GASIFICATION / PYROLYSIS FACILITY

October 14, 2004

Facility Name: Thermoselect Plant (Thermoselect Thermische Abfallbehandlung)

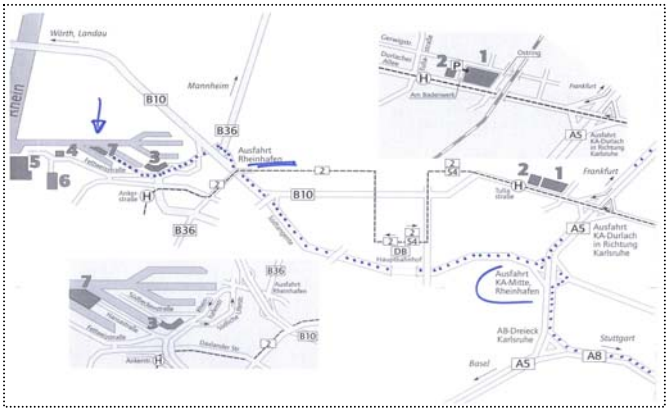
Location: Thermoselect Plant located in the City of Karlsruhe, Germany. The plant started operating in 2002 (see discussion on delay for retrofit of additional environmental equipment) and the site is approximately 20 acres along a canal connected to the Rhine River in an industrial area. The EnBW power plant is adjacent to the Thermoselect plant, where the generated electricity is sold.

Throughput: The plant process 289,000 tons/year of municipal solid waste, about 30 percent of the City of Los Angeles MSW

Conversion Technology: Thermal: Gasification/Pyrolysis

Conversion Technology Supplier: Thermoselect. Interstate Waste Technologies is U.S. representative, on a project-by-project basis. At the present time, Thermoselect is in discussions with another firm regarding potential representation.

Definition: Gasification – Thermal conversion of carbon-based materials in the presence of internally produced heat, typically at temperatures of 1,400 to 2,500°F, and in a limited supply of oxygen (much less oxygen than is needed for combustion) to produce a synthetic gas (syngas) composed primarily of H_2 and CO with inorganic materials converted either to bottom ash (low-temperature gasification) or a solid, vitreous slag (high temperature gasification that operates above the melting temperature of inorganic components). Some of the oxygen injected into the system is used in reactions that produce heat, so that pyrolysis and some (endothermic) gasification reactions can initiate; after that, the exothermic reactions control and gasification is self-sustaining. Air emission control systems remove almost all air pollutants. After cooling and cleaning in emission control systems, the syngas can be utilized in boilers, gas turbines, or internal combustion engines to generate electricity or used to make chemicals.

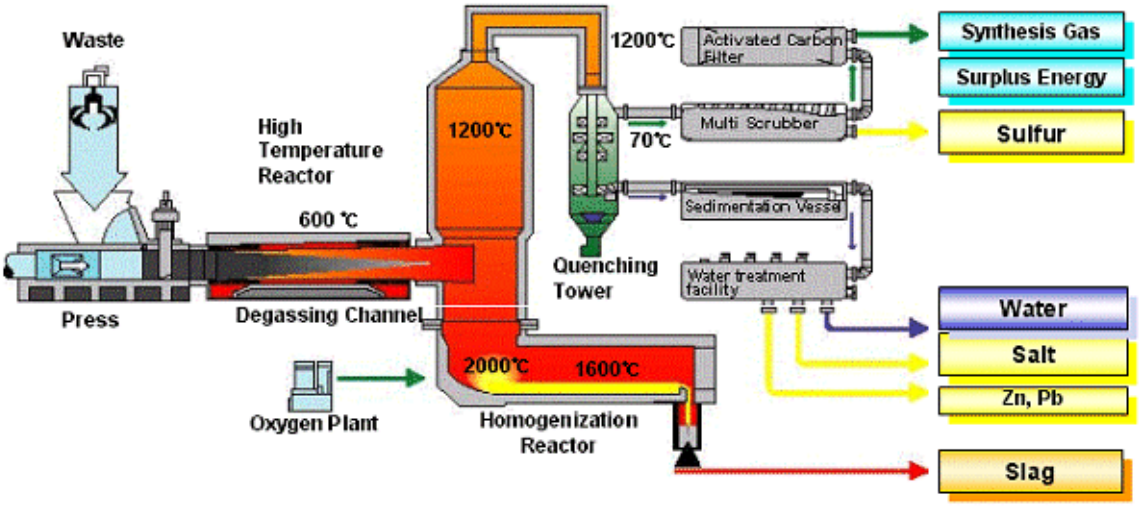


Technical Meeting and Facility Tour with: Dr. Geert Nyhuis. No photography was allowed inside the plant. Thermoselect provides literature with process descriptions.

Owner/Operator: Thermoselect Südwest GmbH, which is majority owned by EnBW (Energie Baden-Württemberg AG, the third largest energy company in Germany.

Feedstock: MSW from cities of Karlsruhe and Baden-Baden, and counties of Karlsruhe and Rastatt are collected and delivered at a rate of 289,000 tons/year.

