MODELING OF BIOMASS GASIFICATION WITH CO$_2$ ENRICH AIR AS GASIFYING AGENT

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Abstract

The biomass gasification has been carried out using an updraft gasifier. This work focuses on the production of producer gas from biomass (Rubber Wood). Mathematical model for thermo-chemical process of biomass gasification is developed in this research work. ASPEN PLUS simulator and pilot plant gasifier were used to investigate the effect of reactor temperature, equivalence ratio and CO_2 to air ratio on composition of producer gas. The gasifier was operated over a temperature range of 500-1000 °C, while varying equivalence ratio from 0.2 to 0.36and CO_2 to air percentage from 1% to 10% and it was found that the most of trends were similar for both the case. The results showed Carbon monoxide concentration in the product gas increases with increase in temperature and CO_2 to biomass ratio but decreases with increasing equivalence ratio.

Keywords: Updraftgasifier, biomass, equivalence ratio, Carbon dioxide to air ratio, ASPEN PLUS.

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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

A/G: Air to gas ratio

G/F: Gas to fuel ratio

GHG: Green House Gases

1. Introduction

1.1 Background of Biomass gasification

Depleting a natural energy sources in oil and gas industries are serious economic and social issues for current generations and especially for future generations, developed societies are making efforts for renewable energy from renewable sources of chemicals. Recovery of biomass energy by using gasification technologies is particularly anticipated as it meets one of the major environmental sustainability needs, producing very less emissions[1].

Biomass gasification is an old technology of over a century. It was colorful before and during World War II. After the Second World War, this technology disappeared soon because availability of the liquid fuels. In the twentieth century, gasification technologies are very famous and create a new interest among the researchers due to its sustainability[2].

Biomass can provide almost everything that fossil fuels provide, whether it is fuel or chemical feedstock. In addition, it provides two important advantages that make it a viable raw material for synthesis gas production. First, it makes no net contribution to the atmosphere when it is burned; second, its use reduces reliance on non-renewable and often imported fossil fuels.

For these reasons, the gasification of biomass into CO and H_2 provides a good basis for the production of liquid transport fuels, synthetic chemicals. This thermo chemical conversion process is carried out in gasifiers and it can be categorized mainly in below three types[3]:

- Moving bed (fixed bed)
- Fluidized bed
- Entrained flow

Biomass gasification is an opportunity to produce chemicals and fuels from renewable resources which energy, power, or moment can be extracted to this end, the main objective of this work is to simulate the gasification of specific sources of biomass, using the Aspen Plus simulator, and to explore the different digital tools available to replicate a specific type of gasifier(Updraft fixed bed), and the different physical and chemical stages that constitute a typical gasification process. Using thermodynamic and kinetic data, available in the simulator database and found in the literature, it is planned to design optimal configurations of gasification processes to recovery of energy from selected biomass sources[4].

1.2 Biomass

Biomass is an organic matter, including plant substances derived from trees, agricultural crops and grasses. The chemical composition of biomass varies from one species to another, but it consists essentially of high but variable moisture content, a fibrous structure consisting of lignin, carbohydrates or sugars and ashes. Biomass is very heterogeneous in nature and has a lower calorific value than fossil fuels[5].

Biomass can be divided into two groups,

1. Virgin biomass: it is extracted from plant or animals
2. Waste Biomass: it is extracted from different products derived from biomass

Specially, virgin biomass is grown to use to fulfill the energy requirement therefore it is known as energy crops. This type includes short rotation or energy plantations, including herbaceous energy crops, woody energy crops, industrial crops and agricultural crops. Typical examples are eucalyptus, willows, poplars, sorghum, sunflowers, and cotton, among others. These crops are intended for use in combustion, pyrolysis and gasification for the production of biofuels, syngas and hydrogen[6].

1.3 Biomass Conversion Processes

The conversion of biomass into energy is done using main three technologies mentioned below

- Thermo chemical: Combustion, Pyrolysis , Gasification & Liquefaction
- Biochemical / biological: Digestion and Fermentation
- Mechanical: Etherification and Transesterification

1.4 Biomass Gasification

Gasification is the process of converting biomass that has been mainly studied as an alternative solution to the environmental and economic problems associated with energy production. This technology is one of the most used technologies because of its economy and efficiency. The physical and chemical properties of the biomass feed are the key design parameters when selecting the gasification system. In third world countries, Biomass gasification can be enhanced with new development technologies to development of rural economies by generating electricity from gasification from local sources of biomass[7].

Gasification is a thermochemical process that converts carbonaceous materials into mixture of combustible gaseous mixture through partial oxidation at elevated temperature.

Some of the main component in the producer gas from typical gasification processes is as mentioned below[8].

Hydrogen (H2)

Carbon monoxide (CO)

Methane (CH4)

Carbon dioxide (CO2)

The final gas composition of the producer gas is the result of the combination of a series of complex and competing chemical reactions. These reactions will be explained in the chapter 2.

1.5 Importance to the Sri Lankan industries

Sri Lanka is on its way to becoming an internationally competitive middle-income country. This energy and energy sector development plan is aligned with the country's drive for development and has been prepared to provide affordable, high quality and reliable energy to all citizens, rich and poor, while preserving the valuable natural environment of the country. Sources of supply and minimize regional disparities in the provision of energy services. The vision of the energy and energy sector is to harness the full potential of all renewable resources and other indigenous resources for Sri Lanka to become a self-sufficient energy nation[9].

Sri Lanka has no reserves of oil or natural gas. Forest products and agricultural residues are of paramount importance for Sri Lankan energy supply. It is estimated that biomass consumption accounts for about 55% of total energy consumption and 49% for wood fuels. Biofuels are mainly consumed by households, but also by industry. The energy consumption of biomass has increased by 3% per year, while the share of biomass used in total energy consumption has decreased slightly in recent years[10].

The Sri Lanka Sustainable Energy Authority of the Ministry of Power and Renewable Energy is implementing the GEF funded Project on Promoting Sustainable Biomass Energy Production and Modern Bio-Energy Technologies with the support of FAO and UNDP. The goal of the project is to reduce greenhouse gas emission from the use of fossil fuel for thermal energy generation in Sri Lanka industrial sector. The goal will be reached by means of removing barriers to the realization of sustainable biomass plantation, increase of market share of biomass energy generation mix and adoption of improved biomass-based energy technologies in Sri Lanka. The project consists of following components[11]:

(1) Policy-institutional support for effective implementation

(2) Barrier removal for sustainable fuel wood production

(3) Enabling environment for fuel wood suppliers

(4) Wood-based energy technology development

This research will be very useful to fulfill the component (4) is mentioned above.

1.6 Aspen Plus Simulation

Simulation is the imitation of how a real-world process or system works over time. Model should be developed, before simulating some process and decomposition of the process into its constituent units are done for the individual study of the performance. Process parameters such as flow rates, temperatures, compositions, pressures.etc. are predicted using analytical techniques. These techniques include empirical correlations, mathematical models, and computer-assisted process simulation tools. In addition to process simulation, process analysis may involve the use of experimental means to predict and validate performance. Therefore, we receive process inputs and flow schema and are needed to predict process outputs in process simulation[12].

Aspen Plus is computer-assisted software that uses the underlying physical relationships to predict process performance and is used to simulate a wide range of chemical engineering processes, including those involving vapors, liquid and solid processing[13].

1.7 Research Objectives and Scope

1.7.1 Objectives

The key objective of this research work is to develop Aspen Plus model for updraft gassifier using CO_2 enrich air as gasifying agent. This study will help to reduce the emission of CO_2 to the atmosphere by reusing the flue gas and feeding as a gasifying agent in a biomass gassifier.

1.7.2 Scope

The research scope has been outlined by considering the compatibility to the available resources. Therefore, the research goals have been sub divided, in order to easier identification of completed tasks.

1. Literature survey on gassifiction technologies and similar simulation cases in Aspen Plus

2. Generate the flow chart by identifying and splitting the process into sub processes

3. Complete the model

4. Validate the simulation results by performing real time experiments with the use of fix bed updraft gassifier in the university.

1.8 Dissertation Outline

Chapter 1: It has a brief introduction about Sri Lankan energy balance, gasification, Biomass, Aspen Plus and objective of this research project.

Chapter 2: In this section, Theory and literature review is presented about biomass, its properties gasification technologies, types of gasifiers and gasification reactions. Using of Aspen plus model for this simulation is also described in this section.

Chapter 3: This chapter is explaining about Aspen plus model development for updraft fixed bed gasifier and its result with sensitivity analysis tool.

Chapter 4: This chapter explainspresent study results and earlier work comparisons are presented while it also contains future work suggestions.

2. Modeling theory and technique

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 that convert sunlight into plant material through photosynthesis and include all terrestrial and aquatic vegetation, as well as organic waste[14]. Plants store solar energy as a chemical energy with strong molecular bonds that, once broken, undergo a conversion process and heat is released. Biomass has always been a major source of energy for humanity and is currently estimated to contribute about 10-14% of the world's energy supply[14]. However, in recent years, he drew attention to the development of biomass conversion technology, lower prices, excess food production especially in European countries, and climate change due to the negative effects of fuel emissions fossils on the environment. We know that biomass was the main source of energy for heat, but with the introduction of fossil fuels in the form of Biomass, oil and natural gas, the world has become increasingly dependent on these fuel sources[15]. Yet, it has not been confirmed how much fossil fuel remains. With the high consumption rate, it is estimated that depletion is fast. In addition, these fuels are not distributed evenly around the world and, as a result, many countries depend on others. This upward trend in the consumption of fossil fuels with its by-products combined with other factors was the main obstacle to the commercialization of biomass. Now, the realization in terms of non-renewable state of fossil fuels and high exhaustion rate gives the opportunity to think seriously about other resources and biomass energy is one of them[16].

2.2 Biomass properties

The following property of the biomass is very important when select the biomass

- Heating value
- Proximate analysis
- Ultimate analysis

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

2.2.1 Calorific value

The *calorific value* of material is the total energy released as heat when a substance combustion with oxygen under standard conditions. The chemical reaction is typically a hydrocarbon or other organic molecule reacting with oxygen to form carbon dioxide and water and release heat. This calorific value can be divided in to two according to the way it calculated[17].

- Higher heating value (HHV)
- Lower heating value (LHV)

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 prevailing weather conditions at 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[18].

Thermal conversion requires low moisture content feedstock (typically<50%), while bio-conversion can utilize high moisture content feedstocks. Thermal conversion technologies can also use feedstocks with high moisture content but the overall energy balance for the conversion process is adversely impacted[14].

Fixed Carbon and volatile matters

Fuel analysis has been developed based on solid fuels, such as Biomass, which consists of chemical energy stored in two 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 $950\ ^0C$ for 7 min)

➢ The fixed carbon content (FC), is the mass remaining after the releases of volatiles, excluding the ash and moisture contents.

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 measurement parameter for solid and liquid fuels. The ash content 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[19].

2.3Processes of Gasification

2.3.1 Process

Gasification converts fossil or non-fossil fuels (Biomass) into useful gases and chemicals. It requires a medium for reaction, which can be gas or Steam. Gaseous mediums include air, oxygen, steam, or a mixture of these. It essentially converts a potential fuel from one form to another. There are three major advantages for such a transformation[20].

• It is removed non-combustible component (Water) and increases the calorific value of the fuel.

• It is removed the sulfur and nitrogen therefore emission can be controlled use the gasified fuel

• It will increase the (H/C) ratio in the fuel and will help to complete combustion in the user point.

Normally, when the hydrogen content increase in the fuel, vaporization temperature will reduce and possibility to remain the fuel in gaseous stage is high. Gasification or pyrolysis increases the ratio of hydrogen-carbon (H/C ratio) in the product through one the followings means[18]:

Direct: Direct exposure to hydrogen at high pressure.
Indirect: Exposure to steam at high temperature and pressure, where hydrogen, an intermediate product, is added to the product. This process also includes steam reforming.
Pyrolysis: Reduction of carbon by rejecting it through solid char or CO_2 gas.

Oxygen content of the biomass is reduced by gasification therefore it also is increased the energy density of the fuel. The typical biomass has around 40 to 60% oxygen by weight, but very small amount of oxygen is contained in a useful fuels[21]. Oxygen is removed from the biomass by dehydration or decarboxylation. This latter process, which releases oxygen through CO_2, increases the H / C ratio of the fuel.

If the gasification and combustion are two closely related thermochemical processes, there is a big difference between them. Gasification fills the chemical bonds in the product gas with energy. Burning destroys these links to release energy. The gasification process adds hydrogen to remove carbon from the feed and produces a gas with a higher hydrogen / carbon (H / C) ratio, In the combustion process produce water and carbon dioxide by converting hydrogen and carbon respectively and release the energy due to this reaction is exothermic[18].

Normally, biomass gasification process includes the following four steps:
- Drying
- Thermal decomposition or pyrolysis
- Partial combustion of some gases, vapors, and char
- Gasification of decomposition products

Instead of burning it entirely, It can gasify the carbon by restricting the oxygen supply. The carbon then produces 72% less heat than that in combustion, but the partial gasification reaction shown here produces a combustible gas, CO[18].

$C + 1/2\, O_2 = CO - 110,530\ kJ/kmol$
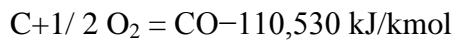
When the gasification product, CO, subsequently burns in adequate oxygen, it produces the remaining 72% of the heat of carbon combustion.

