

ASPEN PLUS SIMULATION AND EXPERIMENTAL STUDIES ON BIOMASS GASIFICATION

**THIS THESIS IS SUBMITTED IN THE PARTIAL
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CHEMICAL ENGINEERING
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2012



National Institute of Technology

Rourkela

CERTIFICATE

This is to certify that the thesis entitled “**ASPEN PLUS SIMULATION AND EXPERIMENTAL STUDIES ON BIOMASS GASIFICATION**” submitted by **CHITTARANJAN PANDA (ROLL NO: 108CH034)** in partial fulfillment of the requirements for the award of **BACHELOR OF TECHNOLOGY** Degree in Chemical Engineering at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

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ABSTRACT

The biomass gasification has been carried out using a fluidized bed gasifier. This work focuses on the production of syngas from biomass (rice husk). ASPEN PLUS simulator and pilot plant gasifier were used to investigate the effect of reactor temperature, equivalence ratio and steam to biomass ratio on composition of product gas. Silica sand was used as bed material in the pilot plant gasifier. The gasifier was operated over a temperature range of 500-700 °C, while varying equivalence ratio from 0.2 to 0.36 and steam to biomass ratio from 0.5 to 1.5 and it was found that the most of trends were similar for both the case. The results showed hydrogen concentration in the product gas increases with increase in temperature and steam to biomass ratio but decreases with increasing equivalence ratio.

Keywords: Fluidized bed gasifier, biomass, equivalence ratio, steam to biomass ratio, ASPEN PLUS.

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CHAPTER 1
INTRODUCTION

INTRODUCTION

The traditional fossil fuels (oil, coal and natural gas) continue to be the major sources of energy in the world. The increasing energy demands will speed up the exhaustion of the finite fossil fuel. With the current proved reserves and flows, years of production left in the ground coal: 148 years, oil: 43 years, natural gas: 61 years ^[1].

Depending of fossil fuels has led to serious energy crisis and environmental problems, i.e. fossil fuel exhaustion and pollutant emission. Carbon dioxide is the main greenhouse gas, and a major part of CO₂ emissions is due to combustion of fossil fuels. Also combustion of fossil fuel produces toxic gases, such as SO₂, NO_x and other pollutants, causing global warming and acid rain. Several researches have been made to explore clean, renewable alternatives. As hydrogen is clean and renewable source of energy it can replace the conventional fossil fuels. Also hydrogen has the highest energy to weight ratio compared to any fuel.

Apart from its use as a source of energy, hydrogen can be used for various other purposes in different industries. It is used in hydrogenation process, saturate compounds and crack hydrocarbons. It is a good oxygen scavenger and can therefore be used to remove traces of oxygen. It is also used in manufacturing of different chemicals like ammonia, methanol etc. ^[2].

Gasification is a process that converts organic or fossil based carbonaceous material into a combustible gas by reacting the material at high temperature with a controlled amount of air/oxygen often in combination with steam. Biomass as a product of photosynthesis is one of the most abundant renewable resource that can be used for sustainable production of hydrogen. Fluidized bed gasifiers are advantageous for gasification of biomass because of their flexibility in feedstock size and better contact between gases and solid.

The objective of this work is to study the effect of different operating parameters (temperature, equivalence ratio and steam to biomass ratio) on gasification of rice husk using a atmospheric fluidized bed gasifier. Silica sand was used as bed material. APSEN PLUS simulator and a pilot plant gasifier are used to investigate the effects.

CHAPTER 2
LITERATURE REVEIW

Hydrogen can be produced from a variety of feed stocks. This includes natural gas, coal, biomass and water. At present, hydrogen is produced commercially from fossil fuels such as natural gas, naphtha, and coal.

2.1. HYDROGEN FROM FOSSIL FUEL

2.1.1. Production from Natural Gas

H₂ is produced from natural gas by steam reforming process which involves the conversion of methane and water vapor into hydrogen and carbon monoxide. The conversion is carried out at temperatures of 700 to 850 °C and pressures of 3 to 25 bar. The product contains approximately 12 % CO, which can be further converted to CO₂ and H₂ through the water-gas shift reaction ^[3].



2.1.2. Production from Coal

Hydrogen can be produced from coal through a variety of gasification processes (e.g. fixed bed, fluidized bed or entrained flow). High temperature entrained flow processes are favored to maximize carbon conversion to gas, thus reduces the formation of char, tars and phenols ^[3].



The Carbon monoxide present in the product gas is further converted to CO₂ and H₂ through the water-gas shift reaction.

2.2. HYDROGEN FROM ELECTROLYSIS OF WATER

Water electrolysis is the process in which water is split into hydrogen and oxygen by the application of electrical energy.



The total energy that is needed for electrolysis of water increases slightly with temperature but the required electrical energy decreases. This is important globally, as most of the electricity produced is based on fossil energy sources with relatively low efficiencies ^[3].

2.3. HYDROGEN PRODUCTION FROM BIOMASS

Major resources in biomass include agricultural crops and their waste byproducts, lignocellulosic products such as wood and wood waste, waste from food processing and aquatic plants and algae, and effluents produced in the human habitat.

Biomass can be converted into useful forms of energy products using a number of different processes. There are two routes for biomass conversion into hydrogen-rich gas

- (i) Thermochemical conversion and (ii) Biochemical conversion

2.3.1 Thermo-Chemical Conversion

There are main three methods for biomass-based hydrogen production via thermo-chemical conversion: (i) pyrolysis, (ii) gasification, and (iii) SCWG

2.3.1.1. Pyrolysis

Pyrolysis is the heating of biomass at a temperature of 650-800 K and at a pressure of 0.1-0.5 MPa in the absence of air to convert biomass into solid charcoal, liquid oils and gaseous compounds. Pyrolysis can be classified into slow pyrolysis and fast pyrolysis. The products of slow pyrolysis is mainly charcoal. So it is not considered for hydrogen production. The products of fast pyrolysis can be found in all 3 phases. Gaseous products of pyrolysis include H₂, CO, CH₄, CO₂ and other gases depending on the organic nature of the biomass ^[4].

