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State of the Art of Alternative Thermal Waste Treatment Processes

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1. Background

Incineration is the globally predominant process for thermal waste treatment considering plant number and treatment capacity. About 255 million tons of waste is processed annually in about 2200 facilities.

In addition to this well established treatment method, waste pyrolysis and waste gasification offer other thermal treatment methods. These so called alternative thermal treatment processes have recurrently been presented by different operators since the 1970s, using more or less creative names. They are typically characterized by a comparably complex technology. According to the providers, the advantages of these processes compared to incineration lie within higher electrical efficiencies and/or higher value of conversion products, for example the production of glazed and therefore non-elutable slags or the production of liquid energy sources.

Due to a number of set backs, these processes have not gained importance in Germany; however, they have recently been rediscussed and demanded abroad by some groups of interest and political decision-makers. Proponents of the processes can meanwhile refer to long-term operation of facilities in Asia, especially in Japan. However, entirely different frame conditions apply in these countries compared to Europe or North America.
The already mentioned practical experiences mainly refer to facilities for gasification and pyrolysis. Among these classical alternative thermochemical processes, other alternatives have been entering the market for the last years. Plasma processes – implemented as plasma pyrolysis or plasma gasification – realize the conversion of waste through contact with hot plasma of at least 2,000 °C – partly ionized gas. According to the providers of these technologies, this ensures low gaseous emissions and at the same time high quality of conversion residues. Another alternative thermochemical process, catalytic depolymerization, aims to convert solid residues into liquid hydrocarbons, typically in one step and with the help of a catalyst. The products are supposed to have fuel-like properties and can be used as a substitute for diesel. So called HTC-processes (hydrothermal carbonization) are preferably used to treat (wet) biowaste and sewage sludge. Residues are converted in an aqueous solution into a carbonized product, which allows for optimized energetic and material use.

Only little reliable operational experience is available for the currently discussed plasma and depolymerization processes as well as processes for hydrothermal carbonization, which are yet to be introduced into the market. In some cases, not even plausible mass- and energy balances are available. For the treatment of problematic by-products, only concepts exist, which have not been field-tested yet.

2. Project objectives

The objective of the presented final report *State of the art of alternative methods for thermal waste treatment* is the provision and evaluation of information on the state of the art of alternative thermal processes for the treatment of solid mixed municipal wastes. Processes with a relevant continuous operation time under industrial conditions have been considered. Technologies that are currently not in operation, but have proven their practicability in the recent past, have also been taken into account. In addition, new developments that are soon to be available on the market have been considered. A certain minimum development status has been required to take these processes into consideration.

In addition to a proven technology of a waste treatment process, local statutory, economic and political conditions are of much importance for the success or failure of a technology. The strong distribution of alternative thermal processes in Japan for example can only be understood when the specific situation is taken into account. Within the study, the country-specific conditions are therefore studied and discussed.

3. Approach

The information search was based on different approaches. Data obtained by an intensive literature research has been verified and completed by the interviewing of operators. Visits to plants have offered insight into processes that are currently in operation in Germany, or that are expected to be relevant soon due to their current development status. Basic process data, essential parameters and environmental performance infor-
mation such as emissions, energy consumptions or the quality of valuables regained from the process have been gathered. Information on economic efficiency and treatment costs respectively has also been documented, if available. The literature research ranged from English, Japanese, and French to German sources. Current developments and processes in practical operation have been considered as well as those historical technologies that have shown continuous operation on an industrial scale in the recent past and therefore represent the state of the art.

Based on existing information, a classification and evaluation according to the following aspects has been made:

- State of development of the technology (classification using VDI 3460),
- required (pretreatment) effort,
- product nature and quality – possibly as input material of a follow-up plant –,
- complexity,
- economic efficiency.

4. Processes and installation variants

4.1. Pyrolysis

Proponents of pyrolysis for the treatment of residual wastes postulate different advantages of pyrolytic conditions, especially compared to waste incineration. The following benefits are mentioned:

- Pyrolysis oil and gas can be used more efficiently in direct power machines (gas turbines, internal combustion engines),
- metals can be regained easier and at a higher value from pyrolysis coke; the extraction and use of soot (carbon black) is also considered beneficial,
- lower emissions.

