



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

WASTE TO ENERGY CONVERSION

GASIFICATION

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Contents

- Definition and Basic chemistry of gasification
- Gasification reaction schemes and steps
- Syngas production and efficiency and Factors influencing gasification
- Advantages of gasification
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- Gasifier types
- Gasifiers for biomass and wastes
- Advanced gasification (Plasma gasification) process
- Comparison between incineration and gasification



What is gasification ?

- Gasification is a process that converts carbonaceous feedstocks including biomass and wastes into combustible gases (e.g., H_2 , CO , CO_2 , and CH_4) with specific heating values in the presence of partial oxygen (O_2) supply (typically 35% of the O_2 demands for complete combustion) and or suitable oxidants such as steam. The produced gas is called as synthesis gas or syngas.
- Syngas can be used for various applications including liquid fuels (diesel and gasoline) production through Fischer-Tropsch synthesis
- If air is used in place of oxygen the produced gas contains high amount of nitrogen and it is termed as producer gas

Oxygen requirement

O_2 /Coal ratio (w/w) (R)	Composition of products	Predominating conversion Process	Remarks
$R > 2.5$	$O_2 + H_2O + CO_2$	Combustion	O_2 content increases with R
R within 0.68-2.5	$CO + H_2 + H_2O + CO_2$	Gasification	CO and H_2 content decreases and $H_2O + CO_2$ content increases with R
$R < 0.68$	$C(s) + CO + H_2$	Pyrolysis	C(s) content decreases with R

Source: "Energy and products from waste," Omega Thermal Tech, USA.

[Online] Available: http://www.ottusa.com/synthetic_fuel/synthetic_fuel.htm 15 Sep, 2016.



Basic chemistry of gasification

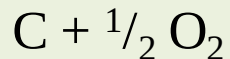
Carbonaceous
Feedstock(s)

Oxygen

Steam

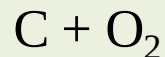
Biomass and wastes
containing high
moisture content may
not require steam

Gasification with Oxygen



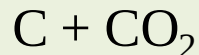
$$\Delta H_{298}^0 = -110.5 \text{ kJ/mol}$$

Combustion with Oxygen



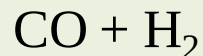
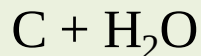
$$\Delta H_{298}^0 = -393 \text{ kJ/mol.}$$

Gasification with Carbon Dioxide (Boudouard reaction)



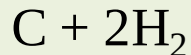
$$\Delta H_{298}^0 = +172.0 \text{ kJ/mol}$$

Gasification with Steam



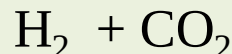
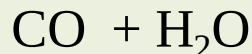
$$\Delta H_{298}^0 = +131.4 \text{ kJ/mol}$$

Gasification with Hydrogen



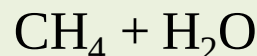
$$\Delta H_{298}^0 = -74.8 \text{ kJ/mol}$$

Water-Gas Shift



$$\Delta H_{298}^0 = -40.9 \text{ kJ/mol}$$

Methanation



$$\Delta H_{298}^0 = -205 \text{ kJ/mol}$$

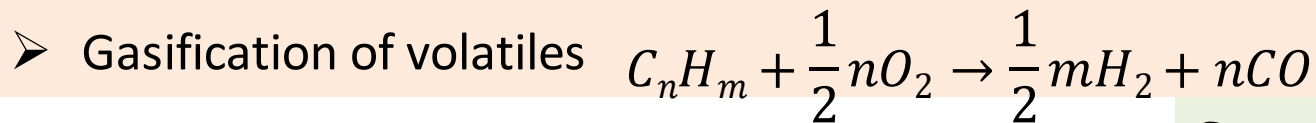
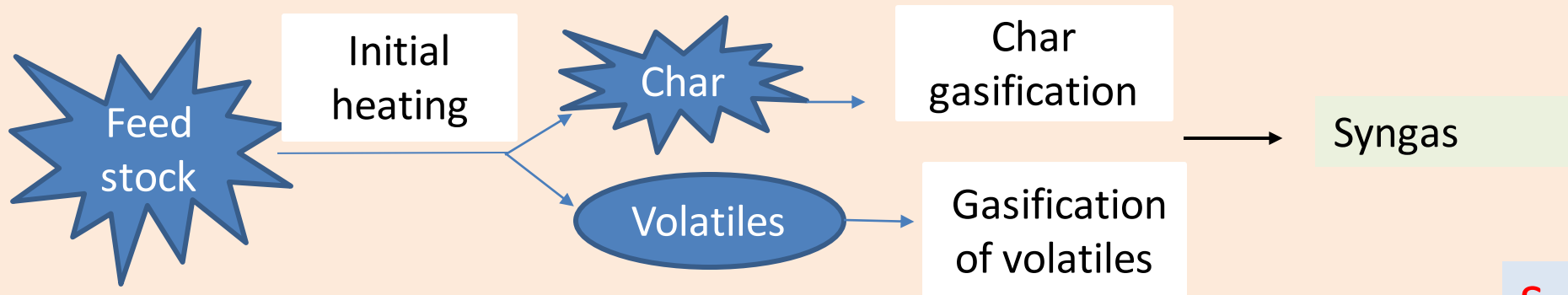


