Synthesis of Integrated Biomass Thermal Processing For Fuel Production

by

Mohd Anas Bin Amir Hamzah

Dissertation submitted in partial fulfillment of
the requirement for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

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CERTIFICATION OF APPROVAL

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ABSTRACT

The objective of this project is to study and identify the feasibility of integrating of thermal processing of biomass for the production of bio-fuel. Three thermal processing of biomass are combustion, gasification and pyrolysis. The project concerned on how to integrate the gasification and pyrolyiss of biomass. Gasification of biomass will produce fuel and a mixture of gases such as carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2) and methane (CH_4). Gasifying agents are used in order to complete the reaction. There are about 70% to 80% of gases reportedly produced from the process. In the other hand, pyrolysis reaction occurs without the use of oxygen in the process. The reaction produces about 65 % to 75 % of liquid, 15 % to 20 % of char and 10% to 15% of gases.

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Biomass is one of the potential renewable sources for energy and fuel production. Biomass materials can be classified in four categories: woody plants, herbaceous plants or grasses, aquatic plants and manures. There is a range of different biomass processing technologies towards converting it into more useful energy form which can be classified in three categories: thermal, biochemical and physical processing. The processing of biomass with its product and applications are summarized in table 1.1.

Table 1.1: Processing of Biomass Materials

Thermal Processing	Combustion	Heat Steam Electricity
	Gasification	Steam Heat Electricity Methane Hydrogen
	Pyrolysis	Bio-oil Bio-gas Charcoal
Biochemical Processing	Anaerobic Digestion	Biogas
		Compost
	Fermentation	Ethanol
Physical Processing	Esterification	Biofuels

Three main thermal processing of biomass are combustion, gasification and pyrolysis. Combustion of biomass is a conventional route and widely practiced in commercial as to generate steam and run a turbine. Alternatively, the development of gasification offers more efficiency of the conversion of biomass than the combustion. Gasification converts the biomass into fuel with a mixture of carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2) and methane (CH_4) by either partial oxidation or by steam/pyrolytic gasification. Another thermal processing of biomass is the pyrolysis which occurs in the absence of oxygen (O_2). This process converts biomass materials to gaseous and liquid products and create carbon rich charcoal residue.

On the other hand, anaerobic digestion and fermentation are the types of biochemical processing of biomass. Anaerobic digestion is where the biomass materials are converted through anaerobic bacterial action in the absence of air. Conversely, the fermentation process converted the biomass sugar to alcoholic fuels through microbial action and distillation. The other alternative of converting biomass is through the esterification which is the physical processing of biomass. This process is the least feasible for direct bio-fuel production.

1.2 Problem Statement

Currently, the fluctuation prices of crude oil have driven the research of using biomass as potential fuel and energy production even though the study started already since the early nineties. Biomass which is a renewable energy sources have very little effect on environment with no carbon dioxide (CO_2) emission. Biomass mainly composed of cellulose, hemicelluloses, lignin and inert ash. Cellulose occupying approximately 40-50%, hemicelluloses contains 20-40%, while lignin portion is about 20-40% of the biomass.

1.3 Objectives And Scope Of Study

The objectives of this project are to build database on the biomass processing technology in order to integrate thermal processing of biomass. In order to achieve this objective, a few tasks and research need to be carried out by collecting all technical details regarding the both thermal processing of biomass that are gasification and pyrolysis. The scope of the study will also focus on the feasibility of integrating both processes for the conversion into bio-fuel. A recommendation is to be made based on the findings of this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Pyrolysis Of Biomass

There are potential to produce fuel from thermal processing of biomass such as pyrolysis and gasification. Pyrolysis is where the biomass is treated under inert atmospheric conditions as to avoid oxidation and gasification of the resultant products. Pyrolysis of the biomass produces three different energy products in different quantities that are bio-oil, biogas and charcoal. Bio-oil can be used to produce direct heat energy to drive electricity generation. Bio-gases can be combusted directly to produce heat or electricity while charcoal can be used as an industrial or domestic fuel. Three different types of pyrolysis: slow, flash and fast pyrolysis in which it is classified according to its applied heating rates. Slow pyrolysis with heating rates of 0.01-1 ^{0}C/s favors the charcoal formation wherein the process is termed as carbonization. On the other hand, the applied heating rates for fast pyrolysis is about 1-100 ^{0}C/s. The flash pyrolysis or fast pyrolysis involves heating of biomass at the rate of 100 ^{0}C/s-10000 ^{0}C/s. All of the pyrolysis technique, the flash pyrolysis gives more yield of liquid (bio-oil). The issue of the flash pyrolysis is the water content of the bio-oil which is significantly high.