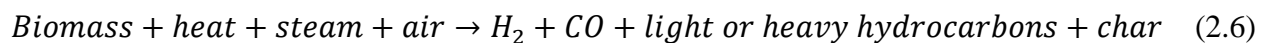
The steam reforming of methane and other hydrocarbon produced can produce more hydrogen.



The gas can be further enriched with H₂ through water gas shift reaction.

2.3.1.2. Gasification

Biomass gasification is a process that converts biomass in to a combustible mixture (mainly CO, H₂, CO₂ and CH₄). This is achieved by reacting the biomass at high temperatures, without combustion, with a controlled amount of oxygen, air and/or steam. It is preferable over pyrolysis for production of hydrogen because almost all the product of gasification are gases with a small amount of tar.



The gases produced can be steam reformed to produce hydrogen and this process can be further improved by water gas shift reaction ^[4].

2.3.1.3. Supercritical Water Gasification (SCWG)

At supercritical conditions, for example, water at temperatures above 374°C and pressures above 22.3 MPa behaves like an adjustable solvent and has tunable properties depending on temperature and pressure. Under such conditions, biomass gets rapidly decomposed by hydrolysis and the cleavage products of biomass (mixture of CO, H₂ and methane) dissolve in the supercritical water thereby minimizing the tar and coke formation ^[6].

2.3.2 Biochemical or Biological Conversion

The production of hydrogen by biochemical or biological conversion is limited to laboratory scale and the practical applications still needs to be demonstrated. Hydrogen production from Biological process can be classified into five different groups: (i) direct bio photolysis, (ii) indirect bio photolysis, (iii) biological water gas shift reaction, (iv) dark fermentation and (v) photo-fermentation. Hydrogen-producing enzymes, such as hydrogenase and nitrogenase control all these processes. This chemical reaction produces hydrogen by a nitrogenase based system:



Where, ADP and Pi refer to adenosine diphosphate and inorganic phosphate, respectively ^[4].

2.4. GASIFIER TYPES

2.4.1. Fixed Bed Gasifiers

Fixed bed gasifiers are subdivided into updraft and downdraft gasifiers. Both require fuel particles of small size (1-3 cm) to ensure an unblocked passage of gas through the bed. So the preferred biomass form is pellets or briquettes ^[7].

2.4.2. Fluidized Bed Gasifiers

Two types of fluidized bed reactors are used: bubbling fluidized bed (BFB) and circulating fluidized bed (CFB).

Advantages of Fluidized bed gasifier:

1. Fluidized bed gasifiers do not encounter scaling-up problems.
2. Particle size of feedstock is not strict.
3. Improved mass and heat transfer.
4. Reduced char formation.

The fluidized bed temperature must be kept below the ash melting point of the biomass, since a sticky ash might glue together with bed particles causing agglomeration and breakdown of fluidization. Hence, these are better suited for materials having high ash melting point e.g. woody bio-material (above 1000°C) ^[7].

2.4.3. Entrained Flow Gasifiers

Entrained flow gasifiers convert the mixture of biomass and oxygen into a turbulent dust flame at high temperatures (significantly above 1200°C, even 2000°C) for a very short period of and at high pressure (about 50 bars). In order to achieve high conversion of the feedstock pulverized solid (particle size below 1 mm) or liquid (e.g. pyrolysis oil) feedstock is used ^[7].

2.5. WHY FLUIDIZED BED GASIFIER COUPLED WITH WATER GAS SHIFT

As the products of fluidized bed gasification are mainly gases, this process is more favorable for hydrogen production than pyrolysis. Using a fluidized bed gasifier along with suitable bed material and catalysts, it is possible to achieve hydrogen production about 60 volume% which can be further enriched with H₂ through the water-gas shift reaction. Such high conversion efficiency makes biomass a potential source for hydrogen production.

2.6.1. Bed Materials

Bed material can be inert (e.g. silica sand) and also bed material with catalytic activity (e.g. dolomite) can be used. The mechanical stability, thermal stability and chemical stability are 3 main factors for usability of bed material. The bed material should have high adsorption capacity in order to carry CO₂ out of the gasification zone to yield a high quality product.

2.6.2. Catalysts Used

Application of suitable material with catalytic effect and adsorption properties may result not only in tar content reduction, but also in the reduction of concentration of undesirable compounds of sulphur and chlorine in the gas. The most frequently used catalysts are either natural catalysts (dolomite, zeolites, calcite and olivine) or catalysts based on metals (Ni, Mo, Co, etc.). The most frequently used nonmetallic (natural) catalyst is dolomite (calcium magnesium carbonate) ^[8].

2.7. PREVIOUS WORKS

Turn et al. ^[9] experimentally investigated with increase in temperature hydrogen yield and total gas yield increases yields which can be attributed to increased steam and carbon dioxide gasification reaction rates brought about by higher reactor temperatures. Higher hydrocarbon concentrations decreased as reactor temperature increased, the result of more favorable conditions for thermal cracking and steam reforming reactions. With decrease in Equivalence ratio the hydrogen and gas yield increases. With increasing the steam to biomass ratio the hydrogen and gas yield increases but it is least sensitive parameter compared to others.

Nikoo M. B. and Nader M. ^[10] developed a process model is for biomass gasification in an atmospheric fluidized bed gasifier using the ASPEN PLUS simulator. The model addresses both hydrodynamic parameters and reaction kinetic modeling. Using pine sawdust as raw material they investigated that temperature increases the production of hydrogen. Equivalence ratio is directly proportional to carbon dioxide production and carbon conversion efficiency. With increase in steam to biomass ratio hydrogen and carbon monoxide production increases and carbon dioxide and carbon conversion efficiency decreases.

