Overview on Thermal Waste Treatment Technology

Fundamentals of Waste Incineration, Pyrolysis and Gasification (Adapted presentation)

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UVP
Environmental Management and Engineering

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Content

- Introduction
- Legal Framework (EU)
- Waste Incineration Technology
  - Grate
  - Fluidised Bed (BFB, CFB)
  - Rotary Kiln
- Flue Gas Cleaning
- Waste Water Treatment
- Energy Recovery
- Pyrolysis, Gasification

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Environmental Management and Engineering

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Environmental Engineering and Consulting Company

Staff: 13 persons

Offices in Vienna and Linz, AT

- **Main Fields of Expertise**
  - Waste Management
  - Thermal Waste Treatment
  - Landfill Sites
  - Energy Efficiency

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Activities
- Project Development
- Pre-Feasibility & Feasibility
- Permitting Procedure
- Engineering
- Commissioning
- Operation

Current Projects (Selection)
- BLRB – Engineering, Commissioning
- Energy Efficiency / Iron and Steel Industry
- Waste Management Plan for the Republic of Uzbekistan

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INTRODUCTION

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Properties of Waste (1)

- **Unknown composition**
- **Heterogeneous**
- May contain contaminants and hazardous components, e.g.
  - heavy metals,
  - chlorine,
  - sulphur,
  - persistent organic pollutants...

ANYTHING might come along. →

Waste Incineration Technology must be safe and sound and equipped with best available abatement technology.

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Properties of Waste (2)

MSW Composition		Content
Carbon	C	20 – 25 %
Hydrogen	H	2 – 4 %
Oxygen	O	15 – 20 %
Nitrogen	N	0,3 – 1,0 %
Sulphur	S	0,2 – 0,5 %
Water	H_2O	25 – 35 %
Ash / Inert Material		20 – 30 %
Lower Heating Value (LHV)		**8 – 12 MJ/kg**

Further Chemical Elements

- P, Cl, F ...
- Na, K, Ca, Mg ... *
- Fe, Ni, Cd, Pb, Hg, Cr, As, Sb ... *

*) Partly as elements, mostly as **Ash**: oxides, chlorides, sulphates, silicates ...

Heating Value (LCV) Range

- 3 MJ/kg (dewatered sewage sludge) up to
- > 30 MJ/kg (plastic waste)
- **8-12 MJ/kg – typical LCV range of MSW**

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Advantages of Waste Incineration

- Volume Reduction ~ 90%
- Mass Reduction ~ 60%
- Destruction of Organic Components →
- → Inertisation
- → Sanitation / Disinfection
- Prevention of PCDD/F (Polychlorinated Dibenzo Dioxins and Furans) Synthesis
- High Energy Efficiency for Heat and Power Production
- Less specific greenhouse gas emissions than landfill: Global warming potential of CH_4 is 28 times higher than of CO_2
- **Waste Incineration is the „State of the Art“ in Thermal Waste Treatment, numerous Reference Plants**

If carefully designed and operated:

- **Minimum Environmental Impact**
- **Reliable & quite easy to operate**

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LEGAL FRAMEWORK (EU)

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Industrial Emissions Directive (IED) 2010/75/EU

- **Chapter IV and Annex VI**

  Special Provisions for Waste Incineration Plants and Waste Co-Incineration Plants

  Additionally, the IED comprises provisions on

- **Integrated Pollution Prevention and Control (IPPC)** and the
- **BAT Reference Document on Waste Incineration (BREF WI)**
  apply for waste Incineration / co-incineration plants with capacities of
  - **> 3 tonnes per hour of non-hazardous waste**
  - **> 10 tonnes per day of hazardous waste**

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IED Chapter IV & Annex VI: Scope of Waste

- Stationary and mobile waste incineration / co-incineration plants treating **solid and liquid waste.**

  Exceptions: Plants treating only

- **vegetable waste**, e.g. from agriculture / forestry / food processing (exception: waste containing **halogenated organic compounds** or **heavy metals**),
- **radioactive waste,**
- **animal carcasses,**
- waste resulting from the exploration for, and the exploitation of, **oil and gas** resources from **off-shore** installations and incinerated on board the installations,
- **experimental plants** used for research/development/testing for **< 50 tonnes** of waste/year.

IED Chapter IV & Annex VI: Scope of Installations (1)

Waste Incineration Plants

- dedicated to the thermal treatment of waste,
- with or without recovery of the combustion heat.

