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American-Eurasian Journal of Sustainable Agriculture
ISSN: 1995-0748

JOURNAL home page: http://www.aensiweb.com/aejsa.html 2014 Special; 8(7): pages 69-74.

Published Online 2014 February 30. **Research Article**

A Review of Biomass Gasification Technology to produce Syngas

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Received: 25 June 2014; **Received**: 8July 2014; **Accepted**: 10 August May 2014; **Available online:** 30 August 2014

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ABSTRACT

This paper reviewed various gasification technologies to produce syngas derived from biomass. Several studies from previous researchers have been summarized to discussed the effect on the efficiency, operability and the yield of the gasifier system of several parameter including temperature, gasifying agent, biomass species, particle size, heating rate, operating pressure, equivalence ratio, catalyst addition and reactor configuration. Recent gasifier technology development including moving bed (or fixed bed), fluid bed, and entrained flow system is critically reviewed. Finally, comparison between those gasifier types will be described based on their typical process condition.

Keywords: Syngas, biomass, gasification, fixed bed, fluidized bed, entrained flow, transport reactor;

INTRODUCTION

Synthesis gas (or syngas) is touted as one of the promising alternative energy due to its environmentally clean fuel characteristic and ability to reduce greenhouse gas effect [1]. Syngas can be directly consumed as gaseous fuel to produce electricity or heat and also a key intermediary in the chemical industry to produce methanol, dimethyl ether (DME), and methyl tert-butyl ether (MTBE) for liquid transportation fuel [2]. There are many types of fuel source or feedstock to produce syngas. It can be obtained from gasification of solid feedstock such as biomass, coal, refinery residual, organic waste and municipal waste [3][4]. Among all of the sources, biomass offers considerable opportunity of major renewable, sustainable and environmental-friendly energy sources [5].

Through energy thermochemical conversion, biomass can be used through three different processes: gasification, pyrolysis and direct combustion [6]. From the processes, biomass gasification is a potential method to provide clean gaseous fuel for combustion in boiler and in internal combustion engines [7, 8]. Fig. 1 shows a generic gasification process from which syngas is produced. In actual condition, unwanted by-products such as tars will be produce by the gasification conversion process [9]. Tars consist of a complex mixture of hydrocarbon materials. Tars need to be removed or further processed, else it will condense downstream of the equipment [10, 11]. Impurities that are contained within the solid feedstock are compounds of sulfur, nitrogen, chlorine. They need to be removed from the syngas produced. [12]. Additionally, solid ash residue is inorganic and noncombustible hence be separated [13, 14].

Gasification method for biomass:

Gasification is the conversion of biomass, or any solid fuel, into an energetic syngas through partial oxidation at elevated temperatures [15, 16]. Gasification process is conducted by heat generated from carbon oxidant to conserve the reaction of gasification [16]. Gasification agent or oxidant (air or oxygen) will be added to solid fuel and produce

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gasify fuel [16, 17]. Some of the gasification reactions involve the participation of water or steam as shown in figure 5 [18, 19]. In addition, water or steam will be used to control reaction temperature [20]. Studies on the development of gasification have long been carried out by many researchers to improve the efficiency, operability and the yield of the system. In general, the product yields and the composition of gases are dependent on several parameters including temperature, gasifying agent, biomass species, particle size, heating rate, operating pressure, equivalence ratio, catalyst addition and reactor configuration [21].

increase syngas yield and reduce formation of tar as well [23, 24]. Reactor type is also one of the main factors in determining yield. Table 1 summarizes syngas production from biomass gasification from palm feedstock.

The main gasifier reactor types are moving bed (or fixed bed), fluid bed, and entrained flow system. Moving bed gasifier can be arranged in updraft (countercurrent) arrangements where the supplied gasification agent such as oxygen and steam enters the reactor from the bottom, while the carbonaceous biomass enters from the top. Conversely for down draft (co-current) arrangements, the feedstock and gasification agents enter from the top of the reactor [32, 33, 34]. Fig. 2 (a) shows the general configuration of an up draft moving bed gasifier.

