Renewable Energy and Fuel from Waste

Thermochemical Pathways

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Gasification Overview

What Is Gasification?

1. Gasification is a thermochemical conversion process in which any carbonaceous feedstock is converted into a combustible gas through partial oxidation; essentially into a mixture of CO and H_2.
2. Feedstock experience: Heating and drying, evaporation, pyrolysis, devolatilization, and combustion
3. *C_nH_m+ n/2 O_2 => n CO + m/2 H_2 is the overall reaction*
4. Gasifier is a high capital cost device ($50,000,000-$500,000,00) and is the main unit in the IGCC plant

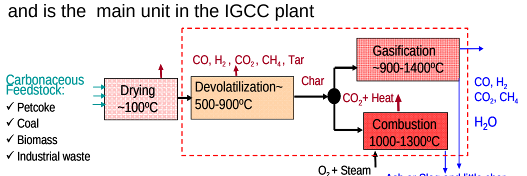


Figure 1: Gasification process

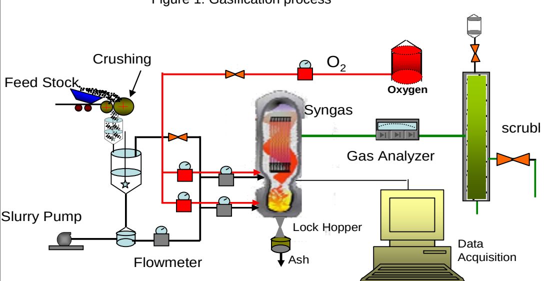


Figure 2: Laboratory scale gasification plant

Why Gasification?

- ❑ Ability to recover 72% - 85% of the chemical energy stored in the dirty feedstock into clean gas

C + O2 => CO_2 -394*MJ/kmol*---"dirty" combustion
C + 1/2O_2 => CO -111*MJ/kmol*---gasification, depletes 28% gas conversion
CO +1/2O_2=> CO_2 -283*MJ/kmol*- -clean combustion,72% gas energy recovery

Typically, H_2 is formed and the recovered energy is over 80%.

- ❑ Feedstock flexibility: refinery residuals, coal, biomass, as well as:

Municipal	*Waste Clinical/Medical*	***Waste Plastic***
Industrial Waste	*Pharmaceutical Waste*	***Oil Wastes***
Domestic Waste	*Biological Waste*	***Hydrocarbons***
Sewege Sluge	*Chemicals*	*Photographics*
Rubber	*Asbestos*	*Classified Nuclear*
Contaminated Water	*Offals*	*Electronic Waste*

- ❑ Product flexibility: fuel, chemicals and fertilizers
- ❑ Plausible environmental impact: Amenable for pollutant and gas clean up, CO_2 capture for EOR
- ❑ Added power station efficiency due to higher operating temperature

Cycle	Fuel	Temp low (oC)	Temp High (oC)	Carnot (η)	Actual (η)	Car(η)/Act(η)%
Conventional Steam Power Plant	Coal	27	540	63	40	63
Ditto Ultra Super Critical	Coal	27	650	67	45	67
IGCC	Coal	27	1350	82	46	56
Open Gas Turbine Cycle	Gas	27	1210	80	43	54
Combined Cycle	Gas	27	1350	82	58	71
Low Speed Marine Diesel (LSMD)	Heavy Fuel Oil	27	2000	87	48	55
LSMD with Super Charger	Heavy Fuel Oil	27	2000	87	53	61

World gasification database (NETL 2007):

- ❑ Current gasification capacity has grown to 56,238*MWth* with a total of 144 plants operating 427 gasifiers.
- ❑ Located in 27 countries, Asia/Australia at 34% and Africa/Middle East are at 27% of this capacity.
- ❑ Consumption rate: Coal 55%, petroleum 33%. Others 12% natural gas, petcoke, and biomas/wastes.
- ❑ Syngas usage: chemicals 45%, Fisher-Tropsch 28%, power generation 19%, and gaseous fuel 8%.