Rapagna et al. ^[11] studied parametric sensitivity of a gasification process, using olivine as the fluidized bed inventory and showed that production of gases with relatively low molecular weights is also favored by increasing gasification temperature. Steam to biomass ratio has a weak effect on gasifier performance and outlet gas composition.

Lv et al. ^[12] experimentally investigated the effect of different parameters on outlet gas composition, carbon conversion efficiency, gas yield etc. using pine sawdust as feed stock and silica sand as bed material. They found that with increase in temperature hydrogen concentration

increases and methane and carbon monoxide concentration decreases. In the steam to biomass range 0-1.35, hydrogen and carbon monoxide concentration decreases and carbon dioxide and methane concentration increases and optimal Equivalence Ratio was found to be 0.23.

Inayat et al. ^[13] studied the impact of temperature, steam to biomass ratio and sorbent/biomass ratio on hydrogen production performance in a steam gasification process using a simulation model developed in MATLAB. They found that with increase in temperature and steam to biomass ratio, the hydrogen concentration and yield increases and the thermodynamic efficiency decreases. The steam feed rate was found to be the most sensitive parameter among the process parameters.

Franco et al. ^[14] studied the effect of temperature and steam to biomass (pinuspinaster, Eucalyptus globulus and holm-oak) ratio on gasification using atmospheric fluidized bed. It was found that with increase in temperature, concentration of hydrogen increases and the concentration of carbon monoxide and methane decreases. Carbon dioxide concentration remains almost constant over the temperature range. Optimum steam to biomass ratio was found to be 0.6-0.7 w/w.

CHAPTER 3
ASPEN PLUS SIMULATION

ASPEN PLUS simulator is used to model and predict the performance of a process which involves the decomposition of the process into its constituent elements for individual study of performance. It is widely used to study and investigate the effect of various operating parameters on various reactions.

3.1 ASSUMPTIONS

The following assumptions were considered in modeling the gasification process: ^[10]

- The gasification process is isothermal and steady state.
- Biomass de-volatilization is instantaneous in comparison to char gasification.
- The biomass particles are spherical and are not affected in course of the reaction.
- All the gases are uniformly distributed within the emulsion phase
- Char consists of only carbon and ash.
- Char gasification starts in the bed and ends in the freeboard.

3.2 GASIFICATION REACTIONS

Generally, biomass gasification undergoes the following steps in a fluidized bed: (1) the biomass particle decomposes quickly to form char, tar and gaseous products; (2) Reactions between the gaseous products and (3) tar cracking and char gasification ^[15]

The following reactions take place during gasification of biomass ^{[10] [15]}:

Basic combustion reactions



Boudouard reaction:



Water gas reaction:



Methanation reaction:



Shift conversion:



Steam reforming of methane:



3.3. ASPEN PLUS MODEL

Four different stages were considered in ASPEN PLUS simulation are decomposition of the feed, volatile reactions, char gasification, and gas solid separation ^[10].

3.3.1. 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.

3.3.2. Volatile Reactions

The ASPEN PLUS Gibbs reactor, RGibbs, was used for volatile reactions. RGibbs models single phase chemical equilibrium, or simultaneous phase and chemical equilibria. This model is used when reaction stoichiometry is not known but reactors temperature and pressure are known. Carbon partly constitutes the gas phase and the remaining carbon comprises part of the solid phase (char) and subsequently undergoes char gasification. A Separation column model was used before the RGIBBS reactor to separate volatiles and solids.

3.3.3 Char Gasification

The ASPEN PLUS CSTR reactor, RCSTR performs char gasification by using reaction kinetics. RCSTR assumes perfect mixing in the reactor, that is, the reactor contents have the same properties and composition as the outlet stream.

RCSTR handles kinetic and equilibrium reactions as well as reactions involving solids. So for char gasification it is preferred. The hydrodynamic parameters of the fluidized bed reactor divide the reactor into two regions, bed and freeboard. Each region is simulated by one RCSTR.

Table 1: Parameters used in the simulation and experimentation

FLUIDIZED BED REACTOR

Temperature (°C)	500-700
Pressure (bar)	1.013

AIR

Temperature (°C)	30
Flow rate (m ³ /hr)	5-20

STEAM

Temperature (°C)	130
Flow rate (kg/hr)	5-15

3.4 SIMULATION FLOWSHEET

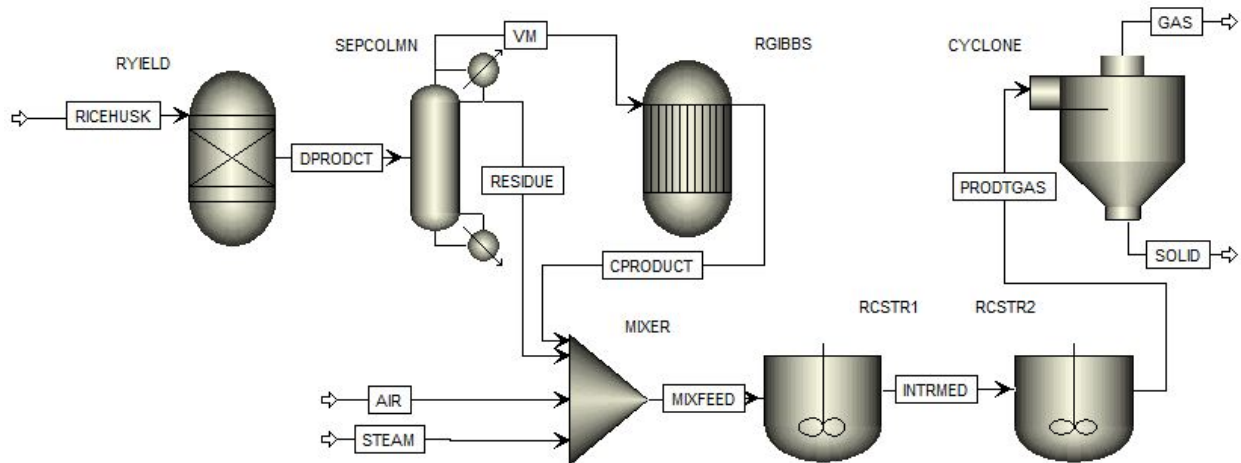


Figure1: Flow-sheet of ASPEN PLUS Simulation for fluidized bed gasification ^[10].

