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CASE STUDY
ThermoSelect Facility Karlsruhe

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Note

TNO-MEP, the Netherlands, performed this study for IEA Bioenergy Task 36: Energy from the Thermal Conversion of MSW and RDF.

The study was executed with use of public information and knowledge available to TNO-MEP, partly supplied by ThermoSelect.

Results are based on the typical local situation in the Karlsruhe area in Germany. The situation in Germany may differ from that in other countries. Therefore, this study may lead to different conclusions about the waste treatment method and financial aspects of waste treatment than a similar study elsewhere might.

The author would like to thank the ThermoSelect and ThermoSelect-Südwest employees for their co-operation during his plant visits, the possibility to visit the control room to analyze online process data, and the information, which they supplied.

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1. Background

1.1 The goal of the monitoring project

This study was performed by TNO-MEP, the Netherlands, for IEA Bioenergy Task 36: “Energy from the Thermal Conversion of MSW and RDF”. The Dutch authorities sponsored the activities through NOVEM and the Dutch Waste Management Association (VVAV).

The study is based on public information and knowledge available to TNO-MEP and the contribution of ThermoSelect and ThermoSelect -Südwest.

The goal of the project is to produce a document on advanced waste treatment systems to help decision-makers in choosing a system.
Important considerations are:
– Risks and organization structure;
– Reliability of technology;
– Environmental impact;
– Financial aspects.

The Karlsruhe facility study is part of a wider project comprising several case studies by the IEA working group. Other facilities selected for case studies are:
– Robbins in Chicago, Illinois, USA [9]
– Tirmadrid in Madrid, Spain [10]
– LDHP in Lidköping, Sweden
– DER in Dundee, Great Britain
– Toshima incineration facility in Tokyo, Japan
– RCP in Bremerhaven, Germany.

1.1.1 Plant monitoring

After receiving permission from ThermoSelect, several visits to the Karlsruhe facility were arranged. On 28 and 29 June 1999 and 2 November 2000 the operation of the plant was roughly observed, and discussions with the plant managers took place.
The final monitoring visits took place on 24 and 25 January 2002 and on 3 July 2002. During both of these visits the control room were visited as well, where discussions, based on real process data, took place with ThermoSelect specialists.

The waste gasification facility of Karlsruhe was monitored as follows:
– Checking of process operation;
– Study of process technology;
– Study of online process data in the control room;

- Gathering of process information, laboratory reports, financial information, official governmental reports [1] till [4], etc.
- Discussions about the gathered information took place with:
  - Dr. Ing. Bernd Hüvel, Plant Manager ThermoSelect Südwest
  - Dr. Geert Nyhuis, Sales manager, ThermoSelect S.A
  - Dr. Stefan Kutzmutz, manager, ThermoSelect S.A

These activities resulted in:
- General plant information: organizational structure, history, general plant characteristics and specification of typical waste composition;
- Information about the process technology: material recovery / production of clean products and steam;
- Insight into the environmental impact: stack emissions, recycled products;
- Insight into the financial aspects of operating the plant: investment costs of the most important parts of the plant, operational costs, tipping fees, etc.

Finally, the information was classified, evaluated and reported:
- Calculations were performed to characterize the facility;
- A preliminary mass and energy balance was made, based on expected future performance;
- An environmental analysis was made in relation to the guidelines;
- The simple POT (Pay-Out time) was calculated, based on the financial information.

1.2 The development of the ThermoSelect process

The ThermoSelect process is an advanced thermal waste treatment process, which minimizes environmental pollution. ThermoSelect claims a closed circuit. Its technology has been under development since 1992 in a 4 Mg/h demonstration plant in Fondotoce Italy (closed in 1998).
The plant in Karlsruhe was designed as a commercial operating plant and is considered to be in the final stages of the demonstration. The official approval of the German authorities (TÜV) on 12 December 2001 of all the safety equipment at the Karlsruhe ThermoSelect plant cleared the road for operating the plant under commercial conditions. It is generally thought this will encourage decision makers in other countries to choose the ThermoSelect process.

In Chiba, Japan, another ThermoSelect plant has been in operation since September 1999.
Additional ThermoSelect plants are under construction, while various contracts are being prepared as well.

The organizational structure of ThermoSelect is presented in Annex A.

The following amounts of waste should be recycled:
- Karlsruhe city: 75,000 tonnes/year;
- Rastat city: 48,000 tonnes/year;
- Baden Baden city 7,000 tonnes/year;
- District of Karlsruhe: 95,000 tonnes/year.

The total capacity was set at 225,000 tonnes/year.

Politically, it was very important that the plant should have low emission values (or no emissions at all) and no residues. For this reason, EnBW proposed to build a ThermoSelect gasification plant instead of a WTE plant. EnBW and ThermoSelect SA eventually joined forces: EnBW now owns 25.1% of the shares of ThermoSelect S.A.

1995:
In September the approval procedures were initiated for the construction of a ThermoSelect gasification plant.

1997:
The founding stone was laid in March. The foundation for the building and machinery was also made.

1998:
The heavy equipment and process halls were installed.

1999:
During the first six months of 1999 trial operation took place. This resulted in an optimizing period, which was partly by order of the authorities.
During the other six months of 1999 problems were solved with the desulfuring equipment, cooling water spray cyclones and concrete lining of the reactors.

2000:
Crane facility deficiencies occurred.
During the last six months of 2000 the sedimentation basins (lining) of the quench water circuits were leaking. Epoxy glass resin tanks were used to replace these basins.

2001:
The process was further optimized under control of German TÜV. A complete combustion line was constructed for operation in case of emergency and the existing flare was changed.

2002:
The German TÜV approved the safety equipment of the ThermoSelect plant. The plant was transferred to ThermoSelect Südwest GmbH and commercial operation

commenced (January). In August and September the plant is out of operation for maintenance. The availability is limited by lack of contractual waste.

1.2.1 The organizational structure of the Karlsruhe facility

ThermoSelect Südwest GmbH owns the Karlsruhe facility. The company employs the following crews:

- Operation: 25 people (5 shifts)
- Maintenance: 10
- Management and administration: 7

Some maintenance activities are outsourced: analyses equipment, compressed air and hydraulic equipment.

ThermoSelect Südwest is 100% owned by EnBW.

1.2.2 MSW composition in Karlsruhe

No typical data on the MSW composition in Karlsruhe were available. The waste is to be considered ‘normal’ domestic waste with a NCV (net calorific value) of 9 – 10 MJ/kg. Because of the presence of a lot of flats in the Karlsruhe area, source separation of waste is limited. End of the year 2002 industrial waste is “contracted”. Addition of this industrial waste to the household waste will increase the NCV of the mixture to approximately 11 MJ/kg.

2. The Process Technology of the Karlsruhe Facility

2.1 General

The ThermoSelect plant in Karlsruhe consists of the following equipment:
- 1 nitrogen filled bunker;
- 3 gasifiers;
- 2 steam boilers;
- 1 steam turbine: pressure: 64 bar, temperature: 485 °C, Power: 12,7 MW;
- district heating equipment.

In Table 2.1, the design characteristics of the Karlsruhe facility are presented.

Table 2.1 Design characteristics of the ThermoSelect plant in Karlsruhe.

Number of lines		3
Capacity per line of waste processing	Mg/h	10
Annual capacity of waste processing	Mg/a	225,000
Additives		
Oxygen	Mm^3/a	82
Natural gas	Mm^3/a	7.2
Water	Mg/a	135,000
Other additives	Mg/a	6,000
Products		
Synthesis gas production	Mg/a	215,000
Water (pure)	Mg/a	180,000
Granulate production	Mg/a	49,500
Metals	Mg/a	6,500
Sulphur	Mg/a	450
Salt residues	Mg/a	2,700
Metal precipitation products of water purification	Mg/a	1,700
Heat recovery		
Thermal performance	MW_{th}	100
District heating power	MW	50 maximal
Power to grid	MW	2,7
Power production	MW	12,7

In principle, the Karlsruhe waste is taken through five treatment steps:
– waste feeding;
– gasification;
– melting;
– synthesis gas cleaning and water treatment;
– heat recovery for district heating and electricity production.

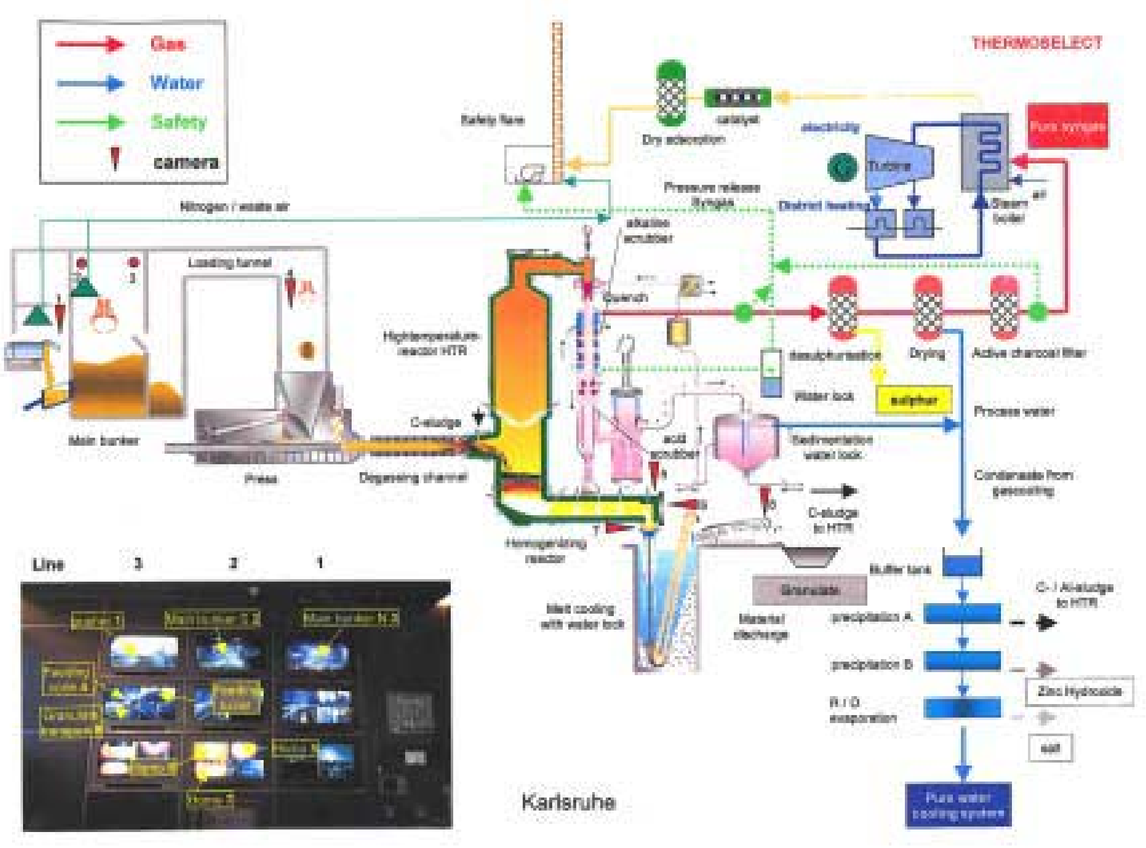


Figure 2.1 A diagram of the ThermoSelect process in Karlsruhe.

In Annex B a complete description of the Karlsruhe facility is presented.

2.2 Waste feeding

The process begins with the arrival of the household waste collection trucks at the plant. Up to 350 Mg per day can also be delivered by train in special containers. After normal business hours the special containers are unloaded with an automated transport system. The waste is fed into the bunker by means of waste compactors. The bunker is nitrogen-inertisated for fire protection. A computer-controlled grapple crane transfers the waste into the feed chute of a bailing press. This press is directly connected to the feed channel through which the bailed waste is transported to the vertical mounted gasifier.

2.3 Gasification

In the gasifier the partly pyrolized waste forms a sloping layer and is gasified with pure oxygen, which is horizontally injected through and up this layer. Organic materials are transformed into a synthesis gas in a thermodynamic equilibrium at a temperature of approximately 1200 °C. A ring of oxygen and natural gas injectors controls this temperature. Under these conditions (oxygen free, 2 seconds of residence time), a synthesis gas is formed with a typical composition of:
- 25 – 42% H_2,
- 25 – 4% CO,
- 10 – 25% CO_2,
- H_2O.

2.4 Melting

Inorganic materials are molten in a lower horizontal part of the reactor. A number of metals are volatilized and mixed up with the synthesis gases. This part of the reactor is also heated with natural gas and oxygen. There, a mineral melt is formed from oxides of base metals consisting of a typical iron alloy (80%) containing nickel, copper and traces of other metals. In the melt, the minerals and metals are automatically separated as a result of differences in density. Any residual carbon in the melt is gasified and mixed with the synthesis gases.
The melt is granulated by a water quench and falls in a basin. The granulates are removed from the basin and stored in a special bunker. After transportation to a sandblasting firm, the metals are separated from the granulates by magnetic separators.

2.5 Synthesis gas cleaning

The synthesis gas is treated in a water quench, an acid scrubber and an alkaline scrubber combined in one tower, a four-stage desulphurization step, and a gas dryer.

Quench
The synthesis gas from the gasifier is quenched from approximately 1200 °C to approximately 70 °C to avoid formation of organic compounds like dioxins, etc. Also some entrained particles and (acid) gases are removed by quenching.

Acid scrubber
In the acid scrubber, flushing water with pH 3 removes acids such as HCl and HF and some volatized heavy metals from the synthesis gas.

Alkaline scrubber
In the alkaline scrubber, NaOH removes carbonates and sulphates and compensates any acid droplets of the acid scrubber.

Safety pressure relief
The gas path is connected to a water lock for safety pressure relief. In case of a sudden pressure rise above 500 mbar, synthesis gas is released to a closed combustion chamber with a complete flue gas cleaning system (quench, scrubber and dry sorption filtration).

Desulphurization
In the four-step desulphurization that follows, the scrubbing liquid contains a Fe3 complex ion (sulpharox) which is used to remove H_2S. In a redox process, the H_2S is oxidized in an elemental sulphur and water. The use of air regenerates the scrubbing liquid (Fe2-ion back to Fe3-complex ion). The elemental sulphur is separated from the liquid by a centrifuge system.

Drying
In a gas drying scrubber, cold water with temperatures of 5 to 10 °C is used to cool (and dry) the synthesis gas and to remove some residual traces of pollutants.

2.6 Energy recovery

In Karlsruhe the cleaned synthesis gas can be used for energy recovery. Energy recovery takes place in two combustion lines, each consisting of a combustion chamber with a boiler, an oxidation catalyst to reduce CO, a deNOx catalyst (to reduce NO_x) and a dry-sorption filtration.

The steam boilers each have a capacity of 9.7 kg/s of steam at 485 ºC and 64 bar. The produced steam can be converted into electricity by a steam turbine and generator with a capacity of 12.7 MWe of which 2.7 MWe can be made available to the electricity grid.
Up to maximally 50 MW of thermal power is theoretically available for the Karlsruhe district heating system. In principle, the heat of the quench is partly available to preheat the district heating system, depending on the temperature levels of the district heating system. The rest of the heat (but with a maximum thermal power of 25 MW) is extracted from the steam turbine.

2.7 Water treatment

Water originates from the reaction products in the gasifier and the water in the waste. Also water is added in the quench and scrubbers. Water is extracted at several places in the process.

Quench water is settled and solids (under which products of incomplete gasification) are removed and turned back into the gasifier.

Water from the alkaline scrubber is oxidized in vessels with hydrogen peroxide. Soluble sulphate and Fe 111 is then formed in a two-stage precipitation process. In the first stage, NaOH is added to raise pH to about 5.5. With polyelectrolyte, aluminium and iron hydroxides are removed. The remaining sludge is dewatered in centrifuges. The remaining solids are returned into the gasifier. In the second stage, NaOH is supplied to a level of pH 9. In a process similar to the one in used in the first stage, heavy metals are removed, producing a cake, which is one of the products of the process. The remaining water is neutralized with HCl and further treated with an ion exchanger, reverse osmosis, and finally evaporated.