Typical installation:

- **Muncipal Solid Waste Incinerator (MSWI)**

Waste Co-incineration Plants

- Main purpose: generation of energy or production of material products
- using waste as regular or additional fuel

3 types of plants:

a) Cement kilns

b) (Large) Combustion plants

c) Co-incineration plants in other industrial sectors.

IED Chapter IV & Annex VI: Scope of Installations (2)

Waste incineration plants and waste co-incineration plants according to IED also include **"other thermal treatment processes**" such as

- **Pyrolysis,**
- **Gasification,**
- **Plasma Process,**

if the substances resulting from the treatment are subsequently incinerated.

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IED Chapter IV & Annex VI: Permit Conditions

- List of all **waste types** which may be treated + their **quantities**,
- Total waste **capacity** of the plant,
- **Limit values** for **emissions into air and water,**
- Requirements for **wastewater discharges** (pH, temperature, flow),
- **Sampling and measurement** (procedures, measurements),
- **Maximum permissible period during which emissions may exceed the limit values** (e.g. due to technically unavoidable stoppages, disturbances, or failures of the purification devices or measurement devices),
- **Additional requirements when hazardous waste is incinerated,** e.g. lowest and maximum calorific values and their maximum contents of polychlorinated biphenyls (PCBs), pentachlorophenol (PCP), chlorine, fluorine, sulphur, heavy metals and other polluting substances.

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IED ELVs for Air Emissions from WI: Continuous Monitoring, Daily Averages (DA)

1.1. Daily average emission limit values for the following polluting substances (mg/Nm³)

Total dust	10
Gaseous and vaporous organic substances, expressed as total organic carbon (TOC)	10
Hydrogen chloride (HCl)	10
Hydrogen fluoride (HF)	1
Sulphur dioxide (SO_2)	50
Nitrogen monoxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2 for existing waste incineration plants with a nominal capacity exceeding 6 tonnes per hour or new waste incineration plants	200
Nitrogen monoxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2 for existing waste incineration plants with a nominal capacity of 6 tonnes per hour or less	400

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IED ELVs for Air Emissions from WI: Continuous Monitoring, Half-hourly Averages (HHA)

1.2. Half-hourly average emission limit values for the following polluting substances (mg/Nm³)

	(100 %) A	(97 %) B
Total dust	30	10
Gaseous and vaporous organic substances, expressed as total organic carbon (TOC)	20	10
Hydrogen chloride (HCl)	60	10
Hydrogen fluoride (HF)	4	2
Sulphur dioxide (SO_2)	200	50
Nitrogen monoxide (NO) and nitrogen dioxide (NO_2), expressed as NO_2 for existing waste incineration plants with a nominal capacity exceeding 6 tonnes per hour or new waste incineration plants	400	200

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IED ELVs for Air Emissions from WI: Discontinuous Monitoring

Parameter	Duration	ELV [mg/Nm³]
Hg *	0.5 – 8 hours	0.05
Σ Cd + Tl *	0.5 – 8 hours	0.05
Σ Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V	0.5 – 8 hours	0.5
PCDD/F	6 – 8 hours	0.000001
CO	Daily average	50
CO	Half-hourly average	100
CO	10 min average	150

*) and their compounds

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IED ELVs for Air Emissions from WI: Reference Conditions

- **Dry flue gas**
- **Pressure: 1 atm = 1,013 bar(a)**
- **Temperature: 0 °C**
- **O_2 concentration in the flue gas: 11 Vol%**
- Calculation of emitted pollutant loads:
  Also the flue gas output in [m^3] has to be re-calculated in order to comply with the reference conditions.
- If (also) **hazardous waste** is incinerated and the **actual O_2 content is <11 Vol%,** ELVs refer to actual O_2 concentration
  → **no „mathematical dilution" is allowed**.

$$E_S = \frac{21 - O_S}{21 - O_M} \times E_M$$

E_S: Emi concentration, reference cond.
E_M: Emi concentration, measured
O_S: O_2 content, reference conditions
O_M: O_2 content, measured

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IED ELVs for Discharges of Waste Water from the Cleaning of Waste Gas from WI

Polluting substances	Emission limit values for unfiltered samples (mg/l except for dioxins and furans)	
	(95 %)	(100 %)
1. Total suspended solids as defined in Annex I of Directive 91/271/EEC	30	45
2. Mercury and its compounds, expressed as mercury (Hg)		0,03
3. Cadmium and its compounds, expressed as cadmium (Cd)		0,05
4. Thallium and its compounds, expressed as thallium (Tl)		0,05
5. Arsenic and its compounds, expressed as arsenic (As)		0,15
6. Lead and its compounds, expressed as lead (Pb)		0,2
7. Chromium and its compounds, expressed as chromium (Cr)		0,5
8. Copper and its compounds, expressed as copper (Cu)		0,5
9. Nickel and its compounds, expressed as nickel (Ni)		0,5
10. Zinc and its compounds, expressed as zinc (Zn)		1,5
11. Dioxins and furans		0,3 ng/l

