

SOLID GASIFICATION

Solid Gasification another thermo-chemical conversion process utilizing the following major feedstock:

- Wood;
- Agricultural & Farming Solid Waste;
- Municipal Solid Waste

Chemical process of gasification means the thermal decomposition of hydrocarbons from solid waste in a reducing (oxygen-deficient) atmosphere.

The process usually takes place at about 850°C. A solid waste gasifier can operate under atmospheric pressure or elevated pressure.

The resulting product of solid gasification is the syngas which contains combustible gases – hydrogen (H₂) and CO as the main constituents.

By-products are liquids and tars, charcoal and mineral matter (ash or slag).

Prevailing chemical reactions are listed in Table 1, where the following main three gasification stages are described.

Stage I ⇒ Gasification process starts as auto-thermal heating of the reaction mixture. The necessary heat for this process is covered by the initial oxidation exothermic reactions by combustion of a part of the fuel (refer to Table 1).

Stage II ⇒ In the second – pyrolysis stage, combustion gases are pyrolyzed by being passed through a bed of fuel at high temperature. Heavier biomass molecules distillate into medium weight organic molecules and CO₂, through reactions (8) and (9). In this stage, tar and char are also produced.

Stage III ⇒ Initial products of combustion, CO₂ and H₂O are reconverted by reduction reaction to CO, H₂ and CH₄.

These are the main combustible components of syngas. These reactions, not necessarily related to reduction, occur at high temperature.

Gasification reactions (10-13), most important for the final quality (heating value) of syngas, take place in the reduction zone of the gasifier.

Heat consumption prevails in this stage and the gas temperature will therefore decrease.

Tar is mainly gasified, while char, depending upon the technology used, can be significantly "burned" through reactions (10) and (11), reducing the concentration of particulates in the product.

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Gasification Stage	Reaction formula	(Reaction number) / Reaction type	Reaction heat kJ/kmol
Stage I Oxidation and other exothermic reactions	$C + \frac{1}{2}O_2 \rightarrow CO$	(1) Partial oxidation	+110,700
	$CO + \frac{1}{2}O_2 \rightarrow CO_2$	(2) CO oxidation	+283,000
	$C + O_2 \rightarrow CO_2$	(3) Total oxidation	+393,790
	$C_6H_{10}O_5 \rightarrow xCO_2 + yH_2O$	(4) Total oxidation	>>0
	$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$	(5) Hydrogen oxidation	+241,820
	$CO + H_2O \rightarrow CO_2 + H_2$	(6) Water-gas shift	+ 41,170
	$CO + 3H_2 \rightarrow CH_4 + H_2O$	(7) Methanation	+206,300
Stage II Pyrolysis	$C_6H_{10}O_5 \rightarrow C_xH_z + CO$	(8) Pyrolysis	<0
	$C_6H_{10}O_5 \rightarrow C_nH_mO_y$	(9) Pyrolysis	<0
Stage III Gasification (Reduction)	$C + H_2O \rightarrow CO + H_2$	(10) Steam gasification	-131,400
	$C + CO_2 \rightarrow 2CO$	(11) Boudouard reaction	-172,580
	$CO_2 + H_2 \rightarrow CO + H_2O$	(12) Reverse water shift	- 41,170
	$C + 2H_2 \rightarrow CH_4$	(13) Hydrogenation	+ 74,900

TABLE 1
THREE MAIN SUCCESSIVE STAGES OF SOLID GASIFICATION

SOURCE: J.B. JONES & G.A. HAWKINS: ENGINEERING THERMODYNAMICS, 1986, P. 456

Gasifiers are designed according to the origin and quality of fuel and the method in which the fuel is brought to contact with the oxidant.

According to the fuel gas end use, the gasifier types can be divided into:-

- Heat Gasifiers - used for fuelling external burners in boilers or dryers; and
- Power Gasifiers - coupled to gas turbine or other internal combustion engine for power generation.

Additionally, apart from being categorized according to heat or power generation purposes, gasifiers can be classified as:-

- Entrained bed;
- Fluidized bed;
- Fixed bed.

Entrained Bed Gasifier (EBG) is high-capacity design apparatus. They require perfect atomisation of feedstock (0.1mm) and therefore are not suitable for biomass gasification.

Fluidised Bed Gasifiers (FBG) can be divided into **Bubbling (BFBG)** and **Circulating (CFBG)** gasifiers.

BFBG give a good temperature control and high conversion rates, good scale-up-potential, possibility of in-bed catalytic processing.

They are not sensitive to particle size and to fluctuations in feed quantity and moisture. Product gas generated by BFBG has low tar content. Their drawback is high content of particulates.

CFBG are suitable for fuel capacity higher than 10 MW_{th}. Compared to BFBG, they have the additional advantage of giving high gas quality.

Fixed bed gasifiers are the most suitable for biomass gasification. Three possible designs of fixed bed gasifiers exist, namely:-

- Down-draft (or co-current);
- Updraft (or counter-current);
- Crossdraft (or cross current);
- Open core (open current)

All gasifiers have strict fuel requirements to size, moisture and ash content.

The typical characteristics of some biomass fuels can be summarised as presented in the Table 2.

Biomass Fuel	Moisture % wet	Ash % dry	Volatile Matter % dry	Bulk density kg/m³	Average HHV MJ/kg dry
Charcoal	2-10	2-5	5-30	200-300	30
Wood	20-40	0.1-1.0	70-80	600-800	20
Rice Husks	3-5	15-25	60	100	15
Coconut Shells	25	0.8	79	not available	20

TABLE 2
CHARACTERISTICS OF TYPICAL GASIFICATION FEEDSTOCK'S

A generalised overview of the most important fuel requirements for different type of gasifiers, are presented in Table 3.

Gasifier Type	Updraft	Downdraft	Open Core	Cross draft
Feedstock	Wood	Wood	Rice Husks	Charcoal
Size, mm	20-100	5-100	1-3	40-80
Moisture, %	<25	<60	<12	<7
Ash, %	<6	<25	Approx. 20	<6

TABLE 3
FEEDSTOCK REQUIREMENTS FOR DIFFERENT GASIFIER TYPES

The biggest advantage of solid gasification is the variety of feedstocks. The produced syngas can be utilized not only as the fuel for power generation but also as the feedstock for chemical industry.

A typical solid gasification process flow diagram is shown in Annex 7 and a simplified diagram of biomass gasification process combined with power and heat generation is shown in the following picture.