2.8 Use of oxygen, nitrogen and natural gas

For the ThermoSelect gasification process, the use of oxygen and natural gas (or other fuel) is necessary. In Karlsruhe a neighboring facility that processes oxygen and nitrogen, delivers part of its production to ThermoSelect. Nitrogen is used for purging the gasifier in case of emergency (oxygen content in the syngas > 2.5%). Also, the fully closed waste bunker is purged with (dry) nitrogen, drying the upper part of the waste in the bunker.
Since the degasification tunnel is not externally heated in the Karlsruhe facility, more oxygen is necessary in the reactor to compensate for the heat loss in this tunnel. Oxygen and natural gas are injected at three levels in the process:
- in the horizontal homogenization reactor to melt the minerals and metals;
- in the gasification zone of the reactor;
- in the upper part of the high temperature reactor.

3. Evaluating the ThermoSelect Process in Karlsruhe

3.1 Operational experience

Adaptations

In the first thirty months of operation, the plant was further optimized, resulting in four major adaptations of the original design:

– improvement of the safety control system: replacement of O_2 analyzers and computer software (a lot of failures in the original system caused unnecessary emergency operation, resulting in emissions of the combustion flare);
– stopping of heating the degasification tunnel;
– cooling construction of melt outlet for granulation was changed by using a copper construction with water cooling;
– replacement of safety flare to a closed combustion chamber with flue gas treatment.

In Annex B the plant’s 1997 and January 2002 lay-outs are presented, indicating a number of these adaptations.

These and other mechanical construction adaptations (see chapter 1.3.1) as well as limitations imposed by the German authorities resulted in a low availability of the plant. After the official safety approval of the German TÜV, almost all three lines were in commercial operation for about four weeks. This is demonstrated in the lists of the daily-gasified waste in Annex C.

Author’s observations

During a visit on 24 and 25 January 2002, the author made the following observations:

– three lines were in operation;
– the capacity of the lines was about 25% lower than designed (7 to 8 Mg/h instead of 10 Mg/h);
– the energy recovery system was not in operation: no transfer to the district heating system and no electricity production.

During a next visit on 3 July 2002 the author made the following observations:

– three lines were in operation, but not all at full load (see Annex D);
– the energy recovery system was in operation.

In Annex D, print-outs of online data produced during the visit to the control room are presented.

During the official approval test of the German TÜV (13, 14 and 15 November 2001 and 22 November 2002) all three lines has demonstrated its capacity of 10 Mg/h during 8 hours.

The restricted capacity of the lines is mainly caused by the contractual availability of the waste. ThemoSelect Südwest expects sufficient waste will be available in the autumn of 2002 to operate all lines at full load. During the first months of 2002

ThermoSelect improved the filter equipment of the quench loop to improve the availability per line.

The super heaters of the syngas boilers were replaced in February-March 2002 and demonstrate its operation as was notified during the visit on 3 July 2002..

Emergency operation

From 25 December 2001 to 25 January 2002, the combustion chamber operated for 8 minutes. Till 17 July it was 36 minutes, which is only 1.3 % of the official available time. (46 hours per year of emergency operating is permitted).
ThermoSelect Südwest stated that the main reasons for emergency operation over the last years were caused by failures in the syngas boiler and in the safety equipment (oxygen analyzers and software).

Recent maintenance and planning

Since week 33 in 2002 the annual revision took place of the Karlsruhe plant (refractory repair, maintenance of valves, pumps, cooling towers, authority controls of apparatus and electric security loops. The plant has been started up in September 2002. The next TüV-measurements were executed in October 2002.

Availability

In Annex C, the throughput per line per day is presented. According to this information the three lines operated at a reduced capacity. From 1 January till 17 July 2002 62,000 Mg of waste had been processed. That means an availability of ca 50%. The management expects a further growth of the availability because of in increase of the contracted waste. It could take another year before the plant will be able to run on its designed capacity (225,000 Mg/a).

Evaluation

In general, the Karlsruhe plant is in the final stage of demonstration. Between 1999 and 2002 many problems have been solved. The problems can be divided into three categories:

- technical problems which are considered to be normal with such a large project, such as the quality of the basin concrete, failures in oxygen analyzers;
- problems with authorities about permits: ThermoSelect states that the authorities lack legal and political experience with this new process, which has also delayed the commercial demonstration;
- problems with the original TS-Karlsruhe design, resulting in major adaptations as described above.

The first two categories are considered normal and partly due to local culture.
The third is considered more seriously. Especially the removal of the pyrolysis step by switching off the heating in the degasification channel and the installation of a complete combustion chamber with flue gas treatment were major adaptations. Switching off the pyrolysis step was necessary because part of the waste was not heated enough for degasification. Due to this measure gasification took place in

the lower section in the reactor, resulting in more methane and oxygen use and probably more fluctuations in the syngas flow and composition and an increase of (ungasified) particles in the first washer.
Installation of the combustion chamber was an ordinance of the local authorities. ThermoSelect expects an increase of the amount of waste and an increase of the availability. Since the latest maintenance stop ThermoSlect expects the plant is fully prepared to demonstrate its reliability and capacity.

3.2 Financial aspects

Investment and costs of maintenance and operation
Since the Karlsruhe ThermoSelect plant has operated commercially for just six months, no reliable financial data are available. The ThermoSelect Südwest management expects that the losses of the last 30 months will be recovered in the coming three years.
The total investment costs including the extra costs of the combustion chamber of the Karlsruhe plant were approximately 110 MUS$ (120 M€). The tipping fee in Karlsruhe is approximately 115 US$ per Mg.
ThermoSelect Südwest did not further specify operational and maintenance costs. A total was mentioned of approximately 8.5 MUS$ per year. This means O&M costs should be 37 US$ per Mg of waste (designed annual throughput).

Income
The income from the products is negligible. However, it is expected that if the plant is continuously in operation and delivery of products can be guaranteed the price of the minerals for sandblasting could rise to 8.5 US$ per Mg. The market for the other products is not very stable and has no influence on the financial results of the ThermoSelect plants anyway.
Data on the income from electricity production and heat supply to the district heating system of the city of Karlsruhe were not available, but the income can be estimated at 0.5 - 1 MUS$ per year (about 0.02 US$ per kWh).

Evaluation
The income from the products (about 1 MUS$ per year for selling energy) is very low, compared to the income from the tipping fee (about 25 MUS$ per year), when the plant is operating at full / designed capacity. This also demonstrates why ThermoSelect's policy is not specially focused on energy recovery.
In Table 3.1, the POT (Pay-Out Time) of the Karlsruhe plant is calculated on the basis of the available estimates. POT is the investment costs divided by the difference between annual income and operational costs.

Table 3.1 Calculation of POT.

	MUS$/a
Investment [MUS$]	110
Tipping fee	25
Sale of energy	1
Total income	26
Costs	8,5
POT [a]	6,3

This POT of 6.3 is relatively low for a plant like this one, but is based on a relatively high tipping fee. The tipping fee will be lower, when a longer POT is accepted. This is a contractual matter. These figures shows the process could be economical feasible.

3.3 Evaluation of environmental aspects

3.3.1 Emission performance

During normal operation, emissions to the air take place at two locations in the process:
- boiler outlets with catalyst and dry absorber filtration;
- bunker ventilation. The nitrogen gas is led to a bag filter for dust removal and a UV lamp for odour control.

In emergency situations, the syngas is destroyed in a closed combustion chamber with flue gas treatment.

The German TÜV measured both emission sources in August and September 2001. The results led to the approval of the plant for normal commercial operation.
In Table 3.2, the results of emission measurements are compared with the permit.

Table 3.2 Emission levels compared to permits.

	Normal operation in mg/nm^3, Daily average values			Emergency operation	
	17.BimSchV	Permit (1996) Stack 50 m		Permit 2001 for combustion chamber with full flue gas treatment	
Emission source	**Normal operation**	**Permit**	**Measured**	**Permit**	**Measured**
Dust	10	3	**0.6**	10	**1**
SO_2	50	10	**0.91**	50	**2.3**
NO_x	200	70	**52.8**	150	**58.8**
CO	50	10	**3.8**	100	**33**
HCl	10	2	**0.2**	10	**<0.4**
HF	1	0.2	**0.003**	1	**<0.1**
Hg	0.03	0.01	**0.007**	0.05	**0.018**
C_xH_y	10	2	**0.68**	10	**6.6**
Cd/Tl	0.05	0.01	**0.0005**	0.01	**0.003**
Heavy metals	0.5	0.03	**0.013**	0.03	**0.005**
PCD/F [ng/nm^3]	0.1	0.01	**0.0025**	0.01	**0.005**

In Annex E (and in Annex B), more detailed information on emission levels is presented (in German).

The emissions presented in Table 3.2 are considered low and easily remain within the permitted emission levels. The influence of annual emissions caused during emergency operation is negligible since a closed combustion chamber with a complete flue gas cleaning treatment has been installed.

3.3.2 Recycling products

The amount of the product stream was already presented in Table 2.1 and is based on a designed waste recovery of 225,000 Mg per year. However in 2002 62,000 Mg of waste is processed. The amounts and destination (designed and realized) of the products are presented in Table 3.3.

Table 3.3 Destination of ThermoSelect products as designed and realized in Karlsruhe.

Product	**Design [Mg/a]**	**Destination**	**Realized in 2002 till 17 July [Mg/a]**		**Destination**
Capacity	225,000		62,000	Corrected for 225,000 Mg/a	
Synthesis gas production	215,000	Combustion to produce heat and electricity	n.a		Combustion to produce heat and electricity
Water (pure)	180,000	Cooling and evaporation	n.a		Cooling and evaporation
Mineral granulate	49,500	Sand substitute (Sand-blasting)	13854	50277	Road and landfill constructions
Metals	6,500	Metal industry	755	2740	Zn recycling
Sulphur	450	Sulphur industry production of sulphuric acid	136	494	Production of sulfur acids
Salt residues	2,700	Filing materials in (salt) mines	1609	5839	Al-recycling , Filing materials in (salt) mines
Metal precipitation products of water purification	1,700	Zinc-recycling or landfills?	246	893	Filing materials in (salt) mines

Table 3.3 shows that the production and destination is realized in general according to the design. The amount of product for filling salt mines is higher as expected. This is considered as a local market situation. The production of metals is lower as expected. When more industrial waste is mixed with the household waste in the future these figures might be different.The results of analyses of the products mentioned in Table 3.3 are presented in Annex B.
The market for these products is not very stable and will have to prove itself in the coming years as production stabilizes. Although recycling such products is not very financially attractive, it offers the advantage of minimizing pollution.

3.3.3 Energetic aspects

In Chapter 2.6, the equipment available for energy was described. Contrary to the policy of ThermoSelect, in which energy recovery is not a top priority, the energy available is recovered as far as is economically reasonable.
In practice, the steam produced can be used in four types of equipment (extracted at 2.5 bar from turbine):

- district heating about 25MW;
- two refrigerators, cooling the cooling water of the syngas: capacity 2 * 1.5 MW;
- process water heating 0.75 MW;

– process water evaporation up to 13 MW.

Evaluation
The ThermoSelect process in Karlsruhe was not designed to produce as much energy as possible but to recycle waste into useful products. That is why the produced energy is relatively low. If the ThermoSelect plant is in full operation, every Mg of waste will substitute about 91 m^3 of natural gas. In Table 3.4 the natural gas substitution (also expressed in MWh of electricity production) of this ThermoSelect plant is presented, based on a NCV of 12 MJ/kg. In practice the NCV is 9.0 MJ/kg. An improvement of the NCV is expected end of the year when more industrial waste should be mixed with the household waste.

Table 3.4 Produced energy presented as natural gas substitution and electricity production of ThermoSelect (NCV of waste 12 MJ/kg).

	Natural gas substitution (m^3/h)	MWhe	Natural gas m^3/ Mg MSW	MWhe per Mg MSW
Natural gas addition	-900	-4.8	-30	-0.160
Heat production	3125	16.7	104	0.556
Electricity to grid	506	2.7	16.9	0.090
Total ThermoSelect	2731	14.6	91	0.486

According to the official data of ThermoSelect Südwest, one hour of operation in Karlsruhe with waste with a (high) NCV of 12 MJ/kg will gasify 30 Mg of waste producing 12.6 MWh of electricity. The electricity consumption of the plant itself includes the energy necessary to produce 10,240 m^3 of oxygen; in order to keep the combustion chamber operational an estimated 10 MWh of electricity is needed. ThermoSelect calculates that a capacity of 2.7 MW of electricity can be made available to the grid.

In the same process, about 900 m^3/h of natural gas are injected into the process, producing about 8 MW of thermal energy to recycle the products. Considering the fact that natural gas can be used to produce electricity in a power plant with efficiencies of 60% (gas turbine with ICC), up to 4.8 MWhe of electricity could be produced with the natural gas injected into the process. This is more than ThermoSelect Südwest produces right now (2.7). But production of thermal heat to the district heating system also substitutes natural gas. This amount of heat should form the basic load of the Karlsruhe district heating system. In that case, about 25 million m^3 of natural gas (or other fuel equivalents), which is now necessary for the district heating, could be substituted annually. This means that during 1 hour of normal operation 3125 m^3 of natural gas could be saved. From this amount of gas a modern power plant could produce 16.7 MWhe of electricity.
In future designs of the ThermoSelect process, more energy could be recovered in:
– quench-water loop at a temperature of about 64 °C: 15 MW in low temperature district heating systems;
– external cooling of high temperature reactor: 2.5 MW.

4. A General Evaluation of the ThermoSelect Process

4.1 Experience

The history of how the ThermoSelect process was developed is extensive.
At first, the technology was developed and demonstrated at a small-scale pilot plant (2 – 4 Mg/h) in Fondotoce in Italy. Then the concept was scaled up and further developed in Karlsruhe (10 Mg/h), Germany, and Tokyo, Japan.
Throughout more than 2 years of optimization, a number of adaptations were made in Karlsruhe, as described in Chapter 3.1. A number of these adaptations were due to typical local conditions and culture and might be different elsewhere. The construction of a closed combustion chamber will not be required everywhere. The total environmental impact of such equipment is not that clear. In normal operation the number of hours of emergency operation is expected to be limited to maximally 50 hours a year. The environmental effect should be balanced with the high consumption of energy, causing emissions elsewhere, and the high investment costs. The effect of emergency operation should be looked at in the context of annual emissions.
The mentioned change by removing the heating of the degasification tunnel should be considered as an incidental action for the Karlsruhe condition. ThermoSelect states, that they will not apply these adaptations in the next generation of ThermoSelect plants.

ThermoSelect has published a list of new orders and possible projects, which are presented in Table 4.1.

Table 4.1 New ThermoSelect orders and projects.

Country/area	Orders/projects
Switzerland	Tessin, arbitration procedure pending
Germany	Ansbach, under construction
Japan	4 in order, Tokyo in operation
Caribbean area, USA	2 projects
Poland	1 project

Some of these plants will be equipped with gas engines for electricity generation, which probably will include adaptations in the syngas treatment of the Karlsruhe concept. This equipment was demonstrated in Fondotoce, which was considered to be a pilot plant.

The general impression is that ThermoSelect is in the final phase of demonstration and seems technical feasible. Up-scaling of the ThermoSelect concept, originally developed in Fondotoce, resulted in a number of adaptations, as demonstrated in Karlsruhe.

It might be assumed that in future plants it will cost less time to prepare the plant for commercial operation.
The operational experience of the ThermoSelect process can be compared to other monitored processes. This is presented in Table 4.2.

Table 4.2 Operational experiences of various plants.

Plant	Location	Technology	Start in operation	Throughput Mg/a	Operational experience	Remarks
TirMadrid	Madrid, Spain	FBC[2)]	1996	441,000	++	In full operation, >90% availability over 2 years
Robbins	Chicago, USA	CFB[1)]	1997	446,000	+	Plant is out of operation and for sale. Financial problems?
RCP	Bremerhaven	Pyrolyses/melting bath, CFB	1997	45,000	-	Plant is out of operation and has been adapted for comercial operations.
WTE	Netherlands	Grate with extended flue gas cleaning	1997	284,000	++	In full operation, 90% availability
Valene	Paris, France	FBC[2)]	1998	80,000	+/-	Plant has been adapted. Availability of close to 90% from mid December 2001
Thermo Select	Karlsruhe	Gasification	1999	225,000	+/-	Just started in 70% operation. Availability is increasing

1) CFB= Circulating Fluidized Bed
2) FBC = Fluidized Bed Combustor

Table 4.2 shows that the ThermoSelect plant is the latest constructed plant and, like the Valene plant, is not yet to be considered as proven technology.

