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GASIFICATION TECHNOLOGY AND ITS FUTURE: A REVIEW

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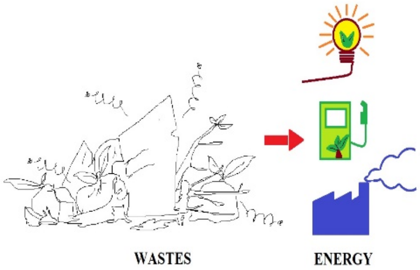
Graphical abstract



Abstract

Gasification technology has the potential to revolutionise the energy industry by providing a clean and efficient way to produce energy from a variety of raw materials. This technology have the ability to produce synthesis gas from raw materials based on negative or low carbon values such as high sulphur fuel oil, petroleum coke, coal, domestic wastes, industrial and biomass wastes. The gas produced from the process is used to replace natural gas, to generate electricity, or as a basic raw material to produce chemicals and liquid fuels. Gasification is a process that uses heat, pressure, and steam to convert substances directly into gases, such as carbon monoxide and hydrogen. Gasification technology has differences in various aspects but there are four engineering factors that are the core of the gasification system such as atmospheric gasification reactor (level of oxygen or air content), internal and external heating, reactor design and operating temperature. The raw material used, prepared and introduced in dry form and small particles to the reactor chamber are called gasification. Raw materials experience heat, pressure and an environment rich or low in oxygen content in the gasification. There are three main products from the gasification process which are hydrocarbon gas (also called syngas), hydrocarbon liquid (oil) and coal (carbon black and ash). Syngas can be used as a fuel to produce electricity or steam or as a based material for many types of chemicals. When mixed with air, syngas can be used in petrol or diesel engines as a vehicle fuel with minor modifications to the engine. Gasification technology has several advantages over traditional fossil fuel-based energy production methods. It is able to produce energy from a wide range of raw materials, including waste, which reduces the need for landfills and incineration. Additionally, gasification can reduce greenhouse gas emissions by producing energy from low or negative carbon value raw materials.

Keywords: Syngas, Gasification Technology, Clean Energy, Environmentally Friendly, Negative Carbon Value

1.0 INTRODUCTION

Gasification is a thermochemical process. It occurs when solid carbonaceous fuels are converted into gaseous fuels at a high temperature. The process occurs in partial oxidation using mediums such as oxygen, air, or steam. Carbon Monoxide (CO), Hydrogen (H_2), Nitrogen (N_2), Carbon Dioxide (CO_2), Methane (CH_4), water vapour (H_2O), contaminants and hydrocarbons are then generated, more commonly known as synthesis gas (syngas). Partial or total transformation of solid fuel to gas through devolatilisation and oxidation are considered important aspects of this method [1]. Five thermal sequences occur during gasification, which are: drying, pyrolysis, combustion, cracking, and reduction, as illustrated in Figure 1. In addition, tar is also produced as a by product, which can be further broken down into smaller molecules through the help of an extended method. Equation 1 shows the chemical reaction during gasification [2].

$$\text{Biomass} \rightarrow \text{CO} + \text{H}_2 + \text{CO}_2 + \text{CH}_4 + \text{H}_2\text{O} + \text{H}_2\text{S} + \text{NH}_3 + \text{C}_x\text{H}_y + \text{Tar} + \text{Char} \qquad (1)$$

The initial stage of gasification is known as drying, whereby biomass moisture removal occurs. Drying transpires at approximately 100°C and 150°C. Additionally, moisture is removed without the material decomposing. Syngas quality and gasification performance may be enhanced when 5% - 35% of the moisture is removed from the feedstock [3]. Drying is considered a vital process to ensure that no water vapour is caught in the container while storing the syngas.

Pyrolysis is the next step in gasification. Biomass is thermally decomposed without the presence of oxygen. Vaporisation of volatile components within a solid carbonaceous material in the presence of heat, producing ash and char residue. Both hydrogen and oxygen exist within the raw material, which is a precursor to various gas compositions produced during pyrolysis. The aforementioned steps drive the formation of light gases such as CO, H_2, CH_4, CO_2, NH_3, and H_2O as well as tar (condensed hydrocarbon vapour) and char (residue produced after the decomposition process). The chemical contents and properties released during decomposition are affected by various parameters, such as the feedstock's pre-gasification composition and structure of the residue, as along with the temperature, pressure, and heating rate imposed by a specific type of reactor [1,4].

Combustion is the exothermal process which is one of the five-gasification process mentioned earlier. It occurs at temperatures between 800°C until 1200°C. The heat used during the drying, pyrolysis and reduction process is generated directly or indirectly from this combustion process through heat exchange inside the gasifier. Fuel for combustion might be from utilising tar gases or char obtained from pyrolysis, depending on the reactor used. In a downdraft gasifier, heat generated by the combustion process is used to reduce CO_2 and H_2O throughout the reduction process. As a result, gas with reduced tar concentrations will be produced.

Cracking is the procedure of converting huge and complicated molecules for instance tar into light gases by exposing them to high temperatures. Cracking is a fundamental process in the production of clean gases for internal combustion engines. Clean gases is considered important as the condensed tar gas will develop into sticky tar and rapidly damage the engine components. Furthermore, cracking may warrant appropriate combustion as complete combustion takes place in the presence of combustible gases combined with oxygen.

A direct reversal combustion process that occurs at temperatures between 650°C until 900°C is known as reduction. This process eliminates oxygen from feedstock at high temperatures to produce combustible gases. The temperature of the gas will fall as heat is absorbed throughout the reduction process. The thermochemical degradation of the lignocellulosic component occurs first in the reduction process of biomass material. This procedure will yield char and volatile substances. In complete combustion, all carbon elements from feedstock will be converted to carbon monoxide, and other elements will be evaporated. The residue consists of some char (unburned carbon) and ash [5].

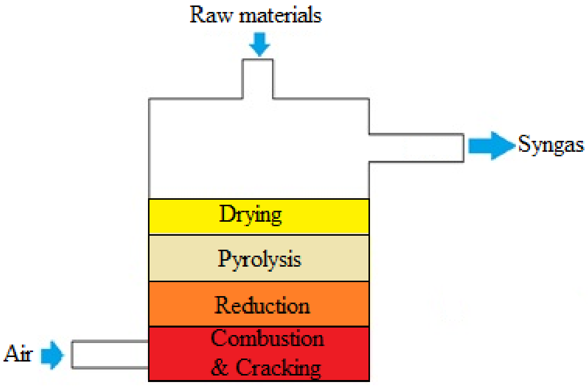


Figure 1 Gasification Process using an Updraft Gasifier [6]

2.0 GASIFICATION TECHNOLOGY

For decades, scientists and industries have investigated gasification technology. Its popularity seemed to fluctuate due to the feasibility of other technologies. Numerous technologies are developed to process various fuels through distinctive and sophisticated techniques to meet the latest requirements. Gasification system performance is frequently evaluated in terms of annual operating time. Currently, the performance of gasification systems is evaluated based on their capacity to operate for around 8,000 hours per year. This assessment is undertaken to observe the ability of the gasification system to run continuously. However, recently, the performance goal has been reduced to achieving continuous operation hours of roughly 8000 hours per year over a few years. The progress of this system has been slower than projected, but its capability has been seen to reach the market, particularly for small and medium-sized applications. In general, gasification technology can be split into three classes:

- Small scale: fixed bed gasifier and staged process for combined heat and power (CHP) production.
- Medium scale: fluidised bed gasifier and dual fluidised bed process for CHP and syngas production (further methanation process and injection into the gas grid).
- Large-scale: gas production in larger circulating fluidised bed reactors or entrained-flow gasifiers, co-gasification of biomass raw materials with fossil fuels.

Each gasification technology has its own level of suitability and range. For example, fluidised bed technology has a range of more than 10 MW, whereas the entrained bed gasifier has a range of more than 100 MW [7, 5].

2.1 Types of Gasifiers

Several types of gasification reactors are suitable for use with biomass, such as fixed bed and fluidised bed gasifiers. Its suitability may be based on the relationship between the movement of solids and gases as well as the bulk density of the feedstock in the reactor. Other gasifiers that are available today include downdraft fixed bed gasifier, updraft fixed bed gasifier, crossdraft fixed bed gasifier, bubbling fluidised bed gasifier and circulating or fast fluidised bed gasifier. There are also entrained flow bed gasifiers and dual fluidised bed gasifiers available on the market [8].

2.1.1 Fixed-Bed Gasifier

The feedstocks within a fixed bed gasifier is laid out on an iron grate, which serves as a plug for the incoming fuel. This kind of gasifier is typically ideal for operations on a small scale, with capacities ranging anywhere from 10 kW to 10 MW. Table 1 shows the three types of fixed bed gasifier technologies and their differences from each other.