$CO + 1/2\, O_2 = CO_2 \quad -383\ MJ/kmol$
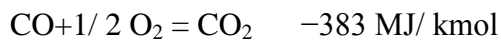
If the CO retains only 72% of the energy of the carbon, total energy recovery of the gasification system is about 75% to 88% due to the production of hydrogen and other hydrocarbons during the gasification reactions[18]. Potential path of the gasification is mentioned in figher1.
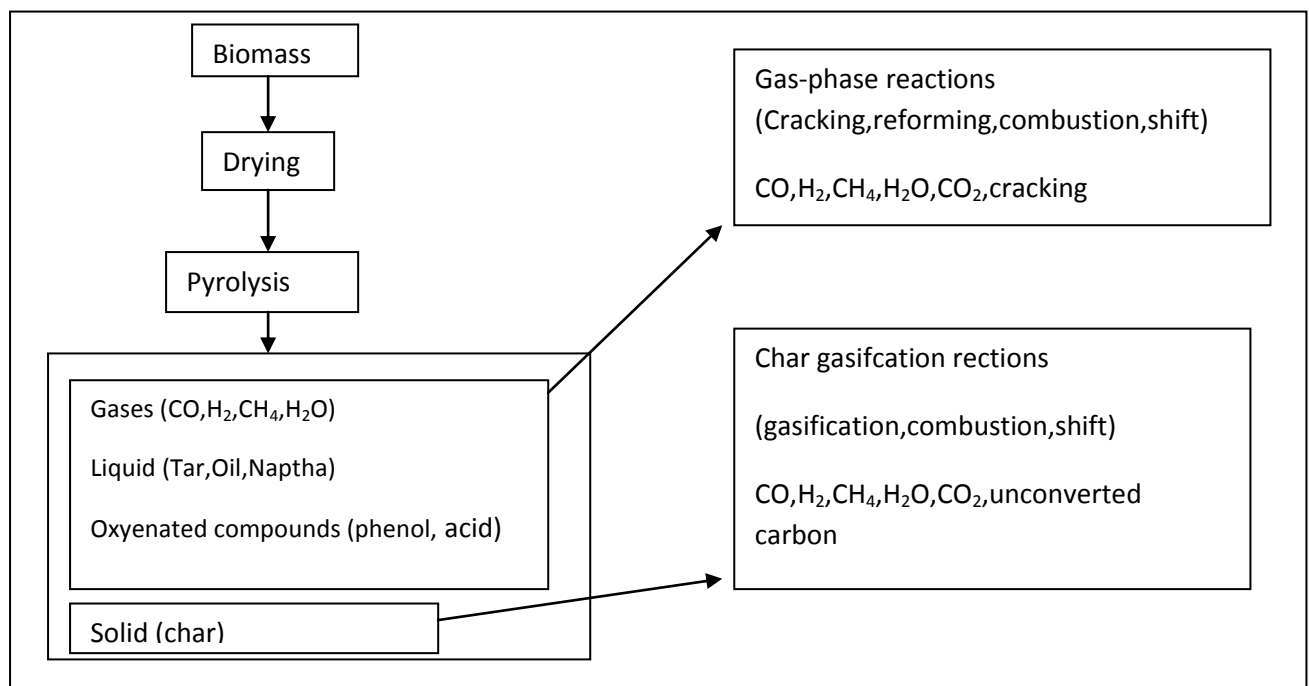
Potential paths for gasification

Figure 1:Biomass Gasification Process

2.4.2 Gasifying Mediums

There are some gents react with solid carbon and heavier hydrocarbons to convert them into low-molecular-weight gases (CO, H_2..ect) and it is known as gasifying agent. The main gasifying agents used for biomass gasification process are mentioned below.

- Oxygen
- Steam
- Air
- CO_2

If all above agents are used as gasifying agent, oxygen is the most popular gasifying agent because it is primarily used for the combustion reactions. It may be entered to a gasifier either in pure form or mixture of air. The calorific value and the composition of the producer gas from a gasifier has strong relation with the type and amount of the gasifying agent used[12].

2.4.3 Drying

The typical moisture content of fresh wood very between 30 to 60%, and for some biomass it can be exceeded 90%. This moisture takes the energy to vaporize the water and this energy cannot be recovered. Therefore, total energy efficiency of the system may be reduced significantly. External or surface moisture can be removed before feeding biomass to the gasifier, but we cannot do much about the inherent moisture residing within the cell structure. A certain amount of pre-drying is necessary to remove moisture from the biomass as much as possible before it is fed into the gasifier[18].

Get the maximum advantages from gasification process, calorific value of producer gas should be high as much as possible. Therefore, most of the gasification system controls the inlet moisture content of biomass between 10% to 20%. However, the final drying takes place after the feed enters the gasifier, due to heat from the hot zone downstream and dries the feed by releasing water above 100 °C. When remove the bound water that is in the biomass is irreversibly, the low-molecular-weight extractives start volatilizing with elevated temperature. This drying process continues till temperature reach up to approximately 200 °C[18].
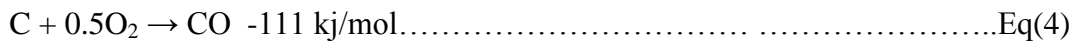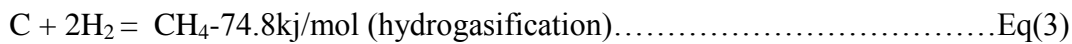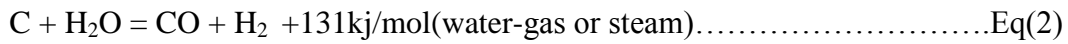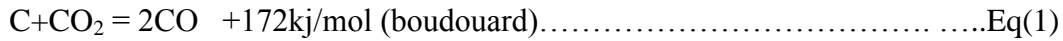
2.4.4 Pyrolysis

Thermal decomposition of biomass in the absence of medium is known as pyrolysis. It is included the chemical reactions and it is broken down the long chain compound in to smaller compounds such as methane, hydrogen, carbon monoxide…ect. This is consisting of both simultaneous and successive reactions when organic material is heated in a non-reactive atmosphere. Thermal decomposition of biomass is started at 350 °C–550 °C and goes up to 700 °C–800 °C in the absence of air/oxygen. Reaction rate of decomposition of each of these components depends on the process parameters of the reactor such as temperature, pressure, type of reactor, property of biomass..etc. The reaction of the gasification process has shown in the table 1[22]
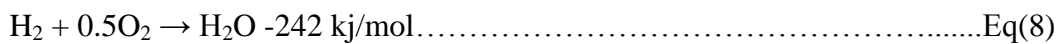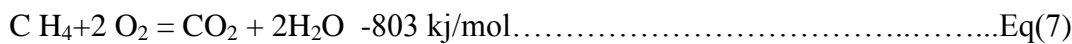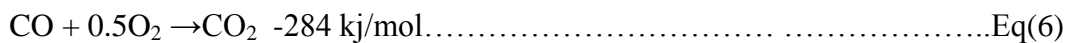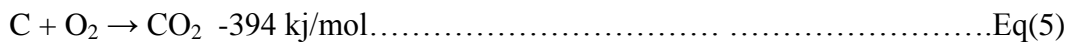
Table 1: Reaction involve in biomass gasification[18]
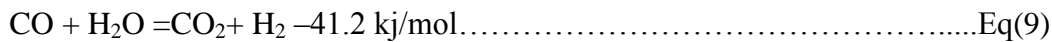
Typical Gasification Reactions at 25 C

Carbon reaction

$C + CO_2 = 2CO$ +172kj/mol (boudouard)…………………………… …..Eq(1)

$C + H_2O = CO + H_2$ +131kj/mol(water-gas or steam)………………………Eq(2)

$C + 2H_2 = CH_4$-74.8kj/mol (hydrogasification)………………………………Eq(3)

$C + 0.5O_2 \rightarrow CO$ -111 kj/mol……………………………… ………………..Eq(4)

Oxidation Reactions

$C + O_2 \rightarrow CO_2$ -394 kj/mol…………………………… …………………….Eq(5)

$CO + 0.5O_2 \rightarrow CO_2$ -284 kj/mol…………………………… ………………..Eq(6)

$C H_4 + 2 O_2 = CO_2 + 2H_2O$ -803 kj/mol………………………………..……..Eq(7)

$H_2 + 0.5O_2 \rightarrow H_2O$ -242 kj/mol…………………………………………......Eq(8)

Shift reaction

$CO + H_2O = CO_2 + H_2$ –41.2 kj/mol…………………………………......Eq(9)

Methanation reactions

$2CO + 2 H_2 \rightarrow CH_4 + CO_2$ –247kj/mol…………………………..……..Eq(10)

$CO + 3 H_2 = CH_4 + H_2O$ –206kj/mol……………………………..…..….Eq(11)

$CO_2 + 4 H_2 \rightarrow CH_4 + 2 H_2O$ –165kj/mol……………………….....Eq(12)

Steam-Reforming Reactions

$CH_4 + H_2O = CO + 3H_2$ +206kj/mol……………………….……….....Eq(13)

$CH_4 + 0.5O_2 = CO + 2H_2$ -36kj/mol…………………………..……....Eq(14)
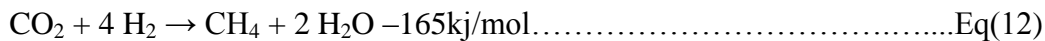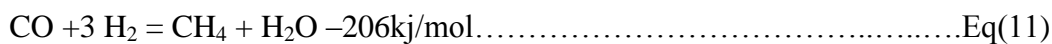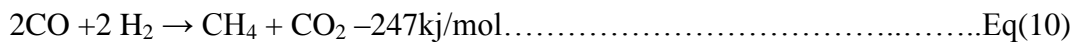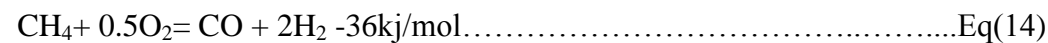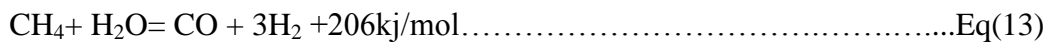
2.4.5 Char Gasification Theory

The gasification step following pyrolysis involves chemical reactions among the hydrocarbons in the fuel, steam, carbon dioxide, oxygen and hydrogen in the reactor, as well as chemical reactions among the waste gases. Of these, the gasification of Arctic char is the most important. Biomass produced by the pyrolysis of biomass is not pure carbon. It contains a certain amount of hydrocarbon including hydrogen and oxygen. Biomass is generally more porous and reactive than coke[23].

The pores of biomass char are much larger (20–30 micron) than those of biomass char (~5 angstrom). Thus, its reaction behavior is different from that of chars derived from biomass, lignite, or peat. For example, the reactivity of peat char decreases with conversion or time, while the reactivity of biomass char increases with conversion. This reverse trend can be attributed to the increasing catalytic activity of the biomass char's alkali metal constituents. Gasification of biomass char involves several reactions between the char and the gasifying mediums[24].
.

Eq (1) through Eq (4) show how gasifying agents like oxygen, carbon dioxide, and steam react with solid carbon to convert it into lower molecularweight gases like carbon monoxide and hydrogen. Gasification reactions are generally endothermic, but some of them can be exothermic as well. For example, those of carbon with oxygen and hydrogen (3, 4, and 5 in Table 1) are exothermic, whereas those with carbondioxide and steam (reactions 1 and 2) are endothermic. The heat of reaction given in Table 1for various reactions refers to a temperature of 25 °C[18].

Reaction rates comparisons

The reaction rate of char gasification depends on its reactivity and the reaction potential of the gasifying agent. As an example oxygen is the most active agent than carbon dioxide and steam. Reaction (4) is the fastest among the four carbon reactions in the above table. The reaction (2) is three to five slower and the boudouard or char–carbon dioxide reaction (1) is six to seven orders of magnitude slower than that of reaction (4). The rate of the water–gas or water–steam gasification reaction (2) is about two to five times faster than that of the Boudouard reaction (1). The char–hydrogen reaction (3) that forms methane is the slowest from all first four reactions.

Boudouard Reaction Model

The gasification of char in carbon dioxide is named as the *Boudouard reaction*. $C + CO_2 = 2CO$ (reaction (1) in Table). This reaction is described through the following steps by Blasi (2009). In the first step, CO_2 dissociates at a carbon-free active site (C^*), releasing carbon monoxide and forming a carbon–oxygen surface complex, $C(O)$. This reaction can move in the opposite direction as well, forming a carbon active site and CO_2 in the second step. In the third step, the carbon–oxygen complex produces a molecule of CO. The rate of the char gasification reaction in CO_2 is insignificant below the temperature is 1000 K[18].

Water–Gas Reaction Model

The gasification of char in steam, known as the *water–gas reaction*, is perhaps the most important gasification reaction. The first step involves the dissociation of H_2O on a free active site of carbon (C^*), releasing hydrogen and forming a surface oxide complex of carbon $C(O)$. In the second and third steps, the surface oxide complex produces a new free active site and a molecule of CO[18].

Shift Reaction Model

The shift reaction is an important gas-phase reaction. It increases the hydrogen content of the gasification product at the expense of carbon monoxide. This reaction is also called the "water–gas shift reaction" in some literature though it is much different from the water–gas reaction (2).

The shift reaction is slightly exothermic, and its equilibrium yield decreases slowly with temperature. Depending on temperature, it may be driven in direction—that is, products or reactants. This reaction has a higher equilibrium constant at a lower temperature, which implies a higher yield of H_2 at a lower temperature. With increasing temperature, the yield decreases but the reaction rate increases. Optimum yield is obtained at about 225 °C. Because the reaction rate at such a low temperature[18].

Char Combustion Reactions

Most gasification reactions are endothermic. To provide the required heat of reaction as well as that required for heating, drying, and pyrolysis, a certain amount of exothermic combustion reaction is allowed in a gasifier. Reaction (5) is the best in this regard as it gives the highest amount of heat (394 kJ) per kmol of carbon consumed. The next best is (4), which also produces the fuel gas CO, but produces only 111 kJ/mol of heat. The speed of (4) is relatively slow[18].

2.5 Classification of biomass gasifier

Several types of gasifiers are currently available in the world for commercial use and some of them are mentioned below.

- Counter-current fixed bed,
- Co-current fixed bed,
- Fluidized bed,
- Entrained flow,
- Plasma..ect

A survey of gasifiers in Europe, the United States, and Canada shows that down draft gasifiers are the most common (Knoef, 2000). It shows that 75% are down draft, 20% are fluidized beds, 2.5% are updraft, and 2.5% are of various ther designs. They are classified according to the way gasifying agent (air/oxygen/steam/CO2) is introduced[25].

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

2.5.1 Fixed bed gasifiers

The fixed bed gasifier has a bed of solid fuel particles through which the gas and the gasification gas move up or down. This is the simplest type of gasifier usually consisting of a cylindrical space for the fuel supply unit, an ash removal unit and a gas outlet. In the fixed bed gasifier, the fuel bed moves slowly into the reactor when gasification occurs. Fixed bed gasifiers are of simple construction and generally operate with high carbon conversion, long solid residence time, low gas velocity and low ash transfer. In fixed bed, tar removal was a major problem, but recent advances in thermal and catalytic tar conversion have provided a credible option for this type of gasifiers[26].