Fluidize bed can be categorized into three different types: bubbling bed, circulating fluid bed and transport reactor [35,36]. Researchers commonly use fluidized bed gasifiers with operating temperature below 1000^{o}C and feedstock size of not more than 50 mm due to their low cost operation and simple construction [23, 37-40]. Fig. 2 (b-d) shows the different type of fluidize bed gasifiers. They are distinguished by the bulk velocity of gas moving in the bed. Bubbling bed is characterized by discrete bubbles of gas, much like a boiling fluid which move at relatively low velocity (less than 5 m/s) [32-34]. Circulating fluid bed has greater fluidization gas velocity at 5 to 8 m/s. It also entrains smaller particles, which are converted to syngas above the bed or separated in a cyclone for return to the bed (circulating process occur). Transport reactor requires high gas velocity at around 15 m/s [20, 32]. This process involves the separation of particulate matter from the gas. They are then collected in a standpipe before being entrained again in the riser reactor for another cycle around the reactor [20].

Entrained flow gasifier is designed to operate at temperatures high enough to melt the coal ash, usually above 1250^{o}C. This is achieved by using more oxygen to achieve higher temperatures in the gasifier [32]. Fig. 2 (e) shows the entrained flow gasifier process.

Comparison of various gasifier types:

Type of feedstock and reactor are greatly influence the quality and quantity of syngas produced from gasification. Prominent features for different type of gasifiers are summarized in table 2. Table 2 indicates that the fixed bed gasifier requires maximum residence time and produces maximum content of CO_2 in the syngas [41]. The highest residence time means the production rate of syngas per unit volume of gasifier is at the least under the same feeding rate [20, 41]. This gasifier is less suitable for the production of hydrogen and chemicals as well since the CO_2 content is high. Fixed bed gasifier can handle only solid feedstocks. However, fixed bed gasifier applicable for highly active The use of catalyst feedstocks like wood, low grade coal etc., containing high ash [33]. Fixed bed is most efficient in terms of cold gas efficiency (ratio of fuel heat content to the syngas heat content at ambient conditions and is a measure of how efficiently fuel energy is converted to syngas energy) but has the disadvantage that some of the syngas energy is produced in tars [20]. Syngas properties and operating conditions also vary upon the gasifier agent (such as air blown and oxygen blown gasifier) [20, 41].

Table 2 show a slight difference between fluidized bed and entrained bed gasifiers for the compositions of syngas. Some properties of fluidized bed gasifiers like O2/feed ratio are greater compared to entrained bed gasifier [32, 36]. However, entrained bed need a very short residence time thus giving high capacity of syngas production [35, 36]. Moreover, the combustion zone of entrained bed gasifier has maximum temperature make it suitable for the gasification of less active feedstock [35, 36]. The drawback of the higher temperature is the sensible energy in the product gas that needs to be recovered for efficient use of fuel [33]. The transport reactor gasifier possesses both properties of entrained bed and fluidized bed gasifier [36, 41]. It applicable for wide range of feedstock and produced syngas with wide range of downstream applications as well. However, the sulfur content of feedstocks should be low as direct desulfurization is used in the transport reactor gasifier [36, 41].

Conclusion:

i. Syngas is produced from the gasification process of biomass. In actual gasification condition, unwanted by-products such as tars will be produce and need to be removed or further processed, else it will condense downstream of the equipment.
ii. The use of catalyst such as dolomite, olivine and nickel-based inside the gasifier could help improving gas product quality, and yield. Moreover, increasing the parameter value such as steam to biomass (S/B) ratio, temperature, equivalent ratio, and biomass feed rate will increase syngas yield and reduce formation of tar as well. Reactor type is also one of the main factors in determining yield.
iii. The main gasifier reactor types are moving bed (or fixed bed), fluid bed, and entrained flow system.

iv. The fixed bed gasifier requires maximum residence time and produces maximum content of CO_2 in the syngas. However, it is most efficient in terms of cold gas efficiency.

v. Fluidized bed gasifiers properties for O2/feed ratio are greater compared to entrained bed gasifier. However, entrained bed need a very short residence time thus giving high capacity of syngas production.

vi. The transport reactor gasifier applicable for wide range of feedstock and produced syngas with wide range of downstream applications.

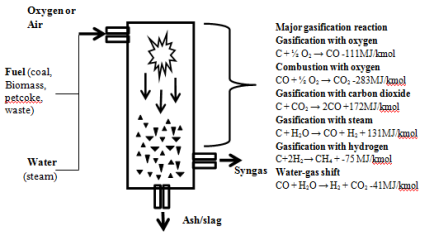

Fig. 1: Gasification Process and major reaction [20].