Table 1 Comparison between three types of fixed-bed gasifiers [9]

Parameter	Type of Gasifier		
	Updraft	**Downdraft**	**Cross draft**
Moisture content, wet based (%)	<60	<25	10-20
Dry Ash based (%)	<25	<6	0.5-1.0
Ash Melting Temperature (°C)	>1000	>1250	-
Fuel Size (mm)	5-100	10-300	5-20
Range of Use (MW)	2-30	1-2	-
Exit Gas Temperature (°C)	200-400	700	1250
Tar (g/Nm^3)	30-150	4.5-5.0	4.0-4.5
Low Heating Value (MJ/m^{3}N)	5-6	85-90	75-90
Efficiency (% Hot Gas)	90-95	3-4	2-3

2.1.1.1 Updraft Fixed Bed Gasifier

In this gasifier, raw materials and gasification agents, for instance air, oxygen, and steam, are moved in opposite directions. In general, the size of the feedstock ranges from 5 to 100 millimetres as mention in Table 1. During operation, the gasifier operates at a range of 0.15 to 2.45 MPa, while residence time ranges from 15 to 30 minutes [10]. By allowing a long combustion residence time, a full gasification reaction is achieved, resulting in a low product and efficiency [11].

The biggest disadvantage of gas production from updraft gasifier is tar formation at the highest level, approximately 10 to 20 percent or 30 to 150 g/Nm^3 by weight. This phenomenon would require concentrated post-cleaning. Oxygenated compounds and tar are produced from a gasification process with low range of temperature.

One of the advantages using this gasifier is low ash content as a result of higher temperature range at the bottom of the reactor during the release of ash. Despite the low ash content produced, this gasifier is known to produce gases with high tar content. Thus, this gasifier gas product is not suggested to applied in engine but is more suitable for thermal applications [12].

An updraft gasifier can accept various types of raw materials. Obernberger *et al.* [12] performed performance tests on sawdust and oil palm kernel shells and found that samples have an input heat energy of 28 kJ and 32 kJ, respectively; an input power of 7.8 kW and 8.79 kW; power output of 5.47kW and 6.15 kW and gasification efficiency of 93% and 67.4% respectively. The research shows that palm kernel shells and sawdust are appropriate raw materials for an updraft gasifier. Figure 1 above shows the updraft gasifier system during gasification.

2.1.1.2 Downdraft Fixed Bed Gasifier

A downdraft fixed-bed gasifier operates by injecting primary gasification air into the reactor's oxidation area or at the top of the reactor. Typically, these gasifiers are used for gasifying fuels with high volatility, such as wood and biomass [5]. Solids and vapours produced from the pyrolysis zone react at the gasifier throat with additional air that supports the gasification of the raw material at atmospheric pressure [13]. This gasification reaction occurs in the contraction region. Homogenous distribution of the gasification agent transpires in the oxidation zone, at a controlled temperature of around 1000° C.

The size of the raw material depends on the throat size. Raw materials that ranges between 10 to 300 mm (Table 1) is usually used for this particular gasifier. This size limits the flow of the material to 500 kg/hour or equivalent to approximately 500 kWe (kilowatt-electricity) [3]. This gasifier is unsuitable for large-scale plant implementation due to its overall and throat size [14]. Despite this barrier, a downdraft gasifier is suitable for biomass materials with high volatile matter content [15]. Raw materials used must be relatively dry, limited to a moisture content of 30% and low ash content (<1% by weight) [16]. Examples of raw materials with low moisture content include peanut shells, miscanthus, pine, rice husk and wheat straw [14, 17]. High volatile matter is found to vaporise faster and it can be burnt quickly. Furthermore, volatile matter that are highly responsive is significant for combustion applications.

The high temperature in the gasifier output section allows for low tar production of less than 5.0 g/Nm^3, as mention in Table 1 [16]. The low tar content of this gasifier makes it particularly suitable for small-scale electricity production, particularly through the help of an internal combustion engine [14]. Figure 2 shows a downdraft fixed bed gasifier system.

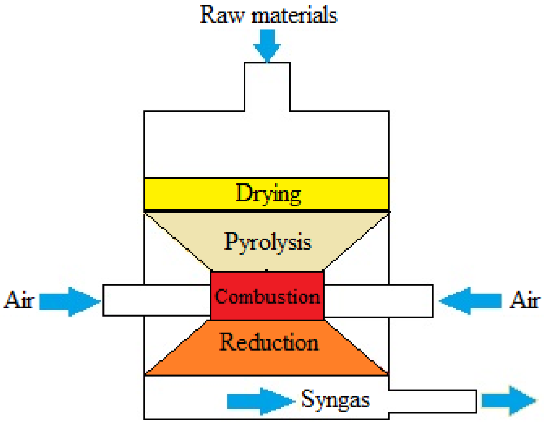


Figure 2 Downdraft Fixed Bed Gasifier [6]

2.1.1.3 Crossdraft Fixed Bed Gasifier

This gasifier as mention in Table 1 is alternatively known as a co-current fixed bed gasifier due to its fuel being introduced from above whilst air is introduced from the side. Compared to other fixed bed gasifiers, a cross-draft gasifier releases its syngas product on the opposite section of its air intake. Figure 3 shows this gasifier system. Air is presented into the reactor at high velocity to produce a hearth, with its temperatures exceeding 1500°C caused by char parts burning. The remaining char will go through the gasification process in the next zone. The heat released from combustion is forwarded to the pyrolysis zone, where the biomass is pyrolysed. These gasifiers are often used in small-scale units and are commonly present in typical reactor development because of their small combustion zone and fuel and ash insulating effects. Tar formation at range 4.0 t0 4.5 g/Nm^3 in a product gas of a crossdraft gasifier is low due to its high temperature [5].

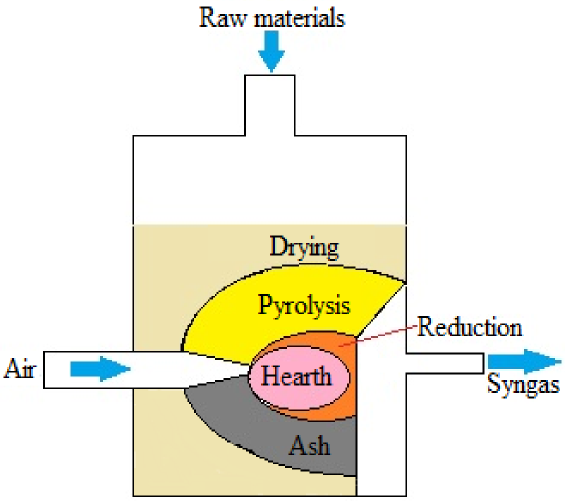


Figure 3 Crossdraft Fixed Bed Gasifier [6]

2.1.1.4 Swirl Fixed Bed Gasifier

The Swirl Fixed Bed Gasifier developments are the ability to generate mixing inside of reactor chamber. Which is radial and axial components are a must for the particle movement in the reactor chamber. The fixed bed gasifier with swirling flow can produce syngas directly from solid agriculture wastes without the need for carbonization process.

To assist the swirling flow, the air that enters from tangential pipe into reactor must be deflected along the swirling flow plenum chamber, to develop a swirling flow and uniform synergy between fuel particle and oxidising agents [18]. Swirling flow generated from gasifier plenum chamber, created a form of strong turbulent flow which helps to increase the temperature of the combustion in a short period of time. With high temperature yields around 1200˚C to 1400˚C in a short residence time will result in the thermal cracking of tar content in the produced gases. This process actually helps to remove tar contents from synthesis gas production. This finding was also acknowledged by Qin et al. [18], based on the experiment conducted, found that at 900 °C, the heat released is capable of cracking heavy tar. While complete tar removal occurs at high temperatures above 1100°C [19]. In addition, it was also stated that the thermal cracking method shown is also capable of boost high tar removal efficiency at 1200 °C with a shorter residence time [20].

Current fixed bed gasifier is usually designed with axial flow, whereby air is introduced into the reactor from a single inlet. Furthermore, the operation has high carbon conversion, long solid residence time, low ash carry over and low gas velocity. However, the swirl fixed bed gasifier has proven its capability of being able to process multi biomass waste and producing higher heating value (HHV) ranging from 17.3 MJ/kg to 22.3 MJ/kg. Gas velocity can be raised using elutriation along with higher vertical mixing rate than lateral mixing. [2, 3]. A swirl fixed bed gasifier comprises of cylindrical reactor, a gas cooling and cleaning system equipped with an ash removal unit along with a gas outlet.