Comparison of gasification product gases

Properties	Syngas	Producer gas
Typical major compositions		
H ₂	20-30 %	13-19 %
CO	40-60 %	18-22 %
CO ₂	5 to 15%	9-12 %
CH ₄	0-5 %	1-5 %
Heavier hydrocarbon	-	0.2-0.4 %
Nitrogen	0.5 -4 %	45-55 %
Water vapour	8-12 %	4 %
Typical Heating value	9.3 to 14.9 MJ/m ³	4.5 to 6 MJ/m ³



Gasification reaction schemes

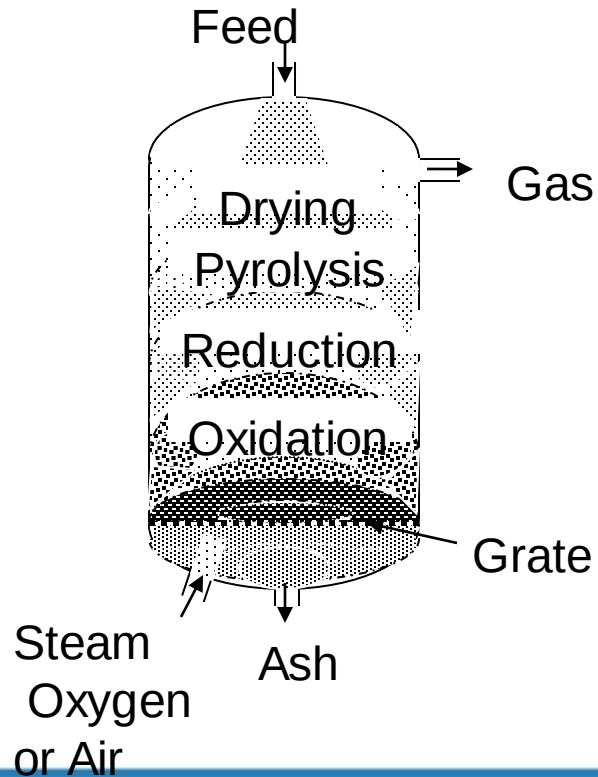


Smoot and Smith, 1989



S
Y
N
G
A
S

Steps involved in gasification

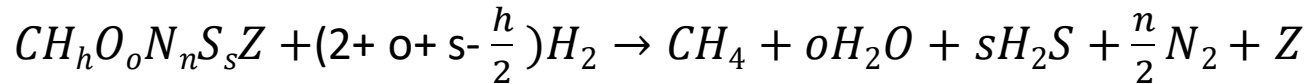
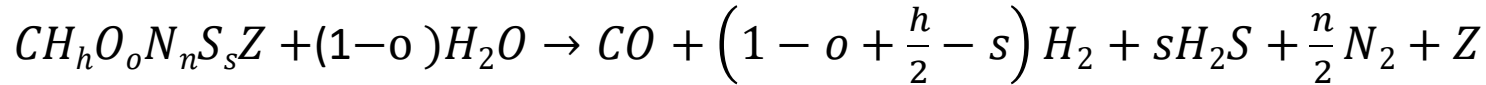
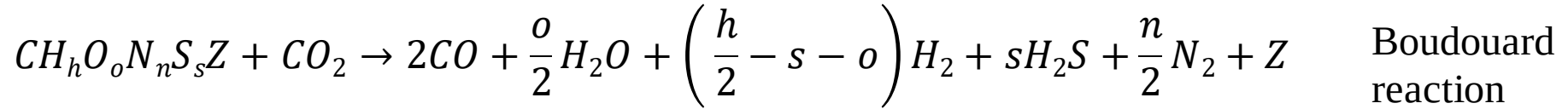
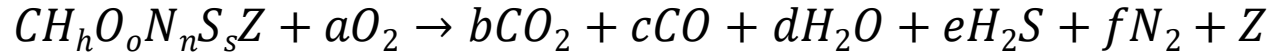


