Umwelt Bundesamt

# THERMAL WASTE TREATMENT THROUGH FLUIDIZED BED INCINERATION *)

**APPLICATION OBJECTIVE**

- Reduction of the volume and risk potential of waste destined for final disposal through a mineralization, destruction of organic compounds and the capture of large parts of the harmful inorganic components in a separable fraction
- Energy recovery from waste

*) The cleaning of exhaust and flue gases as an integrated process and technology is covered by a separate description (see the fact sheet „Emission control – exhaust and flue gas cleaning“)

## OUTLINE ON APPLICATION FRAMEWORK

### PARTICULARLY APPLICABLE FOR WASTE TYPES

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| Glass | | Light-weight packaging | | Biowaste | |
| Paper / paperboard | | Mixed household waste | X | Bulky waste | X[1] |
| Lamps | | Textiles | | Electrical and electronic waste | |
| Scrap metal | | Waste wood | X[2] | C&D waste | X[1] |
| Waste oil | X[3] | Old paint & lacquer | X | Waste tyres | |
| Hazardous waste | X | partly, only combustible fractions | | | |
| Branch specific waste | X | appropriate combustible materials, especially small-sized material mixtures (e.g. rejects of paper mills) | | | |
| Other waste material | X | appropriate combustible materials, especially dewatered or partially dried sewage sludge | | | |

### SPECIAL CHARACTERISTICS AND REQUIREMENTS OF THE APPLICATION

**Pre-treatment of the input material:**
Input material must be freed from disturbing components such as large metal parts and comminution may have to be employed to get particles which are of appropriate size for the fluidized bed incineration. Any radioactive substances must be excluded (entrance control!)

**Options for the utilisation of the generated output:**
Combustion ashes and slag after a further processing can be used in other applications, for example in construction. There exists however less options to use the materials from fluidized bed incineration compared to the ashes resulting from grate combustion (see details in the fact on „Grate combustion“).

**Options for the disposal of process output and/or residues:**
Landfilling combustion residues (ashes and slag) is generally possible. Residues from exhaust and flue gas cleaning however must be handled as hazardous material and need to be deposited in facilities which are suitable and approved for this type of material. Preferred options for this are stowage-mines or underground deposits (see fact sheet on „Hazardous waste landfill“).

**Aftercare requirements:**
Residues which have to be deposited on landfills of the appropriate categories must be subject of monitoring and become part of the usual aftercare procedures applying to these landfills.

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[1] Recycling and the necessary sorting and mechanical processing this possibly requires shall be the preferred options for this waste. Fluidized bed incineration should be applied to treat only the combustible residues which remain after the sorting and processing of this waste.

[2] Any possibilities for this waste to be recycled should be examined and, whenever possible and economically feasible, applied first, in particular if amounts of wood in a natural or widely untreated state are involved. Energy generating facilities specialized on the combustion of woody biomass are also more suited for utilizing this waste in an energetically effective manner.

[3] in small quantities only , any possibilities for this waste to be recycled or material used should be examined first and, whenever possible and economically feasible, preferred. Other forms of thermal utilization should be considered as well, e.g. an industrial co-incineration (see also fact sheet on „Industrial co-incineration“).

**Protective needs:**
Exhaust and flue gases from the incineration must be appropriately treated and cleaned. Protective measures must ensure that no health risks or any negative impacts on sensitive media such as the soil, ground water or sites of special value do occur. Guidance what measures and limits may apply is provided in other documents and fact sheets (see fact sheet on "Exhaust and flue gas cleaning" and the document on "Technology-related EU regulations" in particular the "Directive on industrial emissions"). To erect an incineration facility in or close to dwelling areas requires that minimum distances to the nearest buildings and other precautionary measures, especially such serving noise protection, need to be observed.

**Potential health risks:**
A release of untreated flue gases pose a health risk which can be avoided if contemporary cleaning techniques and protective measures as indicated in this fact sheet and in the fact sheet on "Exhaust and flue gas cleaning" are employed and properly followed. Waste incinerators using state-of-the-art cleaning technologies are nowadays considered as not threatening human health any longer.