The technological advantages have yet to be proven in a long-term stable operation. The literature available offers hardly any specific information on – long-term – operational experience and the economic efficiency of processes for waste pyrolysis. On the contrary, many attempts of practical operation have encountered problems. The following aspects are to be considered problematic when looking at pyrolysis processes:

- Reactors and process management typically require good preparation with accordingly high pretreatment costs,
- the gaseous pyrolysis products contain large concentrations of tars, which complicate their energetic use,
- marketing of low quality coke,
- installations require high maintenance,
- Fossil fuels are used to provide heating for some of these processes.
A large number of pyrolysis technologies has been looked at in the context of the study, the presentation of which would exceed the scope of this summary.

Further information can be obtained from the final report of the project *Sachstand zu den alternativen Verfahren für die thermische Entsorgung von Abfällen – State of the art of alternative methods for thermal waste treatment –*, project number 29217. In order to gain a better overview and to enable an evaluation, different categories for the process variations have been defined. All of the considered technologies could be assigned to one of the following three categories:

- **Pyrolysis as part of an incineration and melting process**
  
  This technology is characterized by a pyrolysis step within a high temperature process, during which pyrolysis gas as well as coke - often after separation of metallic resources - are co-combusted at temperature higher than the melting point of the slag. Slag accumulates as a glazed product with good eluate values.

- **Stand-alone pyrolysis**
  
  This category refers to those pyrolysis processes, during which only the gaseous products are used - normally within the combustion chamber of a steam generator. The pyrolytic coke does not react further and remains product or residue. This approach is followed by some technologies currently entering the market, but has actually been developed decades ago and is still in use in the waste pyrolysis facility in the Bavarian town of Burgau.

- **Pyrolysis as up-stream process step**
  
  This refers to processes that are specifically combined with an existing thermal follow-up process, aiming to produce better usable products - gas and coke. The Contherm facility at the power plant Westfalen in Hamm, which had been operating for years but has meanwhile been put out of operation, is an example for the application of this pyrolysis technology.

### 4.2. Gasification

In order to properly evaluate gasification processes, it has to be differentiated between gasification as part of a staged combustion and an actual gasification technology aiming to produce a variably usable (fuel) gas.

Only the first step of a staged combustion process is actually carried out under understoichiometric conditions, meaning a lack of oxygen. It is followed by a complete oxidation of the produced gases in an afterburning chamber, a part of the reactor that is oftentimes not physically separated from the main part of the chamber. Technically, these technologies have to be categorized as incineration processes, whereas they show less energetic efficiency as a classical waste incineration.

Gasification and melting processes that are particularly offered by several Japanese companies are actually staged (high-temperature) incineration processes. These technologies obtain a significant additional gain by the meltdown of the slag, which is however due to a high energy input.
Considering gasification processes the focus is on actual processes with the objective to produce synthesis or fuel gas. These technologies are also supposed to have high advantaged compared to incineration. More specifically, these are:

- Higher electrical efficiencies through the use of gases in internal combustion engines,
- lower emissions,
- glazing of the slag with realization of outstanding eluate values, using high temperature applications ($T > 1,500 \, ^\circ C$).

The amount of available information on gasification processes is limited, just as it is the case with pyrolysis technologies. Few data has been published especially on operational experience, emissions, costs and long-term experiences.

Gasification technology struggles with several basic challenges, mainly relating to the quality of the gaseous product:

- High requirements for waste processing and elimination of impurities with according additional costs,
- high yields of tar and dust complicate the use of these gases in combustion engines; fuel gas cleaning is accordingly complex,
- high maintenance costs.

As mentioned above, the gasification processes are characterized using the following categories:

- Gasification as part of a staged combustion process,
- gasification as part of incineration and melting process,
- gasification for gas production,
- gasification as up-stream process,
- up-stream processes such as mentioned for pyrolysis technologies, pose an additional category.

4.3. Further technologies

In addition to pyrolysis and gasification, other technologies for municipal solid waste treatment have been considered, all of which are currently on a development or concept stage. These are plasma and depolymerization processes.