3.5. CHARACTERISTICS OF RAW MATERIALS

Table 2: Rice Husk elemental analysis (wt%, dry basis)

Parameter	Value
Carbon	38.62
Hydrogen	5.56
Nitrogen	2.42
Oxygen	36.20

Table 3: Rice Husk proximate analysis (wt%, dry basis)

Parameter	Value
Volatile matter	67.2
Fixed carbon	15.6
Ash	17.2

3.6. SIMULATION ANALYSIS

The product gas compositions were computed on dry, inert free basis.

3.6.1. Effect of Varying Temperature at Constant Steam to Biomass Ratio and Constant Equivalence Ratio on Product Gas Composition

Steam to biomass ratio = 0.5, Equivalence ratio = .25, Biomass = 10 kg/hr

Table 4: Simulated product gas composition (volume %) at different temperatures

Temp (°C)	H ₂ (vol %)	CO (vol %)	CH ₄ (vol %)	CO ₂ (vol %)
500	31.12	42.34	11.99	14.55
550	32.24	41.58	11.62	14.56
600	33.18	40.9	11.35	14.57
650	34.15	40.21	11.06	14.58
700	35.11	39.56	10.76	14.59

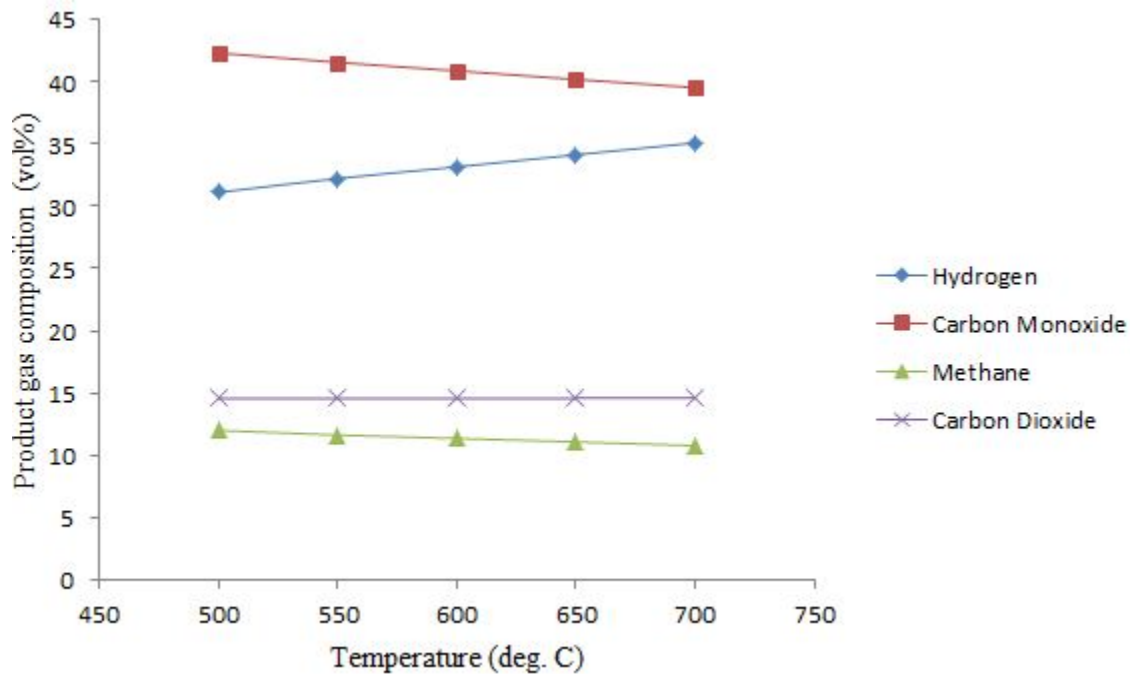


Figure 2: Simulated product gas composition versus temperature

3.6.2. Effect of Varying Equivalence Ratio at Constant Steam to Biomass Ratio and Constant Temperature on Product Gas Composition.

Temperature = 700 °C, Steam to biomass ratio = 0.5, Biomass = 10 kg/hr

Table 5: Simulated product gas composition (volume %) at different Equivalence ratios

ER	H ₂ (vol %)	CO (vol %)	CH ₄ (vol %)	CO ₂ (vol %)
0.20	37.61	39.97	10.79	11.63
0.24	35.61	39.62	10.76	14.01
0.28	33.56	39.39	10.74	16.31
0.32	31.72	39.18	10.72	18.38
0.36	30.07	38.91	10.71	20.31

