20.6

4.2.Producer gas composition

Table 4.2: Producer gas composition (by volume percentage) for different biomass materials without packing plate at variant equivalence ratio

Material	**ER**	**H_2%**	**N_2%**	**CH_4%**	**CO%**	**CO_2%**	**C_2H_4%**	**C_2H_6%**
Coconut Shell	0.2	7.017	46.264	2.136	21.739	14.463	0.084	0.121
	0.25	5.627	48.24	1.149	22.003	7.678	0	0.106
Mango Pit	0.2	2.786	42.995	3.491	11.542	24.077	0.268	0.271
	0.25	5.892	47.863	2.409	11.075	17.969	0.149	0.165
Ginisyria	0.2	7.741	46.106	1.982	20.112	11.053	0.057	0.123
	0.25	4.356	50.902	0.667	22.434	6.325	0	0
Mixture	0.2	5.394	49.218	2.024	13.095	12.979	0.133	0.15
	0.25	4.89	53.346	2.119	9.121	13.385	0.096	0.125

Table 4.3: Producer gas composition (by volume percentage) for different biomass materials with packing plate at variant equivalence ratio

Material	**ER**	**H_2%**	**N_2%**	**CH_4%**	**CO%**	**CO_2%**	**C_2H_4%**	**C_2H_6%**
Coconut Shell	0.2	8.18	45.3	3.085	14.45	19.3	0.18	0.15
	0.25	5.627	48.24	1.149	22.003	7.678	0	0.106
Mango Pit	0.2	5.336	42.935	3.405	9.859	23.147	0.181	0.219
	0.25	5.892	45.3	2.409	10.075	18.9	0.149	0.165
Ginisyria	0.2	7.2	45.862	2.376	14.996	14.531	0.1	0.182
	0.25	6.066	50.9	1.72	14.249	11.5	0.151	0.079
Mixture	0.2	6.066	47.05	1.72	14.249	11.84	0.151	0.079
	0.25	7.017	46.264	2.066	6.837	12.327	0	0

4.3.Specimen for parameters calculation

For specimen calculation values of coconut shell without packing plate at ER of 0.2 are hereby selected. For the others same calculation procedure has been applied and results are presented in Table 4.5 and 4.6. Equations used for specimen calculation are described in detail in section 3.2.8 (Chapter 3).

4.3.1. Calculation of air to gas ratio

Percentage of nitrogen in producer gas is known, N_{gv}=46.264 %.

$A/G = N_{gv}/0.79 = 0.46264/0.79$

=0.5856

4.3.2. Calculation gas/fuel Ratio

$$C_{gv} = \sum \frac{(\text{\% of C comp} \times \rho \text{ of C comp} \times \text{C wt.per mole})}{\text{Molecular weight of component}}$$

$$C_{gv} = \sum (0.0214 \times 0.717 \times \frac{0.012}{0.016}) + (0.2174 \times 1.25 \times \frac{0.012}{0.028}) + (0.1446 \times 1.977 \times \frac{0.012}{0.044}) + (0.0008 \times 1.261 \times \frac{0.012}{0.028}) + (0.0012 \times 1.335 \times \frac{0.012}{0.03})$$

$$C_{gv} = 0.207$$

Gas to fuel ratio is calculated by using equation

$$\frac{G}{F} = \frac{\%age\ of\ C\ inbiomass}{C_{gv}} = \frac{0.50}{0.207} = 2.44$$

4.3.3. ER Calculation

$$\left(\frac{A}{F}\right)o = \left(\frac{A}{G}\right) \times \left(\frac{G}{F}\right) \times \rho \text{ of air} = 0.5856 \times 2.44 \times 1.245 = 1.78$$

A/F operating we have calculated while A/F stoichiometric description is given in section 3.2.9. In this study we are using calculated values based on formulas developed, presented in previous chapter (Chapter 3) so we will encounter different values of (A/F)s for different biomasses due to difference in elemental composition. For coconut shell this value is 9.01 and ER is calculated as.

$$ER = \frac{operational}{Stoichometric} = \frac{1.78}{9.01} = 0.2$$

4.3.4. Calculation of LHV and HHV of producer gas

Lower heating values can be calculated by using equation 3.22 described in previous chapter and the same equation can be used for HHV calculation as well. LHV and HHV of producer gas components are presented in Table 4.4.

Table 4.4: Lower and Higher Heating Value Calculation*[44]

Component	Composition(%)	*LHV (MJ/m^3)	*HHV (MJ/m^3)
N_2	46.264	-	-
H_2	7.017	10.783	12.745
CH_4	2.136	35.883	39.819
CO	21.739	12.683	12.633
C_2H_4	0.084	59.457	63.414
C_2H_6	0.121	64.345	70.293
CO_2	14.463	-	-
Calorificvalueofproducergas(MJ/m^3)		4.4	4.6

$$LHV = \sum Vol.\%\ of\ Combustible\ components \times\ LHV\ of\ Comp$$

$$LHVg = \sum(7.017 \times 10.783 + 2.136 \times 35.883 + 21.739 \times 12.683 + 0.084 \times 59.457 + 0.121 \times 64.345) = 4.40 \text{ MJ/m}^3$$

Same calculation procedure was applied for HHV calculation only by inserting the HHV of gas component values. Results of HHV are also presented in Table 4.5 and 4.6.

4.3.5. Gasification efficiency

Gasification also termed as cold gas efficiency is measured when producer gas has application for power generation.

$$\eta_g = \frac{\text{LHV of Gas}}{\text{Heating value of fuel}} \times \left(\frac{\text{G}}{\text{F}}\right) = \left(\frac{4.4}{18.5}\right) \times 2.44 \times 100 \; = \; 58.27\%$$

4.3.6. Gasifier Efficiency.

When producer gas is used for thermal application then efficiency is termed as gasifier efficiency

$$\eta_{th} \; = \frac{(LHV\ of\ Gas + \rho_g \times C_{p.g} \times \Delta T)}{Heating\ \ value\ \ of\ fuel} \times \left(\frac{G}{F}\right) = \left(\frac{4400 + 1.3 \times 1.45 \times 395}{18500}\right) \times 2.44 \times$$

$100\eta_{th}$ =67.7%

4.4. Analysis of parameters

Variations of parameters such as G/F, A/F, LHVg and ER with respect to different equivalence ratio for all feed stock trials without packing plate and with packing plate are presented in below given Tables 4.5 and 4.6.

