High-Temperature Winkler Gasification of Municipal Solid Waste

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Abstract

The High-Temperature Winkler (HTW) process developed by Rheinbraun is a fluidised-bed gasification process particularly suitable for various types of lignite, other reactive and ballast-rich coal types, biomass and different types of pre-treated residual waste. Depending on the application, the HTW process can be used for efficient conversion of these feedstocks to produce fuel gas, reduction gas or synthesis gas.

The co-gasification of pre-treated municipal solid waste (of differing origins) and lignite was demonstrated in a commercial scale during normal production in the HTW demonstration plant at Berrenrath, Germany.

Approx. 1,000 metric tons of pre-treated municipal solid waste was gasified without any problems together with dried lignite in the three test campaigns. The gasifier operated to the full satisfaction of all partners throughout the test campaigns.

The demonstration project yielded useful operating experience and process engineering data (e.g. energy and mass balances, gas composition, emission estimates) and provided engineering reliability for the design of future plants and an important reference for further applications, most recently for MSW gasification in Japan.

The Krupp Uhde PreCon® process applies the High-Temperature-Winkler (HTW) gasification as a core technology for processing solid wastes, e.g. municipal solid waste, sewage sludge, auto shredder residue or residues from plastic recycling processes. The modules used are based on those used in mechanical pre-treatment and coal gasification being tested successfully in commercial plants for several years.

1. *Introduction*

The eldest and most popular process of fluidised-bed gasification is the well-proven Winkler process, developed by Fritz Winkler (BASF). As early as in 1926, the first Winkler gasifier was introduced in industrial-scale in Leuna/Germany, fed with fine-grain brown coal. Since then, the Winkler gasification process found several further applications for the generation of synthesis gas and fuel gas around the world.

The HTW process constitutes a further development of the Winkler fluidised-bed gasification, which was originally only operating at ambient pressure.

Rheinbraun, as the further developer & licensor of the advanced HTW coal gasification, started the development of the process under pressure and a temperature below the ash melting point (approx. 800–1000 °C) in 1975. Research and development was successfully finished in 1997.

The basic idea for the development of the HTW process was to increase the specific capacity by increasing the operating pressure, to optimize the conversion of carbon and to increase the quality of the raw gas.

In the mid-1980‘s, the requirements of utilising the process in Integrated Gasification Combined Cycle (IGCC) plants for efficient and favorably priced power generation defined another important target.

Towards the end of the 1990‘s, there has been an ever increasing demand for the treatment of solid wastes (e.g. municipal solid waste (MSW), auto shredder residue (ASR), sewage sludge) in many countries around the world. In particular, due to unforeseeable consequences for the future, there is no public acceptance for dumping such as landfilling of solid wastes. Thermal treatment is an ideal mean to transform a selected part of the waste stream into an environmentally harmless and less voluminous substance while simultaneously recovering its energy content. The possibility of converting waste to energy makes the thermal treatment of solid wastes even more attractive.

The Krupp Uhde PreCon® process applies the High-Temperature-Winkler (HTW) gasification as its core technology for processing of solid wastes, e.g. municipal solid waste, sewage sludge, auto shredder residue or residues from plastic recycling processes.

2. HTW gasification of waste at elevated pressure

In the past, several test campaigns for HTW were carried out for gasification of ASR and MSW in small scale pilot gasifiers. The promising results gained provided the incentive to prepare a campaign for gasification of approx. 1,000 metric tons of MSW in the commercial HTW plant at Berrenrath (capacity: 30 t/h), which has been in full commercial operation under the responsibility of Rheinbraun for over 10 years. This commercial-scale campaign was supported by the „Thermie-program“ of the European Commission (SF /0263/97/DE/ES) and executed by three partners: Rheinbraun AG, Cologne; Krupp Uhde GmbH, Dortmund and Intecsa-Uhde S.A, Madrid.

The project comprises three phases: preparation, demonstration and verification. The engineering for the performance of demonstration tests commenced in June 1997, these tests being implemented in three campaigns between mid-October and early November 1997. The evaluation of the tests and the incorporation of the results in the basic engineering for a commercial plant was performed in early 1998.

The aims of the project can be summarized as follows:

- Efficient and low-cost utilisation of lignite and municipal waste for the generation of energy.
- Demonstration of the applicability and reliability of the High-Temperature-Winkler process (HTW) for lignite and municipal waste in commercial scale.
- Supporting the introduction of the process on the market by securing the data bases in a commercial plant, especially with regard to the gasification behaviour, gasifier design, product gas quality and environmental pollution.
- Opening up new European and international market segments in the sphere of progressive technologies for the utilisation of municipal waste and lignite for the generation of energy.
- Reduction of the adverse environmental effects of municipal waste by
  - a progressive and efficient utilisation process;
  - utilisation of the waste as an alternative fuel;
  - the conversion of waste into appropriate and useful forms of energy;
  - a long-term contribution towards the European strategy for reducing the emission of CO_2;
  - the avoidance of residues that are detrimental to the environment;
  - a significant reduction of the future requirements for waste dumps and the associated risks (e.g. uncontrollable CH_4 emission and dump seepage water).