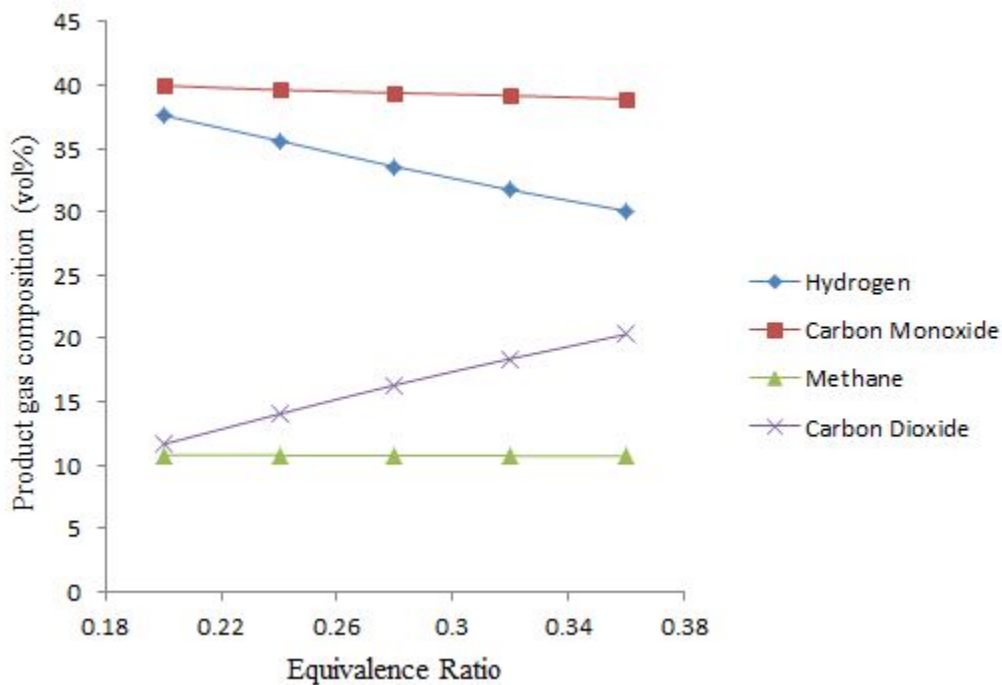


Figure 3: Simulated product gas composition versus equivalence ratio

3.6.3. Effect of Varying Steam to Biomass Ratio at Constant Equivalence Ratio and Constant Temperature on Product Gas Composition

Equivalence ratio = 0.26, Temperature = 700 °C, Biomass = 10 kg/hr

Table 6: Simulated product gas composition (volume %) at different steam to biomass ratios

S/B ratio	H ₂ (vol %)	CO (vol %)	CH ₄ (vol %)	CO ₂ (vol %)
0.50	35.28	39.68	10.75	14.29
0.75	35.89	39.32	10.72	14.07
1.00	36.42	39.19	10.70	13.69
1.25	36.86	39.08	10.69	13.37
1.50	37.22	39.01	10.69	13.08

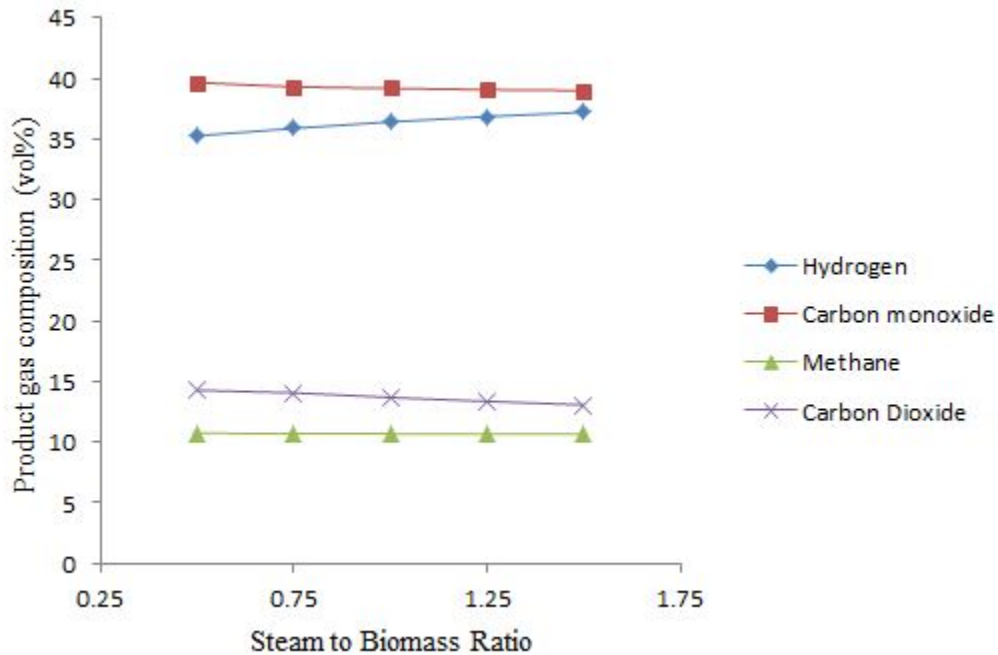
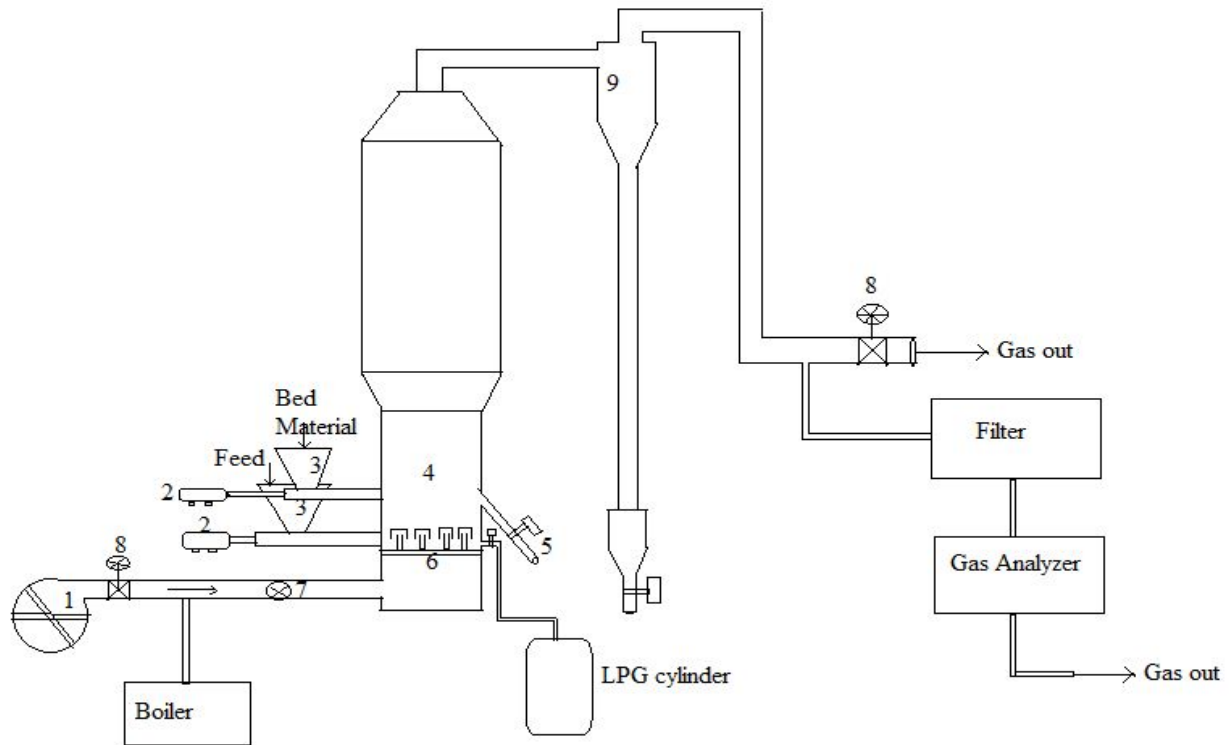