4.4.1. Variation of parameters for different biomass with variant ER

Table 4.5: Variation of parameters for different biomass without packing plate

Biomass	**ER**	**A/G**	**G/F**	**LHV_g** MJ/Nm^3	**HHV_g** MJ/Nm^3	**η_g%**	**η_{th} %**
Coconut Shell	0.2	0.5856	2.4441	4.40	4.6	58.23	67.7
	0.25	0.6106	3.0479	3.87	4.0	63.88	74.7
Mango Pit	0.2	0.5442	2.2501	3.35	3.56	40.75	47.50
	0.25	0.5734	2.8094	3.09	3.31	47.06	54.79
Ginisyria	0.2	0.5836	2.8162	4.20	4.43	64.85	75.12
	0.25	0.6443	3.1925	3.55	3.65	61.33	73.45
Mixture	0.2	0.6231	3.3435	3.14	3.33	56.82	65.0
	0.25	0.6753	3.817	2.58	2.76	53.72	62.79

Table 4.6: Variation of parameters for different biomass with packing plate

Biomass	**ER**	**A/G**	**G/F**	**LHV_g** MJ/Nm^3	**HHV_g** MJ/Nm^3	**η_g%**	**η_{th} %**
Coconut Shell	0.2	0.5734	2.502	4.02	4.31	54.44	63.5
	0.25	0.6106	3.03	3.87	4.02	63.63	72.4
Mango Pit	0.2	0.5435	2.3728	3.29	3.54	42.27	48.8
	0.25	0.5734	2.8149	2.97	3.19	45.22	56.3
Ginisyria	0.2	0.5805	2.8906	3.70	3.94	57.92	68.8
	0.25	0.6443	3.3596	3.21	3.41	58.45	66.6
Mixture	0.2	0.5956	3.5178	3.21	3.41	61.21	69.8
	0.25	0.5856	4.3782	2.36	2.58	55.97	67.0

4.5.Graphical analysis of performance parameters

4.5.1. Variation of LHV of producer gas

Variation of LHV of product gas with ER variation for both cases without and with packing has been studied and results are presented &discussed below in Figure 4.2 & 4.3.

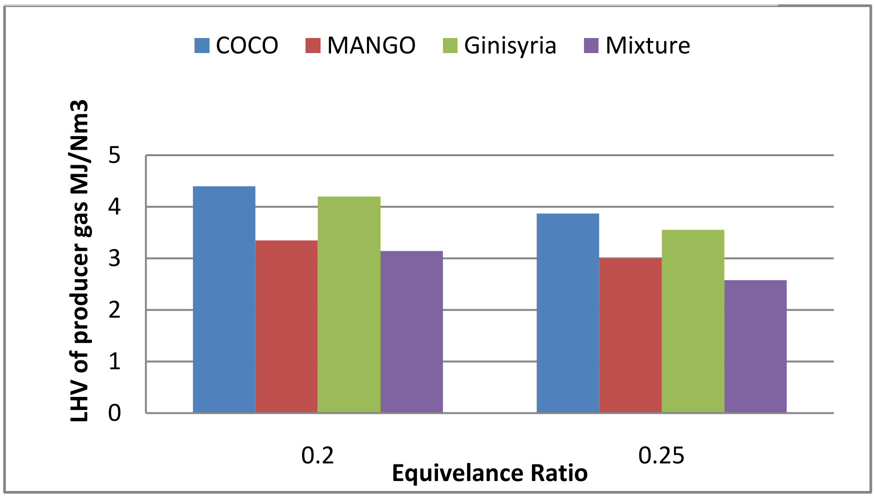


Figure 4.2: Variation of LHV of producer gas with equivalence ratio for different biomass without packing Plate.

As it can be observed from above figure that coconut shell has highest heating value among all while mixture has the lowest. Mango pit shell has energy contents lower than gliricida and coconut shell but higher than the mixture. With increase in equivelance ratio decreasing trend in LHV for all feed stock has been observed.

Figure 4.3 below is presenting the comparison of LHV of producer gas obtained from different biomass with variation of ER by using packing plate. It shows that coconut shell has energy contents 4.0 MJ/Nm^3 which is highest among all. While comparing figure 4.2 and figure 4.3 it is observed that with increase in equivelance ratio heating value has decreased.

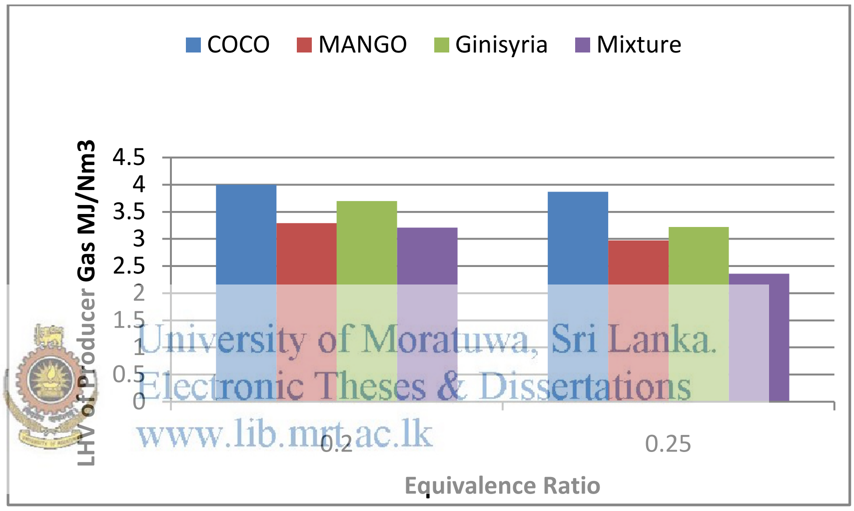


Figure 4.3: Variation of LHV of producer gas with equivalence ratio for different biomass with packing Plate.

4.5.2. Comparison of LHV of producer gas with and without packing plate

In this section LHV of producer gas comparison without and with packing plate has been studied. Results of lower heating value are presented and discussed below in Figure 4.4 & 4.5.

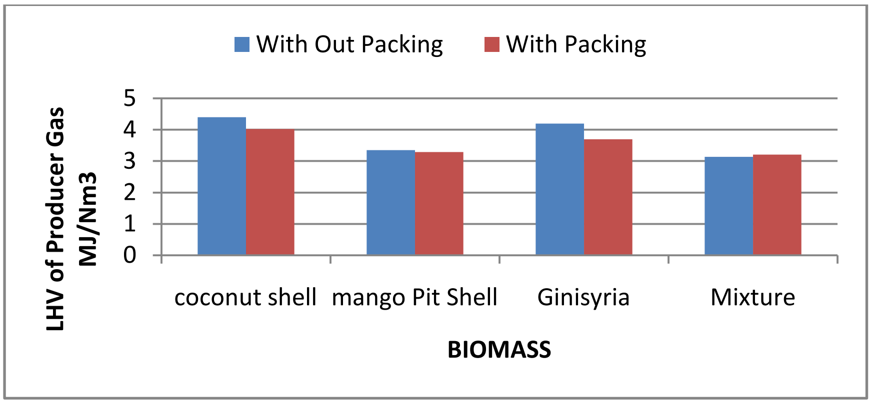


Figure 4.4: Comparison of LHV of producer gas with packing and without packing for different biomass at equivalence ratio 0.2.

