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ANALYSIS OF SYNTHESIS GAS PRODUCED FROM BIOMASS GASIFICATION

A thesis Submitted to the
National Institute of Technology, Rourkela
In Partial Fulfilment for the Requirements
of
BACHELOR OF TECHNOLOGY
In

CHEMICAL ENGINEERING
By

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CERTIFICATE

This is to certify that the report entitled "**ANALYSIS OF SYNTHESIS GAS PRODUCED FROM BIOMASS GASIFICATION**" submitted by **RAMESHWAR KUMAR BOCHALYA (ROLL NO: 109CH0105)** in partial fulfilment 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 report has not been submitted to any other University/ Institute for the award of any degree or diploma.

DATE: 6 May 2013

Prof. Abanti Sahoo

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ABSTRACT

The biomass gasification has been carried out using a fluidized bed gasifier. This work focuses on the production and analysis of syngas from biomass. In the present work four samples namely, rice husk, wood chips , sugarcane bagasse and coconut coir have been studied. The effect of different parameters viz. temperature, steam to biomass ratio and equivalence ratio on syngas composition has been studied. It is found that with the increase in temperature (from 500^{o} C to 800^{o} C) within the fluidized bed gasifier hydrogen percentage increases continuously while other parameters are held constant. It is observed that with the increase in steam to biomass ratio yield of hydrogen increases while equivalence ratio (ER=0.25) and temperature of fluidized bed are fixed.

Similarly effect of equivalence ratio is studied by contenting other two parameters constant

KEYWARDS- Fluidized bed gasifier, biomass, equivalence ratio, steam to biomass ratio

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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: 145 years, oil: 41 years, natural gas: 58 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 CO_2 emissions is due to combustion of fossil fuel**s**. Also combustion of fossil fuel produces toxic gases, such as SO_2, NOx and other pollutants, causing global warming and acid rain. Several researches have been made to explore clean, renewable alternatives. As synthesis gas is clean and renewable source of energy it can replace the conventional fossil fuels.

Apart from its use as a source of energy, synthesis gas 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 analysis of synthesis gas composition by using different catalyst with different biomass using a atmospheric fluidized bed gasifier. Silica sand was used as bed material.

CHAPTER 2

LITERATURE REVEIW

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

2.1. SYNGAS FROM FOSSIL FUEL

2.1.1. Production from Natural Gas

Synthesis gas is produced from natural gas by steam reforming process that involves the conversion of methane and water vapour into hydrogen and carbon monoxide. The conversion is carried out at temperatures of 750 to 850 °C and pressures of 2 to 25 bar. The product contains approximately 10 % CO, which can be further converted to CO_2 and H_2 through the water-gas shift reaction [3].

$$CH_4 + H_2O + Heat \rightarrow CO + H_2 \quad (2.1)$$

$$CO + H_2O \rightarrow CO + H_2 + Heat \quad (2.2)$$

2.1.2. Production from Coal

Syngas 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 support to maximize carbon conversion to gas, that is reduces the formation of char, tars and phenols [3].

$$C\,(s) + H_2O + Heat \rightarrow CO + H_2 \quad (2.3)$$

2.2. SYNGAS PRODUCTION FROM BIOMASS

Major resources in biomass include agricultural crops and their waste by-product 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 methods for biomass conversion into hydrogen-rich gas

(i) Thermochemical conversion

(ii) Biochemical conversion

2.2.1 Thermo-Chemical Conversion

There are main three technique for biomass-based synthesis gas production via thermo-chemical conversion:

(1) pyrolysis,

(2)gasification,

(3)SCWG

2.2.1.1. Pyrolysis

Pyrolysis is the heating of biomass at a temperature of 500-800 K and at a pressure of 0.1-0.8

MPa in the absence of air to convert biomass into solid charcoal, liquid oils and gaseous by-product. 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 H_2, CO, CH_4, CO_2 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.

$$CH_4 + H_2O \rightarrow CO + H_2 \qquad (2.4)$$

The gas can be further enriched with H_2 through water gas shift reaction.

2.2.1.2. Gasification

Biomass gasification is a process that converts biomass in to a combustible mixture (mainly CO, H_2, CO_2 and CH_4). This is done by reacting the biomass at high temperatures, without combustion, with a fixed amount of oxygen, air and/or steam. It is more useful then pyrolysis for production of hydrogen because almost all the product of gasification are gases with a small amount of tar and ash.

$$Biomass + heat + steam + air \rightarrow H_2 + CO + light\ or\ heavy\ hydrocarbons + char \qquad (2.5)$$

2.2.1.3. 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 changing properties depending on temperature and pressure. Under these conditions, biomass gets rapidly decomposed by hydrolysis and the syngas produced by biomass (mixture of CO, H_2 and methane) mix in the supercritical water to minimizing the amount of tar and coke formation .

2.2.2 Biochemical or Biological Conversion

The production of syngas 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:

$$2e + 2H^{+} + 4ATP \rightarrow 4ADP + 4Pi \tag{2.6}$$

2.3. GASIFIER TYPES

2.3.1. 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 [5].

2.3.2. 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. it is easy to operate gasifier
2. Particle size of feedstock is not strict.
3. Improved mass and heat transfer.
4. Reduced char formation.
5 simple in construction

Various zones of gasification

1. Drying zone
2. Pyrolysis zone
3. Reduction zone
4. Oxidation zone

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) [6].

2.4.1. 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[7]

2.5 Previous work

Turn et al. [8] experimentally investigated with increase in temperature hydrogen percentage and total gas percentage increases which can be attributed to increased steam and carbon dioxide gasification reaction rates are increase due to increase in temperature because they are generally endothermic reactions. Higher hydrocarbon concentrations decreased as reactor temperature increased, the result of more favorable conditions for thermal cracking and steam reforming reactions. With increase in Equivalence ratio the hydrogen and gas yield decrease. With decreases the steam to biomass ratio the hydrogen and gas percentage composition.

Rapagna et al. [9] worked on parametric sensitivity of a gasification process, using olivine as the fluidized bed material and observed that production of gases with relatively low molecular weights is also favours the increasing gasification temperature. Steam to biomass ratio has a weak factor on gasifier performance and syngas composition.

Lv et al. [1o] experimentally investigated the effect of different parameters on syngas composition, carbon conversion efficiency, gas yield etc. using pine sawdust as feed stock and silica sand as bed material. They found that with decrease in temperature hydrogen concentration is decreased.

Franco et al. [11] observed that the effect of temperature and steam to biomass ratio on gasification using atmospheric fluidized bed. It was found that with c in temperature, concentration of hydrogen decrease and the concentration of carbon monoxide and methane increases . Carbon dioxide concentration remains almost constant over the temperature range. Optimum steam to biomass ratio was found to be 0.5-0.8 w/w.

CHAPTER 3

EXPERIMENTATION

3.1 GASIFICATION REACTIONS

Generally, biomass gasification undergoes the following steps in a fluidized bed:

(1) the biomass particle decomposes very fast to form char, tar and gaseous products

(2) Reactions between the gaseous products and

(3) tar cracking and char gasification

The following reactions take place during gasification of biomass [7]

Basic combustion reactions

$$C + 1/2O_2 \rightarrow CO$$

$$C + O_2 \rightarrow CO_2$$

Boudouard reaction:

$$C + CO_2 \rightarrow 2CO$$

Water gas shift reaction:

$$C + H_2O \rightarrow CO + H_2$$

Methanation reaction:

$$C + 2H_2 \rightarrow CH_4$$

Shift conversion:

$$CO + H_2O \rightarrow CO_2 + H_2$$

Steam reforming of methane:

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

3.2. 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.