In the HTW demonstration plant, approx. 600 metric tons of dried lignite (0-6 mm grain size) had been processed daily to approx. 800,000 m^3 (at STP) specification-grade synthesis gas, from which about 300 metric tons per day of methanol were produced. The gasifier operated at a pressure of 10 bar and a gasification temperature of about 950°C. Oxygen and steam have been used as gasification agents.

A principle process flow diagram of the HTW demonstration plant is illustrated in Fig. 1.

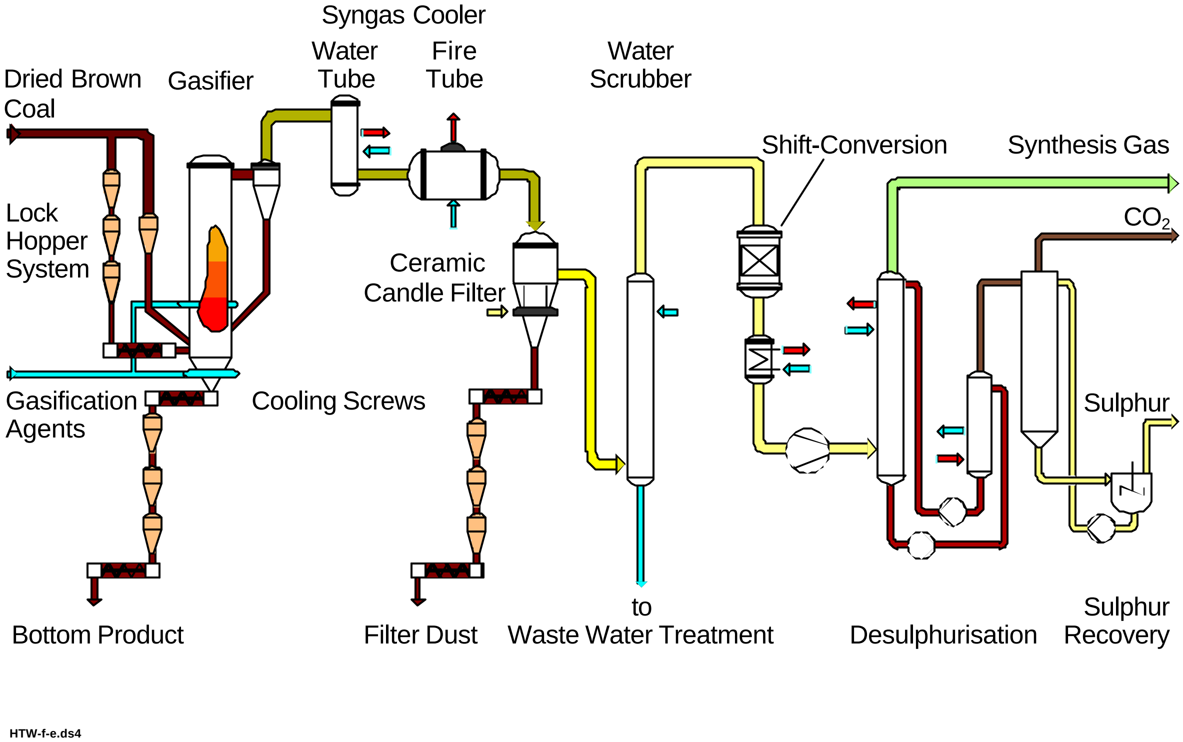


Fig. 1 : HTW demonstration plant, process flow diagram

All elements of a modern gasification plant were installed and investigated during the test campaign – raw gas cooling by either a water tube cooler or a fired tube cooler, a ceramic candle filter, high efficient COS and H_2S removal.

Control and regulation of the HTW demonstration plant was effected by a process control system with an integrated fuzzy-logic-based control system for the gasifier. Raw gas analyses were predominantly performed with the aid of in-line instruments and likewise acquired by the process data processing system.

Special analyses (e.g. dioxins/furanes) and analyses of the solids and waste waters were carried out batch-wise by the Rheinbraun laboratories.

The HTW demonstration plant at Berrenrath also offered all necessary facilities for the co-gasification and handling (supply, storage, conveying, metering) of waste.

It was initially decided that the tests were to be conducted using standard dried MSW pellets, sized 15-20 mm, in order to limit the effort and costs involved in the MSW pre-treatment.

After thorough investigations and tests it was found that all the existing facilities for delivery, storage, conveying and metering of residual materials as operated for co-gasification, could be used without any modifications, despite the fact that pellets had a considerably larger size than the lignite grain.