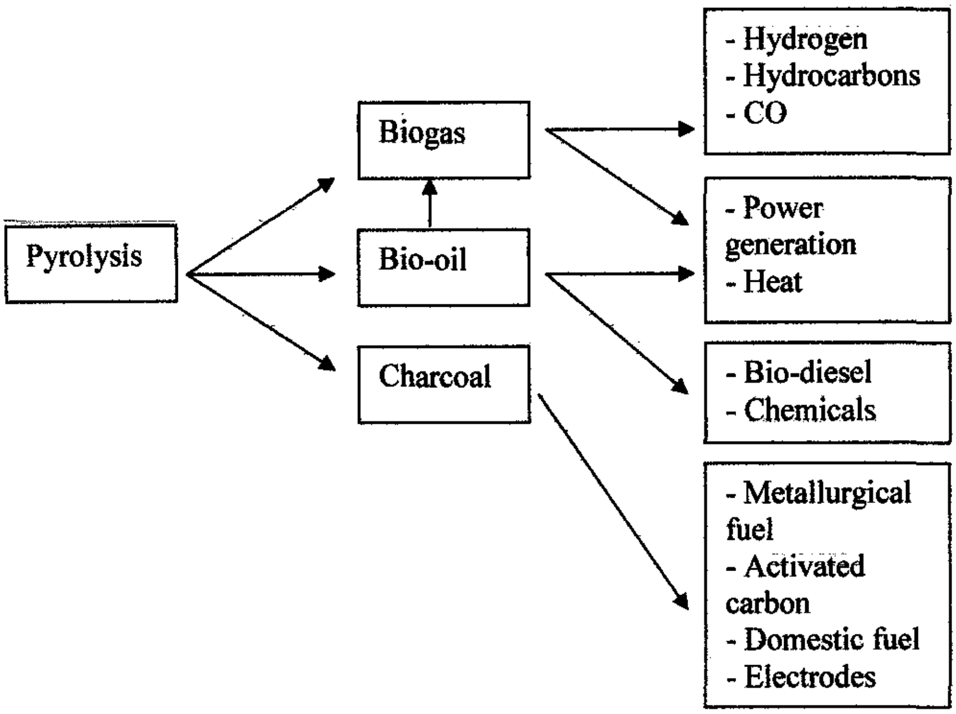

Figure 2.1: Product of Biomass Pyrolysis

2.2 General Process Of Pyrolysis Of Biomass

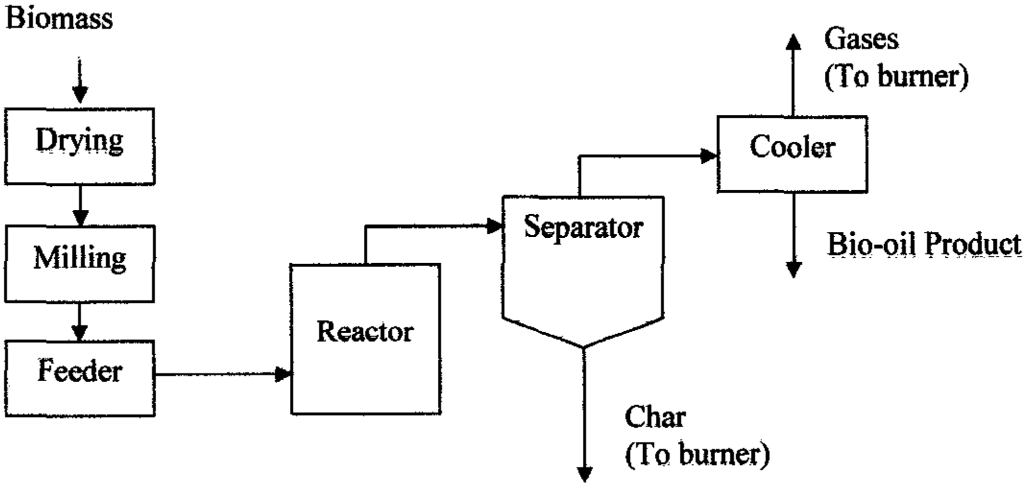

Figure 2.2: Block Flow Diagram for a Bio-Oil Plant (Source: Meier, 2002)

Figure 2.2 shows the general flow diagram of biomass pyrolyis. Biomass underwent pre-treatment before it is processed in the pyrolysis reactor. Basically, the pre-treatment of biomass are drying, grinding and milling process. Example of the pre-treatment in which empty palm fruit bunch which consists of 18.1 weight % of lignin, 59.7 weight % of cellulose and 22.1 weight % of hemicelluloses(M. Mission et al.2009). It is reported that 47.89% carbon, 45.41% oxygen and 6.05% hydrogen contains in EPFB. Sample of seasoned EPFB aged approximately 6-12 months will be crush in a high-speed rotary cutting mill in order to downsize the particle as small as 0.1 cm. The allowable range of the particle is in between 0.10 to 0.50 cm. For instance, H_2O_2 and NaOH solution are used in the pre-treatment as it will result in easy lignin degradation. Lignin is linked by carbon-carbon and ether bonds to form tri-dimensional network associated with the hemicelluloses polysaccharides inside the cell wall (Ibrahim et al, 2005) which explains why lignin is the most difficult component of biomass to be degraded. Following the pre-treatment, EPFB at a rate of 50 kg/h will undergone pyrolysis process at temperature around 500 ^{0}C which then will gives yield of 65% liquid, 15% char and 20% gases. Most of the current plant recovered char and gases so that it can be used for of heating requirement of the reactor.

2.3 Pyrolysis Technologies

The pyrolyis of biomass have long been introduced to the chemical industries. Current globalization eras and the fast development of technologies have somehow influenced major chemical companies to open pyrolysis plant. A demonstration plant of 500 kg/h is currently operating in Italy for liquid production while a 250 kg/h pilot plant based on Waterloo processes has been constructed in Spain.

2.3.1 Circulating Fluid Beds and Transported Bed

An upflow circulating fluid reactor has been operated by Ensyn in Ottawa, Canada (Graham, 1998). Good temperature control can achieve in the reactor in which the typical operating temperature of 60 ^{0}C. Biomass feed flow of 100 kg/h signifies that CFBs capability of handling larger throughputs of feed. The use of poplar wood as the feed stocks has been reported that it will gives yield of 60% of bio-oil. As shown in figure 2.3, the second reactor is basically used for char combustion and sand reheating. Short residence time of gas for this type of reactor will result in secondary tar cracking being suppressed.

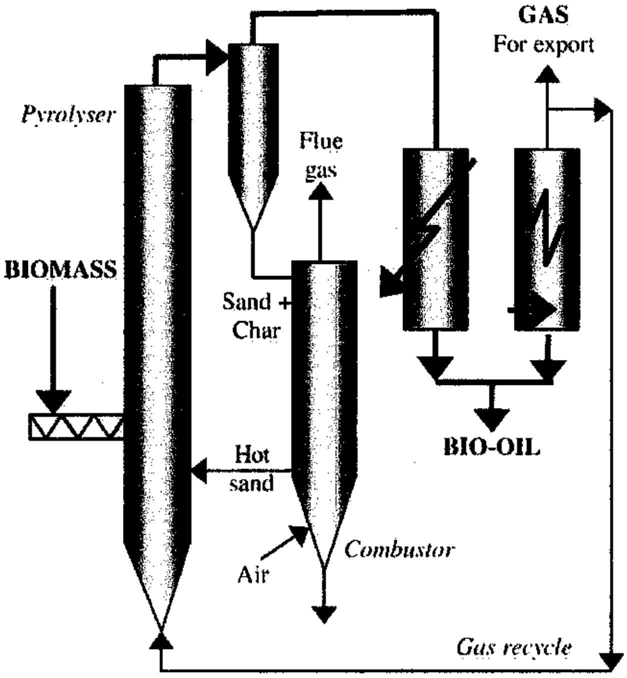

Figure 2.3: Circulating fluid bed reactor(Ensyn)

2.3.2 Entrained flow reactor

Georgia Institute of Technology and Egemin has been using entrained flow reactor for fast pyrolysis process. The typical operating conditions of this reactor are temperature of 900 °C with atmospheric pressure and feed flow of 500kg/h. This simple technology requires high gas flows which cause difficult liquid collection. Lower liquid yields are believed to be the reason as why currently both GTI and Egemin are not considering in continuing the process. The schematic diagram of the reactor is shown in figure 2.4.