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Further Relevant Regulations of the IED (Examples)

- **Operating Conditions**
  - <3% TOC in solid residues,
  - Flue gas ≥ 850°C (hazardous waste: 1100°C) for ≥ 2 seconds,
  - Heat recovery as far as practicable
  - Infectious clinical waste: straight into the furnace (no direct handling, no mixing with other waste categories),
  - Operation and control of the plant by a competent person etc.
- **Reception of Waste**
- **Reporting Obligations**
- **Residues**
  - amount and harmfulness shall be minimized,
  - shall be recycled, where appropriate;
  - no dispersal in the environment.
- **Provisions for Site Closure (definitive cessation of activity)**
  - including Baseline Report
- **Information of the Public**
- **Best Available Technique has to be applied → BREF Waste Incineration**

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BREF Waste Incineration (1)

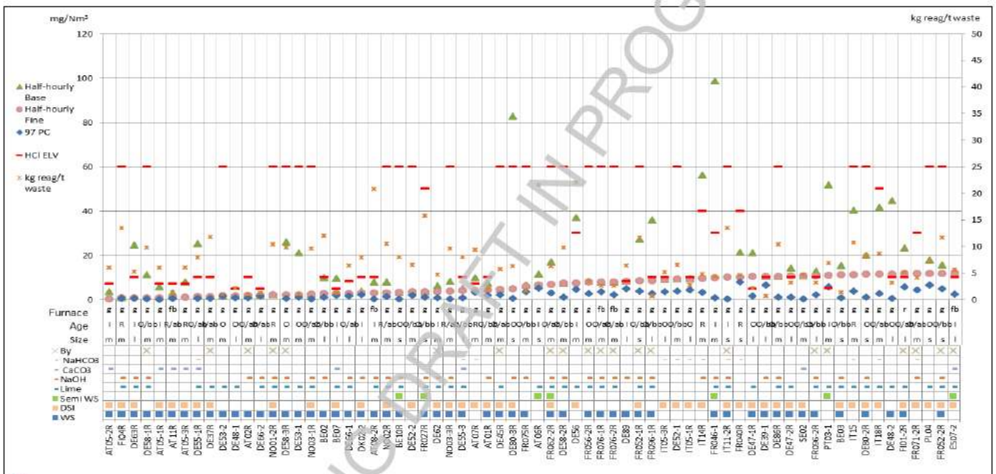
- **Defines the State of the Art in Waste Incineration.**
- **BAT:** Best Available Technique
- **BREF:** BAT Reference Document
- Technique means more than Technology!
- Developped in the so-called Sevilla Process of the European Commission.
- Existing BREF WI from 2006
- BREF WI Revision 2014-2018
- Publication of revised BREF WI to be expected this year (2019)
- **BAT-AELs:** BAT Associated Emission Levels. They correspond with BAT operation. They are no ELVs...
- ... but all over the EU, operating permits have to comply with them within 4 years after publication.

Information: http://eippcb.jrc.ec.europa.eu/reference/

Datenerhebung an ca. 350 europäischen Abfallverbrennungsanlagen & Auswertung
Beispiel: HMW für HCl [mg/Nm3] - Auszug

Annexes

8.7 Half-hourly and monthly average emission levels achieved by the waste incineration plants reporting continuously monitored emissions in the 2016 data collection: detailed graphs



NB:
Furnace type: g = grate; r = rotary kiln; fb = fluidised bed; f = furnace other than the former types; gas = gasification; o = other.
Plant age: O = old; I = intermediate; R = recent // year of retrofitting: bb = before previous WI BREF (2006); ab = after previous WI BREF (2006).
Plant size: s = small; m = medium; l = large.
By = bypass.
Reagents used: NaHCO3 = sodium bicarbonate; CaCO3 = limestone; NaOH = sodium hydroxide; Lime includes: quicklime, hydrated lime, and high-surface/porosity hydrated lime.
Techniques installed: Semi WS = semi-wet scrubber; DSI = dry sorbent injection; WS = wet scrubber.
Source: [81, TWG 2016].