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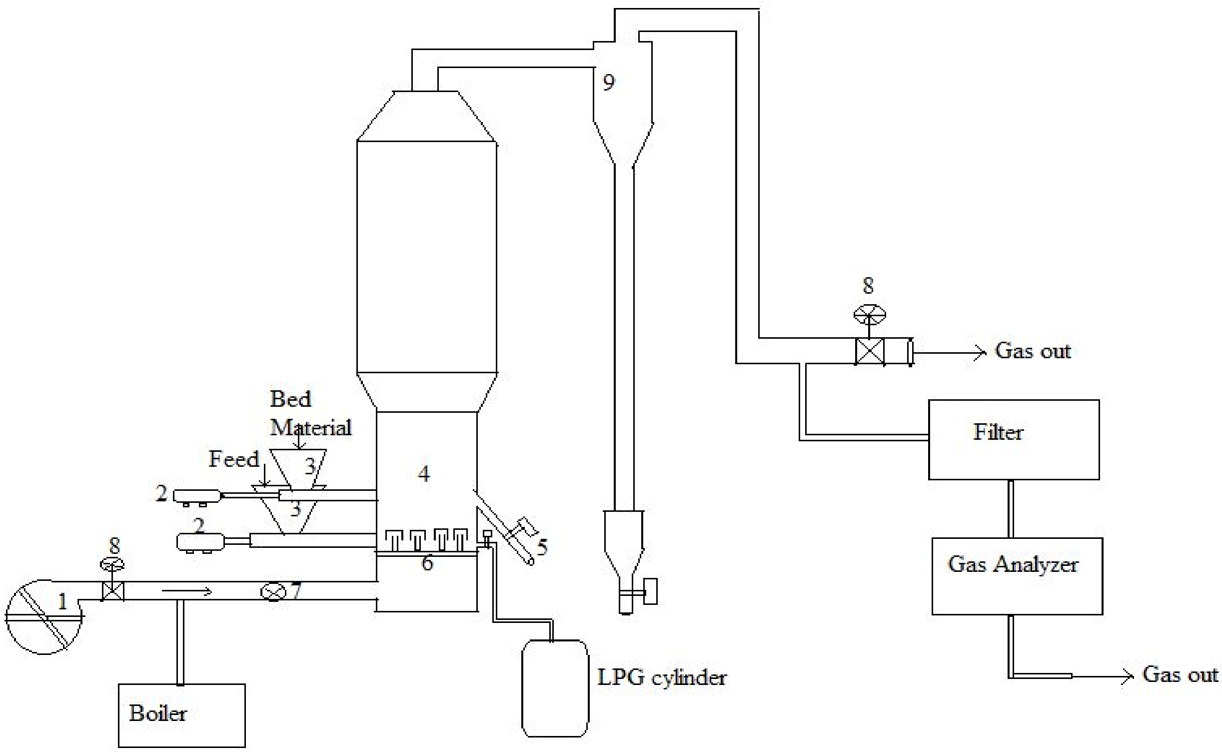


1	Air blower	6	Bubble cap
2	Motor	7	Orifice meter
3	Screw feeder	8	Valve
4	Fluidized bed gasifier	9	Cyclone separator
5	Continuous cleaning system		

Figure 3.1: The schematic diagram of the Experimental setup.

3.3. EXPERIMENTAL PROCEDURE

At the startup of each experiment, 3 kg of the bed material (silica sand of size < 1 mm) was fed to the reactor by the help of the screw feeder; the blower, temperature indicators and the boiler for steam generation were started. Then the bed was fired using LPG as a fuel at a flow rate of 10-12 LPH. After the fluidized bed temperature reached a desired value, the flow of LPG into the gasifier was stopped and the biomass was fed to the reactor by the help of the screw feeder and the gasification starts.

A filter is connected to the outlet of syngas by which the solid particles are removed by water and the remaining particles are removed by a filter of pore size 0.01 micrometres . Before going to the analyzer the moistures present in the syngas has to removed by passing it through silica gel. ACE 9000X CGA portable infrared coal gas Analyzer was used to measure the concentration of Hydrogen carbon dioxide, carbon monoxide and methane.

CHAPTER – 4

EFFECT OF SYSTEM PARAMETERS ON SYNGAS

4.1. Effect of Varying Temperature on syngas analysis

Biomass =**Rice husk**
Biomass feed rate =10Kg/hr
Bed material= silica sand

Table 4.1.1: product gas composition (volume %) at different temperatures

Temp (^oC)	H_2 (vol %)	CO (vol %)	CH_4 (vol %)	CO_2 (vol %)
500	26.42	26.77	8.02	39.21
550	31.74	25.42	7.62	37.42
600	33.26	23.14	7.52	36.81
650	35.87	24.92	8.91	34.72
700	36.32	23.43	8.63	31.63
750	39.82	22.62	7.52	29.48
800	43.62	23.42	7.68	26.73

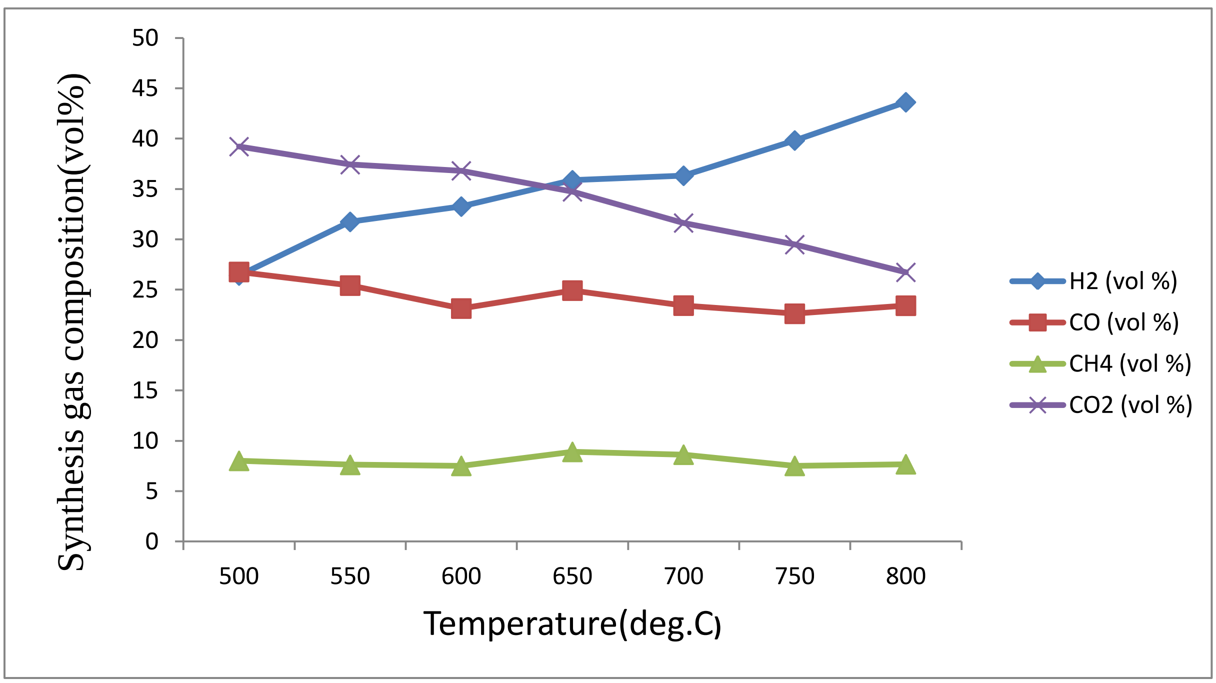


Figure 4.1.1: Experimental product gas composition versus temperature

4.1.2. Effect of Varying Temperature on syngas analysis

Biomass =**wood chips**
Biomass feed rate =10Kg/hr
Bed material= silica sand

Table 4.1.2: product gas composition (volume %) at different temperatures

Temp (^oC)	H_2 (vol %)	CO (vol %)	CH_4 (vol %)	CO_2 (vol %)
500	24.42	28.43	8.62	36.39
550	26.24	27.52	8.43	34.42
600	29.37	25.63	7.59	33.12
650	33.18	24.42	8.12	31.81
700	36.63	23.61	7.56	29.78
750	39.84	22.81	7.51	26.42
800	41.16	21.06	8.03	26.73

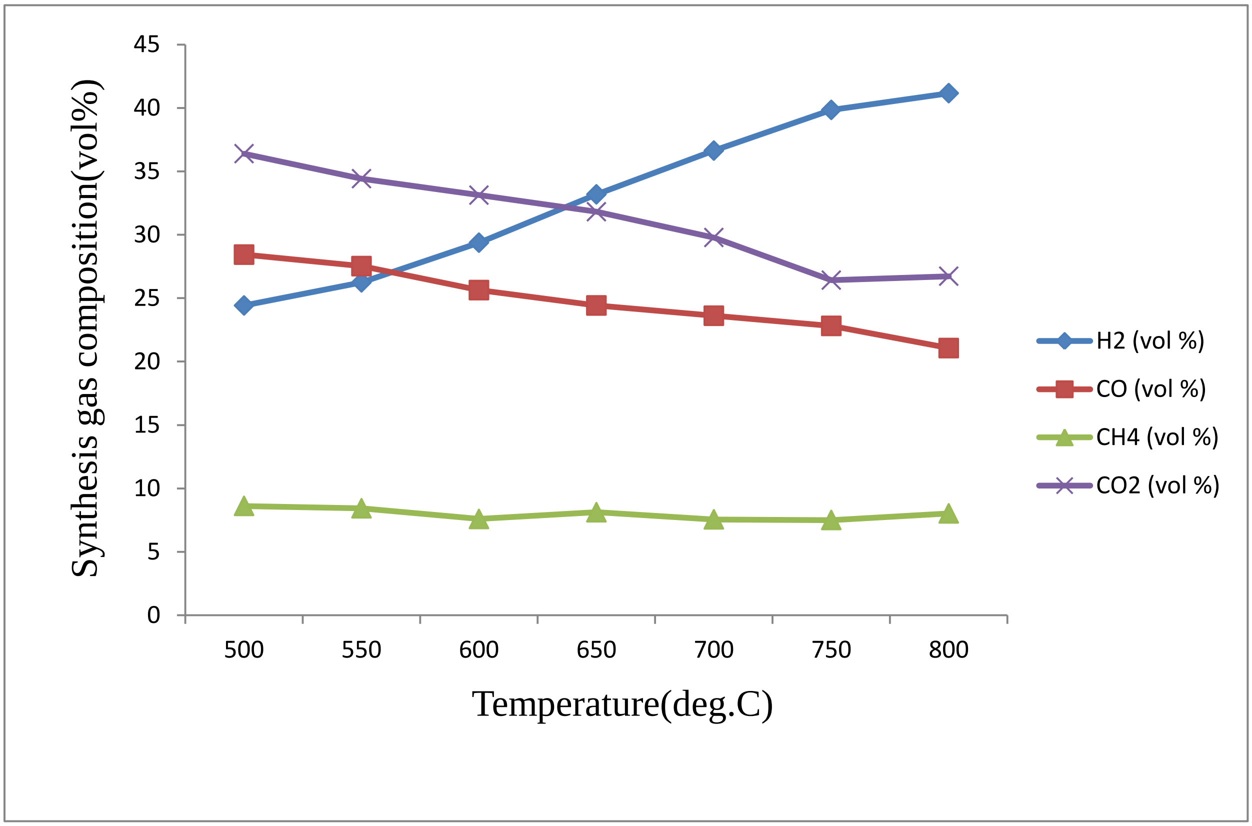


Figure 4.1.2: Experimental product gas composition versus temperature

4.1.3. Effect of Varying Temperature on syngas analysis

Biomass =**Sugarcane bagasse**
Biomass feed rate =10Kg/hr
Bed material= silica sand