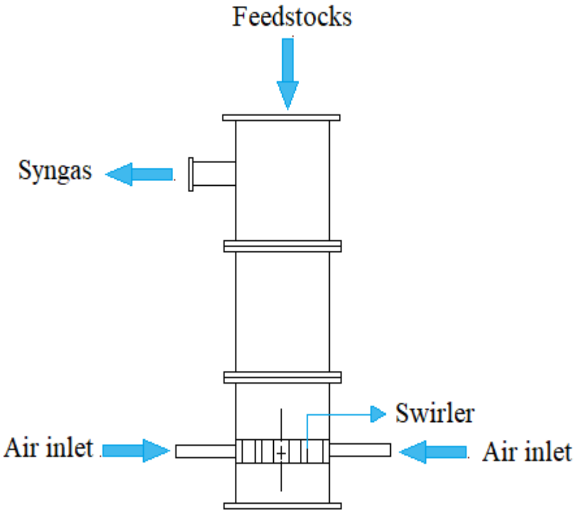


Figure 4 Swirl Fixed Bed Gasifier [21]

2.1.1.5 Twin Fire Gasifier

The twin fire gasifier (Figure 5) is a type of fixed bed gasifier, where it combines two types of bed: updraft and downdraft. The idea is to develop this gasifier based on the experience gathered from the pilot plant in Domsland (Germany) [22], where the advantages of combining updraft and downdraft gasifier is able generate the best and cleanest syngas. It consists of two reaction zones: upper and lower. Low-temperature carbonization, gas cracking and drying occur in the upper zone while permanent gasification of charcoal occurs in the lower zone with the presence of air as a contributor to a post-gasification of the remaining char. The temperature for synthesis gas production is around 460 to 520˚C and the whole process takes place at a pressure below -30 mbar [23]. The upper part of this gasifier refers to the downdraft method where the flow occurs in the same direction as gas products and raw materials, while the lower part refers to the updraft method in which gas products and raw materials flow in opposite directions. Ash formation in the reactor, which consists of high carbon content, is fed to the biomass boiler for post-combustion. Raw material is fed into the hopper using a pusher plate and sent to the rotary filter dryer using a screw conveyor. In this gasification unit, the raw materials used meet the fuel specifications in terms of size and water content. The boiler – heated air is used to dry the raw materials, while the outgoing air is recirculated into the boiler to remove odours and dust released from the dryer after combustion. Small raw material particles are then sieved and fed into the boiler to be used as additional fuel [24, 25].

At a temperature of around 650°C, the gas product is discharged from the reactor, the hot gas is cooled in the air preheater chamber of the gasifier, and then the temperature is further lowered using water until it reaches a temperature of 50°C. For the final purge gas, a wet electrostatic precipitator is installed. Afterwards the clean gas is compressed and cooled before being supplied to the equipment. Particles and tar filtered from the quench water are reintroduced into the boiler, along with the wet electrostatic precipitator residue for combustion purposes. Therefore, the residual CO and other combustible components released can help meet the desired emissions. The gas composition resulting from the use of this gasifier is very stable with an average value of 4.5–5.0 MJ/Nm³. Table 2 shows the composition of the gas produced using this type of gasification [24].

Table 2 Composition of raw gas [24]

Gas Composition	Volume (%)
Hydrogen	16 - 18
Carbon monoxide	17 - 20
Carbon dioxide	9 - 11
Methane	2 - 4
Nitrogen	Remaining vol%

Table 3 shows the comparison of pollutants found in raw gas and clean gas. The particle content after the gasification process is very low, and is suitable for direct application in gas engines. However, the tar content is still too high to use in equipment and it requires further reduction process.

Table 3 Pollutants in raw and clean gas [24]

Items	Raw Gas	Clean Gas

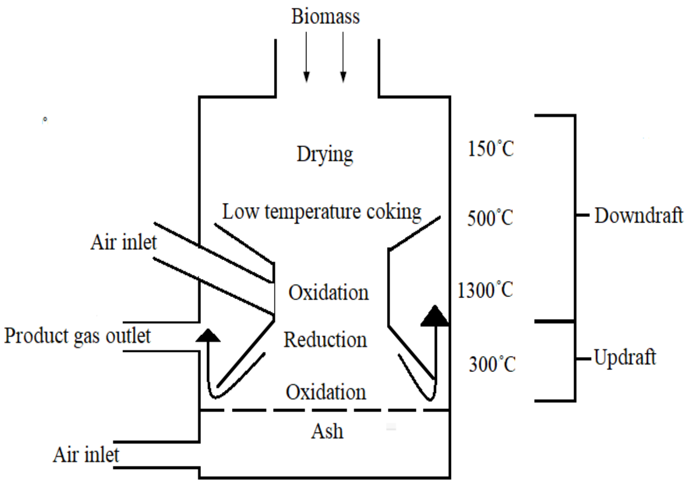


Figure 5 Twin Fire Gasifier [24]

Based on Table 2 it was found that wet electrostatic precipitator performance generates relatively good clean gas by producing a very low dust and tar content which is about 15–35 mg/Nm³.

Stable gas conditions and low pollutant content can provide good performance when gas products are used in equipment operation. In addition, this gasifier can achieve a cold gas efficiency of 66%. While the remaining 34% is converted to heat power in raw product gas.

2.1.2 Fluidized Bed Gasifier

A fluidized bed utilizes the fluidisation principle, which influences its configuration. Both fuel and inert bed acts as a fluid with the help high velocity fluidisation medium (gas). Frequently used fluidisation medium include: a mixture of steam, air or steam/oxygen. Silica sand is frequently used as bed material. Additional bulk solids, particularly those showing catalytic activity, for instance olivine sand and dolomite, are also used.

Fluidised bed gasifiers have many distinct characteristics such as high heat and mass transfer rates as along with good solid phase mixing, meaning that high reaction rates and temperatures are somewhat uniform within the bed.

Fluidised bed can be categorised into two types, depending on the fluidisation medium velocity: bubble fluidised bed gasifiers (BFB) and circulating fluidised bed gasifiers (CFB) [5].

2.1.2.1 Bubbling Fluidised Bed Gasifier

This gasifier is characterised by its relatively low (<5 m/s) distinctive gas bubble velocities. This particular gasifier is equipped with a container at the bottom of the reactor and a grate through which air flows. Finely ground biomass raw material is placed on a grate, which is then transferred into hot fluidised sand bed by recycling the gaseous product [26]. Ruiz *et al.* [27] stated that a regulated steam flow through the bed at 1.26 kg/h is able to produce a low fluidisation velocity of 0.18 m/s.

A strong solid-gas rotation can be produced through pairing a bubbling fluidised bed gasifier paired with a fluidised bed. This combination increases the movement of the reactor liquid to ensure homogeneous temperature conditions for the biomass reaction. Agglomeration may be avoided by maintaining the temperature between 700°C to 1000°C by controlling the air/biomass ratio due to the bed consisting mostly of ash [28, 29]. Using alumina as an alternative bed material may prevent ash from defluidization and soften [30].

The biomass in this gasifier is pyrolysed to produce char with high-temperature gas within the bed. The hot bed material acts to crack the char and gas compounds. The cracking process reduces the formation of tar. Therefore, the gas product produced will usually contain a low tar content of between 3 and 40 g/Nm^3 [31]. In addition, the cyclone acts as a separator of ash/char particles extracted from the flue gas. This cycle is followed by solids that re-enters the fluidised bed and create an internal solid circulation [31].

Arromdee et al. [32] gasified cotton stalk and hazelnut shell through a bubbling fluidised bed gasifier using steam and air as gasification agents. The findings indicate that hazelnut shells generate higher LHV syngas compared to cotton stalks. This is signified by the calorific value of hazelnut shells at 4493 kcal/kg, which is higher than the calorific value of cotton stalks at 3990 kcal/kg.

It appears that steam is more efficient as a gasification agent than air, as the LHV of hazelnut shells and cotton stalks actually increased by 44% and 84%, respectively. This can be explained by the increased production rate of H_2, which is enhanced by involving water (steam) in the water-gas process [32], which contributes to an increase in production rate.

The high inertial thermal properties of the bed material make the bubbling bed ideal for burning fuels with high moisture content, such as sewage as well as industrial sludge, sawdust and peat. This is the important part of driving off the substantial moisture before the combustion takes place. Figure 6 (a) illustrates a bubbling fluidised bed gasifier.