Figure 8.51: Half-hourly average emission levels for continuously monitored HCl emissions to air from reference lines incinerating predominantly MSW (1/3)

598 December 2018 GC/FN/JG/EIPPCB/WI_Final_Draft

BREF WI (Chapter 5): BAT Conclusions

- BAT 1 — Environmental Management System
- BAT 2 – BAT 8 — Monitoring
- BAT 9 – BAT 18 — General Environmental and Combustion Performance
- BAT 19 – BAT 20 — Energy Efficiency
- BAT 21 – BAT 24 — Air Emissions - Diffuse Emissions
- BAT 25 – BAT 31 — Air Emissions - Channelled Emissions
- BAT 32 – BAT 34 — Emissions to Water
- BAT 35 – BAT 36 — Material Efficiency
- BAT 37 — Noise

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BREF WI (Chapter 5) - Example Section of BAT 30 (Auszug)

Table 5.5: BAT-associated emission levels (BAT-AELs) for channelled emissions to air of TVOC, PCDD/F and dioxin-like PCBs from the incineration of waste

Parameter	Unit	BAT-AEL		Averaging period
		New plant	Existing plant	
TVOC	mg/Nm^3	< 3–10	< 3–10	Daily average
PCDD/F (¹)	ng I-TEQ/Nm^3	< 0.01–0.04	< 0.01–0.06	Average over the sampling period
		< 0.01–0.06	< 0.01–0.08	Long-term sampling period (²)
PCDD/F + dioxin-like PCBs (¹)	ng WHO-TEQ/Nm^3	< 0.01–0.06	< 0.01–0.08	Average over the sampling period
		< 0.01–0.08	< 0.01–0.1	Long-term sampling period (²)

(¹) Either the BAT-AEL for PCDD/F or the BAT-AEL for PCDD/F + dioxin-like PCBs applies.
(²) The BAT-AEL does not apply if the emission levels are proven to be sufficiently stable.

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WASTE INCINERATION TECHNOLOGY

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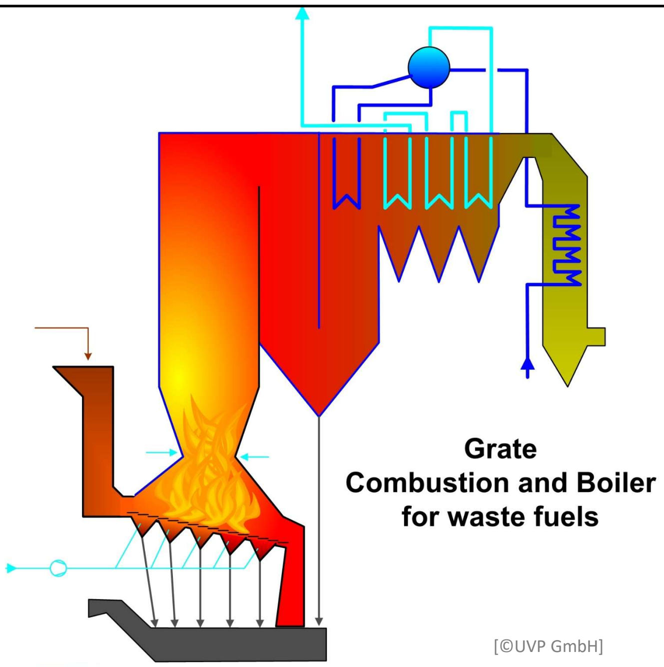
Incineration Technology

- **Grate Firing**
  Standard Process for MSW Incineration
  (Pre-treated) MSW, various waste fractions
- **Fluidized Bed Reactor**
  Bubbling Fluidized Bed (BFB)
  Circulating Fluidized Bed (CFB)
  Pre-treated MSW, various pre-treated waste fractions
- **Rotary Kiln**
  Hazardous Waste