2.5.2 Updraft Gasifiers

Fuel flexibility is the main feature of up-flow gasifiers. These gasifiers can run on Biomass or biomass and fuel switching does not require any changes in the reactor. Updraft gasifiers tolerate higher ash content, higher moisture content and greater fuel size variation compared to down flow gasifiers[27].

In up-flow gasifiers, the producer gas is removed from the top of the fuel bed while the gasification reactions occur near the bottom as shown in Figure 2. When producer gas passes through the fuel bed, it captures volatile matter (tars) and fuel moisture. Therefore, the gas from the up-flow gasifier contains condensable volatiles[28]. The design and operation of

16

the gasifiers is such that the gas exits at a temperature of 200 to 400 °C. At this temperature, most of the volatile hydrocarbons are in the form of vapor, which adds to the energy content of the gas. It is more appropriate to use hot gas updraft gasifier tightly coupled for direct heating applications. However, if the application warrants, the purification of the gas to remove the volatiles / tars is also performed.

This is the model which is considered in this dissertation to modulate with aspen plus and run the trial to validate the model.
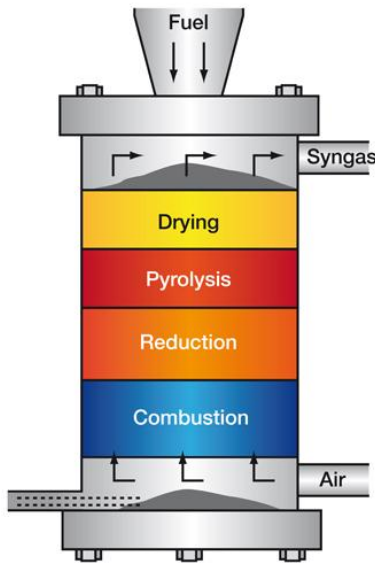
Figure 2:Ufdraft Gasifier

2.5.3 Downdraft Gasifiers

Downflow gasifiers are fuel specific. Downflowg asifiers can operate on wood such as biomass materials and biomass briquettes with a minimum bulk density of 250 kg / m3 and an ash content of less than 5%. In downflow gasifiers, the gas is removed from the bottom of the reactor while the hottest reaction zone is in the middles shown in Figure 3[29].

The volatile material in the fuel cracks in the reactor and, as a result, the exit gas is almost free of tar. However, the gas leaving the reactor contains small amounts of ash and soot. The gas exits the gasifier at 250-450 °C. This gas can also be used hot (after preliminary cleaning) or in the cold cleaning state (after proper gas cleaning). The gas from the downflow gasifiers can be cleaned to very high purity so that it can be used in internal combustion engines or for direct heating applications where the purity of the gas is a critical requirement[10].
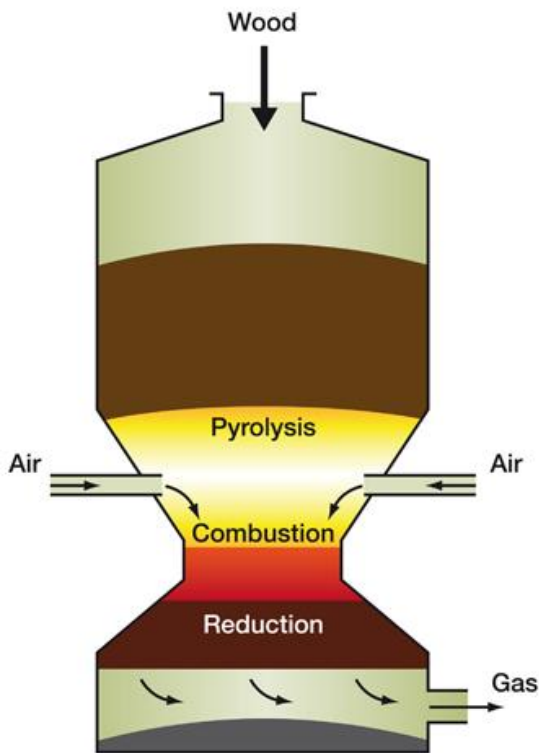
Figure 3: Downdraft Gasifier

2.5.4 Cross-draft gasifier

Countercurrent gasifiers have many operating characteristics of the draw units. Mixtures of air or air and steam are introduced into the side of the gasifier near the bottom while the product gas is withdrawn from the opposite side. Normally, an inlet nozzle is used to bring air into the center of the combustion zone, as shown in Figure 4. The velocity of the air entering the combustion zone is considerably higher in this design, which creates a hot combustion zone. The combustion (oxidation) and reduction zones are both concentrated at a low volume around the sides of the unit. Countercurrent gasifiers respond quickly to load changes. They are normally simpler to build and more suitable for running engines than other types of fixed bed gasifiers. However, they are sensitive to changes in biomass composition and moisture content[25].
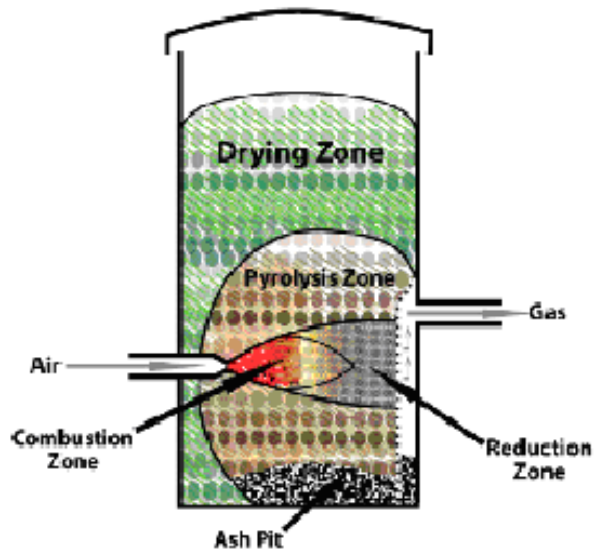
Figure 4:: Cross-draft gasifier

2.6 Model Development

In Aspen Plus software, each block of operation of the unit is resolved according to certain sequences. This simulation software consists of several unit operation blocks, which are models of specific process operations (reactors, combustion chamber, cyclone, etc.). The built-in physical property database helps to perform simulation calculations. These blocks were placed on a flowchart specifying flows of materials and energy[30]. Each process is identified and broken down into its most basic components for this simulation. Once the process (all stages - chemicals and reactions) is identified, the model is built in the Aspen Plus environment. Following the Aspen Plus User Guide, the template is created by:

- Identifying major stages of the process and select model blocks to represent each stage.
- Creating a flow diagram for process identification and linking streams.
- Setting up thermodynamic and chemical properties and feed rates of each stream.
- Setting the properties of each block.
- Defining sensitivity calculations.
- Running simulation and verify the results.
- Making corrections as required and repeat the previous step.

2.6.1 Model Block Selection

Blocks are the most important part for the development of the model because the materials are modified through different physical and chemical activities. Each block requires a unique set of conditions if it needs to work properly. A wide range of parameters, including operating conditions, reactions, thermal response calculation parameters, convergence parameters and possible outputs shall be specified in the reactor blocks. In the Aspen Plus reactor model, the blocks are classified on the basis of equilibrium, equilibrium and kinetics such as Balance (RYield, RStoic), Equilibrium (REquil, RGibbs) or Kinetics (RCSTR, RPlug, RBatch). In the model developed, two different types of reactor designs are used. A brief description with the block names and block identifiers of some unit operation blocks used in the Aspen Plus gasification model is described in Table 2.

Table 2:Aspen plus Reactors

Model	Description	Purpose	Used for
RStoic	Stoichiometric reactor	Models stoichiometric reactor with specified reaction extent or conversion	Reactors where reaction kinetics are unknown or unimportant, but stoichiometry and extent of reaction are known
RPlug	Plug flow reactor	Models plug flow reactor	One-, two-, or three-phase plug flow reactors with rate-controlled reactions in any phase based on known stoichiometry and kinetics
RGibbs	Equilibrium reactor with Gibbs energy Minimization	Performs chemical and phase equilibrium by Gibbs energy minimization	Reactors with phase equilibrium or simultaneous phase and chemical equilibrium. Calculating phase equilibrium for solid solutions and vapor-liquid- solid systems.

To produce the Aspen Plus model flow diagram, a series of operation blocks has to be used. The user must place these blocks on a process flow sheet by specifying flows of materials and energy. The Aspen Plus computer program can quantitatively model the gasification process. The process simulator has not built-in gasification model, but there are several built-in unit block models. In Aspen Plus, the blocks are chosen so that the different parts of the process can be specified as realistic as possible. The blocks relate to appropriate link flows to develop the flow diagram. The flow chart of the gasification process for rubber chips is shown in Figure 5[31].
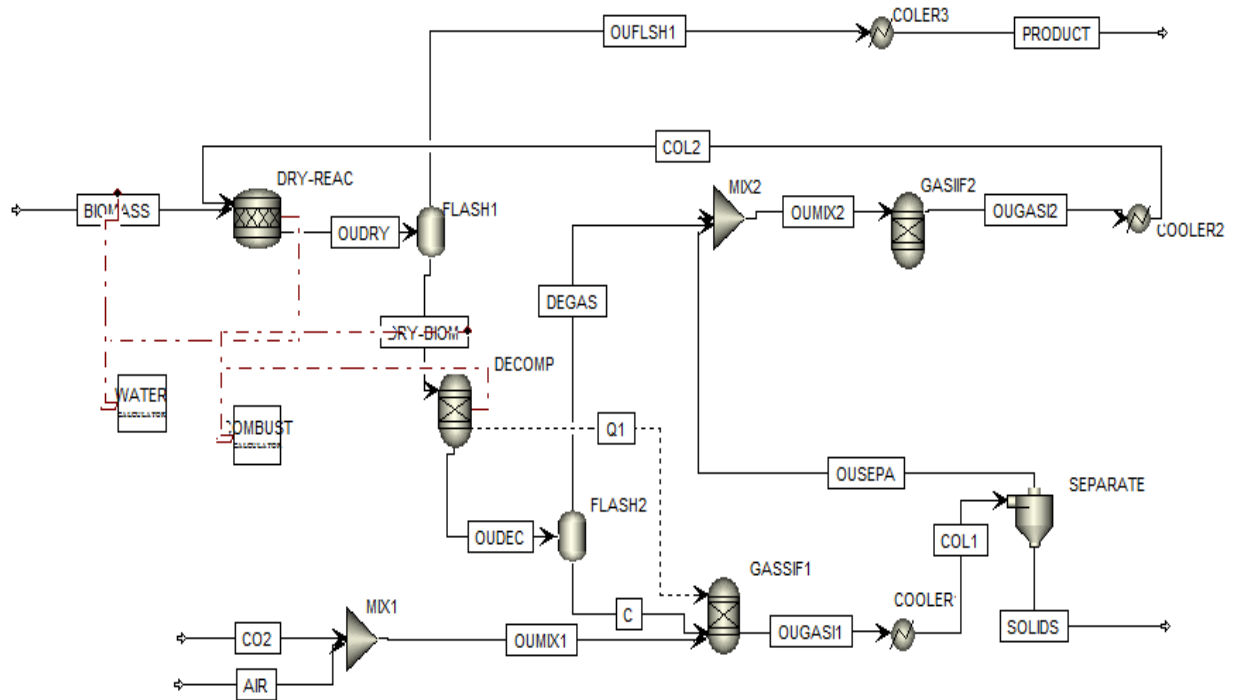
Figure 5: Aspen model for updraft fixed bed gasification of biomass

1. Drying.
2. Separation of moisture and dry Biomass
3. Decomposition of the feed
4. Char gasification
5. Gas solid separation
6. Volatile reactions

2.6.2 Drying

This step is the first step in the simulation process and aims to reduce the moisture in the feed to improve the performance of the gasifier. The block Yield Reactor (block ID: DRY-REA in Figure 5) in Aspen Design was used to set the composition of Rubber Chips (C, O, H) and the moisture. Rubber chips is fed to the process unit and through the increase of temperature, the water bound to the biomass is vaporized. The yield of the water is specified by the water content in the proximate analysis. The moisture content of rubber is 15%[32]. Accordingly, the mass yield of gaseous water is set as 15%, due to the assumption that the physically bound water is vaporized completely in the drying process. The mass yield of dried chips is correspondingly equal to $100\% - 15\% = 85\%$. After this process, water and dried rubber chips flow into the gas and solid separator, (Block ID: DRY-FLASH in Figure 5).

The simulation flowsheet above appears for dying is different from the process diagram in the figure 1 because the simulation flowsheet uses two-unit operation models to simulate a single piece of equipment. Also, the simulation flowsheet defines an extra stream (IN-DRIER) to connect the two simulation unit operation models. There is no real stream that corresponds to the simulation stream IN-DRIER.

2.6.3 Separation of moisture and dry Biomass

The splitter (Block ID: DRY-FLASH in Figure 5) is used to separate the dried feed into solids and volatile matter. This block allows splitting the feed directly from the knowledge of the compositions, without the need to define reaction stoichiometry and reaction kinetics.

2.6.4 Biomass Decomposition

The ASPEN PLUS yield reactor, RYield was used to simulate the decomposition of the feed. It is used when Reaction stoichiometry is unknown or unimportant, Reaction kinetics is unknown or unimportant but Yield distribution is known. In this step, biomass is converted into its components including carbon, oxygen, hydrogen, sulfur, nitrogen, and ash by specifying the composition according to its ultimate analysis (Block ID: DECOMP in Figure 5).

2.6.5 Char Gasification

In the Aspen Design an Equilibrium Reactor (block ID: SASSIF 1 in Figure 5) is considered to model the gas phase reactions during the gasification of char particles. Those reactions are, respectively, the partial combustion reaction of combustible gases (CO, H2), the water-gas shift reaction and the steam-methane reforming reaction. These reactions are simulated by minimizing the Gibbs free energy in R-EQUILIBRIUM Reactor. From this unit leaves the syngas stream to the gas solid separator.

2.6.6 Gas solid separation

In the Aspen flow sheet gas solid separator (block ID: SEPERAT in Figure 5) is used to separate the Ash and syngas.

2.6.7 Volatile Reactions

Dried moisture and gasified product are mixed in the upper section of the updraft gasifier and there is some chemical reactions happen therefore a RGIBB(block ID: GASSIF2 in Figure 5) reactor is used for simulation of this zone.

2.6.8 Stream Class Selection

There are three stream classes defined in Aspen Plus: material, heat and work streams. The material stream is used to classify chemical composition, thermodynamic conditions and flow rates. The heat streams are used to pass heat duties from one process unit to another. Similarly, work streams carry power between two blocks. In the current model, the Rubber Chips feed stream was defined as a non-conventional component.