The co-gasification of municipal waste and dried lignite proceeded in three campaigns, in the course of which approx. 1,000 metric tons of MSW had been processed. Each test series lasted about 3 days. In the first two campaigns, municipal waste from the Netherlands was used. The feed rate was 5 t/h, i.e. approx. 25% of the total solids input to the gasifier.

Contrary to the original plan, the admixing rate in the third campaign was increased, with the permission of the competent authorities, from 5 t/h to approx. 10 t/h. Thus, operational experience is available for this elevated ratio as well.

In the third test series, co-gasification proceeded with Danish municipal waste.

During the third campaign, a part stream of the dust-laden raw gas was subjected to desulphurisation tests by partial oxidation of H_2S (direct desulphurisation) in the existing pilot filter.

The co-gasification tests using municipal waste were conducted during normal plant operation. Nothing unusual occurred in exporting the synthesis gas.

Throughout all test campaigns, gasifier operation was virtually trouble-free and to the full satisfaction of all partners.

Municipal waste feed

Thanks to the good pouring characteristics of the pellets, the discharge from the bin and the feed into the gasifier did not present any problems during the campaigns with a 5 t/h feed rate.

A temporary blockage in the supply line occurred during the 10 t/h campaign, but this could be cleared by opening the line. No deterioration of gasifier performance was observed during this time.

Gasification

No unusual phenomena occurred during the gasification of municipal waste and no significant differences from the gasification of 100 % lignite were noted, even when the municipal waste portion was increased to 50 %. This is substantiated by the comparison

(Fig. 2) of the max. gasification temperature and the quantity of synthesis gas produced for pure lignite operation and the tests with municipal waste.

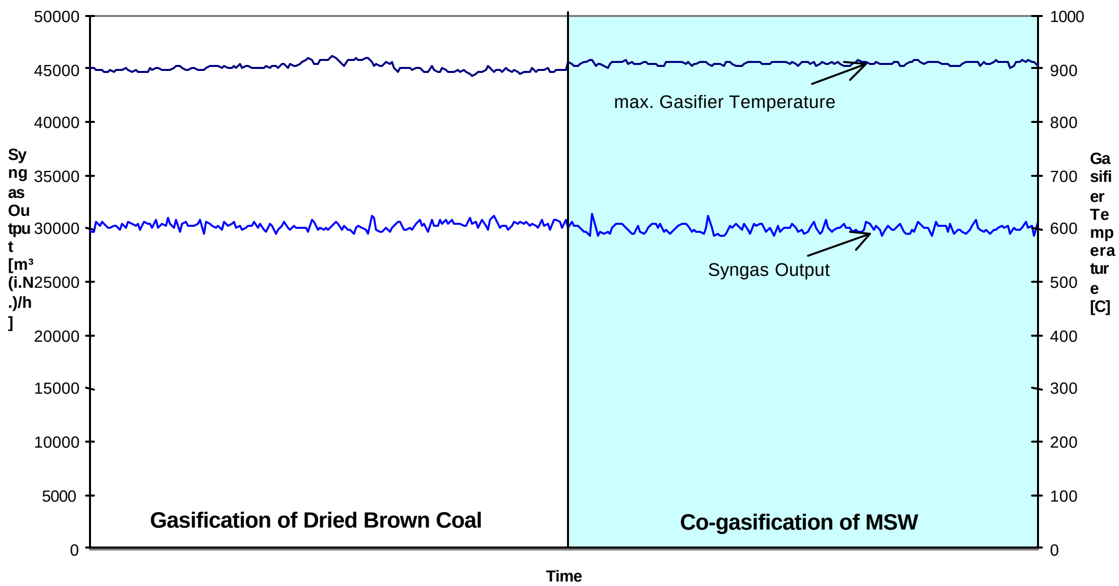


Fig. 2: Comparison of operating data

<u>Residues</u>

The discharge and further processing of the solid residues was not affected by the co-gasification of municipal waste. After removal of magnetic metals, the bottom product was undergrate-fired in the boiler of the adjacent power station, as is done in the case of pure lignite gasification. The dust was separated in the existing hot gas filter without any detectable effect on the operating behaviour of the plant and was then used as a filter aid together with the waste water of a biological treatment unit.

<u>Direct desulphurisation</u>

During the last campaign, tests were carried out with the pilot filter for direct desulphurisation. These tests proved that the process of partial H_2S oxidation (direct desulphurisation) can achieve desulphurisation rates of up to 95%, even when operating with MSW. Compared to the use of lignite, neither the operating behaviour nor the desulphurisation rates differed in any way.

