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Programme: M.Sc., Environmental Science
Course Title: Solid and Hazardous waste Management
Course code: CC07

Unit III
Thermal Treatment of Waste

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Thermal treatment of waste

Waste to Energy

<u>Incineration is the combustion</u> of waste in a controlled manner in order to destroy it or transform it into:

- less hazardous
- less bulky
- more controllable constituents.

Incineration may be used to dispose off a wide range of waste streams including municipal solid waste (MSW), commercial, clinical and certain types of industrial wastes.

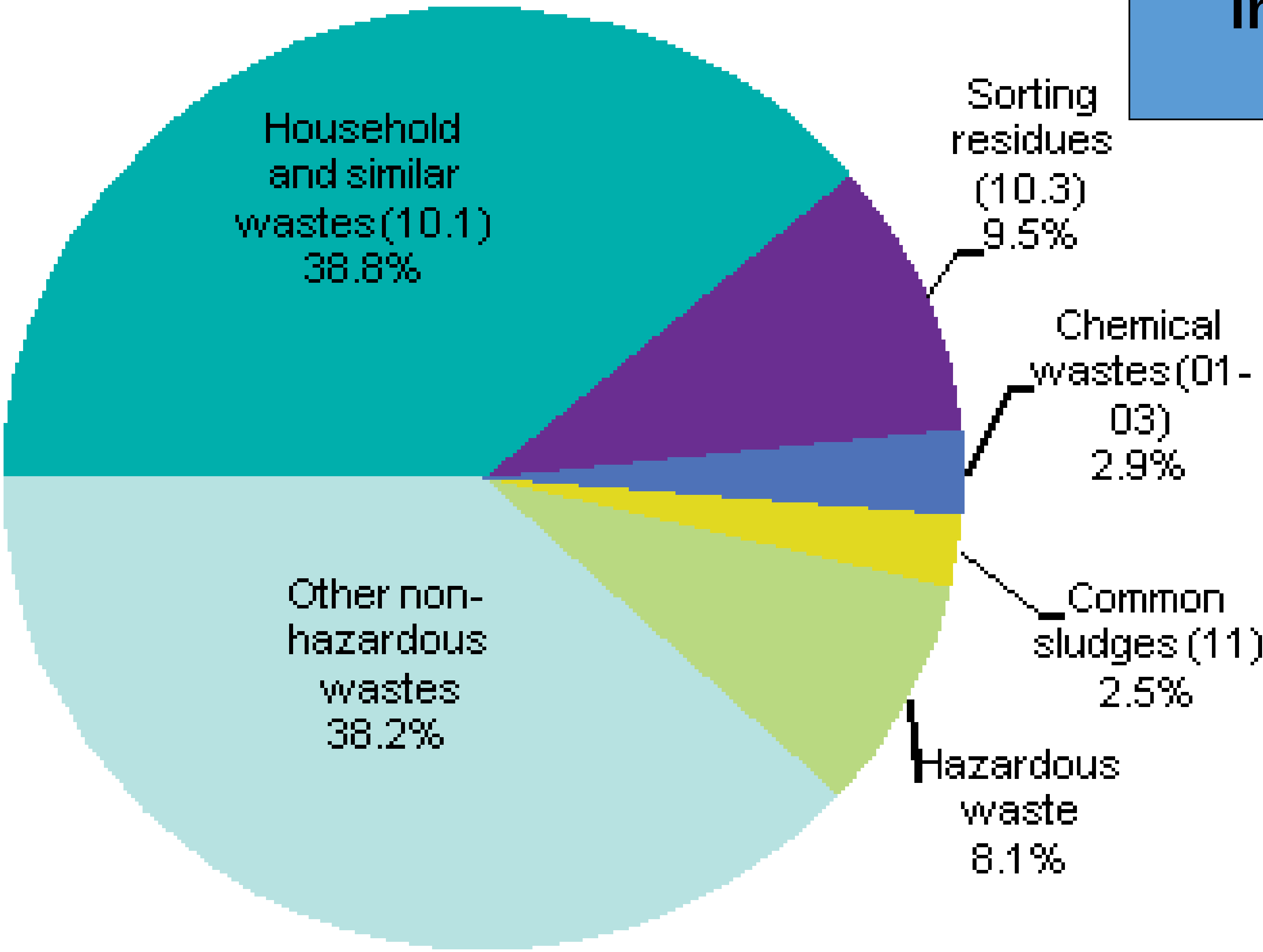
Incineration is generally the second more frequently selected method of waste management after landfilling. Disposal is a major concern of incineration because landifill space is becoming scarce.

Incineration of MSW with energy recovery can be viewed as an attractive alternative to landfilling in many situations.