4.2 Financial Aspects

A POT of 6.3 years as calculated for the Karlsruhe plant is low compared to that of other monitored plants. On the other hand, the tipping fee is relatively high.

In Table 4.3 several financial data expressed per Mg of input waste of several monitored plants are presented. These data are derived from [5] to [10].

Table 4.3 Financial data per Mg of waste.

Plant	Location	Through-put	Invest-ment	Tipping Fee	Electri-city	POT	O&M
		Mg/a	US$/Mg[1)]	US$/Mg	US$/Mg	[a]	US$/Mg
Robbins	Chicago, USA	446,000	676	64	27	10.2	36
TirMadrid	Madrid, Spain	441,000	283	29	28	9.6	26
Valene [2)]	Paris, France	80,000	413	75	18	13.5	75
WTE	Netherlands	284,000	824	99	21	11.7	51
Thermo Select [2)]	Karlsruhe	225,000	489	115	1.8	6.3	38

1) Mg capacity per year

2) These costs are estimates and have not been not commercially demonstrated.

The data of a new ThermoSelect plant, as presented in Annex F, indicate that future ThermoSelect plants will be cheaper than the Karlsruhe plant described in Table 4.4. A new TS plant with a capacity of 240,000 Mg/a should cost about 100 MUS$ (including engineering and ground costs), i.e. about 416 US$/Mg of waste. With these figures in view, the ThermoSelect process can become financially attractive, depending on local conditions and market prices.

4.3 Substitution of fossil fuels

The ThermoSelect process in Karlsruhe was not designed to produce as much energy as possible but to recycle waste into useful products. That is why the produced energy is relatively low, as shown in Table 3.4.

In Table 4.4, the natural gas substitution (also expressed in MWh of electricity production) of this ThermoSelect plant is compared to a conservative (steam: 40 bar, 400 °C) WTE plant equipped with an advanced bottom-ash recovery treatment.

Table 4.4 Produced energy presented as natural gas substitution and electricity production of ThermoSelect compared to a (conservative) WTE plant with the same waste throughput (NCV 12 MJ/kg).

	Natural gas substitution (m^3/h)	MWhe	Natural gas m^3/ Mg MSW	MWhe per Mg MSW
Karlsruhe TS + distr. Heating	2731	14.6	91	0.486
WTE (22% efficiency)	4125	22	138	0.733
WTE + distr. Heating	7250	38.7	242	1.289

The table shows that in a normal WTE-plant up to 3 times more natural gas could be substituted. The bottom ash of such a plant is not molten, as in several countries it is accepted as a substitute for sand in road construction. If melting of bottom ash is obliged the efficiency for electricity production of a WTE-plant will be reduced with 10 till 20 %.

According to a calculation of ThermoSelect (see Annex F), more electricity could be produced than is produced at the Karlsruhe plant. The electricity production could rise from 0.090 MWe/Mg (in Karlsruhe) to 0.556 MWe/Mg of waste. This calculation assumes the use of a normal flare and a gas engine with a 44% efficiency, which is considered to be very high for syngas use. Even in that case, a normal WTE plant can produce more electricity from this waste with 12 MJ/kg.

5. Conclusions and General Comments

Operational experience
The general impression is that the Karlsruhe plant is in the final stages of demonstration and is almost technical feasible. Between 1999 and 2002 many problems have been solved and mechanical constructions were improved. Major differences as compared to the original ThermoSelect Karlsruhe design are:

- the heating of the feeding system tunnel has been switched off, resulting in a different gasification process using more oxygen (to compensate heat) and probably resulting in more ungasified particles in the quench loop;
- the emerging flare has been replaced by a closed combustion chamber with flue gas treatment by order of local authorities. This resulted in more energy losses and higher investment and operating costs.

The German authorities' lack of experience with an advanced process like this one may have delayed the demonstration of this technology.
The formal government approval of the plant's safety at the end of 2001 may be considered a milestone in the demonstration of the technology and will probably result in more international interest.
Another ThermoSelect process is in operation in Tokyo, Japan, And at least 6 plants are in order and 3 are under negotiation.

Financial aspects
Financial data on O&M (Operating and Maintenance) costs in commercial operation are not proven. Compared to other systems, however, these costs seem to be low considering the costs of oxygen production. The investment costs of the Karlsruhe plant were calculated at approximately 500 US$/Mg, which is not very high compared to other monitored systems.
Considering the calculated costs of a new ThermoSelect plant (see Annex F), this gasification process could be financially attractive and feasible, depending on local conditions.

Environmental aspects
In principle, the process is designed to recycle all products (ThermoSelect states: thermal recycling, closed loop) and to recover the available energy within acceptable costs.
There are no water emissions from the process. Wash water produced in the process is cleaned and evaporated.
Air emissions take place at three places from:

- the waste reception bunker;
- the syngas combustion boilers;
- the emergency combustion chambers.

The air emissions easily meet all local emission standards, even during operation of the combustion chambers.

ThermoSelect products

A sandblasting company located in Karlsruhe reuses the mineral products. This material is since 2002 also applied in road and landfill constructions. The first application can be regarded as a typical local recovery solution. In most countries, the latter application is also suitable for bottom-ash products from WTE plants (Waste-to-Energy plants). Generally speaking, the market for these recycled products is not very stable and depends on typical local situations.

Energetic aspects

In addition to recycling products, the ThermoSelect process also generates energy. With this energy fossil fuel is substituted. Compared to common WTE plants, the ThermoSelect process performs poorly in this respect. The Karlsruhe plant substitutes 91 m^3 of natural gas (with 25 MW district heating as a basis load) per Mg of waste. This figure can be raised in future ThermoSelect processes with an optimal energy recovery of probably 25%.

In general, a normal WTE plant with bottom-ash treatment, combusting waste with a NCV of 12 MJ/kg, could substitute 138 m^3 of natural gas per Mg of waste. This figure can rise, if the efficiency of that WTE plant is increased and decrease if melting of bottom-ash should be required. If district heating is applied as well, it could rise from 138 m^3 up to about 242 m^3 of natural gas per Mg of waste.

6. References

[1] Official Approval: Gutachten Nr. TPA/01/AS/2302-02/01-12-01, TÜV-Palz.

[2] Report of TÜV-Pfalz
No. US/01/1/1270/25.

[3] Report of TÜV-Pfalz
No. US/01/1/1270/26.

[4] Documentation ThermoSelect November 2000.

[5] Hesseling, W.F.M., “Case study: Valene, Waste Recovery Facility in Mantes la Jolie, France IEA Bioenergy Task 23 Report, April 2000.

[6] The thermal destruction of waste, IEA Greenhouse gas R&D Programme, Report no. PH2/18, November 1998.

[7] Granatstein, D.L. CANMET (613-947-0151)
Techno-economic Assessment of Fluidized Bed Combustors as MSWI:
A Summary of Six Case Studies.

[8] Hesseling, W.F.M., March 2001, Report 2EWAB01.12
“Vergelijking van drie wervelbed installaties met een Nederlandse AVI”
(Comparison of three fluidized bed plants and a Dutch MSWI).

[9] Granatstein, D.L. and Hesseling, W.F.M., “Case Study: Robbins Resource Recovery Facility, Robbins, Illinois”, IEA Bio-energy Task 23 Report, September 1999.

[10] Hesseling, W.F.M., “Case Study: Madrid Waste Recovery Facility”, IEA Bioenergy Task 23 Report, April 2000.

7. Authentication

Name and address of the principal:

- Novem (Netherlands)
- VVAV (Netherlands)
- IEA BIOENERGY TASK 36 Energy from Integrated Solid Waste Management systems

Names and functions of the co-operators:

Ing. W.F.M. Hesseling

Date upon which, or period in which, the research took place:

11-1999 – 12-2002

Signature:	Approved by:
W.F.M. Hesseling, B.Sc. Project Leader	S. van Loo, B.Sc. Head of Department

Annex A Organization of ThermoSelect S.A.

1 Thermoselect Company Information

1.1 Name

THERMOSELECT S.A.

The Company is the main engineering resource of the THERMOSELECT Group of companies, responsible for development, engineering, design, construction and sales of Turn Key THERMOSELECT Plants all over the world.

1.2 Address

Via Naviglio Vecchio 4
CH – 6600 Locarno

Tel.:	+41 – 91 – 756 25 55
Fax.:	+41 – 91 - 756 25 26
E-mail:	gl@thermoselect.ch

1.3 Ownership Details

The THERMOSELECT S.A. is a non public joint-stock company, located and registered in Locarno / Switzerland, Register No. CH-509.3.001.101-7.

The THERMOSELECT S.A. is held 100% by the Holding Company THERMOSELECT AG, Vaduz / Fürstentum Liechtenstein

The shareholders of the Holding THERMOSELECT AG are:

25.0 % of the shares	Mr. Günter Kiss, (Inventor of the Technology)
25,1 % of the shares	EnBW, Energie Baden – Württemberg AG, Karlsruhe, Germany
49,9 % of the shares	several private shareholders

1.4 Annual report and Accounts

THERMOSELECT AG as a non public joint-stock Company is not obliged to edit annual reports for public information, thus there is no annual report available.

The annual reports and company information of the EnBW are available on the Internet: www.EnBW.de

1.5 Brief Company Profile

The THERMOSELECT Company is the developer and sole supplier of the THERMOSELECT®-Process, which is a high temperature recycling process of all kinds of waste, based on high temperature gasification technology.

Business aims

The business aims of the THERMOSELECT Group of Companies are

- to create a new way of thinking within the waste management companies and authorities, whenever thermal treatment of waste is an issue
- to utilize the world wide intention to protect the environment and to save resources
- to generate a new understanding in the market for utilization of waste for producing besides energy future oriented products, like e.g. hydrogen, methanol and other chemical feedstock's
- to continue building up and establishing a strong and capable Group of THERMOSELECT – Companies and associated Companies, acting on a world wide basis
- to become the world market leader for supplying and constructing thermal treatment plants for waste of all kinds using our THERMOSELECT® - technology

Customer Service objectives

The design guidelines of THERMOSELECT – plants and its components are strictly oriented towards a minimization of complexity of equipment, to ensure high availability of THERMOSELECT – plants with as less as possible spares and down times.

The standards for ancillary equipment and components avoiding a high amount of various different types, which causes small and effective spare stock.

Specific THERMOSELECT spares are available from stock of the Customer Service Center at production and construction company THERMOSELECT Heavy Machinery AG / Dottikon, Switzerland.

The staff of operator companies will be trained continuously to cover their own service and maintenance requirements.

Company structure, Employees and Associated Companies

THERMOSELECT S.A.

Operative Headquarter of the THERMOSELECT group of Companies, located in Locarno / Switzerland, containing 90 employees and is responsible for:

- General Management of the THERMOSELECT Group
- Marketing and Public Relations
- Research and Development
- Engineering and design of THERMOSELECT plants and equipment
- Sales and Contracting of turnkey THERMOSELECT plants
- General Project Management
- Strategic planning and Licensing

THERMOSELECT Heavy Machinery AG

Production and assembly company, located in Dottikon / Switzerland, specialized for heavy machinery equipment made of steel as well of high quality stainless steel, also for third parties. The company is equipped with newest machining facilities, under others the largest CNC-tooling center within the entire Switzerland. This company contains 85 employees and is responsible for:

- Shop drawing design work for specific THERMOSELECT components
- Manufacturing of specific THERMOSELECT components and equipment
- Assembling and testing of Process-Modules for THERMOSELECT plants
- Construction and installation of turnkey THERMOSELECT plants
- Customer Service and spare part supplies

THERMOSELECT Engineering S.r.l.

Engineering company, located in Fondotoce / Italy

- THERMOSELECT component development & testing
- Engineering services
- Jobsite management and commissioning for THERMOSELECT plants

Management structure

THERMOSELECT S.A.

General Management

Administration	Dr. Jürgen Riegel	President	
Technical	Dr. Wulf Kaiser	Technical Director	

Deputy Management

Public Affairs, Marketing	Gudula Freytag	Proc.
Law / Contracts	Marianne Volonté	Proc.
Controlling, Org.	Christoph Sollberger	Proc.
Purchasing	Gustavo Ruga	Proc.
R&D	Prof. Rudi Stahlberg	Proc.
Sales	Dr. Geert Nyhuis	

Senior Management

Technology Dr. Wulf Kaiser Technical Director

Management

Process Engineering	Carlo Riva	Head of Department
Design Engineering	Ulrich Kollmann	Head of Department
Controls & Elec. Eng.	Alexander Angermayr	Head of Department
Authority Engineering	Dr. Barbara Kaiser	Head of Department
Site Supervising	Dr. Stefan Kutzmutz	Head of Department

Administration Ciro Lüscher Chief Administrator

Management

Financial / Accounts	Gabriella Bottoni	Head of Department
Organization / IDV	Jorge Pereira	Head of Department
Staff / Social Affairs	Beatrice Bühlmann	Head of Department

1.6 Licensees

THERMOSELECT has sold exclusive regional licenses to:

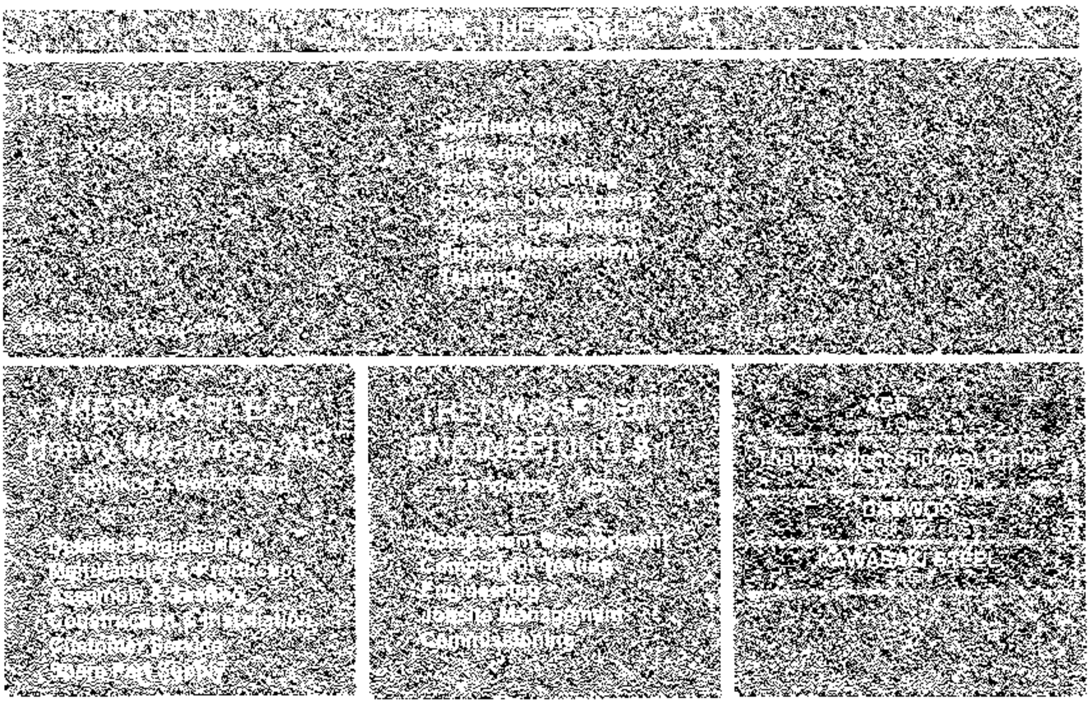
THERMOSELECT SÜDWEST GmbH, Karlsruhe / Germany

AGR - Abfallentsorgungsgesellschaft Ruhrgebiet, Essen / Germany

KAWASAKI STEEL CORPORATION, Tokyo /Japan

KIA / DAEWOO Corporation, Seoul / Korea

1.7 Diagrammatic Representation of Company Structure



1.8 Financial Documents

The following documents are attached:

- Commercial Register in Locarno/Switzerland - Main Register dated December 19th, 2001
  - English translation
  - Italian language original
- Ernst & Young declaration from January 30th, 2002
  - English original
- Coopers & Lybrand declaration from November 27th, 2000
  - English translation
  - German language original
- Office for Execution and Bankruptcy, Locarno/Switzerland - Statement from November 17th, 2000
  - English translation
  - Italian language original
- Municipal Cash Department, Locarno/Switzerland - Statement from November 17th, 2000

- English translation
- Italian language original

- Tax and Conditional Amnesty Office, Bellinzona/Switzerland - Certificate from November 17th, 2000
  - English translation
  - Italian language original
- National Suisse Assurances, Chiasso/Switzerland - Statement from November 17th, 2000
  - English translation
  - Italian language original
- Credit Suisse, Locarno/Switzerland - Bank confirmation from November 23rd, 2000
  - English translation
  - German language original

1.9 Thermoselect's capabilities and experience

THERMOSELECT has built, owned and operated a commercial size demonstration facility in Fondotoce/Italy from 1992 until 1998.