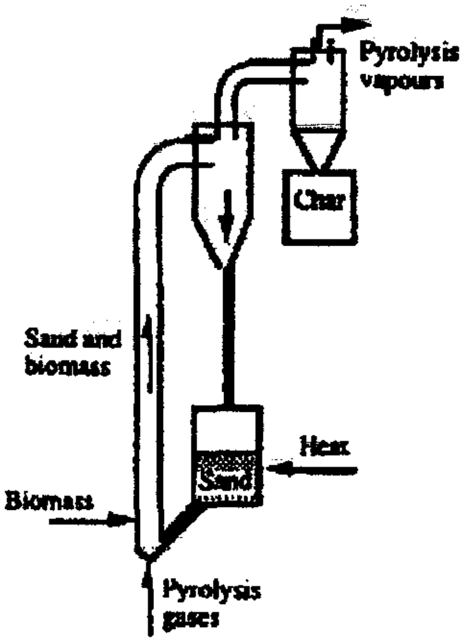

Figure 2.4: Entrained flow reactor (GIT)

2.3.3 Vacuum furnace reactor

Vacuum pyrolyis can be considered as not a true fast pyrolysis process. The reason is that the high residence time of solids and the fact that the heat transfer rate is much slower that the other technology. The technology was developed at the University of Laval, Quebec, Canada. Another difference of this reactor that most of fast pyrolyis reactors are that it can process larger particles. No carrier gas is needed for this reactor as can be seen in figure 2.5. The temperature at the top is about 200 °C and increases to 400 °C at the bottom in order to achieve maximum bio-oil products.It has been reported that liquids yields of 35-50% on dry feed can be achieved by using vacuum furnace reactor. Pyrovac, which currently operates at Jonquiere in Canada, has been used this technologies with a scale up from 50 kg/h to 3.5 t/h.

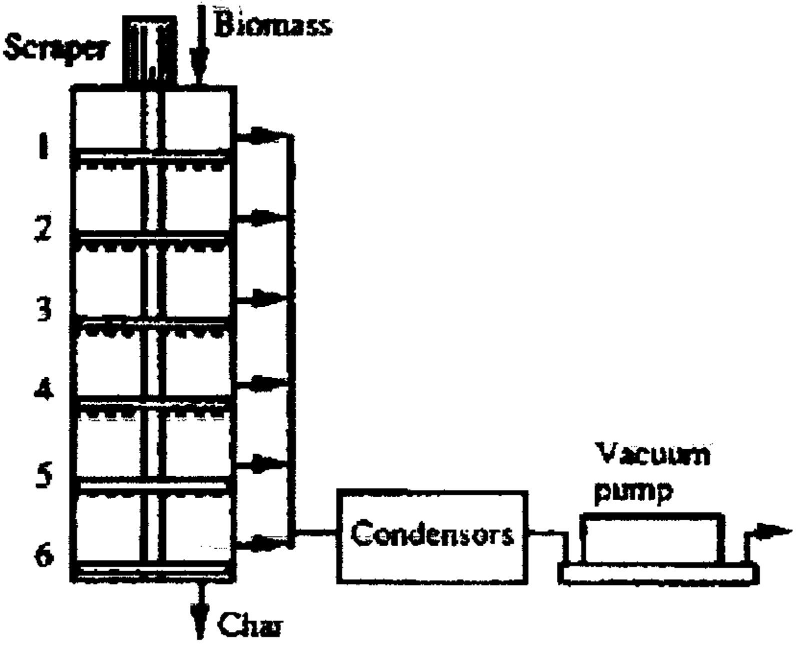

Figure 2.5: Multiple hearth reactor (Univ. Laval)

2.3.4 Vortex Ablative Reactor

A vortex reactor has been constructed by Diebold and Power (1988) at Solar Energy Research Institute (SERI), U.S.A. One of the features of this reactor is that high relative motion between particle and reactor wall. High pressure of particle on hot reactor wall can be achieved due to centrifugal force as being done by National Renewable Energy Laboratory, NREL. It also can be operated with larger particle sizes compared to other reactors. Typical operating temperature is about 625 °C with liquid yields of 60-65% on dry feed basis can be achieved.

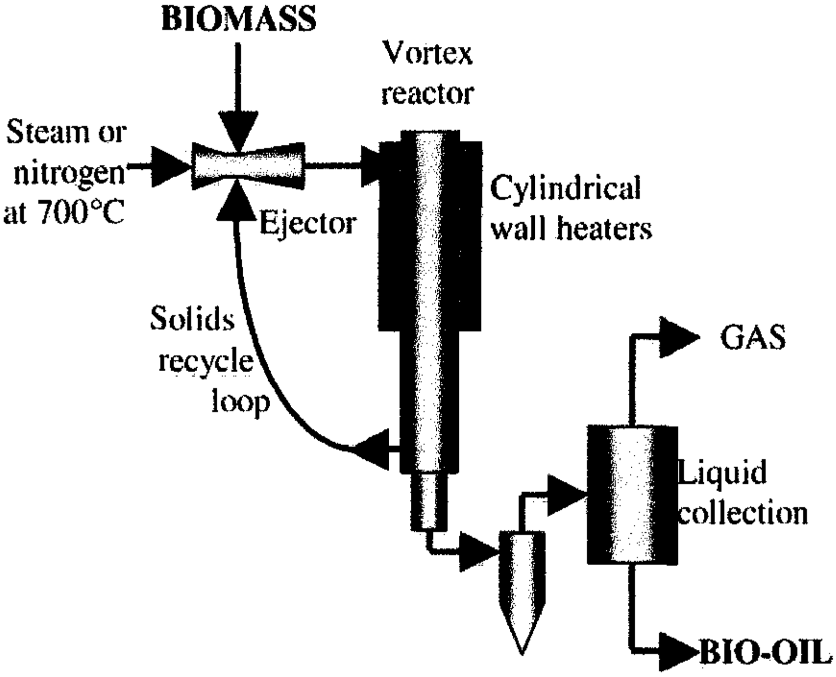

Figure 2.6: NREL Vortex Ablative Reactor

2.3.5 Bubbling fluid beds

Bubbling fluid beds reactors are the most chosen technologies for further development due to the fact that it is easy to construct and operate while in the other hand, it produce good results. 250 kg/h plant has been built by Wellman in UK, while a 75 kg/h plant operated by Dynamotive in Canada. Typically, liquid yields of 70-75% from wood on dry feed basis can be obtained. The particle sizes of less than 2-3 mm required in order to achieve high biomass heating rates. The reactor provides good temperature control and has very efficient heat transfer to biomass particles due to high solids density.