2.1.2.2 Circulating Fluidised Bed Gasifier

This kind of gasifier works using a method of volatile circulation (including hydrogen gas and coal) with a bed material derived from raw materials. Its circulation cycle is between the cyclone separator and the reaction chamber, displayed in Figure 6 (b). The remaining bed material and char re-enters the reactor whilst ash extraction occurs with the help of a cyclone. Recycled gas particles, sand and biomass products along with bed particles move together through orifice holes at the riser base to attain a solid mass of flux material up to 700 kg/m^2 with gas velocities between 5.5 and 8.5 m/s [32]. Hydrocarbon gas is produced as a result of rapid pyrolysis of biomass. Tar is trapped in the gasifier by a bed, while coke is gasified with steam on top of the bed [33]. Solids circulating along the solid circulation loop are known to undergo thorough mixing with a high residence time [34]. Gas is prevented from passing through the bed by the absence of bubbles [32]. Reduced tar content in the syngas is seen as an advantage of using a fast reaction in a reactor at a high heat transport rate compared to the commonly used bubbling bed [35].

Raw materials that are both small (< 400 µm) and wide in size can be processed using circulating fluidised bed gasifier without experiencing loss of traction – making it suitable for a variety of feedstock [36,37]. Meng *et al.* [38] investigated the impact of two kinds of sawdust pellets and willow wood on the gas compositions. Gases are produced through a CFB gasifier using controlled steam-oxygen at atmospheric pressure of 100 kWth. Results suggested that the average concentration of H_2 obtained for the two raw materials is around 20 to 30% when the temperature range lies between 800 to 820 °C. For biomass gasification, the range of the obtained H_2 composition is very high.

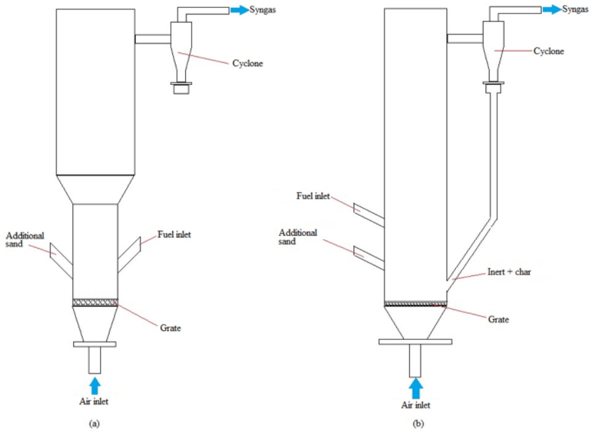


Figure 6 (a) Bubbling Fluidized Bed Gasifier (b) Circulating Fluidized Bed Gasifier [6]

2.1.3 Transport Reactor Gasifier

Generally, transport reactor gasifiers (Figure 7) are designed for high gas velocity (15 m/s). This is catered by creating a smaller gasifier vessel diameter to transport bed materials. This gasifier reacts and fluidises feedstock in an upward flow of gas (oxygen, air, and steam). Uniform temperature distribution is ensured through adding secondary air at high mixing level. This prevents ash from melting, clinker production, and loss of bed fluidity in combustion mode. In order to prevent the loss of circulating material, recirculation of fly ash that are low in ash content from firing fuels is required. This results in the fly ash acting as the new bed material.

It is necessary to recirculate make-up sand and fly ash for the solid mass to be stored in the bed inventory [30].

After the feedstock has been devolatilised or gasified, it is burned in a combustor (riser) by char combustion. Carbon conversion and eventually high cold gas efficiency at low operating temperature is improved, unlike other gasifier system. The temperature distribution in the transport reactor must be closely monitored in order to minimise the sulphur content generated during gasification. High sulphur concentrations can be produced by a gasifier reactor, particularly during the direct desulphurisation process [31]. Low – rank, high moisture and high – ash coals are a good fit for transport gasifiers due to its low temperature operation and high circulation rate. Thus, it can burn sewage and industrial sludge, sawdust, and peat with significant moisture removed before combustion begin [35].

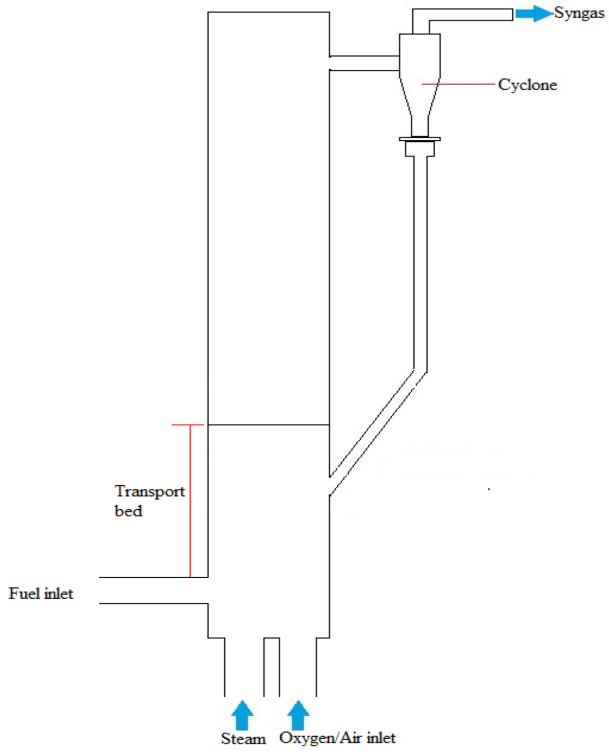


Figure 7 Transport Reactor Gasifier [6]

2.1.4 Entrained Bed Gasifier

An entrained flow gasifier performs at a temperature range of 1200 to 1500 °C, which is higher compared to a fluidised layer gasifier or a moving bed gasifier. The composition of the producer gas is linearly proportional to the quality of the gas. High conversion rate is accomplished through crushing solid raw materials to a very small particle size (<100 µm) to facilitate the functioning of the feed system. For a single-stage system as shown in Figure 8, the raw material and the oxidising agent are introduced simultaneously at high speed into the combustion reactor for gasification to occur [39]. Pneumatic transport is prompted by high flow speed. With a residence time ranging from 1 to 5 seconds, the raw material is completely oxidised [40]. High temperature setting results in high gas quantity which makes it appropriate for less active raw materials. High temperatures cause hydrocarbons, oils and phenols to be effectively removed during the devolatilisation stage, whilst mineral matter is removed as crust or slag [41].

Higher oxygen supply is required to reduce cold gas efficiency. This allows the operating temperature within the gasifier to increase. Entrained bed gasifiers are commonly used for chemical synthesis processes (methanol, ammonia, and acetic acid), electrical power generation and also for liquid fuels [42]. In addition, entrained bed gasifiers are also capable of receiving various types of raw materials from biomass sources such as oil palm kernels and wood waste but the study of their use of such materials is limited [43].

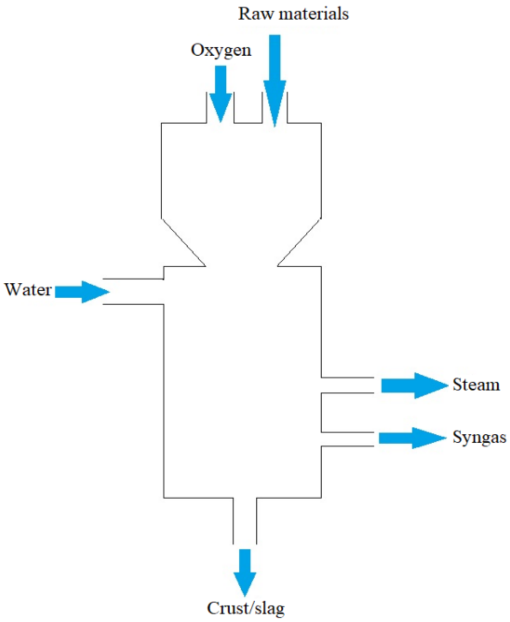


Figure 8 Entrained Bed Gasifier [6]

2.1.5 Dual Fluidized Bed Gasifier

Liquefaction of gaseous products by nitrogen is considered as one of the many major problems in air gasification. The use of oxygen as a gasification agent may avert the problem. Despite its advantage, an oxygen generator is required – further increasing the cost. Liqufaction process may be avoided when the combustion and the gasification process in two separate reactors.

A riser combustor and gasifier are amongst the chambers available in this type of gasifier. Figure 9 displays the structure of said gasifier Its structure is influenced by both bubbling and circulating fluidised bed gasifiers. The effect of this combination can be observed during pyrolysis. Indirect heating from hot sand within a riser combustor is fed back into the gasifier after conversion of char and air products. Hydrogen generation is enhanced through reaction conversion and improving steam – carbon reaction. The heating value of the producer gas is somewhat good despite very low tar formation. This gasifier is able to achieve a nitrogen free producer gas with a low heating value (LHV) of 10 to 14 MJ/Nm^3 [5].