THERMOSELECT has delivered a turnkey commercial facility with an annual waste treatment capacity of 225'000 tons to the German Power Provider EnBW (Energie Baden Württemberg) in Karlsruhe/Germany. The plant started operation in spring 1999.

THERMOSELECT has delivered the technology and equipment for a commercial facility with a capacity of 100'000 tons/a in Chiba/Japan. The plant is owned by the Japanese THERMOSELECT licensee, Kawasaki Steel Corporation. The plant started operation in autumn 1999.

THERMOSELECT is currently erecting a turnkey facility with an annual waste treatment capacity of 75'000 tons/a for the TAE (Thermische Abfallentsorgung Ansbach GmbH) in Ansbach/Germany.

THERMOSELECT is generally interested also in BOO contracts. In Europe there are already two Projects where THERMOSELECT is involved as investor and Operator.

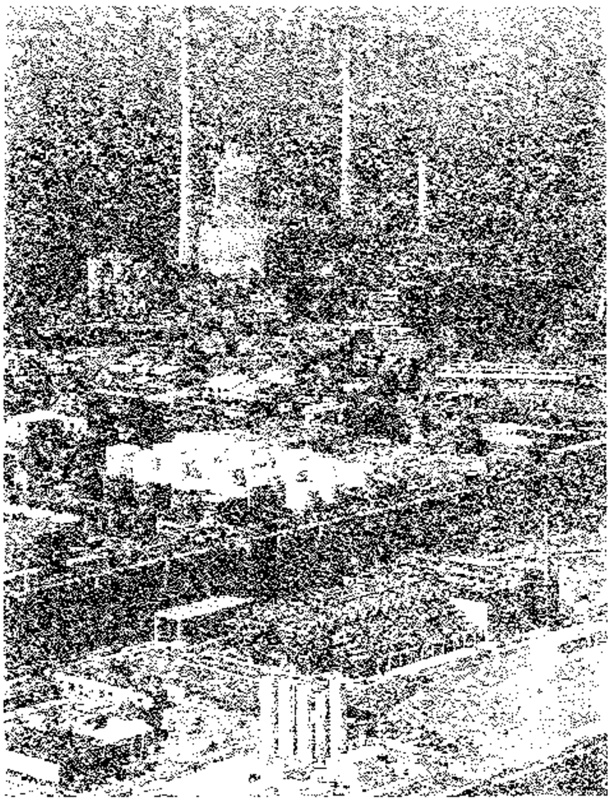
In Switzerland THERMOSELECT will build and operate its own plant in a consortium jointly with the EnBW.

In Germany THERMOSELECT will have a major part of the shares of a government operating company for a THERMOSELECT plant.

In both cases THERMOSELECT will ensure the financing of the investment.

Operation Results of the THERMOSELECT High Temperature Recycling Facility in Karlsruhe, Germany

H. K. Mucha and R. Stahlberg



1 Summary

Over the past decade, an innovative waste recycling technology -the THERMOSELECT process- has been developed, proven in a large scale demonstration facility and commercialized by the THERMOSELECT S.A. company. Solid wastes, including MSW, are continuously processed in a fixed bed oxygen blown gasification and residue melting reactor to achieve a maximum recovery of recyclable raw materials, with simultaneous utilization of the chemical energy contained within the waste material and minimum impact to the environment. Commercial plants have been recently erected in Karlsruhe, Germany, and in Tokyo-Chiba, Japan. The Karlsruhe plant has a waste treatment capacity of 225'000 Mg/a and the Chiba plant of 100'000 Mg/a.

The waste is compacted in a high pressure press and fed in discrete packages into a degassing channel. During a period of 1 to 2 hours –the time a package needs to travel through the channel being pushed by the subsequent packages– the material is dried and organic fractions are converted to gas and char. Downstream of the channel the material enters a high temperature reactor. The gas phase residence time is 2 to 4 seconds and the gas discharges at 1200°C ensuring that all organic compounds are decomposed. Controlled quantities of oxygen are fed into the reactor to convert the char at high temperature to a synthesis-gas mainly comprising a mixture of H_2, CO, H_2O and CO_2. Using pure oxygen instead of air dramatically reduces the apparatus size of the reactor, piping, and gas cleaning and secondly avoids any NO_x formation.

The inorganic components of the feed are molten at temperatures of 1600°C – 2000°C and oxidized. The molten material flows into a water quench bath where the material forms mineral chip and iron rich metal pellets which are magnetically separated for recycling.

The hot synthesis-gas is passed into a rapid water quench in which it is cooled below 70°C hence avoiding any re-formation of organic compounds. The gas is then purified by means of conventional scrubbing processes. In the Karlsruhe plant, the treated synthesis gas is used as fuel in a steam generator. A steam turbine produces enough electrical power to cover the needs of the plant as well as a surplus being injected into the local network. Furthermore, a large amount of heat is delivered to a local district heating network.

Figure 1 Process Overview

2 Process Description

The THERMOSELECT Resource Recovery Facility recovers pure synthesis gas, useable vitreous mineral substances and iron rich materials from mixed wastes such as Muncipial Solid Waste (MSW) and Commercial and Industrial Wastes. In an uninterrupted recycling process the organic waste fractions are gasified and the inert materials are simultaneously molted down. The subsequent purification of the synthesis gas and process water yields clean water, salt, zinc concentrate and sulfur as products. In contrast to other processes, no ashes, slags, inerts, chars or filter dusts have to be deposited in a costly manner or subjected to secondary treatment. A process overview is depicted in Figure 1.

2.1 Waste Feed System

In the first process step the untreated as received municipal solid waste is discharged directly into a storage bunker. The bunker has storage capacity for about a week and is used to dampen out fluctuations in waste receival cycles. A grapple crane is used to transfer the waste to the feed chute of the bailing press. The press in turn compacts the waste, distributes liquid within the bail and forces out the residual air (nitrogen ballast). Dense waste plugs are thus formed which are fed one after the other into the degassing channel of the reactor. These waste briquettes also form the seal of the reactor at the inlet.

2.2 Gasification of waste

The press is directly connected to the degassing channel. The channels cross sectional area increases slightly as the gasification reactor is approached, which eases the movement of the waste plugs and the transportation of the gases (evaporation of water, pyrolysis and synthesis gases) from the waste into the reactor.

Radiated heat from the gasification reactor initiates the waste drying and decomposition processes in the degassing channel and are brought to completion within the reactor itself (Figure 2). The dried and charred briquettes emerge from the degassing channel and are exposed to steam (from water in the waste) and controlled injection of pure oxygen as the gasification medium.

All organic materials in the waste are trans-formed into a synthesis gas with a composition that reflects the thermodynamic equilibrium of the temperature at the top of the reactor (approximately 1200°C).

The high temperature, oxygen free environment and long residence time of 2 seconds in the upper part of the reactor ensures that only small molecular species such as H_2, CO, CO_2 and H_2O leave the reactor as prime constituents of the synthesis gas. The main prevailing exothermic reactions occurring in the upper part of the reactor are:

$$C + \tfrac{1}{2}O_2 \rightarrow CO$$

$$C + O_2 \rightarrow CO_2$$

$$2C_xH_y + (2X+Y/2)O_2 \rightarrow 2x\ CO_2 + yH_2O$$

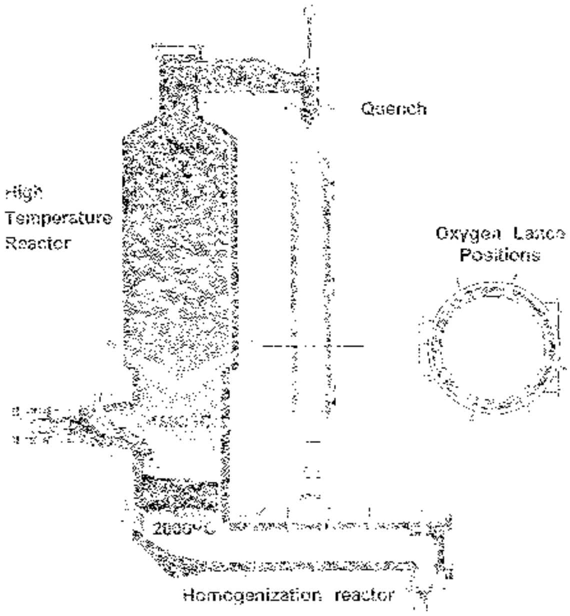


Figure 2 High temperature reactor

with a simultaneous endothermic Boudouard reaction

$$C + CO_2 \rightarrow 2CO$$

and the endothermic water shift reaction, e.g.

$$C + H_2O \rightarrow H_2 + CO$$
$$C_xH_y + X\,H_2O \rightarrow (x+Y/2)H_2 + XCO$$

After gasification at a gas exit temperature of 1150-1200°C, a synthesis gas is obtained being typically composed of 25-42 Vol.-% H_2, 25-42 Vol-% CO, 10-25 Vol.-% CO_2 and nitrogen (Figure 3), depending mainly on the waste input composition.

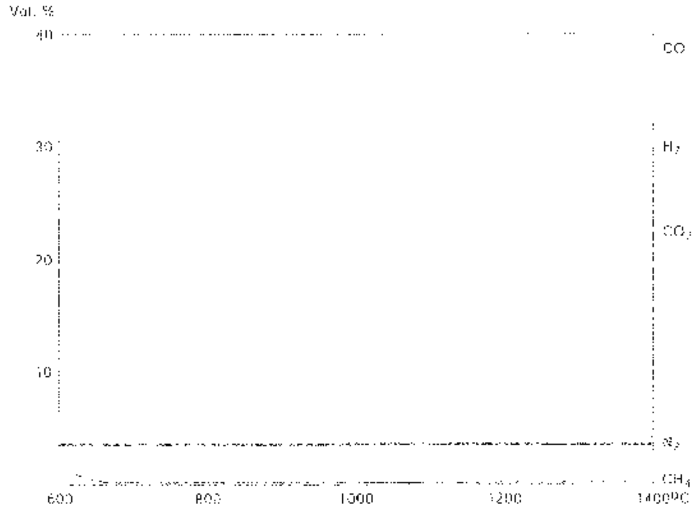


Figure 3 Calculated High Temperature Equilibrium Composition

2.3 Melting of inorganic materials

In the lower part of the reactor all metallic and mineral components are molten. Metals such as mercury, zinc etc. are volatilized at the high temperatures in the lower part of the reactor (locally up to 2000°C) and are extracted with the synthesis gas. The oxides of the base metals form a mineral melt in the lower part of the reactor as shown in Figure 4. Simultaneously other metals are also molten down. A typical iron alloy is formed containing nickel, copper and traces of other heavy metals. The typical iron content is more than 80%.

The mineral and metal melts collect in the lower homogenization reactor, which is heated with natural gas and oxygen. A two phase flow occurs in the melt with the minerals and metals separating automatically as a result of the differences in relative density (RD 3 and 7 respectively). Any residual carbon in the melt is synthesized to further syngas.

The molten substances are then granulated by water quenching and extracted from the quench basin using a bucket elevator. The difference in heat conductivity between mineral and metal melt results in the two products automatically granulating separately within the same quench basin. The metal granules can be separated from the mineral granules by magnetic separators.

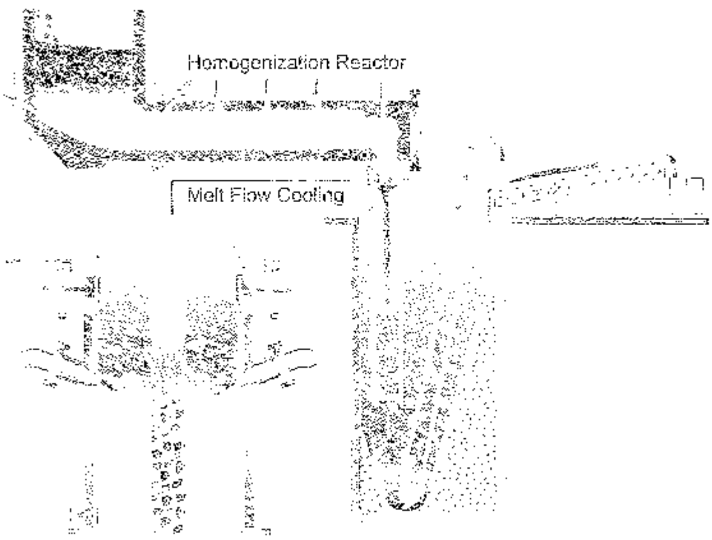


Figure 4 Homogenization reactor and granulate extraction

2.4 Synthesis gas cleaning

The synthesis gas passes through a water quench, acidic scrubber, alkaline scrubber, desulphurisation and gas drying stages.

Firstly the crude synthesis gas exits the reactor at approximately 1200°C and flows into a water jet quench where it is cooled almost instantaneously to about 70°C. The shock-like cooling avoids the formation of dioxins, furans and other organic compounds from elementary molecules in the syngas due to the de novo Synthesis back reactions (Figure 5). De novo synthesis reactions are known to occur in waste heat boilers where a slow cooling in the range from 400°C to 250°C of flue gases with chlorine compounds, uncombusted organic molecules and catalysts such as dust will result in dioxin formation.

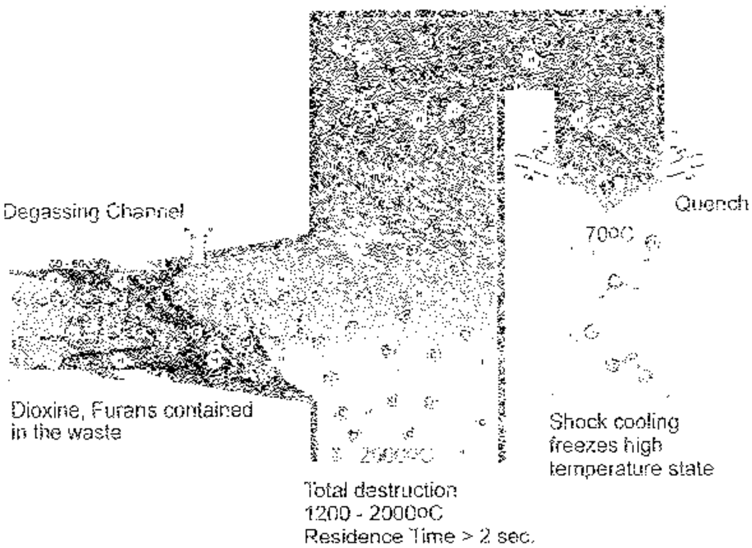


Figure 5 Destruction of organic compounds

Measurements have proven that this is avoided in the THERMOSELECT process. Entrained particles such as graphite and mineral dusts are also separated out in the quench.

The gas path is connected to a water lock tank serving as a safety pressure relief device. In case of a sudden pressure rise above 500 mbar in the gasifier, for example due to a propane bottle burst, the synthesis gas is relieved to the safety flare where it is combusted.

Following the quench the synthesis gas flows through an acidic scrubber where further HCl and HF acids are removed. The acid content of the gas depresses the flushing liquid of these scrubbers to pH~3 which results in the volatilized heavy metals and their compounds dissolving as metal ions. Weaker acid formers such as H_2S, SO_2, and CO_2 do not dissolve at this pH value.

The acid scrubber is followed by an alkaline scrubber which uses NaOH in solution to knock out any residual acid liquid droplets. The alkaline solution contains traces of the ions HCO_3^-, HSO_3^-, and HS^-.

The synthesis gas is then passed through a desulphurisation process. The scrubbing liquid contains an Fe-III complex (Sulferox) which is used to remove the H_2S from the gas. The process allows the conversion of the H_2S into elemental sulfur. The process is a redox-process in which the H_2S is oxidized to elemental sulfur and water by the conversion of the Fe-III into a sulfur Fe-II complex. This conversion process takes place within the Sulferox scrubber. In a regeneration unit, the scrubbing liquid is then oxidized by blowing air through it which converts the Fe-II back into the Fe-III complex. Elemental sulfur precipitates during this stage which is removed from the liquid by means of a centrifuge system.