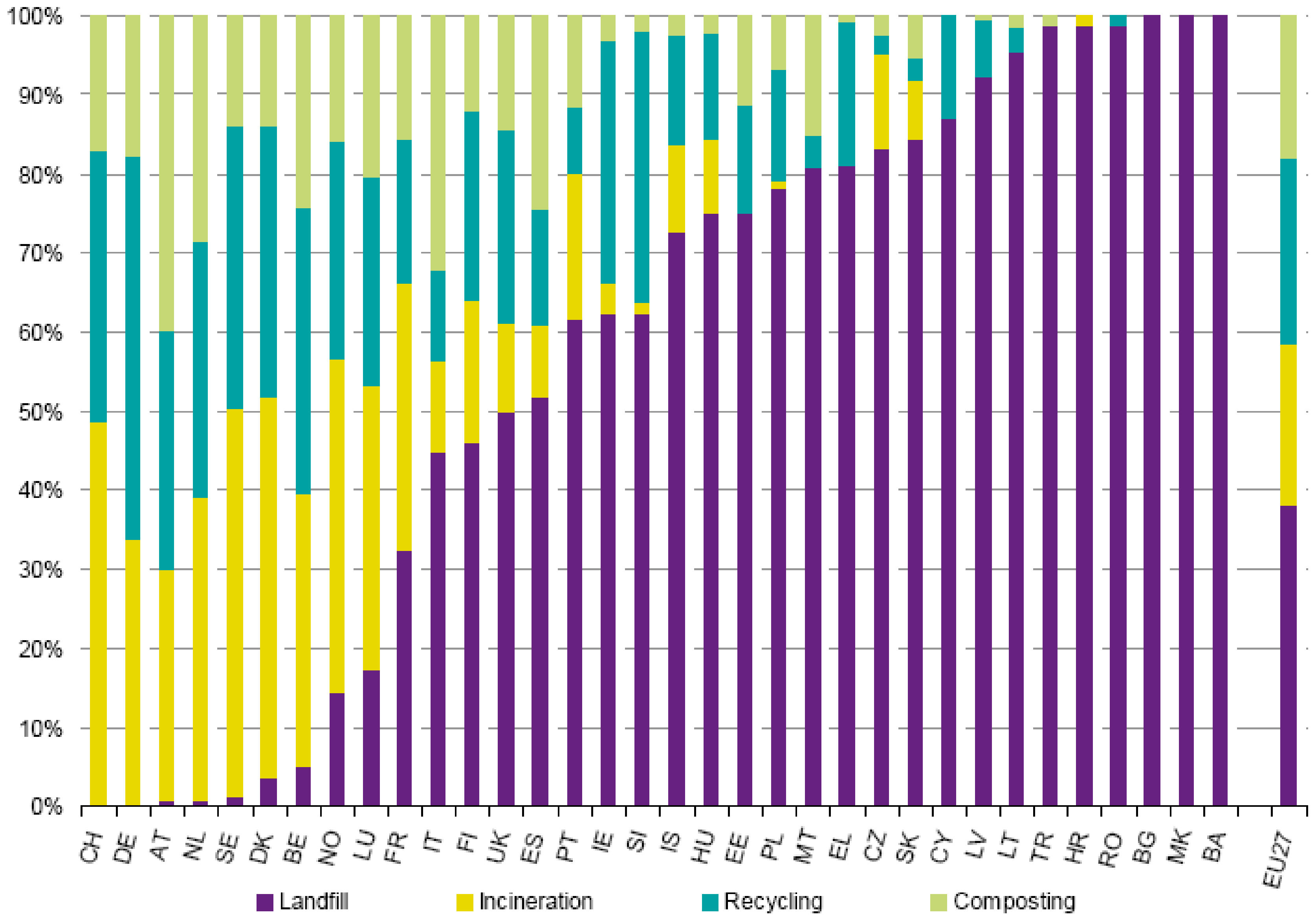
Waste incineration brief history

- The first incinerators were developed in the United Kingdom at the end of 19th century based on the need to manage waste in a sanitary fashion and at the same time to supply energy for industry.
- After some trials with co-incineration of coal and waste, the first municipal solid waste incinerator was constructed in 1876 in Manchester.
- After some years incineration spread to other countries: Hamburg, Germany in 1896, followed by Brussels, Stockholm, Copenhagen and Zurich in 1904.
- British technology was used for the first plants in other parts of Europe.

Waste incineration statistics



Incinerated waste amounts by waste category in the EU-27 in 2008 *(http://epp.eurostat.ec.europa.eu)*



Municipal waste treated in 2009 by country and treatment category, sorted by percenta

-https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_wasmun&lang=en

http://epp.eurostat.ec.europa.eu

The incineration proces

The nature of materials selected for incineration is always checked, because of the very variable character of waste to be incinerated.

In the furnace, the overal reaction of the incineration proces is that combustible components react with oxygen of the combustion air, releasing significant amount of hot gas.

Furthermore the moisture content of the waste is evaporated in the initial stage of the incineration process and the incombustible parts of the waste form solid residues (bottom ash, fly ash).

During incineration process in the furnace, the solid constituents of the waste undergo a range of processes as a result of exposure to heat and contact with combustion air:

- drying
- gasification (formation of combustible gases)
- ignition and combustion of gases
- burnout of the solids.