Table 4.1.3: Syngas composition (volume %) at different temperatures

Temp (^oC)	H2 (vol %)	CO (vol %)	CH4 (vol %)	CO2 (vol %)
500	28.02	48.18	12.11	11.04
550	28.17	48.12	12.06	11.02
600	29.34	47.16	11.21	11.01
650	29.29	47.32	11.04	10.81
700	30.16	46.17	10.64	10.72
750	31.24	46.31	10.31	10.44
800	32.42	45.98	9.54	10.16

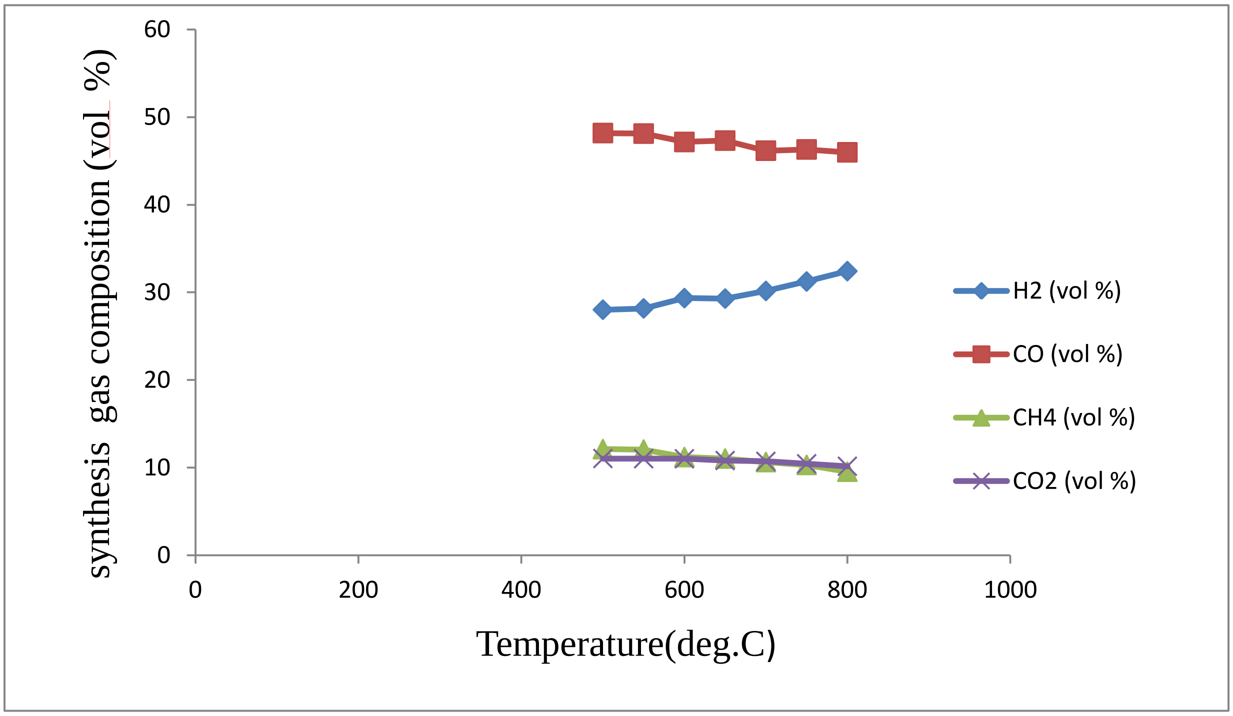


Figure 4.1.3: Experimental product gas composition versus temperature

4.1.4. Effect of Varying Temperature on syngas analysis

Biomass =**Coconut coir**

Biomass feed rate =10Kg/hr

Bed material= silica sand

Table 4.1.4: Syngas composition (volume %) at different temperatures

Temp (^oC)	H2 (vol %)	CO (vol %)	CH4 (vol %)	CO2 (vol %)
500	26.46	40.81	16.32	15.04
550	27.84	38.92	15.94	13.89
600	28.24	37.62	15.38	12.96
650	28.38	35.87	14.62	11.75
700	29.64	33.86	13.94	11.32
750	30.38	31.24	13.56	10.62
800	31.69	30.63	12.65	9.87

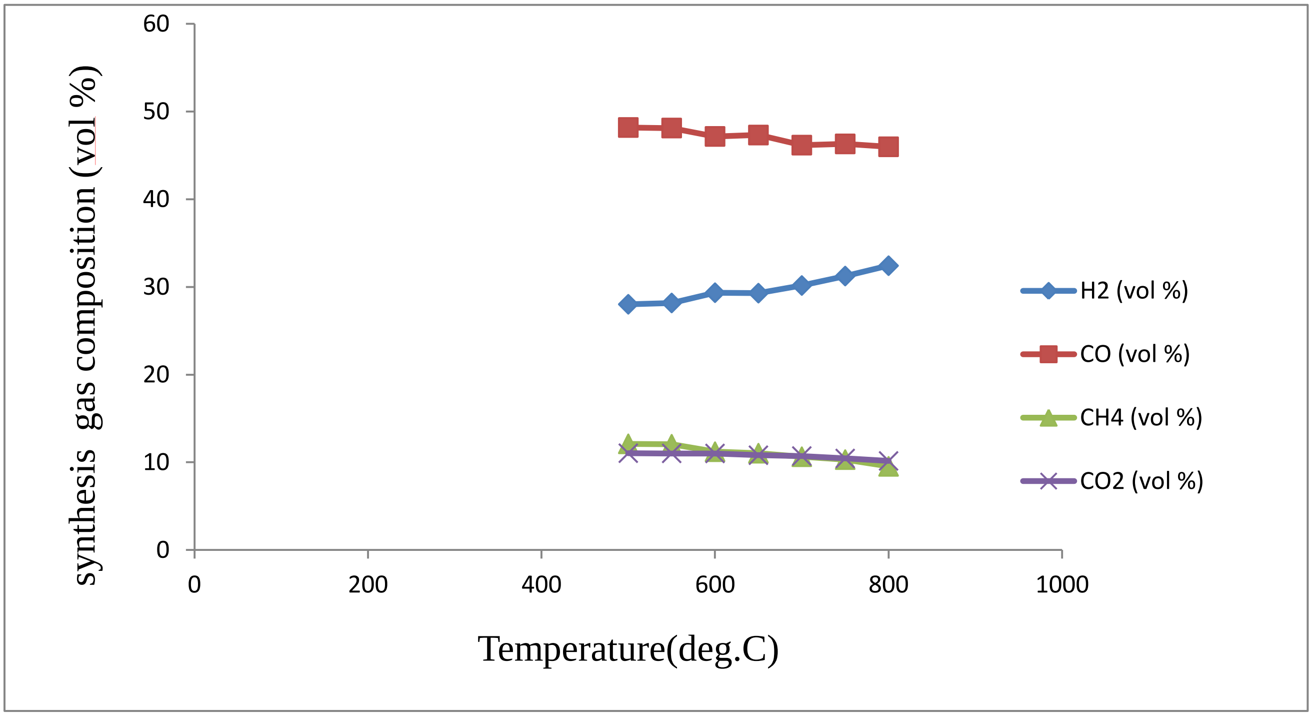


Figure 4.1.4: Experimental product gas composition versus temperature

4.2. Effect of steam to biomass ratio on syngas

Biomass = **Rice husk**

Biomass feed rate =10Kg/hr

Temperature = 700°C

Equivalence ratio = 0.25

Bed material= silica sand

Table 4.2.1: Syngas composition (volume %) at different steam to biomass ratio

S:B Ratio	H2 (vol %)	CO (vol %)	CH4 (vol %)	CO2 (vol %)
0.50	33.21	40.42	10.16	15.21
0.75	34.41	40.12	10.03	14.81
1.00	34.86	39.62	9.84	14.24
1.25	35.47	39.18	9.62	13.92