Grate Firing



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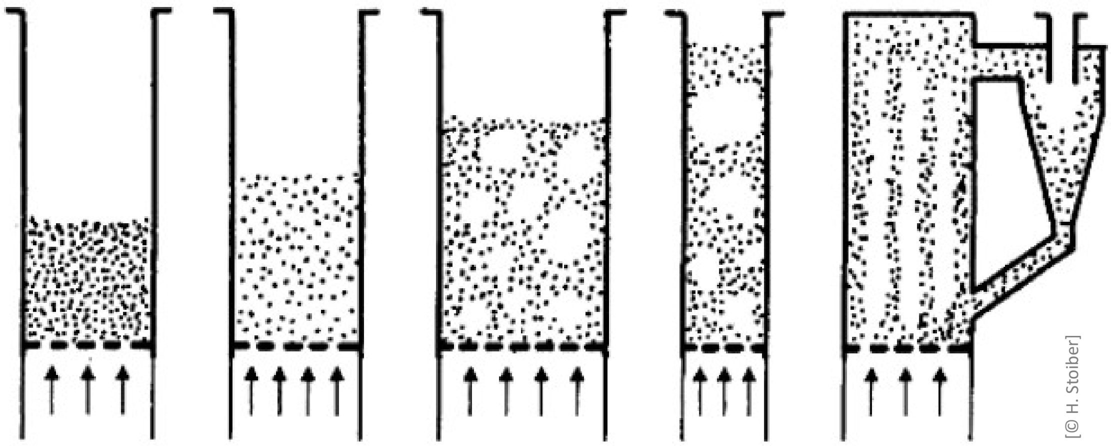
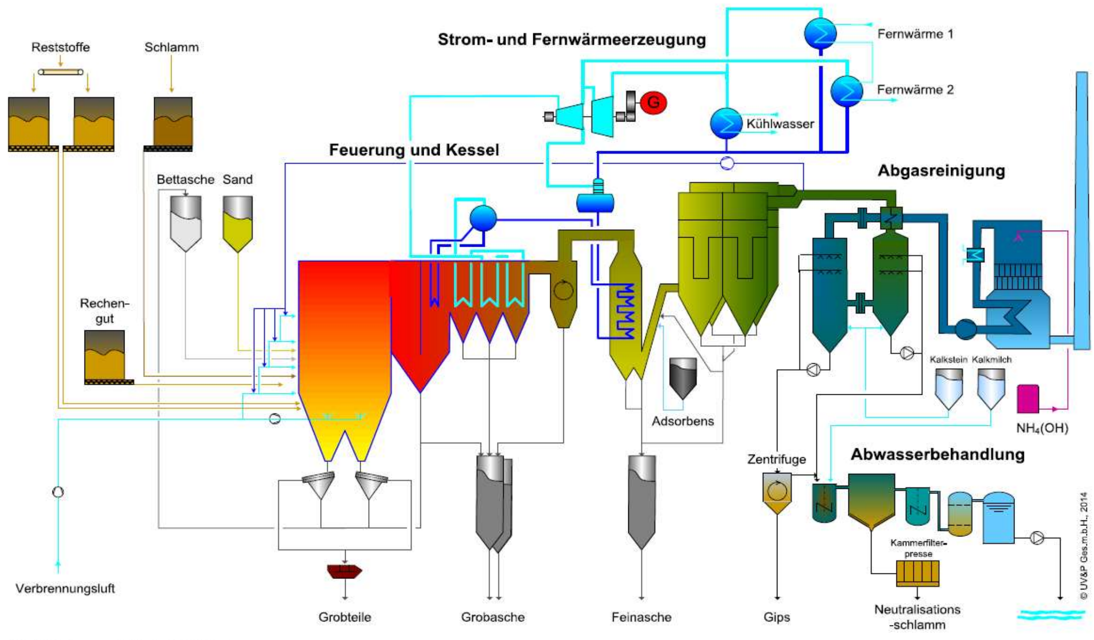
Fluidized Bed