Figure 4: Simulated product gas composition versus steam to biomass ratio

CHAPTER 4
EXPERIMENTATION

4.1. EXPERIMENTAL SET UP

The experimental system is a pilot plant consists of (1) atmospheric fluidized bed, (2) biomass feeding section, (3) bed material feeding section, (4) air/steam feeding section, (5) gas analysis section and (5) temperature measuring section. The gasifier was a continuous type gasifier. The experiments were carried out by using rice husk as raw material and silica sand as bed material.



1	Air blower	6	Bubble cap
2	Motor	7	Orifice meter
3	Screw feeder	8	Valve
4	Fluidized bed gasifier	9	Cyclone separator
5	Continuous cleaning system		

Figure 5: The schematic diagram of the Experimental set up.

The feeding rate of biomass (rice husk) was controlled by the speed of the screw. Air and steam are introduced from the bottom of the gasifier. Orifice meter was used to measure the flow rates of air and steam.

4.2. EXPERIMENTAL PROCEDURE

At the startup of each experiment, 3 kg of the bed material (silica sand of size < 1 mm) was fed to the fluidized bed reactor by the help of the screw feeder; the blower, temperature indicators and the boiler for steam generation were turned on. Then the bed was fired using LPG as a fuel at a flow rate of 10-15 LPH. After the fluidized bed temperature reached a desired level, the flow of LPG into the gasifier was stopped and the rice husk was fed to the reactor by the help of the screw feeder and the gasification starts.

A filter was connected to the outlet gas in which the solid particles are captured by water and the remaining particles captured by a filter of pore size 0.01 micron. Before going to the analyzer the moistures present in the gas was removed by passing it through silica gel. ACE 9000X CGA portable infrared coal gas Analyzer was used to measure the concentration of H₂, CO, CH₄ and CO₂ in the outlet gas.

A series of experiments were performed to determine the effect of different operating parameters (temperature, equivalence ratio and steam to biomass ratio) on product gas composition. Table 2 shows the operating parameters studied and their ranges. The product gas compositions were computed on dry, inert free basis and neglecting gases of very low concentrations.

Table 7: Operating parameters studied and their ranges

Operating Parameter	Range
Temperature	500-700 °C
Equivalence ratio	0.20-0.36
Steam to Biomass ratio	0.5-1.5

4.3. EXPERIMENTAL ANALYSIS

4.3.1. Effect of Varying Temperature on Product Gas Composition at Constant Steam to Biomass Ratio and Constant Equivalence ratio

Steam to biomass ratio = 0.5, Equivalence ratio = 0.25, Biomass = 10 kg/hr

Table 8: Experimental product gas composition (volume %) at different temperatures

Temp (°C)	H ₂ (vol %)	CO (vol %)	CH ₄ (vol %)	CO ₂ (vol %)
500	28.73	26.77	8.24	36.26
550	33.16	25.42	7.16	34.26
600	36.34	23.14	8.33	32.19
650	37.89	24.92	8.11	29.08
700	43.58	23.43	7.37	25.62