<u>Raw gas quality</u>

The raw gas composition for MSW feedstock showed that, except for a minor increase of the methane content, there were no changes as compared to pure lignite gasification. With respect to the trace components (benzene, naphthalene, ammonia and hydrogen sulphide), the measured differences were also of a minor nature (Figs. 3 and 4). Specification-grade synthesis gas could be generated at all times.

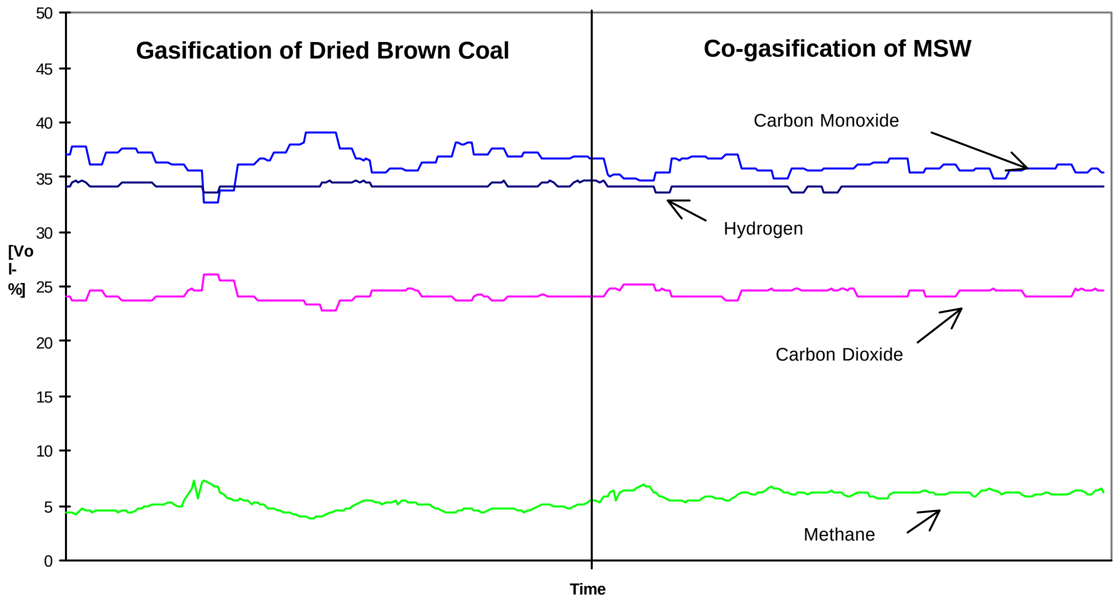


Fig. 3: Main components of dry raw gas

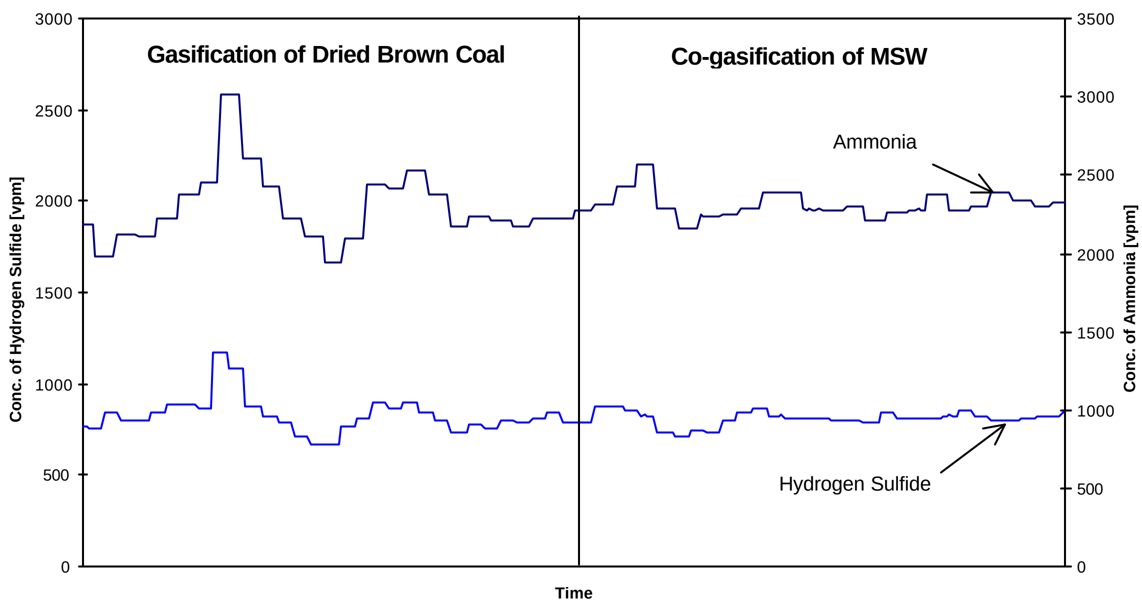


Fig. 4 : Trace components of dry raw gas

Environmental aspects

To assess the behaviour of environment pollutants, such as halogens, heavy metals, sulphur and nitrogen compounds, dioxins/furanes, extensive analyses were carried out during the co-gasification of MSW. The evaluation of the results led to the findings described below regarding the concentration and distribution of the pollutants.