Process and energy recovery

The combustion gases pass from the furnace to the after burning chamber. To ensure complete burnout the combustion gases must be retained at least 2 second in the afterburning chamber (850°C for municipal waste, 1100°C for certain types of hazardous waste). No waste is fed into the incinerator before the required temperature has been reached.

The flue gas is cooled in boiler and the pressurised water is heated and in high pressure boiler for evaporation and steam may be superheated. The purpose is to exploit its energy contents by expansion in steam turbine connected to power generator.

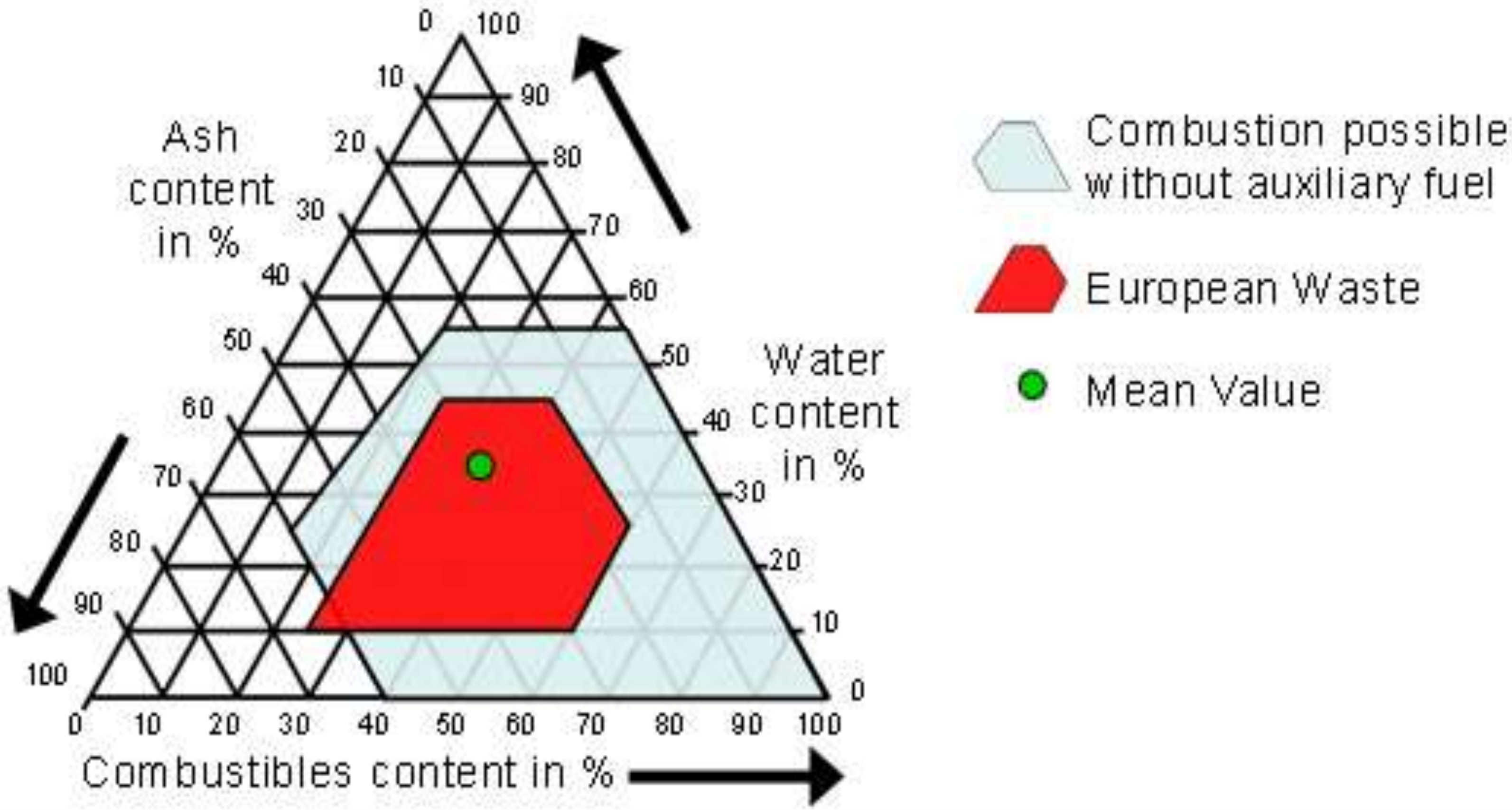
In a combined heat and power plant (co-generation system) typically 25% of steam's energy is transformed into electrical power. The remaining energy is regained by condensation of the steam from turbine in a heat exchanger generating hot water for heating purposes.

Waste as a fuel

- Waste incineration plants are designated to treat waste with great variation in the composition of the incoming waste.
- The waste being led to the incineration plant often consists of several types of waste, such as household waste, commercial and institutional waste and some industrial waste.
- The different waste types received at the incinerator have significantly different characteristics.
- In addition, the Tanner triangle is used to indicate the suitability of MSW for burning. According to the Tanner triangle, the wastes that are theoretically feasible for combustion without auxiliary fuel .