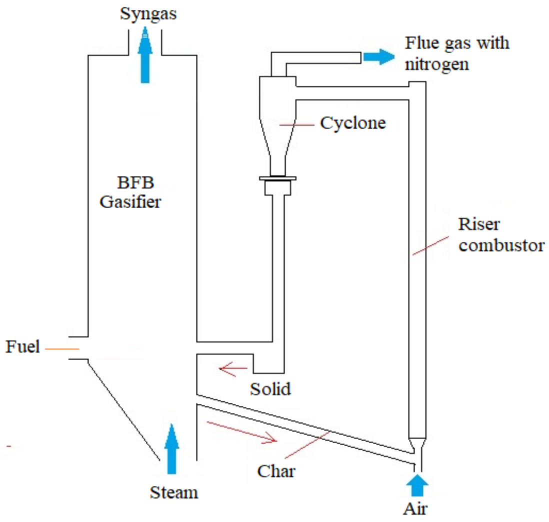


Figure 9 Dual Fluidized Bed Gasifier [44]

2.1.6 Advantages and Disadvantages of Different *Types of GasifierS*

Syngas production is influenced by the raw materials used, gasification technology and type of gasifier used. Table 4 below shows the advantages and disadvantages of each gasifier used to produce a quality of syngas.

Table 4 Advantages and disadvantages of gasifier [45-48]

Gasifier	Advantages	Disadvantages
Updraft	• Efficiency of thermal energy production was from a solid carbon oxidation. • Suitable for various types of raw materials whether high moisture contents, organic and inorganic • Size of the feedstock ranges from 5 to 100 mm • Low ash contents. • Gasifier operates at a range of 0.15 to 2.45 MPa, while residence time ranges from 15 to 30 minutes • Suitable for small-scale heat applications • Able to operate in high moisture • It has been proven as easy to operate, simple and low- cost technology	• Oxygenated compounds and tar are produced from a gasification process. • High tar content. • Limitation on feed size • Limitations on scale • Produce Low heating value gas (LHV) • Potential on slagging formation
Downdraft	• Gasification reaction occurs in the contraction region. Homogenous	• Raw materials used must be relatively dry,

	distribution of the gasification agent transpires in the oxidation zone, at a controlled temperature of around 1000° C • Size of feedstock between 10 to 300 mm. • Higher temperature for gas product • Low tar content • Small-scale applications • Low particulates • Minerals remain in the form of char and ash.	• Limited to a moisture content of 30% and low ash content. • Limitation on feed size • Limitations on scale • Produce Low heating value gas (LHV) • Sensitive on moisture contents.
Crossdraft	• Suitable for various types of raw material. • The formation of tar in gas product is low due to high temperature of gasification. • Gas production is flexible. • The response time to load is so fast. • Small scale operation. It is suitable for small engines	• Pressure is high. • Sensitive on formation of slag •
Swirl flow	• Suitable for various types of raw material. • The formation of tar in gas product is low due to high temperature of gasification. • Gas production is flexible. • The response time to load is so fast. • Small scale operation. • It is suitable for small engines	• Limitation on feed size • limitations on scale • Produce Low heating value gas (LHV) • Sensitive on moisture contents. • Potential on slagging formation
Twin Fire	• High gasification efficiency • Stable gas production • Obvious in environmental protection. • Generates effects of zero nitrogen oxides, sulphur oxides, and carbon dioxide emission. • Wide range of raw materials • Low operating cost • Low dust and tar content	• High exit gas temperature • Poor CO reduction • High gas velocity
Bubbling bed	• Used in large-scale applications • Feed characteristics • Direct/indirect heating • Can produce higher heating value gas	• Yield of tar (medium) • Particle loading (higher)
Circulating bed	• Applied in large scale gasification process • Produce higher heating value gas	• Yield of tar (medium) • Particle loading (higher)
Dual bed	• Offers a nearly nitrogen-free product gas • Reduce the influence of the particles • Lower tar content. • Increased gasification efficiency • Difficult to coking • Higher calorific value and hydrogen content.	• Gasification efficiency need to be proof due to the time residence of is short. • Mixing gas between the combustion chamber and gasification chamber limits its application. • High cost
Entrained bed	• Operating at a pressure of 20 to 70 bar • Potential for low tar • Potential for low methane • Can produce higher heating value gas	• Large amount of carrier gas • Higher particle loading • Particle size limits • Potentially high Sulphur/Carbon
Transport reactor	• Low – rank, • High moisture and high – ash coals • Low temperature operation • High circulation rate	• High sulphur concentrations

3.0 GASIFICATION AGENT

Endothermic and exothermic reactions are amongst the possible categories of gasification process. Gasification can also be categorised according to its agents such as air, steam, and oxygen. Agents may influence the production of by-products, heating values and different gas compositions. Table 5 presents a summary of the three gasification agents performance using municipal solid waste (MSW) [49–52].

Table 5 Product yield differences, gas consumption and gas composition for different gasification agents using urban solid waste (MSW) [49-52].

Characteristics	Air	Steam	Oxygen*
Moisture Content (%)	7.59	-	8.31
Temperature (°C)	777	900	800
Equivalence Ratio (ER)	0.4	-	0.2
Steam to Biomass Ratio (S/B)	-	0.8	-
CO_2 (% volume)	15	17.5	35.5
CO (% volume)	19	16.5	30.3
CH_4 (% volume)	5	21	10.3
H_2 (% volume)	5	28	11.8
LHV (MJ/Nm^3)	2.4	15.0	8.5
Carbon Conversion Efficiency (%)	61	44.1	-
Dry Gas (m^3/kg)	1.4	0.5	-
Char (% mass)	-	7.9	15.5

Tar (% mass)	11.4 (g/m^3)	0.2	43.5
Advantage	Easy to use and operate Cost effective	Able to selectively produce hydrogen gas Produces gas with high energy content.	Average heating value Additional source of heat from burnt char.
Disadvantage	Low heating value due to diluted nitrogen Requires high cost to separate nitrogen from other gases	Requires an internal heating source to renew vapor reaction Low energy efficiency.	High capitol cost to obtain pure oxygen.
Use for	engine and boiler	Fischer-Tropsch Synthesis	Heating

* Average value of MSW

3.1 Air

Air is a common gasification agent due to its availability and simplicity. Gasification performance is thus strongly dependant on the equivalence ratio (ER) and the temperature. Higher dry gas fuel heating value is achieved when higher injected air temperature is used [53]. Despite the aforementioned the high nitrogen content found in air (up to 79%) causes the produced gas to be dilute and thus requires high costs to separate nitrogen from the gas produced [54]. In addition, the resulting gas also has a low heating value (LHV) of approximately 3.5 to 7.8 MJ/m^3 [52]. As such, the use of air is limited to thermal heating at the location of use as well as being used for power generation only [55].

A study conducted by Meng *et al.* [38] suggested that raising the equivalence ratio from 0.15 to 0.35 significantly decreased the coal and tar production from empty fruit bunch gasification. Oxygen contents in the air promoted oxidation of tar and char along with enhancing the production of CO and CO_2. The effect of this equivalence ratio on char and tar production was found to further strengthen the findings from other studies [51, 52, 56, 57]. Carbon conversion and gasification efficiency seemed to improve when equivalence ratio is increased, before experiencing a decline.

Others like Gao *et al.* [58] found that enhancing the equivalence from 0.18 to 0.22 resulted in an increase in gasification efficiency of pine sawdust from 61.43% to 68.15%, but later decreased by 59.56% as the equivalence ratio increased to 0.28. The same can be said for carbon conversion efficiency. Increasing the equivalence ratio from 0.22 to 0.31 enhanced the carbon conversion efficiency of pine board dust from 81% to 91.5%, and is lowered to 88.5% when equivalence ratio reached 0.34 [59]. This is caused by hindering heat transfer between the heater and the solid particles. Heat transfer is decreased as air is further supplied into the reactor causing the carbon conversion and gasification efficiency to decrease.

Using air as a medium also influences H_2 and CO_2 content. A simultaneous increase in H_2, CO and the equivalence ratio may be observed until a maximum limit is reached. Once it reaches its maximum, the pattern will tend to decrease. In addition, CH_4 concentration also decreases while both CO_2 and the equivalence ratio experience an increase [56, 60, 61]. Zhao *et al.* [59] further solidified this statement through enhancing the equivalence ratio to 0.34 from 0.22. This resulted in a decrease in CO content from 25.7 to 21.5 % by volume and a decrease in CH_4 concentration from 2.45 to 0.87 % by volume. Similar trend applied to H_2 content, where a decrease was observed from 14.6 to 10.2 % by volume. However, an increase in equivalence ratio transpires promoted the concentration of CO_2 from 11.7% to 12.3% whilst its low heating value (LHV) was found to decrease from 6.67 MJ/m^3 to 4.65 MJ/m^3 [59].