Owing to the moderate temperatures prevailing in the gasifier, most of the heavy metals introduced into the gasifier with the municipal waste remained in the fluidised bed and were discharged from the gasifier with the bottom product. The bottom product could be used as standard fuel in the adjacent power station without any problems. Eluate tests confirmed the complete compliance with the eluate criteria of waste dump class 1 as specified in TA-Siedlungsabfall (technical instructions dealing with municipal solid waste).

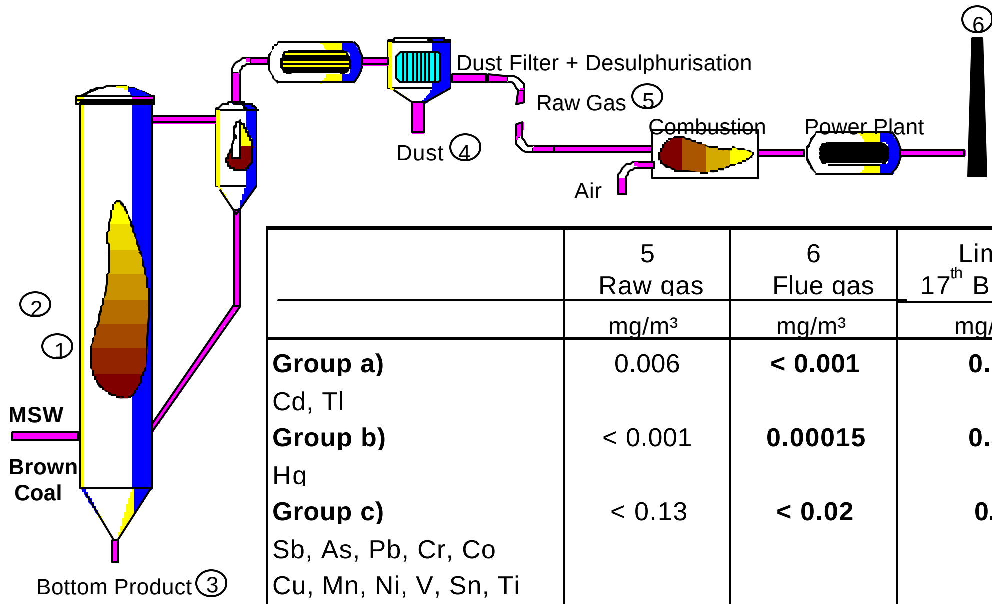
The heavy metals released in gaseous state were retained together with the halogens during dust separation in the hot gas filter and, consequently, removed from the raw gas. The desulphurisation of the main raw gas stream was effected in the downstream low-temperature methanol scrubber. As the raw gas was completely converted to synthesis gas, no emission occurred. The warm gas-filter dust could be used as filter aid in a biological waste water plant without any further treatment.

Tests in the pilot filter for direct desulphurisation yielded desulphurisation rates of up to 95% and emphasised the suitability of this simple process for the thermal utilisation of municipal waste.

Hence, all environmental pollutants with the exception of nitrogen compounds can be removed from the raw gas stream. The ammonia that is formed during gasification can be removed either in a water scrubber or in NO_x-poor burners.

All dioxins and furanes (PCDD/F) introduced into the process could be destroyed almost completely and only minute traces could be detected in the outgoing streams.

Assuming a thermal utilisation of the raw gas, Fig. 5 tabulates the pollutant concentrations that would be present after raw gas combustion at the outlet of the hot gas filter on the stack.



	5 Raw gas	6 Flue gas	Limits 17^{th} BImSchV
	mg/m³	mg/m³	mg/m³
Group a)	0.006	**< 0.001**	**0.05**
Cd, Tl			
Group b)	< 0.001	**0.00015**	**0.05**
Hg			
Group c)	< 0.13	**< 0.02**	**0.5**
Sb, As, Pb, Cr, Co			
Cu, Mn, Ni, V, Sn, Ti			
Dust	< 5	< 1	10
HCl	6,98	1,38	10
HF	< 0.09	< 0.02	1
H_2S+COS	95		
SO_2		38	50
NH_3	1525		
NOx		< 200	200
PCDD/F, TE	0.012 ng/m³	0.002 ng/m³	0.10 ng/m³

Fig. 5 : Concentrations of components limited by 17^{th} BImSchV

Fig. 6 tabulates the relevant pollutant loads determined when using municipal waste of Danish origin. The process stream numbers shown correspond with those in fig. 5.