3 MODEL SIMULATIONS

3.1 ASPEN UNIT MODELS

Figure 5 shows the complete process model developed for biomass gasification and some of most important points has been described below.

- Define nonconventional solid components
- Defining properties
- Specify physical properties for nonconventional solid components
- Stream classes and sub streams
- Calculator block for control drying
- Calculator block for control decomposition
- Analyze the results.

3.1.1 Define nonconventional solid components

The components – specifications selection sheet is used to enter the components present in the simulation. The components in this simulation are H_2O, N_2, O_2, Biomass,…ect. Above all components are present in the databank except biomass. AspenPlus does not recognize biomass. It is actually a mixture of different compounds, but for this simulation it will be treated as a single component.

By default, Aspen Plus assumes all components are of the type conventional, indicating that they participate in phase equilibrium calculations. However, in this simulation, biomass will be modeled as a non-conventional solid[33].

3.1.2 Defining Properties

The Methods - Global Specifications worksheet is used to select the thermodynamic methods used to calculate properties such as K values, enthalpy, and density. Property methods in Aspen Plus are categorized into different types of processes. Because physical property methods for solid components are the same for all property methods, select a property method based on the conventional components of the simulation. The IDEAL properties method is a good choice for this simulation because the process involves the conventional low pressure H_2O, N_2 and O_2 components[34].

3.1.3 Specify physical properties for nonconventional solid components

The Methods - NC Props Property Methods worksheet is used to specify the models used to compute non-conventional solid properties. Since non-conventional components are heterogeneous solids that do not participate in the chemical or phase equilibrium, the only physical properties calculated for non-conventional components are enthalpy and density. In this simulation, use the HCOALGEN and DCOALIGT models to calculate enthalpy and biomass density.

When you select HCOALGEN in the Model Name field, the PROXANAL, ULTANAL, and SULFANAL component attributes are automatically included in the component attribute field required for biomass. Aspen Plus uses component attributes to represent nonconventional components in terms of a set of identifiable constituents needed to compute physical properties. HCOALGEN uses the proximate analysis, ultimate analysis and Sulfur analysis to calculate enthalpy of biomass.

The Option Codes fields define how the HCOALGEN model calculates the heat of combustion, the standard heat of formation, the heat capacity, and the enthalpy basis for Biomass.

3.1.4 Stream classes and sub streams

Stream classes are used to define the structure of the simulation flows when inert solids are present. The default stream class for most simulations is CONVEN. The CONVEN flow class has a single sub stream: the MIXED sub stream. All components of the MIXED sub stream participate in the phase equilibrium whenever flash calculations are performed [35]. To introduce inert solid components into a simulation, one or more additional sub streams must be included. Aspen Plus has two other types of sub streams: the CISOLID sub streams type and the NC sub streams type.

The CISOLID sub stream is used for homogeneous solids that have a defined molecular weight. The NC sub stream is used for heterogeneous solids that have no defined molecular weight. Both the CISOLID sub stream and the NC sub stream give you the option of including a Particle Size Distribution (PSD) for the sub stream. Sub streams are combined in different ways to form different stream classes.

The MIXNCPSD stream class contains two sub streams: MIXED and NCPSD. The default stream class of the solids application type, MIXCISLD, is insufficient for this simulation since this will use an NC sub stream with a particle size distribution for the feed biomass. In this simulation, use the MIXNCPSD stream class.

3.1.5 Calculator Block for Control Drying

The material balance equations for drying process define relations between the following quantities:

- Water content of the feed biomass.
- Fractional conversion of biomass to water.
- Water content of the dried biomass.

$BIOMASSIN$ x (H2OIN/100)= BIOMASSOUTx (H2OOUT/100) +$BIOMASSIN$ x $CONV$...(1)

$BIOMASSIN$ = BIOMASSOUT+ $BIOMASSIN$ x $CONV$..(2)

Where:

BIOMASSIN = Mass flow rate of biomass in stream WET-BIOMASS

BIOMASSOUT = Mass flow rate of biomass in stream IN-DRIER

H2OIN = Percent moisture in the biomass in stream WET-BIOMASS

H2ODRY = Percent moisture in the biomass in stream IN-DRIER

CONV = Fractional conversion of biomass to H_2O in the block DRY-REAC

Equation 1 is the material balance for water, and equation 2 is the overall material balance. These equations can be combined to yield equation 3:

$CONV$ = (H2OIN-H2OOUT)/(100-H2OOUT).. (3)

Use equation 3 in a Calculator block to ensure these three specifications are consistent. The Calculator block specifies the moisture content of the dried biomass and calculates the corresponding conversion of biomass to water.

FORTRAN statements for drying calculator are given below:

H2ODRY = 0.0

CONV = (H2OIN - H2ODRY) / (100 - H2ODRY)

3.1.6 Calculator Block for Control decomposition

ULTANAL is defined as the ultimate analysis on a dry basis. The variable WATER, defined as the percentage of H_2O in PROXANAL for biomass, is used to convert the final analysis to a wet basis. The remaining eight variables (H_2O to O_2) are defined as the yields of individual components of various species in the RYield block. ULT and WATER can then be used to calculate the yield of each species in the RYield block. The following FORTRAN statements are for the biomass decomposition calculator:

C FACT IS THE FACTOR TO CONVERT THE ULTIMATE ANALYSIS TO

C A WET BASIS.

FACT = (100 - WATER) / 100

H2O = WATER / 100

ASH = ULT(1) / 100 * FACT

CARB = ULT(2) / 100 * FACT

H2 = ULT(3) / 100 * FACT

N2 = ULT(4) / 100 * FACT
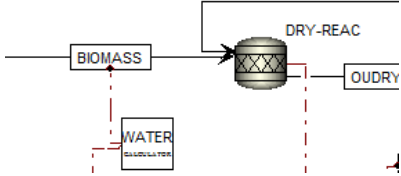
CL2 = ULT(5) / 100 * FACT
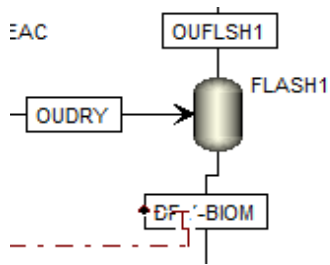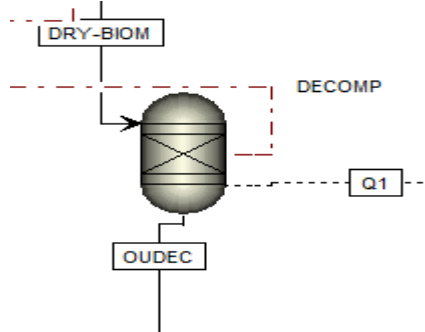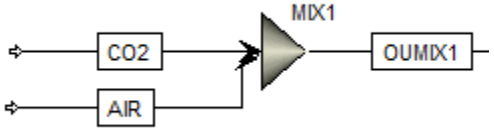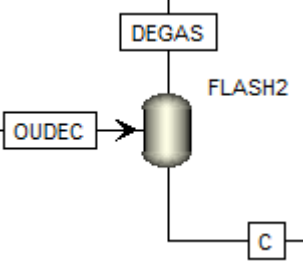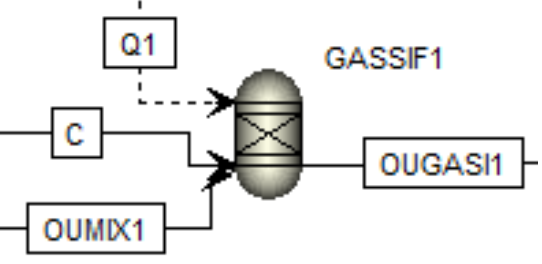
SULF = ULT(6) / 100 * FACT
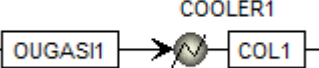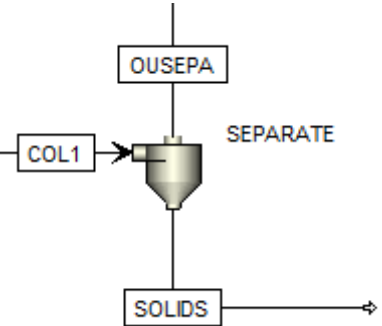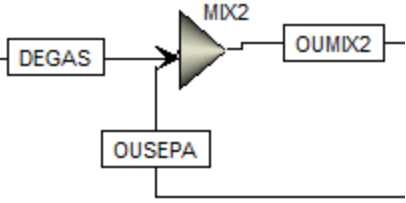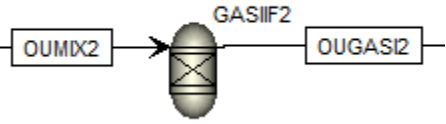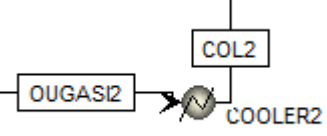
O2 = ULT(7) / 100 * FACT
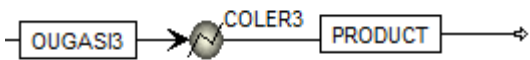
3.1.7 Aspen Unit Model Description

Table 3: Aspen unit models

Aspen Unit Block	Function	Specification
Drying	**Rstoichiomectric Reactor** removes free-moisture present in Biomass.	Temperature: 373K Pressure: 14.7 psia Yield: water: 10% (Wood chips) Dry-wood: 0%

Separator1	**Flash separator** Separates water from Dry-wood.	Flash Pressure: 14.7 psia Split fraction: 1 for water and 0 for dry-biomass in stream H_2O.
Decomposition	**Yield reactor** converts dry biomass into its constitute element oxygen, hydrogen, Nitrogen, char and ash.	Pressure: 14.7 psia Yield: Oxygen =0.424 Hydrogen =0.069 Nitrogen =0.003 Char = 0.487 Ash = 0.014
Mixture 1	**Mixture** mixes incoming oxygen and carbon dioxide to be used as fuel for combustion zone.	Pressure: 14.7 psia Valid phase: vapor
Separator 2	**Flash separator** separate solid carbon from gases created from decomposition reactor	Flash Pressure: 14.7 psia Split fraction: 1 for gases and 0 for Solid carbon in stream
Combustion	**RGibbs reactor** Char combustion reaction carryout in this reactor and Air and CO_2 mixture introduce as a gasifying medium.	Pressure: 14.7 psia

Heat loss 1	**Cooler** Cooler use to indicate the heat losses in real models and cooler1 is used to show heat loses from combustion zone	Pressure: 14.7 psia
Ash separator	**Separator** This will separate the un-burn carbon and ashes from combustion zone	Pressure: 14.7 psia
Mixture 2	**Mixture** Mixes the gases coming from separator and flash separator 2	Pressure: 14.7 psia
Reduction	**RGibbs reactor** This represents the reduction zone by doing equilibrium reactions in RGIBBS reactor.	Pressure: 14.7 psia
Heat loss 2	**Cooler** Cooler use to indicate the heat losses in real models. Cooler 2 is used to show heat losses from reduction zone.	Pressure: 14.7 psia

Heat loss 3	**Cooler** Cooler use to indicate the heat losses in real models. Cooler 3 is used to show heat loses from drying zone.	Pressure: 14.7 psia

3.2 Results

3.2.1 Elemental analysis of biomass

Analysis of rubber wood chips done by SGS Lanka (Pvt) Ltd and its report is given below (Appendix A)

Proximate analysis

Table 4: proximate analysis of wood chips

Element	Wight Percentage (w/w%)
Fixed Carbon	17.25
Volatile Matter	81.28
Ash	1.47
Moisture	36.7

Ultimate analysis

Table 5: Ultimate analysis of wood chips

Element	Wight Percentage (w/w%)
Ash	1.47
Carbon	48.74
Hydrogen	6.97
Nitrogen	0.35
Sulfur	0.04
Oxygen	42.43

3.2.2 Aspen Results

By inserting above parameters which are given in biomass test report to Aspen Plus model following test results can be obtained with various options.

1. When the CO_2 is zero and assuming heat loss from the gasifier is zero
   1.1. Temperature profile with various ER
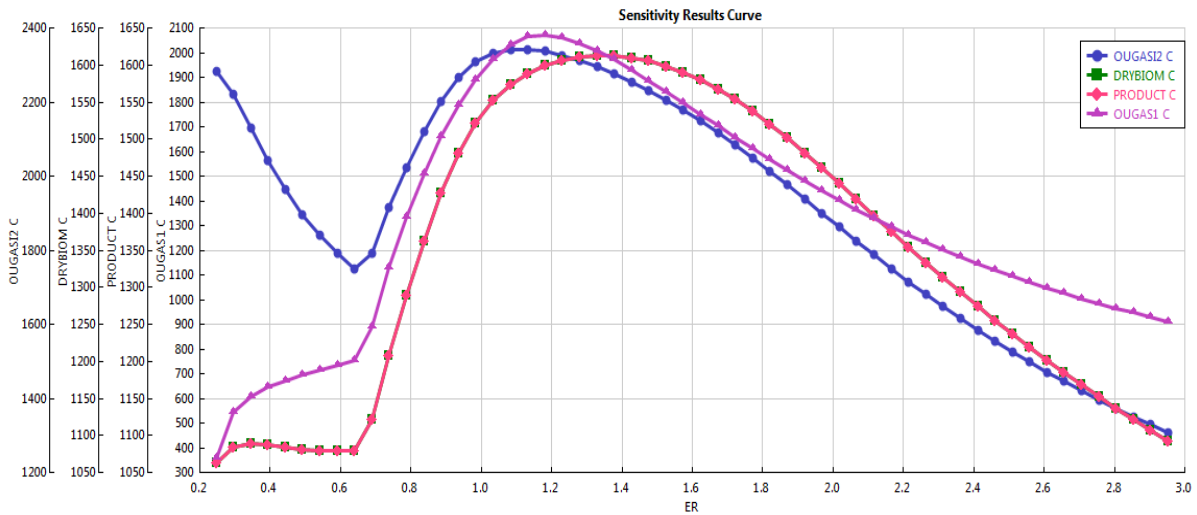
Figure 6: ER Vs. Temperature
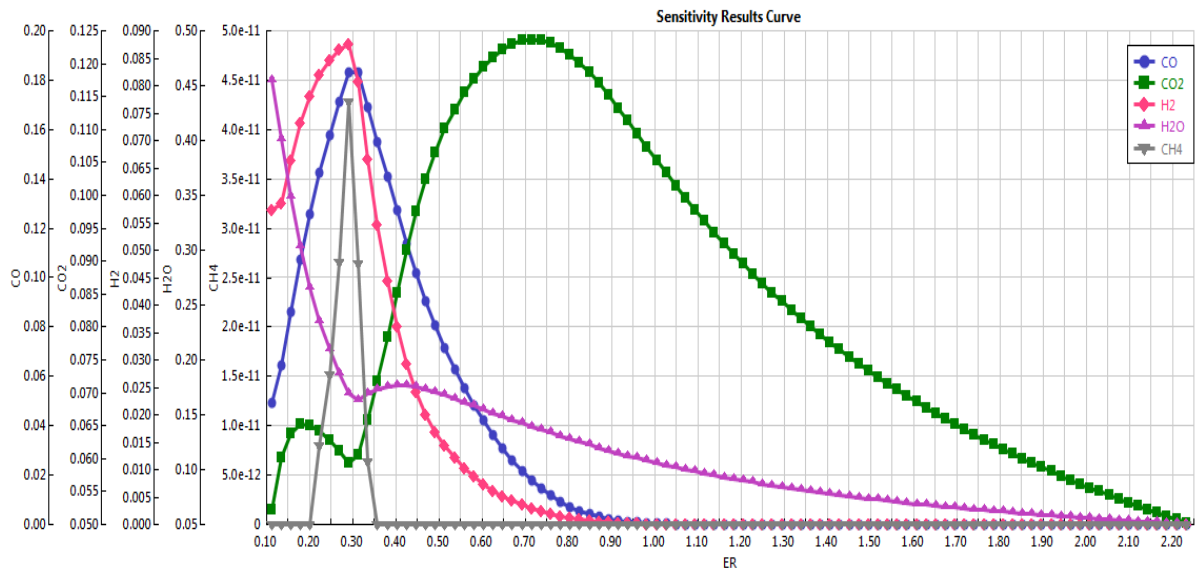
   1.2. Composition of producer gas with various ER

