INTRODUCTION

• In most developing countries, burning and landfilling are the common placed methods for municipal solid waste (MSW) management → glass and plastics are recycled

• However, these methods are largely inadequate and also pose a threat to the environment, public health, quality of air, landscape and ground water (Adefeso, 2012).

• Waste-to-Energy technologies

THERMO-CHEMICAL SOLID WASTE TREATMENT

• Thermo-chemical solid waste treatment involves thermal decomposition of organic matter to produce heat energy or fuel oil or gas

• This process is suitable particularly for solid wastes (or feedstock) having high percentage of organic non-biodegradable matter and low moisture content

• It is characterized by higher temperature and conversion rates

• The main technological options include:
  - Combustion,
  - Pyrolysis,
  - Gasification
  - Incineration
  - Plasma Treatment

(Bosmans and Helsen, 2010)
Thermo Chemical Conversion Processes and Products
(Begum et al., 2012)

**THERMO-CHEMICAL TREATMENT**

The important **physical parameters** include:
- size of constituents,
- density and
- moisture content.

The important **chemical parameters** include:
- Volatile Solids,
- fixed carbon content,
- inerts,
- calorific value,
- C/N ratio (carbon/nitrogen ratio) toxicity.

### PYROLYSIS

- It is thermal degradation of organic material in the absence of oxygen or with such a limited supply that gasification does not occur to an appreciable extent; the latter may be described as partial gasification and is used to provide the thermal energy required for pyrolysis at the expense of product yields.
- Relatively low temperatures (400-900 °C, but usually lower than 700 °C) are employed compared to gasification.
- Three products are obtained: pyrolysis gas, pyrolysis liquid and solid coke, the relative proportions of which depend very much on the pyrolysis method and reactor process parameters.

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- Three products are obtained: pyrolysis gas, pyrolysis liquid and solid coke, the relative proportions of which depend very much on the pyrolysis method and reactor process parameters.
- The heating values of pyrolysis gas typically lie between 5 and 15 MJ/m³ based on MSW and between 15 and 30 MJ/m³ based on RDF
PYROLYSIS

Basic stages in Pyrolysis:

• Preparation and grinding: the grinder improves and standardizes the quality of the waste presented for processing and so promotes heat transfer.
• Drying (depends on process): a separated drying step improves the lower heating value of the raw process gases and increases efficiency of gas-solid reactions within the rotary kiln.
• Pyrolysis of wastes: in addition to the pyrolysis gas, a solid carbon-containing residue accumulates which also contains mineral and metallic portions.
• Secondary treatment of pyrolysis gas and pyrolysis coke: through condensation of the gases for the extraction of energetically usable oil mixtures and/or incineration of gas and coke for the destruction of the organic ingredients and simultaneous utilization of energy.

Advantages:

• possibility of recovering (part of) the organic fraction as material/fuel (e.g. as methanol),
• possibility of more efficient electricity generation using gas engines or gas turbines (instead of steam boilers),
• reduced flue gas volumes after combustion, which may reduce the flue gas treatment capital costs to some degree,
• possibility of recovering the char for external use, after pretreatment (e.g. washing of chlorine).

EXAMPLE OF PYROLYSIS

Gasification is the thermochemical conversion of carbon-based materials into a combustible gaseous product (synthesis gas or syngas).

It involves the reaction of carbonaceous materials with air, oxygen, steam, carbon dioxide, or a mixture of these gases at 500-1800 °C or higher.

Air gasification produces a low heating value (LHV) gas (4-7 MJ/Nm³ higher heating value)

Oxygen gasification produces a medium heating value (MHV) gas (10-18 MJ/Nm³ higher heating value) (Helsen, 2000).

Gasification is the conversion of carbonaceous materials into a combustible gaseous product.

The syngas contains CO₂, CO, H₂, CH₄, H₂O, trace amounts of higher hydrocarbons, inert gases originating from the gasification agent, various contaminants such as small char particles, ash and tars (Bridgewater, 1994).