Tanner´s diagram

Waste within the shaded area (W<50%, A<60%, C>25%) can be combusted without auxiliary fuel



Tanner´s triangle for assessment of combustibility of waste

http://www.wtert.eu

Key variables in characterizing waste as fuel

- **moisture content** (W) (typically 15-35%, when drying at 105°C)
- **ash (inorganic)** (A) content (typically 10-25% after ignition at 550°C)
- **combustible (organic)** solids (C) as the difference between the dry solids and the ash content (typically 40-65%)

Principles of waste incineration

Incineration can be viewed as the flame-initiated, high temperature air **oxidation of organic matter**. Incineration is currently practised to some extent on municipal waste, medical waste and hazardous waste. Incineration can only destroy the organic compounds, it cannot destroy inorganic (mineral) compounds – which end up as residual ash. Because waste must be oxidised nearly completely (99.99% destruction and removal capacity is required) a large excess of air is used to ensure the sufficient oxygen to complete the process.

Emissions from waste incinerators include unburnt organic wastes, products of incomplete combustion or by–products of combustion, heavy metals, acid, gas, ash and others.

Emissions of these pollutants can be controlled to very low rates by modern **air pollution control equipment**.

Waste incineration

The specific benefits of incineration:

- A reduction in the volume and weight of waste especially of bulky solids with a high combustible content. Reduction achieved can be up to 90% of volume and 75% of weight of materials going to final landfill.

- Destruction of some wastes and detoxification of others to render them more suitable for final disposal, e.g. combustible carcinogens, pathologically contaminated materials, toxic organic compounds or biologically active materials that could affect sewage treatment plants.

- Destruction of organic components of biodegradable wastes which when landfilled directly generates landfill gas (LFG).

- The recovery of energy from organic wastes with sufficient calorific value.

- Replacement of fossil fuels for energy generation with consequent beneficial impact in terms of the „greenhouse“ effect.