- Drying
- Devolatilization/ Pyrolysis
- Reduction
- Oxidation
- Ash cooling

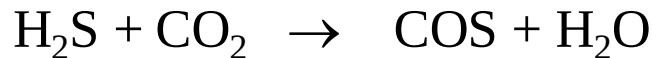
- Unlike incineration, in case of gasification the volatilized gases do not get burnt completely.
- Chars also get gasified as oxygen supply is less

Alternatively

Valero et al. 2006



Important Gas phase reaction



Syngas production and efficiency

- Syngas production can be determined if air flowrate, feeding rate and composition of syngas is known.
- If a waste is composed of C and H only and syngas contains CO, CO₂, H₂, CH₄ and C₂H₂, the syngas production can be related as:

$$\text{Fuel gas production}(\text{Nm}^3/\text{kg}) = \frac{\text{air flow rate}(\text{Nm}^3/\text{s}) * 0.79}{\left[1 - \frac{\text{CO} + \text{CO}_2 + \text{H}_2 + \text{CH}_4 + \text{C}_2\text{H}_2}{100}\right] * \text{feeding rate}(\text{kg}/\text{s})}$$

Yield of H₂ and CO can be expressed as :

$$\text{H}_2 \text{ yield} = \frac{\text{H atoms in the syngas}}{\text{H atoms injected}}$$

$$\text{CO yield} = \frac{\text{C atoms in formed CO}}{\text{C atoms injected}}$$



- Energy efficiency of the process (or cold gas efficiency) is defined by the ratio of the LHV of cold gas to the LHV of the waste treated, incremented by the added energy (electric or fuel) for allothermal processes per kg of waste.

$$\eta = \frac{\text{LHV of cold gas}(\text{kJ} \cdot \text{Nm}^{-3}) * \text{fuel gas production}(\text{Nm}^3/\text{kg})}{\text{LHV of waste treated}(\text{kJ} \cdot \text{kg}^{-1}) + \frac{\text{allothermal Power}(\text{kW})}{\text{waste flow rate}(\text{kg/s})}}$$

- Generally, the conversion efficiency of thermal power plant is between 30 % and 40 % for a single cycle steam power plant and can be up to 60 % for a Combined Cycle Gas Turbine (CCGT) power plant.

Source: Frederic Fabry, Christophe Rehmet, Vandad-Julien Rohani, Laurent Fulcheri. Waste Gasification by Thermal Plasma: A Review. Waste and Biomass Valorization, 2013, 4 (3), pp.421-439

Factors influencing Gasification

- **The type of feed injection**: biomass is either fed from the top of the gasifier, or from the side and then is moved around either by gravity or air flows.
- **The gasification agent used**
Air or oxygen
- **The type of heating**: it can be done either by partial combustion of the biomass in the gasifier (directly heated), or from an external source (indirectly heated), such as circulation of an inert material
- **The temperature range**
- **The pressure range under which the gasifier is operated**

