EXPERIMENTAL STUDIES OF SPRERI DESIGN FLUIDIZED BED GASIFIER

By

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10MMET07

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EXPERIMENTAL STUDIES OF SPRERI DESIGN FLUIDIZED BED GASIFIER

Major Project Part -I

Submitted in partial fulfillment of the requirements

For the Degree of

Master of Technology in Mechanical Engineering

by

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Declaration

This is to certify that

1. The thesis comprises my original work towards the degree of Master of Technology in Thermal engineering at Nirma University and has not been submitted elsewhere for a degree.

2. Due acknowledgement has been made in the text to all other material used.

Jignesh P. Makwana

Certificate

This is to certify that the Major Project Part-I entitled "EXPERIMENTAL STUDIES OF SPRERI DESIGN FLUIDIZED BED GASIFIER" submitted by **Mr. Jignesh P. Makwana (10MMET07)**, towards the partial fulllment of the requirements for the degree of Master of Technology in Mechanical Engineering of Nirma University of Science and Technology, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project part-I, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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Jignesh P. Makwana

Abstract

Fluidized beds are used for a broad variety of fuels; this flexibility with respect to different fuels is actually another stronghold of fluidized beds. In terms of the utilized fuels, coal has been most often applied so far, but also waste and biomass have been utilized and are forecast to play a more important role in the future. The fluidization principle is straight forward: passing a fluid upward through a packed bed of solids produce a pressure drop due to fluid drag.

Several researchers had worked on bubbling fluidized bed gasifier and use sized biomass like sawdust, rise husk, coir pitch, pomace and olive pits, and coconut shell. But with biomass used as fuel in fluidized bed gasifier with good quality of producer gas can be achieve by changing equivalence ratio and fluidization velocity. In this project work we had tried to use sawdust and pigeon pea (size: 0.4 to 0.841 mm) material as a feed material and sand (size: 0.4 to 0.595 mm) as a bed material for its easiness of fluidization and local availability.

Nomenclature

ER	Equivalance Ratio
FB	Fluidized Bed
HHV	Higher Heating Value
LHV	Lower Heating Value

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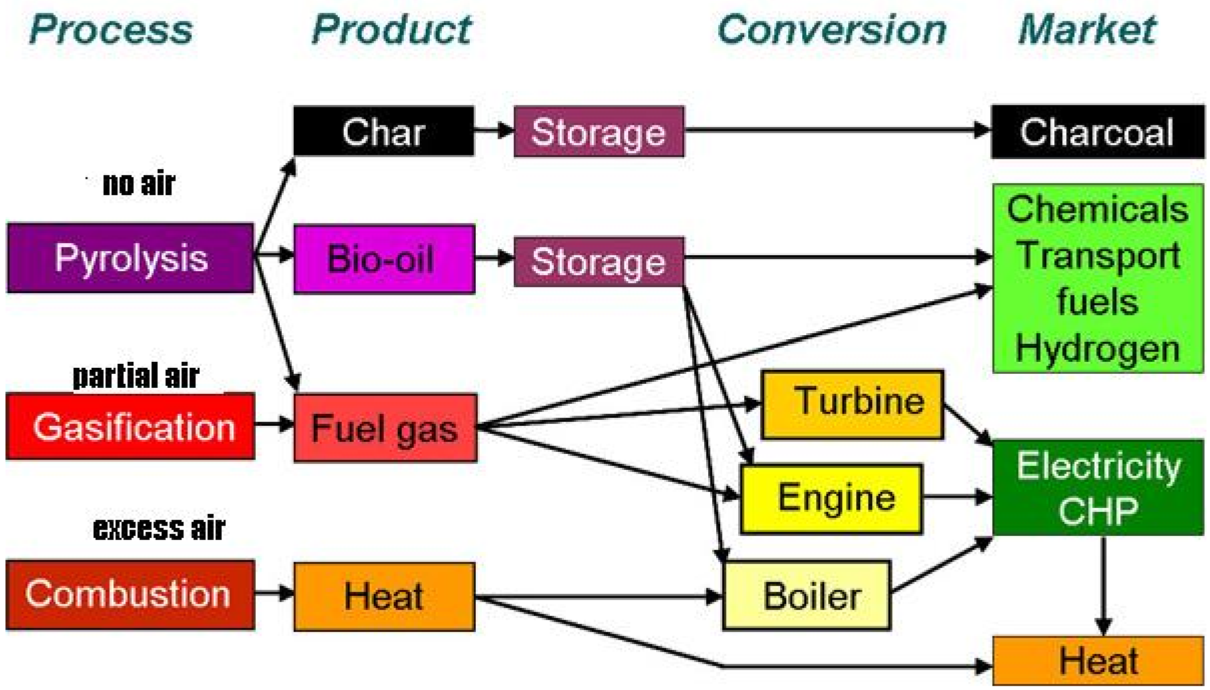
Chapter 1

INTRODUCTION

Globally, the accelerating rate of energy consumption leads to emptying of reserves of conventional energy sources and also causes major problem of pollution, which ultimately affects mankind in many ways. These concerns require finding out substitute or alternative sources of energy in place of non-renewable energy sources. To reduce the dependency on conventional energy sources and address the environmental issues, development and promotion of technologies using renewable natural resources such as biomass are required. Biomass can be converted into gaseous or liquid biofuels such as biogas, synthetic gas, ethanol/methanol, or used directly as fuel. These can be utilized for applications like, thermal/heat, mechanical, power generation (stand alone/grid connected) including village electrification and industrial applications. Among the biomaterials considered for energy production, granular biomass such as coir pith, rice husk, bagasse pith, sawdust, etc. need more attention due to its lesser density and lower energy content. Feasible technical and economical routes have to be identified for the efficient and effective energy conversion of such granular materials. Biomass gasification produces fuel gas or synthesis gas through the chemical conversion of biomass, usually involving partial oxidation of the feedstock in a reducing atmosphere in the presence of air, oxygen and/or steam. From the stand point of gas production, fluidized beds are highly desirable because of their higher heat transfer characteristics and their capabilities for maintaining isothermal conditions for low dense granular materials [1].The world is currently facing an ever-increasing energy demand and together with a largely fossil fuel-based economy this results a greenhouse effect due to increasing CO_2 emissions. Moreover, political instabilities and economical constraints result in increasing energy prices and more turbulent energy markets. Various forms of biomass are already used as a CO_2 neutral energy source, despite their generally lower energy density. Although up until now biomass is mainly used for cooking and heating in developing countries, a large share of increased biomass usage is anticipated to take place in large-scale heat and power generation, mainly driven by strong government policies. Here, one of the fastest growing conversion routes for biomass fuels is the co-combustion in large-scale fluidized bed installations, having the advantage that existing facilities can be utilized. Relatively low co-firing shares, in the range of up to about 10% of thermal input, are now commonly utilized. If that share increases and/or more “difficult” fuels should be used, agglomeration phenomena become more likely [2].The environmental benefits of adding biomass to coal includes decrease in nitrogen and sulphur oxides which are responsible for causing smog, acid rain and ozone pollution. In addition, relatively lower amount of carbon dioxide is released into the atmospheres[3].Biomass converted to energy by three thermo chemical conversion processes:(1)Pyrolysis,(2)Gasification,(3)Combustion.



Source : P. Abdul Salam, S. Kumar and Manjula Siriwardhana "The Status of Biomass Gasification"

Figure 1.1: Applications of biomass thermochemical conversion processes

1.1 Biomass Pyrolysis

Biomass pyrolysis is defined as the thermal decomposition of biomass in the absence of an oxidizing agent (air/oxygen) and occurs at temperatures in the range of 400 to 800ºC. With the addition of heat the biomass breaks down to condensable vapours, non-condensable gases (pyrolysis gas), and charcoal. In some cases a limited amount of air, not enough for gasification, may be admitted to promote the process by heat generation. The pyrolysis gas contains carbon monoxide, carbon dioxide, hydrogen, methane and higher hydrocarbons. The condensable vapours form a liquid known as bio-oil or pyrolysis liquid, which contains a wide range of oxygenated chemicals and water. All products are combustible. It is possible to some extent to influence the product mix so that one of the products is promoted[4].