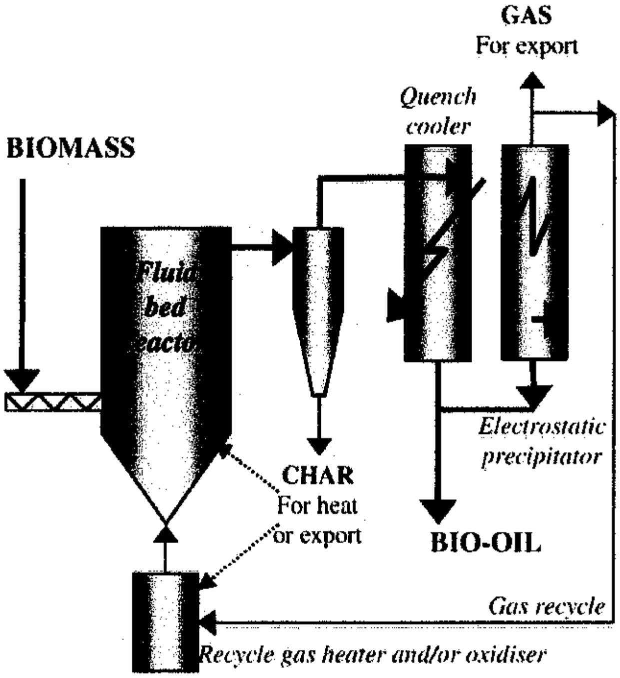

Figure 2.7: Bubbling fluid bed reactor

2.4 Gasification Of Biomass

Gasification of biomass has a long history and has been seen as an attractive alternative to produce power and heat, however, despite many achievements it can only be considered to be commercial for heat applications. Gasification is a process that converts biomass, into carbon monoxide and hydrogen by reacting the raw material at high temperatures with a controlled amount of oxygen and/or steam. Gasification relies on chemical processes at elevated temperatures >700°C, which distinguishes it from biological processes such as anaerobic digestion that produce biogas. Currently, four types of gasifiers are available for commercial use that is counter-current fixed bed; co-current fixed bed, fluidized bed and entrained flow. Among the gasification technology available, probably the most suitable option for processing biomass would be small scale downdraft gasifier using air as gasifying agent, in order to obtain electricity.