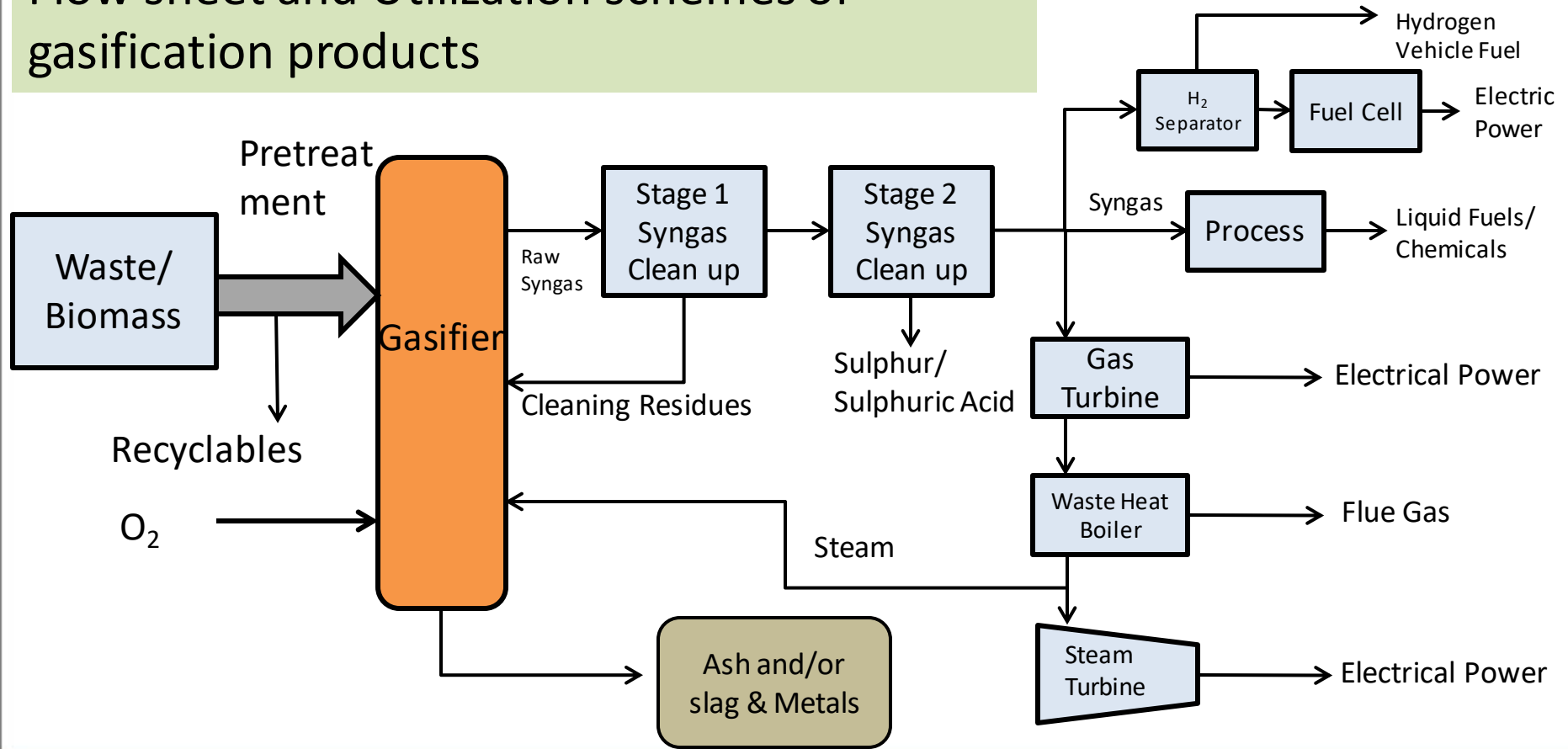


Advantages of gasification

- Reduced CO₂ emissions
- Compact equipment requirements with a relatively small footprint
- Accurate combustion control
- High thermal efficiency



Flow sheet and Utilization schemes of gasification products



Syngas Cooling and Conditioning

- Reduce syngas temperature
 - Extract valuable energy
 - Use conventional/commercial processes
- Remove chemical species that
 - Foul, corrode, or erode system components
 - Poison or deactivate chemical processing agents
 - Are environmentally unacceptable for release
- Target Syngas purity
 - H_2S and COS concentration
 - CO_2 concentration
- Adjust H_2/CO ratio

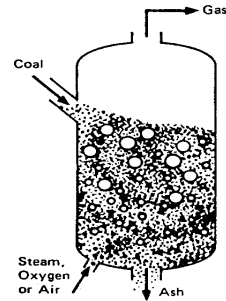
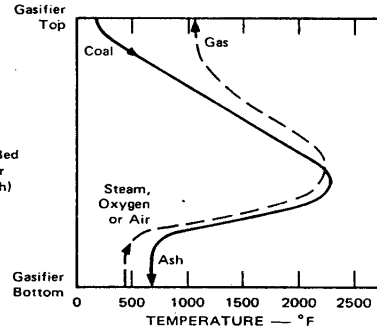
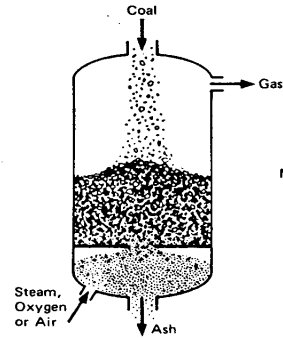
Table : Desired quality of treated syngas for various downstream applications