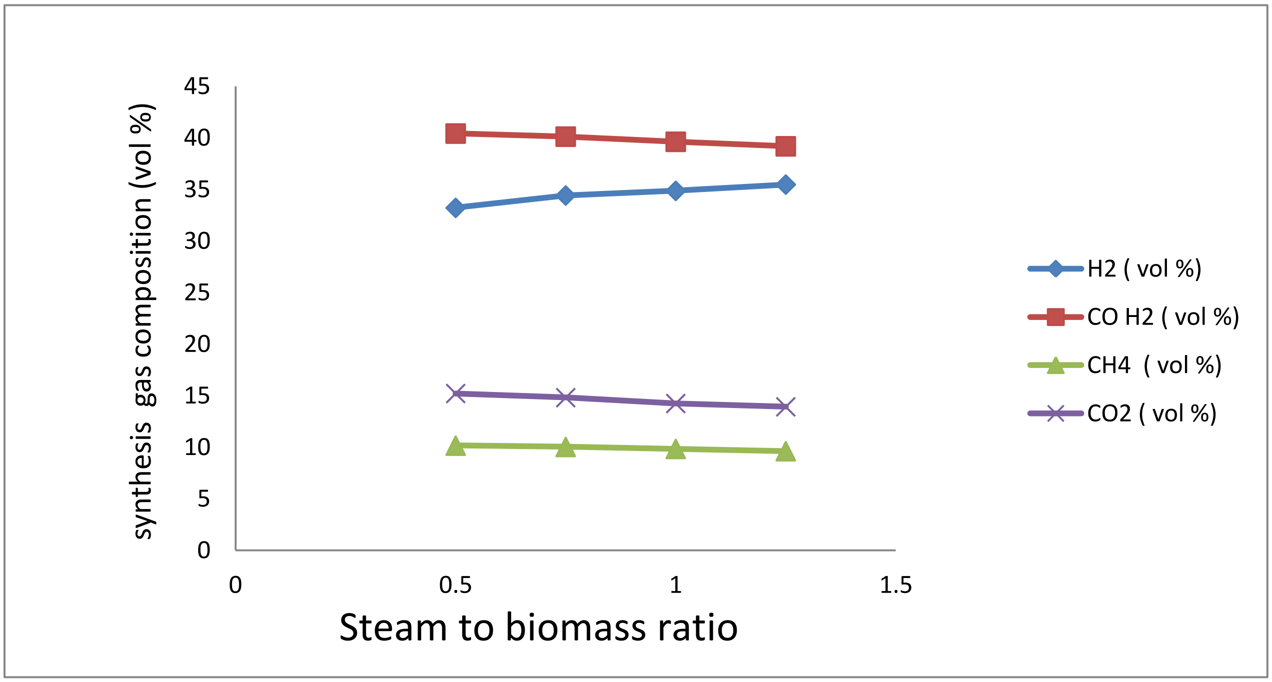


Figure 4.2.1: Experimental product gas composition versus steam to biomass ratio

4.2.2. Effect of steam to biomass ratio on syngas

Biomass = **wood chips**

Biomass feed rate =10Kg/hr

Temperature = 700°C

Equivalence ratio = 0.25

Bed material= silica sand

Table 4.2.2: Syngas composition (volume %) at different steam to biomass ratio

S:B Ratio	H2 (vol %)	CO (vol %)	CH4 (vol %)	CO2 (vol %)
0.50	31.41	41.34	10.12	16.02
0.75	32.06	41.20	9.81	15.84
1.00	32.37	40.67	9.84	15.24
1.25	33.21	39.24	8.52	14.74

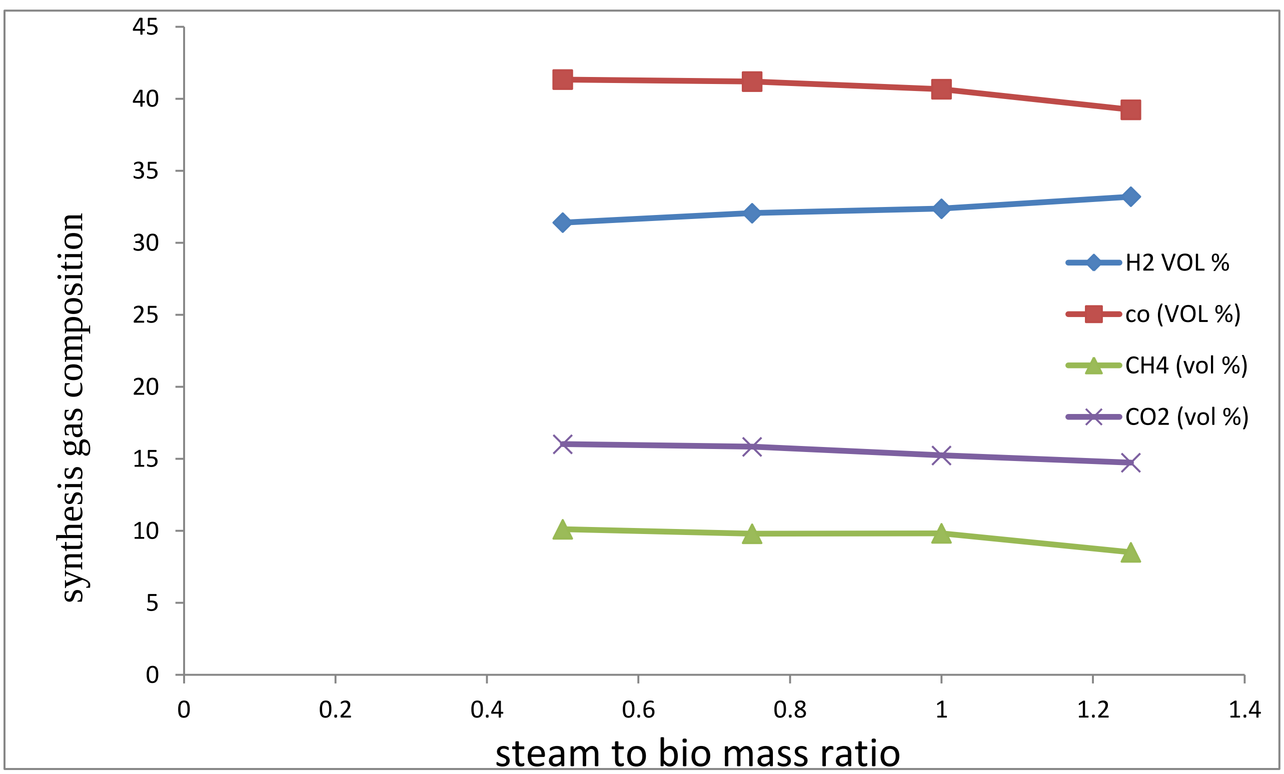


Figure 4.2.2: Experimental product gas composition versus steam to biomass ratio

4.2.3. Effect of steam to biomass ratio on syngas

Biomass = **Sugarcane bagasse**

Biomass feed rate =10Kg/hr

Temperature = 700°C

Equivalence ratio = 0.25

Bed material= silica sand

Table 4.2.3: Syngas composition (volume %) at different steam to biomass ratio

S:B Ratio	H2 (vol %)	CO (vol %)	CH4 (vol %)	CO2 (vol %)
0.5	34.34	39.27	11.43	14.23
0.75	35.29	38	11.14	13.68
1	35.02	38	10.67	12.34
1.25	36.28	37	10.24	12.08