From above graph it has been clearly observed that heating value obtained without packing plate was good rather than with packing plate for all tested feed stock. This might be due to shrinkage effect of biomass particles, resistance to heat and mass transfer.

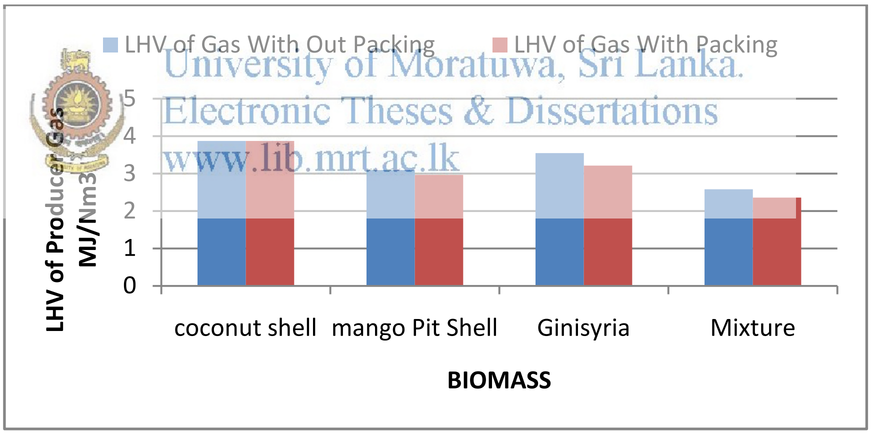


Figure 4.5: Comparison of LHV of producer gas with packing and without packing for different biomass at equivalence ratio 0.25.

From above figure which is indicating that at increased air flow, LHV of coconut shell did not have so much variation while for other feed stock lower heating value in without packing case is higher. Highest value was achieved by coconut shell.

4.5.3. Gasification efficiency variation with ER

Gasification efficiency which is also termed as cold gas efficiency is studied and discussed here. The variation of cold gas efficiency with air flow rate for different biomass materials with and without packing plate results are presented in Figures 4.6, 4.7 & 4.8.

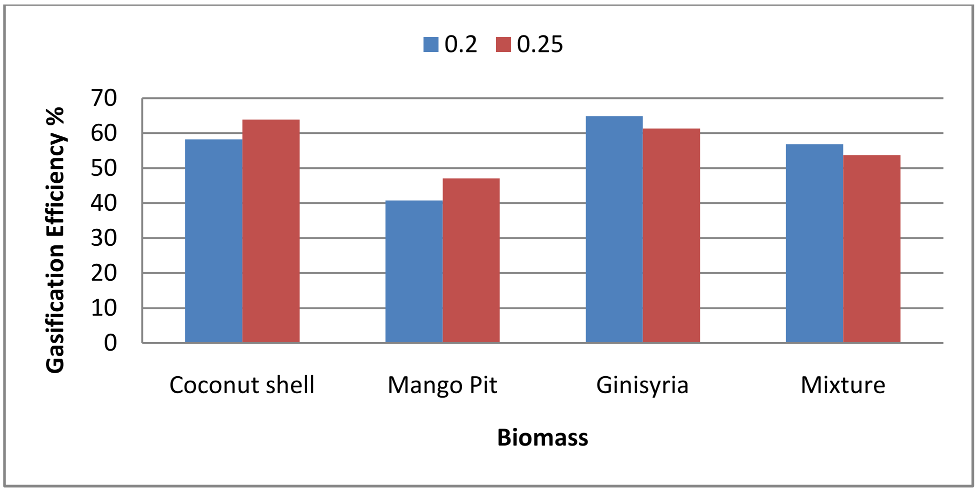


Figure 4.6: Variation of Gasification efficiency(Cold Gas Efficiency) with variation of ER for different biomasses without packing plate.

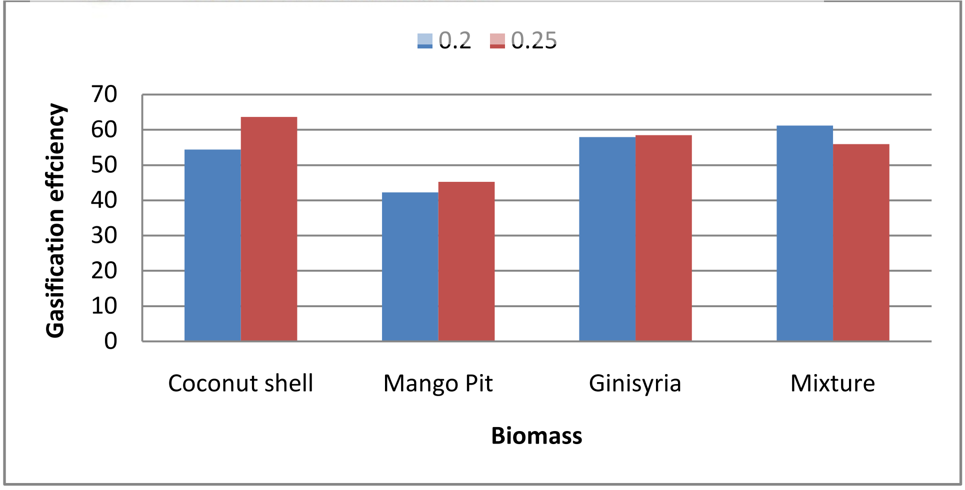


Figure 4.7: Variation of Gasification efficiency (Cold Gas Efficiency) with variation of ER for different biomass with packing plate.

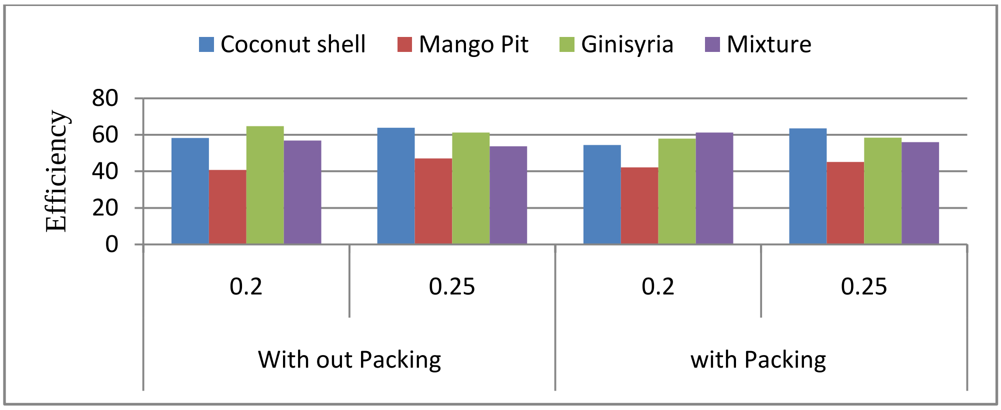


Figure 4.8: Comparison of Gasification efficiency Variation (Cold Gas Efficiency) with variation of ER for different biomass with and without packing

Above Figure describe that in the case of without packing plate cold gas efficiency for coconut shell and mango pit shell increased with ER while decreasing trend has been observed for other two feedstocks. Variation in ginisyria is small comparedto other materials. This variation trend is due to different properties of material in terms of parameters such as lower heating value, G/F etc.