Downstream use	Power	Hydro-processing	Chemical
Sulfur (wppm)	10-15	<1	<0.01-1
CO_2 (vol.%)	-	<0.1	0.05-2.0
CO	-	<50 wppm	H_2/CO control as per requirement

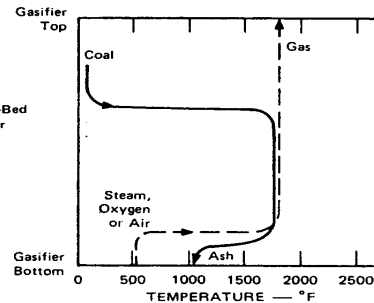


Major Types of Gasifiers for coal and petcoke

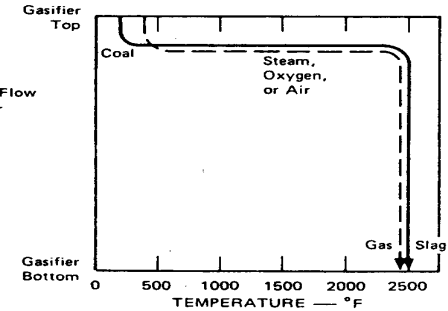
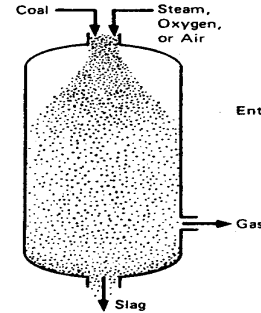
Moving Bed



Fluidized-Bed Gasifier



Entrained Bed



Fluidized Bed

Source: National Energy Technology Laboratory - Department of Energy, USA.

Available: <https://netl.doe.gov/File%20Library/Research/Coal/energy%20systems/turbines/handbook/1-2-1.pdf>



Major Types of Gasifiers for coal and petcoke

Gasifier	Technology	Typical Process conditions
Fixed bed	BGL, Lurgy Dry ash	Combustion Temp. : 1300 °C (slurry feed) and 1500-1800 °C (dry feed) Gas out let Temp. : 400-500 °C; Pressure: 0.15 - 2.45 MPa R.T. : 15-30 min ; Feed particle size : 2-50 mm O ₂ /Feed : 0.64 Nm ³ /kg; Gas heat value (MJ/Nm ³) : 10.04 Cold gas efficiency : High
Fluidized bed	HTW, IDGCC, KRW, Mitsui Babcock	Combustion Temp. : 900-1200 °C ; Gas outlet Temp. : 700-900 °C Pressure : 0.1 -2.94 Mpa; R.T : 10-100 s Particle size : 0.5-5.0 mm; O ₂ /Feed : 0.37 Nm ³ /kg Gas heat value(MJ/Nm ³) :10.71; Cold gas efficiency : Medium



Major Types of Gasifiers for coal and petcoke

Gasifier	Technology	Typical Process conditions
Entrained bed	BBP, Hitachi, MHI, PRENFLO, SCGP, E-Gas, Texaco	Combustion Temp. : 1500 ° C; Gas out let Temp.: 900-1400 ° C Pressure : 2.94-3.43 Mpa; R.T : 1 -10 s Particle size : < 200 mesh (90%); O ₂ /Feed :1.17 Nm ³ /kg Gas heat value (MJ/Nm ³) : 9.58; Cold gas efficiency : Medium
Transport reactor	KBR	Combustion Temp. : 900-1050 ° C ; Gas out let Temp. : 590-980 ° C Pressure : 0.29 1.47 Mpa; R.T : 1 -10 s Particle size : < 50 μm; O ₂ /Feed : 1.06 Nm ³ /kg Gas heat value (MJ/Nm ³) : -; Cold gas efficiency : Medium



Thanks...

