# 1. Gasification

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## 1.1. Introduction

Gasification is the controlled partial oxidation of a carbonaceous material, and it is achieved by supplying less oxygen than the stoichiometric requirement for complete combustion. A central process between combustion (thermal degradation with excess oxygen) and pyrolysis (thermal degradation in the absence of oxygen), it proceeds at temperatures ranging between 600 and 1500 $^{o}$C. Depending upon the process type and operating conditions, low- or medium-value producer gas (which is a combination of combustible and non-combustible gases) is created.

Gasification technology has been widely used to produce commercial fuels and chemicals. Current developments in the chemical manufacturing and petroleum refinery industries show that use of gasification facilities to produce synthesis gas will continue to rise. A striking feature of the technology is its ability to produce a reliable, high-quality syngas product that can be used for energy production or as a building block for chemical manufacturing processes.

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In addition, it includes the ability to house a wide variety of gaseous, liquid, and solid feedstocks. Conventional fuels such as coal and oil, as well as low- or negative-value materials and wastes such as petroleum coke, heavy refinery residuals, secondary oil-bearing refinery materials, municipal sewage sludge, and chlorinated hydrocarbon byproducts have all been used successfully in gasification operations. Biomass and crop residues also have bee gasified successfully. Gasification of these materials has many potential benefits over conventional options such as combustion or disposal by incineration.

## 1.2. Gasification Process

During gasification of biomass, the material is heated to a high temperature, which causes a series of physical and chemical changes that result in the evolution of volatile products and

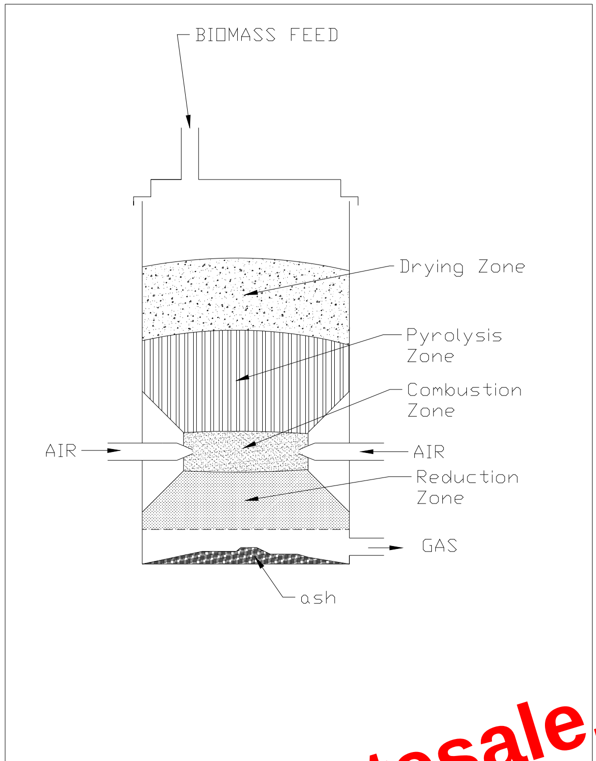


Figure 1.3. Downdraft gasifier

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### 1.4.1.3 Cross-draft Gasifier

Cross-draft gasifiers exhibit many operating characteristics of the down draft units. Air or air/steam mixtures are introduced in the side of the gasifier near the bottom while the product gas is drawn off on the opposite side. Normally an inlet nozzle is used to bring the air into the center of the combustion zone as shown in Figure 1.4. The velocity of the air as it enters the combustion zone is considerably higher in this design, which creates a hot combustion zone. The combustion (oxidation) and reduction zones are both concentrated to a small volume around the sides of the unit. Cross-draft gasifiers respond rapidly to load changes. They are normally simpler to construct and more suitable for running engines than the other types of fixed bed gasifiers. However, they are sensitive to changes in biomass composition and moisture content.

of the reactor body.

Because fluidized bed reactors operate at pressures slightly above atmospheric levels, their design and construction must prevent leakage. Hence, the fuel feeding system must be equipped with a pressure-locking device. Because the fuel is immediately gasified as it is fed into the bed, these gasifiers respond slowly to load changes. Simply put, there is no buffer stock of gas within the gasifier to supply fluctuating demands. Due to their complicated and expensive control systems, fluidized bed gasifiers appear to be commercially viable over 30 MW thermal outputs.

Like all fluidized models, bubbling fluidized beds are categorized as either a single fluidized bed and multi-fluidized beds.