3.2 Steam

Using steam as an agent seemed to produce higher H_2 concentration along with a high heating value, as shown in Table 2 [15]. It promotes water-gas (primary) reactions, steam reforming reactions, and gas-water transitions. Both gas – water and steam decomposition reactions are fundamental in oxidative formation of raw materials, as they are the basis of organic carbon conversion to H_2 and CO. During combustion, the water-gas transition reaction converts H_2O and CO gases into H_2 and CO_2.

According to Garcia *et al.* [62], A surge in steam to biomass ratio generates higher CO_2 and H_2 and lowered CH_4 and CO concentration. H_2/CO and H_2/CO_2 ratios increases whilst the CH_4/H_2 ratio decreases when steam to Table 5 biomass ratio rises. This indicates that steam influences tar steam reforming, gas-water shift, methane steam reforming, as well as carbon oxidation reactions. Other reactions such as methane and coal reforming are enhanced during gasification, causing a H_2 concentration to enhance and decline in CH_4. Moreover, water – gas shift reaction is favoured when steam to biomass ratio is increased – causing the CO/CO_2 ratio to decline.

As a gasification agent, steam lowers by -products formed during gasification. Research conducted by Rapagna *et al.* [63] shows that raising steam to biomass ratio lowered tar yield by 49% and its charcoal concentration by 76%. This reduction is caused by steam prompting numerous condensation reactions with char – lowering its concentration and leaving the remaining char porous [64, 65]. Kihedu *et al.* [66] conducted a comparison of air and air-steam for pallet wood of black pine and found that air produced 75.3 g/m^3 of tar in its syngas, whereas air-steam produced only 58.7 g/m^3 of tar. In addition, steam is able to reduce tar to 17% to 24% compared to air [67].

3.3 Oxygen

Producer gas with a moderate heating value is often achieved when opting for oxygen as an agent. Niu *et al.* [51] suggested that the heating value of the producer gas can reach 8 to 10 MJ/m^3 when the equivalence ratio lies between 0.18 and 0.23. On the other hand, the heating value of producer gas is lowered when the equivalence ratio is raised greater than 0.23. gasification reaction begins to undergo complete oxidation when equivalence ratio is increased due to rapid increase in CO_2 content [51]. Gao *et al.* [58] found that a decline in H_2 and CO concentration along with the increase in CO_2 content is attributed to the surge in equivalence ratio from 0.05 to 0.30. Oxygen is seen to promote higher carbon conversion efficiency compared to air. Furthermore, a study conducted by Dai *et al.* [68] shows that increased carbon conversion efficiency from 0.9 to 1.4 is owed by a raise in equivalence ratio from 0.9 to 1.4. Despite this advantage, oxygen is an expensive gasification due to limited amount of natural oxygen in nature. In addition, it is expensive to isolate oxygen from syngas. This drawback is thus hindered by pairing oxygen with steam [52].

4.0 EFFECT OF PARAMETERS TOWARDS GASIFICATION

4.1 Physical Properties

The calorific value of solid material and resulting gas, gas composition and characteristics, gas emission concentration, temperature and flame profile are among the parameters investigated during gasification. These parameters determine the quality of producer gas.

4.1.1 High Heating Value (HHV)

The calorific value of solid materials or higher heating value (HHV) is the main parameter used to assess the quality of biomass fuels for energy production, as it indicates the energy density of an energy source. Compared to fossil fuels, biomass contains less energy. Moisture is seen to influence calorific value of biomass and is found to be particularly high in green biomass and waste. Aside from moisture, Özyuğuran and Yemen [69] found that fixed carbon content has a positive correlation with calorific value. Highly volatile matter biomass are also found to have an average calorific value – due to the influence of non-combustible gases such as CO_2 and H_2O. Calorific value is also affected by ash content – affecting the visible heat generated from biomass combustion. Ash formation, inorganic thermal decomposition and phase transition were found to require high energy sources. It is derived from the combustion energy of biomass, which is indirectly seen to have a reducing effect on the calorific value. Other factors may also influence higher heating value (HHV) of biomass, which create difficulties in determining the properties of a material.

4.1.2 Proximate Analysis

Nunes, De Oliveira Matias, and Da Silva Catalão [70] defines proximate analysis as a technique to ascertain combustible material percentages in gaseous and solid states as well as corresponding inorganic waste in the form of ash. Materials exists in two phases when burned. In the gaseous state as the property is known as volatile matter whereas fixed carbon is used to indicate the property in its solid state. Aside from the aforementioned parameters, the moisture content of materials can also be measured in proximate analysis. The analysis aids in the development of power plant design by providing an understanding of the combustion behaviour [71]. Furthermore, volatile matter and fixed carbon content are forms of chemical energy storage [72].

Cavalaglio *et al.* [73] believed that peak temperatures are influenced by a surge in volatile matter. Peak temperatures are points at which maximum weight loss is observed. Moreover, Muthu Dinesh Kumar and Anand [74] added tar production is favoured with the use of fuels with high volatile matter. Phenol, benzene, naphthalene and others volatile matters are amongst the aromatic compounds found in tar. These materials undergo condensation during gasification and posed negative effects on combustion equipment. Tar formation often occur at high temperatures, but it can also occur at low temperatures, particularly when involving short organic chains such as acids, ketones, aldehydes and others. The study shows that 73 to 83% of agricultural wastes by weight and 77% to 86% of urban solid wastes by weight tend to produce high tar due to their high volatile matter content [52]. Ash content is also another parameter deterimed in proximate analysis. Initial product composition generated during initial, pyrolysis and gasification phase can be estimated through determining the ash content [73]. High ash raw materials can have a negative impact on reactor connection, catalytic sintering, and waste disposal. Using chicken manure, Gregorio *et al.* [75] found that as ash content increased from 17.2% to 25.1% whilst gasification efficiency decreased from 63% to 33% along with a significant decrease in H_2 and CO and the higher heating value (HHV) from 4.3 MJ/m3 to 2.6 MJ/m^3.

Basu [72] believed that the proximate analysis of solid fuels can be determined using the E-870-06 standard, or now known as ASTM E-870-82. In addition, Basu [76] further added that standards used must match the components analysed. For instance, ASTM E-872 may be used to determine volatile matter whilst ASTM-D-1102 can be used to determine ash content of fuels. ASTM E-871 is more commonly used to determine the moisture of woody samples whilst whereas. fixed carbon may be found through other different techniques.

4.1.3 Ultimate Analysis

Carbon, nitrogen and hydrogen in fuel samples can be determined using ultimate analysis [77]. It is a method to verify the composition of solid fuel [78]. Analysing the composition allows researchers to understand the energy production and combustion emission, which in return helps them to analyse the combustion performance. Other elements such as nitrogen, sulphur and oxygen can also be found and all results are presented in weight percentage. Sophisticate technologies such as multi – elemental analyser are now used to carry out whilst using ASTMD5373 standard.

Previously aforementioned elements are determined through chemical analysis and is expressed in percentage by mass and is free of moisture. Carbon (C) and Hydrogen (H) are determined by burning each sample (approximately 0.2 g) in oxygen vapor. C and H char are then converted to CO_2 and H_2O, respectively.

The gaseous product is then absorbed into KOH and $CaCl_2$ tubes respectively at specified weight rate as well as at a specified incremental rate. Nitrogen content may be determined by processing 1g of char sample in a long neck thermos using a concentrated H_2SO_4 solution together with K_2SO_4. Once the solution became clearer, it was then treated using KOH. Ammonia is released and distilled before being absorbed into an acid solution with a predetermined volume. The unused portion of the acid can be determined through titration using NaOH. This technique may determine the amount of ammonia released. Therefore, the percentage of N in each sample can be calculated. On the other hand, sulphur is determined from washing used char in the bomb calorimeter. Washing converts sulphur into sulphate. Barium chloride is used to treat the wash – resulting in barium sulphate. Filtration, washing, and heating are conducted until uniform weight is achieved. Sulphur concentration can thus be found using equation 1.

$$\text{Percentage of S} = \frac{32 * m_{BaSO4}}{233 * m_{PKS}} 100 \qquad (1)$$

High quantities of nitrogen and sulphur in feedstock result in the production of NO_X or SO_X emissions as along with catalytic poisoning. Complex organic state are often favoured by nitrogen during gasification – resulting in the formation of ammonia and hydrogen cyanide. In addition, small amounts of molecular nitrogen, nitrogen oxides and other aromatic organic compounds is released whilst a small amount of nitrogen is stored as unreacted raw material solids [79,80]. Sulphur is often released in the form of H_2S, which cause treatment and separation of gases problems. Based on the study, most bio waste raw materials contain less than 1.5% by weight of sulphur, while for sewage sludge and animal waste products contains ~ 1% of sulphur by weight and 0.5% by weight [80].