4.5.4. Variation in gasifier efficiency (Thermal)

Variation in gasifier efficiency at different equivalence ratio for different biomass material without packing and with packing is presented in Figure 4.9 and discussed below

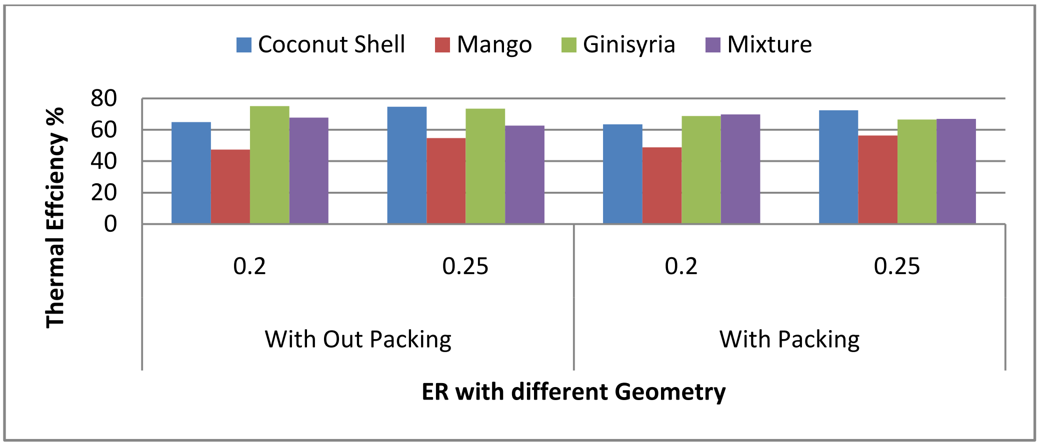


Figure 4.9: Comparison of Variation in gasifier thermal efficiency with ER for without packing plate vs. packing plate for different biomass materials.

From above Figure 4.9 it is concluded that gasifier efficiency at ER 0.2 without packing plate for ginisyria and mixture is higher than other two materials while within same case increase in air flow at ER 0.25 mango pit and coconut shell show increasing trend while other two materials are slightly in decreasing manner. In the case with packing plate same trend as for without packing has been observed. In comparative view of both cases, highest efficiency at ER 0.2 was observed for ginisyria in without packing plate while at ER 0.25 coconut shell has the highest rank.

4.5.5. Variation in producer gas components

Variation in producer gas components with air velocity variation is very much important which is presented here. Variation was studied at two ER values for packing and without packing plate case results of which are presented in Figure 4.10 & 4.11. Figure4.10showsthat in case of without packing plate total of combustible components in producer gas from coconut shell is 31 % which is highest among all. The mixture has the lowest value. In same case increase in flow rate shows a decrease in the fraction of combustible components in producer gas from coconut shell, ginisyria and mixture while a very slight increment is observed for mango pit shell. In the second case with packing plate at ER 0.2 except in mixture and mango which show a little increase in percentage of combustible components, other two materialsshow a decreasing trend compared to without packing plate. At ER 0.25 with packing plate coconut shell did not show a variation while other biomass materials have less values compared to without packing plate at same ER.

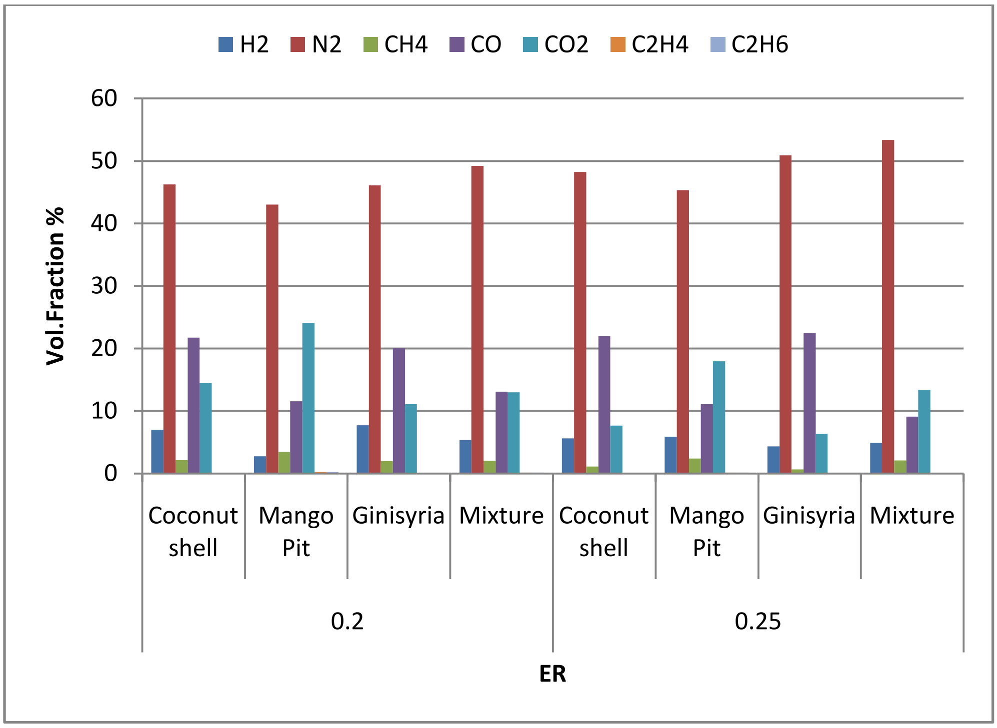


Figure 4.10: Comparison of Variation in producer gas components with equivalence ratio for without packing plate for different biomass materials.