#### 1.4.2.1.1. Single fluidized bed gasifier

This system consists of only one bed into which the feedstock and gasifying agent enter and out of which the produced gas and char exit. The advantages of the system include: (1) lower cost than dual and multi-fluidized beds; (2) less maintenance; and (3) the produced gas is ready for utilization. On the other hand the system has some disadvantages. These include: (1) heating value of the produced gas is lower than that produced by the dual bed; (2) inorganic materials in the feedstock cannot be separated; and (3) pyrolysis occurs at the bottom of the gasifier leading to a non-uniform temperature distribution.

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One of the earliest studies of thermochemical conversion in a single fluidized bed was carried out by Morgan et al. (1953). They studied distillation of hardwood in a 0.051 m single fluidized bed batch reactor. The bed material was powdered hardwood and the fluidizing gas was preheated nitrogen. They obtained charcoal, liquid, and gas yields of 32%, 29% and 16% (by weight of the initial charge) after operating for 30 minutes at 673 K. The remaining 23% loss was attributed to tar and char accumulation within the sampling train and the inaccuracies in the gas yield measurements.

#### 1.4.2.1.2. Dual and multi-fluidized beds gasifier

This system consists of more than one bed. The first bed is usually used to burn some of the char to produce the energy for the second bed, which is where the pyrolysis occurs. The advantages of the dual bed system include: (1) the gas heating value is larger because char combustion occurs in a separate reactor and hence the combustion gas does not dilute the pyrolysis gas; (2) inorganic materials in the feed can be separated; and (2) heat of pyrolysis in the reactor is distributed evenly, thus pyrolysis occurs at a relatively uniform temperature. Higher construction costs and greater maintenance are the disadvantages of this system.

#### 1.4.2.2 Circulating fluidized bed gasifier

If the gas velocity in a bubbling fluidized bed is further increased, more particles will be entrained in the gas stream and leave the reactor. Eventually the transport velocity for most of the particles is reached, and the vessel can be quickly emptied of solids unless additional particles are fed to the base of the reactor. If the solids leaving the vessel are returned through an external collection system, the system is called a circulating or fast fluidized bed (CFB) system (Figure 1.6). The streams of particles moving upward in the reactor are at solid concentrations well above that for dilute phase transport. Compared to conventional furnaces, circulating beds have a higher processing capacity, better gas-solid contact, and the ability to handle cohesive solids that might otherwise be difficult to fluidize in bubbling fluidized beds. Despite these advantages, circulating fluidized beds are still less commonly used that bubbling models, primarily because their height restricts their applications in terms of cost analysis.

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presence of catalysts. These parameters are quite interrelated and each of them affects the gasification rate, process efficiency, product gas heating value and product distribution.

### 1.6.1. Bed temperature

The gasification rate as well as the overall performance of the gasifier is temperature-dependent. All gasification reactions are normally reversible and the equilibrium point of any of the reactions can be shifted by changing the temperature.

As part of a wider investigation, Harris et al. (2005) presented gasification conversion data for a suite of Australian coals reacting with oxygen/nitrogen mixtures at 2.0 MPa pressure and at temperatures up to 1773 K. Combustible gas concentration increased with increases in temperature. Char yield decreased with increases in temperature. Scott et al. (1988) reported that the product gas yield from maple sawdust (1.4% M.C.) increased as the reactor temperature increased whereas the liquid and solid products decreased with increases in temperature. The decreasing amount of char indicated that the conversion increased with increases in temperature. Voloch et al. (1983) found the conversion of corncobs to increase from 94% at 500°C to 99% at 900°C in air gasification. Elliot and Sealock (1985) reported 10% and 50% wt basis conversion of lignin at 350 and 400°C, respectively. Alves and Figueiredo (1989) reported that tar production at low temperatures (below 500°C) was found to increase initially with increases in temperature and then drop with further increases in temperature. Utioh et al. (1989) reported increases in hydrocarbon gases, especially $CH_4$ and $C_2H_4$ (ethylene) with increases in temperature. The yield of higher hydrocarbons ($C_3$-$C_8$) decreased with increases in temperature above 650°C, which indicated the onset of cracking/reforming reactions. Other gas components ($H_2$ and CO), also increased with increases in temperature (Font et al., 1988). The heating value of the producer gas is also influenced by temperature. Sadakata et al. (1987) found the calorific value of crop residue gasification producer gas increased steadily up to 700°C and then decreased. The increase in the gas heating value is due to the increase in concentrations of CO, $H_2$ and hydrocarbon gases in the gas mixture. The decline at higher temperatures is probably due to the cracking of hydrocarbons. The first-order rate constant of gasification was found to increase with temperature in accordance with the Arrhenius equation (Edrich et al., 1985). Brink (1981) pointed out that gasification rates are too fast and are controlled by heat and mass transfer

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rates above 900$^{o}$C while in the range of 600-900$^{o}$C, the gasification reactions are rate controlling. Below 600$^{o}$C, the gasification reaction rates are too slow.