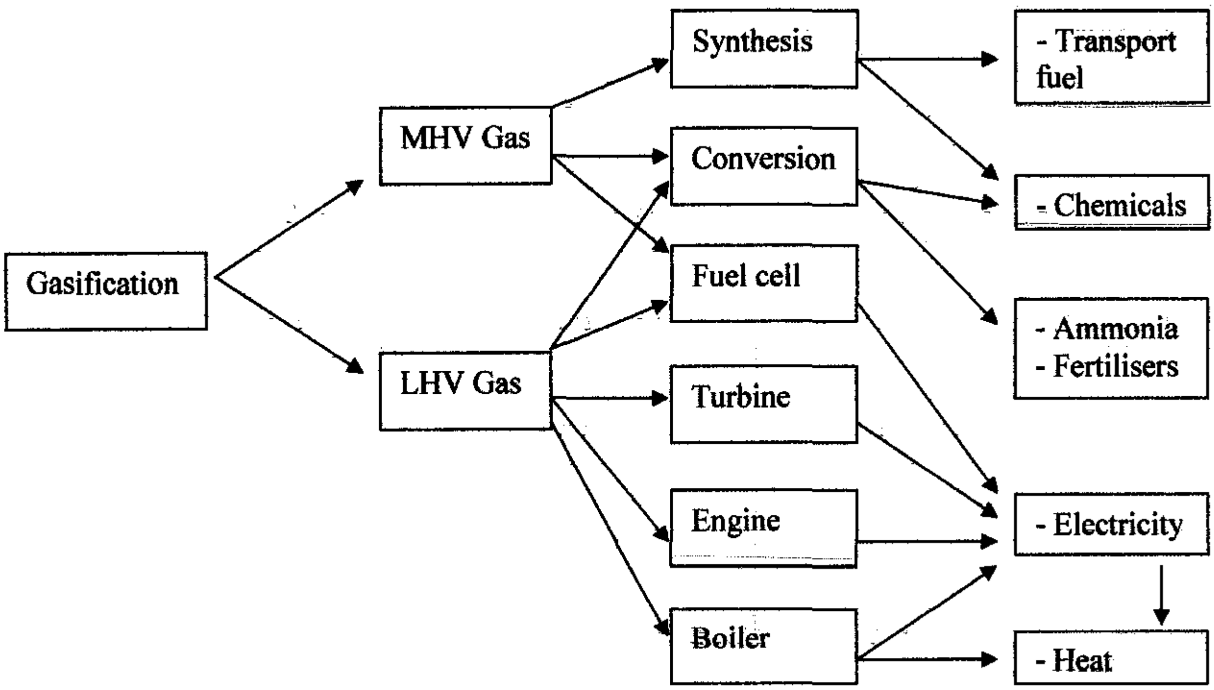

Figure 2.8: Product of Biomass Gasification

2.5 General Process of Gasification of Biomass

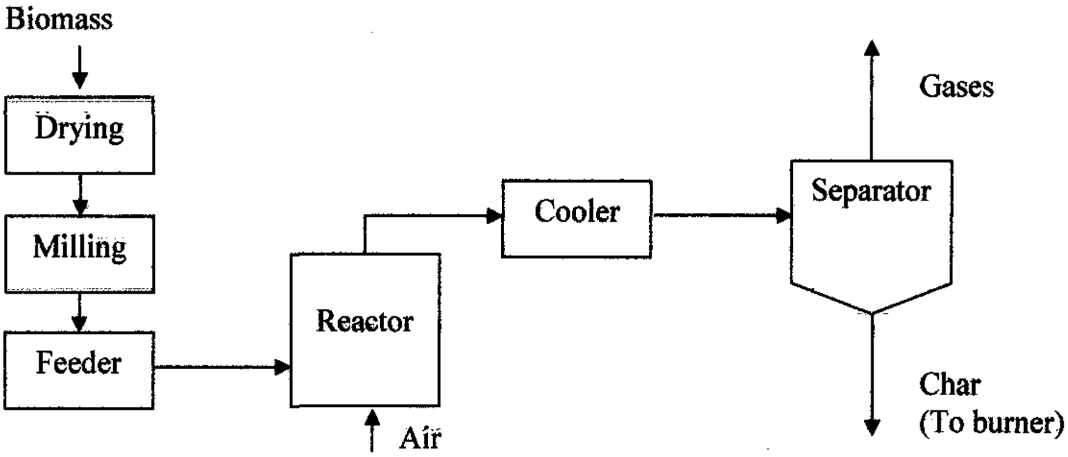

Figure 2.9 Block Flow Diagram for a Gasification Process

The block flow diagram of gasification process is shown in figure above. The process is similar to the pyrolysis, where the biomass will be undergone pre-treatment before the feed are supplied to the gasifier reactor. Woody chips which contains 19.6 weight % of lignin, 58.8 weight % of cellulose and 21.4 weight % of hemicelluloses used for the pre-treatment of biomass gasification. It is reported that 47.2% carbon, 45.1% oxygen and 6.1% hydrogen contains in woody chips. The samples are grind or mill with the particle size specification of 0.2 cm to 0.4 cm. In gasification reaction, air will be supplied at specific ratio which will be enough to complete the reaction. The typical operating temperature is 850°C and can go as high as 1400°C. The yield from the reaction is of 80% gases and 20% char in which the char and gases will be used for the heating of the reactor and in some cases for the drying of the feed stocks.

2.6 Gasification Technologies

The earliest biomass gasification plant was dated back to early 1970 concurrently with the first oil crisis. Since then, the technologies developed slowly until the year of 1994. The increase in energy costs is the major factor of the renaissance of gasification technologies. Biomass gasification plants are now available from as little as 250 kW to over 100 MW. A recent survey of gasifier manufacturers found that 75% of gasifiers offered commercially were downdraft, 20% were fluid beds, 2.5% were updraft and 2.5% were other types.

2.6.1 Downdraft-fixed bed reactor

Downdraft fixed bed reactor have been developed by Biomass Engineering UK, Rural Energy UK, and Fluidyne. The gasification agent gas flows in co-current configuration with the fuel (downwards), hence the name "down draft gasifier". It is simple, reliable and proven for fuels that have a low content of fines (below 5 mm). The scale-up of the reactor is limited to about 500kg/h feed rate. One of the reason it is the most commercially used is because of the product which is cleaner gases of low tar and high carbon conversion.

2.6.2 Updraft-fixed bed reactor

The counter-current fixed bed or up-draft gasifier consists of a fixed bed of carbonaceous fuel through which the gasification agent flows in counter-current configuration. It has been developed commercially by Wellman, Volund Denmark and Bioneer Inc, Korea. The scale-up of the reactor is limited to around 4 dry tonne/h feed rate. The downside of the technologies is that high levels of tars in the product in addition to the dirty gases compared to the downdraft gasifier.

2.6.3 Circulating Fluid Bed

The reactor has large minimum size viability and can operate at above around 15 t/h dry feed rate. In-bed catalytic processing is not as easy as bubbling fluid bed. Lurgi TPS and Foster Wheeler are some of the companies that have been used these technologies.

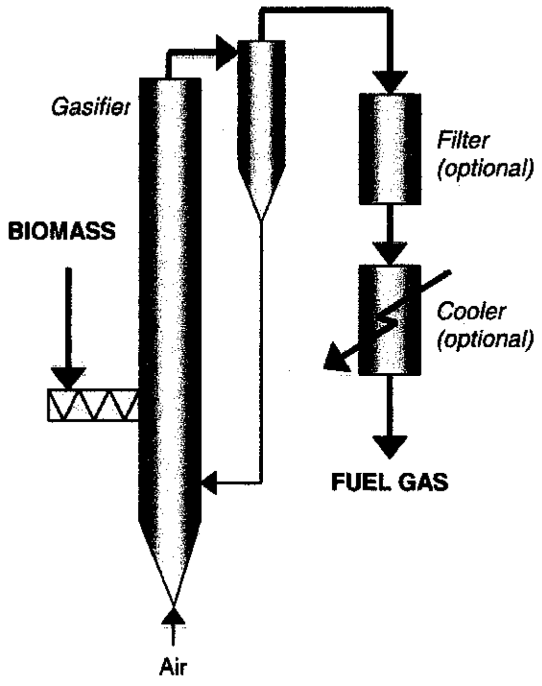

Figure 2.10: Circulating Fluid Bed Gasifier

2.6.4 Bubbling Fluid Bed

The reactor features good temperature control and high reaction rates. The scale-up potential is about 10-15 dry t/h and the product gas contains moderate tar level. In addition, the bed can be added with tar cracking catalyst. It has been commercially developed by Dinamec, Carbona and EPI Canada.

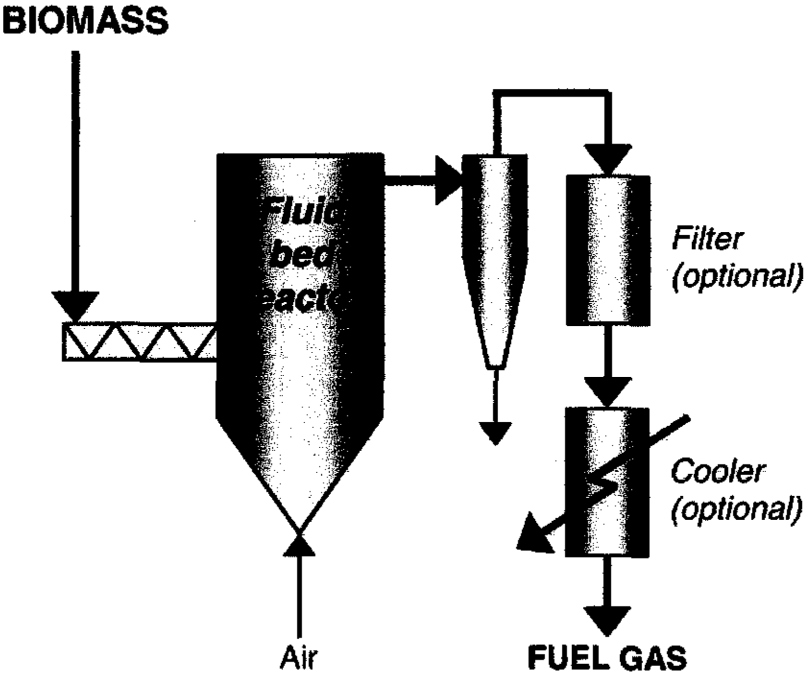

Figure 2.11: Bubbling Fluid Bed Gasifier

CHAPTER 3

METHODOLOGY

3.1 Project Flow Chart

Investigations of the pyrolysis and gasification process of biomass are to be done. A thorough search will be made through the internet and from the libraries to collect all available information on the both of thermal processing of biomass. The collections of technical details regarding various pyrolysis and gasification technologies in the world are essential to obtain datasheet of both processes. Material balances analysis will be carried from the datasheet obtain. The results of the analysis will be used in the modeling and intergration of the process.