Table 1: Summary of several studies on biomass gasification to produce syngas.

Biomass type	catalyst	Rector type	Gasifying agent	Reaction temperature	Syngas Yield	Tar reduction	Ref.
Oil palm frond	-	Semi-batch reactor	steam	700 °C	Energy ratio was increased by 33% with an increase in reactor temperature from 600 to 1000°C.	-	[25]
Oil palm frond	-	downdraft fixed-bed	Atmospheric air	850 °C	CO composition increase from 5% to 28% with increasing temperature from 500 °C to 1200 °C	-	[26]
Oil palm frond	-	downdraft fixed-bed	Preheating air	985 °C	Preheating air improved the composition for all component (H2, CO and CH4)	-	[27]
Empty fruit bunch	-	Entrained flow	steam	900 °C	Obtaining hydrogen rich gas with steam agent (H_2O)	Tar yield was very low (<1.0wt.%)	[28]
Empty fruit bunch	-	Bubbling Fluidized bed	air	600 °C to 1050 °C	H2 content increase from7.3% to 12.4% with increasing temperature	-	[29]
Empty fruit bunch	Calcined dolomite and tri-metalic	Fluidized bed	Steam or air	800 °C to 900 °C	Highest hydrogen produced by steam gasification with tri-metalic catalyst as 58 (%v/v)	-	[30]
Palm kernel shell	-	Fluidized bed	steam	600 °C to 750 °C	H2 composition of 82.11 vol% is achieved at 675 °C	-	[31]

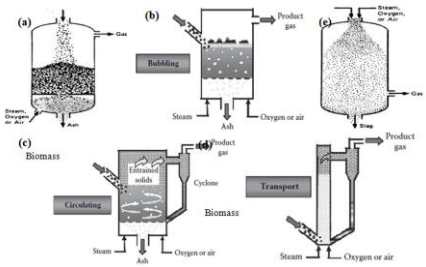

Fig. 2: (a) Moving bed gasifier (b-d) Fluidized bed (bubbling bed, circulating fluid bed and transport reactor) (e) Entrained flow gasifier [20, 36].

Table 2: Comparison of various gasifier types.

Gasifier	Typical process condition		Ref.	Remarks	Ref.
Fixed/moving bed	Combustion temp.	1300°C (slurry feed) and 1500-1800 °C (dry feed)	[41]	– Steam requirement is high	[41]
	Outlet temperature	425-650°C	[20]	– Syngas contains tar and phenolic compound	[33,35, 36]
	Feedstock size	5-50mm	[20]	– More loss of fine particles of feed preparation	[20,33]
	Preferred feedstock type	Handle biomass with high moisture for updraft and low moisture for downdraft	[33]		
	Residence time	15-30 min	[41]		
	Cold gas efficiency	84% (high)	[20,41]		
	O_2/feed	0.64 Nm^3/kg	[41]		
Fluidized bed	Combustion temp.	900-1200°C	[41]	– Moderate steam requirement	[41]
	Outlet temperature	600-1050°C	[20]	– Syngas does not contains tar and phenolic compound	[33,35, 36]
	Feedstock size	<5mm	[20]		
	Preferred feedstock type	Any biomass	[33]	– Reduced loss of fine	[41]
	Residence time	10-100sec	[41]		
	Cold gas efficiency	80.8(medium)	[20,41]		
	O_2/feed	0.37 Nm^3/kg	[41]		
Transport reactor	Combustion temp.	900-1200°C	[41]	– High throughput and conversion	[36,41]
	Outlet temperature	600-1050°C	[20]	– Not well proven	[36,41]
	Feedstock size	<50µm	[20]		
	Preferred feedstock type	Any biomass	[33]		
	Residence time	1-10sec	[41]		
	Cold gas efficiency	medium	[20,41]		
	O_2/feed	1.06 Nm^3/kg	[41]		
Entrained flow	Combustion temp.	1500°C	[41]	– Moderate steam requirement	[41]
	Outlet temperature	1250-1600°C	[20]	– Syngas does not contains tar and phenolic compound	[33,35, 36]
	Feedstock size	<100microns	[20]		
	Preferred feedstock type	Any biomass	[33]	– In-situ sulfur removal and no fine loss	[20,33]
	Residence time	1-10sec	[41]		
	Cold gas efficiency	81(medium)	[20,41]		
	O_2/feed	0.37 Nm^3/kg	[41]		

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