Technology Description:



MSW is delivered by truck and by rail from the two cities and two counties. It is dumped into the below grade waste bunkers, which have a total capacity of 5 days of storage. The waste is compacted in the waste bunker. However, the compactor unit will be modified in future design to improve maintenance performance. The MSW is then picked up by a grapple hook crane and fed to the overhead degassing chamber feed bunkers. This facility

has three 11 ton/hour processing lines. In order to help keep oxygen out of the feed bunker, nitrogen (from the Air Liquide air separation unit) is added as an inerting agent. The overall processes are as follows (shown in the diagram above):

1. MSW Treatment
   - Compacting
   - Degassing
   - Gasification
   - Melting
   - Homogenization
   - Byproducts – slag and metals

2. Gas Scrubbing
   - Gas cooling
   - Gas washing
   - Desulfurization
   - Gas drying
   - Byproducts – clean syngas

3. Process Water Treatment
   - Neutralization
   - Precipitation
   - Separation
   - Concentration
   - Evaporation
   - Byproducts – sulfur, zinc concentrate, salts, condensate

Some pre-shredding is used to reduce the inlet feed MSW size to no more than 20 inches. A ram press is used to move the MSW into the degassing chamber, compacting each waste "plug" to ten times its loose density (to about 2,100 lbs/ft^3). Slide gates are used to seal each plug as it is moved into the degassing chamber. The compaction and slide gates are used for two primary reasons:

- Prevent free air/oxygen from entering the degassing chamber, where pyrolysis occurs, and
- Prevent pyrolysis and gasification syngas from blowing back toward the inlet

The MSW "log" moves down the degassing chamber for about 60-90 minutes, where pyrolysis occurs at about 570 ºF, thermally decomposing the organic fraction of the MSW into syngas (CO and H_2). The original design used a recirculating hot-oil system to provide the temperature needed for pyrolysis, but Thermoselect found that the adjacent gasification reactor provided sufficient radiant and convective heat for this purpose. At the end of the degassing chamber, the char and inorganic materials enter the high-temperature (2,200 ºF) gasification section of the reactor, where additional reactions (water gas and water gas shift reactions) form more syngas. Residence time is at least 2

seconds. The syngas produced by pyrolysis and gasification of the MSW contains the following gases:

Hydrogen (H_2)
Carbon monoxide (CO)
Carbon Dioxide (CO_2)

Heating value of the syngas is 227 Btu/scf (the MSW from the City of Karlsruhe contains less heating value than the City of Burgau, heating value is 268-376 Btu/scf).

At the bottom of the gasifier, referred to as the homogenization chamber, pure oxygen (for gasification) and natural gas are added to increase the temperature to about 2,000ºC. The pure oxygen (and nitrogen noted above) is generated by Air Liquide at an adjacent facility. Typically, a Thermoselect facility would have its own air separation unit. Due to a reduction in the heating value of the MSW (higher moisture content and lower organic fraction reduced the value from 5,160 Btu/lb to about 3,870 Btu/lb), the amount of natural gas needed to assure that the process temperature is high enough for the pyrolysis and gasification reactions has been significantly increased. The process requires 110 lbs. natural gas/ton MSW.

At this high temperature, the metals and minerals melt. Due to their different thermal conductivities, they form two separate slag melt layers. These two streams fall into a below grade water quench basin, where they cool and solidify into granules. The cooled slag/water mix is picked up with a bucket elevator and brought up to an underground conveyor that transports the slag to the slag storage pit. As the slag is conveyed, magnetic separators and eddy current separators are used to recovery the metals. The homogenization chamber sees hot, corrosive/erosive conditions. Inside the chamber is copper cooling coils, which are lined with refractory. Due to the high silica conditions in the slag, the refractory wears quickly, and must be replaced.

During the site visit, we were shown a chamber that had been removed for maintenance. Dr Nyhuis noted that the entire chamber can be rebuilt, with a new cooling coil and refractory layer replaced. While this seems to be a robust design, the maintenance requirements are significant. Dr. Nyhuis said that they plan on about 4% of the capital cost for annual maintenance, based on a 25-year facility life.

In the gasifier, the syngas exits and is quickly quenched-cooled from 2,200 ºF to 165 ºF to prevent formation of dioxins and furans. In this cooling system, some unreacted carbon char and fly ash are removed, as well as some chlorides. The resulting scrubbing liquor has a pH of about 2.

The syngas then flows through an aqueous washing system to remove acids, then to desulfurization (sulfur by-product) and gas drying. The water treatment system uses neutralization, precipitation flocculation, reverse osmosis, and filtration (zinc and lead concentrates which can be saleable – the zinc can be used in galvanization), and concentration evaporation to produce an industrial grade salt.

The syngas is burned in two boilers that provide steam to power a single 12.7 MW steam turbine and to provide steam for district heating. Internal load is about 10 MW. Therefore, most of the power generated in this plant is used for internal use and only 20 percent of the power produced help to generate revenue to offset the capital cost investment.

The overall process has the following input and outputs for a base input of 1 ton of MSW:

Inputs
Oxygen required: 1,028 lbs

Outputs
Syngas – 1,780 lbs.
Metal – 58 lbs.
Mineral slag – 460 lbs.
Zinc concentrate – 6 lbs.
Salt – 20 lbs.
Water – 700 lbs.

Flue gas monitored pollutants include (actual measured emission values achieved are lower than the permitted values):

Particular Matter (PM)
Hydrochloric Acid (HCl)
Sulfur dioxide ($SO_{2)}$
C total
Cadmium / Thallium
Mercury
Dioxins / Furans

These values change based on the characteristics of the MSW. For example, a lower heating value MSW would produce less syngas. A higher inorganic portion would result in more metals and slag.

Products: Steam for power generation (12.7 MWe, 10MWe are used for running the facility) and district heating (50 MWth)

By-products: Slag, sulfur, metals, zinc and lead salt concentrate (a whitish gel, which presently has no market), salt (90% NaCl and 10% KCl). The salts are presently disposed of in a salt mine. The sulfur is sold for production of sulfuric acid.

Other Issues: Thermoselect has had considerably better experience in Japan than in Europe. In Japan, JFE (formerly Kawasaki Steel) is the licensee for the Thermoselect process. Several plants are already in operation, with more on the way. By the end of 2005, there will be over 3,000 tons/day of Thermoselect processing capacity in Japan.