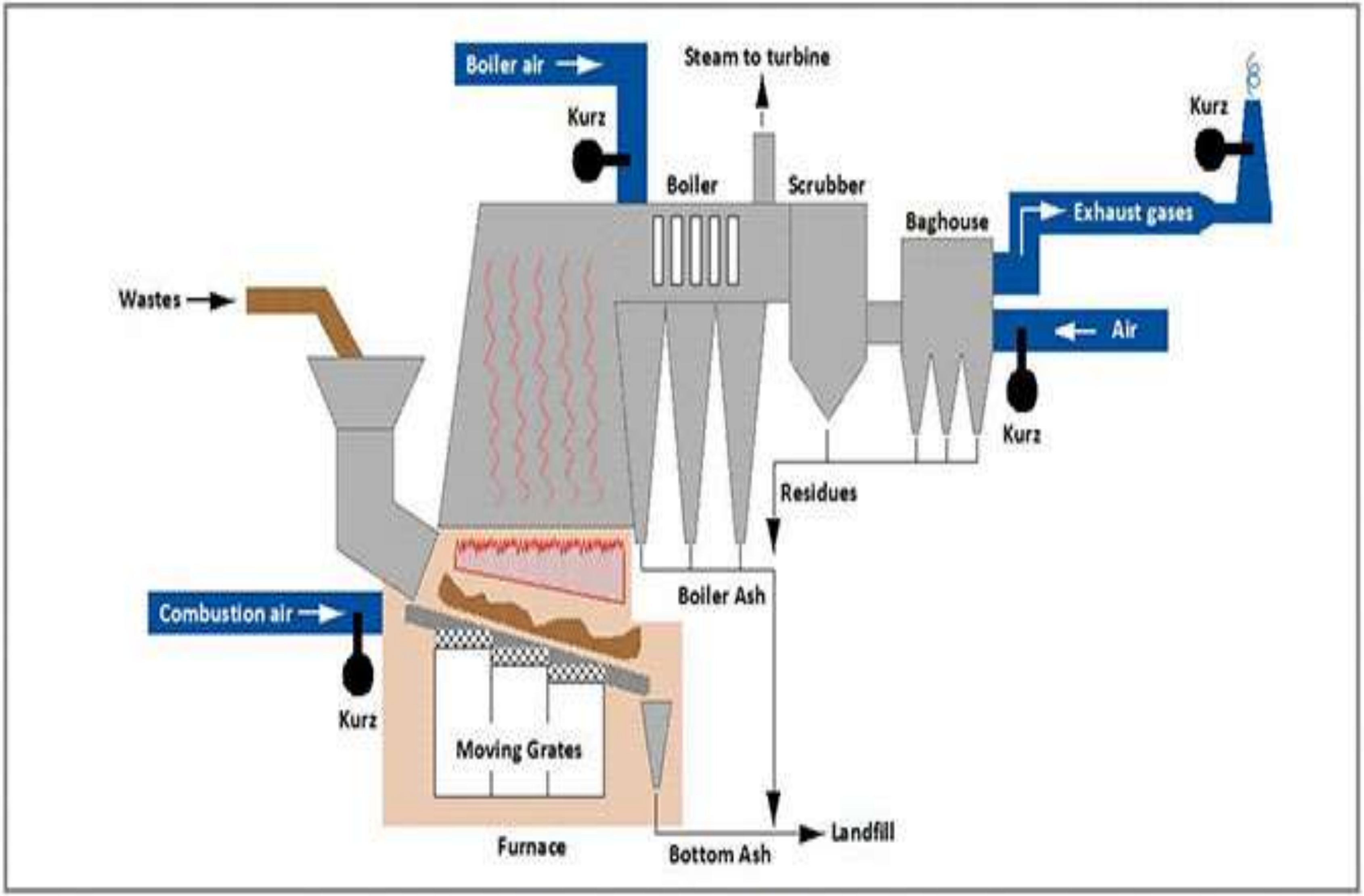
Solid residues

The main part of the ash content of the waste leaves the furnace as a solid residue i.e. bottom ash or slag. The remaining ash leaves the furnace as fly ash.

The fly ash is normally separated from the flue gas in the flue gas treatment system in an electrostatic precipitator or bag house filter.

There are three types of incinerators:

- moving grate incinerator – mostly for municipal waste
- rotary kiln incinerator – for industrial waste (liquid, solid and sludge)
- fluidised bed incinerator – solid particles mixed with fuel are fluidised by air



Simplified Moving Grate Incinerator

http://www.wtert.eu

Moving grate incineration

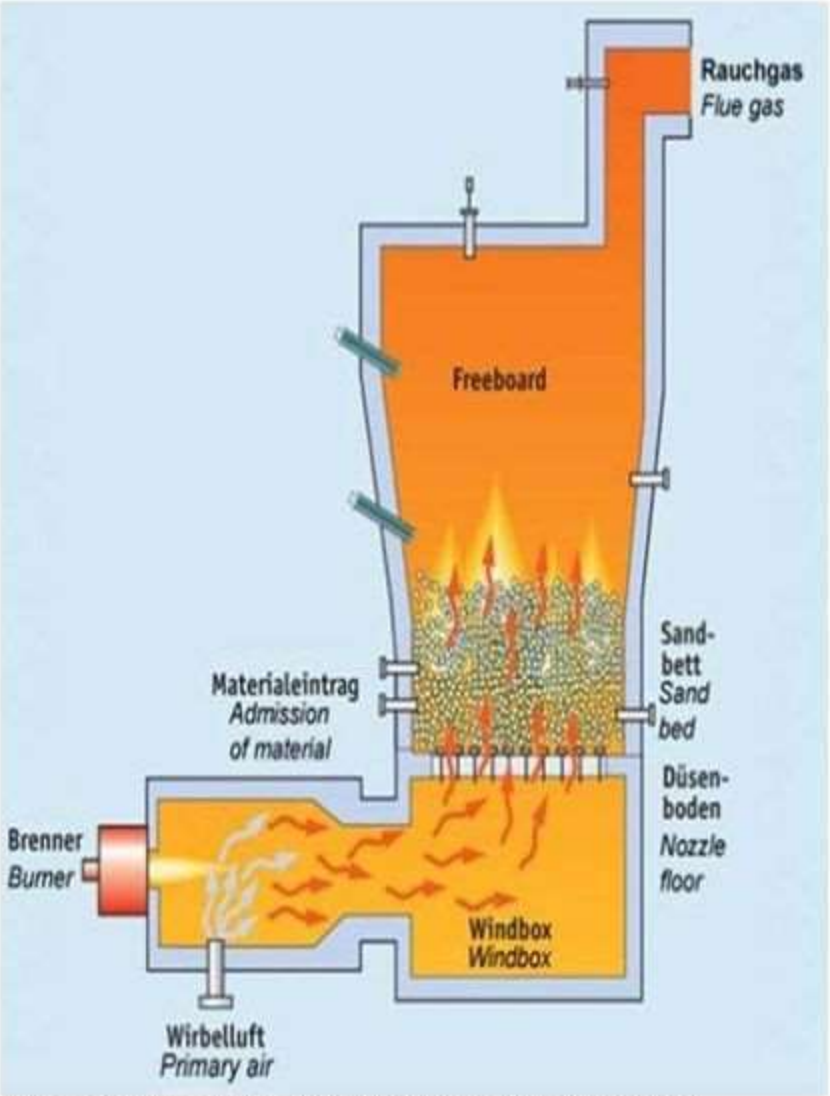
The convential mass burning incinerator based on a moving grate consists of layered burning of the waste on the grate that transport the waste through the furnace.
On the grate the waste is dried and then burnt at the high temperature while air is supplied.
The ash (including noncombustibile waste fractions) leave the grate via the ash chute as slag (bottom ash).
The main advantages of the moving grate are that it is well proven technology, can accomodate large variations in waste composition and in heat values and can be built in the very large units (up to 50 t/h).
The main disadvantage is the investment and maintenance cost which are relatively high.
The bottom ash (slag) drops from the end of the grate into the water trap of the slag and pass to the conveyor system. The amount of slag is usually 10 - 25 % by weight of the waste feed.