1.2 Biomass gasification

Gasification processes convert biomass into combustible gases that ideally contain all the energy originally present in the biomass. In practice, conversion efficiencies ranging from 60% to 90% are achieved. Gasification processes can be either direct (using air or oxygen to generate heat through exothermic reactions) or indirect (transferring heat to the reactor from the outside). The gas can be burned to produce industrial or residential heat, to run engines for mechanical or electrical power, or to make synthetic fuels[3]. Biomass gasifiers are of two kinds – updraft and downdraft. In an updraft unit, biomass is fed in the top of the reactor and air is injected into the bottom of the fuel bed. The efficiency of updraft gasifiers ranges from 80 to 90% on account of efficient counter-current heat exchange between the rising gases and descending solids. However, the tars produced by updraft gasifiers imply that the gas must be cooled before it can be used in internal combustion engines. Thus, in practical operation, updraft units are used for direct heat applications while downdraft ones are employed for operating internal combustion engines. Large scale applications of gasifiers include comprehensive versions of the small scale updraft and downdraft technologies, and fluidized bed technologies. The superior heat and mass transfer of fluidized beds leads to relatively uniform temperatures throughout the bed, better fuel moisture utilization, and faster rate of reaction, resulting in higher throughput capabilities.Based on the design of gasifiers and the type of fuels used, there exists different kinds of gasifiers. Figure 1.2 shows three principal types of gasifiers: fixed bed systems, fluidized bed systems and entrained flow systems. All these processes can be operated at ambient or increased pressure and serve the purpose of thermo-chemical conversion of solid biomass[4].

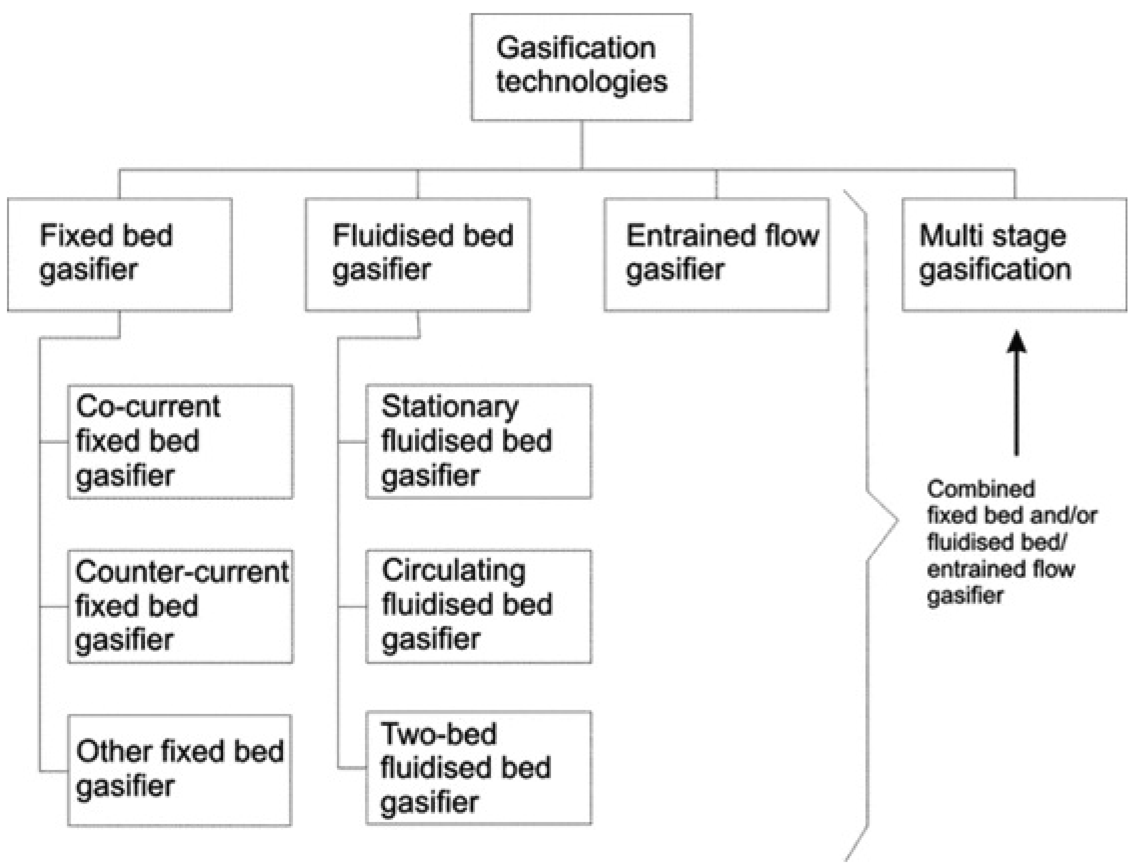


Figure 1.2: Overview of the different gasification technologies

Five major types of classification are fixed-bed updraft, fixed-bed downdraft, fixed-bed cross-draft, bubbling fluidized bed, and circulating fluidized bed gasifiers, which are demonstrated in Figure 1.3. Differentiation is based on the means of supporting the biomass in the reactor vessel, the direction of flow of both the biomass and oxidant, and the way heat is supplied to the reactor (Ciferno and Marano, 2002). Fixed bed gasifiers are typically simpler, less expensive, and produce lower heat content - producer gas. Fluidized bed gasifiers are more complicated, more expensive, and produce a gas with a higher heating value[4].

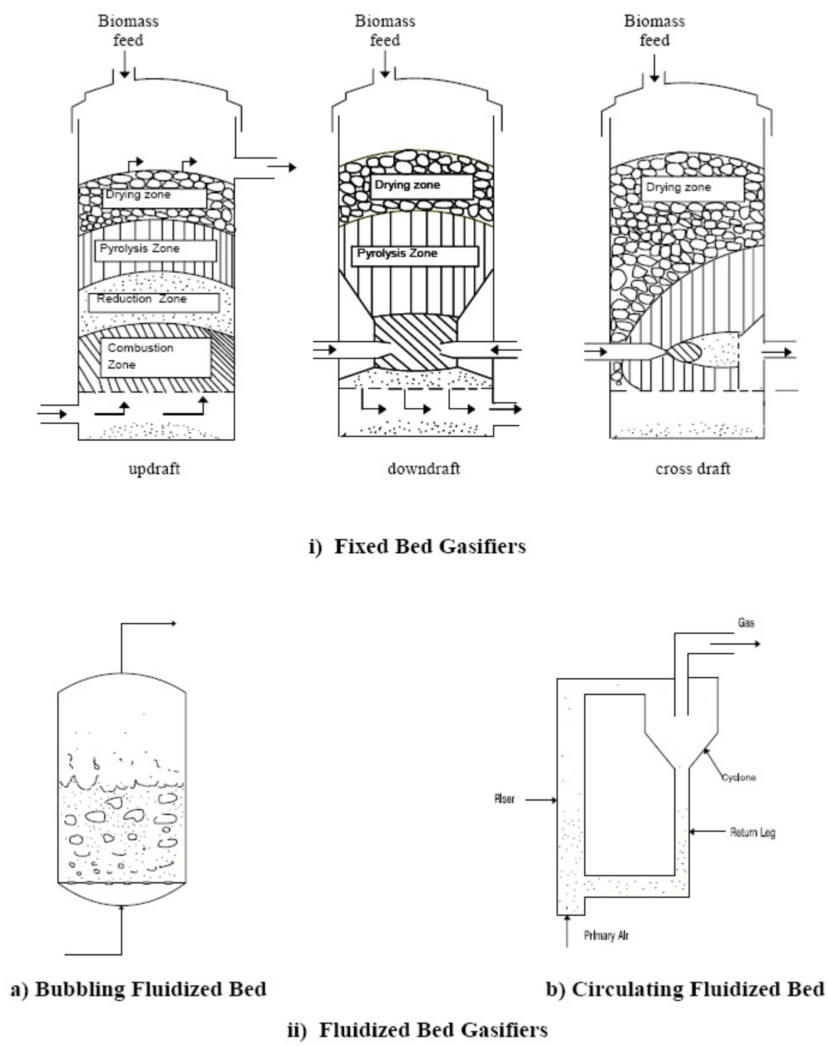


Figure 1.3: Different kinds of gasifier configurations

Table 1.1: Comparision of the four gasifiers

	Downdraft	Updraft	BFBG	CFBG
Thermal Output	Low	Low	High	Higher
Scale-up Potential	Low	Low	High	High
Fluidization Agent Velocity	N.A.	N.A.	Low	High
Quality of Gas	High	Low	Low	Low

Fluidized beds are used for a broad variety of fuels; this flexibility with respect to different fuels is actually another stronghold of fluidized beds. In terms of the utilized fuels, coal has been most often applied so far, but also waste and biomass have been utilized and are forecast to play a more important role in the future. Fluidized bed conversion of solid fuels is also of significant economic importance nowadays; especially in quickly developing countries.The development of fluidized bed gasifiers for small particle materials has made a great progress in biomass gasification. The productivity of the fluidized bed gasifiers was raised about 5 times as many as of the fixed bed gasifier and the heating value of the gas increased about 20%. Bed materials such as silica sand, calcined limestone, etc. are used in fluidized bed gasification systems for effective heat and mass transfer. This study was carried out for efficient energy generation through gasification process from the available biomaterials for decentralized applications at rural locations [4].