Following desulphurisation, the dew point of the gas is lowered by direct contact with cold water in a gas drying scrubber. The lowering of the gas dew point prevents condensation in downstream equipment such as the power generation infrastructure and also removes residual traces of vaporized heavy metals.

2.5 Process water treatment

The process water originates from the condensed water vapour inherent in the processed waste and from the reaction products of the gasification process. Other small process water streams are generated from the gas scrubbing processes.
The water from the quench circuit is settled, solids are removed and returned back into the high temperature reactor.
The water from the alkaline scrubber, with traces of hydrogen sulfide dissolved in it, is fed into vessels and oxidized using hydrogen peroxide. Soluble sulfate is formed and prevents the evolution of H_2S gas in later processing stages. Also Fe-II is converted to Fe-III which assists in subsequent precipitation steps.
A two stage precipitation then takes place. In the first stage NaOH is added to raise the pH to about 5.5. At this point aluminum and iron hydroxides precipitate which are settled out with the aid of a polyelectolyte. The sludge is captured and dewatered in centrifuges. Again, the solids are returned to the high temperature reactor.
In the second precipitation stage the pH is raised to about 9 through the addition of NaOH. This causes heavy metals such as zinc to precipitate as a hydroxide, which together with the addition of polyelectolyte is settled out. The resultant sludge is dewatered by separate centrifuges. The resultant cake is a product of the process.
The next process is a neutralization step in which the pH of the water is reduced to 7 with the addition of HCl acid.
Thereafter the water is passed through an ion exchange unit. The ion exchanger reduces any residual concentrations of multi-valent ions such as calcium and traces of zinc and other heavy metals. The metal ions are exchanged for sodium ions. The regenerate from the ion exchanger is returned to the first precipitation step. The increased concentration of ions in the regenerate will allow capture of these residual ions in the subsequent precipitation processes.
In the final step the process water is passed through a reverse osmosis and then through an evaporation unit. Condensing clean water is reused in the plant. The remaining salt is extracted by centrifuges and is a product of the process.

2.6 Synthesis gas utilisation

There are multiple end uses for the purified synthesis gas:

- Hydrocarbon production e.g. Petrol
- Hydrogen e.g. Fuel cells, gas engines
- Ammonia production e.g. Fertilizers
- Methanol manufacture e.g. Chemical industry
- Electricity e.g. gas engines, steam boiler and turbine and combined cycle options, gas turbines

The choice of power generating equipment is dependent on the price of power. Higher power generating efficiency processes would need to be supported by higher electricity prices. The Karlsruhe plant synthesis gas utilisation is described in chapter 6.1.

2.7 Ancillary units

An air separation unit supplies oxygen, nitrogen and compressed air. Oxygen is required as the gasification medium and is in a pure form to manufacture high quality products. Nitrogen is used for atmosphere inertisation during maintenance and compressed air is required for control equipment.

The mineral and metal granulate is stored in a bunker storage. The bunker is equipped with a loading crane.

3 Technology Maturity

The THERMOSELECT Resources Recovery Facility process has been one of the most exhaustively assessed processes in the world. All assessments have been carried out by 10 independent Government audit authorities from Germany, Switzerland and Italy including the German TÜV (Technischer Überwachungs-Verein) and several Universities. A wealth of information exists on the process, documented in books and International Journal papers (see chapter 8). This extensive independent evaluation process has been undertaken primarily to satisfy community and government perceptions on emerging technologies. THERMOSELECT has shown that combined gasification and smelting of the inorganic fractions of waste is a desirable alternative to incineration since it does not create dioxin contaminated dusts, ash, slags and flue gases.

An independent audit of emerging technologies revolving around pyrolysis and gasification has been undertaken by Juniper Consultancy Services Ltd. (Sheppards Mill, Uley, Gloucestershire, GL11 5SP, England) in January 2000, culminating in the report "Pyrolysis and Gasification of Waste, A Worldwide Technology & Business Review". Over 100 companies were identified that are developing pyrolysis/gasification technologies. The report identified THERMOSELECT as the leader in the field in commercializing the technology for MSW and that has been able to account for all elements of emissions and the quality of products.

4 Input Quality & Quantity Flexibility

The chemical composition (ultimate and proximate analysis) of the waste will determine the quality and amount of raw synthesis gas. This in turn will determine the extent of gas refining required. It has been shown that the automated nature of the THERMOSELECT process adjusts itself to any deviations in waste quality (for example water content). Also, within reason, the quality of the products produced has been shown to vary very little as the waste source is changed from one to another.

One significant advantage of the THERMOSELECT process is its flexibility to handle raw as received waste of various kinds. Large bulky items (e.g. furniture) may be shredded and tipped into the bunker.

Liquid wastes such as sewage sludge etc. can also be processed. They are metered into the high temperature reactor together with the recycle streams into the transition section between the degassing channel and the reactor.

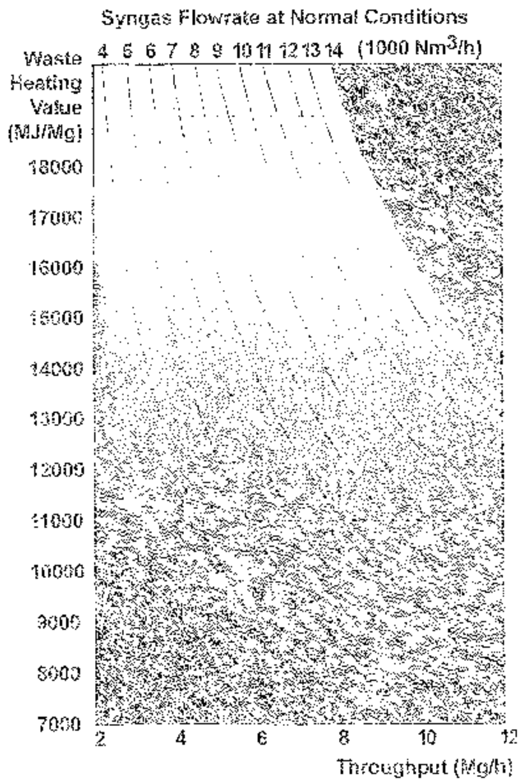


Figure 6 Synthesis gas production

The process can also treat industrial wastes. The Chiba plant in Japan has been specially configured for this.

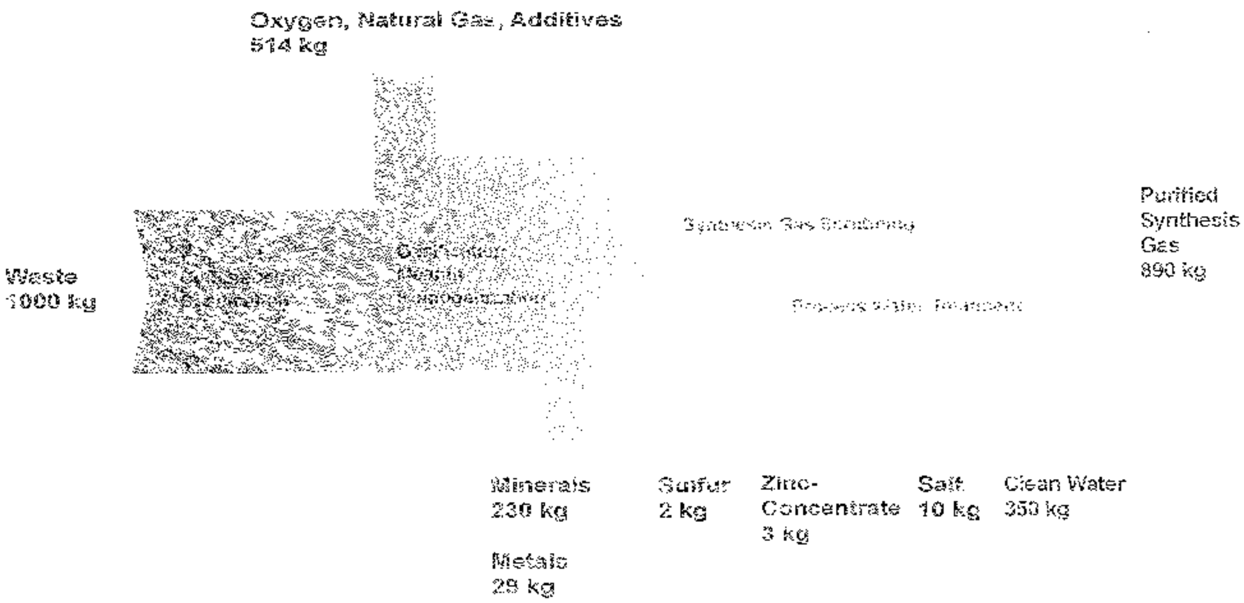
The capacity range of a thermal train is depicted in Figure 6 as function of waste heating value. The upper bound of the process is the capacity of the gas scrubbing and process water treatment equipment, whereas below the lower bound the consumption of secondary fuel becomes excessive.

5 Resource Conversation

The THERMOSELECT Resource Recovery Facility was conceived as a means to recover the maximum possible benefit out of mixed wastes that cannot be economically recycled. The process is for the continuous processing of mixed wastes with the primary goal of achieving the highest possible yield of high quality recyclable products at the lowest possible ecological pollution level, with simultaneous utilisation of the chemical energy contained in the waste.

The products that are manufactured together with their reuse potential are:

- Mineral granulate reused as gravel substitute in concrete, as shot blast or as road base
- Metal granulate recycled into the metal industry
- Sulfur reused in the sulfuric acid and fertilizer industry
- Zinc concentrate reused in the zinc smelting industry
- Salt reused in the chlorine manufacturing industry
- Water reused in the process
- Synthesis gas either converted to further chemicals or power



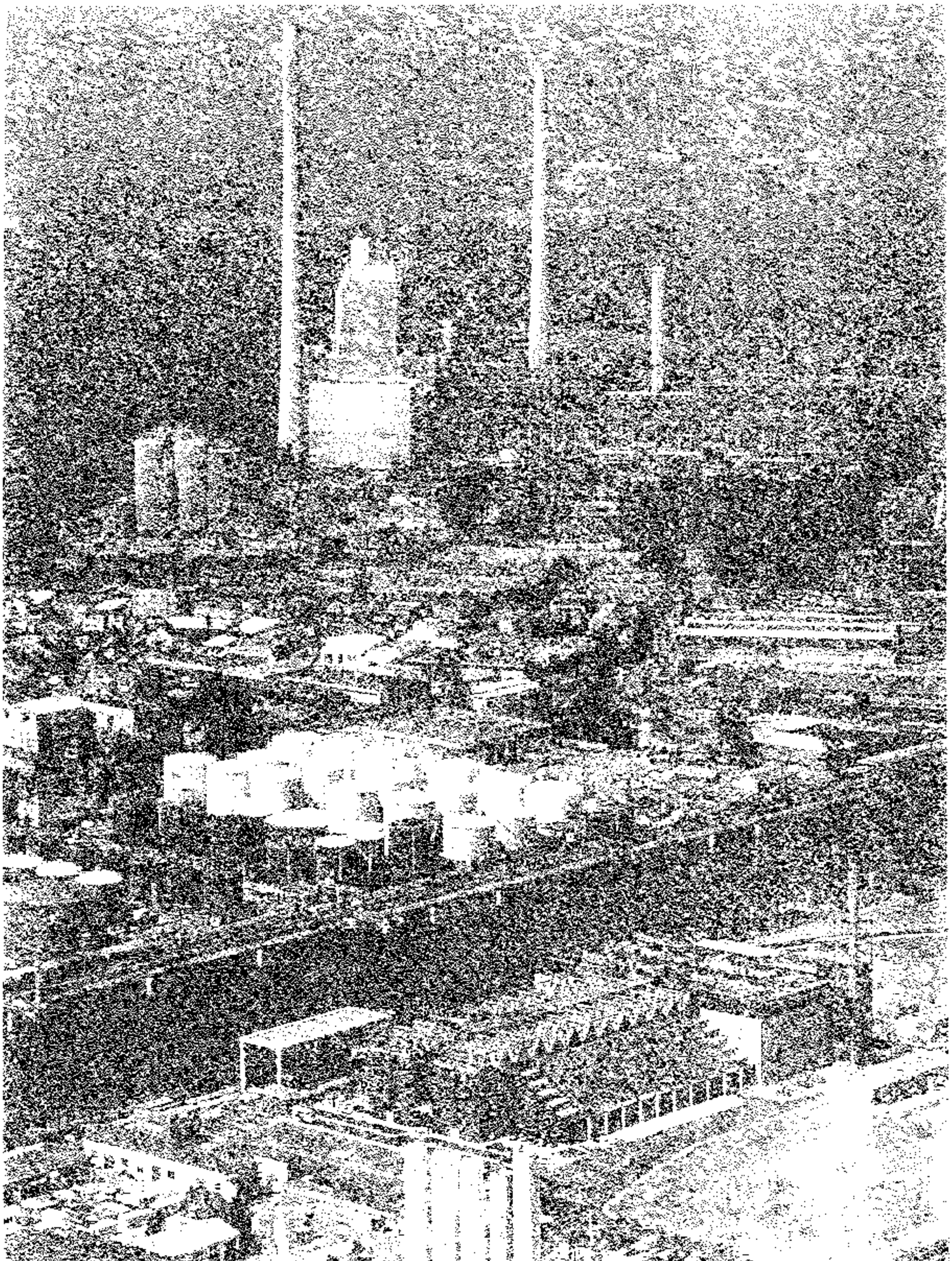


Figure 7 Thermoselect facility at the Rhine harbor, Karlsruhe

6 THERMOSELECT facility in Karlsruhe (Germany)

The THERMOSELECT facility in Karlsruhe (Figure 7) is equipped with 3 thermal lines for waste treatment. Each line has a nominal throughput of 10 Mg/h, a brief operation with up to 50% excess capacity, however, is possible.

• Number of thermal lines	3	
• Nominal capacity per line	10	Mg/h
• Annual availability	7'500	h/a
• Annual capacity	225'000	Mg/a
• Thermal performance	100	MW
• Thermal performance (incl. natural gas)	104.2	MW
• Gross synthesis gas performance	67.6	MW
• Thermal power of steam generator	63.1	MW
• District heating power (condition for approval)	50	MW
• Process heat – own requirements	5.7	MW
• Number of steam generators	2	
• Number of steam turbines	1	
• Gross power generation	12.7	MW
• Net surplus power	2.7	MW

In Karlsruhe, the waste is delivered by trucks and train. Vehicle scales at the entrance record the quantities delivered by truck and transmit the results to a central data acquisition system. By train, up to 350 Mg of waste can be delivered daily and are handled by an automated container terminal.

The waste is introduced into the waste bunker by means of waste compactors (plunger and bed system). This type of feed mechanism ensures a nearly air-tight sealing towards the environment. The nitrogen inertisation of the bunker is an efficient and meanwhile proven fire protection measure. The occurrence of a fire within the bunker may thus generally be excluded under the aforementioned conditions. Louvered walls are installed above the funnel-shaped walls of the waste compactors for air extraction. This air flow is routed through various dedusting and odor reduction stages before it is discharged through the outer chimney tube together with the nitrogen used in the inert process.

The thermal treatment of waste, synthesis gas purification and process water cleaning are described in chapter 2.

6.1 Synthesis gas utilization

The synthesis gas generated in the three high temperature reactors is utilized in two steam generators. An oxidation catalyst to reduce the CO emissions and a DENOX catalyst with urea injection to reduce the NOx emissions are installed upstream of the feed water preheater. At nominal load, 19.3 kg/s of steam are supplied to the steam turbine at a pressure of 64 bar and a temperature of 485°C. The steam turbine generates 12.7 MW of electrical power, 2.7 MW of which are fed as surplus into the local electricity grid. Up to 50 MW of thermal power are furthermore fed into the district heating network. The district heating water is preheated with the thermal power of the quench cooling water circuit and then raised further to the required supply temperature with steam extracted from the steam turbine.