### 1.6.2. Bed pressure

Bed pressure has been reported to have a significant effect on the gasification process. Nandi and Onischak (1985) found the weight loss during devolatilization of crop residues in $N_2$ atmosphere at 815$^{o}$C, to decrease with increases in pressure. However, at a constant temperature, the first-order rate constant (k) for the char gasification increased as pressure increased. Using a gasifying medium of 50:50 $H_2O/N_2$ at a temperature of 815$^{o}$C, the values of the rate constant (k) for wood char were 0.101, 1.212 and 0.201 min$^{-1}$ at pressures of 0.17, 0.79 and 2.17 MPa, respectively. McLendon (2003) co-gasified mixtures of coal and biomass in a jetting, ash-agglomerating, fluidized-bed, pilot scale gasifier at an operating pressure of 3.0 MPa. Feed mixtures ranged up to 35% by weight biomass. The results of gasification tests of sub-bituminous coal/sawdust mixtures showed few differences in operations compared to sub-bituminous coal only tests. The bituminous coal mixture had marked differences. Transport properties of coal/biomass mixtures were greatly improved perhaps due to the high pressure used in this study. Plante et al. (1988) reported that the gasification rate of crop residues chars prepared at atmospheric pressure increased with increases in pressure. The increase was more significant at high temperatures (900-950$^{o}$C). Nandi and Onischak (1985) found weight loss during devolatilization of crop residues in an $N_2$ atmosphere at 815$^{o}$C to decrease with increases in the pressure. Increasing the pressure caused a significant increase in methane yield (Liinanki et al., 1985). Another advantage of pressurized reactors is the high reaction rate which allows for a smaller reactor vessel. Richard et al. (1985) found that $H_2/CO$ and $CO_2/CO$ molar ratios increased with an increase in the total pressure of a char-steam gasification process.

### 1.6.3. Bed height

At a given reactor temperature, a longer residence time (due to higher bed height) increases total gas yields. Sadaka et al. (1998) showed that a higher bed height resulted in greater conversion efficiency as well as a lower bed temperature due to the fly-wheel effect of the bed material. The fly-wheel effect is significantly reduced when the amount of bed material is reduced thereby resulting in higher bed temperature. Their results also reported that increasing

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fuel N per GJ is considerably higher than coal, which may result in increased $NO_x$ emissions. The N and S contents per GJ increase with composting of feedlot manure while the volatile ash oxide decreases with composting. Based on heating values and alkaline oxides, partial composting seems preferable to a full composting cycle. Even though the percentage of alkaline oxides is reduced in the ash, the increased total ash percentage results in an increase of total alkaline oxides per unit mass of fuel. The adiabatic flame temperature for most of the biomass fuels can be empirically correlated with ash and moisture percentage.

Raman et al. (1981) tested the gasification of feedlot manure with different superficial gas velocities. They found that the superficial velocity did not have a significant influence on produced gas yield, composition, or heating value. Walawender and Fan (1978) studied the air gasification of the feedlot manure and found that the produced gas yield, the higher heating value and the energy recovery increased by 131%, 77% and 244% when the temperature increased from 627 to 827°C. Halligan et al. (1971) gasified feedlot manure in a 0.05 m I.D. fluidized bed reactor. The fluidizing gas was a mixture of air and steam and the bed consisted of the feed material only. Over the temperature range of 693°C to 796°C, the off gas volumetric yield increased from 0.6 to 1.3 $m^3$/kg and the gas heating value increased from 8.7 to 9.8 MJ/$m^3$. The energy recovery and carbon conversion, also, increased from 23 to 49 % and from 20 to 50 %, respectively.

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## 1.9. Gasification Applications

The produced gases from biomass gasification contain both combustible and non-combustible gases. The gas can be used in industrial application areas, irrigation, vehicular power, direct heating and production of value added products.

### 1.9.1. Gasification Technology for Power Generation and Industrial Applications

Currently, electric utilities and various industrial firms have expressed growing interest in finding economical and environmentally attractive methods of converting coal, wastes, and renewable fuels into replacement energy sources for use in combined heat and power applications. Biomass gasification will become significantly more attractive in industrial shaft power applications in rural area where grid electricity is either expensive or unavailable. In urban areas, the technology will be unattractive since grid electricity is usually a cheaper source of