1.3 Biomass combustion:

Biomass combustion simply means burning organic material. For millennia, humans have used this basic technology to create heat and, later, to generate power through steam. While wood is the most commonly used feedstock, a wide range of materials can be burned effectively. These include residuals and byproducts such as straw, bark residuals, sawdust and shavings from sawmills, as well as so-called "energy crops" such as switchgrass, poplar and willow that are grown specifically to create feedstock. Pelletized agricultural and wood residues are also an increasingly popular option because they are very easy to handle. Farmers and other rural homeowners are increasingly looking to biomass heat as an economical alternative to propane or furnace oil. Stoves and fireplaces can provide direct space heating or be hooked up with a back boiler that feeds heated water to radiators throughout the building. One recent technology advance is the introduction of pellet stoves, which use an electrically driven auger to deliver a steady supply of compressed pellets of wood or other biomass into the fire. These stoves can operate for at least 24 hours without being tended. On a larger scale, biomass-fed boilers can be used to meet hot water needs, heat a building or generate steam to power equipment. Many farmers are choosing to use them as the primary heat source in greenhouses, where they heat very large spaces[5].

1.4 Fluidization

The fluidization principle is straight forward: passing a fluid upward through a packed bed of solids produce a pressure drop due to fluid drag. When fluid drag force is equal to the bed weight the principles no longer rest on each other; this is the point of fluidization. The superficial velocity at this point is known as the ‘minimum fluidization velocity (U_{mf}).If the fluid velocity is increased further the pressure drop does not significantly increase-it remains equal to the bed weight per unit area. Commercial gaseous fluidized beds are usually operated at the flow rates many times that required for minimum fluidization typically 5 to 20 times . Fluidization is one of the most promising technology due to a series of reasons. The great operating flexibility makes possible to utilize different fluidizing agents, reactor temperatures and gas residence times, to add reagents along the reactor freeboard or riser and to operate with or without a specific catalyst. The FB gasification systems can be categorized as entrained bed and moving/fixed/bubbling bed.

– Oxygen blown, high-temperature entrained gasification systems do not produce any tars or heavy oils.

– Moving/fixed/bubbling bed gasifiers can produce heavy oils and tars which are typically separated from the syngas and recycled to the gasifier [6].

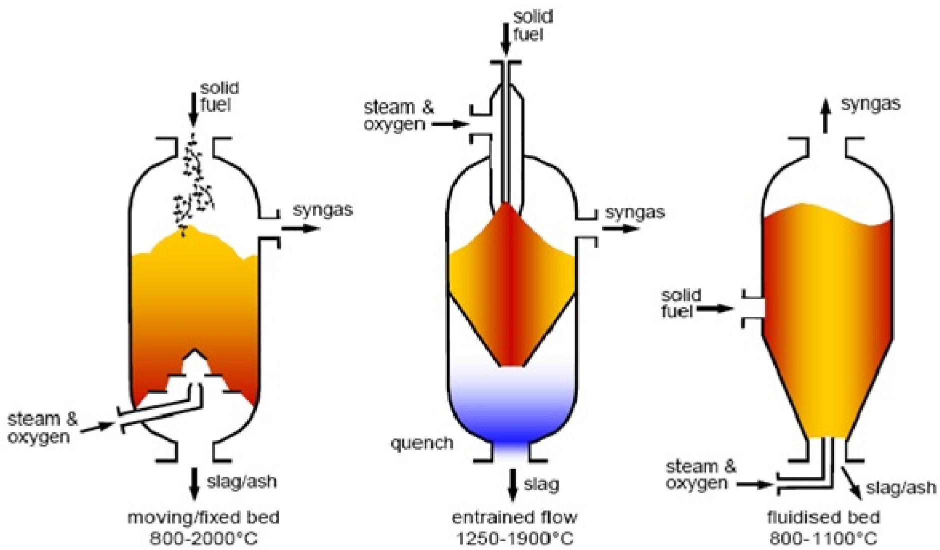


Figure 1.4: Gasification systems

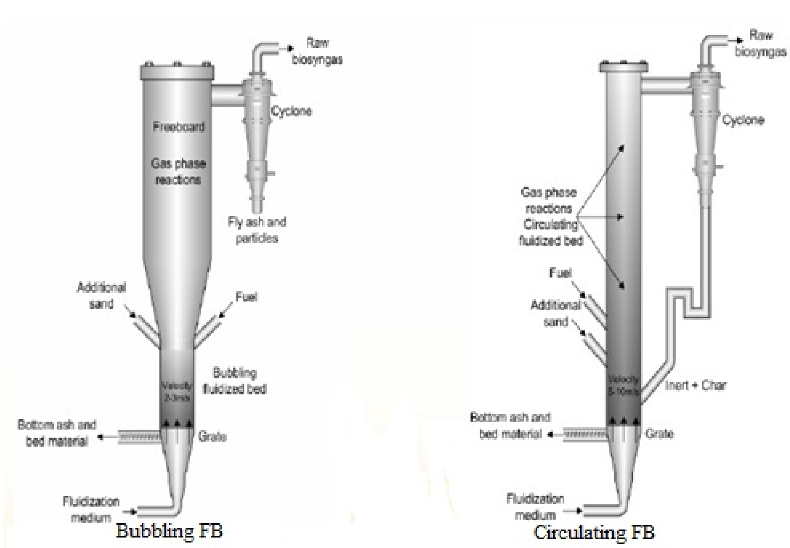


Figure 1.5: Reactor types of the FB gasification system

1.5 Minimum fluidization velocity

The superficial fluid velocity at which the upward drag force exerted by the fluid is equal to the apparent weight of the particles in the bed". Velocity at which the pressure drop reaches to maximum, at that point the velocity is called as minimum fluidization velocity. For minimum fluidization velocity we increase the flow of fluid in the bed to be fluidized. then let the bed Seattle and re-increase the flow rate of fluid, the minimum velocity at which bed re-fluidized is called minimum fluidization velocity.Theoritically it can be determined by erguen equation or buke pulmer equation [2].

$$U_{mf,m} = \frac{dp_{eff}^2(\rho_{eff} - \rho_g)}{1650\mu_g} \tag{1.1}$$

Where,
dp_{eff} represents the effective diameter of the particles in a bed, m
ρ_{eff} represents the effective density of the bed, kg/m^3
ρ_g represents the gas density in a bed, kg/m^3
μ_g represents the viscosity of gas, kg/ms

1.6 Equivalence Ratio

The equivalence ratio of a system is defined as the ratio of the fuel-to-oxidizer ratio to the stoichiometric fuel-to-oxidizer ratio[2]. Mathematically,

$$\phi = \frac{fuel-to-oxidizerratio}{(fuel-to-oxidizerratio)_{st}} = \frac{\frac{m_{fuel}}{m_{ox}}}{\left(\frac{m_{fuel}}{m_{ox}}\right)_{st}} = \frac{\frac{n_{fuel}}{n_{ox}}}{\left(\frac{n_{fuel}}{n_{ox}}\right)_{st}} \tag{1.2}$$

Where,
m represents the mass,
n represents number of moles,
suffix st stands for stoichiometric conditions

1.7 Organization of the report

In the first chapter introduction about the importance, availability and easiness of the biomass is given. Also fluidized bed gasifier importance and some brief information regarding the working and some important definitions like minimum fluidization velocity, equivalence ratio is given. Second chapter contains literature review for the project. Three papers literature review given according to the project objectives. Third chapter contains brief description of the experimental set up and parts of the set up. Also contains materials to be used and method of the experiment. Fourth chapter contains results and discussion of the data taken during experiment.