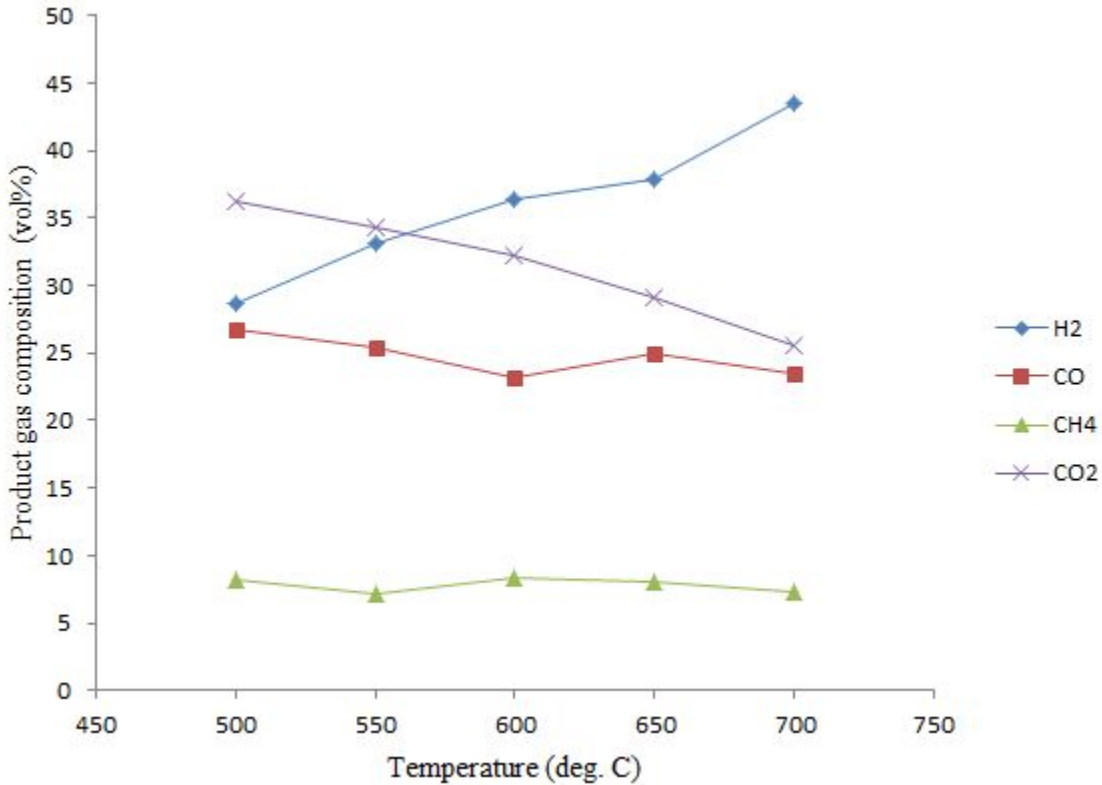


Figure 6: Experimental product gas composition versus temperature

4.3.2. Effect of Varying Equivalence Ratio on Product Gas Composition at Constant Steam to Biomass Ratio and Constant Temperature

Temperature = 700 °C, Steam to biomass ratio = 0.5, Biomass = 10 kg/hr

Table 9: Experimental product gas composition (volume %) at different equivalence ratios

ER	H ₂ (vol %)	CO (vol %)	CH ₄ (vol %)	CO ₂ (vol %)
0.2	44.81	24.11	8.11	22.97
0.24	43.86	21.55	7.34	27.25
0.28	38.1	19.8	7.44	34.66
0.32	34.14	18.64	7.34	39.88
0.36	26.6	16.5	7.27	49.63

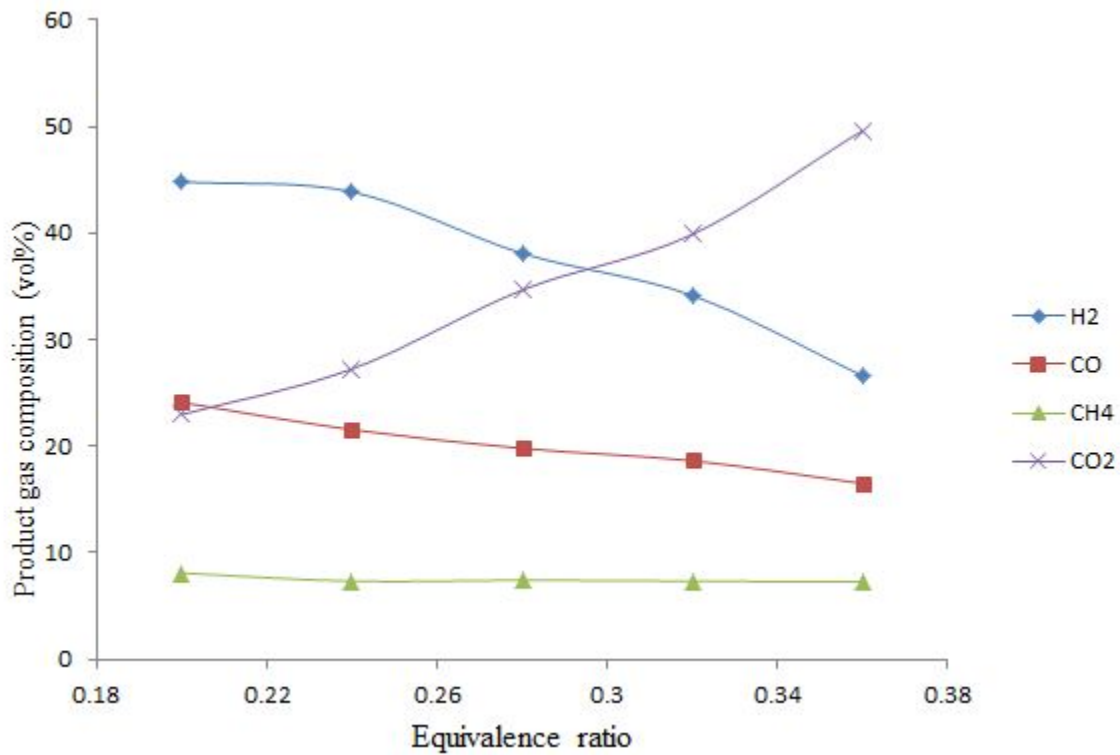


Figure 7: Experimental product gas composition versus equivalence ratio

4.3.3. Effect of Varying Steam to Biomass Ratio on Product Gas Composition at Constant Equivalence Ratio and Constant Temperature

Temperature = 700 °C, Equivalence ratio = 0.26, Biomass = 10 kg/hr

Table 10: Experimental product gas composition (volume %) at different steam to biomass ratios

S/B Ratio	H ₂ (vol %)	CO (vol %)	CH ₄ (vol %)	CO ₂ (vol %)
0.50	43.12	21.91	7.88	27.09
0.75	48.15	20.15	6.29	25.41
1.00	51.37	16.02	5.9	26.71
1.25	53.14	11.98	5.12	29.76
1.50	56.54	7.35	4.28	31.83