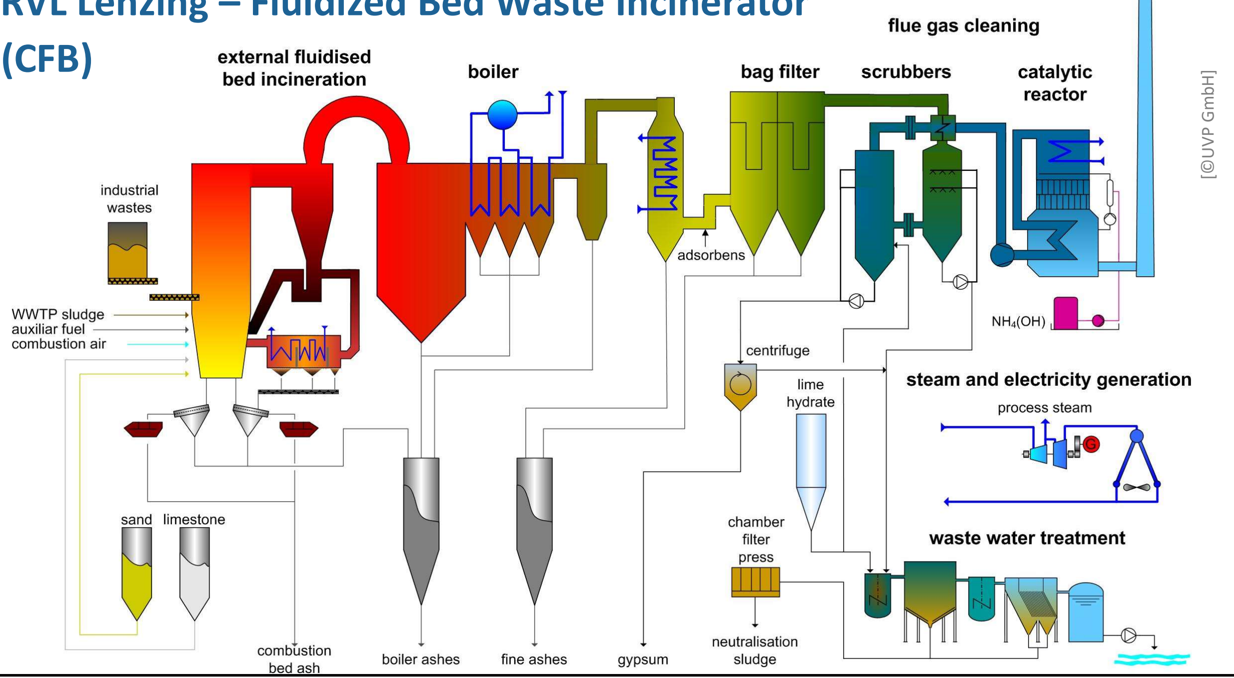
[© H. Stoiber]

RHKW Linz – Fluidized Bed Waste Incinerator (BFB)



296_7_3 Prinzipschema RHKW Linz_02-09-2014.vsd

RVL Lenzing – Fluidized Bed Waste Incinerator (CFB)



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Overview: Grate – Fluidized Bed – Rotary Kiln

Grate Firing

- Standard Process for MSWI
- LCV range ca. 8 – 12 MJ/kg
- 850° C
- **MSW (+ certain amounts of sewage sludge, shreddered bulky waste ...)**

Rotary Kiln

- 1100 °C
- **Hazardous waste**

Fluidized Bed Incinerator

- 850° C
- Solid waste has to be mechanically pre-treated.
- LCV range ca. 3 – 35 MJ/kg →
- → High fuel flexibility
- **Pre-treated MSW, RDF, residues from mechanical or mechanical-biological waste treatment, plastic waste, sewage sludge, shreddered bulky waste, rejects from paper recycling, ...**

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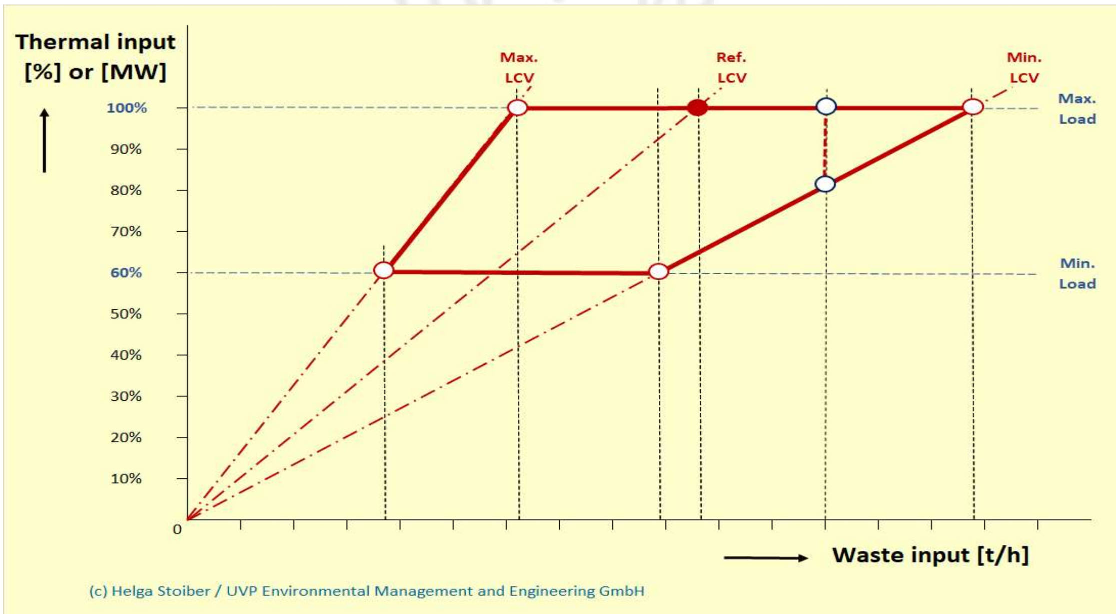
Operating Diagram of a WI Plant