## RESTRICTIONS OR INFLUENCE OF EXTERNALITIES ON THE APPLICATION

**Infrastructural conditions:**
To allow for economical operations of waste incineration plants a minimum throughput capacity (approx. 50,000 Mg/a) shall be ensured. Areas with a concentration of waste generation (i.e. especially in or nearby large cities) are therefore favorable places for this type facilities. Such areas do also offer the necessary infrastructural conditions, like a good accessibility and connection to road, railway or waterways, and the possibility to supply nearby users with the electric energy and/or steam produced. An increase in traffic movements in the area of the plant must be considered.

**Climatic conditions:** No special restrictions apply.

**Suitable financing mechanism:**
The incineration of waste should be financed by charges imposed to the generators of the waste. Introducing an incineration tax or additional waste treatment fee specifically for the combustible waste may help to ensure that only the non-reusable, non-recyclable parts of the waste are forwarded to incineration, both are also instruments for an additional financing of the treatment.

# TECHNICAL DETAILS

## GENERAL OVERVIEW

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| ABSTRACT | Fluidized bed combustion is used in modern incinerators and power plants as a particularly efficient and low-emission technology. Fluidized beds suspend solid fuels (which is waste in the specific case looked at here) on upward-blowing jets of air during the combustion process. The result is a turbulent mixing of gas and solids. The tumbling of the waste material provides more effective chemical reactions and heat transfer. Fluidized-bed combustion evolved from efforts to design a combustion process with minimized pollutant emissions and a reduced need for very cost intensive external emission controls (like for example scrubbers). The use of this technique is meanwhile often seen for the combustion of dried sewage slude (see the fact sheet on „Sewage sludge treatment") and is further very common for the thermal utilization of refuse-derived fuel (RDF) products (see the fact sheet on „Industrial co-incineration"). |
| BASIC REQUIREMENTS | - The process must be controlled in a way that temperatures remain below a level where ashes sinter and noxious nitrogen oxides can form<br>- Pretreatment of the waste has to ensure that the process input is a small-sized (approx. 50 mm) mixture of waste with rather homogenous physical properties<br>- The average heating value of the input can be up to 20 MJ/kg for a stationary fluidized bed combustion process and go up to 35 MJ/kg for circulating bed combustion. |