Figure 7: ER vs composition
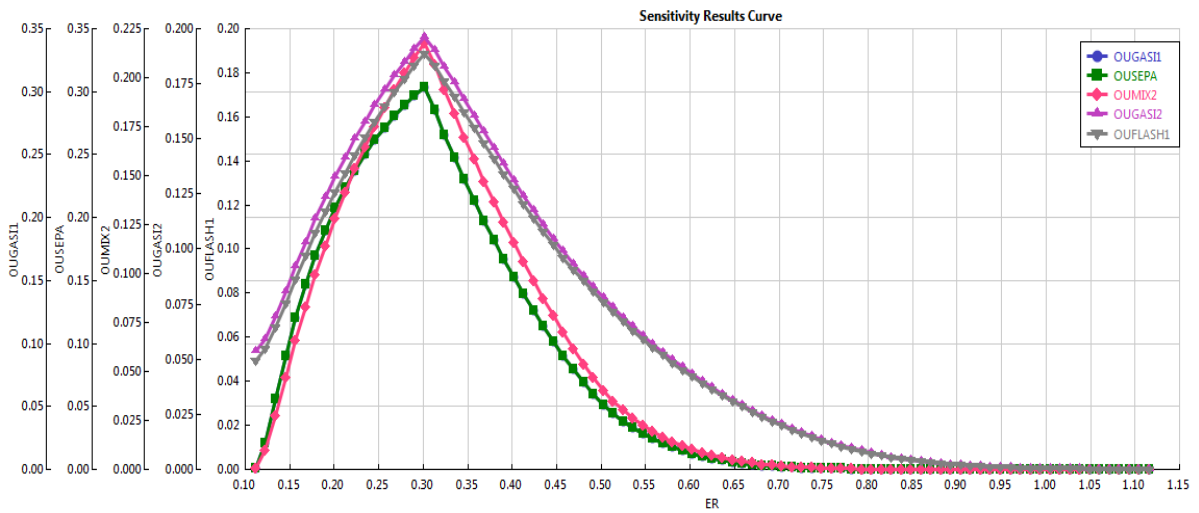
1.3. CO composition in different zones with various ER

Figure 8: CO composition in different zone with ER

2. Assuming heat loss from the gasifier is zero and CO_2 enrich air as gasifying agent

    2.1. Temperature profile with variations of Air By keeping CO_2 constant(6.6LB/HR)
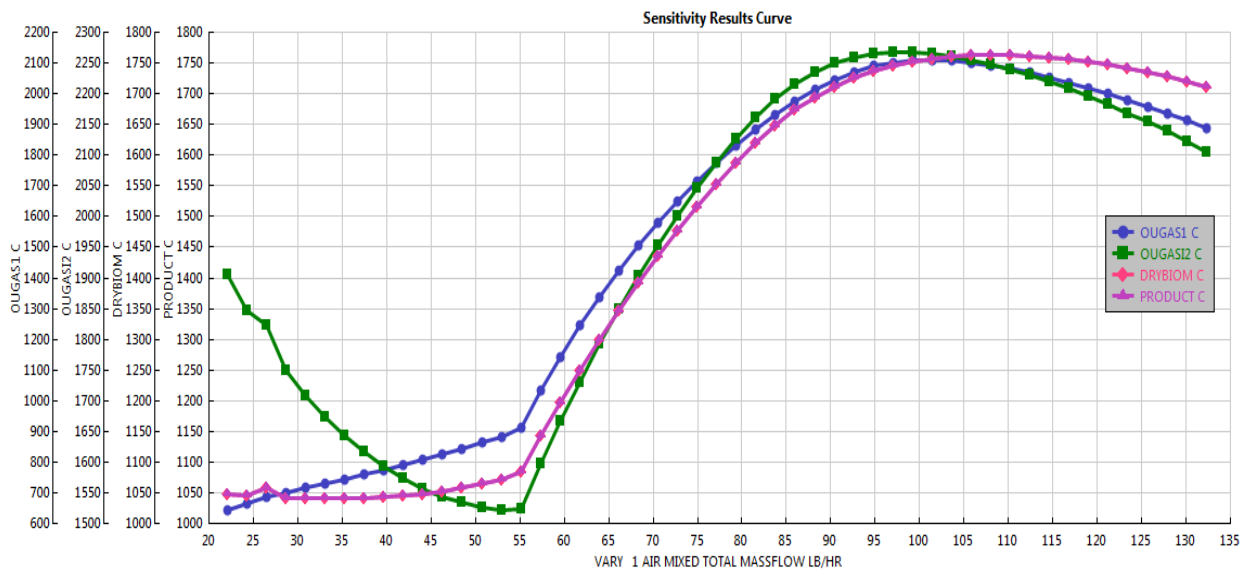
Figure 9: Air flow rate vs. Temperature with constant CO_2

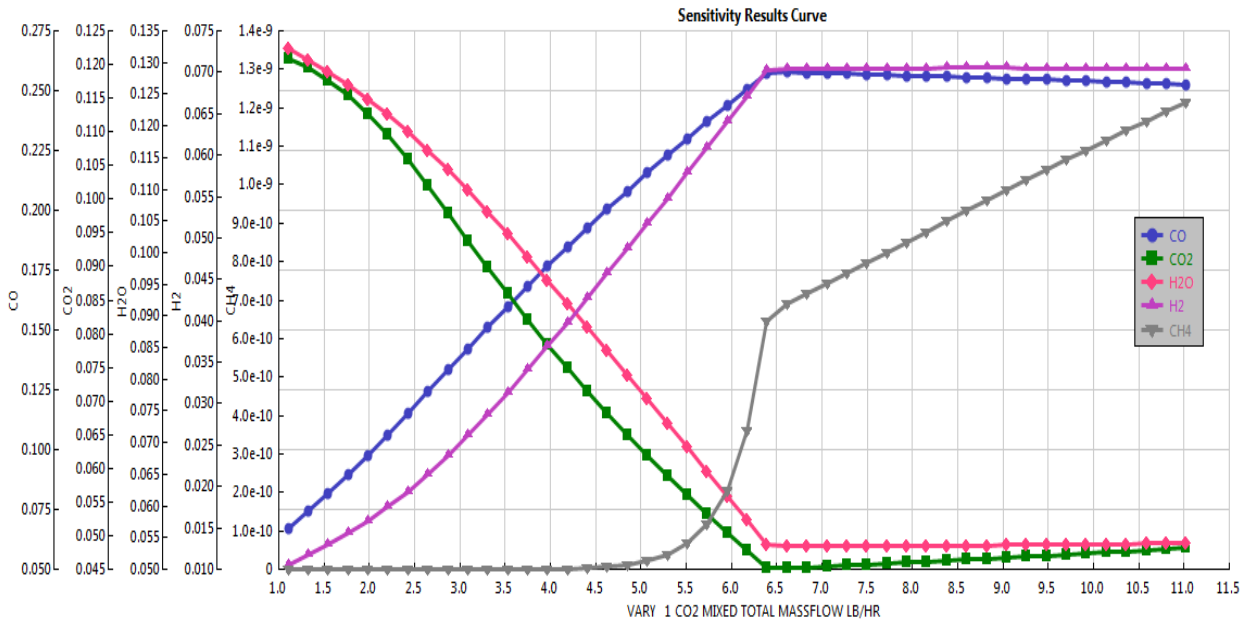## 2.2. Composition of producer gas with variations of CO_2 by keeping air constant (66LB/HR)

Figure 10: CO_2 flow rate vs. Composition with Constant air

2.3. Product composition with variation of air By keeping CO_2 constant(6.6LB/HR)
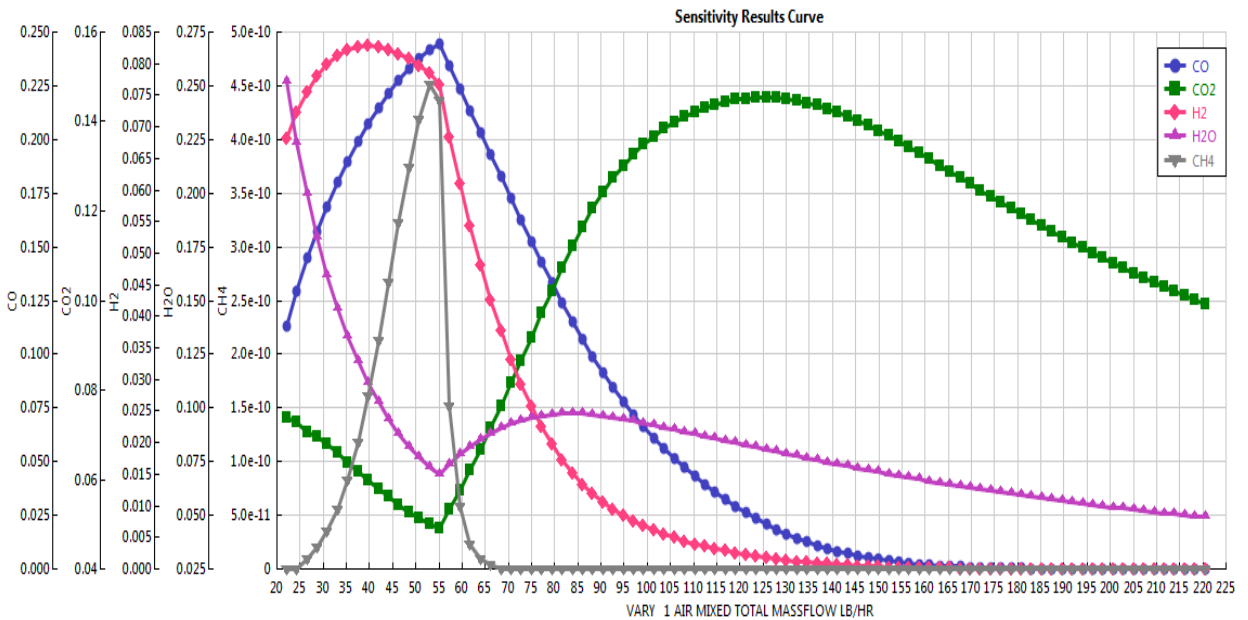
Figure 11: Air flow rate vs. product composition with constant CO_2

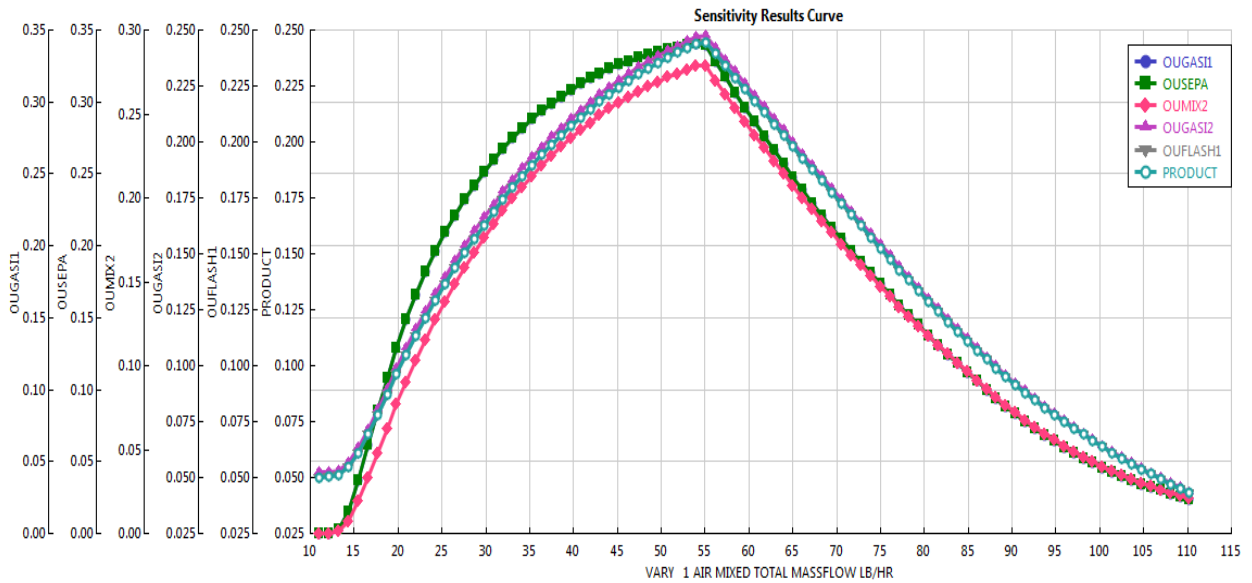2.4.CO composition in different location with various air by keeping CO_2 constant(6.6LB/HR)