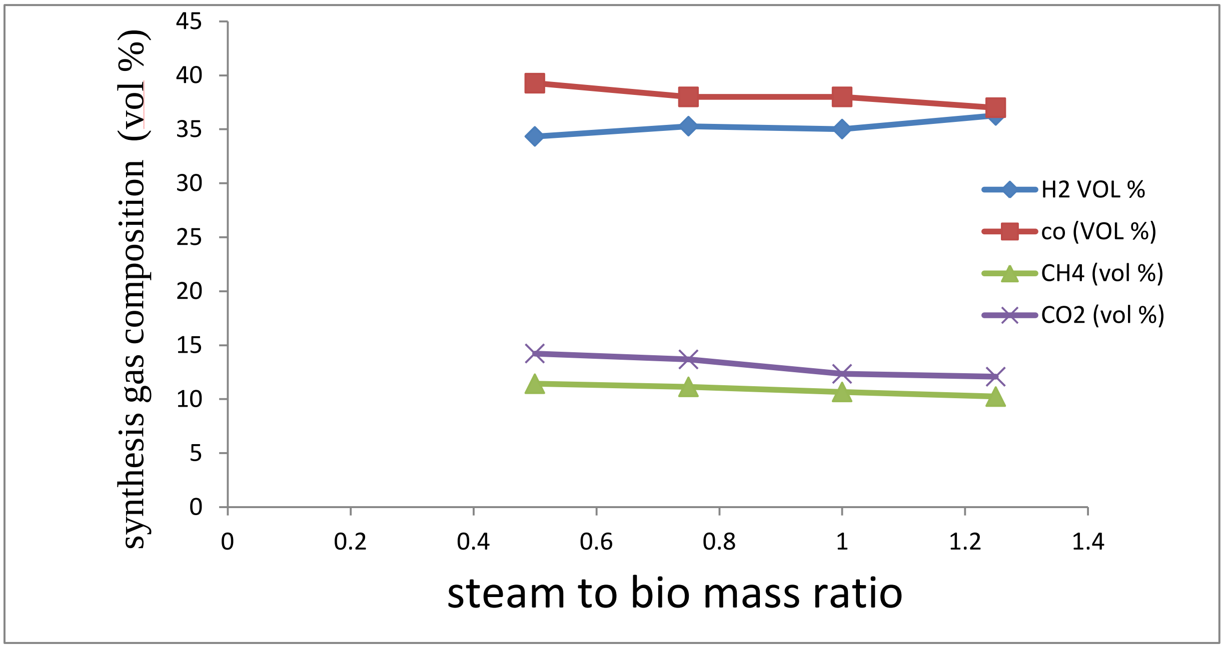


Figure 4.2.3: Experimental product gas composition versus steam to biomass ratio

4.2.4. Effect of steam to biomass ratio on syngas

Biomass = **Coconut coir**

Biomass feed rate =10Kg/hr

Temperature = 700°C

Equivalence ratio = 0.25

Bed material= silica sand

Table 4.2.4: Syngas composition (volume %) at different steam to biomass ratio

S:B Ratio	H_2 (vol %)	CO (vol %)	CH_4 (vol %)	CO_2 (vol %)
0.5	32.54	40.28	12.36	13.46
0.75	33.72	39.42	11.84	13.04
1	37.64	37.42	10.68	12.72
1.25	38.89	36.48	10.14	11.72

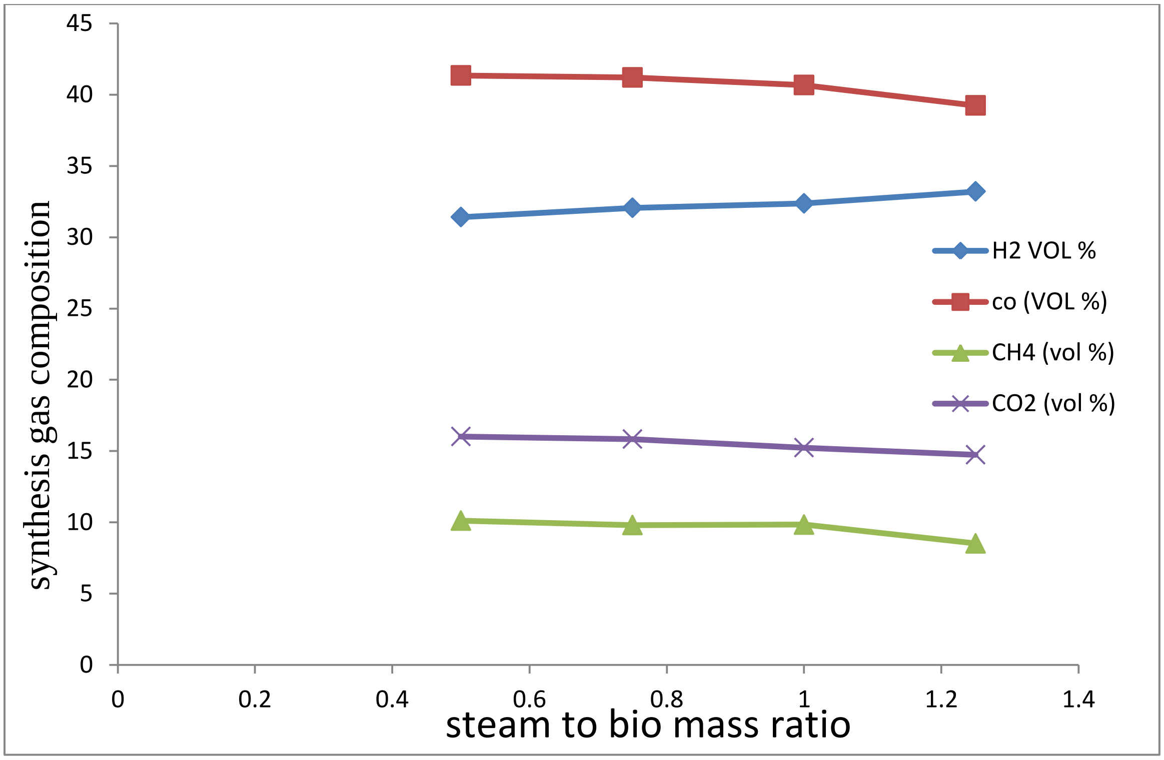


Figure 4.2.4: Experimental product gas composition versus steam to biomass ratio

4.3: Effect of Equivalence ratio on syngas

Biomass = Rice husk

Biomass feed rate =10Kg/hr

Temperature = 700°C

Steam to biomass ratio = 0.5

Bed material= silica sand

Table 4.3.1: Syngas composition (volume %) at different Equivalence ratio

ER Ratio	H2 (vol %)	CO (vol %)	CH4 (vol %)	CO2 (vol %)
0.2	34.26	42.14	10.62	12.24
0.25	33.17	41.82	10.34	14.22
0.3	31.67	40.34	10.18	17.22
0.35	28.12	40.21	9.26	22.21

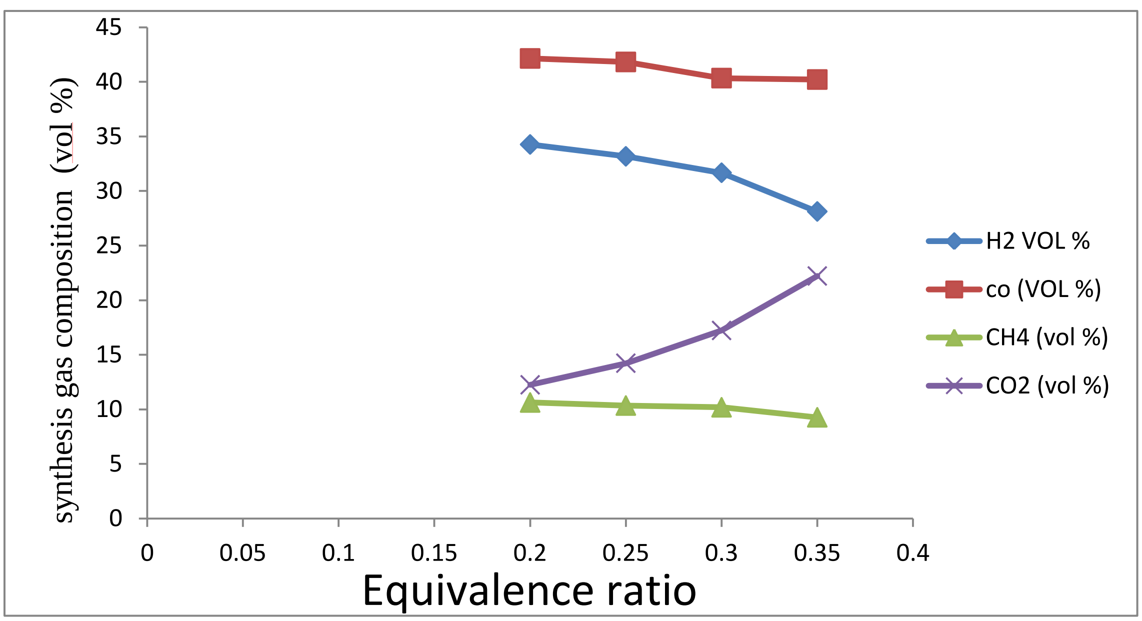


Figure 4.3.1: Experimental product gas composition versus Equivalence ratio

4.3.2. Effect of Equivalence ratio on syngas

Biomass = Wood chips

Biomass feed rate =10Kg/hr

Temperature = 700°C

Steam to biomass ratio = 0.5

Bed material= silica sand

Table 4.3.2: Syngas composition (volume %) at different Equivalence ratio

ER Ratio	H2 (vol %)	CO (vol %)	CH4 (vol %)	CO2 (vol %)
0.2	32.14	44.28	9.62	13.28
0.25	30.24	43.62	8.54	16.24
0.3	27.62	43.27	8.21	19.87
0.35	26.54	42.02	7.69	23.04