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| EXPECTED RESULTS | <u>Output:</u><br>- Ashes with no or little slag (reaching a carbon content in the range of 0.5% or ignition loss of less than 0.5 % by weight)<br>- Caldron dust<br>- Gaseous emissions (exhaust/flue gas)<br>- Low $NO_x$ –formation and reduced binding of heavy metals in the ashes due to comparatively low process temperature |
| SPECIFIC ADVANTAGES | - Process is less sensitive to changes in the calorific value of the waste and can be used for the incineration of sludge and paste-like substances in particular<br>- Low or reduced denoxification demands in result of little pollutant generation due to incineration at rather low temperatures,<br>- Good burnout results<br>- Technology qualifies for high heat power output (for circulating bed combustion up to 1000 $MW_{th}$) and high calorific input material (for circulating bed combustion up to 35 MJ/kg)<br>- Capital requirements in comparison to other techniques often lower |
| SPECIFIC DISADVANTAGES | - Process is marked by a lower throughput as compared to other techniques<br>- Higher probability of wear and tear in the combustion chamber and the boiler due to the high quantity of abrasive material (sand) in the fluidized bed,<br>- The binding of heavy metals into the ashes occurs to lower extent,<br>- Possible risk of a formation of laughing gas ($N_2O$) in the exhaust gas stream<br>- Problems of general public acceptance may exist here and there and must be overcome |
| APPLICATION DETAILS | |
| TECHNICAL SCHEME | In the fluidized-bed combustion, mostly crushed waste is brought into a fluidized-bed of inert matter where it is incinerated at comparatively low temperatures (750–850°C). High detention time, large specific surfaces, and good heat transmission lead to a good burnout (remaining content of carbon < 0.5% by weight). The combustion temperatures well below the threshold where nitrogen oxides form, lead to a comparatively low $NO_x$ formation, developments of nitrous oxide (laughing gas) as highly active greenhouse gas must be observed, however. The low process temperature also guarantees that ashes do not sinter so that heavy metals are bound into the ash to a lower degree. The mixing action of the fluidized bed brings the exhaust gases furthermore into contact with a sulfur-absorbing substance, such as limestone or dolomite. With this a high degree of the sulfur pollutants can be captured inside the boiler by the sorbent. Fluidized-bed combustion systems fit into essentially two major groups, atmospheric systems (FBC) and pressurized systems (PFBC). PFBC systems operate at elevated pressures and produce a high-pressure gas stream at temperatures that can drive a gas turbine. Steam generated from the heat in the fluidized bed is sent to a steam turbine, creating a highly efficient combined cycle system.<br>Basically, there are three different procedural types of fluidized bed systems which are distinguished by the directing of the flue gas stream. The three types are<br>- stationary<br>- rotating and<br>- circulating fluidized bed.<br>In the *stationary fluidized bed* the bed height is constant. There are basically no diagonal transports in the fluidized bed. The stationary fluidized bed is mostly used for sewage sludge. It is especially useful for the burning of wastes with a low calorific value (6.5 to13 MJ/kg). Certain conditions provided (heating surfaces are present in the fluidized bed) waste with a calorific value of up to 18 MJ/kg can also be incinerated efficiently.<br>In the *rotating fluidized bed* the bed is also a stationary one. However, a rotation along its own axis takes place so that a diagonal mixing occurs. The rotating fluidized bed is put into place for wastes with higher calorific value (7 up to max. 20 MJ/kg). Sludge can be burned, too. |

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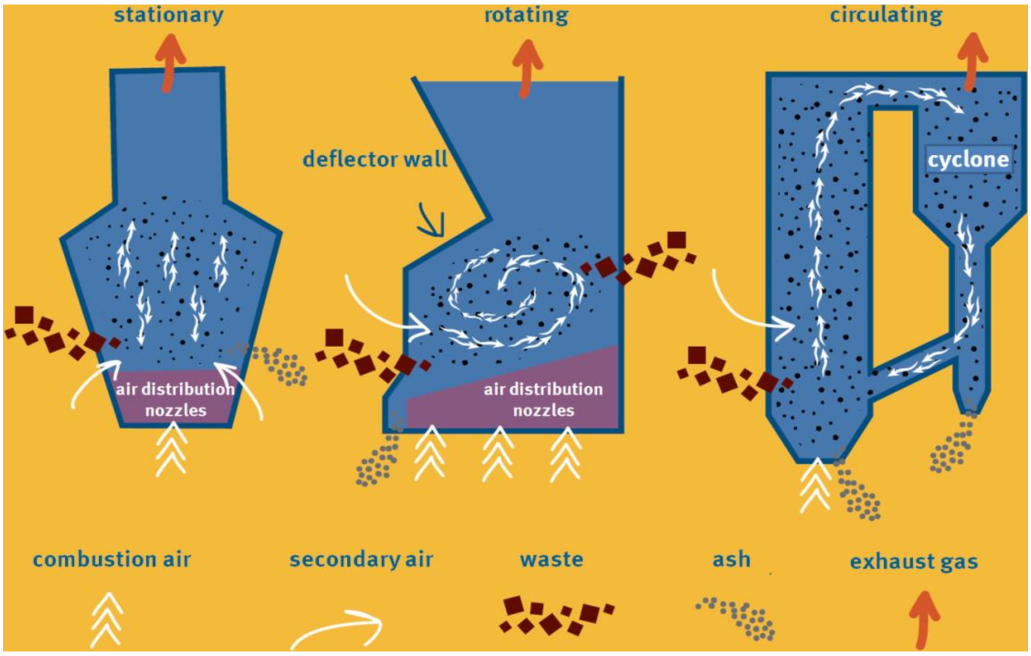
| | Figure 1: Variants of directing the gas stream in different fluidized bed systems<br><br><br>In the *circulating fluidized bed* the bed height is not constant. Instead bed ash and bed sand constantly leave the furnace through a high air velocity. These bed materials are separated in a cyclone and for the most part returned to the furnace. The high air velocities allow the use of high calorific waste. |
| QUANTITY ASPECTS | Input:<br>- solid and paste-like waste material<br>- sand/inerts (bed material)<br>- water (steam generator), the fresh water demand is about 1 $m^3/h$ per Mg/h throughput in the minimum<br>Output:<br>- 200 to 250 kg bottom ash/Mg input<br>- 50 to 100 kg cyclone ash/Mg input<br>- 5 to 20 kg caldron dust/Mg input<br>- 4,500 to 5,500 $m^3$ exhaust gas/Mg input<br>- water (from steam generator) |
| SCALE OF APPLICATION | - Applications of this technology at the moment are seen in a capacity range<br>- starting from 4 Mg/h up to 150,000 Mg per line and annum for RDF fractions<br>- between approx. 5,000–75,000 Mg dry matter per annum for sewage and industrial sludge |
| INTEROPERABILITY | Fluidized bed combustion is meant for the treatment of combustible waste materials which cannot otherwise be used (e.g. waste ‹30 mm, sludge). Thus a fluidized bed combustion can be combined with all preceding measures and processes for waste treatment.<br>It is useful to establish synergies with processes with a high demand of thermal energy (e.g. paper mills who in return can feed most of their process residues into such facilities). Alternatively there should be the possibility for the incinerating plant to supply surplus thermal energy (steam or warm water) to external users or to feed electrical energy into the public grid.<br>- The incineration process in any case must be combined with an exhaust gas cleaning because untreated flue gases may contain harmful components (see fact sheet on “Exhaust and flue gas cleaning“). |