In case of a synthesis gas consumer malfunction, the synthesis gas generated is safely combusted in a closed combustion chamber. The flue gases are shock-cooled in a rapid water quench to avoid a de novo synthesis of organic compounds, and then pass through an alkaline scrubber and a dry-sorption filtration unit, before being exhausted via the chimney of the facility. The emission values are reported online via the continuous emission control system to the responsible authority, as during normal operation.

6.2 Oxygen and nitrogen generation

The air separation facility supplies oxygen for the gasification process in the high temperature reactor and nitrogen for the inertisation of the waste bunkers and components of the facility during the startup and shutdown processes. Contrary to the initial planning, the facility was separated from the THERMOSELECT plant and installed as an independent facility adjacent to the area where the plant is operated in such a way that the THERMOSELECT plant may be supplied with the oxygen and nitrogen quantities required under all operating conditions without any interruption.

6.3 Planning and erection of the plant

The initial planning of a conventional combined waste heating and power station in the area of the Rhine harbor/Karlsruhe was abandoned at the end of 1994 due to the convincing experience gained from the operation of the THERMOSELECT plant in Fondotoce/Italy. The approval procedures for the new plant concept were initiated in 1995, the approval was granted in October of 1996. The remedial treatment of historical burden on the estate previously used for the storage of oil and fuel was carried out in parallel.

In early 1997, the plant design was modified, since the air separation facility - which was up to that time integrated - was to be erected adjacent to the plant as an independent facility to supply both the district and to ensure a continuous supply of oxygen and nitrogen to the THERMOSELECT plant.

A costly securing of the construction site started after the founding stone was laid in March of 1997, with the driving of piles for the foundations of buildings and machinery equipment as well as the installation of sheet piling for areas down to −12 m (granulate basin). In July 1997 the actual concrete work started. The erection of the heavy components was carried out in January 1998, the erection of the process halls was completed in the first half of 1998 and the remaining construction work end of 1998. The startup prerequisites for one process line were established in December 1998.

Deficiencies of the crane facilities and bad quality of the sedimentation basins (concrete and PP panel lining) integrated into the quench water circuit were responsible for a start up delay of approx. 3 months and have ultimately resulted in the need to remedy this specific functional area after an operation of approx. 1 ½ years (the quench water leakage could not be stopped even after several repairs on warranty, the sedimentation basins were therefore completely replaced by epoxy-glass resin tanks in August/September/October 2000).

The trial operation that was officially monitored by the authorities during the first half of 1999 resulted in a number of findings and conditions imposed which had to be processed on a step-by-step basis, accompanied by the experts from the authorities. In the following, the essential experience gained is outlined and explained.

6.4 Operation experience during start up

The target during the trial operation was to systematically test all components of the facility and to optimize these, taking into account the ordinances imposed by the authorities.

June 1999

- Replacement of the surge tanks used as a flame and gas arrester by nitrogen injection tubes on the basis of the Venturi effect (ordinance imposed by the approving authority)
- Retrofitting of startup lines for a further reduction of the emissions during startup (ordinance imposed by the approving authority)
- Retrofitting of salt decanters (customer request for a modified consistency of the salt)
- Retrofitting of melt outlet armoring for a high melting performance (customer request)
- Adaptation of the melt outlet cooling system to the increased melting performance

August-September 1999

The waste sulfur values were higher as expected (up to approx. 100% higher than the values stipulated in the contract) and made the installation of additional desulfurization capacity necessary. The integration of a dry sorption stage downstream of the synthesis gas utilization for a micro-purification of the flue gas resulted in a higher safety margin in respect to the extremely low values stipulated in the operation permit.

October-November 1999

The original safety flare used for the elimination of synthesis gas in case of a malfunction of the synthesis gas utilization exceeded the authorized – extremely low – emission limits for heavy metals. In an attempt to reduce these emissions, cold water spray cyclone systems were installed into the synthesis gas path upstream of the flare inlet.

December-January 1999/2000

The strong alternating thermo-mechanic loads resulting from the frequent startup and shutdown of the facility during the trial operation made the renewal of the refractory in the high temperature reactors necessary.

April 2000

A routine replacement of the granulate basin heat exchangers and the repair of the sedimentation basin (quench circuit) was carried out.

August 2000 - July 2001

The concrete sedimentation basins with PP plate lining failed to be permanently leak-tight as a result of initial manufacturing deficiencies (hollow sections in the concrete beneath the PP lining) and thus had to be replaced with epoxy-glass resin tanks.

The safety flare was replaced by a closed combustion chamber with downstream gas scrubbing including a rapid water quench system, alkaline scrubbing and dry sorption filtration.

6.5 Karlsruhe plant products

Synthesis gas (approx. 215'000 Mg/a)
Heat and electricity are produced in a power plant on site. An electricity surplus of 2.7 MW is available to the local power grid and up to 50 MW thermal power is delivered to a district heating network.

Pure water (approx. 180'000 Mg/a)
All water streams created during the process from the moisture of the waste, the reaction products and the auxiliary water are processed and purified in the process water treatment system. The total amount is used for cooling purposes within the plant and is evaporated in hybrid cooling towers.

Granulate (mineral 49'500 Mg/a, metal 6'500 Mg/a)
The mixed granulate produced in the high temperature process (cf. tables 1 and 2) is magnetically separated into its mineral and metal constituents. The iron-rich metal fraction is used in the metal industry. The inert vitreous mineral granulate is utilized as sand blasting agent, gravel substitute for concrete or as road bed material. The customer for the granulate in Karlsruhe is the company Weisenburger.

Sulfur (450 Mg/a)
In the synthesis gas purification, elemental sulfur is produced mixed with residual carbon (cf. table 5). The sulfur may be used industrially for the production of sulfuric acid. The customer of the sulfur is PVS Chemicals Inc. in Kelheim.

Salts (2'700 Mg/a)
The main constituent of the mixed salt is sodium chloride (cf. table 4). Since an economic utilization does not make sense for the relatively low quantities of salt produced, the salt is used as filling material in the mining industry.

Metal precipitation products (1'700 Mg/a)
The main components of the metal precipitation products obtained during the purification of water in addition to zinc are e.g. Pb, Cd, Hg etc. (cf. table 3). B.U.S Zinkrecycling Freiberg GmbH makes use of the material for the recovery of metal.

Component	Unit	Composition
Water	%age by weight	5-10
Bulk density	kg/m³	approx. 1,400
Ignition loss	% TS	0.1
Carbon, total	% TS	< 0.01
Aluminum	% TS	3.4
Calcium	% TS	8.9
Iron	% TS	9.3
Silicon	% TS	24.5
Cadmium	mg/kg TS	< 5.0
Mercury	mg/kg TS	< 2.6
Antimony	mg/kg TS	18
Arsenic	mg/kg TS	< 3.7
Lead	mg/kg TS	202
Chrome (total)	mg/kg TS	2,670
Copper	mg/kg TS	2,240
Manganese	mg/kg TS	1,470
Nickel	mg/kg TS	265
Tin	mg/kg TS	93
Zinc	mg/kg TS	890

Table 1 Analysis of the granular mineral substance (THERMOSELECT facility Fondotoce, THERMOSELECT facility Karlsruhe

Component	Unit	Composition
PH-value	-	6 – 8
Electrical conductivity	µS/cm	11
Phenol index	mg/l	< 0.01
Chloride	mg/l	< 0.5
Fluoride	mg/l	< 0.1
Sulfate	mg/l	< 1.0
Borate	mg/l	< 0.01
Cyanide total	mg/l	< 0.01
TOC	mg/l	n.a.
AOX	mg/l	n.a.
Aluminum	mg/l	0.07
Antimony	mg/l	< 0.01
Arsenic	mg/l	< 0.001
Barium	mg/l	< 0.05
Beryllium	mg/l	< 0.02
Lead	mg/l	< 0.02
Cadmium	mg/l	< 0.0002
Chrome (total)	mg/l	< 0.001
Cobalt	mg/l	< 0.05
Iron	mg/l	0.04
Copper	mg/l	< 0.05
Manganese	mg/l	< 0.02
Molybdenum	mg/l	< 0.2
Nickel	mg/l	< 0.05
Mercury	mg/l	< 0.0001
Selenium	mg/l	< 0.002
Thallium	mg/l	< 0.001
Vanadium	mg/l	< 0.01
Zinc	mg/l	0.03
Tin	mg/l	< 0.01

Table 2 Eluate values of the granular mineral substance (THERMOSELECT facility Karlsruhe)

Component	Unit	Composition
Water	g/kg	< 800
Metal hydroxides	g/kg	> 200
Metal hydroxides (dry)		
Aluminum	g/kg	< 100
Antimony	g/kg	0.5
Arsenic	g/kg	< 0.05
Lead	g/kg	< 10
Cadmium	g/kg	< 5
Calcium	g/kg	< 100
Iron	g/kg	< 5
Copper	g/kg	< 10
Magnesium	g/kg	< 5
Manganese	g/kg	< 5
Nickel	g/kg	< 5
Mercury	g/kg	< 0.02
Zinc	g/kg	400
Tin	g/kg	< 1

Table 3 Analysis of the zinc concentrate (THERMOSELECT facility Fondotoce, THERMOSELECT facility Karlsruhe)

Component	Unit	Composition
Water	g/kg	< 300
Sulfur	g/kg	> 400
Carbon total	g/kg	< 200
Impurities	g/kg	100
Impurities		
Iron	g/kg	20
Cadmium	g/kg	< 0.2
Mercury	g/kg	< 0.1
Arsenic	g/kg	< 0.1
Lead	g/kg	< 50
Chrome	g/kg	< 1
Copper	g/kg	< 10
Manganese	g/kg	0.5
Nickel	g/kg	0.2
Tin	g/kg	< 5
Antimony	g/kg	0.1
Chloride	g/kg	< 10
Fluoride	g/kg	0.2

Table 4 Analysis of the sulfur (THERMOSELECT facility Fondotoce, THERMOSELECT facility Karlsruhe)

Component	Unit	Composition
Water contents	g/kg	100
Sodium chloride	g/kg	> 785
TOC (carbon)	g/kg	20
Carbonate (as CO_2)	g/kg	50
Fluor	g/kg	30
Impurities	g/kg	< 12
Impurities		
Arsenic	g/kg	0.05
Lead	g/kg	0.01
Cadmium	g/kg	0.01
Chrome	g/kg	0.02
Iron	g/kg	0.05
Copper	g/kg	0.01
Manganese	g/kg	0.03
Nickel	g/kg	0.01
Mercury	g/kg	0.002
Tin	g/kg	0.005
Zinc	g/kg	0.01
Calcium	g/kg	1
Magnesium	g/kg	0.05
Potassium	g/kg	10
Cyanide	g/kg	0.05

Table 5 Analysis of the mixed salt (THERMOSELECT facility Fondotoce, THERMOSELECT facility Karlsruhe)

6.6 Emissions

There are no water emissions from the process. The water in the waste is purified to drinking water quality and is reused in the process as cooling tower make up.
Air is extracted from the waste receival and bunker areas and routed through a small bag filter for dust removal followed by a UV lamp unit which oxidizes any odors.

Other emissions to air are the exhaust gases from the unit that converts the synthesis gas into power. The basis for the definition of the respective emission limit values is the German 17th Ordinance for the Execution of the Federal Pollutant Protection Law (ordinance on incineration facilities for waste and similar combustible substances – 17. BImSchV). Table 6 compares the limit values stipulated in the 17. BimSchV with the values approved for the Karlsruhe facility. The comparison makes clear that for normal operation emission values are specified which are 3 to 10 times lower than those stipulated by law.

For the synthesis gas elimination in case of operational malfunctions, severe voluntary agreed control values were approved being for heavy metals 10 times lower than those prescribed by law for normal operation. One should note in this context that German law foresees virtually no emission limits during malfunction situations, except on total carbon and dust.

Pollutant		**17th BimSchV** 12th edition section 5	**Limit value specified 1996 Synthesis gas utilization normal operation**	**Limit value specified 1996 Synthesis gas elimination combustion chamber**
Total dust	mg/m³	10	3	10
Total C	mg/m³	10	2	10
HCl	mg/m³	10	2	10
HF	mg/m³	1	0.2	1
SO_2	mg/m³	50	10	50
NO_2	mg/m³	200	70	400
CO	mg/m³	50	10	200
Hg	mg/m³	0.03	0.01	0.05
Cd, Tl	mg/m³	0.05	0.01	0.05
Sum total HM	mg/m³	0.5	0.03	0.05
Dioxins, furans	ng/m³	0.1	0.01	0.1

Table 6 Emission value limits for intended synthesis gas utilization and deviations (mean daily values). Note: HM – Heavy metals

Figure 8 shows the measured values for normal operation, recorded at the chimney after the steam boilers in comparison to the values specified by the approving authority as well as those required by law. The actual measured emission values achieved are lower than the permitted values (blue bars). No other thermal technology treating waste in the world today can achieve such low gas emission levels at competitive conditions.

THERMOSELECT are currently setting the standards for Best Available Technology.

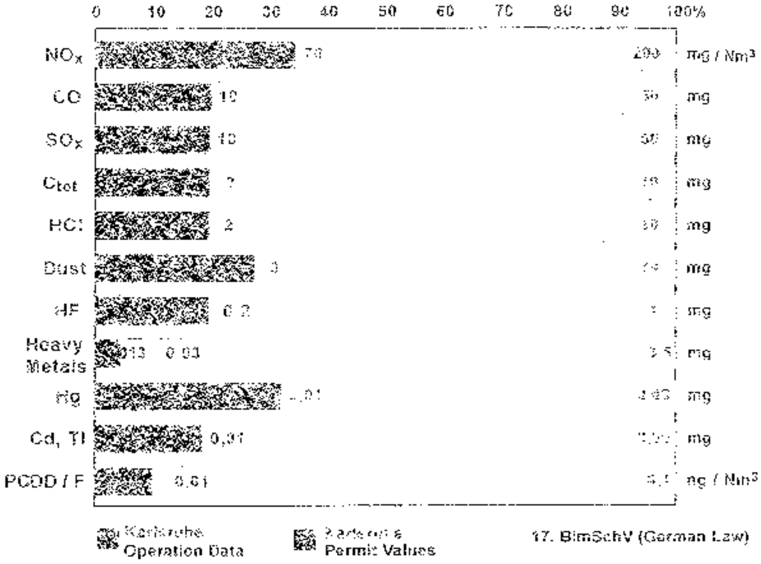


Figure 8 Karlsruhe plant air emissions

6.7 Synthesis gas elimination in the combustion chamber

In case of a malfunction, the combustion chamber is used to reliably eliminate the synthesis gas still created due to the inertia of the system. Depending on the type of deviation from the intended operation, a differentiation is made between two cases: Either raw synthesis gas enters the combustion chamber downstream of the high-temperature reactor directly via the surge tank or pure synthesis gas is supplied.

Section 16 of the German 17th Federal Pollutant Protection Ordinance outlines the conditions for thermal waste treatment facilities in case of malfunctions. According to it, exhaust gas may be discharged to the atmosphere during a maximum of 96 hours per annum without emission restrictions. Excepted from this are carbon and dust. For these components, 30 minutes mean emission limit values of 20 mg/m^3 resp. 150 mg/m^3 must be adhered to.

In the interest of a better ecological quality of waste disposal, however, severe restrictions were imposed on the THERMOSELECT facility in Karlsruhe in two ways. Not the 96 hours which are permissible per annum were specified, but rather only 50 hours. In addition to it, emission values were to be adhered to, which correspond to the limit values required by law for normal operation resp. which are 10 times lower for heavy metals. Refer to table 6 for these authorized emission limit values.

The experience gained during trial operation, however, has shown that the expectations could not be fully met with the original safety flare system. In particular the limit value for heavy metals which is 10 times lower than the respective value stipulated in the 17th BImSchV could not be reached.

The system was thus replaced by a closed combustion chamber (resistant to pressure surges, water-cooled and lined steel vessel). After combustion in this chamber, the flue gas is shock cooled from 1200°C to 85°C (acidic gas washing) and then routed through an alkaline washer. In a next step, the exhaust gas temperature is raised to 170°C to obtain optimum treatment conditions in a subsequently passed dry sorption stage. The purified gas is discharged via the chimney for regular operation and monitored at the measuring point of the authorities.

An extensive testing campaign was carried out with this new combustion chamber system in July and August 2001 at typical waste treatment operation conditions both with raw and purified synthesis gas. Measurements conducted under the surveillance of the responsible authority proved that the emission values entirely fulfill the requirements and remain below the limits stipulated in the permit (Table 6). Acceptance of the combustion chamber emission levels was certified by the Regierungspräsidium Karlsruhe on August 28th, 2001.