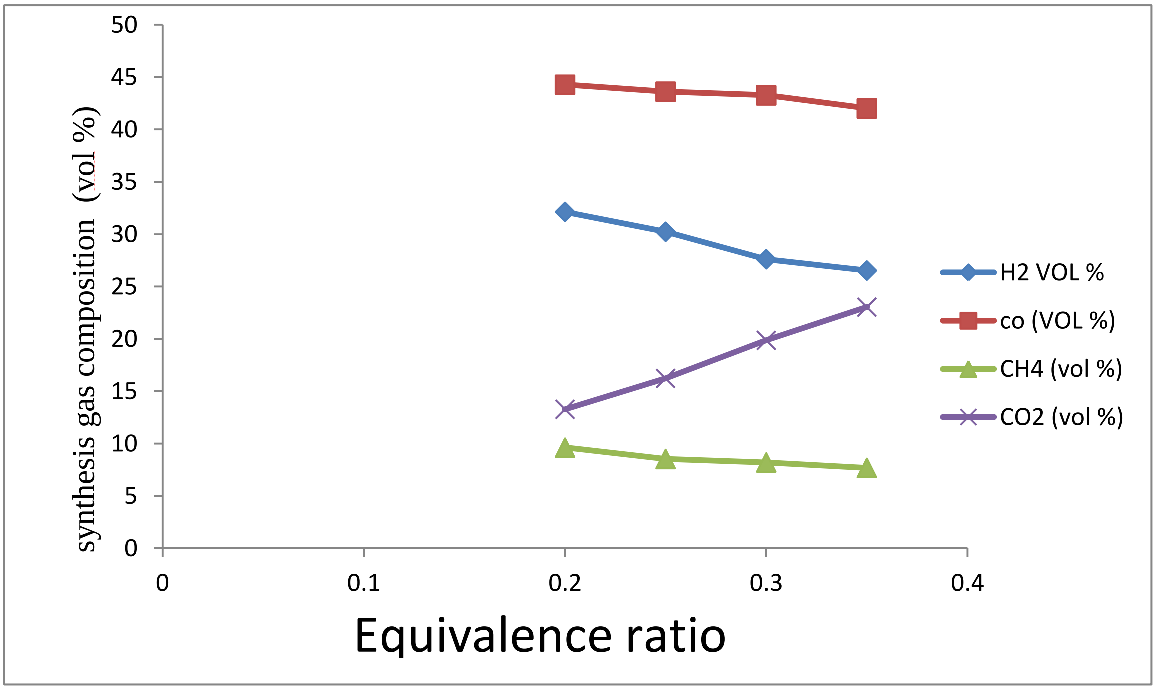


Figure 4.3.2: Experimental product gas composition versus Equivalence ratio

4.3.3. Effect of Equivalence ratio on syngas

Biomass = Sugarcane bagasse

Biomass feed rate =10Kg/hr

Temperature = 700°C

Steam to biomass ratio = 0.5

Bed material= silica sand

Table 4.3.3: Syngas composition (volume %) at different Equivalence ratio

ER Ratio	H2 (vol %)	CO (vol %)	CH4 (vol %)	CO2 (vol %)
0.2	35.24	41.42	11.14	11.21
0.25	34.82	41.29	10.21	14.02
0.3	32.14	40.61	9.84	16.28
0.35	30.21	39.82	9.52	19.68

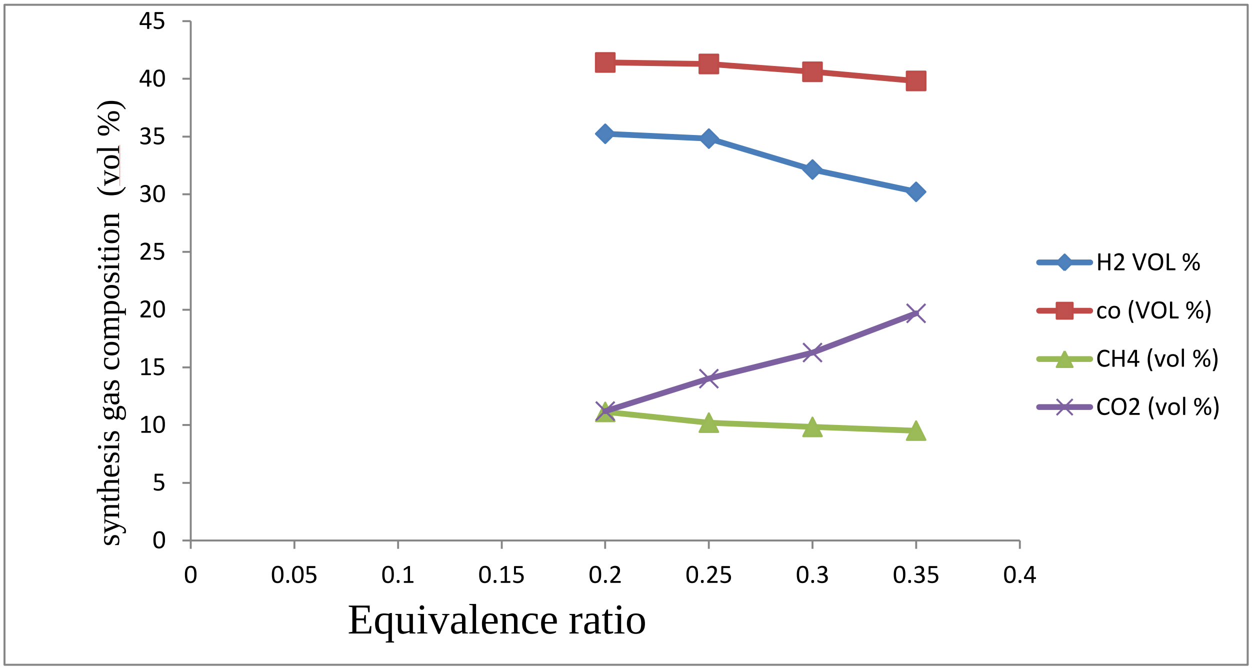


Figure 4.3.3: Experimental product gas composition versus Equivalence ratio

4.3.4. Effect of Equivalence ratio on syngas

Biomass = Coconut coir

Biomass feed rate =10Kg/hr

Temperature = 700°C

Steam to biomass ratio = 0.5

Bed material= silica sand

Table 4.3.4: Syngas composition (volume %) at different Equivalence ratio

ER Ratio	H2 (vol %)	CO (vol %)	CH4 (vol %)	CO2 (vol %)
0.2	32.42	43.62	12.28	11.42
0.25	31.82	42.62	11.12	13.89
0.3	30.52	42.14	10.62	15.38
0.35	30.21	41.72	9.57	17.67

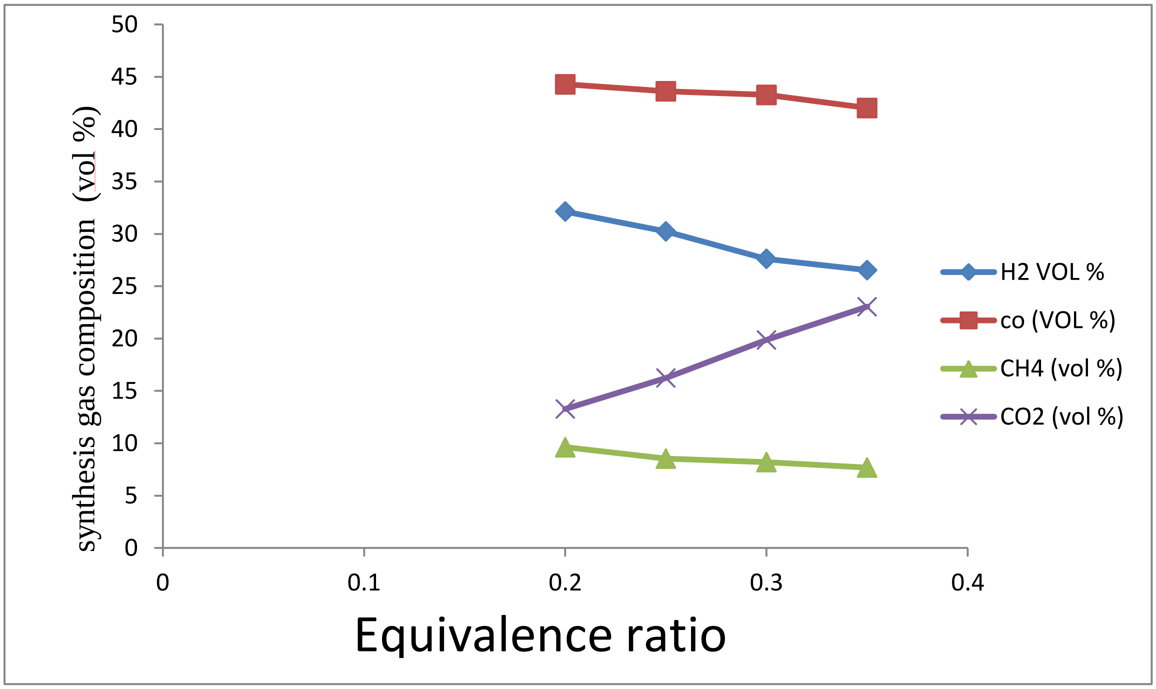


Figure 4.3.4: Experimental product gas composition versus Equivalence ratio

CHAPTER-5

RESULTS & DISCUSSIONS

Overall discussion on results

The effect of different system parameters (viz. temperature , S/B, E/R) on the composition of syngas was studied using a fludized bed gasifier. It is found that the concentration of hydrogen increases with increase in temperature for all the four biomass. The concentration of CO remains almost constant for all the four biomass in the temperature range of 500°C to 800°C. The effect of steam to biomass ratio on product gas composition was studied over the range of 0.5 to 1.25 at 700°C with equivalence ratio 0.25. To study the effect of Equivalence ratio on product gas composition we first constant the steam to biomass ratio at 0.5 and a constant bed temperature at 700°C