4.1.4 Gas Composition and Characteristics

Inconsistent gas composition and syngas heating value makes syngas a challenge to use, particularly in practical combustion systems. Gas composition is influenced by several elements present in its solid materials such as the type of plant used, water content, temperature reaction process and gasification process. The formation of synthesis gas composition is also influenced by the lignocellulosic component of the raw material (plant-based). According to a study conducted by Huang et al. [81], there is a relationship between the content of hemicellulose components and the composition of H_2 and CO_2 gases, which is the presence of high hemicellulose components also affects the formation of H_2 and CO_2 gas quantities [82]. In general, when hemicellulose component increases by about 6% by weight, then the composition of H_2 and CO_2 gas also increases from 51 to 76% and 44 to 118% respectively. Compared to CO_2 gas, H_2 gas is considered more valuable and suitable as a clean energy source without causing a greenhouse effect. However, as the material's hemicellulose content lies between 15 and 35%, the material may be deemed unsuitable to produce H_2 gas during the pyrolysis process. High cellulose component, on the other hand, affects the production of high CH_4 and CO gas, based on research by Huang et al. [81], which further stated that a 16% increase of cellulose components result in increased CH_4 and CO gas from 51 to 183% and 43 to 66%, respectively. According to Samiran *et al.* [83], 50% of the energy in syngas products is owed to H_2 and CO, whilst the remaining 50% is found in CH_4 and hydrocarbons (aromatic). Gas composition may also influence the low heating value (LHV) of syngas. High unburned gas concentration can cause LHV reduction. Solid material, gasification methods and temperature may also alter LHV.

In general, synthesis gas composition is highly dependent on the type of raw material and the method of gasification technology used. However, it should be remembered that nitrogen gas (N_2) is also one of the main gases in the composition of synthesis gas in addition to H_2, CO, CO_2 and CH_4. The formation of N_2 gas occurs when air is used as a gasification agent. Most simple conversion methods utilise air as a gasification agent. This phenomenon can be found in small gasifiers, where N_2 rich gas (50% to 65% N_2) is generated with a low calorific value of approximately 4 to 8 MJ/Nm^3 alongside low concentrations of H_2 and CO. The gas produced is suitable for direct heating applications or used in engines [84, 85, 86]. On the other hand, the use of oxygen and vapour/steam as a gasification agent can increase the production of gas containing higher energy values with high H_2 and CO concentrations. The use of oxygen may prevent the liquefaction of gas during the gasification process. Steam, however, may act as both heat moderator and gasification agent. It is able to increase the calorific value of the producer gas. However, oxygen and steam gasification require high costs and are not required for biomass gasification but are suitable for gasification of less active fuels such as coal [85]. A thorough and suitable preparation is thus necessary during experiment to ensure data accuracy.

4.1.5 Gas Purification

A high level of gas purity is very important to produce a synthetic reaction compared to the use of syngas in power generation. From gasification, raw syngas contains an organic and inorganic impurities as well as solid particles [87]. Tar is a pollutant consisting of a mixture of different organic compounds ranging from primary oxygenated carbon to heavier oxygenated hydrocarbons and polycyclic aromatic hydrocarbons (PAHs). The formation of this tar usually appears as a secondary reaction during the pyrolysis stage in the gasification process and produced during thermal or partial oxidation [88, 89]. Others also define Tar as a hydrocarbon with a higher molecular weight compared to benzene (C_6H_6, MWbenz= 78.11 g/mol), despite benzene not being able to be defined as tar [90]. Tar formation was found to cause many negative effects, especially to the downstream section of the gasifier. The main contributor of tar formation is the condensation point, where tar formation occur in the vapor phase due to high process temperatures. The resulting tar is thick, very sticky, and poisonous, this causes it to stick to the surface of equipment and cause interference with the equipment operation [91].

Generally, tar can be classified into three categories namely primary, secondary and tertiary. Primary tar is produced from three lignocellulosic components, namely cellulose, hemicellulose, and lignin. It usually contains heavier hydrocarbon content; high oxygen levels and it is also soluble in water. As for secondary and tertiary tar, the formation appears after the primary tar has been cracked. The difference between the three is difficult to determine, but secondary tar characterization is more commonly known as olefin and phenolic, while tertiary tar is known as methyl derivatives and aromatic compounds (PAH) [92]. According to Li and Suzuki [93] tar formation is significantly influenced by the type of gasifier used, the gasification temperature and the type of gas carrier either oxygen or nitrogen.

Several methods have been identified to help reduce tar formation. Examples of tar removal methods include cyclone construction, the use of barrier filters or cloths, scrubbing solvents and electrostatic filters in the particle removal process. High temperature cracking, or catalytic cracking and scrubbing using organic liquid is aimed at removing tar and removal of inorganic impurities is done in sequence, aiming to prevent the formation of unnecessary components from one specific removal process to another removal process [44]. Arni [94] stated, further classified tar removal method into two categories: the primary method and the secondary method. The primary method focuses on expanding gasifier technology such as using several types of catalysts such as dolomite, olivine, coal and calcined which are found to be suitable for using on biomass raw materials either as is or mixed directly in the gasifier hearth zone [95]. As for the secondary method, it is divided into two further techniques, namely wet and dry techniques. Wet techniques are more focused on physical separation and absorption of tar into liquid scrubbers. Despite focusing on physical separation, not all tar content can be dissolved in water. This is caused by difficulties faced when separating water-soluble tar which in return, causes large amount of waste stream that cannot be used and is difficult to treat. For this reason, organic liquids are introduced to provide better absorption of tar content, as well as contributing to easier and more effective wastewater treatment [96]. On the other hand, dry technique involves thermal cracking, catalytic cracking and plasma cracking, which eliminates tar in gas through cracking of heavy hydrocarbon molecules during gas phase without any absorption of liquid agents or separation by initially introducing liquefaction [97, 98].

In the application of energy and power consumption from the gasification system, in addition of tar, the formation of NO_X emissions can also occur in the downstream. The effect of high level of hydrogen in syngas composition contribute to the formation of high NO_X emissions during the combustion process of gas product. According to Sahoo et al. [99] and Bika et al. [100] higher H_2 composition in syngas caused higher NO_X emissions, and lowers UHC (unburned hydrocarbon) and CO concentration during the combustion of gas product.

5.0 ADVANTAGES OF GASIFICATION

For different fuel types such as solids, concentrated oils, carbonaceous industrial and domestic wastes, gasification possess several environmental advantages compared to conventional combustion methods. Gasification allows clean syngas to be produced. This implies that the formation of nitrogen oxide (NO_X) and sulphur (SO_2) emissions is reduced. Sulphur found in raw materials is converted to H_2S whilst nitrogen oxide is converted into two atoms which are nitrogen (N_2) and NH_3. H_2S and NH_3 that are released in a downstream process promote clean syngas generation. The conversion of both sulphur and nitrogen oxide into said compounds allows for a reduced (or non-existent) sulphur and nitrogen oxides production. This is particularly important for syngas used in gas turbines or boilers. When used as an intermediate, other possible adverse consequences such as acid rain are unlikely to occur. Moreover, multiple stage gas purification system reduces particles found in syngas - syngas allowing it to meet specifications set by gas turbine manufacturer. cyclones, scrubbers, dry filters are added to remove particles [101].

Another advantage to gasification is the non-occurrence of furan and dioxin formation. Furan is a colourless and organic compound that is heterocyclic and possess five aromatic ring atoms made of four carbon atoms and one oxygen atom. It is flammable and highly volatile liquid with a boiling point at ambient temperature. Dioxins, on the other hand, are persistent organic pollutants (POPs) that takes a long time to expend in the environment. Dioxin compounds are toxins that are carcinogenic; cause reproductive, developmental and immune impairment as well as disrupt hormones. Combustion of organic compounds is the main contributor of furans and dioxins in the environment.

Dioxins and furans generation can be avoided during the gasification process. Oxygen deficiency in the gasifier hinders HCl from free chlorine compounds - restricting chlorination of other compounds. Aside from lack of oxygen, high temperature may effectively destroy initial furan and dioxins present in raw materials. Therefore, Free chlorine formation should be avoided if syngas is burned in a gas turbine in using oxygen at a high combustion temperature. Moreover, dioxins or furans formed post-combustion does not recur due to too minute particles necessary for post-combustion formation.