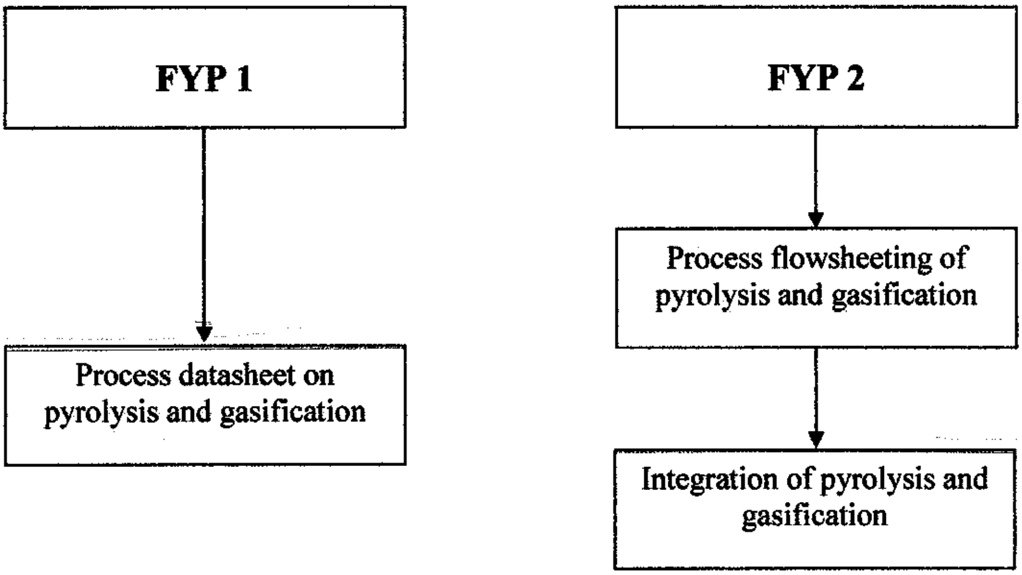

Figure 3.1: Project Flow Chart

3.2 Process Datasheet on Pyrolysis and Gasification

Each pyrolysis and gasification technologies gives different yields. The yields also vary along with the difference operating parameters and the type of biomass used. The data obtained from each technology are collected and the summary for both pyrolysis and gasification are summarized.

3.3 Process Flowsheeting of Pyrolysis and Gasification

From the summarized data being done before, a simple process flowsheet is to be developed for both pyrolysis and gasification process. The process flowsheet starts from biomass pre-treatment followed by gasification or pyrolysis process before the end product is obtained. Each process such as drying and cooling are represented in block diagram with generalized material balance calculation so that a feasible integration can be achieved.

3.4 Integration of Pyrolysis and Gasification

The final stage is the integration of the process. There are many ways that both processes can be integrated; hence it is required to verify the feasibility of the integration. In general, biomass undergone pyrolysis and the end product (char) will be the feed for the gasification process.

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 Yields

4.1.1 Pyrolysis

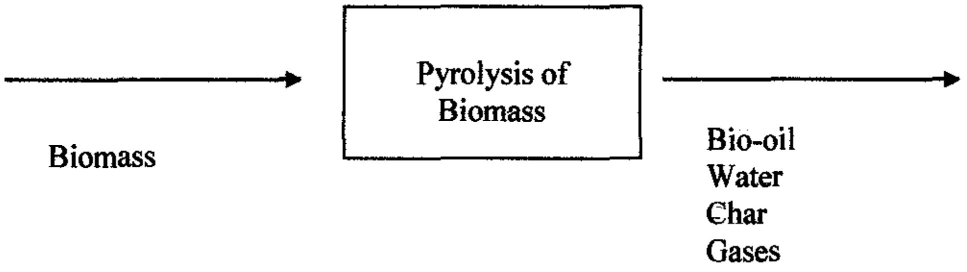

Figure 4.1: Pyrolysis of Biomass

From figure 4.1above, biomass undergone pyrolysis will convert to liquid (bio-oil and water), gases and char. Four different technologies are chosen in obtaining the product data for pyrolysis. First is the fast pyrolysis process which uses the entrained flow reactor. Ensyn which uses the circulating fluid bed reactor gives yield of approximately 0.40 of bio-oil per biomass. The other two technologies are vortex ablative reactor by SERI and vacuum furnace reactor by Universtiy of Laval, Quebec, Canada. The yield of different pyrolysis technologies are shown table 4.1

Table 4.1: Yield of Different Pyrolysis Technologies

	Material	GTI	Ensyn	Laval	SERI	Range
Input(kg)	Biomass	1	1	1	1	1
Output(kg)	Liquid(Bio-Oil)	0.21	0.40	0.59	0.66	0.21-0.66
	Water	0.26	0.25	0.26	0.10	0.10-0.26
	Char	0.21	0.10	0.15	0.14	0.10-0.21
	Gas	0.32	0.25	-	0.10	0.10-0.32

Table 4.2: Average Yield of Pyrolysis

Output	Yield
Liquid (Bio-Oil)	0.60 kg bio-oil/1 kg of Biomass
Water	0.10 kg of water/1 kg of Biomass
Char	0.10 kg of char/1 kg of Biomass
Gas	0.20 kg of gas/1 kg of Biomass

Table 4.3: Weight Percentage and Phase of Pyrolysis

Input	Output	Weight Percent (%)	Phase
1 kg of Biomass	Liquid(Bio-Oil)	60.0%	Liquid
	Water	10.0%	Liquid
	Char	10.0%	Solid
	Gas	20.0%	Gas

From table 4.3, in general, for each 1 kg of biomass undergone pyrolysis reaction, it will yields about 70 wt% of liquids, 10 wt% of solids and 20% of gases. The gases mainly consist of carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2) and methane (CH_4). Solids (char) and gases are recovered and combusted in order to supply the heating required in the reactor.