The syngas can be used for efficient production of electricity and/or heat, or second generation liquid biofuels.

Gasification processes are suitable for the treatment of MSW, certain hazardous wastes and dried sewage sludge.

The nature (size, consistency) of the waste input should remain within certain predefined limits → adequate gas-solid contact for maximal conversion of carbonaceous material into CO and H₂ and minimal tar formation.

Typically, this requires pre-treatment of MSW, thereby increasing the cost.
GASIFICATION

Advantages of gasification processes include:

- smaller gas volume compared to incineration (up to a factor of 10 by using pure $O_2$),
- smaller waste water flows from synthesis gas cleaning,
- predominant formation of CO rather than $CO_2$,
- capturing of inorganic residues, e.g. within slag in high temperature slagging gasifiers,
- high operating pressures (in some processes), leading to small and compact aggregates,
- material and energetic utilization of the synthesis gas.

Four main types of gasification reactors used in practice: entrained flow gasifier, fluidized bed gasifier, cyclone gasifier and packed bed gasifier.

EXAMPLE OF GASIFICATION

Incineration is the oxidation of the combustible materials contained in the waste.

- It is full oxidative combustion at 1000 °C.
- It is aimed to treat waste to reduce its volume and hazardous characteristics, hereby capturing (and thus concentrating) or destroying potentially harmful substances.
- Incineration processes can also provide a means to enable recovery of the energy, mineral and/or chemical content of solid waste.
- Waste material is converted into ash, flue, gas and heat.

INCINERATION

- During incineration, flue gases are generated that contain the majority of the available fuel energy as heat.
- The organic waste substances burn when they have reached the ignition temperature and come into contact with oxygen.
- The actual combustion process takes place in the gas phase in fractions of seconds and simultaneously releases energy.
- Incineration is by far the most widely applied.
- Depending on the combustion temperatures during the main stages of incineration, volatile heavy metals and inorganic compounds (e.g., salts) are totally or partly evaporated.
- These substances are transferred from the input waste to both the flue gas and the fly ash.
**EXAMPLE OF INCINERATION**

- Combustion of waste has been used for many years as a way of reducing waste volume and neutralizing many of the potentially harmful elements within it.
- Combustion can only be used to create an energy source when heat recovery is included.
- Heat recovered from the combustion process can then be used to either power turbines for electricity generation or to provide direct space and water heating.

**COMBUSTION**

- The combustion reaction needs fuel (from waste materials) and oxygen (from the atmosphere).
- Organic solid waste materials are mainly composed of carbon, hydrogen, oxygen, sulfur, and nitrogen.
- To simplify, the combustion reaction is as follows:
  \[ C \text{(in the waste)} + O_2 \rightarrow CO_2 + \text{heat} \]
  \[ H_2 \text{(in the waste)} + O_2 \rightarrow H_2O + \text{heat} \]

**PLASMA TREATMENT**

- Plasma-based technologies – combination of (plasma-assisted) pyrolysis/gasification of the organic fraction and plasma vitrification of the inorganic fraction of waste feed.
- The presence of charged gaseous species makes the plasma highly reactive and causes it to behave significantly different from other gases, solids or liquids.
- Plasma is generated when gaseous molecules are forced into high energy collisions with charged electrons, resulting in the generation of charged particles.
- The application of plasma-based systems for waste management is a relatively new concept.

**PLASMA TREATMENT**

The principal advantages that plasma offers to waste treatment processes have been summarized by Heberlein (1992):

(a) High energy densities and high temperatures, characteristics which allow:
- rapid heating and reactor start-up,
- high heat and reactant transfer rates,
- smaller installation size for a given waste throughput,
- melting of high temperature materials.

(b) Use of electricity as the energy source, resulting in:
- decoupling of the heat generation from the oxygen potential and the mass flow rate of the oxidant or air,
- increasing process controllability and flexibility,
- lower off-gas flow rates and consequently lower gas cleaning costs,
- the possibility of producing valuable (saleable) co-products.