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FLUE GAS CLEANING AFTER WASTE INCINERATION

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Techniques to reduce Air Emissions (1)

- **Cyclone** — **Coarse Dust** (no stand-alone de-dusting!)
- **Baghouse filter (Textile filter)** — **Dust,** Adsorbents from dry injection
- **Catalytic filter bags** — **PCDD/F, NOx** (when NH_3 is added)
- **Electrostatic Precipitator (ESP)** — **Dust**
- **Direct desulphurisation** — **SOx** (by addition of Mg or Ca based adsorbents directly into the fluidized bed)
- **Boiler sorbent injection** — **SOx, HCl, HF** (by injection of Mg or Ca based adsorbents into the post-combustion chamber

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Techniques to reduce Air Emissions (2)

- **Dry sorbent injection** — Injection of a dry sorbent into the flue gas
  SOx, HCl, HF - $Ca(OH)_2$, $NaHCO_3$
  PCDD/F, Hg(0) - Activated carbon
- **Fixed bed or Moving Bed Adsorption** — **Hg(0)** - Activated carbon, activated lignite...
- **Flue gas recirculation** — **NOx** – Reduction of NOx formation by reducing the O_2 content in the furnace and by cooling
- **Selective non-catalytic reduction (SNCR)** — Reduction of **NOx** by NH_3 injection into the flue gas at 800-1000 °C → N_2 formation
- **Selective catalytiv reduction (SCR)** — Reduction of **NOx** by NH_3 injection into the flue gas at 200-400 °C in the presence of a catalyst → N_2 formation

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Techniques to reduce Air Emissions (3)

- **Semi-wet absorber (Semi-wet absorber)**
- **Wet scrubber**

- **SOx, HCl, HF** - Injection of an alkaline aqueous solution into the flue gas, product is dry
- SO_2, HCl, HF, Hg(I, II) - Water or aqueous solutions/suspensions of alkaline salts or lime are used as absorbent.

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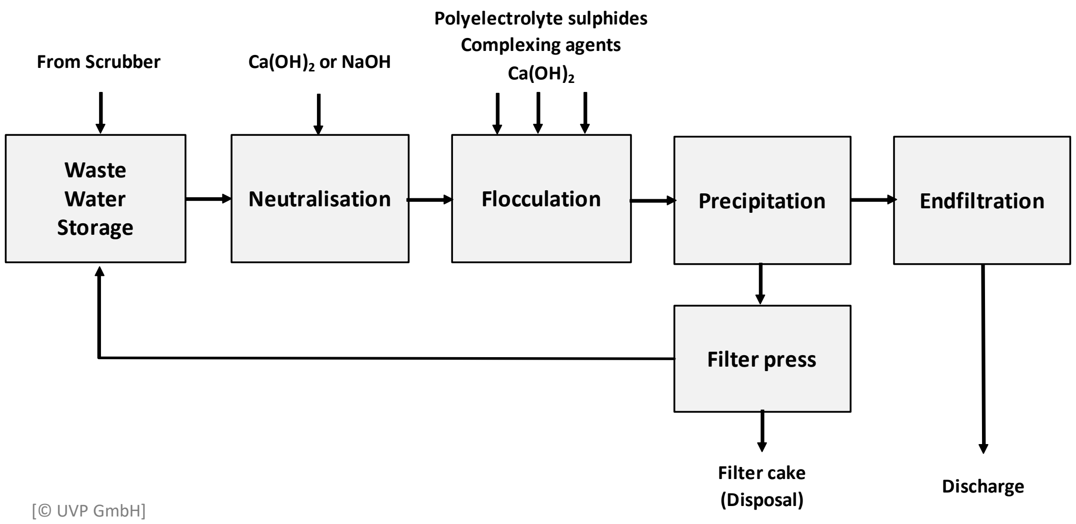
WASTE WATER TREATMENT AFTER WASTE INCINERATION

Waste Water Treatment - Example



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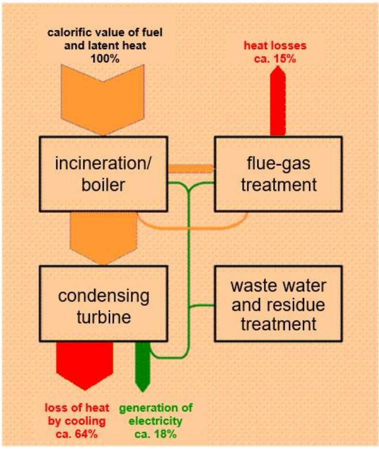
ENERGY RECOVERY