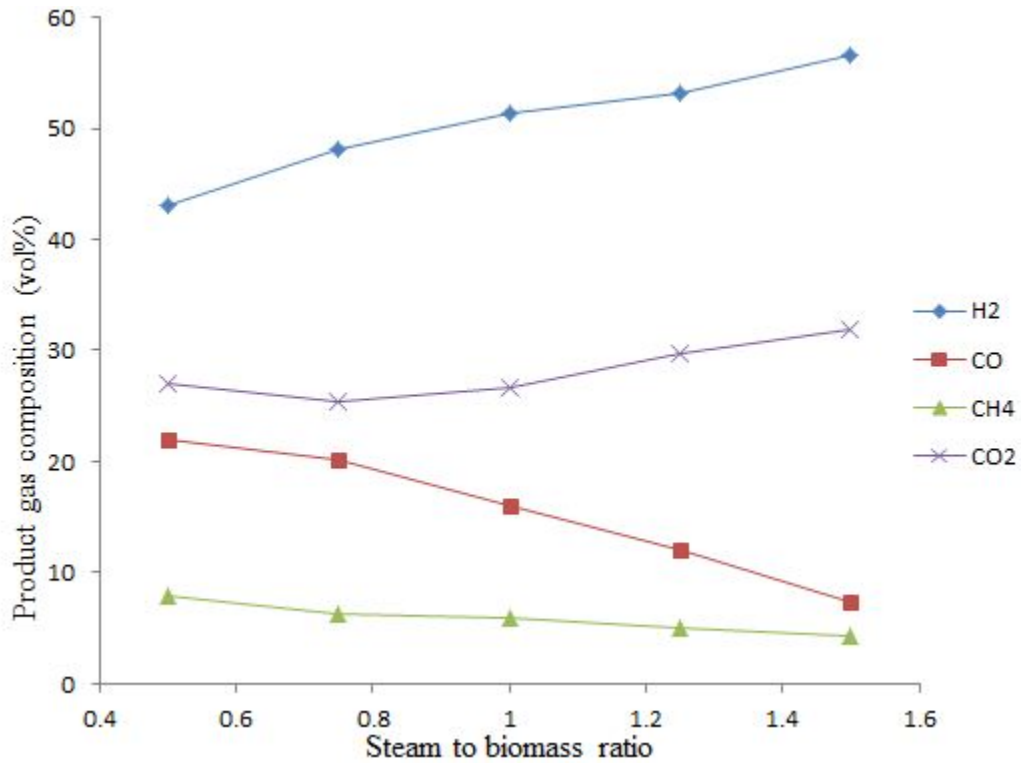


Figure 8: Experimental product gas composition versus steam to biomass ratio

CHAPTER 5
DISCUSSIONS

DISCUSSIONS

Using ASPEN PLUS simulator and fluidized bed gasifier the effect of different operating parameters (temperature, equivalence ratio and steam to biomass ratio) was studied and it was found that the most of trends were similar for both the case but the concentrations were different because of some simplified assumptions were considered for simulation model.

Since gasification is an endothermic reaction, the product gas composition is sensitive towards temperature change. It was observed that the concentration of H_2 increases with increase in temperature. The concentration of CO remains almost constant over the range of temperature. Higher temperature provides more favorable condition for cracking and steam reforming of methane. So with increase in temperature the concentration of methane decreases in the product gas and this is attributed to increase in concentration of hydrogen. The CO_2 concentration decreases with increase in temperature because higher temperature favors endothermic formation of CO from CO_2 via boudouard reaction.

Equivalence ratio is the most important parameter of gasification. The effect of equivalence ratio on product gas composition was studied in the range 0.2 to 0.36 at $700\text{ }^\circ\text{C}$ with steam to biomass ratio 0.5. The figure-7 shows CO_2 concentration is directly proportional to the equivalence ratio. With increase in equivalence ratio more complete combustion of carbon takes place producing more CO_2 and this leads to decrease in concentration of CO. So, less H_2 is produced from water gas shift reaction which leads to decrease in concentration of H_2 . Methane concentration remains almost constant over the range of equivalence ratio.

Steam to biomass ratio also plays an important role in gasification of biomass. The effect of steam to biomass ratio on product gas composition was studied over the range 0.5-1.5 at $700\text{ }^\circ\text{C}$ with equivalence ratio 0.26. Higher steam to biomass ratio favors more conversion of CO to CO_2 and H_2 through water gas shift reaction. So with increase in steam to biomass ratio H_2 and CO_2 concentration increases and CO concentration decreases in the product gas. Also higher steam to biomass provides more favorable condition for steam reforming of methane. So methane concentration decreases with increase in steam to biomass ratio.

CHAPTER 6
CONCLUSION

CONCLUSION

Using ASPEN PLUS simulator, a model for biomass gasification in an atmospheric fluidized bed was simulated using rice husk as feed material. Also an experimental study of biomass gasification was conducted using a pilot plant fluidized bed gasifier. A series of experiments and simulations were performed to investigate the effect of bed temperature, equivalence ratio and steam to biomass ratio. The volume percentages of H₂, CO, CH₄ and CO₂ were calculated on dry, inert free basis neglecting other gases of very low concentrations. The results show that the hydrogen concentration in the product gas increases rapidly with increase in temperature (500-700 °C). Higher equivalence ratio is not preferred for gasification as it results complete combustion of carbon present in the feed resulting higher percentage of CO₂ in the product gas. Also low equivalence ratio (<0.2) is not preferred as it results pyrolysis rather than gasification. For the present work the optimum equivalence ratio lies between 0.20 and 0.24. Further detailed analysis will give the exact value of the optimum equivalence ratio. Higher steam to biomass ratio results higher water gas shift reaction. This leads to better yield of hydrogen but much higher steam flow rates will have an opposing effect on gasification rate because it reduces the reactor temperature.

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