Figure 12: Air flow rate vs. CO in different zone with constant CO_2

3. Effect of heat losses from gassifier to end result

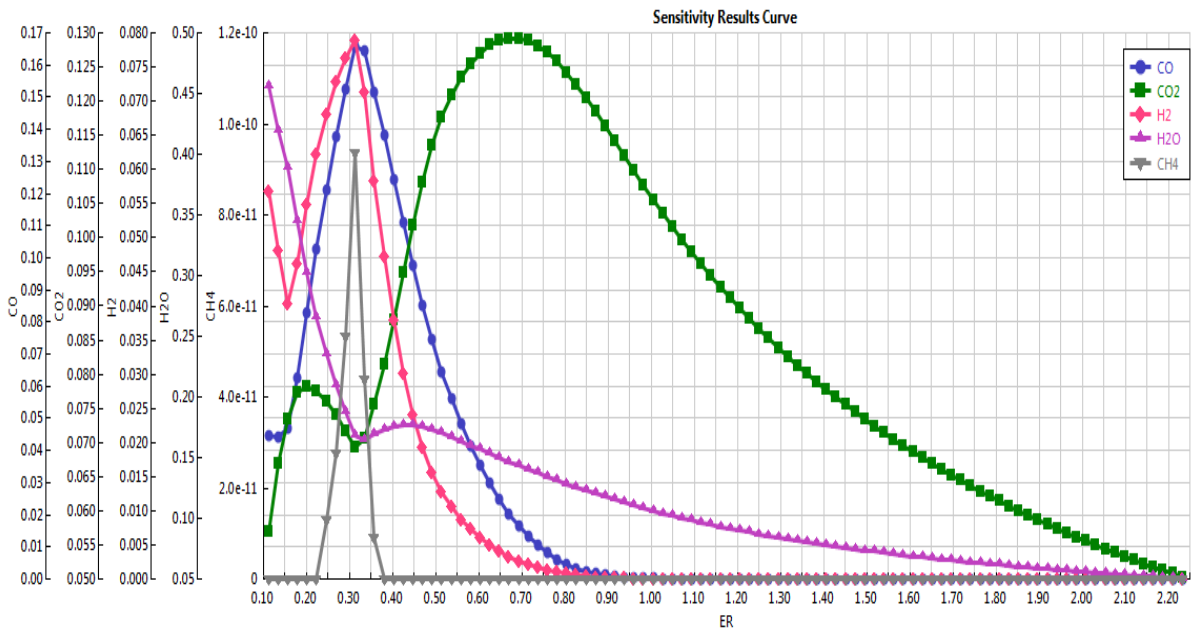3.1.Product gas composition changes with zero CO_2 and air changes

Figure 13: Air flow rate vs. composition with heat loss

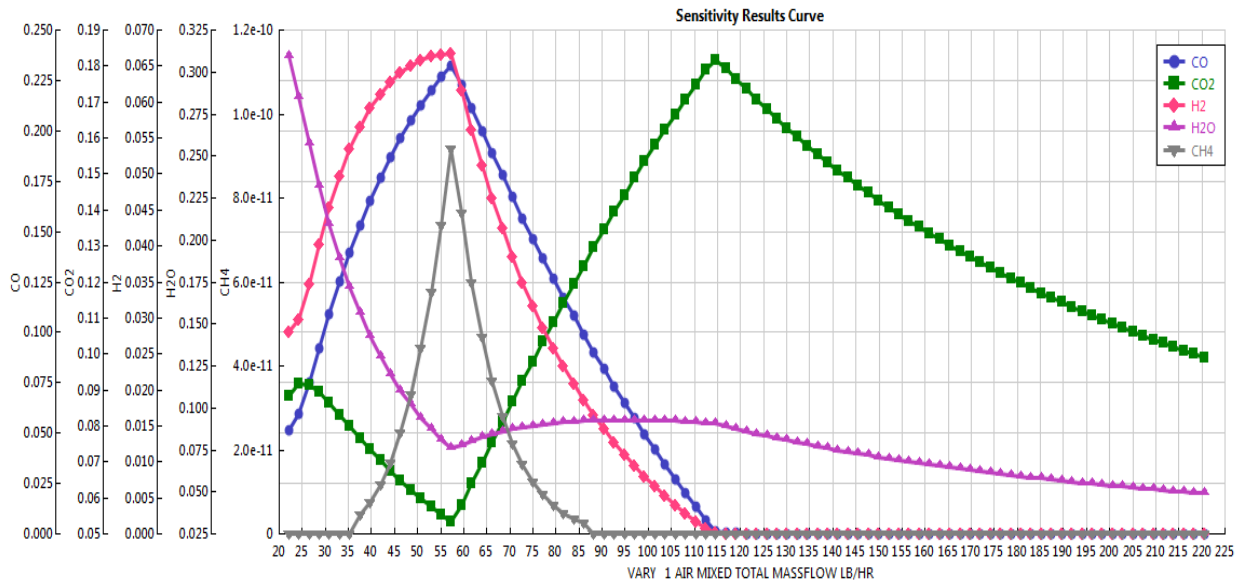### 3.2. Product gas composition changes with constant CO_2 (6.6LB/HR) and air changes

Figure 14: Air flow rate vs. product composition with constant CO_2 and heat loss

3.3. Product gas composition changes with various CO_2 and constant air(66LB/HR)
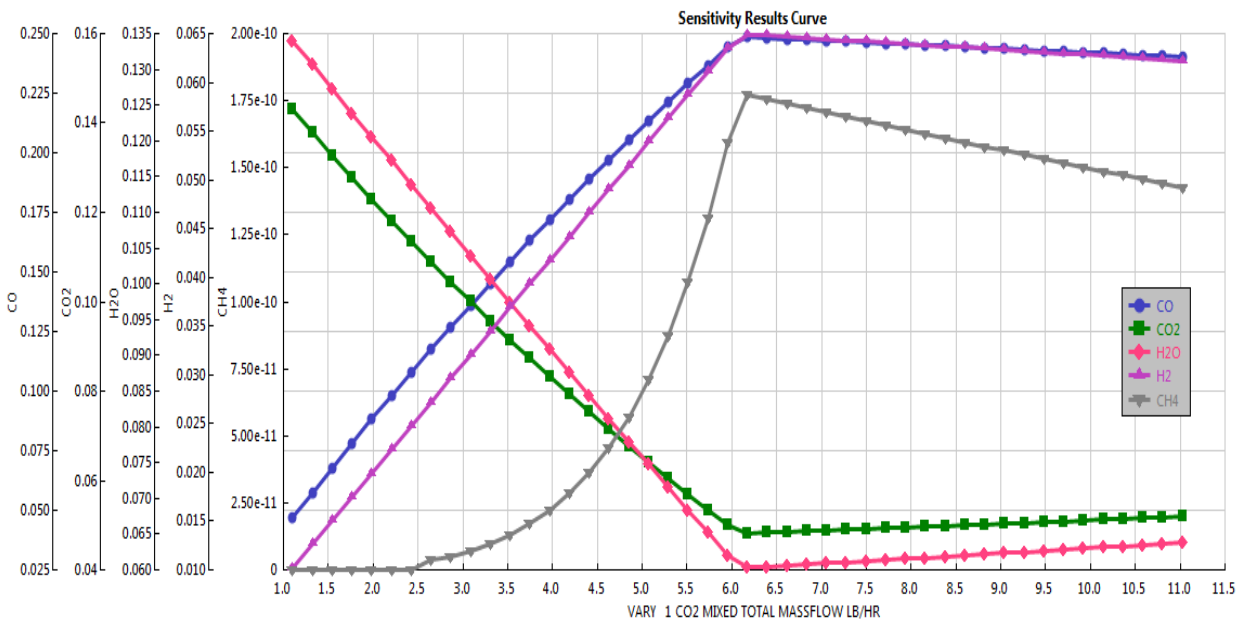

Figure 15: CO_2 flow rate vs. product composition with constant air and heat loss

4. Effect of moisture in inlet biomass to final product when zero heat loss condition and CO_2

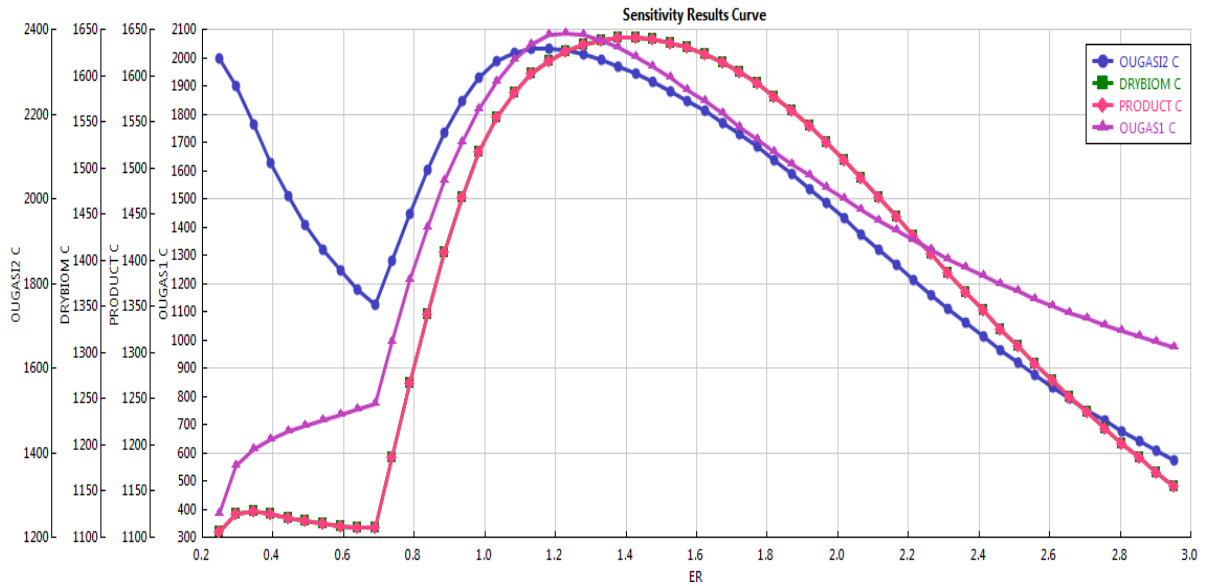   4.1.With 5% moisture in inlet biomass

Temperature variation

Figure 16: ER vs. Temperature with 5% inlet moisture
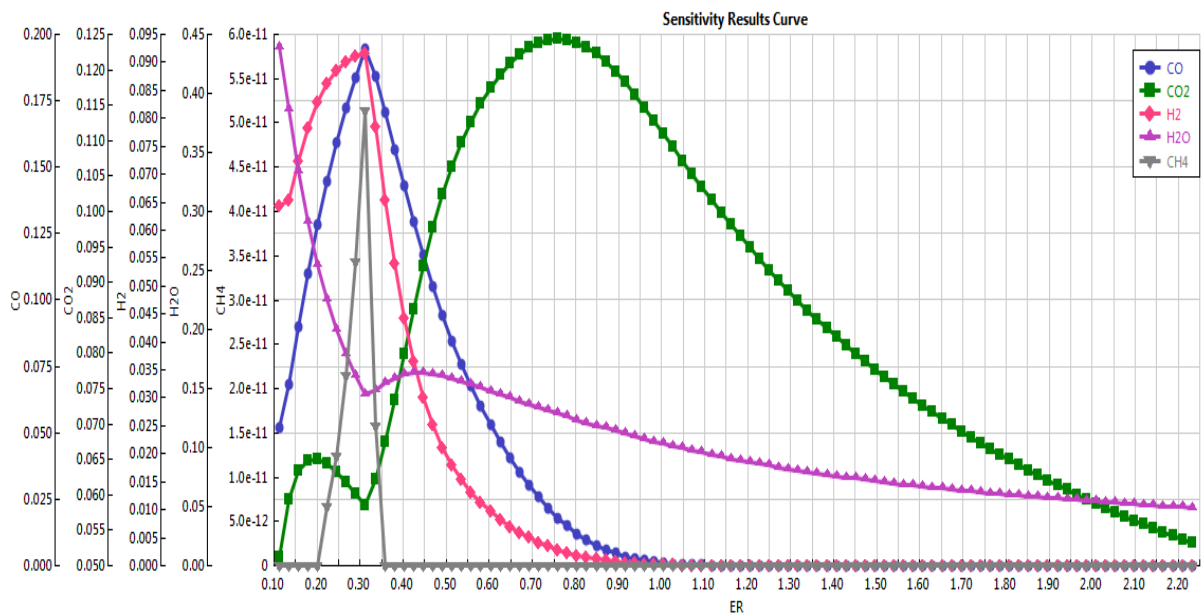
Composition variations