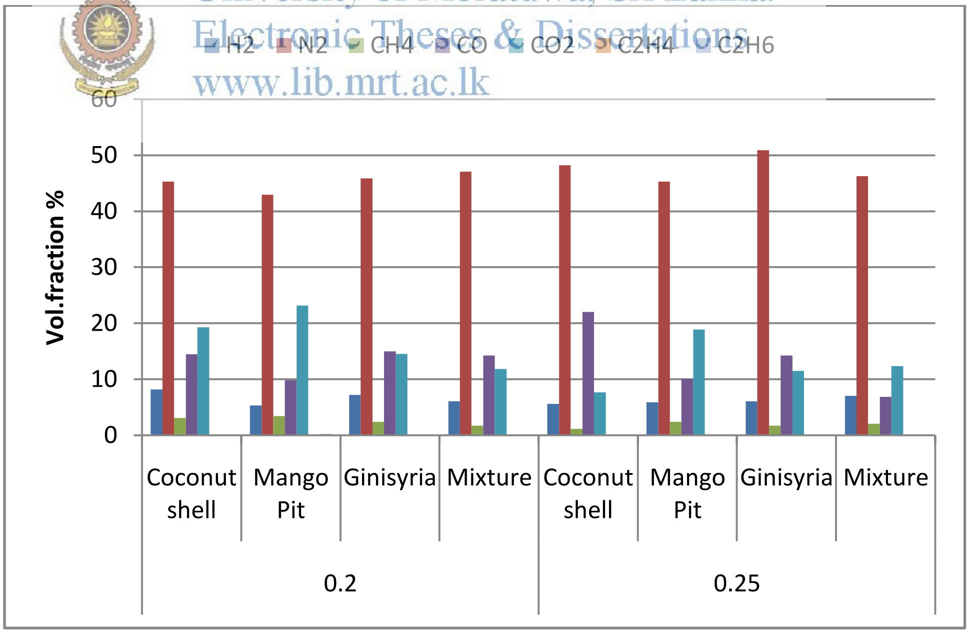


Figure 4.11: Comparison of Variation in producer gas components with equivalence ratiofor with packing plate for different biomass materials.

In case of without packing plate as shown in Figure 4.12, combustible components at ER 0.2 are 31, 18, 29, 20 percent for coconut shell, mango pit shell, ginisyria and mixture respectively. With increase in airflow rate decrease in combustible components has been observed which is 23, 13, 23, and 11 percent for coconut shell, mango pit shell, ginisyria and mixture respectively.

Figure 4.13 shows that combustible components at ER of 0.2 are 25,18,24,22 percent for coconut shell, mango pit shell, ginisyria and mixture respectively. While with increase in air decreasing trend has been observed. Collectively results are lower than without packing plate case.

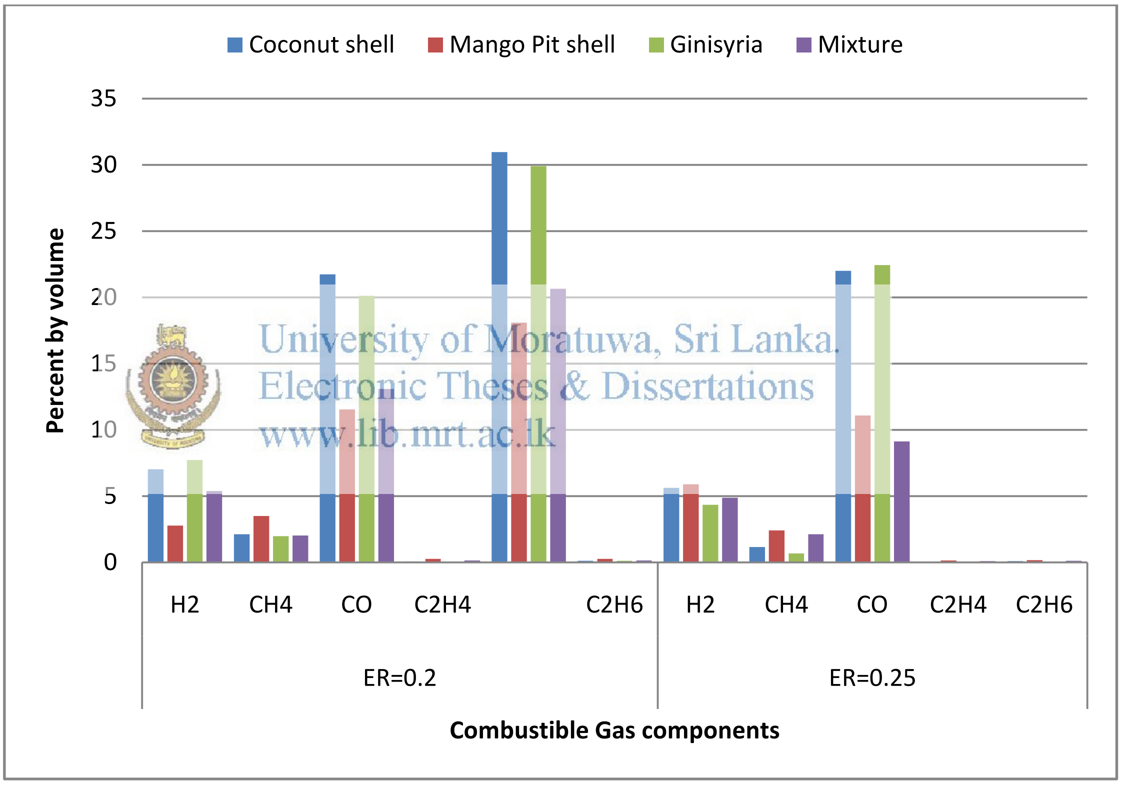


Figure 4.12: Comparison of variation in combustible components of producer gas with equivalence ratio for different biomass materials without packing plate.