## OPERATIONAL BENCHMARKS: RESOURCE CONSUMPTION

**ENERGY BALANCE**

Energy balance for an example from practice (state of data 2010)

Input: -fuel (waste), auxiliary energy, e.g. natural gas < 3 % of the fuel input

Output: -electricity; maximum output 20 % (considering own process demands)
-thermal energy; maximum output up to 60 %

Combinations of electric and thermal energy supplies are possible and desirable but the rule is that the more thermal energy is supplied the less electric current can be generated.

Table 1: Example for the energy flows in a monovalent sewage slude incineration using fluidized bed technology (Source: Franck, Monoverbrennung von Klärschlamm, 2015)

| Parameter | Unit | Absolute value range | |
|---|---|---|---|
| Throughput | $Mg_{dry\ matter}$/annum | 35,000 | 2,000 |
| Pre-heating of air stream | °C | 120 | 200 |
| Turbine power output in extraction mode operation | $MW_{el}$ | 1.4 | - |
| Net electricity output turbine | $MW_{el}$ | 0.4 | - |
| Energy demand sludge drying | $MW_{th}$ | 7.0 | 0.430 |

**$CO_2$-BALANCE**

- A positive balance can be obtained through the saving of primary fossil fuels and the utilization of the renewable waste components as an energy source

**AIDS/ADDITIVES NEEDED**

- Sand
- Caustic lime
- Hearth furnace coke
- Fuel oil or natural gas for startup and support heating

**HUMAN RESOURCES**

- a minimum of 10–15 skilled persons per incineration line including exhaust gas cleaning per day for the 24h/7 days operation mode, at least 1 engineer and 2 foreman should be among the staff, additional personnel for maintenance, cleaning services and gate control, especially qualified personnel is needed for the technical management

**SPATIAL NEEDS**

- The minimum space demands are at about 5,000 to 10,000 m² depending on throughput capacity

## OPERATIONAL BENCHMARKS: COST DIMENSIONS

**INVESTMENT COSTS**

A specific investment in the range of EUR 180–400 per $Mg_{Dry\ matter}$ provides a reasonable estimate for large-scale plants engaged in the exclusive incineration of sewage sludge with the help of fluidized bed incineration technology. The following table lists the investment costs for comparable plants of larger and smaller size designed for the incineration of sewage sludge with the help of fluidized bed incineration technology.