7 Thermoselect Plants and Projects

Fondotoce, Italy.

Plant Capacity: Single line, 32000 t/a
Operation: Demonstration plant in operation from 1992 to 1998
Synthesis gas utilisation: Gas motor power generation

Karlsruhe, Germany.

Plant Capacity: 3 lines, 225 000 t/a
Operation: 1999
Synthesis gas utilisation: Steam turbine power and district heating

Chiba, Japan, Kawasaki Steel licensee.

Plant Capacity: Two lines, 100000 t/a (MSW and industrial wastes)
Operation: September 1999
Synthesis gas utilisation: As fuel in Chiba Works

Ansbach, Germany.

Plant Capacity: One line, 75000 t/a
Operation: Under construction, Startup in 2002
Synthesis gas utilisation: Gas motor power generation

Hanau, Germany.

Plant Capacity: Two lines, 90000 t/a
Operation: Permit granted February 2000. startup 2004.
Synthesis gas utilisation: Steam turbine power generation

Giubiasco, Switzerland.

Plant Capacity: Two lines, 150000 t/a
Operation: Concession Arbitration Procedure pending, startup in 2003.
Synthesis gas utilisation: Steam turbine power generation

Herten, Germany.

Plant Capacity: Three lines, 225000 t/a
Operation: Permit request phase, startup 2004.
Synthesis gas utilisation: Steam turbine power generation

Mitsubishi Materials Mutsu, Japan - Kawasaki Steel sub-licensee

Plant Capacity: Two lines, 50000 t/a
Operation: Firm Order received
Synthesis gas utilisation: Gas motor power generation

Other licensees: Daewoo, South Korea

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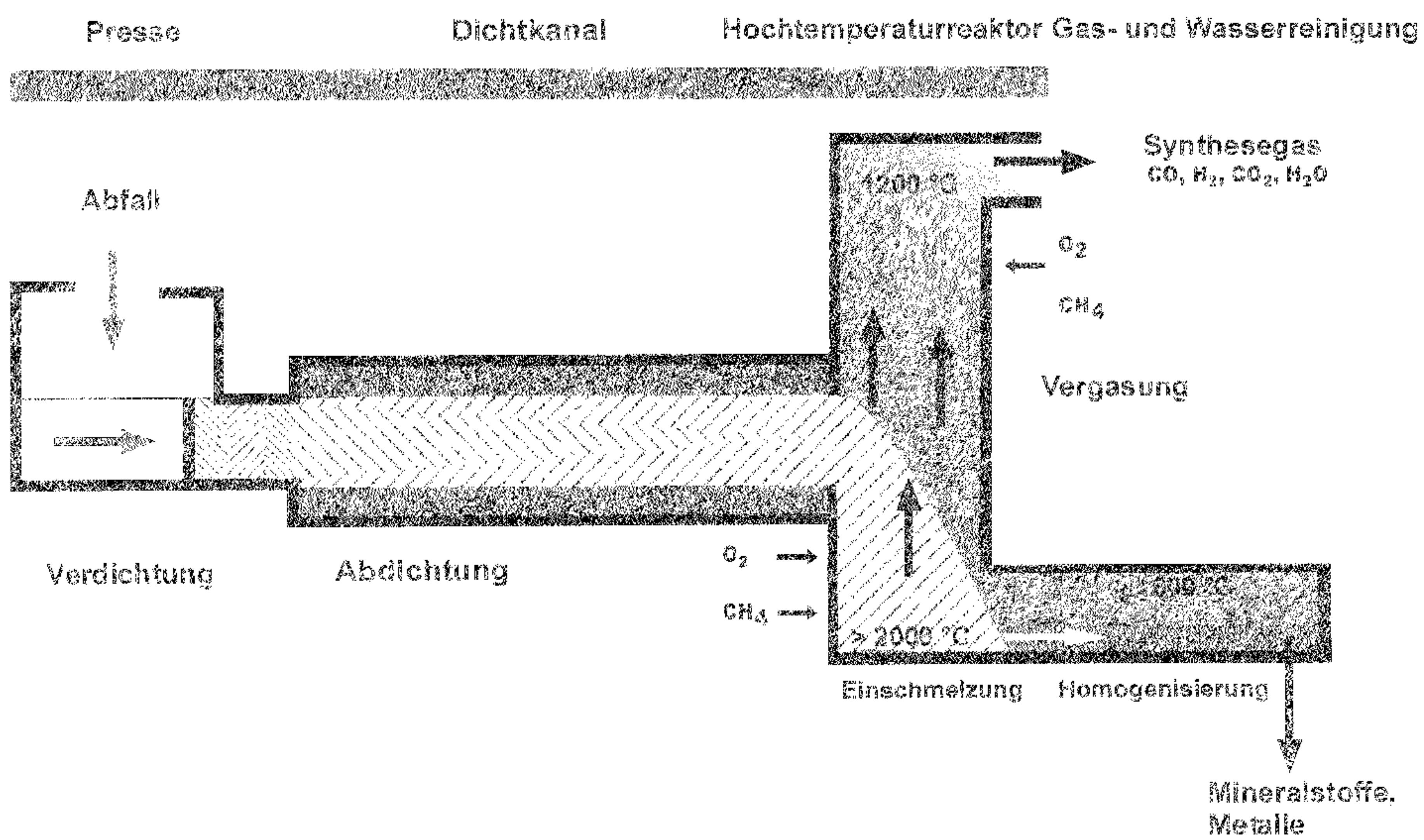
Annex B Description of Karlsruhe Facility



Hauptkomponenten der thermischen Behandlung

Thermoselect Südwest

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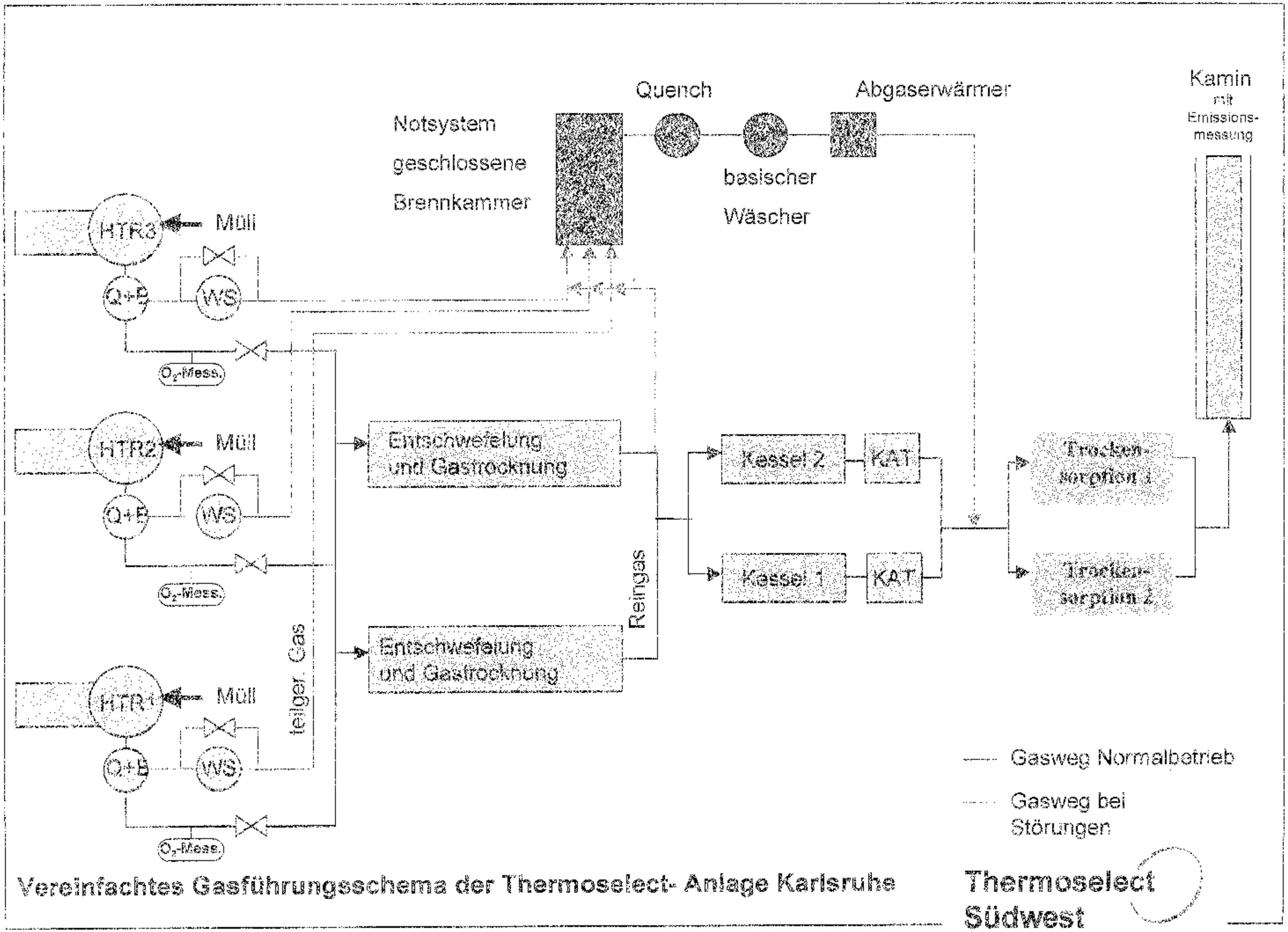


Vereinfachtes Gasführungsschema der Thermoselect- Anlage Karlsruhe

Karlsruhe: Original design 1999

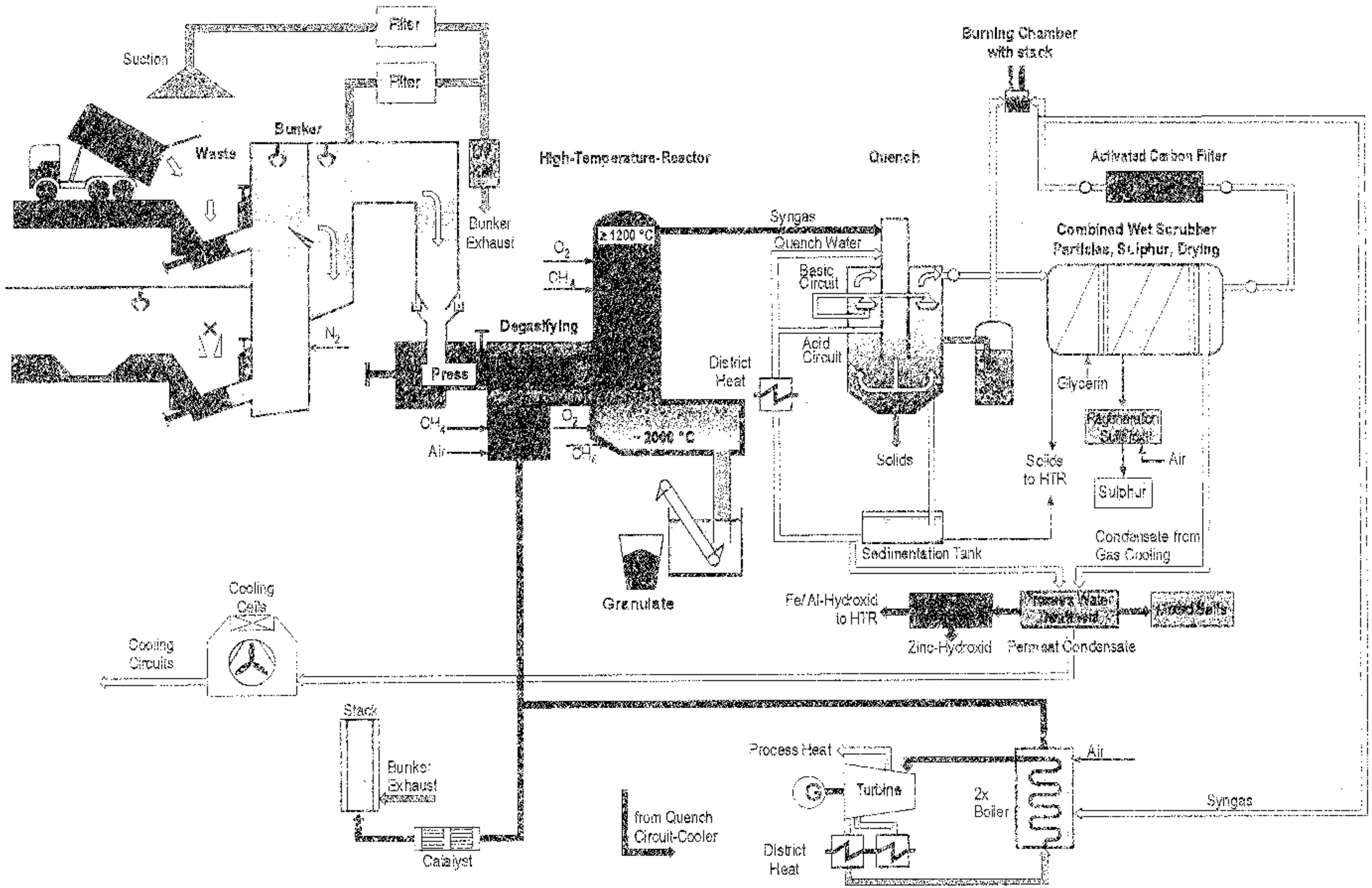
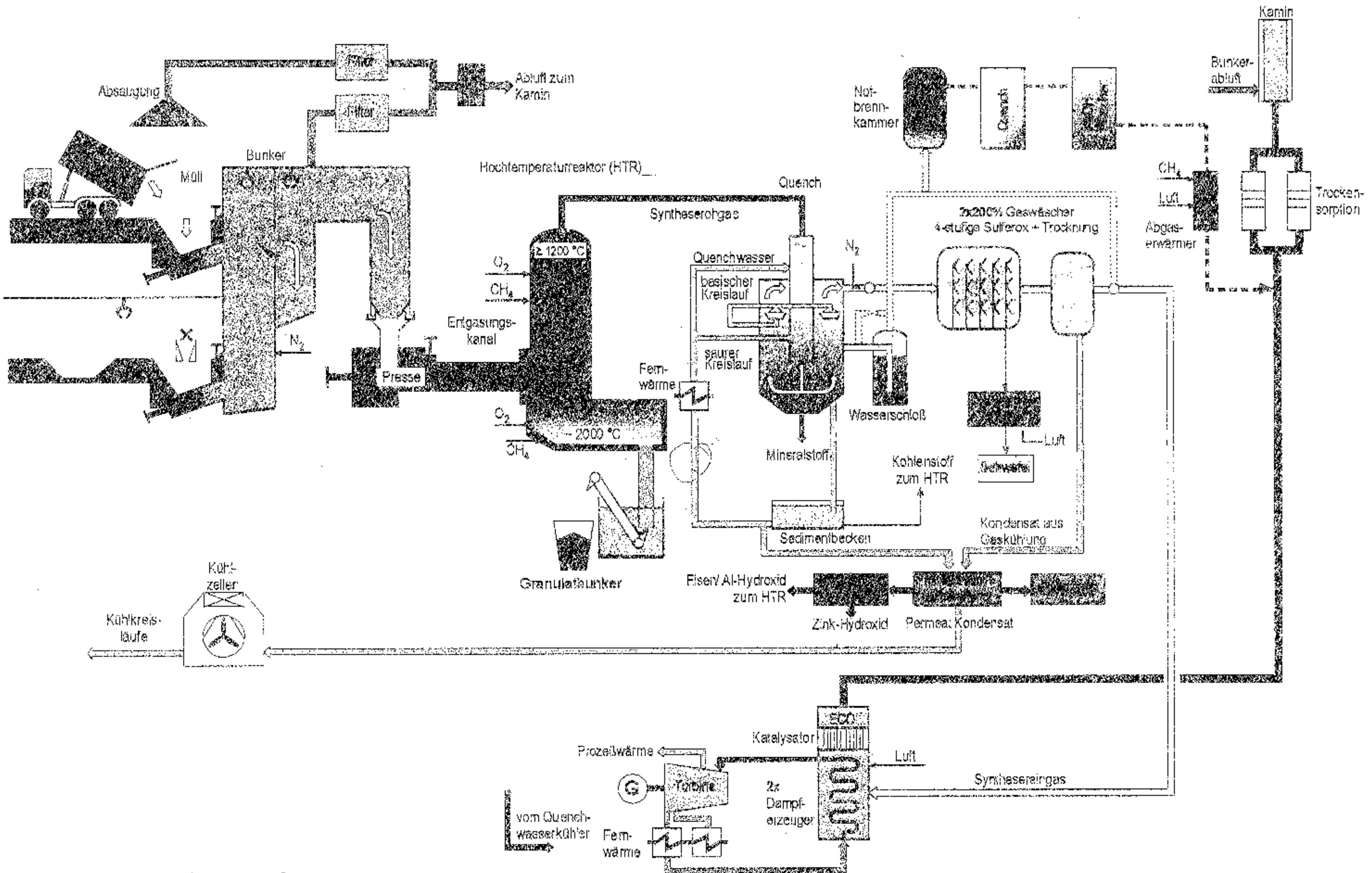