	1 MSW	2 TBK	3 BP	4 Dust	5 Raw Gas
	g/h	g/h	g/h	g/h	g/h
Heavy metals					
Cd + Tl	55	20	21	26	< 0,27
Hg	1.6	1.3	0.26	2.48	0.05
Others	15,685	1,613	9,965	8,713	< 7
Halogens					
Cl	68,890	5,786	5,328	43,302	226
F	547	636	189	914	4
Sulphur	20,960	55,538	3,333	75,906	4,418
PCDD/F, TE	141 µg/h	n.d.	0.62 µg/h	0.14 µg/h	0.60 µg/h

TBK = Dried lignite / Brown Coal BP = Bottom product n.d. = not determined

Fig. 6 : Mass flow of trace components limited by 17^{th} BImSchV

The thresholds specified in the 17th BImSchV (Federal Law on the protection against harmful effects on the environment) are observed without exception. The NO_x concentration in the flue gas was estimated on the assumption that the above possibilities of ammonia treatment would be used.

3. HTW gasification of waste at atmospheric pressure

The high heterogeneity of municipal waste causes variations in composition (e.g. content of ash, moisture, volatiles, calorific value). In order to guarantee excellent thermal conversion in a fluidised-bed system and to prevent unselective treatment (mass burn), preparation of the waste is very important.

The residues of the HTW gasification process are bottom and fly ash. On account of the demands of individual customers or statutory requirements, unleachable slag must be produced in some countries. To meet the demand of these markets for unleachable slag, additional processing of the bottom and fly ash is required.

Fig. 7 shows a simplified flow diagram of the PreCon® process. After receipt and storage, the municipal waste is pre-treated by crushing and subsequently separating useful materials, such as ferrous and non-ferrous metals. In the next step, the pre-treated municipal solid waste and sewage sludge are dried to a residual moisture content of about 10% by weight. Then, the feedstock is fed to the gasifier; the operating pressure depends on the utilisation of the product gas. The use of either air or oxygen as the gasification agent depends on the required quality of the product gas.

The bottom and fly ash (from gas treatment) of the HTW gasification can be processed in a melting reactor, if required.

After recovering waste heat from the gas stream (for producing HP or MP steam), pollutants such as halides, heavy metals and sulphur-containing compounds are removed in a gas treatment step using a dry process.

There are many possibilities for the utilisation of the pure product gas. The product gas can be used for power generation (i.e. gas turbine, gas engine, steam boiler, co-combustion in an existing power plant) as well as for chemical synthesis. Furthermore, the product gas can be used as a reducing gas in blast furnaces or as an energy source for cement kilns.

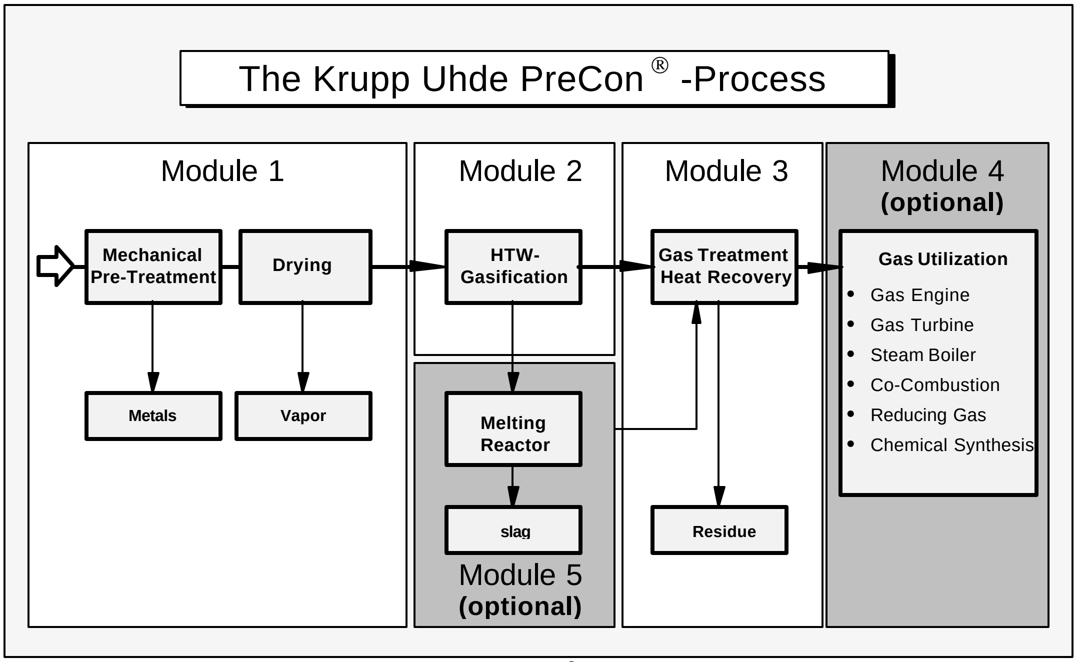


Fig. 7: Concept of the Krupp Uhde PreCon^{â} process

The characteristic features of the PreCon®process are:

- **Reducing atmosphere**
  Due to the reducing atmosphere, the re-formation of toxic components, such as dioxins and furans via the "De-Novo Synthesis" is prevented. Moreover, there is no risk of dioxin and furan formation during subsequent incineration of the pure product gas, because the required components (Cl, fly ash) are missing.
  Compared to the conventional incineration process, the gas volume is smaller and thus the costs for gas treatment are considerably lower.
- **Product gas**
  The gas produced can be used for chemical synthesis (syngas), for power generation (fuel gas) or for co-generation. Hence, there are a number of possibilities to integrate this production process into existing industrial processes.
- **Modularity and flexibility**
  In contrast to conventional incineration, the PreCon® process provides a high degree of flexibility. While modules 1, 2 and 3 (pre-treatment, HTW gasification, gas treatment) are the basic modules, modules 4 and 5 (syngas application, melting reactor) are optional. For example, if the pure product gas is used outside battery limits, module 4 can be omitted. Module 5, the melting system, is not necessary if no bottom and fly ash processing is required.

4. *The HTW SHI Plant in Japan*

Since early 1998, the PreCon® process is also licensed to Japan through the Japanese company, Sumitomo Heavy Industries, Ltd. (SHI). SHI constructed a 20 metric tons per day demonstration plant at a pressure of 1.5 bar (abs) for thermal treatment of MSW in its Niihama facility. On the Japanese market, SHI is one of the six leading suppliers for thermal waste treatment plants, with annual sales of over 500 million USD in this field.

This MSW gasification demonstration plant has successfully been operated since its construction in 1999. The 100 days of continuous plant operation was already completed.

One of the fundamental components of the project known as „N3T“ (**N**ew **T**hermal **T**reatment **T**echnology) is the HTW gasifier, which operates here in conjunction with a short kiln. One of the main aims of this combination is to reduce the amount of waste, that can only be disposed of by landfilling. The minister for health and welfare in Japan now requires a verifiably successful demonstration-scale operation period of over 1 year for every “new” technology imported to Japan, prior to granting the right for a commercial application of such system in Japan.

The basic principle of the process is shown in Fig. 8.