5.1: Effect of temperature

As we know that gasification is an endothermic reaction, the product gas composition is effect towards temperature changes. It is found that the concentration of hydrogen increases with increase in temperature for all the four biomass. The concentration of CO remains almost constant for all the four biomass in the temperature range of 500°C to 800°C. Higher temperature provide favourable condition for cracking and steam reforming of methane so it is found that concentration of methane is slightly decrease as we increase the temperature of bed. The concentration of carbon monoxide is significantly decrease on increase in the bed temperature as higher temperature favours endothermic formation of carbon monoxide from carbon dioxide via boudouard reaction

5.2: Effect of steam to biomass ratio

Steam to biomass ratio play a major role in fluidised bed gasification of biomass. The effect of steam to biomass ratio on product gas composition was studied over the range of 0.5 to 1.25 at 700°C with equivalence ratio 0.25. Higher steam to biomass ratio favours more conversion of carbon monoxide to carbon dioxide and hydrogen through water gas shift reaction . Higher steam to biomass ratio (S:B) give more favourable condition to steam reforming of methane .Therefor methane concentration decrease with increase in steam to biomass ratio.

5.3: Effect of equivalence ratio

Equivalence ratio is an important parameter in fluidisation bed gasifier process. To study the effect of Equivalence ratio on product gas composition we first constant the steam to biomass ratio at 0.5 and a constant bed temperature at 700. I took Equivalence ratio in the range of 0.20 to 0.35 . When we increase Equivalence ratio then complete combustion of biomass takes place and we got more carbon monoxide and this is leads to decrease in concentration of carbon monoxide. Methane concentration is almost constant over this range of Equivalence ratio. Due to complete combustion of biomass rate of water gas shift reaction is decrease and therefor concentration of hydrogen is decrease as we increase the Equivalence ratio.

5.4 future work

Study of ash produced by biomass gasification

Application of biomass bottom ash

(1) Use in agriculture;

(2) Use in construction.

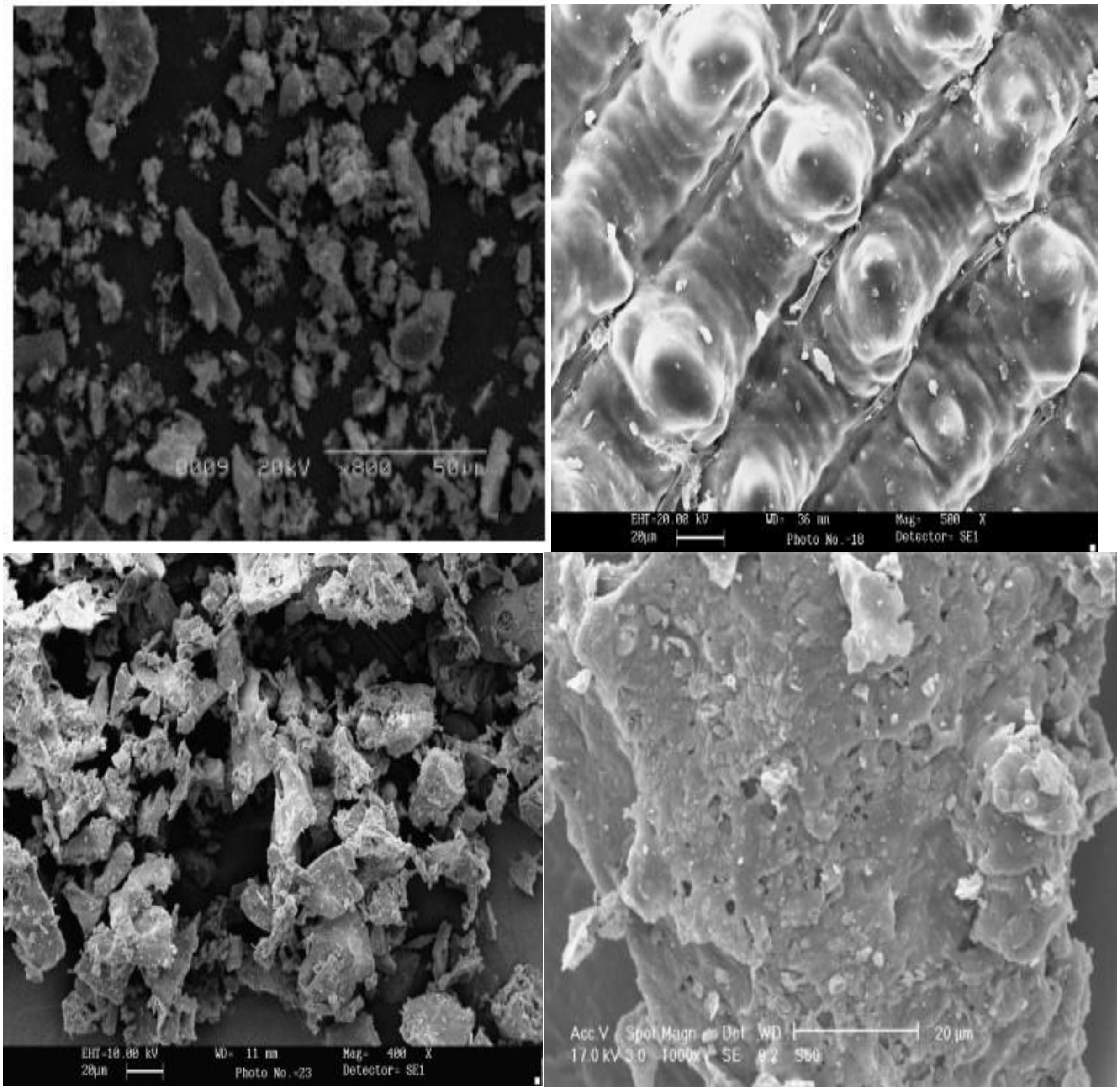
(3) Use in cement industry

(4) Use to construct Lightweight Plasterboard

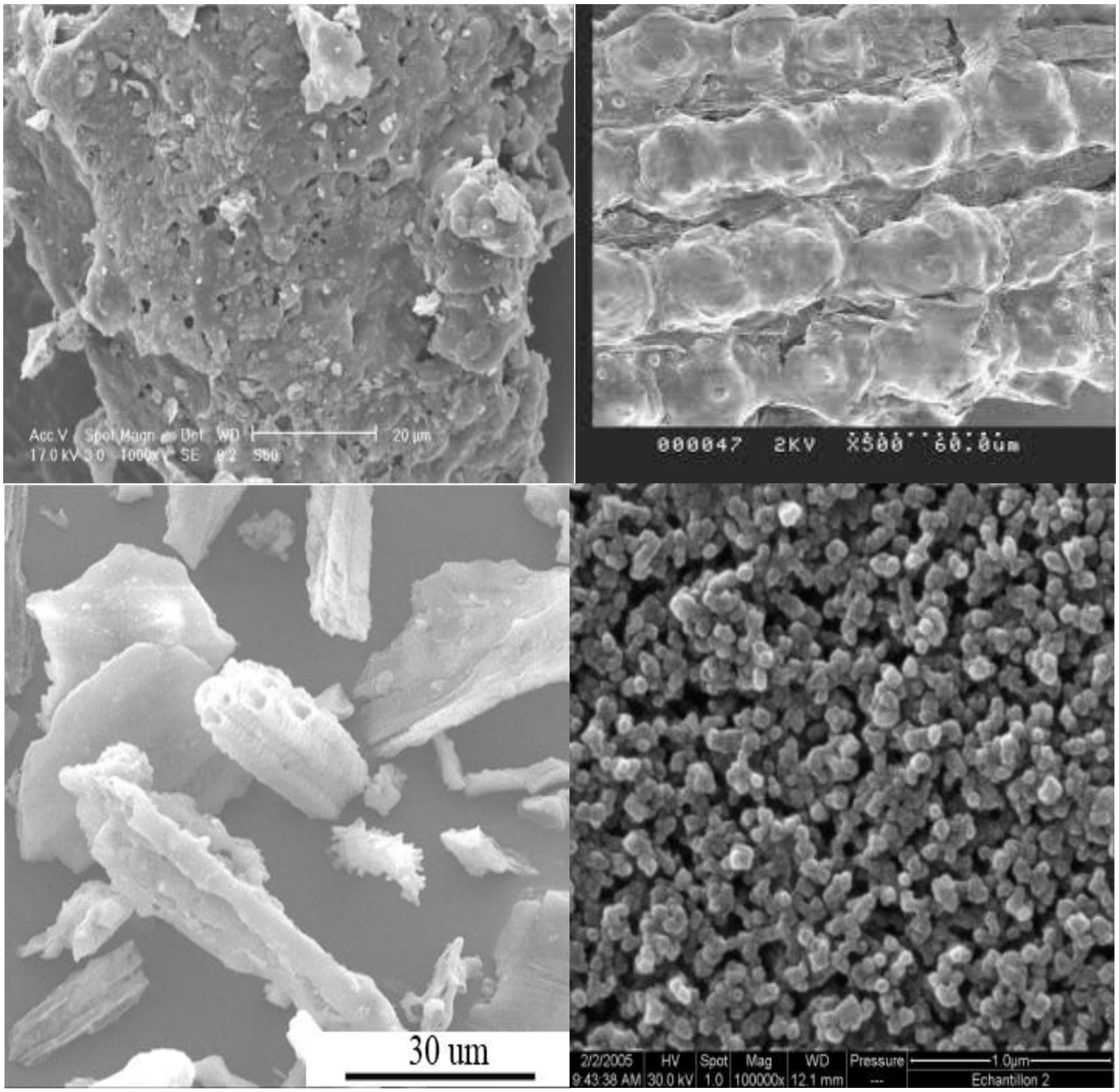
(5) Use in development of biomass ash filters