Chapter 2

LITERATURE REVIEW

Several researchers had worked on bubbling fluidized bed gasifier and use sized biomass like sawdust, rise husk, coir pitch, pomace and olive pits, and coconut shell. Following some literature reviews given here.

P. Subramaniam(2010) studied the factors affecting fluidized bed gasification of coir pith, rice husk and saw dust and process optimization, experiments were conducted in a 40 kg/h fluidized bed gasifier at equivalence ratios of 0.3, 0.4 and 0.5. The hot gas efficiency of the system was in the range of 41.59–82.80%. It is observed that with the increase of equivalence ratio, CO_2 content was increasing whereas CO was reducing. The fluidized bed gasifier system is useful for thermal applications and power generation in agro industries viz. coir industry, rice mills, timbering and other small-scale industries.They reported that reduction in carbon monoxide content with increase of equivalence ratio, whereas CO was increased with increase of gasification process time. The value of carbon monoxide was in the range of 8.24–12.68%, 9.32–19.55% and 12.39–17.73% for coir pith, rice husk and sawdust, respectively and carbon dioxide content indicated that, with the increase of equivalence ratio from 0.3 to 0.5, the CO_2 content was also increasing. The maximum (16.24%) and minimum (11.05%) value of CO_2 was observed at 0.5 and 0.3 ER, respectively, in coir pith gasification. The minimum (10.21% and 10.78%) and maximum (17.14% and 16.84%) content of CO_2 was observed with 0.3 and 0.5 ER for rice husk and sawdust gasification, respectively. study on fluidized bed gasification of rice husk reported an increasing trend of CO_2 and decreasing trend of CO with increasing equivalence ratio. The content of hydrogen in the product gas was in the range of 5.62–10.61% (coir pith), 5.34–8.62% (rice husk) and 5.24–10.14% (saw dust). The overall range of methane content was 0.98–3.82% in all the trials of fluidized bed gasification. The results showed that the increase in reaction time as well as equivalence ratio resulted in increase of gas production during fluidized bed gasification of coir pith, rice husk and sawdust. The data on gas yield during fluidized bed gasification of coir pith, rice husk and sawdust were found to be in the range of 1.98–3.24, 1.79–2.81 and 2.18–3.70 Nm^3/ kg, respectively. The minimum (2.18 MJ/Nm^3) and maximum (4.23 MJ/Nm^3) value of HHV of coir pith synthetic gas was resulted at 0.5 and 0.3 ER, respectively. It is noted from the data that, at increased values of ER, the higher heating value of synthetic gas was reduced[1].

Table 2.1: Gas composition and energy content of product gas during coir pitch gasification

Sr. No.	ER	Time min	CO %	CO2 %	H2 %	CH4 %	N2 %	O2 %	Gas Yield Nm^3/Kg	HHV Nm^3
1	0.30	10	08.71	14.62	08.49	1.52	66.41	0.25	1.98	2.65
2		20	09.26	14.88	07.89	1.36	66.38	0.23	2.02	2.58
3		30	10.12	12.12	09.54	1.89	66.08	0.25	2.26	3.08
4		40	10.28	11.63	10.17	1.53	66.21	0.18	2.18	3.04
5		50	11.53	11.58	10.55	2.67	63.50	0.17	2.21	3.67
6		60	12.57	11.05	10.61	3.82	61.78	0.17	2.32	4.23
7	0.40	10	08.24	15.61	07.54	1.08	67.21	0.32	2.24	2.31
8		20	09.21	15.22	08.62	1.59	65.12	0.24	2.12	2.75
9		30	10.52	14.17	08.79	1.32	65.00	0.20	2.24	2.82
10		40	11.12	12.83	09.53	2.54	63.77	0.21	2.68	3.44
11		50	10.91	11.69	10.46	2.50	64.25	0.19	2.52	3.52
12		60	12.68	11.83	10.57	3.60	61.14	0.18	2.69	4.16
13	0.50	10	06.54	16.24	05.62	1.91	69.37	0.32	2.73	2.18
14		20	08.94	15.48	06.87	1.21	67.29	0.21	3.14	2.36
15		30	08.31	14.32	07.23	1.86	68.00	0.28	2.83	2.57
16		40	10.52	13.67	09.61	1.33	64.68	0.19	3.24	2.93
17		50	11.61	13.14	09.78	2.42	62.88	0.17	2.90	3.40
18		60	12.47	12.68	09.64	2.91	62.19	0.11	2.84	4.14

Table 2.2: Gas composition and energy content of product gas during rise husk gasification

Sr. No.	ER	Time min	CO %	CO2 %	H2 %	CH4 %	N2 %	O2 %	Gas Yield Nm^3/Kg	HHV Nm^3
1	0.30	10	10.54	15.24	6.18	1.04	66.81	0.19	1.86	2.40
2		20	11.26	14.31	7.54	1.25	65.47	0.17	2.14	2.73
3		30	10.12	12.87	6.09	1.49	69.23	0.20	1.79	2.51
4		40	14.67	12.19	7.46	2.88	62.67	0.13	2.18	3.75
5		50	15.42	11.68	8.59	3.21	61.00	0.10	2.25	4.10
6		60	19.55	10.21	8.62	3.24	58.33	0.05	2.31	4.61
7	0.40	10	10.11	16.28	5.54	1.08	66.68	0.31	2.23	2.29
8		20	09.87	15.44	6.65	1.27	65.53	0.24	2.37	2.47
9		30	10.53	13.89	6.78	1.66	65.98	0.16	2.31	2.71
10		40	12.64	12.17	6.59	2.26	66.14	0.20	2.40	3.16
11		50	14.78	10.66	7.42	2.01	65.06	0.07	2.56	3.43
12		60	16.13	10.68	7.77	2.78	62.58	0.06	2.57	3.92
13	0.50	10	09.32	17.14	5.34	1.03	65.90	0.27	2.18	2.15
14		20	10.24	16.82	5.88	1.19	65.62	0.25	2.35	2.39
15		30	10.11	15.96	6.65	1.57	65.52	0.19	2.42	2.61
16		40	12.57	14.56	7.49	1.62	63.64	0.12	2.57	3.02
17		50	15.48	12.92	7.12	1.71	62.71	0.06	2.68	3.36
18		60	15.29	11.76	7.42	2.06	63.43	0.04	2.81	3.51

Table 2.3: Gas composition and energy content of product gas during saw dust gasification

Sr. No.	ER	Time min	CO %	CO2 %	H2 %	CH4 %	N2 %	O2 %	Gas Yield Nm^3/Kg	HHV Nm^3
1	0.30	10	14.23	14.51	6.54	1.02	63.58	0.12	2.42	2.88
2		20	15.19	12.62	7.54	1.81	62.76	0.08	2.51	3.42
3		30	16.28	13.89	7.98	2.04	59.75	0.06	2.43	3.69
4		40	15.61	12.18	8.23	1.60	62.31	0.07	2.52	3.47
5		50	17.38	11.96	9.98	2.45	58.05	0.18	2.71	4.21
6		60	17.54	10.78	10.14	3.21	58.29	0.04	2.64	4.54
7	0.40	10	13.55	15.31	5.59	1.06	64.31	0.18	2.84	2.70
8		20	14.41	14.87	6.78	1.17	62.70	0.07	2.92	2.99
9		30	15.82	13.25	7.69	1.24	61.91	0.09	2.89	3.29
10		40	15.67	12.55	7.82	1.80	62.12	0.04	3.01	3.50
11		50	16.32	11.16	8.12	2.14	62.14	0.12	3.15	3.75
12		60	17.73	11.87	9.35	2.62	58.29	0.14	3.21	4.24
13	0.50	10	12.62	16.84	5.24	0.98	62.44	0.27	3.01	2.52
14		20	12.39	15.56	5.63	1.25	62.19	0.18	3.41	2.64
15		30	13.42	14.24	6.87	1.62	60.86	0.13	3.61	3.05
16		40	14.56	12.63	7.29	1.24	63.15	0.08	3.57	3.09
17		50	15.85	12.81	7.38	1.82	60.57	0.04	3.64	3.48
18		60	16.48	12.33	8.42	2.18	59.50	0.03	3.70	3.82

The W.A.Wan Ab Karim Ghani(2009) has been experimental schedule designed in order to analyze the individual effects of the main parameters governing the produced gas quality (composition, production) and the gasification performance (gas yield, energy content), such as:

- varying the temperature (700 to 900°C);
- varying the fluidizing ratio (2.0 to 3.3 m/s);
- varying the average static bed height (10 to 30 mm) and
- varying the air to fuel ratio or equivalence ratio (ER) (0.15 to 0.45).