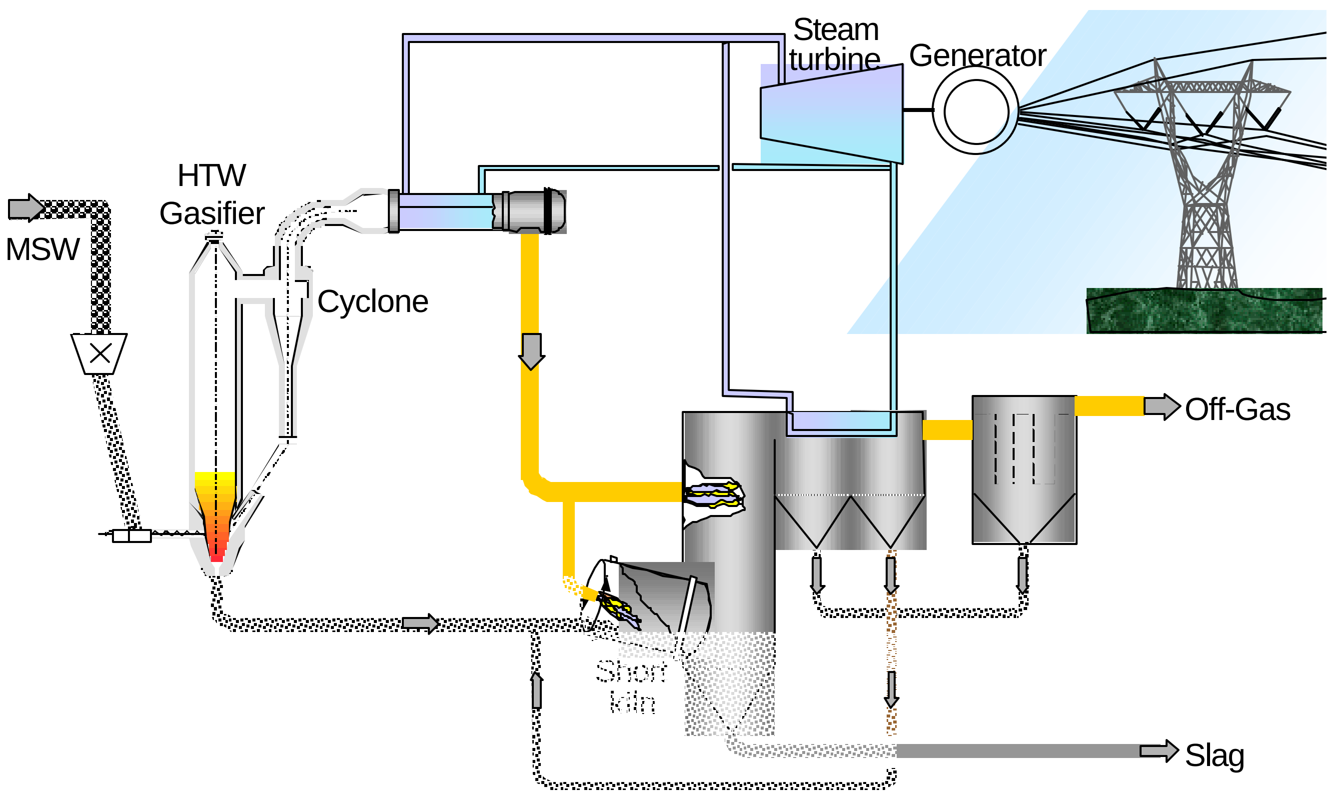


Fig. 8: N3T – HTW for MSW in Japan - basic process principle

After undergoing a mechanical pre-treatment stage, the MSW is fed into the HTW gasifier, operating at a pressure of 1.2 bar, where the MSW is thermally converted to 1,800 m³ (STP) fuel gas with a low calorific value. The bottom ash leaving the HTW gasifier is then melted and converted to slag in the short kiln by using a part stream of the fuel gas. The slag can be subsequently used e.g. as building material.

Prior to being used in the short kiln and in secondary incineration stage, the fuel gas produced during the gasification process is cooled in a raw gas cooler. The sensible heat is utilized in the plant steam system for power generation. The flue gas leaving the incineration stage is treated further in a conventional process.

Fig. 9: The 20 tpd HTW waste gasification plant at Niihma, Sikuku, Japan

5. *Outlook*

On the basis of the operating results achieved and experience gained in the demonstration operation, essential fundamental data are available for the subsequent engineering of an overall concept. The principal results are listed below:

- High on-stream factors are achieved by the extensive use of proven components.
- The pollution abatement requirements are easily met by the technology used.
- The modular structure permits the plant to be tailored for the particular locality and minimises the investments.
- The co-gasification process permits a substantial improvement of the plant economy by substituting municipal solid waste for primary energy. The savings that can be realised depend on various criteria such as plant location, energy and feedstock costs and credits etc. and can therefore not be quantified herewithin.

The very positive results are a motivation for continued development of the overall concept.

Both the overall concept and the individual technical details can be optimised further still. There are a number of promising approaches, especially for the feed system, the gas purification section and for the energy part:
Contrary to the demonstration test, the overall concept dispenses with municipal waste pelletising. This reduces the operating costs by savings in electric power and by lower maintenance costs. On the other hand, due to the poor pourability of the uncompacted municipal waste, additional costs are involved with respect to the feeding system, especially because of higher gasifier pressures. This point has to be examined in more detail and optimised, if necessary, before implementing this solution in a commercial scale.

In case of high and restrictive demands for the quality of the ashes produced in the gasification process (bottom ash and fly ash), if necessary the ashes can be processed in a thermal ash treatment (melting).

Distinct cost advantages are expected through the removal of pollutants from the raw gas in a process step and the return of part streams of residues to the process.

The co-gasification tests for municipal waste and lignite in a fluidised bed show that the HTW process is reliable and suitable for this application.

The existing conveying equipment and the feed system are also suitable for coarser feedstocks. It was shown that the HTW gasifier works without any problems even when the municipal waste portion of the feedstock was raised to 50%. The analyses of the raw gas did not reveal any significant differences to the mono-gasification of dried lignite.

The fact that the raw gas quality downstream of the hot gas filter, especially during the direct desulphurisation tests, already has a high degree of purity was considered to be a particular success of the tests. In thermal utilisation of this gas, the thresholds prescribed by the 17th BImSchV would not be exceeded, except that measures would have to be taken for NH_3 or NO_x reduction. This applies to heavy metals and halogens in particular. Dioxins and furanes are already only just detectable upstream of the hot gas filter.

The pollution forecast made before the tests was confirmed to a large extent. This reflects the extensive experience in the gasification of different feedstocks.

With the simplified basic engineering, optimised plant technology that is adapted to the special requirements for the co-gasification of lignite and municipal waste or the mono-gasification of waste can be offered for new plants based on the HTW process.

The N3T concept applied in a demonstration plant shows excellent operating results. Several test for other types of wastes (e. g. paper residues) are scheduled to proof the feedstock flexibility of the process.

Due to the good economic performance of the N3T HTW pilot plant, a commercial plant for 100 TPD of MSW is currently in the planning stage.