Current Technology & Objective

Gasification Technology:

- ❑ Three primary technologies are distributed: Sasol-Lurgi: 34%, GE 31% and shell at 28%
  1) the fixed/moving bed gasifiers
  2) fluidized/bubbling bed gasifiers
  3) Entrained flow gasifiers
- ❑ Current focus: Two-stage, upflow with multiple feed-inlets high conversion rate (>99%), high throughput, and high HV and most clean syngas.

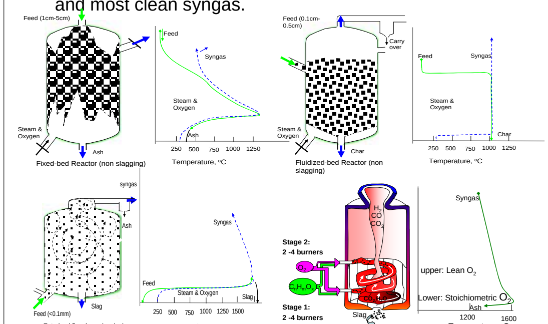


Figure 3: Gasifier technology types

Category	Moving Bed		Fluid Bed		Entrained-Flow
Ash condition	Dry Ash	Slagging	Dry Ash	Agglomerating	Slagging
Typical processes	Lurgi	BGL	Winnkler, HTW, CFB	KRW, U-Gas	Shell, Texaco, E-Gas, Noell, KT
Feed characteristics					
Size	6-50mm	6-50mm	6-10mm	6-10mm	<100 μ m
Acceptability of fines	Limitted	Better than dry ash	good	better	unlimitted
Acceptability of caking coal	yes (with stirrer)	yes	possibly	yes	yes
Prefered coal rank	any	high	low	any	any
Operating characteristics			l		
Outlet Gas Temperature	low (425-650C)	low (425-650C)	moderate (900-1050C)	moderate (900-1050C)	high (1250-1600C)
Oxidant demand	low	low	moderate	moderate	high
Steam demand	high	low	moderate	moderate	low
Other characteristics	hydrocarbone in gas	hydrocarbone in gas	lower carbon	lower carbon	pure gas, high c conversion

Source: Adapted from Simbeck et al. 1993

What are the Technology Challenges?

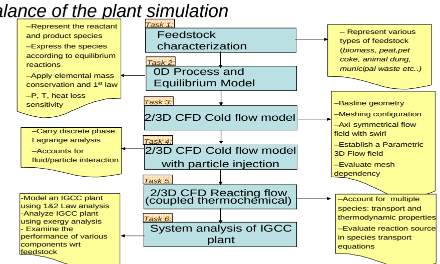
1) Lack of feedstock flexibility
2) Hot spotting, slag blockages, downstream fouling, refractory, and injector failures
3) Lack of knowledge of the flow dynamics, temperature field, chemical kinetics within the gasifier
4) Process scalability: effect on gas heating value and composition, cold gas efficiency, carbon conversion
5) Accurate and reliable systematic analysis, and advanced CFD simulations coupled with kinetic analysis

Objective:

1. Achieve a fundamental improvement in gasification technology through modeling and advanced simulation of the fluid dynamics, transport processes, and chemical kinetics
2. Exploit the integration of the gasification unit with the balance of the plant and optimize the performance and the economic benefits of converting waste streams into high value products.
3. Develop a laboratory facility for testing novel thermochemical conversion concepts and evaluating performance metrics for different feedstock and processes

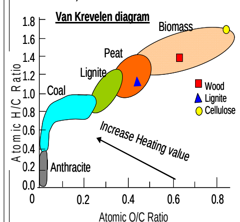
Approach:

- ❑ *Feedstock Characterization:*
- ❑ *Physical and Numerical Analysis:*
- ❑ *Cold/non-reacting flow:*
- ❑ *Two-phase non-reacting flow*
- ❑ *Reacting flow Analysis*
- ❑ *Integrating CFD analysis into The balance of the plant simulation*