I use **scanning electron microscope** (**SEM**) to study the biomass bottom ash for rice husk ash, wood chips ash, sugarcane bagasse ash and coconut coir ash. The images are as follows

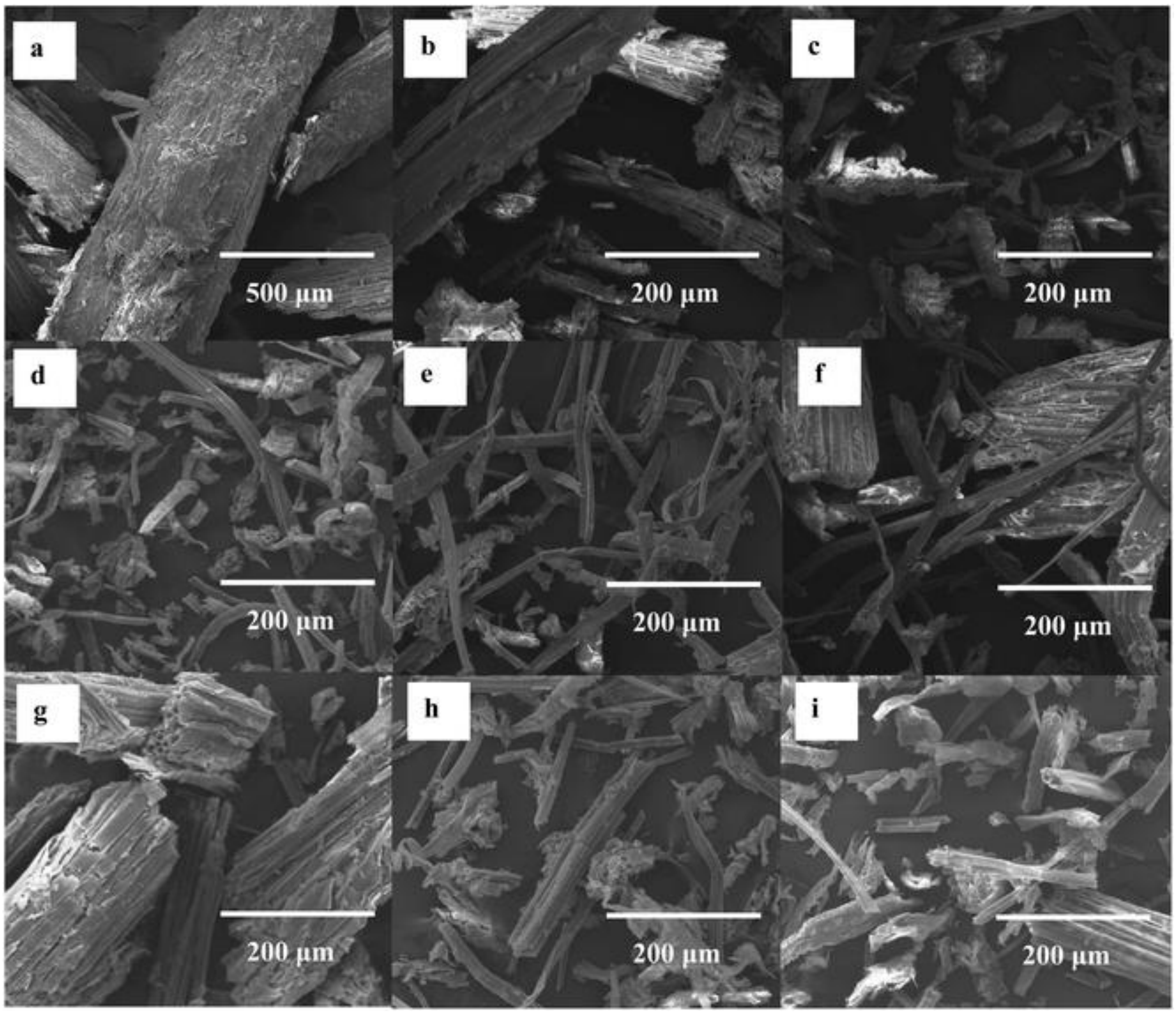
8.1 **SEM** images of rice husk ash



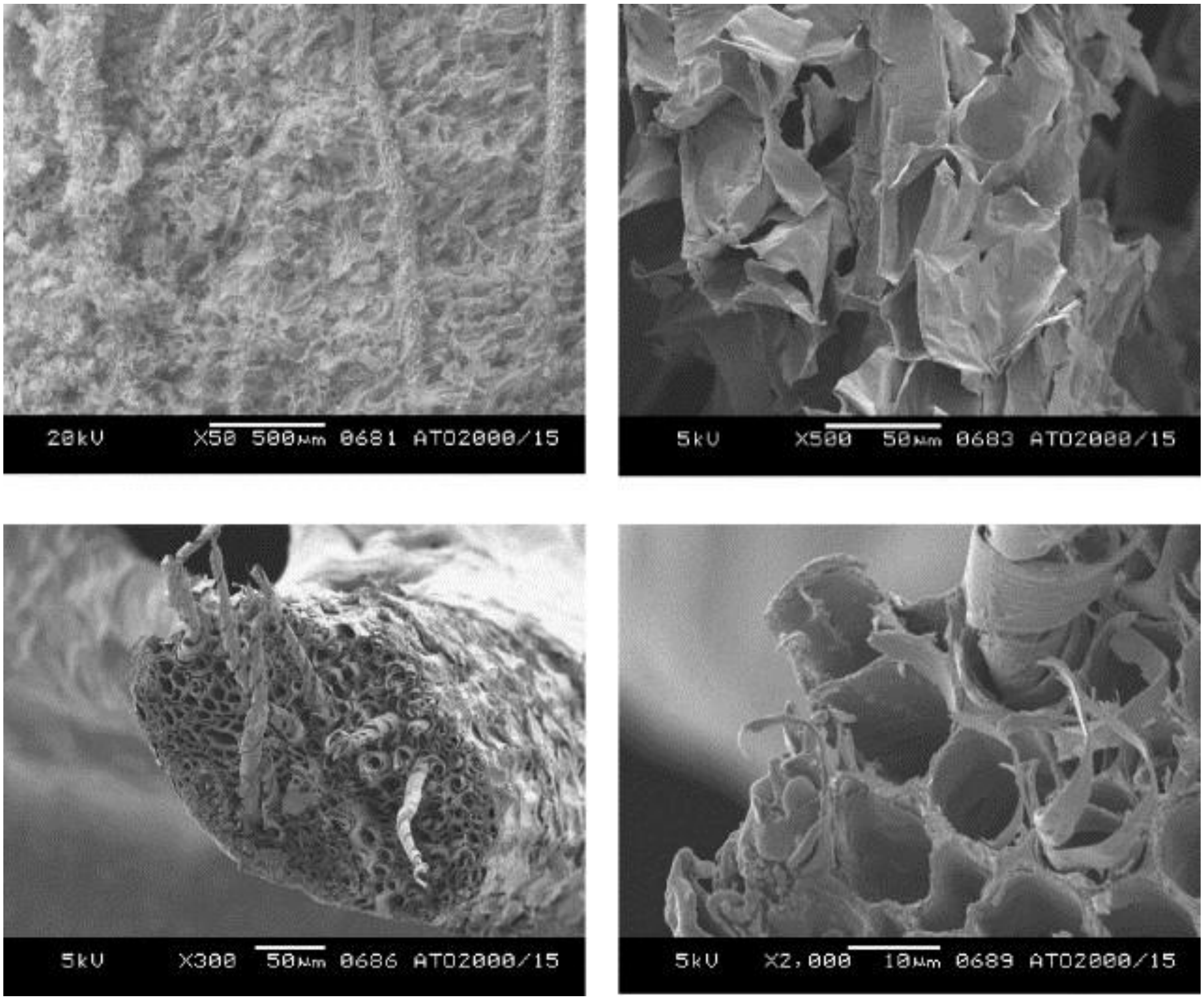
8.2 **SEM** images of wood chips ash



8.3 **SEM** images of sugarcane bagasse ash



8.4 **SEM** images of coconut coir ash



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