4.1.2 Gasification

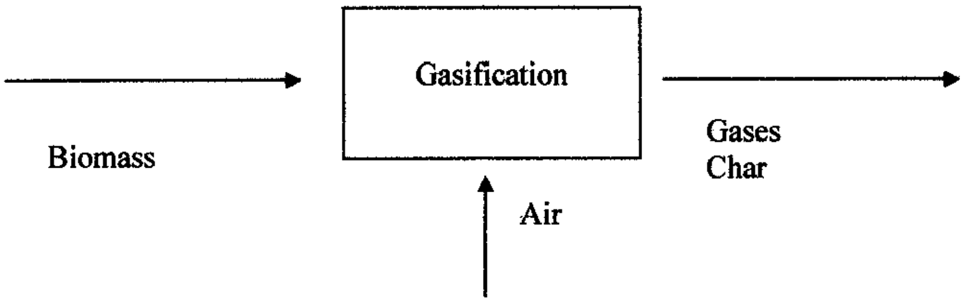

Figure 4.2: Gasification of Biomass

For gasification process, biomass is converted to mixture of gases and char by either partial oxidation or by steam/pyrolytic gasification. The product gases contain carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2) and methane (CH_4) by either partial oxidation or by steam/pyrolytic gasification. Two different technologies synthetic natural gas production by Energy research Center of Netherlands (ECN) and gasification by BGL are being chosen for the general mass balances of gasification process. Summarize of yields for both technologies are shown in table 4.4.

Table 4.4: Yield of Different Gasification Technologies

	Material	ECN	BGL	Range
Input(kg)	Biomass	1	1	1
	Air	4	4	4
Output(kg)	Gases	0.80	0.76	0.76-0.80
	Char	0.20	0.24	0.20-.024

Table 4.5: Average Yield of Gasification

Output	Yield
Gases	0.80 kg gases/1 kg of Biomass
Char	0.20 kg of char/1 kg of Biomass

Table 4.6: Weight Percentage and Phase of Gasification

Input	Output	Weight Percent (%)	Phase
1 kg of Biomass	Gases	80%	Gas
	Char	20%	Solid

Gasification of biomass generally will yields 80 weight % of gases and 20 weight % of char. SNG product gases contains 27 volume % of H_2 , 26 volume % CO_2, 16 volume % of CH_4 and 16 volume % of CO. For BGL gasifier, the product gas components are 30.8 volume % of H_2, 4.9 volume % CO_2, 6.2 volume % of CH_4, 7.2 volume % of CO, 0.4 volume % of other hydrocarbons and 0.5 volume % of non combustibles gases.

4.2 Process Flow Sheeting

4 .2 .1 Pyrolysis

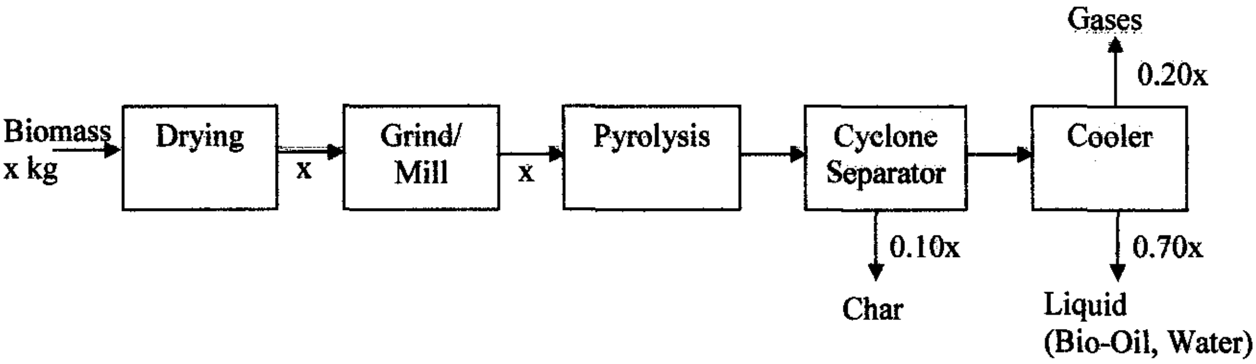

Figure 4.3: Process Flowsheet for Pyrolysis

Process flowsheet for pyrolysis are shown in figure 4.3in which biomass will undergoes pretreatment before the pyrolysis reaction takes place. In pretreatment, biomass will be dried and followed by grinding or milling. The particle size of biomass is in the range of 0.1 to 0.5 cm. The pyrolysis reaction takes place at about 480 ^{0}C to 500 ^{0}C in which it will yield char, liquid and gases. The char that are recovered at the cyclone separator will be burned to supply the heat required for heating the reactor. Yield from the reaction are shown in table 4.2.

4.2.2 Gasification

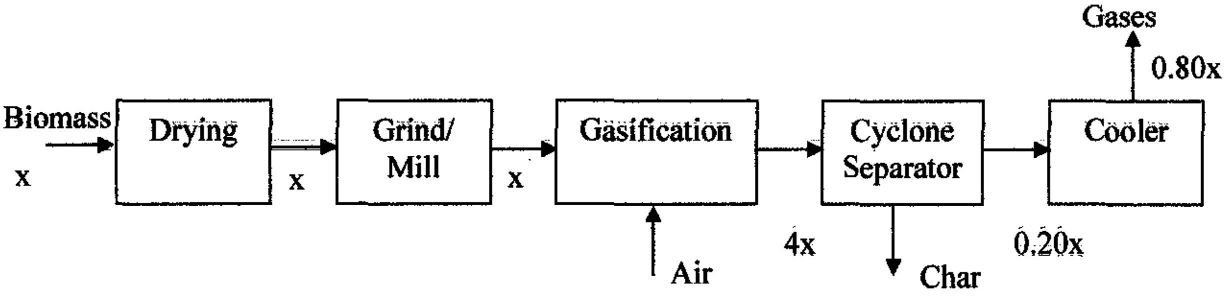

Figure 4.4: Process Flowsheet for Gasification

In gasification, biomass particle size must be in the range of 0.2 to 0.3 cm. The pretreatment of gasification are similar to the pyrolysis pretreatment in which the biomass will be dried and grind before undergoes gasification reaction. The reaction takes place at about 1200 ^{0}C to 1400 ^{0}C. For each 1 kg of biomass, 4 kg of air will be supplied in order for the reaction to complete. The reaction will approximately yields 80 % of gases in which the gases consisting of H_2, CO, CO_2, and CH_4. Yield from the reaction are shown in table 4.5.