SSWM sustainable sanitation and water management

3. Design Principle (Large-scale)

Fluidised-bed Incinerator

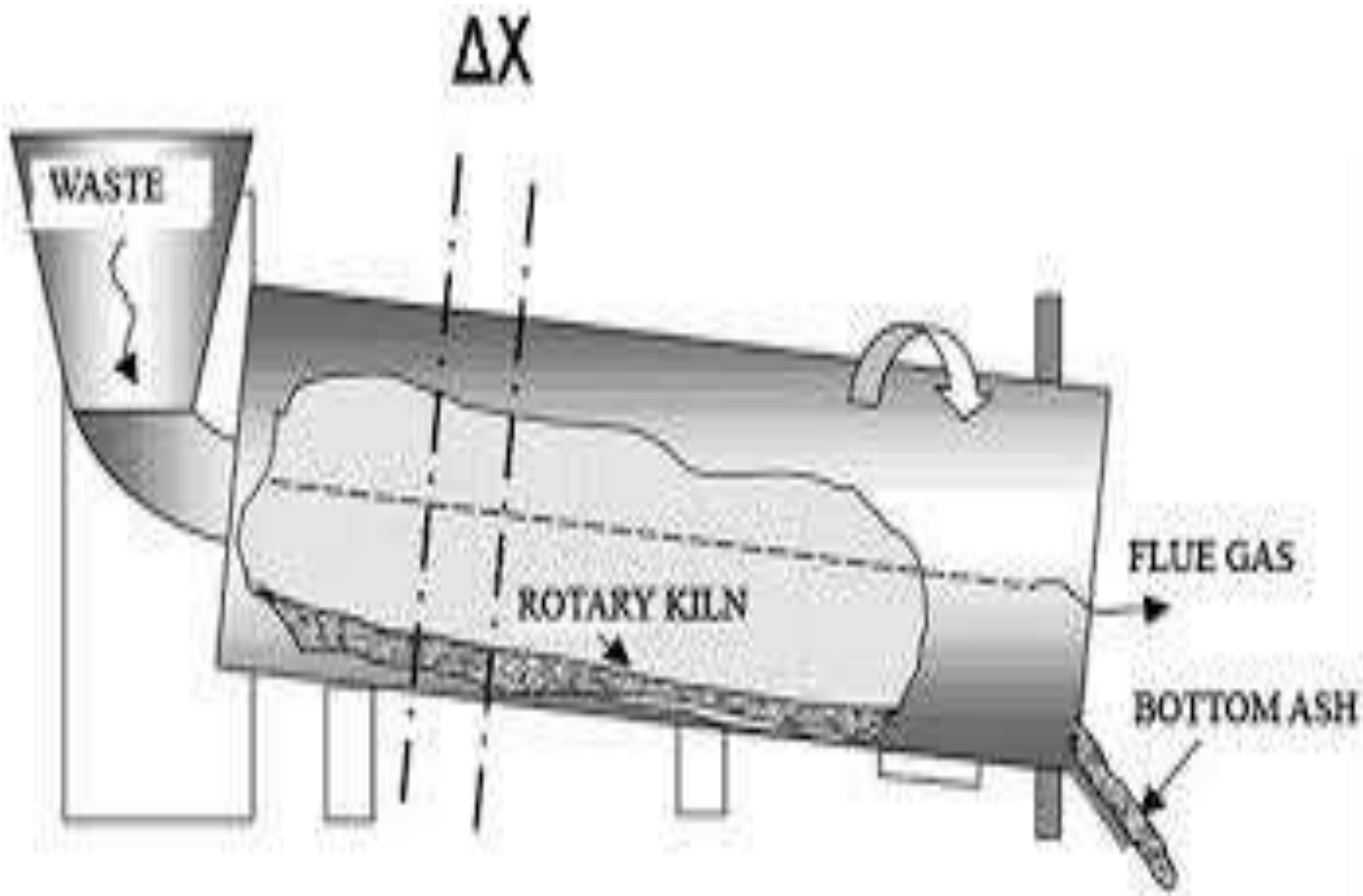
- Bed of limestone or sand
- Circulating or bubbling technology
- Capacity of 50 to 150 tons/day
- Energy recovery system applicable



The scheme of a fluidised-bed incinerator (bubbling bed). Source: EISENMANN (n.y.)

Fluidised bed incineration

Fluidised bed incineration is based on a principle where solid particles mixed with the fuel are fluidised by air.
By fluidisation the fuel and solids are suspended in an upward air stream, thereby behaving **like a fluid**.
The reactor usually consists of a vertical refractory lined steel vessel containing a bed of granural material such as silica sand, limestone or a ceramic material.
The fluidisation of the bed is ensured by air injection through a large number of nozzles in the bottom of the incinerator. This causes a vigorous agitation of the bed material in which the incineration of waste takes place in close contact with the bed material and combustion air.
This allows for relatively low excess air level, thereby allowing for a high thermal efficiency, up to 90 %.
The fluidised bed incinerator is primarily used for homogenous waste type including liquid waste.



