



# Notes on Terminology and Technology in Thermal Conversion

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### Summary

This note is to define common terms and basic technology in biomass and wastes thermal conversion. There are numerous reviews in the literature on the exact types and configurations of technologies available (e.g. 1).

### 1. Terminology; Pyrolysis, Gasification and Combustion

When biomass is burnt completely (combusted) sufficient air is added to oxidise all of the combustible components. Thus:

Combustion is the reaction of a material with air/O<sub>2</sub> with the intent of completely oxidising it ( $\lambda > 1$ ).

$\lambda$  (lambda) is defined as the exact air (O<sub>2</sub>)/fuel ratio required to completely oxidise the fuel. This is also known as the stoichiometric ratio.

Gasification is the sub-stoichiometric conversion of a material into a gas, commonly referred to as "producer gas" if the reaction is with air and "syngas" if the reaction is with O<sub>2</sub>. Steam is also sometimes added along with the oxidant to promote gasification, but steam may also be used in its own right to gasify a material at high temperatures. The "ideal" stoichiometric air/fuel ratio is in the 0.3-0.4 to assure complete gasification of the solid fuel and obtain the optimal heating value of the gas product.

Pyrolysis is defined as the thermal degradation of biomass in the absence of oxygen to produce condensable vapours, gases, and charcoal; in some instances a small amount of air may be admitted to promote this endothermic process (where  $\lambda < 0.2$ ).

Liquefaction is low temperature (250° - 350°C), high pressure [50 – 200 atm] thermo-chemical conversion in the liquid phase, usually with a high hydrogen partial pressure and also a catalyst to enhance the rate of reaction and / or improve the selectivity of the process.



## 2. Terminology: other

Biomass is defined as a renewable source of fixed carbon in the short term, i.e. less than 10-20 years. This includes agricultural residues such as crop residues, manures, industrial wastes such as paper mill sludge and residues from sugar mills, waste wood products, etc.

Biochar is char derived from the thermal conversion of biomass which is used for non-energy purposes. It may however have an alternative use as an energy carrier.

Syngas or pyrolysis gas is the non-condensable product of pyrolysis containing CO, CO<sub>2</sub>, H<sub>2</sub>, CH<sub>4</sub>, and higher hydrocarbons.

Tar is the generic (unspecific) term for all organic compounds present in the gasification product gas excluding gaseous hydrocarbons [in the range C<sub>1</sub> - C<sub>6</sub>] (2)

Producer gas is the primary non-condensable product of gasification containing CO, CO<sub>2</sub>, H<sub>2</sub>, CH<sub>4</sub>, and higher hydrocarbons [C<sub>1</sub>-C<sub>6</sub>].

Pyrolysis liquid [also know as "bio-crude-oil", "bio-oil", "pyroligneous acid", "pyrolysis tar" and "biofuel-oil"] is the condensable [< 25°C] liquid product of pyrolysis containing a wide range of oxygenated chemicals.

Pyrolytic lignin is the fraction recovered from pyrolysis liquids by the addition of water to the pyrolysis liquids causing precipitation of the lignin-derived components.

## 3. Pyrolysis

### 3.1 Slow pyrolysis

Slow pyrolysis has been used for centuries to produce charcoal, tars, alcohols such as ethanol and methanol and other solvents. This is usually carried out in batch processes using kilns or retort furnaces (e.g. 3, 4, 5). Conventional pyrolysis is characterised by:

- long solids and volatiles residence times [typically greater than 5 s for volatiles; solids residence times can be minutes, hours or days],
- relatively low reactor temperatures [< 400°C],
- atmospheric pressure,
- very low heating rates ranging from 0.01°C/s to up to 2°C/s,
- very low rate of thermal quenching of the products [minutes to hours].



Char, viscous tarry liquid and gases are formed in approximately equal mass proportions due to the slow degradation of the biomass and extensive secondary intraparticle and gas/vapour phase reactions.

### 3.2 Conventional pyrolysis

Conventional pyrolysis is similarly characterised by:

- long solids and volatiles residence times [typically less than 5 s for volatiles; solids residence times can be longer] up to one minute,
- relatively low reactor temperatures [ $< 450^{\circ}\text{C}$ ],
- slow heating rates [of the material] of about  $2\text{-}10^{\circ}\text{C/s}$ ,
- atmospheric pressure,
- low rate of thermal quenching of the products (6, 7).

Yields of organic liquids products from conventional pyrolysis are typically low, e.g. 20 % with char yields of typically 20-25 wt%, 20 wt% water and the balance non-condensable gases comprised mainly of carbon dioxide (8). Yields are subject the composition of the starting material.

### 3.3 Flash and fast pyrolysis

Flash pyrolysis was formerly characterised up to the early 1990's by:

- moderate pyrolysis temperatures [ $400\text{-}600^{\circ}\text{C}$ ],
- atmospheric pressure,
- high heating rates [ $10\text{-}1000^{\circ}\text{C/s}$ ],
- gas/vapour product residence times less than 2 s to maximise liquid yields at gas/vapour product temperatures less than  $500^{\circ}\text{C}$ .

Fast pyrolysis was characterised similarly by:

- higher heating rates than flash pyrolysis [ $>10^5\text{ C/s}$ ],
- higher reactor temperatures [ $> 600^{\circ}\text{C}$ ] to give primarily a gaseous product at the expense of liquids and char,
- shorter gas/vapour product residence times of less than 0.5 s (9),
- rapid thermal quenching of the products [ $100\text{-}1000^{\circ}\text{C/s}$ ].

Fast pyrolysis therefore gives higher reaction rates due to the higher temperatures. The distinction between flash and fast pyrolysis has largely disappeared and now the term "flash" has largely disappeared and is gradually being replaced by a more generalised definition for fast pyrolysis of:

- high heating rates [ $> 1000^{\circ}\text{C/s}$ ],
- reactor temperatures greater than  $450^{\circ}\text{C}$ ,
- short vapour product residence times [ $< 2\text{ s}$  for liquid fuels,  $< 1\text{ s}$  for speciality chemicals],
- rapid product quenching [ $< 40\text{ ms}$ ] (10).



The fast pyrolysis process can be operated from ~425-550°C to optimise liquid yields [depending on the feedstock] and above 600°C to increase or optimise the gas yield, commonly referred to as "syngas". This may also be referred to as high temperature pyrolysis.

## 4. Gasification

### 4.1 Steam Gasification

Steam gasification is the gasification of biomass using steam > 800°C to yield a producer gas. Heat is added indirectly to the biomass via a solid heat carrier or the steam to effect reaction.

### 4.2 Oxygen Gasification

Oxygen gasification is the gasification of biomass using either oxygen-enriched air or pure oxygen to yield a producer gas. Heat may be added indirectly to the biomass via a solid heat carrier to effect reaction.

## References

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