Two different agricultural waste coconut and palm kernel shell was used as a feed material. Gas composition obtained at five different temperatures (700 to 900°C) showed that the Hydrogen (H_2) concentration increased significantly from 43-67% for coconut shell and 56-66% for palm kernel shell, based on dry inert-gas with temperature and the content of CH_4 showed an opposite trend. Gas yield increased ranging from 0.91 to 2.95 kg/kg biomass and 2.36-5.90 kg/kg biomass for coconut shell and palm kernel shell with increasing temperature (700 to 900°C).Increasing the fluidization ratio from 2.20 to 3.30 m/s decreased the combustible gas components CO from 0.17 to 0.15 mol % and 0.32 to 0.13 mol% for coconut shell and palm kernel shell, respectively. However, a different trend was observed for H_2, where the fraction decreased about 17% for coconut shell but increased up to 26% for palm kernel shell with increased fluidization ratio. The variations in the gas composition with fluidization velocity caused a decrease of the gas yield and LHV. Increases of CH_4 content were observed as higher fluidization ratio which verified the above statement. While, the content of CO_2 increased about 43% and 62% for coconut shell and palm kernel shell, respectively with the increase in fluidization velocity which is again reflects the less efficient conversion process as fluidization ratio increase.The H_2 and CO content increased from 0.68 to 0.70 mol gas/mol biomass and 0.06 to 0.17 mol gas/mol biomass for coconut shell but for palm kernel shell H_2 decrease from 0.70 to 0.47 mol gas/mol biomass and CO increase from 0.19 to 0.25 mol gas/mol biomass. Meanwhile, the CH_4 content decreased slightly from 0.04 to 0.011 mol gas/mol biomass for coconut shell but an increase in CH_4 from 0.023 to 0.042 mol gas/mol biomass for palm kernel shell was observed. However, CO_2 content significantly increased in both cases, with averages of 11% and 38% for coconut shell and palm kernel shell, respectively. The gas yield was decreased when the static bed height was increased to 30 mm. This indicated that there might an optimum bed height for a particular ER, at which the gas yield reached a maximum. This can be explained by the fact that a significant change of the hydrodynamic conditions due to the formation of larger bubbles in the bed height.Equivalence ratio (ER) was varied from 0.15 to 0.45, the H_2 and CO content increased first and then decreased as ER increased. ER not only represents the oxygen quantity introduced to the reactor but also affects the gasification temperature under the condition of auto thermal operation. On the one hand, a higher ER will cause gas quality, while on the other hand, higher ER means higher gasification temperature, which can accelerate the gasification and improve the product purity to a certain limit. Therefore the gas composition is affected by the two contradictory factors of ER. It was noted that a significant decrease in LHV from 117 and 2286 to 85 and 1482 kJ/Nm^3 for coconut shell and palm kernel shell, respectively with increasing ER due to consumption of hydrocarbons by combustion.Air gasification of agricultural wastes was successfully performed in a lab scale fluidized bed gasifier, producing a fuel gas with a lower heating value in the range of 85 and 2384 kJ/Nm^3 and 1482 and 5578 kJ/Nm^3 for coconut shell and palm kernel shell, respectively, which could be used in many end use applications. Among the gasification parameters tested, the equivalence ratio appeared to have the most pronounced effect on the reactor temperature, the gas composition, the gas yield, and the gas heating value. The selection of suitable equivalence ratio would depend on the final use of the gas produced. As a higher equivalence ratio (ER) had complex effects on tests results and there existed an optimal value for this factor, which was different according to different operating parameters. The influence of equivalence ratio on the performance of a gasifer could be regarded as the effect of reactor temperature as the reactor was found to be ER dependent. The fluidizing velocity and static bed height would only show minor effect during the gasification process. The fluidization velocity was observed to have an influence on the gasification process to some extent because it will result in the carryover of fine chars from reactor. The bed height would affect the residence time of gases in the high temperature dense bed. Hence, the rise of the bed height favored tars and hydrocarbon cracking reactions, but too high a bed height showed a negative effect due to formation of large bubbles[7].

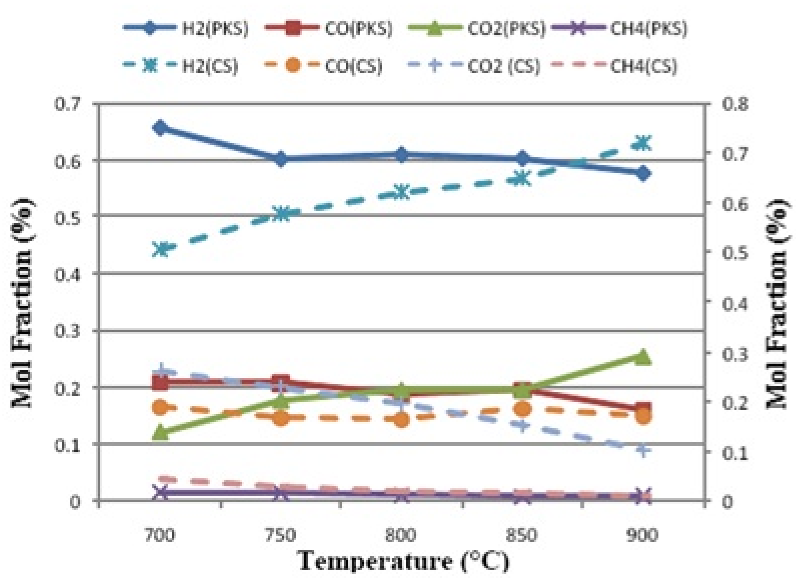


Figure 2.1: Effect of temperature on gas composition of palm kernel shell and coconut shell

Table 2.4: Gas yield and LHV at different Reactor temperature

Reactor temperature(^{0}C)	700	750	800	850	900
Gas ield(mol/kg biomass)					
a) Coconut shell	0.91	1.81	1.42	2.12	2.95
b) Palm kernel shell	2.36	3.46	4.37	5.25	5.90
Gas LHV(KJ/Nm3)					
a) Coconut shell	930	1033	1174	1874	2384
b) Palm kernel shell	2783	3276	3711	4451	3720

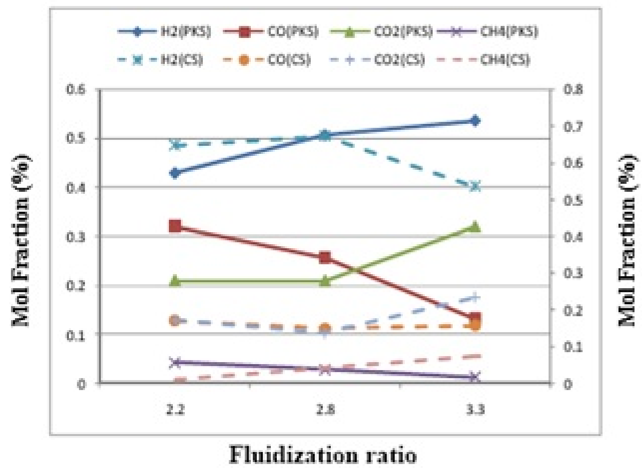


Figure 2.2: Effect of fluidisation ratio on gas composition of palm kernel shell and coconut shell