Figure 17: ER vs. Product composition with 5% inlet moisture

4.2. With 10% moisture in inlet biomass

Temperature variation

Figure 18: ER vs. Temperature with 10% inlet moisture

Composition variations

Figure 19: ER vs. Product composition with 10% inlet moisture

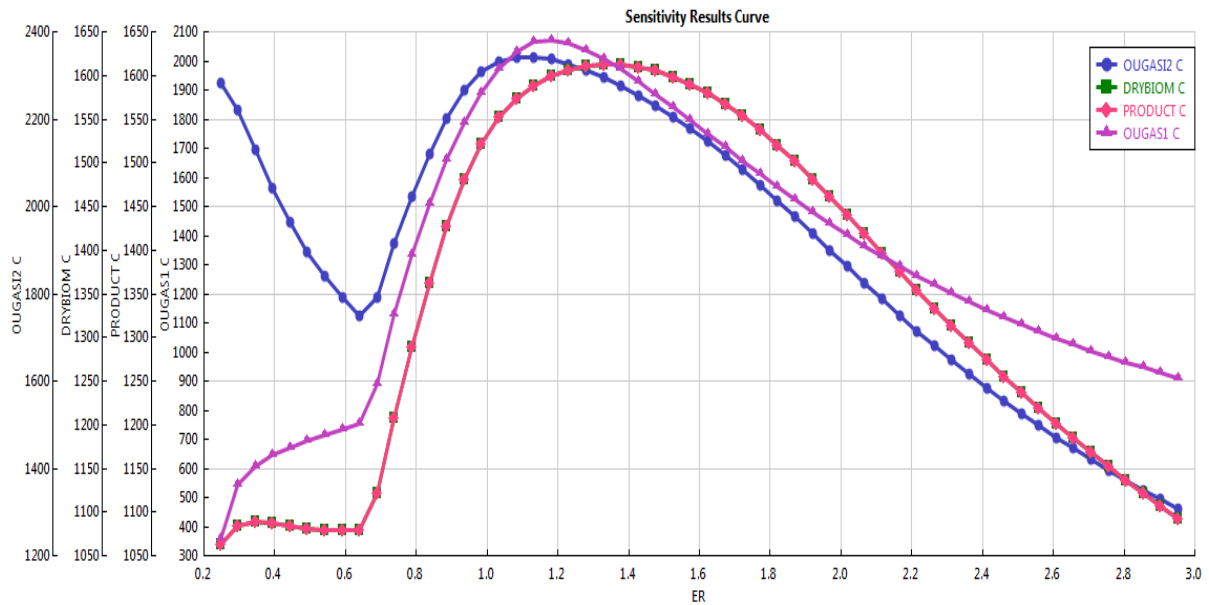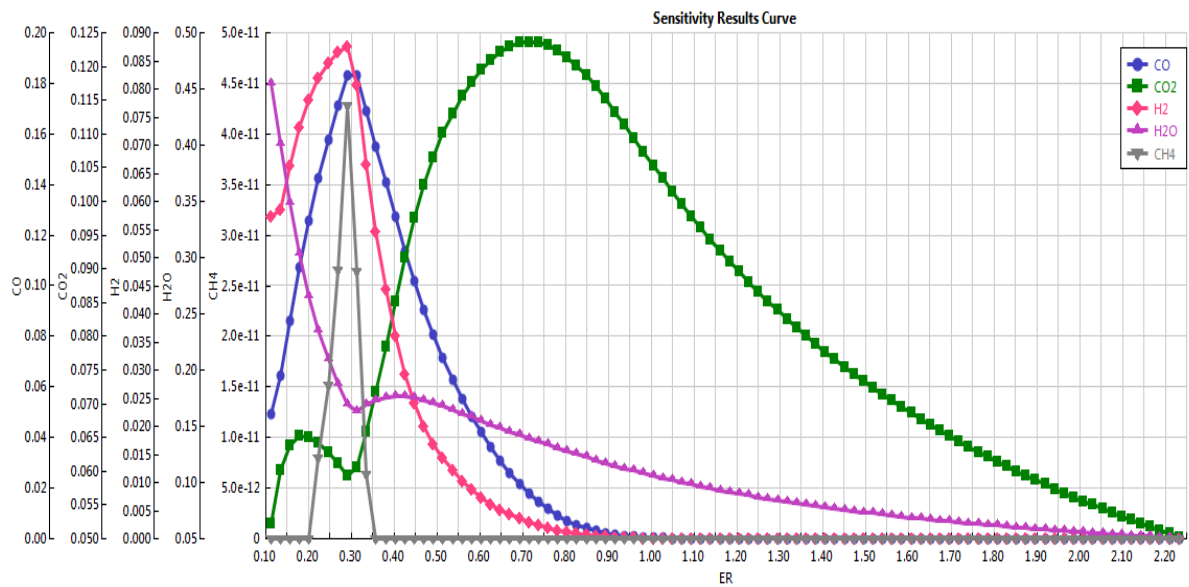### 4.3. With 20% moisture in inlet biomass
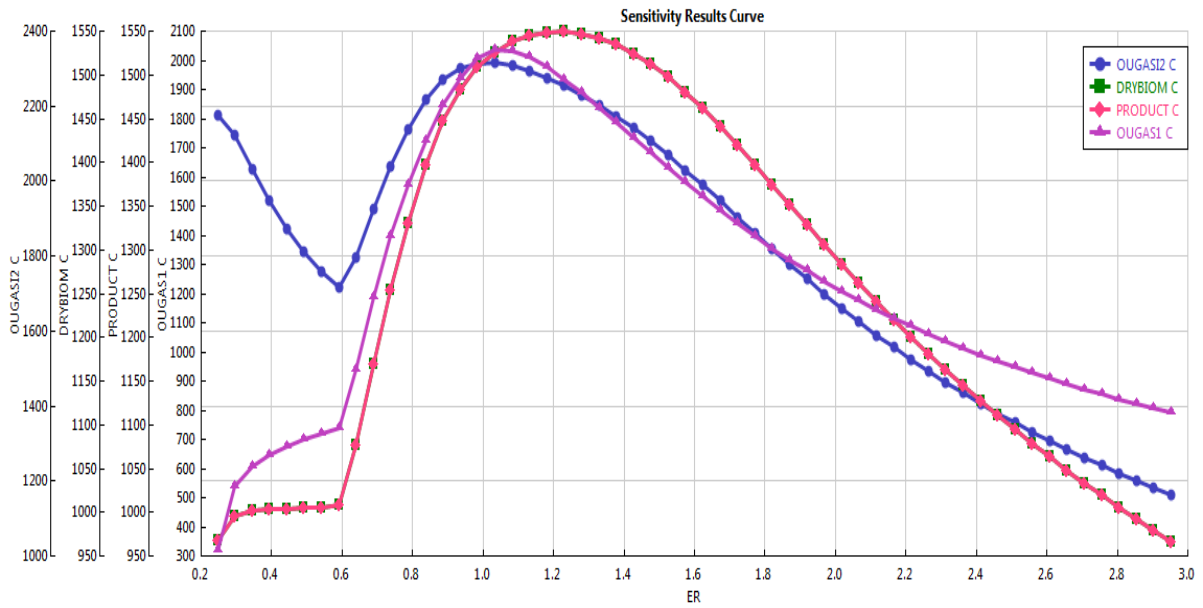
Temperature variation

Figure 20: ER vs. Temperature with 20% inlet moisture

Composition variations
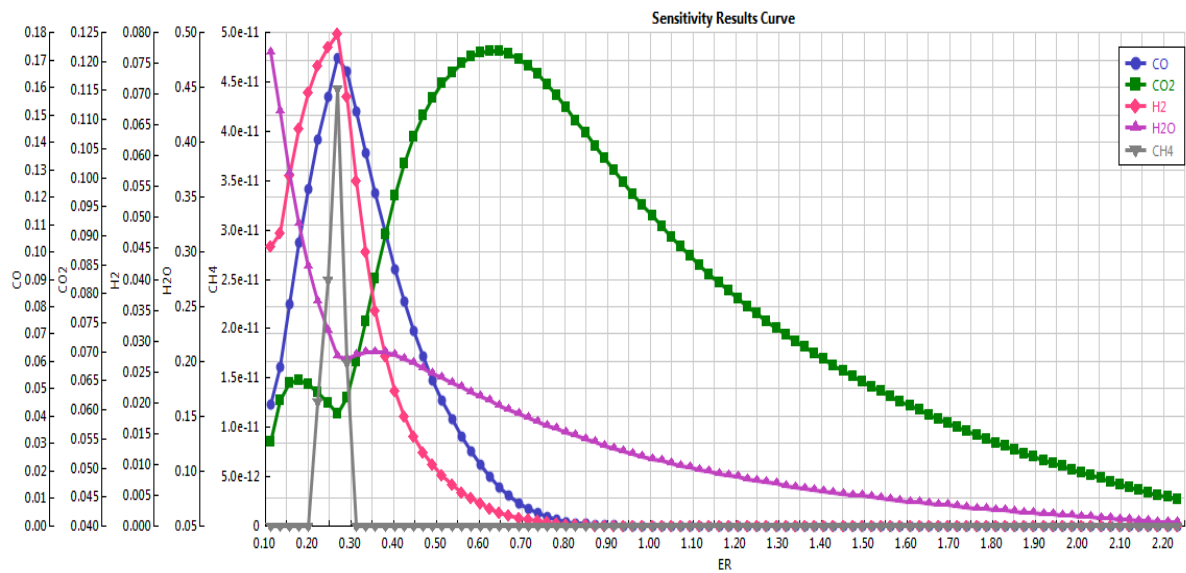
Figure 21: ER vs. product composition with 20% inlet moisture

5. Effect of air flow rate to unburned carbon with CO_2 and without CO_2

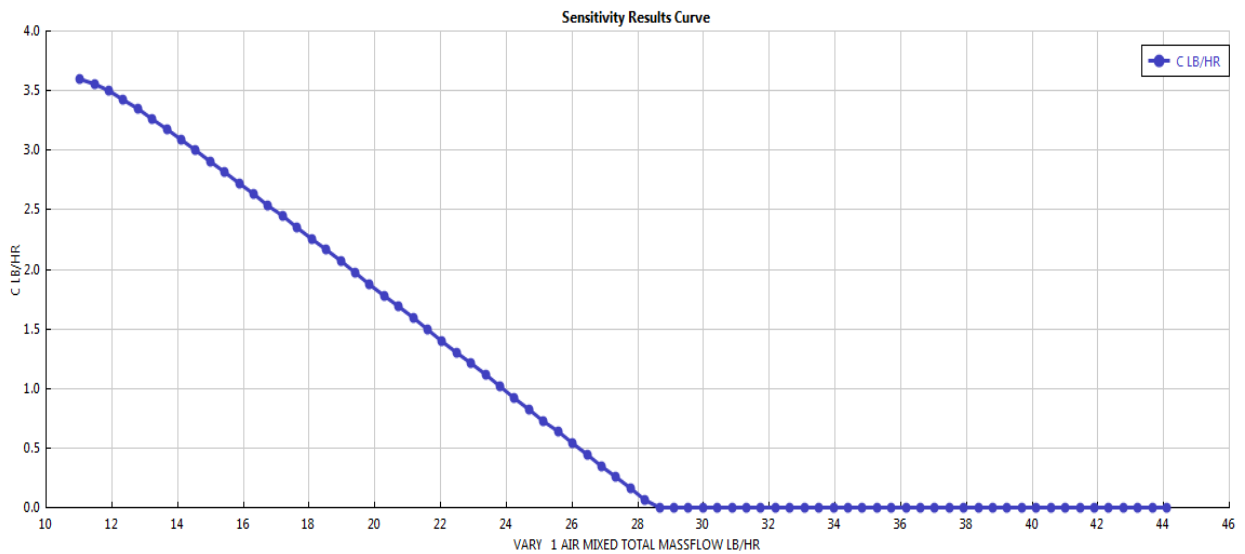5.1 Unburned carbon with various air flow rate and zero CO_2

Figure 22: Air flow rate vs. unburned carbon - with zero CO_2

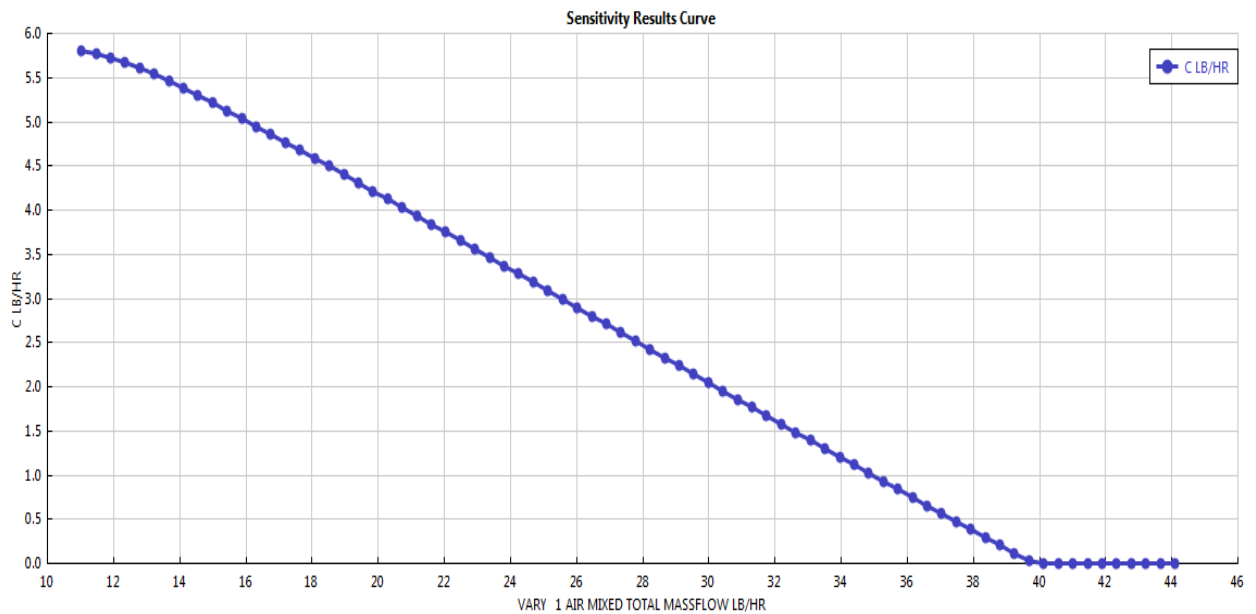5.1 Unburned carbon with various air flow rate and with CO_2 flow rate of 2.2 LB/HR

Figure 23: Air flow rate vs. unburned carbon-with 2.2LB/HR CO_2

3.3 Validation

### Comparison with previous work

Current study has been compared with previous work in terms of composition of producer gas in updraft gasifier[36].