Work in Progress

1) Characterizing the physical and chemical properties of feedstock using traditional proximate and ultimate analysis method: Examining the physics and chemistry of gasification as applied to a wide variety of feedstock, from refinery residue to industrial, agricultural and/or municipal waste, to biomass…



Composition, Heating Value, and gasifier reactions:

- ❑ Biomass ===> $CH_{1.4}O_{0.6}$
- ❑ Cellulose ===> $CH_{1.67}O_{0.83}$
- ❑ Peat =======> $CH_{1.1}O_{0.4}$
- ❑ Coal =======> $CH_{0.95}O_{0.2}$
- ❑ Tire waste ===> $CH_{1.12}O_{0.11}$

❑ HHV[MJ/kg]= **34.91*C+117.83*H-10.34*O -1.51*N+10.05*S-2.11*Ash**

where C, H, O, N, S, and Ash are mass fraction from the ultimate analysis

2) Carrying out "systematic" zero-dimension analysis:

Combustion reactions:
C + 1/2O_2= CO - 111MJ/kmol
CO +1/2O_2= CO_2 - 283MJ/kmol
H_2 + 1/2O_2= H_2O - 242MJ/kmol

Boudouard reaction:
C + CO_2⇔ 2CO + 172MJ/kmol

Water gas reaction:
C+H_2O⇔CO+H_2+131MJ/kmol

Methanation reaction:
C + 2 H_2 ⇔ CH_4 -75MJ/kmol

Two reaction solution:

✓ CO + H_2O⇔H_2 + CO_2-41 MJ/kmol

$$K_{p_1}=\frac{k_f}{k_r}=\frac{[CO_2].[H_2]}{[CO].[H_2O]}=\frac{p_{CO_2}\cdot p_{H_2}}{p_{CO}\cdot p_{H_2O}}$$

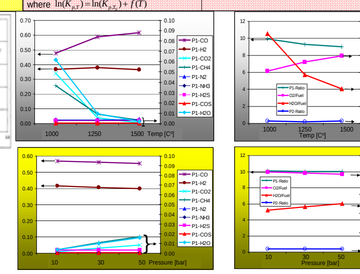
✓ CH_4 +H_2O⇔CO+3H_2+206 MJ/Kmol

$$K_{p_2}=\frac{k_r}{k_f}=\frac{[CO].[H_2]^3}{[CH_4].[H_2O]}=\frac{p_{co}\cdot p_{H_2}^3}{p_{CH_4}\cdot p_{H_2O}}$$

where $\ln(K_{p,T})=\ln(K_{p,T_0})+f(T)$

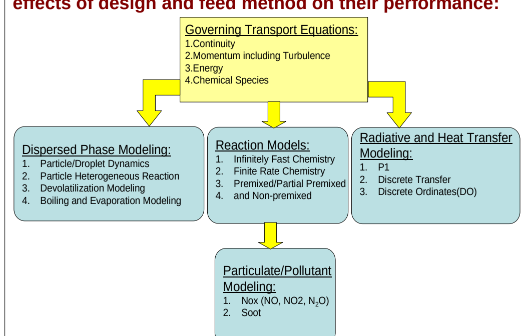
❑ Number of Unknowns 6:
✓ [CO_2] [CO] , [H_2], [H_2O], [CH_4]
✓ and Temperature **T**

❑ Number of Equations:
✓ 3 elemental balance (O, C, H)
✓ 1 heat balance
✓ 2 equilibrium reactions



Temperature & Pressure Sensitivity

3) Performing advanced CFD simulations to examine the effects of design and feed method on their performance:



Detailed CFD modeling is necessary to evaluate chemical kinetics and transport processes and predict species, oxidizer and moderator amounts, temperature, heat release and distribution, rate of reaction, syngas yield