The suitability of plasma technology for thermal waste treatment has been proven in the past, as it was used for the treatment of hazardous wastes such as asbestos or chemicals. Another application is the glazing of reactive wastes. In addition to these processes for the treatment of specific mono-fractions, technologies with plasma support for the thermal treatment of municipal waste have globally been offered by different manufacturers. These include plasma gasification as well as pyrolysis.
The objective of the depolymerization process is the direct conversion of residue and biomass into standard fuels or semifinished products comparable to crude oil or gasoil (diesel/fuel oil). Newer technologies claim to achieve hydrocarbons with high product quality merely by using catalysts in a direct process. So far, scientific research has not been able to support this statement.

5. Assessment

The assessment of alternative methods for thermal waste treatment conveys a clear impression:

Amongst the variety of alternative treatments, some up-stream facilities combined with other thermal processes (power plant, cement plant, lime plant) offer direct utilization of the products (gas, possibly coke) under optimized conditions – e.g. higher electrical efficiencies in power plants. These have to be considered as potentially reasonable and economically operable processes for the utilization of preprocessed wastes, partly also under European conditions.

Interest lies also in processes that enable the treatment of special fractions such as highly toxic, chlorine containing or low calorific substances – e.g. organically contaminated soil – that are actually non-combustible. Higher efforts such as in plasma processes can be justified by the ecological necessity of a high quality treatment for these problematic residues. Legal requirements play an important role.

Treatment methods that are unable to reach a full inertion of the products are to be considered critical. For example, the production of pyrolysis coke with the quality of hazardous waste results in high subsequent costs for product disposal. This condition seems to prevent an economically feasible operation. According to the currently valid BREF Waste Incineration, alternative methods can only be state of the art, if they are equipped with a subsequent combustion stage with energy recovery or if the products are being recovered or supplied for use of substances. This requirement is not met by processes that produce coke or residues with a high loss of ignition as products with no specific follow-up use.

Comparably simple methods – e.g. low temperature pyrolysis or direct depolymerization – typically result in high efforts necessary for product treatment – such as gas treatment following pyrolysis/gasification or fuel refining after direct polymerization. The allegedly simplicity of the main process is achieved at the expense of a more complex product treatment. Accordingly, these treatment steps are weak points in the process. Sometimes, these problems are simply ignored during the development of the technology.

It is to be mentioned that for all alternative thermal methods, a higher effort compared to classical waste incineration is necessary. An intense pretreatment of the feedstock is essential. At least, shredding of the waste is required, oftentimes also fractioning and removal of metals and inert materials. Some processes even require pre-drying or pelletizing (briquetting) of the feedstock. The few Japanese melting processes, that
can – according to the manufacturers – be operated without waste pretreatment – even though size limitations apply, are very complex in operation. The addition of coal or coke and the utilization of oxygen are common amongst these processes.

Long-term operation and experience cannot significantly reduce the effort in operation of complex alternative processes, as can be seen from Japanese examples or from SVZ Schwarze Pumpe. This contradicts the occasionally expressed opinion only the development status of alternative methods for thermal waste treatment limits their comparability to classical waste incineration, but would improve with more operational experience and process optimization.

In conclusion, it can be said that the following criteria have to be met in order to have a chance to operate alternative waste treatment methods in a reasonable and economic way:

- Meeting of special legal guidelines (e.g. melting processes in Japan),
- realization of certain product properties (e.g. glazed slag, lowest possible contamination),
- treatment of special fractions (e.g. highly toxic of chlorine containing materials, fractions with low calorific value such as contaminated soil ),
- up-stream facilities (e.g. combined with power plants, cement plans, lime plants) for the substitution of fossil fuels.

Waste incineration therefore remains state of the art for the treatment of mixed residual wastes. None of the so-called alternatives reaches similar capacities or flexibility under comparable conditions.

There are no alternative treatment methods available that could be compared to waste incineration in an economical and also ecological way. This is not expected to change due to the complexity of these alternative methods.

The treatment of mixed residual waste should therefore be preferably carried out in incineration processes specially designed and proven for this purpose.
Gasification as an Alternative Waste to Energy

Waste gasification technology is recognized as an alternative thermal treatment technology. NSENGI's gasification and melting technology is a proven waste gasification technology based on more than 35 years operating experience.

Direct Melting System
(Main)
Shinmoji Plant
- Capacity 10 t/h, 3 lines
- Start Up Apr.2007
- Waste to be treated
  MSW, Incombustibles, Sludge

(Left)
Waste Pit & Waste Crane

(Right)
Interior of Facility