Table 6: 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	-	-
Amin	**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
Wei Chen	Updraft	Junipar	5.56	56.42	20.78	14.96	1.9	-	0.37

Test result from the experiment which is done in university of Moratuwa is given below

Table 7 : CO variation in producer gas with CO_2 variation in inlet air
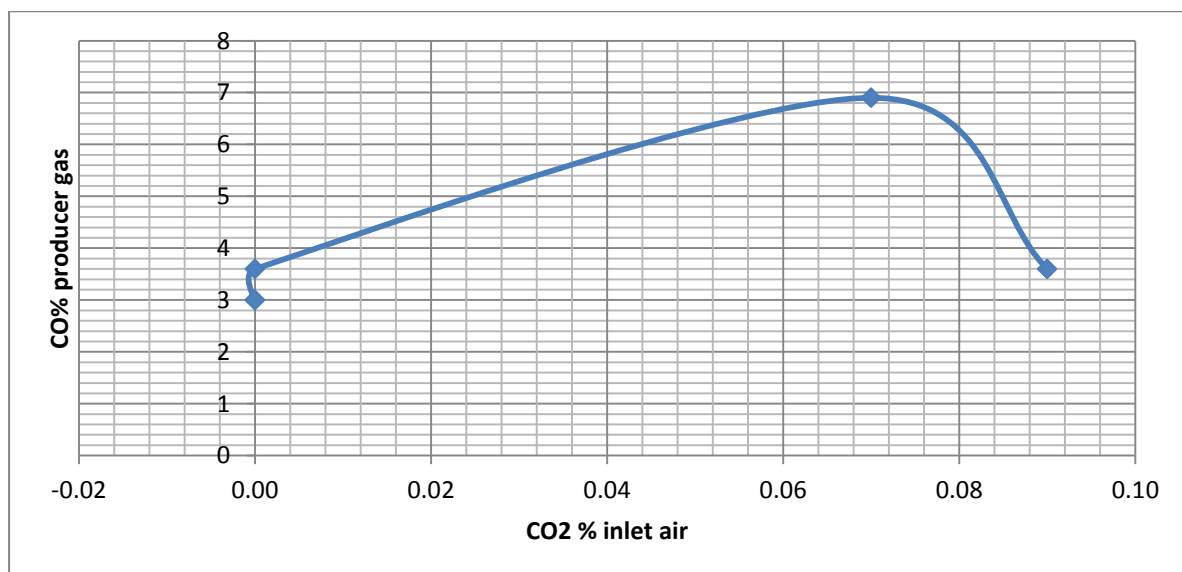
4. DISCUSSION AND CONCLUSION

4.1 Result Discussion

Gasification of biomass is very sensitive process because small change in the operating parameters or composition of inlet biomass change the composition of producer gas. In addition to these, the type of gasifier used, and the design of gasifier also affected the composition of producer gas. Therefore, it is important to carry out research on this topic with considerations for various biomass and gasifying agents over a wide range of operating parameters. However, the sheer number of experiments to be performed for such a study will be both expensive and impractical. Computational model simulating the working of a gasifier solves the problem by allowing the user to tweak the necessary parameters and understand its effect without having to physically perform the experiment.

Many efforts have been made to accurately simulate the operation of gasifiers and predict the composition of production. In order to develop a complete model, it is important to select the right method and to adapt the most appropriate modeling tools, as well as the mathematical knowledge of the parameters to be varied. Gasification modeling focuses on modeling the three individual steps involved in gasification as well as considerations of the reactions that occur and the properties of the gasifier. Fixed bed gasifiercan be easily modeled because of their simple design. Based on the type of tools used for simulation, gasification models can fall into different categories[37].

Thermodynamic equilibrium models are the simplest models used to describe the operation of the gasification process. The thermodynamic models are independent of the design of the gasifier and are very useful for preliminary comparison and for process studies on the influence of basic operating parameters. These models consider the condition of chemical equilibrium, where the reaction system is the most stable, obtained when the entropy of the system is maximized while the Gibbs free energy is minimized. This model does not consider the kinetic or dynamic aspects of the process and instead focuses on the composition of the most "stable" product assuming that the reactants react in a fully mixed state for an infinite period of time.

The objective of this study was to develop simulation capable of predicting the study-state performance of an updraft gasifier by considering the equilibrium reaction kinetics. The product of homogeneous reaction was defined by Gibbs equilibrium, and Ryield Rector was

used to decomposition of biomass. The result obtains from the sensitivity analysis are in good agreement with experimental work. Therefore, the Aspen Plus model can predict accurately gasifier performance over a range of operating conditions.

The Aspen model was validated by the data obtained by tests using air as gasification agent[36] and my experiment with CO_2 enrich air as gasification agent which was done in a lab scale gasifier in University of Moratuwa.

Following point can be explained using the result which was obtained by running the above Aspen Plus model.

1. CO concentration variation with CO_2 % in gasification agent
2. CO concentration variation with heat loss from gasifier
3. Effect of moisture in inlet biomass to final product
4. Effect of ER ratio with CO_2% in inlet air
5. Effect of ER ratio to Unburned carbon

1. CO concentration variation with CO_2 % in gasification agent

When CO_2 is introduced into the gasification air, the CO composition in the producer gas is initially increased and begins to reduce the CO_2 above 9% in the gasification air as shown figure10. The temperature of the reactor is being reduced when increase CO_2%. This may due to the endothermic reaction with CO_2 and it may be the reason to reduce the CO concentration in the producer gas when the CO_2 composition exceeds 9% in the input vapor. In the lab test maximum yield of CO is given when 9% of CO_2 in the inlet air.
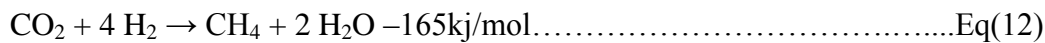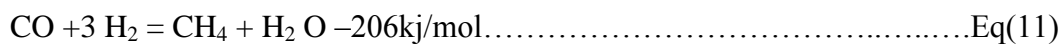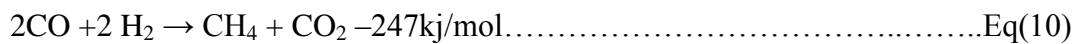
2. CO concentration variation with heat loss from gasifier

Most of the reaction during the gasification process are Endothermic and it's required energy is obtained from combustion zone which is released energy by exothermic reaction. Therefore, heat loss from reactor is affected to the final product composition. Heat loss from the reactor is simulated by 3 numbers of coolers in the Aspen model. When adding the temperature cure which was got from the test run to the model composition of CO in producer gas will be decreased when compare the graph in figure 7 & figure 11

3. Effect of moisture in inlet biomass to final product

The model is proof that moisture contents of feed stock have great impact on quality of producer gas by reducing the CO% and H_2 % (figure 16, 18&20). When increase the moisture content in inlet biomass it is reduced the temperature of reactor due to moisture absorbs considerable energy to evaporate from biomass (figure17, 19&21).

When increase the moisture percentage, reduce the CO and H2 in the product stream by increasing the CH_4 due to methanation reactions is given below.

$2CO +2 H_2 \rightarrow CH_4 + CO_2$ –247kj/mol……………………………..……..Eq(10)

$CO +3 H_2 = CH_4 + H_2 O$ –206kj/mol…………………………….…..….…Eq(11)

$CO_2 + 4 H_2 \rightarrow CH_4 + 2 H_2O$ –165kj/mol……………………….…....Eq(12)

4. ER ratio change with CO_2% in inlet air

The ER does not only mean the amount of oxygen injected into the reactor but also affects the gasification temperature under the conditions of automatic thermal operation. On the one hand, a lower ER represents less oxygen in the system, which is not favorable for achieving equilibrium of the gasification reaction. In addition, a higher ER represents higher gasification temperatures, which favors gasification reactions, thus improving the characteristic of the synthesis gas to a particular limit. Thus, the gaseous constituents were affected by the two ambiguous dynamics of ER.

In the present study, the influence of ER on product distributions and syngas from gasification was investigated. It is observed that ER varied from 0.1 to 0.35 through changes in the air flow rate, CO_2 flow rate while other conditions were held constant. With zero CO_2, it is around 0.3(Figure 7) but it was drastically increased with CO_2 enrich air and it is around 0.6(figure 11).This may due to the endothermic reaction when increase the CO_2%.

Additionally, increasing the equivalence ratio (ER) in air or oxygen gasification implies increasing the amount of oxygen as compared to the amount of biomass. As ER increases, oxidation/ combustion reactions lead to decrease in the amount of CO and H_2 and an increase in the output CO_2 is observed.

5. Effect of ER ratio to Unburned carbon

   Temperature remains the most important parameter affecting the overall biomass conversion with major influence on the final product compositions. The fundamental role of temperature is to supply heat of decomposition to break the bonding structure of the feedstock as well as providing more thermodynamically favorable conditions for the endothermic gasification reactions such as steam reforming, reverse Boudouard, and char and tar gasification to CO and H_2 products as opposed to CH_4 product.

When the ER ratio is low, the reactor cannot operate automatically due to insufficient heat generation from combustion. As a result, the percentage of unburned carbon will be increased (Figure 22). With CO_2 injection, this is an increase in unburned carbon due to the increase in endothermic reactions (Figure 23). The reactor must therefore operate with a higher ER ratio to obtain optimal results.

4.2 Future Work

   For the future experimental work it is proposed to use the actual productfor decomposition product instead of decomposition to its constituent element. The compositions of the decomposition product are temperature and heating rate dependent. Tar product can be taking in account by defining non- equilibrium products in the RGIBBS.

   Mass transfer inside solid particles is also an important parameter in gas–solid reactions and heat transfer inside particles. Heat transfer is also important between phases;particles. This is another feature that should be included in the model in order to achieve better simulation prediction.

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Appendix A

Test Report

SAMPLE NOT DRAWN BY SGS INDIA PVT. LTD.

			Print Date	:	30/06/2016
Report No	: CG16-013423.001		JOE No	:	CG16-013423

Report Control No : CGR0000570437

Sample described by customer as : WOOD CHIPS

Customer Name	:	SGS LANKA (PVT) LIMITED
Customer Address	:	1ST FLOOR,140,VAUXHALL STREET
City	:	COLOMBO
Postal Code	:	2
Country	:	SRILANKA
Sample Type	:	WOOD CHIPS
Received	:	22/06/2016
Sample Qty. Recd.	:	1kg
SGS Internal No.	:	7660016003
Test Start	:	22/06/2016
Test End Date	:	30/06/2016

Test/Parameter	Method	Result	Unit
Total Moisture	ASTM D2961 : 11	36.70	% (w/w)
Ash (on dry basis)	ASTM D3174 : 12	1.47	% (w/w)
Ash (as received basis)	ASTM D3174 : 12	0.93	% (w/w)
Volatile matter (on dry basis)	ASTM D 3175 : 11	81.28	% (w/w)
Volatile matter (as received basis)	ASTM D 3175 : 11	51.45	% (w/w)
Fixed carbon (on dry basis)	ASTM D3172 : 13	17.25	% (w/w)
Fixed carbon (as received basis)	ASTM D3172 : 13	10.92	% (w/w)
Gross calorific value (on dry basis)	ASTM D5865 : 13	4753	kcal/kg
Gross calorific value (as rceived basis)	ASTM D5865 : 13	3009	kcal/kg
Sulphur (as received basis)	ASTM E 775- 87, Reaff:2008	0.03	% (w/w)
Sulphur (on dry basis)	ASTM E 775- 87, Reaff:2008	0.04	% (w/w)
Carbon (on dry basis)	ASTM D5373 : 2014	48.74	% (w/w)
Carbon (as received basis)	ASTM D5373 : 2014	30.85	% (w/w)
Hydrogen (on dry basis)	ASTM D5373 : 2014	6.97	% (w/w)
Hydrogen (as received basis)	ASTM D5373 : 2014	8.52	% (w/w)
Nitrogen (on dry basis)	ASTM D5373 : 2014	0.35	% (w/w)
Nitrogen (as received basis)	ASTM D5373 : 2014	0.22	% (w/w)
Sulphur (as received basis)	ASTM D5373 : 2014	0.03	% (w/w)
Sulphur (on dry basis)	ASTM D5373 : 2014	0.04	% (w/w)
Ash (on dry basis)	ASTM D5373 : 2014	1.47	% (w/w)
Ash (as received basis)	ASTM D5373 : 2014	0.93	% (w/w)
Oxygen (as received basis)	ASTM D3176 : 2015	59.45	% (w/w)
Oxygen (on dry basis)	ASTM D3176 : 2015	42.43	% (w/w)

Page 1 of 2

SGS India Pvt. Ltd.
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Member of the SGS Group (SGS SA)

SGS

Test Report

SAMPLE NOT DRAWN BY SGS INDIA PVT. LTD.

Report No : CG16-013423.003

Print Date : 30/06/2016
JOE No : CG16-013423

Report Control No : CGR0000570437

Test/Parameter	Method	Result	Unit
Silica (as SiO2)	ASTM C : 114 - 2013	87.90	% (w/w)
Aluminum (as Al2O3)	ASTM D : 6349 - 2013	1.61	% (w/w)
Iron (as Fe2O3)	ASTM D : 6349 - 2013	1.30	% (w/w)
Calcium (as CaO)	ASTM D : 6349 - 2013	1.41	% (w/w)
Magnesium (as MgO)	ASTM D : 6349 - 2013	0.79	% (w/w)
Sodium (as Na2O)	ASTM D : 6349 - 2013	0.07	% (w/w)
Manganese (as MnO)	ASTM D : 6349 - 2013	0.07	% (w/w)
Potassium (as K2O)	ASTM D : 6349 - 2013	1.47	% (w/w)
Sodium (as Na)	ASTM D : 6349 - 2013	0.05	% (w/w)
Titanium (as TiO2)	ASTM D : 6349 - 2013	0.27	% (w/w)
Phosphorous (as P2O5)	ASTM D : 6349 - 2013	1.39	% (w/w)
Sulphur trioxide (as SO3)	ASTM C : 114 - 2013	0.773	% (w/w)

Per pro SGS India Private Ltd

L_SIVAKUMAR
Authorized Signatory

****End of Report****

**Appendix B**

Stoichiometric air and gasification air flow rate calculation

Required air flow rate calculation should be done according to biomass formulas developed based on analysis report and assume that nitrogen is leaving without reaction. Balanced Stoichiometric equations for all biomass materials are as following

Rubber Wood

$$C_{1.53}H_{2.62}O + 2.175(O_2 + 3.76N_2) \rightarrow 1.53CO_2 + 1.31H_2O + 8.05N_2$$
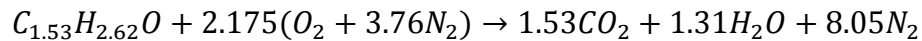
Stoichiometric air required is calculated as for Rubber wood.

Molecular weight of rubber wood = 36.98 g

Oxygen-Fuel mass ratio$= \frac{2.175 \times 32}{1 \times 36.98} = 1.88$ kg of oxygen /kg of fuel

Oxygen in air by mass percent is 21 so we need

$1.88 \times \frac{100}{21} = 8.96$ kg of air /kg of feed

$$Airflowrate = \frac{ER \times FCR \times Stoichiometricairfuelratio}{\rho ofair}$$

Air flow rate for different ER

ER	Air flow rate kg/hr	Air flow rate lb/hr
0.2	8.6	18.92
0.25	10.75	23.65
0.3	12.9	28.38
0.35	15.05	33.1