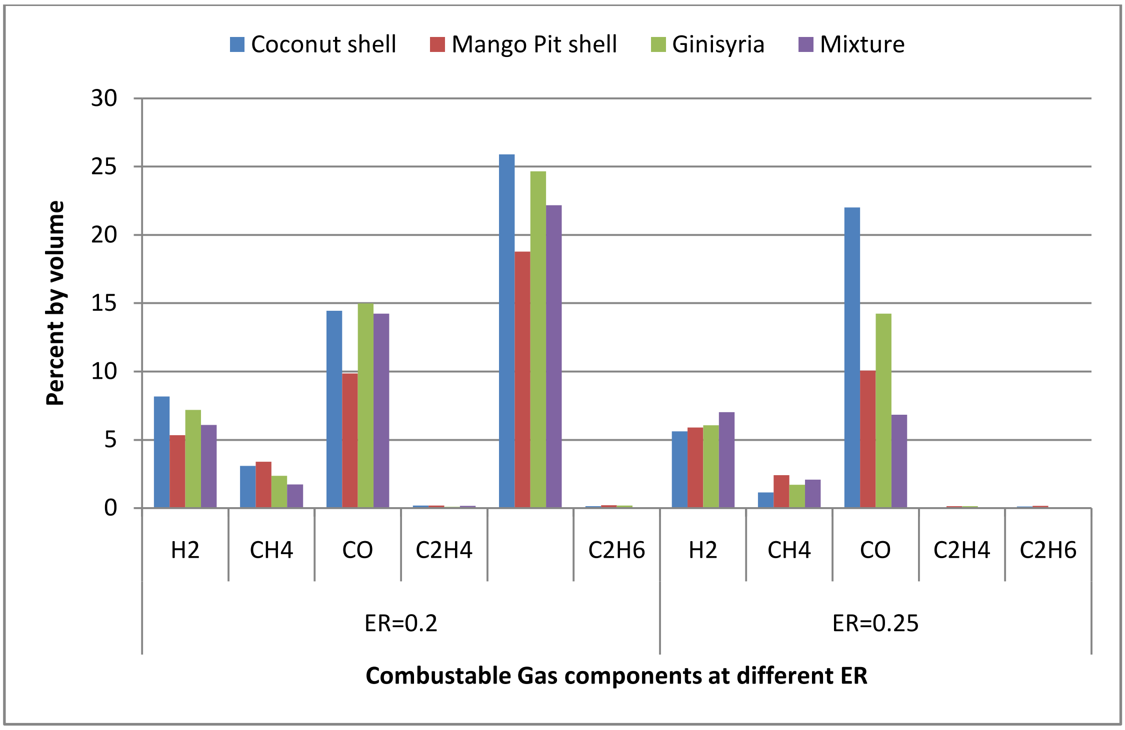


Figure 4.13: Comparison of variation in combustible components of producer gas with equivalence ratio for different biomass materials with packing plate.

4.6. Comparison with previous work

Current study has been compared with previous work in terms of lower heating value of producer gas and composition of producer gas in updraft as well as downdraft gasifier. In Table 4.7 it is clearly depicted that in current study LHV with comparison to LHV of producer gas obtained from downdraft gasifier NERDC is less but very close however with comparison to updraft studied by Prince yadav et,al. our developed gasifier is giving much good heating value especially from coconut shell.

In Table 4.8 it can be clearly seen that in current study two major combustible components namely CO and CH_4 are more than previous studies either in downdraft or updraft but hydrogen contents are more than "Weichan" studies while lower than Dulika,2013 and K.Shiva work and almost very close to Yadav studies.

Table 4.7: comparison in terms of Lower heating value of Gas

NO	**Presenter/ reference**	**Gasifier**	**Biomass/Organization**	**LHV (MJ/Nm^3)**	**Parameter**
1	Duleka, 2013	Downdraft	NERDC	4.6	ER=0.36
2	*Prince Yadav et.all	Updraft	Coconut shell	3.55	N/A
3	Present Work	Updraft	Coconut Shell Mango Pit shell Ginisyria Mixture	4.4 3.35 4.20 3.14	ER=0.2

[*For comparison, parameters and composition at ER=0.2 without packing plate for all studied biomass is selected only.*]

Table 4.8: Comparison in terms of producer gas composition(by Vol.Percentage)

Presenter	**Gasifier**	**Biomass**	**H_2**	**N_2**	**CO**	**CO_2**	**CH_4**	**C_2H_4**	**C_2H_6**
Prince Yadav	Updraft	Coconut shell	9.5	49.4	14	18	2.1	-	-
		Sugarcane waste	8.8	46	9.4	24	1.8	-	-
		Wood Chips	7.5	44.6	8.5	27	1.5	-	-
Duleka	Downdraft	Wood	12.77	49.90	19.48	11.62	1.87	0.19	0.04
Present	**Updraft**	Coconut shell	7.017	46.26	21.73	14.46	2.13	0.084	0.12
		Mango	2.786	42.99	11.54	24.07	3.49	0.268	0.27
		Ginisyria	7.741	46.10	20.11	11.05	1.98	0.057	0.12
		Mixture	5.394	49.21	13.09	12.97	2.02	0.133	0.15
K.Shiva	Downdraft	N/A	21	45	24	15	2.1	-	-
Wei Chen	Updraft	Junipar	5.56	56.42	20.78	14.96	1.9	-	0.37

5. Conclusion

Updraft gasifier unit was successfully designed, fabricated and operated for different biomass feed stocks, s coconut shell, mango pit shell, ginisyria &mixture. Average density of biomass calculated was 350 kg/m^3. This value can vary with the location and state of biomass obtained. Heating value of wood according to different literature is in the range of 18-20MJ/kg while in present study the measured average heating value of biomass was 18.5 MJ/kg .

According to the literature survey almost no studies have been found regarding the usage of mango pit shell, ginisyria and mixture gasification while most of studies have been done for coconut shell using downdraft gasification technique but less in updraft gasification especially in India.

Performance was analyzed in terms of different parameters especially lower heating value of producer gas and it has been found that coconut shell has the highest LHV among all in both cases without packing plate and with packing plate. Mango pit has shown good results as well with LHV of 3.4 MJ/Nm^3 in case of without packing plate. However it is very important to note that gas was almost free from tar contents because much handsome quantity of tar is separated in cyclone separator and obtained from bottom with water contents.

Gasifier performance results with the packing plate in terms of gas LHV was lower than without packing plate. With increase in air flow rate, ER value ,gasifier, as well as gasification efficiency, was observed in increasing trend for coconut shells and mango pit while decreasing trend for ginisyria and mixture. Increase in air increases free nitrogen in product gas composition which is considered as not taking part in reactions. Low results with packing plate might be due to poor heat and mass transfer caused by resistance due to this packing in pyrolysis zone which has major contribution in product yield.

Temperature variation with respect to time in different zones was recorded for different biomasses which can be seen in Appendix A. Maximum temperature was recorded as 1020 °C in combustion zone. It was also observed that initially temperature variation was at sharp rate but with the passage of time it became steady state. With increase in air flow rate increase in temperature was observed as well.

It has been observed that moisture contents of feed stock as well as in air have great impact on quality of producer gas. In present study coconut shell with low moisture contents shown good quality product while mango pit which have more moisture contents have less LHV of producer gas with compare to coconut shell and ginisyria.

5.1. Future Work

In present study batch operation was carried out for different biomass studies in which only air velocity was the controllable parameter. Further studies can be done in following areas.

- By developing continuous feeding system
- Automated controlling strategy for unit
- More depth study for more air velocity variation
- Particle size variation and its impact on process as well as product
- Black condensate obtained as by product can be further investigated which contains black thick liquor which might contain heavy hydrocarbons and can be used to derive more valuable products.
- Char obtained from different biomass can be investigated especially using as fly ash in water treatment processes.
- Impact of moisture contents variation of feed on process parameters and product yield.