**PLASMA TREATMENT**

Plasma technologies for waste treatment can be divided into different categories (Heberlein and Murphy, 2008):

- plasma pyrolysis,
- plasma gasification,
- plasma compaction and vitrification of solid wastes, and
- combinations of the three already mentioned (in particular for solid wastes with high organic contents).

Plasma pyrolysis of organic waste usually results in two product streams: a combustible gas and a carbonaceous residue (char).
PLASMA PYROLYSIS

- Plasma pyrolysis is an attractive technique for material recovery. For waste streams that contain high concentrations of organic materials with high heating value.
- In selecting the optimal waste treatment process, the waste composition is an important parameter.
- Laboratory experiments have shown that plasma pyrolysis offers potential for carbon black recovery from used tires (Tang and Huang, 2005).
- Plasma pyrolysis of hazardous liquids and gases is becoming increasingly important and is already a commercially proven technology.

PLASMA PYROLYSIS

- The PLASCON process (developed by CSIRO and SRL Plasma Ltd. in Australia, and now owned by DoloMatrix International Ltd.) uses plasma pyrolysis to treat fluid wastes containing halogenated hydrocarbons, CFCs, HFCs, PCBs and other harmful components.
- The process uses a direct current (DC) plasma torch with tungsten cathode and argon as plasma gas.
- Presently, ten plants are operating in Australia, Japan, USA and Mexico (Heberlein and Murphy, 2008).

PLASMA GASIFICATION

- Plasma gasification, an innovative technology for converting waste streams into a valuable synthesis gas and a vitrified slag by means of thermal plasma.
- Gas plasma technologies for waste treatment use electricity as energy source instead of the energy content of the treated substances, makes the system very flexible and controllable.

PLASMA GASIFICATION

- The NRG/Westinghouse plasma gasification reactor (WPC, 2010)

COMBINATION TREATMENT

- Besides the individual processes (incineration, gasification or pyrolysis), combinations of these processes, possibly combined with other processes (e.g. melting, distillation) are also applied:
  - Combination pyrolysis – gasification
  - Combination gasification – combustion
  - Pyrolytic distillation
Combination pyrolysis – gasification

- Two different types of pyrolysis – gasification combinations are applied, subsequent processes and directly connected processes
- Although directly connected processes (see Figure below) are characterized by improved electricity generation rates, the metals and inert material go into a melt for which no use has been found to date.
- The un-shredded waste is dried in a push furnace and partially pyrolyzed, whereafter it is transferred directly and without interruption into a packed bed gasifier.
- In the lower part oxygen is added resulting in gasification at temperatures up to 2000 °C.
- Pure oxygen is also added in the upper part of the gasification reactor to destroy the remaining organic components in the generated synthesis gas, through oxidation, gasification and cracking reactions

Combination gasification - combustion

- the combination of a fluidized bed gasifier and high temperature combustor, resulting in ash melting
- Shredding residues, waste plastics or shredded MSW are gasified in an internally circulating bubbling fluidized bed, which operates at about 580 °C.
- Products from this process – besides power or steam – are ferrous and non-ferrous recyclable metals, a vitrified slag (low leaching risks and stable) and metal concentrates derived from the secondary ash
- this process is operated at atmospheric pressure and using air rather than oxygen. Pretreatment of MSW by shredding is necessary to reduce particle size to 300 mm diameter

Pyrolytic distillation

- It is the combination pyrolysis – distillation
- Pyrolysis reactions occur in the warm zone at the bottom of a high reactor column.
- Both temperature and pressure decrease stepwise with the height of the column, similar to what is found in a distillation process
- The main difference with conventional pyrolysis is the absence of a liquid product due to the successive cracking, cooling and condensation processes when a vapour is flowing upwards.
- After condensation on the solid products it moves downwards again, being exposed to higher temperatures and being cracked again.
- Pyrolytic distillation results in solid and gaseous products only

Pyrolytic distillation - Example

- The Chartherm process is a pyrolytic distillation process which aims at maximizing the useful recovery of both materials and energy from waste