Table 2.5: Gas yield and LHV at different Fluidization ratio

Fluidization ratio	2.20	2.80	3.33
Gas yield(mol/kg biomass)			
a) Coconut shell	0.60	0.32	0.26
b) Palm kernel shell	3.15	3.57	4.42
Gas LHV(KJ/Nm3)			
a) Coconut shell	484	292	279
b) Palm kernel shell	4607	1756	1961

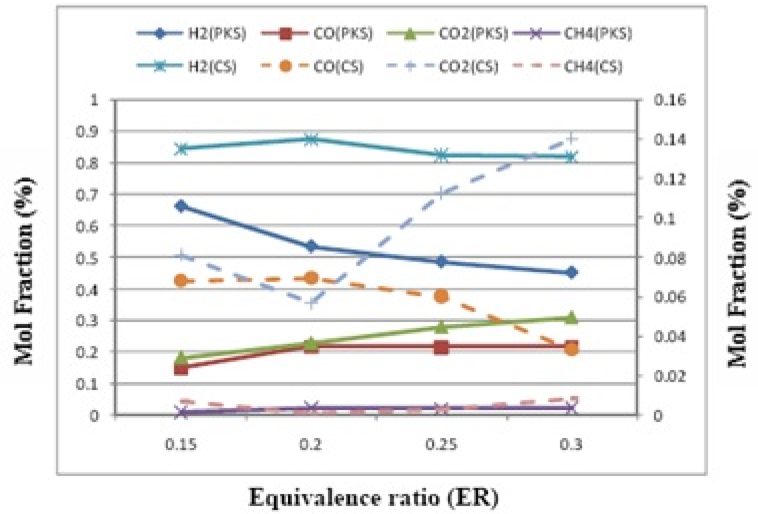


Figure 2.3: Effect of Equivalence ratio on gas composition of palm kernel shell and coconut shell

Table 2.6: Gas yield and LHV at different ER

Equivalence Ratio(ER)	0.15	0.20	0.25	0.30	0.45
Gas ield(mol/kg biomass)					
a) Coconut shell	0.31	0.41	1.08	0.64	0.25
b) Palm kernel shell	2.7	4.02	2.81	1.86	1.08
Gas LHV(KJ/Nm3)					
a) Coconut shell	117	190	473	261	85
b) Palm kernel shell	2286	2863	3467	1812	1482

Maria C. Palancar effects of the moving zone temperature and ER on the gasification efficiency, flue gas composition and LHV were studied under the following operating conditions:

- Equivalent ratio, ER: 0.18–0.82.
- Temperature: in the moving bed, 529–848 °C; in the fluidized bed, 840–860 °C.
- Superficial throughput: around 580 kgsolid/(m^2 flu. bed).
- Superficial air velocity in the fluidized bed (850 °C): around 1 m/s.
- Input solid moisture: 8% (wet basis).
- Water air ratio (extra water feeding): 0.1–0.3 kg water/kg air.

The ultimate analysis of pomace and olive pits shows that both have roughly the same composition (mean dry ash free analysis: 47% C, 5.7% H, 1.5% N and 0.01% S). The content of ash is about 3.2%. The LHV of the flue gas is similar to other biomass gasification processes (between 4 and 6 MJ/Nm^3). The effects of the moving bed temperature, ER and water/air ratio on the composition of the flue gas have been determined experimentally. The best results obtained for temperatures around 825 °C (805–845 °C) and ER around 0.2 (0.13–0.26) are: efficiency, 43%, LHV, 5.5 MJ/Nm^3, and a flue gas with 12% H_2 and 18% CO. The production of tar increases as ER decreases.The concentrations of H_2, CO and CH_4 increase with the moving bed temperature, due to an increasing of temperature that enhances the endothermic and steam reactions. The C_2H_4 concentration shows a low sensitivity to the moving bed temperature range used because the temperature in the bed was not very high. The LHV of the flue gas increases with the moving bed temperature. The increasing LHV is a direct consequence of the increase of the productions of H_2 and CO. The gasification efficiency, increases with the moving bed temperature. The same comments made above for the effects of the moving bed temperature on LHV are applicable to the gasification efficiency. The LHV variation with the ER for temperatures of 700, 750, 800 and 850 °C. The LHV is not influenced by ER for values of this parameter less than 0.18. However, for ER higher than 0.18, the LHV decreases with ER. The variation of LHV decreases with the moving bed temperature; this fact can be explained by considering that the thermal cracking of tar is endothermic and becomes more important as the temperature increases. The concentration of H_2 and CO is more sensitive to changes of ER than the one of CH_4 and C_2H_4. Approximately, the H_2 and CO concentrations are proportional to ER. The product distribution is more sensitive to changes in the ER than to the moving bed temperature. For moving bed temperatures up to about 800 °C and ER up to 0.32, the gasification efficiency, decreases with ER. If the moving bed temperature is higher than 800 °C and the ER is less than 0.32, the gasification efficiency does not depend on ER. The decrease in the efficiency with ER can be explained based on the decreasing values of LHV with ER. Consequently, as the efficiency is proportional to the LHV, the efficiency also decreases with the ER[8]

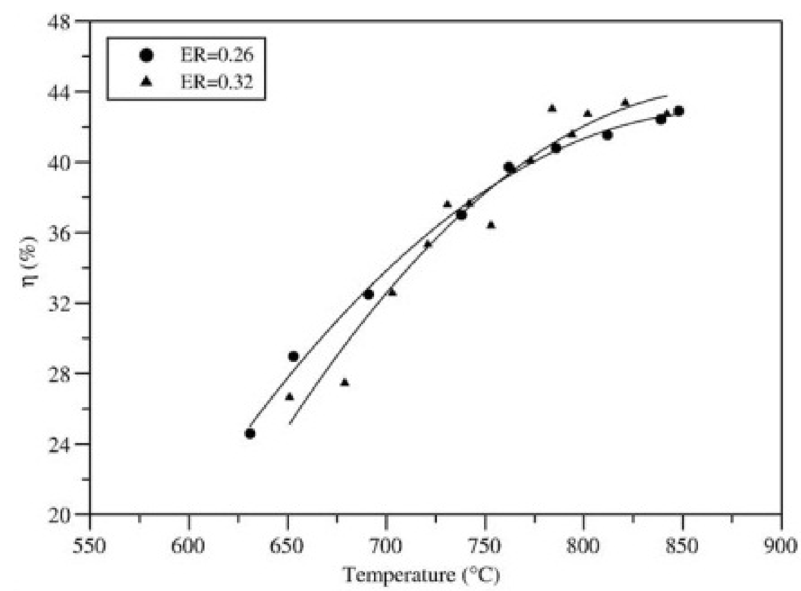


Figure 2.4: Influence of the moving bed temperature (bottom) on the gasification efficiency.

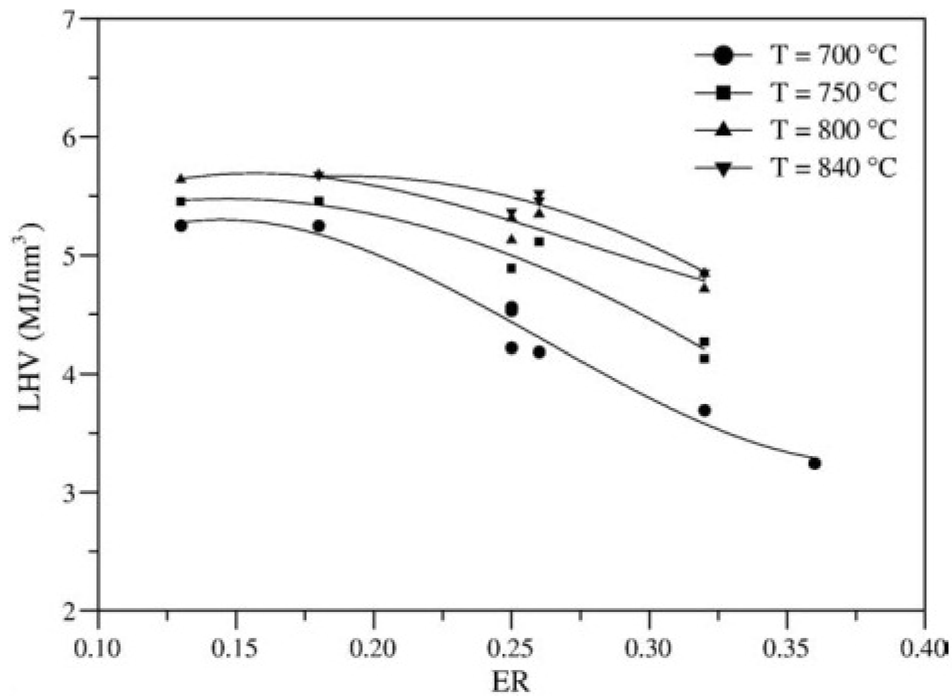


Figure 2.5: Influence of the equivalent ratio on the LHV of the flue gas.