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APPENDICES

Appendix –A: Temperature profiles summary of gasifier zones

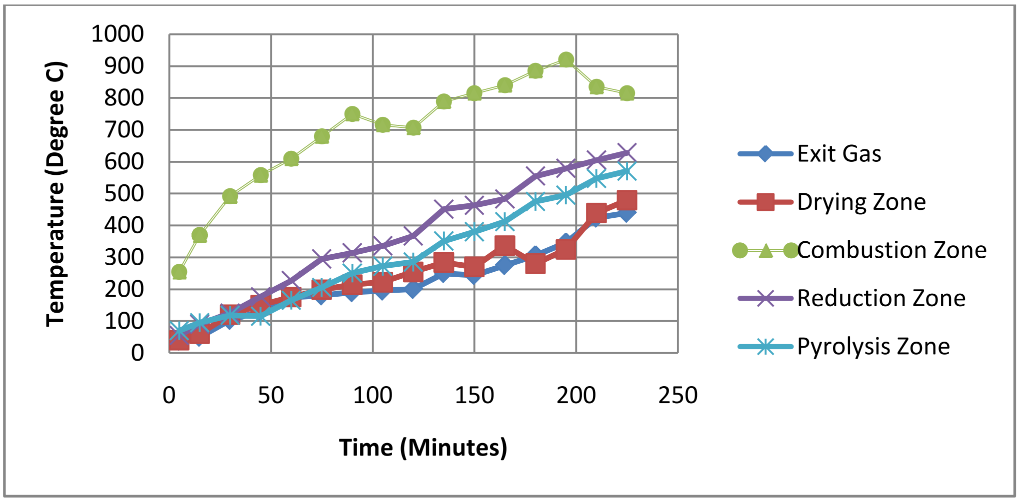

Figure. A-1: Temperature profile of different zones of gasifier for coconut shell

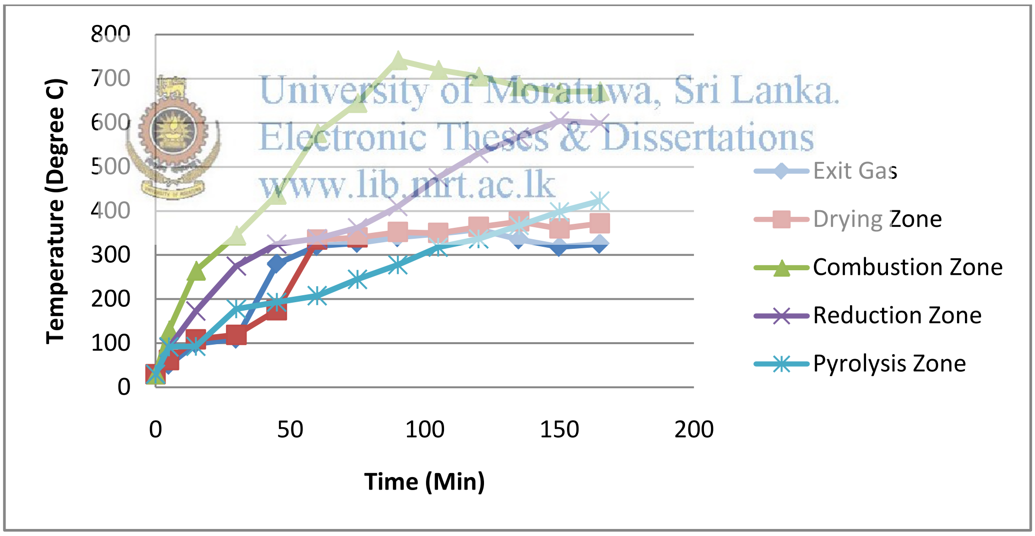

Figure. A-2: Temperature profile of different zones of gasifier for Mango Pit Shell