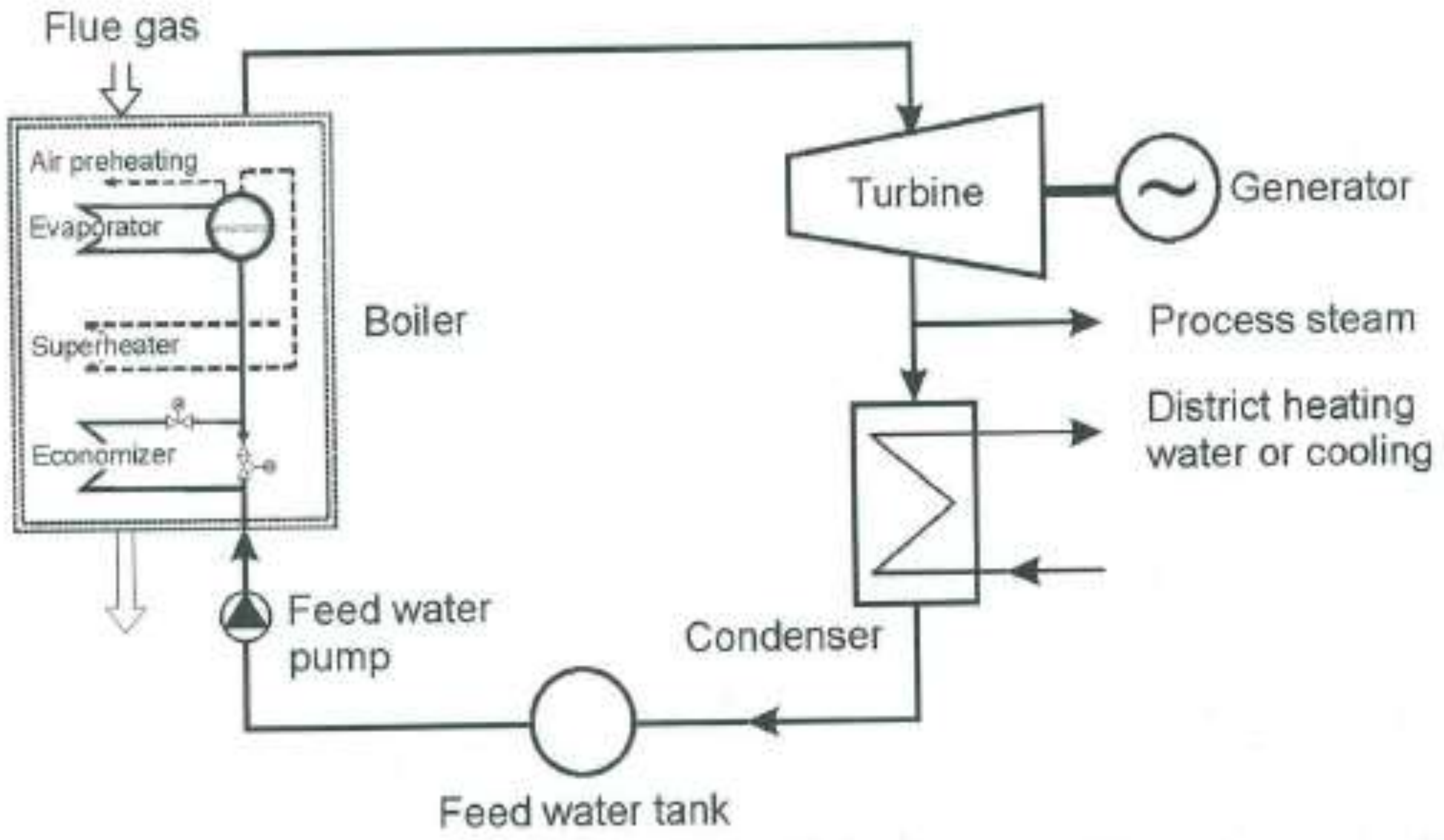
Rotary kiln incinerator

Rotary kiln incineration

The mass burning incinerator based on a rotary kiln consists of a layered burning of the waste in a rotary cylinder.
The material is transported through the furnace by the rotations of the inclined cylinder. The rotary kiln is usually refractory lined.

The diameter of the cylinder may be 1 - 5 m and the length may be around 8 - 20 m. The capacity may be as low as 2.4 t/day and is limited to a maximum of approximately 480 t/day. The kiln rotates with a speed of typically 3-5 rotations/h.

The excess air ratio is well above that of the moving grate incinerator and the fluidised bed. Consequently, the energy efficiency is slightly lower and may not exceed 80 %.
As the retention time of the flue gas usually is too short for complete reaction to take place in the rotary kiln itself, the cylinder is followed by an after burning chamber, which may be incorporated in the first part of the boiler.