Table 2: Investment costs for sewage sludge incinerators of different size with fluidized bed technology (Source: Franck, Schröder: Zukunftsfähigkeit kleiner Klärschlammverbrennungsanlagen, 2015)

| Parameter | Larger-sized plant | Smaller-sized plant |
|---|---|---|
| Annual throughput capacity | 35,000 $Mg_{dry\ matter}$/a | 2,000 $Mg_{dry\ matter}$ /a |
| Process technology | 24,150,000 EUR | 3,590,000 EUR |
| Construction engineering | 5,150,000 EUR | 880,000 EUR |
| Electronic measurement and control technology | 2,250,000 EUR | 1,130,000 EUR |
| Incidental expenses | 3,200,000 EUR | 1,000,000 EUR |

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| OPERATING COSTS | - vary strongly and particularly in dependence from the market prices for operating supplies (such as auxiliary fuels) and the local labor costs.<br>- For the plant examples in above table the amount of EUR 5.5 million (larger-sized plant with 35,000 Mg sludge$_{dm}$ annual capacity) respectively EUR 1 million (smaller-sized plant with 2,000 Mg sludge$_{dm}$ annual capacity) can be given as orientation values<br>Repair and maintenance<br>- for each structural element approx. 1% of the initial investment<br>- machinery and electronic: 3–4% of the initial investment<br>Further indices can be obtained from the reference literature and sources listed below. |
| POSSIBLE PROCEEDS | - from the supply of electricity and steam/warm water |
| MASS SPECIFIC OVERALL COSTS | Costs are supposed to be in the same range as in the case of grate combustion (see the fact sheet on "Grate combustion"). Possible savings may arise from the reduced denoxification demands. There might be slightly higher costs due to the increased risk of wear and tear and particular pre-treatment needs for the input, however.<br>Especially where fine material such as dried sludge or undersized screening material <30mm from the mechanical treatment are burnt, cost savings between 20-30% as compared to grate combustion become possible with the fluidized bed technology<br>An example for the incurring costs in Germany is:<br>- Input dried sludge or waste material <30mm: 80 to 120 EUR/Mg, less sophisticated exhaust gas cleaning procedures and equipment and a good market situation for the sale of electricity and steam normally improve the cost ratio significantly |
| OTHER RELEVANT ASPECTS | |
| MISCELLANEOUS | |
| MARKET INFORMATION | |
| REFERENCE FACILITIES<br>*(Note: the list of sites and/or firms does not constitute a complete compilation)* | The incineration of appropriate waste materials, sewage sludge and refuse derived fuel products in particular with fluidized bed technology has strongly evolved recently and is meanwhile in worldwide use. Germany by now has plants with a total capacity above of 2 million Mg annual throughput in operation with fluidized bed technology (state of 2016). Some reference facilities in Germany are for example:<br>- TEV Neumünster: circulating fluidized bed, 150,000 Mg annual throughput<br>- RDF incinerator in the industrial park Höchst www.infraserv.com |
| RECOGNIZED PRODUCER AND PROVIDER FIRMS<br>*(Note: the list of firms does not constitute a complete compilation of companies)* | Recognized producer/provider firms for grate combustion technology and related plant components are for example:<br>- Eisenmann SE, Böblingen www.eisenmann.com<br>- Küttner GmbH & Co. KG www.kuettner.de<br>- Strabag Umwelttechnik GmbH www.strabag.de |
| ADDITIONAL REMARKS AND REFERENCE DOCUMENTS | |

As important reference documents on this combustion technique are available:

VDI 3460 and Reference Document on the Best Available Techniques for Waste Incineration

Further information and compilations on relevant details and plants can be obtained from:

- ITAD – Interessengemeinschaft der thermischen Abfallbehandlungsanlagen in Deutschland e.V. www.itad.de
- CEWEP – Confederation of European Waste-to-Energy Plants www.cewep.com