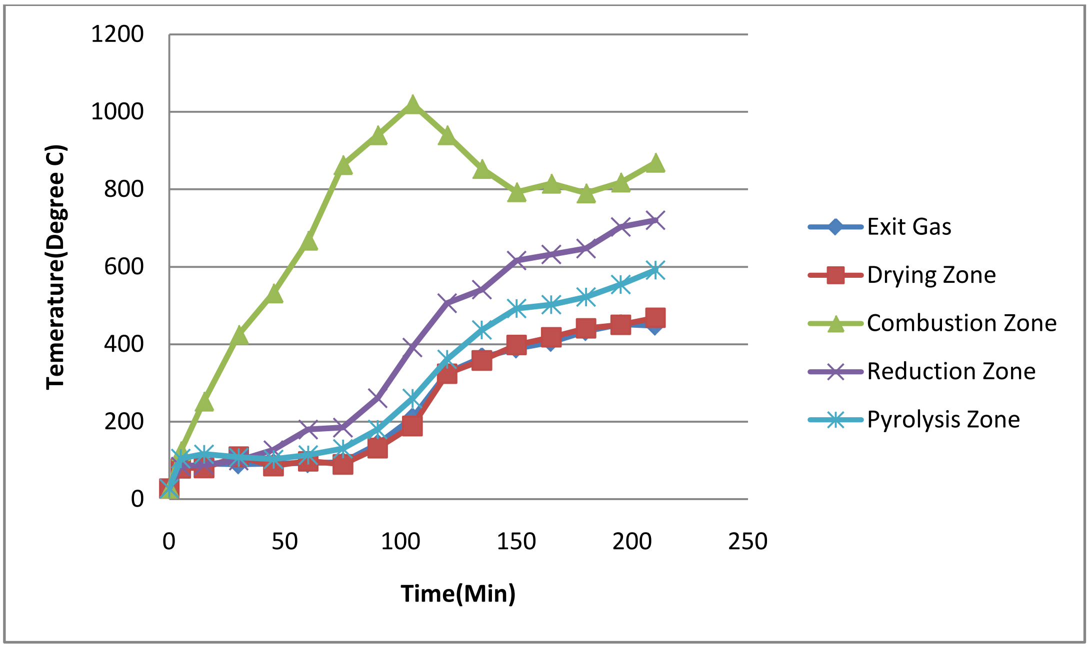

Figure. A-3: Temperature profile of different zones of gasifier for Ginisyria

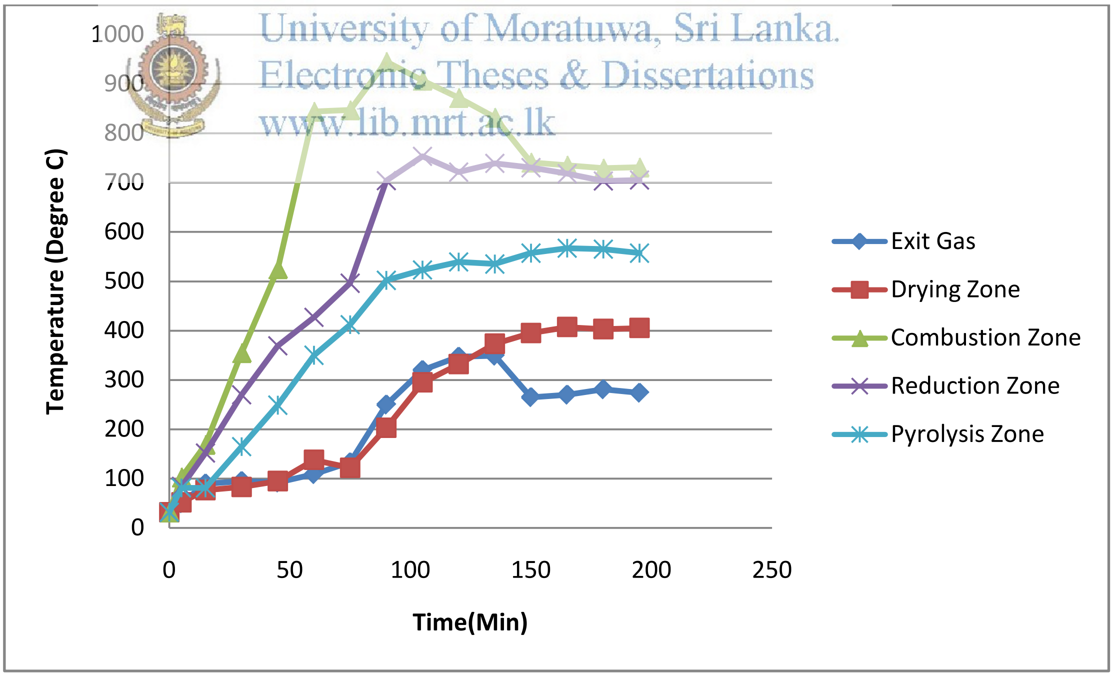

Figure. A-4: Temperature profile of different zones of gasifier for Mixture

Appendix –B : Elemental analysis results detail

Table B-1: Tabulated results of moisture contents of biomass feed stock

Sample	Weight of sample(gm)	Weight of Empty Crucible (gm)	Weight of crucible with sample before drying (gm)	Weight after drying in oven (gm)	Moisture removed (gm)	%by wt. of Moisture removed
Mango Pit	5	16.10	21.10	20.25	0.85	17
Coconut Shell	5	15.39	20.39	19.85	0.54	10.8
Ginisyria	5	15.63	20.63	19.95	0.68	13.6
Mixture	5	36.50	41.05	40.47	0.58	11.6

Table B-2: Tabulated results of ash contents of biomass feed stock

Sample	Weight of sample(gm)	Weight of Empty Crucible (gm)	Weight of crucible with sample	Weight after taking from muffle furnace	Wt of ash (gm) (wt after muffle-wt of empty)	% of ash by wt.
Mango Pit	5	19.21	24.21	19.28	0.07	1.4
Coconut Shell	5	19.63	24.63	20.24	0.61	12.2
Ginisyria	5	19.61	24.61	19.91	0.3	6
Mix	5	19.19	24.19	19.57	0.38	7.6

Table B-3: Volatile matters determination of different biomass

Sample	Weight of sample(gm)	Weight of Empty Crucible (gm)	Weight of crucible with sample	Weight after taking from muffle furnace	Loss in weight
Mango Pit	5.0	26.17	31.17	26.98	4.19
Coconut Shell	5.0	21.58	26.58	22.79	3.79
Ginisyria	5.0	26.16	31.16	27.11	4.05
Mix	5.0	21.58	26.58	22.46	4.12

Volatile Matters percentage calculated according to this formula

$$VM\% = \frac{\text{loss in weight on ignition} - \text{loss in weight from moisture}}{\text{Weight of sample}} \times 100$$

Volatile Matter on dry ash free basis %

$$VM_{daf}\% = \frac{\text{loss in weight on ignition} - \text{loss in weight from moisture}}{\text{Weight of sample} - (\text{Calculated wt. of ash} + \text{calculated wt. of moisture})} \times 100$$

Table B-4: Volatile matters of different biomass

Property	Coconut shell	Mango Shell	Ginisyria	Mixture
Volatile Matter %	65	67	67.4	70.8
Volatile Matter on dry ash free basis %	84.4	81.9	83.8	87.6

Table B-5: Fixed carbon of different biomass

Property	Coconut shell	Mango Shell	Ginisyria	Mixture
Fixed Carbon %	19.08	11.06	14.63	11.21

Table B-6: Moisture Contents on dry basis of different biomass

Sr.No	Component	Moisture content on Dry Basis (%)
1	Mango Shell	14.52
2	Coconut Shell	9.74
3	Ginisyria	11.97
4	Mixture	10.39

I. Moisture content on dry basis

Formula: MC_wx100/MC_w+100 [42]

1. Mango shell : 17x100/17+100= 1700/117 =14.52%
2. Coconut shell: 10.8x100/10.8+100= 1080/110.8 =9.74%
3. Ginisyria : 13.6x100/13.6+100= 1360/113.6 =11.97%
4. Mixture : 11.6x100/11.6+100=1160/111.6 = 10.39%

II. Fixed carbon Calculation (volatile matters % basis)

Formula =100-(Moisture % +Ash %+ Volatility %)

1. Mango Pit= 100-(14.52+1.4+65) =19.08
2. Coconut shell= 100-(9.74+12.2+67) =11.06
3. Ginisyria=100-(11.97+6+67.4) =14.63
4. Mixture= 100-(10.39+7.6+70.80) =11.21

III. Calculation of Wt. percent of carbon in the fuel

C%= DMMFC+0.9(DMMFVOL-14)x(vol+FC)/100

a. Mango Pit : 22.6+0.9(77.3-14)x(84.08)/100 =48.1
b. Coconut shell= 14.1+0.9(85.83-14)x(78.06)/100=50.6
c. Ginisyria = 17.83+0.9(82.16-14)x(82.03)/100 =50.4
d. Mixture= 13.66+0.9(86.33-14)x(82.01)/100 =53.52

IV. Calculation of percentage of nitrogen in the fuel

N_2%= ((2.1-0.012xDMMFVOL)x(VOL+FC)/100

a. Mango Pit= (2.1-0.012x77.3)x(84.08)/100 = 0.98
b. Coconut shell= (2.1-0.012x85.83)x(78.06)/100 = 0.83
c. Ginisyria= (2.1-0.012x82.16)x(82.03)/100 =0.911
d. Mixture =(2.1-0.012x86.33)x(82.01)/100 =0.87

V. Calculation of percentage of hydrogen in fuel

H_2% =(DMMFVOLx7.35/DMMFVOL+10)-0.013x(VOL+FC)

a. Mango Pit= (77.3x7.35/77.3+10)-0.013(84.08)= 6.50-1.09= 5.41
b. Coconut= (85.83x7.38/85.83+10)-0.013(78.06) = 6.609-1.014 = 5.6

c. GINISYRIA= (82.16x7.35/82.16+10)-0.013(82.03)= 6.55-1.066= 5.48

d. Mixture= (86.33x7.35/86.33+10)-0.013(82.01)= 6.586-1.066 =5.52

Percentage of O_2 in Fuel: Formula: 100- Ash-S-H_2-C-Moisture-N_2