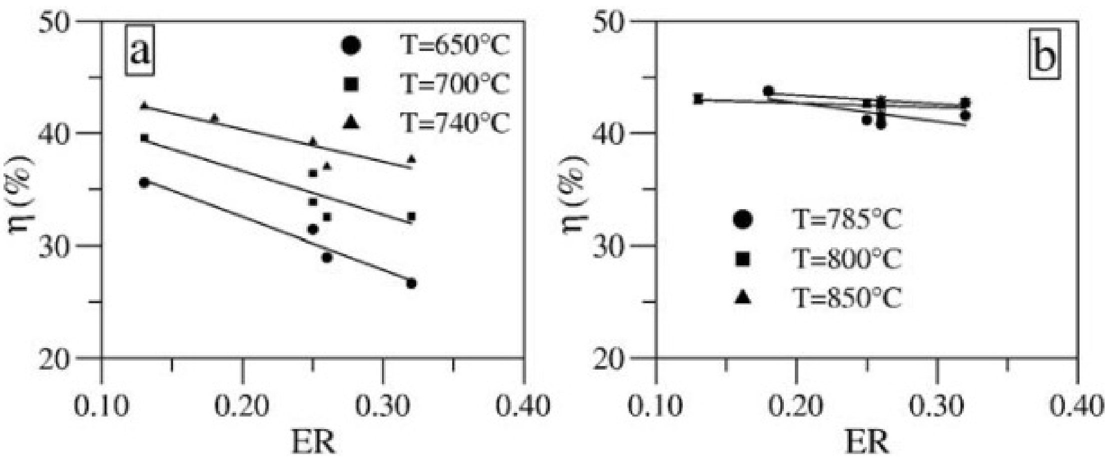


Figure 2.6: Influence of the equivalent ratio on the gasification efficiency.

After literature survey it is observe that there are very big scope to work in different equivalence ratio and different fluidization velocity. So, decided to work in that area. Objectives of the project work are as follow.

- To evaluate the effects of equivalence ratio and fluidization velocity on the performance of the gasifier
- To observe the bed temperature profiles with different velocities and air flow rates.
- Techno-economic Evaluation.

Chapter 3

EXPERIMENTAL SET UP

3.1 Materials and Methodology

3.1.1 Feed materials and bed materials

The feed materials or biomass selected to study the fluidized bed gasification are pigeon pea and saw dust, which are granular in nature and particle size was selected as 0.4 mm to 0.841 mm. The inert bed material used was sand and its particle size distribution was selected as 0.4 mm to 0.595 mm using sieve analysis. The properties of these materials and the procedures followed in finding out physical and chemical properties are given below.Bulk density was determined by measuring weight of sample occupied in the known volume of vessel. Absolute specific gravity of the selected materials was measured using specific gravity bottle method. Sieve analysis is commonly used to predict the particle size distribution of the granular materials having size of 0.075–3 mm. The test materials were dried and then sieved in a set of standard sieves and particle size distribution was observed. Using oven method (110^{o}C till reaching standard borne dry weight), moisture content of these granular biomaterials was measured (ASTM, E – 871). Proximate composition such as volatile matter (ASTM, E – 872), ash (ASTM, E – 830) and fixed carbon (by weight difference) content of pigeon pea and saw dust was found out by ASTM procedures. The minimum fluidization velocity was measured using pressure drop method. U tube manometers are used to measure the pressure drop below and above the distributor plate and at different heights of fluidized bed reactor. The air velocity corresponding to the peak pressure drop gives the experimental value of minimum fluidization velocity.

Table 3.1: Proximate Analysis of the feed material

Material	Moisture content (%)	Ash content (%)	Volatile matter (%)	Fixed Carbone (%)	Calorific value (Kcal/kg)
Saw Dust	7.4336	4.8179	78.4249	9.3237	4350
Pigeon Pea	7.8363	4.5508	78.6119	9.0010	4225

3.1.2 12-point Temperature Indicator and Thermocouples

For measurement of the temperature of the various section six K-Type thermocouple probes (range: 0-1200^{o}C) fitted on the reactor at different heights. Out of which two thermocouple probes fitted at bed section, another two are fitted at freeboard section, one is at air inlet to bed section below the distributor plate and one is at gas outlet after cyclone separator. These temperature thermocouples connected to 12-point digital temperature indicator with K-type thermocouple wires. The thermocouple probes are nominated T_1-T_6 for simplicity from below to top of the reactor.

Figure 3.1: 12-point digital Temperature indicator with thermocouple.

3.1.3 U-Tube Manometer

For measurement of the pressure drop U-Tube manometer fitted at three different places. One U-Tube manometer (range: 0-500 mm H2O) is across the orifice plate of 2” orifice meter fitted at inlet of the regenerative blower. Second manometer (range: 0-2000 mm H2O) is across the distributor plate and bed material. And third manometer (range: 0-500 mm H2O) is at ventury meter just before the burner.

Figure 3.2: U-Tube Manometer

3.2 Experimental Setup

The schematic diagram of the system is shown in the figure 3.3.

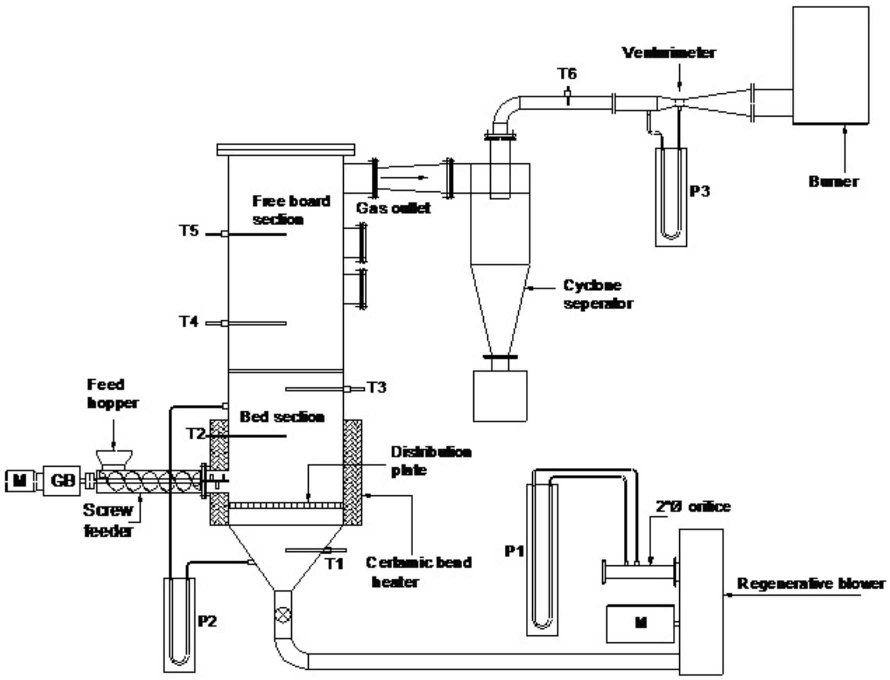


Figure 3.3: Schematic diagram of the fluidized bed gasification system

3.3 Gasifier Reactor

Biomass fuels are processed in an atmospheric bubbling fluidized bed reactor. Because fluidized beds can handle a variety of feedstock, they are well suited for this application. The reactor is made of 3 mm-thick stainless steel with a total height of 1.6 m. The reactor is 21 cm (8 inches) in diameter and measures 1.6 m (5.2 feet) tall. The Reactor is split into two sections: a bed section and a freeboard section. The height of the bed section is 0.6 m and freeboard section is 1 m. In the bottom, perforated plate distributors are used to ensure good gas distribution for a wide range of operating parameters. The distributor plate consists of 101 numbers of 2 mm diameter holes spaced intervals. The reactor bed section is surrounded by one ceramic band heater of 2.5 KW with temperature controller. The ceramic band heater is 21 cm (8 inches) inside diameter and height of 30 cm (12 inches). Numerous access ports that allow for temperature and pressure monitoring and temperatures of the different zones. The bed is fluidized with air provided by a regenerative blower. Bed temperature is of 500 ° C to 700°C. The primary fluidization gas enters the bottom of the reactor in the plenum and then flows through a drilled-hole distributor plate. The distributor plate consists of 101 numbers of 2 mm diameter holes spaced 2 inches intervals. The fluidization media consists of 14 kg of 0.4 mm to 0.595 mm sized sand with a bed height of 30 cm. The bed is heated to normal operating temperatures by ceramic band heater located at the bed section of the reactor. After the reactor is heated to reaction temperatures, solid fuel can be processed. The particulate-laden exhaust stream exits the reactor through the freeboard and passes through the cyclone. The combustible gas is ignited at the burner after the cyclone.