The energy recovery system of a waste fired in combined heat and power plant

T. Christensen: Solid Waste Technology and Management

Energy conversion technology

The energy recovery from a steam producing boiler is known from conventional power plant technology as the Rankine process. The Rankine process allows for energy output in the form of power, steam and various combinations of power, steam and hot water.
The energy from the hot flue gases is recovered via the boiler and passed in the internal circuit of steam. The steam energy may be converted to power by menas of a turbine/generator set.
The superheated and high-pressured steam from the boiler expands via the steam trurbine and the energy content of the steam is hereby transformed to kinematic (rotation) energy, which is further transform to electrical energy by the generator.
The excess heat of the low pressure steam is via the heat exchanger (condenser) converted to hot water and passed to district heating network or cooled away.
When producing electric power only it is possible to convert an output up to 35 % of the available energy in the waste to power. When producing a combination of heat and power so called **co-generation**, it is possible to utilise more then 90 % of the energy in the waste (27 % electricity output, 60 - 65 % heat output).

Disadvantages of waste incineration

- High capital investments requires longer pay back period than final disposal to landfill.

-The incinerator is designed on the basis of certain calorific value for the waste.

-Removal of materials such as paper or plastics for recycling and resource recovery reduce the overal calorific value of the waste and consequently affect incinerator performance.

- The incineration proces still produce a solid waste residue that requires management and final disposal.

Emissions from waste incinerator

The most important compounds of emissions from incinerator are:

- acidic gases – hydrochloric acid (HCl), hydrofluoric acid (HF), sulphuric acid (H_2SO_4)

- particulates

- oxides of nitrogen (NO_x) – formed from waste containing nitrogen compounds or mostly by high temperature fixation of nitrogen in the combustion air. Formation of thermal NO_x depends on oxygen availability and the temperature, pressure and residence time of gas in the combustion unit

- organic compounds such as dioxins and furans

- carbon dioxide – not considered as pollutant, however, contributing to the formation of greenhouse effect

Emissions from waste incinerator

Technologies for their removal

Particulates – electrostatic precipitators, fabric filter (general efficiency more than 99%)

Acidic gases – neutralisation with $Ca(OH)_2$ or NaOH in scrubbers (wet, semi-dry, dry)

Oxides of nitrogen – catalytic or non-catalytic reduction with ammonia or urea resulting in the transformation of NO_x to N_2.

Dioxins and furans – sorption on activated carbon or decomposition by special catalysts simultaneously with NO_x removal.

Alternative thermal processes

- Pyrolysis
- Gasification

Pyrolysis represents the thermal decomposition of organic molecules in **absence** of gasification aids such as oxygen, air, CO_2, steam, etc. In the temperature range between 150 – 900^{o}C volatile compounds are expelled and complex molecules are broken down into simpler ones. This process is also called low temperature gasification or destructive distillation. Pyrolysis is endothermal transformation, in the absence of oxygen, of biomasses or liquid, solid or gaseous fractions of wastes. Pyrolysis can also be applied in the production of bio-oils with an efficacy reaching 80%.

Generated pyrolysis products are:- pyrolysis gas, pyrolysis coke, oil,tar.

Main product is a gas with heating value 12.5 to 46 MJ/Nm^3.

The solid residue consists of pyrolysis coke containing varying amount of residual carbon that, unlike gasification, is not converted to gas in this process.

Pyrolysis of organic materials generates several hundred different polycyclic aromatic hydrocarbons (PAH) but only small quantity of dioxins (PCDD) and furans (PCDF) because oxygen is necessary for these to form.

Waste pyrolysis

The technology of pyrolysis is a form of incineration that chemically decomposes organic materials by heat in the absence of oxygen.

Pyrolysis typically occurs under pressure and at operating temperatures above 430°C. During pyrolysis organic matter is transformed into gases, small quantities of liquid and a solid residue containing carbon and ash.

Off-gases are generally treated in a secondary thermal oxidation unit.

There are several variation of pyrolysis system, including rotary kiln, rotary hearth furnace and fluidized-bed furnace. Unit designs are similar to incinerators except that they operate at lower temperature and with less air supply.

Major applications of pyrolysis are in the treating and destruction of semivolatile organic compounds, fuels and pesticides in soil.

Pyrolysis systems may be applied to a number of organic materials that crack or undergo a chemical decomposition in the presence of heat.

The technology is likely more economical on a small scale, such as in treatment of certain types of contaminated soils or hospital wastes.

Gasification

The process of gasification and pyrolysis, discovered at the outset of the XIX century, has only recently (20 – 30 years ago) been proposed for use in the treatment of wastes as an alternative to the „traditional“ thermovalorisation based on combustion process.

Gasification is the conversion of organic fraction of wastes or biomasses into a mixture of combustible gases by means of partial oxidation at high temperatures (400 – 1500°C).

The gas thus produced made up mainly of a mixture of CO and H_2 has calorific potential 4 – 6 MJ/Nm^3 and may be used to fuel internal combustion engines or gas turbines.

In addition, the gas may be used as raw material for the manufacturing of chemical products (e.g. methanol).