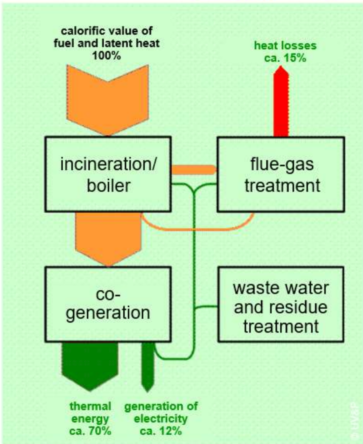
Site-specific Options for Energy Utilization

Condensing Turbine (electricity only)



Energy utilization approx. 20 %

Co-Generation (electricity + heat)



Energy utilization approx. 80 %

Site selection is crucial for energy efficiency!

Possible energy customers:
- **Process heat** (steam) for nearby industrial sites
- **District heating** for nearby municipalities
- **District cooling** for nearby municipalities
- Heat & electricity use in a nearby **seawater desalination** plant.

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PYROLYSIS AND GASIFICATION OF WASTE

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Process Characteristics (1)

	COMBUSTION	GASIFICATION	PYROLYSIS
Oxygen	$\lambda > 1$	$\lambda < 1$	$\lambda \sim 0$
Medium	Air	Air, Steam	Steam, Inert Gas
Reaction Enthalpy	Exothermic $\Delta H > 0$	Endothermic $\Delta H < 0$	Endothermic $\Delta H < 0$
Product	Flue Gas, Solid Residue	Synthesis Gas, Solid Residue	Gas, Tar, Coke, Solid Residue

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Process Characteristics (2)

	COMBUSTION	GASIFICATION	PYROLYSIS
Products (Gas)	CO_2 H_2O SO_2 NOx HCl, HF ...	CO_2, CO H_2O, H_2 SO_2, H_2S NOx, NH_3 HCl, HF ...	CO_2, CO H_2O, H_2 SO_2, H_2S, R-SH, R-S-R NOx, NH_3, R-NH_2, ... HCl, HF ... Alkanes, Alkenes, Alkines Organic S-Compounds Organic N-Compounds Organic Cl-Compounds ...

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Process Characteristics (3)

	COMBUSTION	GASIFICATION	PYROLYSIS
Products (Liquid)	-	Tar (small amount)	Tar (considerable amount) CxHy in any form including POPs
Products (Solid)	Inerts max. 3% TOC	Inerts Low TOC	Inerts High TOC (carbon loaded with gaseous and liquid CxHy products)
Reaction	Can be well controlled	Can be fairly well controlled	Mere cracking of organic matter, can merely be controlled by p, T, time

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Gasification

- Under certain circumstances, gasification of waste may make sense.
- Not many installations in operation.
- According to IED, syngas must be cleaned before incineration. Otherwise, the entire combustion plant becomes a co-incineration installation.
(Cf. ECJ Decisions Lahti I, Lahti II)

Example:

Gasification plant in **Lahti, Finnland**: Gasification of Wood Waste, Incineration of the Syngas in an adjacent LCP plant →

→ Good energy efficiency due to water/steam parameters of the LCP plant.

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Pyrolysis

- Pyrolysis of waste has been subject to R&D since about 50 years.
- **Up to now, no process has been developped that is ecologically and economically feasible.**
- **Pyrolysis DOES NOT produce a „marketable Diesel oil" (never).**
- **Pyrolysis is NOT state-of-the-art and is NOT a technology for thermal treatment of MSW.**

Pyrolysis for thermal waste treatment **makes sense only in very few special cases**, e.g.

- Removal of plastic insulation from **cables** as pre-treatment in copper recycling.
- Removal of plastic pieces from **WEEE** as pre-treatment in rare earth metals recycling.
- **Feedstock recycling** in the context of a mineral oil refinery.

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Plastic Pyrolysis for Feedstock Recycling in a Refinery: OMV ReOil Pilot Project

Plastic waste is pyrolysed.

The pyrolysis products are fed into the refinery and processed there together with the normal mineral oil feed-stock.

They contribute to the production and output of the refinery.

Information about the project:

https://www.omv.com/de/blog/reoil-aus-kunststoff-wieder-oel-gewinnen

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Thank you for your attention!

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