4.3 Integration of Pyrolysis and Gasification

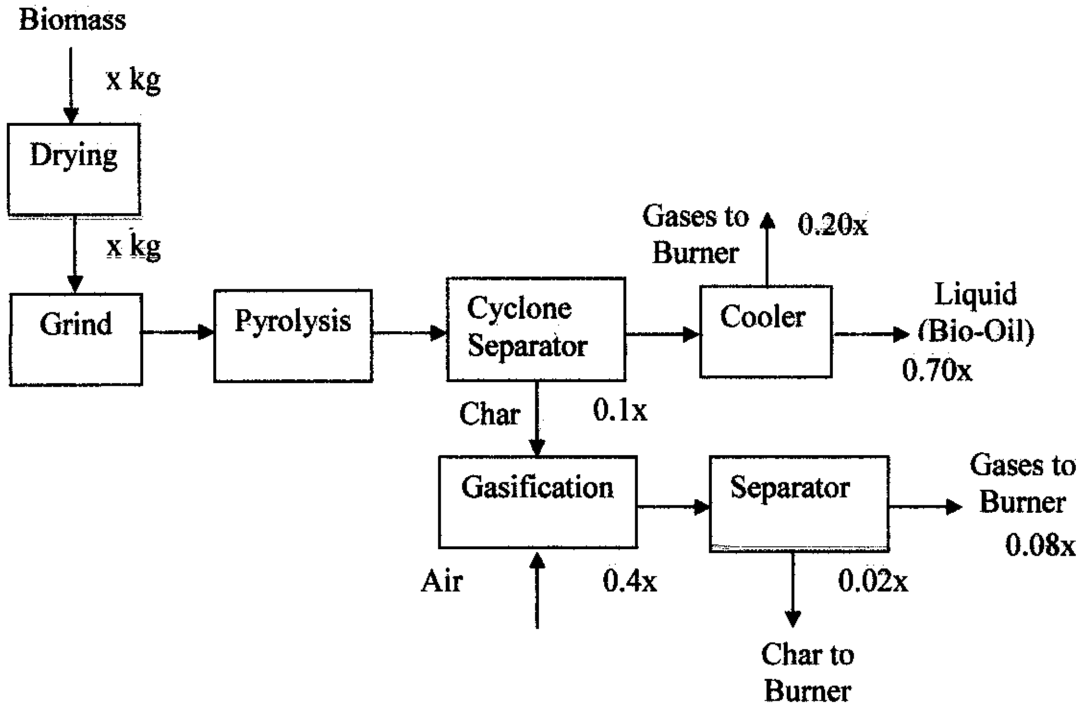

Figure 4.5: Integration of Pyrolysis and Gasification of Biomass

From pyrolysis and gasification process flow sheeting, the integration of both processes can be done. The integration sequence is that the biomass undergone pyrolysis followed by gasification. 1 kg of biomass which underwent pre-treatment process is feed into the pyrolysis reactor. The product of the reaction is 0.70 kg of bio-oil/kg of biomass, 0.20 kg of gases/kg of biomass and 0.10 kg of char/kg of biomass. The process continued with separation of char from the product of pyrolysis. Char will be used as feed to the gasification reaction. Gases and liquid product will be cooled in which the gases sent to burner for use of heating requirement by the process. The liquid which contains 60% of bio-oil and 10% of water will be collected as final product. The process continued with char being feed to the gasifier whereas specific ratio of air entered to the reactor in order to complete the reaction. This will result in 0.02 kg of char/kg of biomass and 0.08 kg of gases/kg of biomass being produced. Both gases and char will be used for heating purposes.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Biomass is one of the renewable energy sources have become more prominent in contributing to the energy demand. Biomass can be processed through three process; bio-chemical, thermal and physical process. Thermal processing of biomass which is pyrolysis and gasification has potential in the fuel production. The datasheet that have been developed can be used for the integration of pyrolysis and gasification can be done.

Both processes undergo similar process flow such as drying, grinding/milling and separation. Different type of pyrolysis and gasification technologies will give varies the yields. Operating conditions and different type of biomass also contribute to the production of fuel. The result shows that the integration of both processes can be done.

5.2 Recommendation

Simulation

One of the improvements that can be made for the feasibility of this project is to simulate using iCON or HYSIS for the process flow that has been developed. This is step in which to verify datasheet of all the process flow.

Economic analysis and optimization

Economic analysis of the integration can be evaluated before any optimization can be done. The next step need to be done is the optimization of the integration of the process. The optimization will finally give shows the real potential of biomass in order to produce not only fuel, but also fulfilled the increasing demand of energy consumption.

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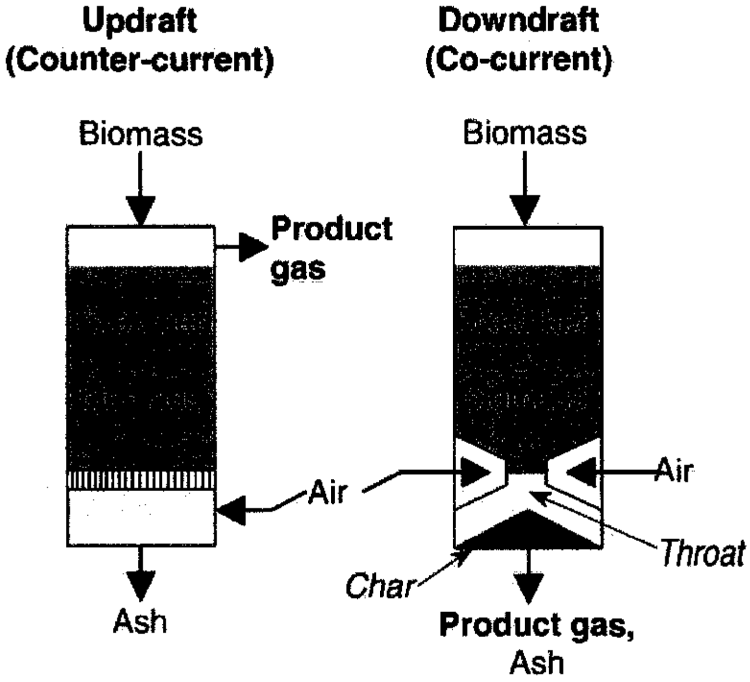
APPENDIX 1: DIAGRAM OF UPDRAFT AND DOWNGRAFT FIXED BED GASIFIER



APPENDIX 2: BIO-SYNTHETIC GASIFICATION BY ECN