Dioxins and furans are caused by changes in oxygen and carbon compounds. Toxins are generated by both compounds when paired with halogen elements such as chlorine and bromine. These toxins are by-products of combustion processes from domestic, medical waste and other incineration processes [101]. Initially, hydrocarbons react with chlorinated compounds to generate dioxins or furans. Aside from combustion, furans and dioxins are also formed during post-combustion of flue gas cooling systems due to the existence of initial compounds, free chlorine or unburned carbon and copper species in flying ash particles [102].

Limited volatile organic compounds, semi-volatile organic compounds (SVOCs) and polycyclic aromatic hydrocarbons (PAHs) data are available. Data suggested that VOCs, SVOCs, and PAHs are either undetectable or low in the flue gas stream particularly in IGCC process. In other detectable cases, they seemed to be very low in concentration (in billions of parts or lower). Analysis of syngas has indicated that 99.99 percent of chlorobenzene and hexachlorobenzene undergo destruction and elimination while the levels of PAHs as well as selected VOCs concentrations are part of a billion or less [101, 103-107].

6.0 DIFFERENCE BETWEEN GASIFICATION AND COMBUSTION

Gasification cannot be classified as combustion, as they are a conversion process that generates valuable and useful products than carbonated raw materials. Whilst both combustion and gasification convert carbonated raw materials to gas, gasification occurs without oxygen or with limited oxygen whereas combustion operates with full oxygen. The main objective of combustion is to destroy raw materials by generating heat using thermal energy. Gasification, on the other hand, has the purpose of converting raw materials into more environmentally friendly, high-value products, or into intermediate products that can be used to produce various types of chemicals, fuels, and energy [108].

Gasification of materials convert C, H, O, N, S and Cl which into syngas that comprises of HCN, HCL, COS, N_2, CO, H_2, CO_2, H_2O, NH_3 and H_2S. In contrast, the products produced from combustion are composed of HCL, CO_2, H_2O, SO_2, NO, CO and NO_2 [101].

Different by-products are generated during both combustion and gasification. Gasification with low-temperature conditions results in char. Char comprises of unreacted carbon and minerals from the gasification reactor. Activated carbon is then created from charcoal to be used in water and dirty water treatment as well as bleach. Furthermore, activated carbon are able to trap volatile organic compounds (VOCs) and pesticide from industry. At high temperatures, gasification yields a glassy crust as a byproduct. This crust consists of inorganic matter that failed to vaporise in the reactor. Mineral matter will melt if the gasifier reaches a point at which its temperature is above the fusion and melting temperatures, thus releasing a molten crust as a byproduct. This crust is harmless and is often used as a mixing material to make roads or as a rough material for breaking up sand [101].

Bottom ash is considered the main byproduct produced from the combustion process. It is classified as unburned waste and consists of minerals and a small amount of inactive carbon. This bottom ash is considered hazardous, except when obtained from the combustion of biomass sources [101].

7.0 DEVELOPMENT OF GASIFICATION TECHNOLOGY

The demand for energy resources, chemical markets and world geopolitical influences has affected the advancement of gasification technology. Gasification technology was first introduced in 1792 by Murdoch, who carried out pyrolysis on coal to supply light in his residence, which then grew into one of the methods of supplying energy for street lights around Westminster Bridge in 1816 and around Boston and New York in 1826 [109].

The development of coal gasification grew rapidly in the middle of this century [102]. By 1875, gas production was widely used as a residential lighting project. Biomass gasification emerged in the 1900s, focusing on the synthesis gas generation for fuels. Approximately 1 million air-blown gasifiers were built during the second world war to produce synthesis gas from wood and coal sources used as fuel and for steam and electricity generation [110].

Gasification technology gained increasing attention, particularly during the 1960s and 1970s, when controversies over the depletion of world fuel reserves began. By the 1980s and 1990s, it had led to an awareness of obtaining fuels from alternative sources. Researchers and industry thus discovered the advantages of using gasification technology on the environment. The discovery was in line with the situation at that time, where fairly strict standards were set to maintain environmental quality, especially in terms of emissions, domestic and industrial waste and greenhouse effects. Understanding the advantages of gasification technology prompted governments and industry shareholders to continue to explore this technology as well as promote it for commercialisation [101].

A survey in 2003 suggested that over 163 commercialised gasification projects were available worldwide, including a total of 468 types of gasification [111]. More than 120 power plants started their operations from 1960 to 2000, with 72 power plants operating after 1980. The majority of these power plants were intended to generate synthesis gases that are rich in hydrogen and carbon monoxide. Hydrogen produced within syngas undergoes a process known as Fischer-Tropsche (F-T) to produce vehicle fuels, lubricants and special waxes. In addition, hydrogen can also be used to create various types of chemicals and fertilisers. Power plants are now currently designed to produce synthesis gas suitable for gas turbines in order to produce clean electricity. Examples of this application include Global Energy's Wabash River Power Station in Indiana and Tampa Electric's Polk Country Power Station in Florida. These power stations started operating in 1995 and 1996 and use coal as their raw material. Additionally, examples of power stations which utilised biomass as its source include Rudersdorfer Zement project in Germany, the Corenso United Oy Ltd project and Oy W. Schauman ab Mills in Finland.

Gasification technology, particularly biomass gasification, is seen as a feasible and suitable option in the future. It is one of the methods to meet the high demand for energy consumption while also reducing the rate of dependence on fossil fuels. Energy consumption increase is driven by the increase in world population. China, for instance, has seen a high increase in energy consumption per capita over the past few decades and is likely to experience a further increase in the future. With a population of around 1.35 billion, China's per capita energy consumption increased to 5000 kWh in 2012 and may require additional generation capacity of around 250 GW to meet the needs of the population. Similarly, India, which has a population of around 1.25 billion people, requires more than 600 GW of additional power capacity. These numbers will continue to increase over time to meet the increasing demand for energy. The main focus of gasification technology must be expanded to meet future energy needs. Gasification should not only be aimed at producing chemicals, but more towards producing clean fuel as an energy source. The shift to biomass sources as an alternative fuel for gasification is also seen as being able to accommodate the demand for energy sources in the future [112].

8.0 BIOMASS FEEDSTOCK

Biomass feedstock consists of various types of sources and also refers to organic matter derived from plants and animals [113-116]. Basu [44] has divided this source of biomass into two categories: virgin biomass (lignocellulose biomass) such as plants, woods, and leaves; and carbohydrate-based biomass which consists of vegetables and crops. Solid and liquid waste from urban living, sewage, animal and human waste, gases from landfills and agricultural waste are also examples of carbohydrate-based biomass.

Lignocellulose biomass is further classified into two categories: herbaceous plants that have leaves and stems of seasonal crops and non-seasonal crops. Examples of seasonal crops include rice, wheat, oats and grass, whilst examples of the second type are woody trees, creepers and shrubs. Woody biomass, for instance, consists of extractors, cell wall components and ash. Typically, a neutral solvent made of fats, resins, sugars, oils, essences, tannins, glues, and alkaloids are used to remove the extractor. Cell wall components, on the other hand, comprises of o cellulose, lignin, and hemicellulose. The cell wall component is a polysaccharide. Cellulose, which is a part of the cell wall, is an interweaving of glucose molecules in a long chain-shaped skeleton structure of plant cell walls, whereas hemicellulose has a chain-like structure and is built of several types of monosaccharides, and lastly, the complex aromatic polymer is known as lignin. Ash is considered an inorganic material from plant parts consisting of Si, K, Ca, S and Cl. In wood cell wall, for instance 40 to 45% of its dry mass is made of cellulose, almost similar to softwood and hardwood, whereas lignin is 25% to 35% in softwood and 17 to 25% in hardwood; hemicellulose in softwood is approximately 20% and in hardwood between 15 to 35%; extractor concentration vary from 1 to more than 10% and lastly, the ash content is 1 to 3% [5].

9.0 CONCLUSION

Gasification technology can be considered a clean technology as it reduces CO_2 emissions. It can convert raw materials into fuels that are more environmentally friendly. Its main product, syngas, acts as an intermediate product to produce various types of chemicals, fuels, and is intended for energy production. With a small and compact equipment required, gasification can attain high level of thermal energy efficiency and a good level of control. In addition, various raw materials including biomass can be processed through gasification. Gasification offers more economical technological advantages compared to other power generation technologies. Using biomass as the raw material in gasification is one of the strategies used to help reduce environmental pollution as the NO_X and SO_X formation rates are low. Moreover, the use of crop-based raw materials for gasification has also broaden opportunities for farmers to sell crop waste for energy generation.

Compared with combustion technology, gas production through gasification has a lower volume and temperature. This allows complete combustion to occur in the burner, which results in cleaner syngas. The production of syngas from gasification is then observed to reduce the formation of emission gases.

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