3.4 Feedstock feeding section

It consists of a frame, a hopper, a stirrer, a screw feeder and a drive system with an electric motor with gear box and a variable frequency drive. The funnel shaped hopper, which served as a reservoir for the fuel material, has a capacity of about 15 L. The stirrer is used to loosen and mix the fuel, in order to prevent it from settling and consolidating to form a bridge, and to keep the fuel supply homogeneous and consistent. The feedstock is fed by a variable rotating screw feeder (of 100 mm diameter) from the feedstock storage hopper. The feeding point is at 50 mm from the distributor plate.

3.5 Air supply section

The air required for fluidization is supplied to the plenum by an air supply unit. The unit consists of an air regenerative blower, orifice meter and U-tube manometer. Orifice meter is fitted at air inlet pipe of the regenerative blower for measurement of the air velocity. U-tube manometer pipes are fitted across the distributor plate for measurement of the pressure drop across the distributor plate.

3.6 Modification done in the existing system

3.6.1 Distance piece between screw feeder and bed section of reactor

As reported by SPRERI scientists with their experience of screw feeding system, screw feeder was block with biomass and pyrolysed gas also flows back to the screw feeder. T overcome this problem, added a distance piece of 4” diameter and 4” long between screw feeder and bed section of reactor. Also weld a square bar to the shaft of the screw feeder of 4” long having 2” flat welded at 1” interval after 2” space provided for biomass plug which prevents the pyrolysed gas flows back and welded flat reduce biomass blockage.

3.6.2 Ceramic band heater instead of Electric heater

For heating bed material they were use temporary electric heater .But they had to feed the heater from open top of the reactor and when they achieve the temperature of the bed material, take out the heater from the reactor and close the top cover of the reactor .But after some time of removal of the heater bed material temperature decreases and further they had to feed the electric heater.Solution of this problem is purchase the ceramic band heater of 2.5KW, 8” inside diameter and 12” long which is permanently fitted outside to the bed section of the reactor.

3.6.3 2” orifice meter instead of 1.25” orifice meter

1.25” orifice fitted at inlet of the regenerative blower but inlet of the regenerative blower is 2” so we replace the 1.25” orifice meter with 2” orifice meter.

3.6.4 Discharge pipe for cyclone separator ash bin

As reported by SPRERI scientists with their experience, during running of the gasifier after one hour cyclone separator ash bin fully filled and choke up with ash and some unburned materials. For removing this unburnt material and ash we had weld one 2” pipe with ball valve. During the operation we open the valve to remove the ash and unburnt material.

Chapter 4

RESULTS AND DISCUSSION

4.1 Distributor plate calibration:

Stainless steel Distributor plate with 101 number of 2 mm orifice diameter is fitted at bottom of the reactor for uniform distribution of the air flow. We had measure the pressure drop across the distributor plate and bed for velocity of the air at the bed section.

4.2 Cold flow fluidization property of the feed material and bed material

Table 4.1: Fluidization properties of the feed materials and bed material

Material	Particle size(mm)	Fluidization Regime	Minimum fluidization velocity(m/s)	Maximum air velocity(m/s)
Sand	0.4-0.595	Bubbling	0.4	0.6
Saw dust	0.4-0.841	Bubbling	0.26	0.6
Pigeon pea	0.4-0.841	Bubbling	0.28	0.6

4.3 Purchase and installation of Ceramic band heater

4.4 Feed Rate calibration as per the frequency:

Geared motor of the screw feeding system is controlled by variable frequency drive. We had calibrated the output in kg/hr of the screw feeder motor for different frequency. The output of the feeder for both biomass materials is given in table 4.2.

Table 4.2: Feed Rate of the screw feeder for feed materials

Frequency(Hz)	Feed rate(Kg/hr)
49.5	116
40	99.8
30	72.9
20	51.5
10	24.1

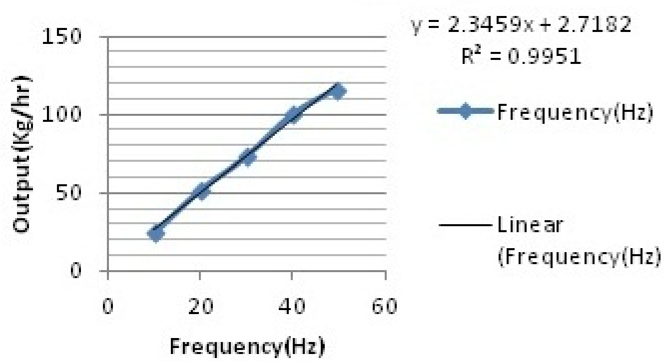


Figure 4.1: Output of the screw feeder in reference to frequency

4.5 Actual running data of the fluidized bed gasifier

We had run the gasifier on sawdust (size-0.4 to 0.841 mm) as a feed material and sand (size-0.4 to 0.595 mm) as a bed material with air as fluidizing agent. The gasifier runs successfully with good quality of gas. The cyclone separator ash bin was not fully filled and collected very low ash in the ash bin which indicates that the full gasification of the feed material have been done or less unburned particles present in the producer gas. After about 1 hour running of the gasifier there was a short-circuit in the panel of the fuel feeding system so we had to shut down the gasifier. Following are the some resulting data of the gasifier run on sawdust.

Figure 4.2: Fluidized bed gasifier run on sawdust

Table 4.3: Result of Fluidized bed gasifier run on sawdust

Time(hr)	Feed Motor Frequency(Hz)	P_1 (mm H_2O)	T_1	T_2	T_3	T_4	T_5	T_6
02:00 pm	23	20	63	690	541	372	455	86
02:10 pm	23	20	67	1003	762	672	667	220
02:20 pm	23	20	74	1043	788	676	674	258
02:30 pm	23	20	70	1048	787	649	661	200
02:40 pm	23	20	73	1110	876	691	706	244

Chapter 5

FUTURE WORKS

5.1 Technical Program

- To collect raw material of two types of biomass (saw dust & pigeon pea).
- Differentiate sized biomass (0.4 to 0.841 mm) from raw material.
- Instrumentation of the test setup(5 no. of thermocouple for measuring temp. of freeboard section ,bed section, and outlet gas. Three no. of U-tube manometer for measurement of the pressure of air and outlet gas)
- Run the gasifier at different feedrates(15, 20, 25, & 30 kg/hr) and different fluidization velocities(0.4, 0.5, 0.6 m/s)(Different Equivalence ratio (0.19, 0.21, 0.25, 0.31 & 0.38) for selected biomass.
- Keeping fluidization velocity 0.4 m/s constant and change the feedrates 15 kg/hr, 20kg/hr, 25kg/hr, 30kg/hr and taking readings. Repeat the experiment for 0.5 m/s and 0.6 m/s fluidization velocities for saw dust.
- Further repeat experiment for pigeon pea.
- Taking temperatures of gas at different locations.
- Taking gas sample for measurement of the gas quality.
- Analysis of the data report writing.
- Further repeat experiment for low grade coal (lignite).

5.2 Expected Output

- Most efficient Equivalence ratio and fluidization velocity for selected sized biomass.

- Required temperature of the bed material and freeboard temperature for selected sized biomass.
- Economical cost of the gas.

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