Figure 8: Process Flow Sheet

Thermoselect Südwest

99033.cdr TESS/InG/Wi 26.05.99

Karlsruhe: Situation January 2002



TSAK Funktionsschema

Thermoselect Südwest

G:\Ebert\THERMOSELECT\99033_geschl_BK.cdr (EBE/SZA,30.11.00)

Annex C Availability of Karlsruhe Facility

/usr/GRF/S2/1/REPORT_D_1 16:35 25-1-02

Alarm

PRESSE 1 : TAGES REPORT

DATE: 25 Jan 2002

TIME: 16:35

0-1 =	[illegible]	8-9 =	[illegible]	16-17 =	[illegible]
1-2 =	[illegible]	9-10 =	[illegible]	17-18 =	[illegible]
2-3 =	[illegible]	10-11 =	[illegible]	18-19 =	[illegible]
3-4 =	[illegible]	11-12 =	[illegible]	19-20 =	[illegible]
4-5 =	[illegible]	12-13 =	[illegible]	20-21 =	[illegible]
5-6 =	[illegible]	13-14 =	[illegible]	21-22 =	[illegible]
6-7 =	[illegible]	14-15 =	[illegible]	22-23 =	[illegible]
7-8 =	[illegible]	15-16 =	[illegible]	23-24 =	[illegible]

PRINT

[/usr/GKF/S2/2/REPORT_M_2] 16:34 25-1-02

Alarm

PRESSE 2 : MONATS.REPORT

DATE: 25 Jan 2002
TIME: 16:35

1 =	[illegible]	9 =	[illegible]	17 =	[illegible]	25 =	[illegible]
2 =	[illegible]	10 =	[illegible]	18 =	[illegible]	26 =	[illegible]
3 =	[illegible]	11 =	[illegible]	19 =	[illegible]	27 =	[illegible]
4 =	[illegible]	12 =	[illegible]	20 =	[illegible]	28 =	[illegible]
5 =	[illegible]	13 =	[illegible]	21 =	[illegible]	29 =	[illegible]
6 =	[illegible]	14 =	[illegible]	22 =	[illegible]	30 =	[illegible]
7 =	[illegible]	15 =	[illegible]	23 =	[illegible]	31 =	[illegible]
8 =	[illegible]	16 =	[illegible]	24 =	[illegible]		

PRINT

[/usr/GRF/S2/3/REPORT_M_31 15:15 25-1-02

Alarm

PRESSE 3 : MONATS REPORT

DATE: 25 Jan 2002
TIME: 15:15

1 =	[illegible]	9 =	[illegible]	17 =	[illegible]	25 =	[illegible]
2 =	[illegible]	10 =	[illegible]	18 =	[illegible]	26 =	[illegible]
3 =	[illegible]	11 =	[illegible]	19 =	[illegible]	27 =	[illegible]
4 =	[illegible]	12 =	[illegible]	20 =	[illegible]	28 =	[illegible]
5 =	[illegible]	13 =	[illegible]	21 =	[illegible]	29 =	[illegible]
6 =	[illegible]	14 =	[illegible]	22 =	[illegible]	30 =	[illegible]
7 =	[illegible]	15 =	[illegible]	23 =	[illegible]	31 =	[illegible]
8 =	[illegible]	16 =	[illegible]	24 =	[illegible]		

PRINT

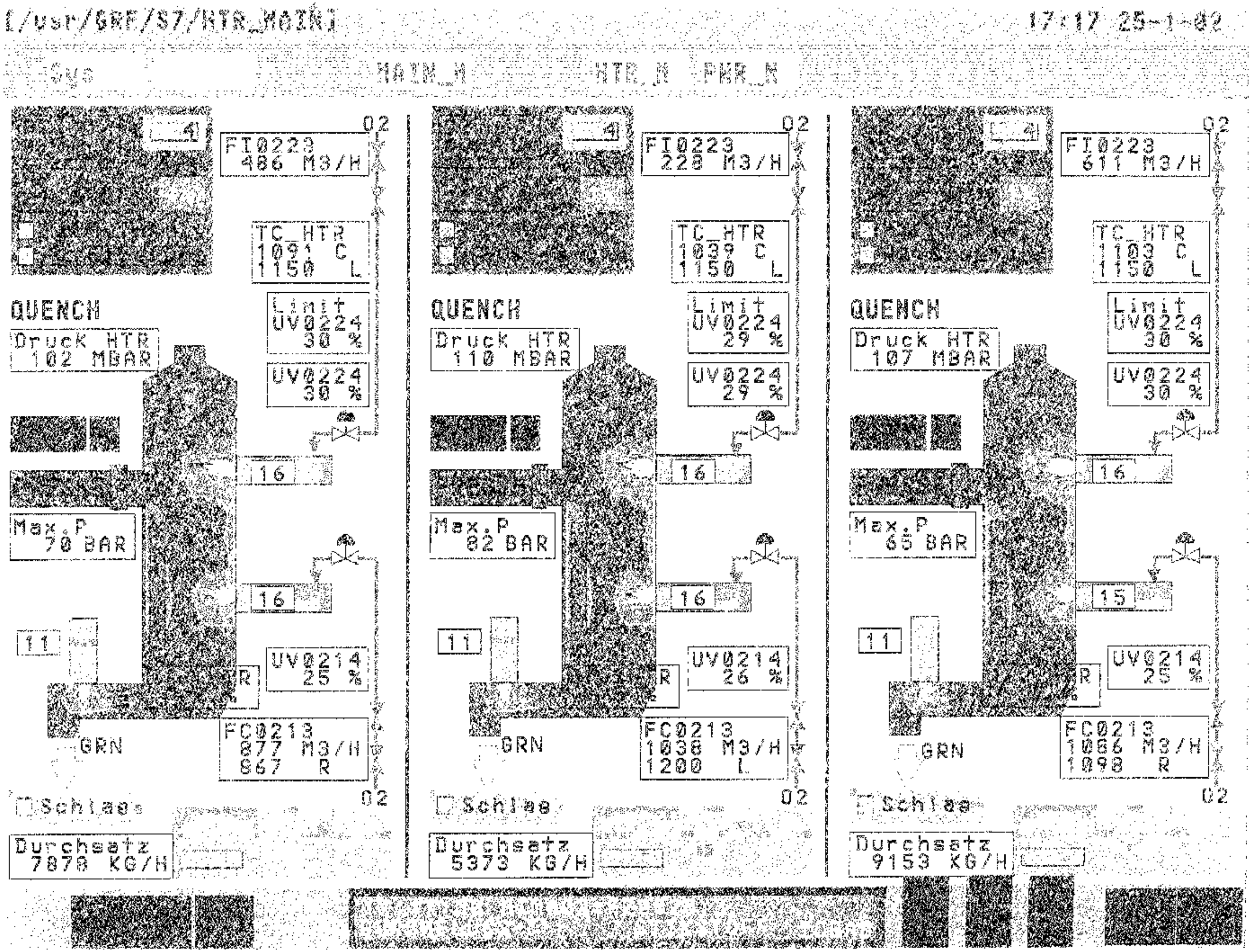
PRESSE 3 TAGES REPORT

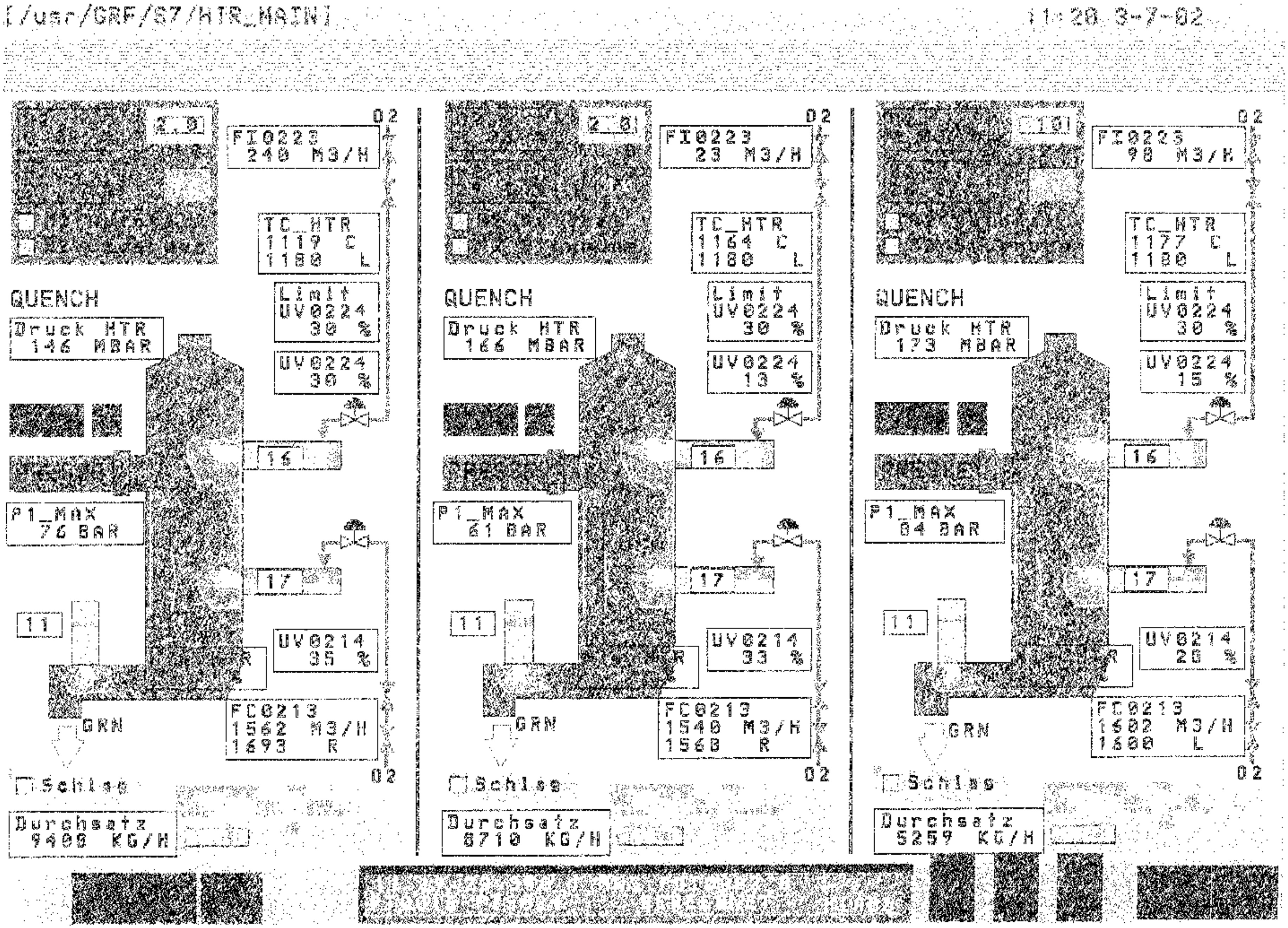
3 Jul 2002
11:21

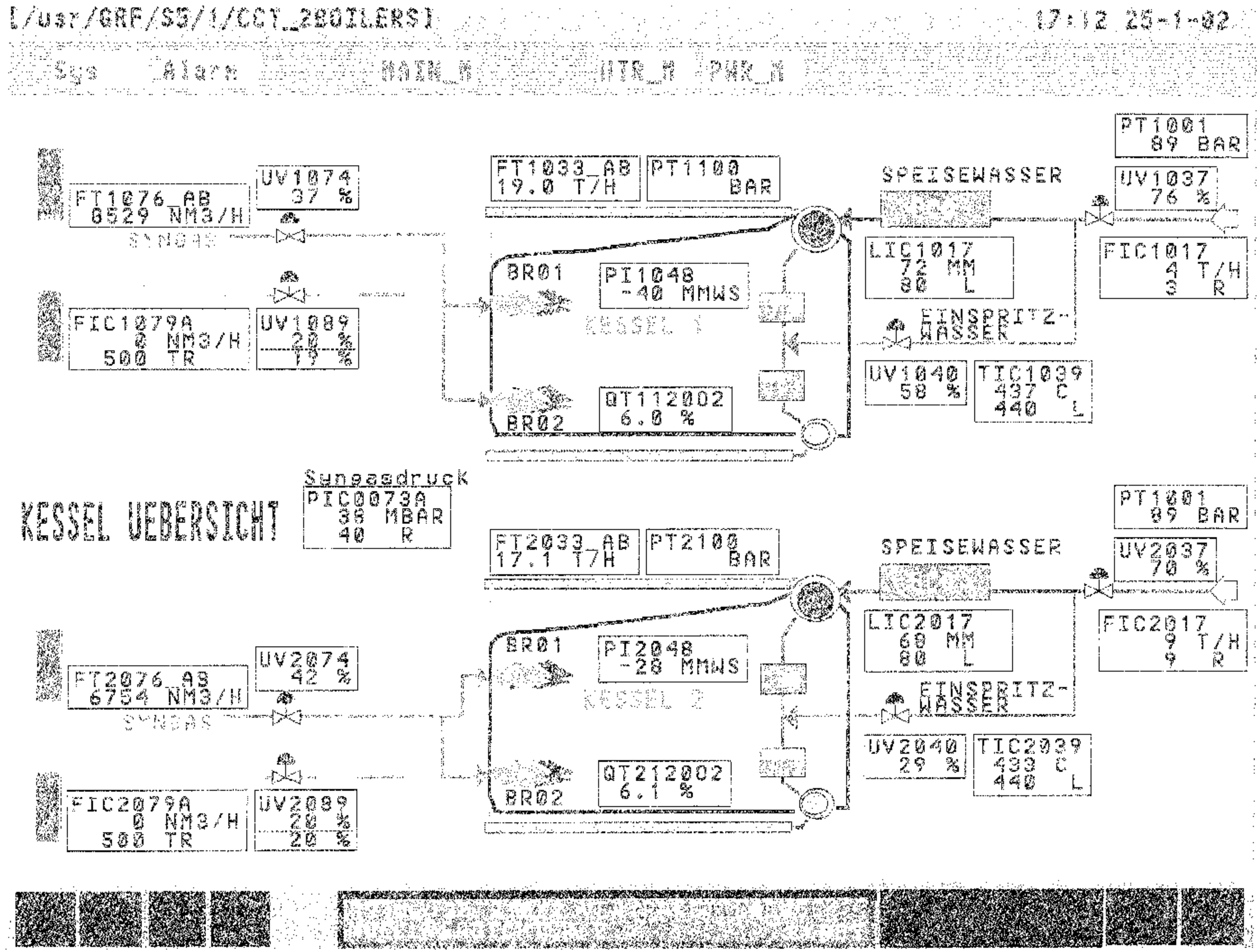
[illegible]	8344	11	[illegible]	9017	14	[illegible]	0	0
[illegible]	2687	13	[illegible]	9201	14	[illegible]	0	0
[illegible]	10212	13	[illegible]	6377	9	[illegible]	0	0
[illegible]	9189	14	[illegible]	3031	5	[illegible]	0	0
[illegible]	9191	13	[illegible]	0	0	[illegible]	0	0
[illegible]	9720	13	[illegible]	0	0	[illegible]	0	0
[illegible]	9250	13	[illegible]	0	0	[illegible]	0	0
[illegible]	10384	14	[illegible]	0	0	[illegible]	0	0

[illegible] 102504

Annex D Control Room Print-outs During Author's Visit

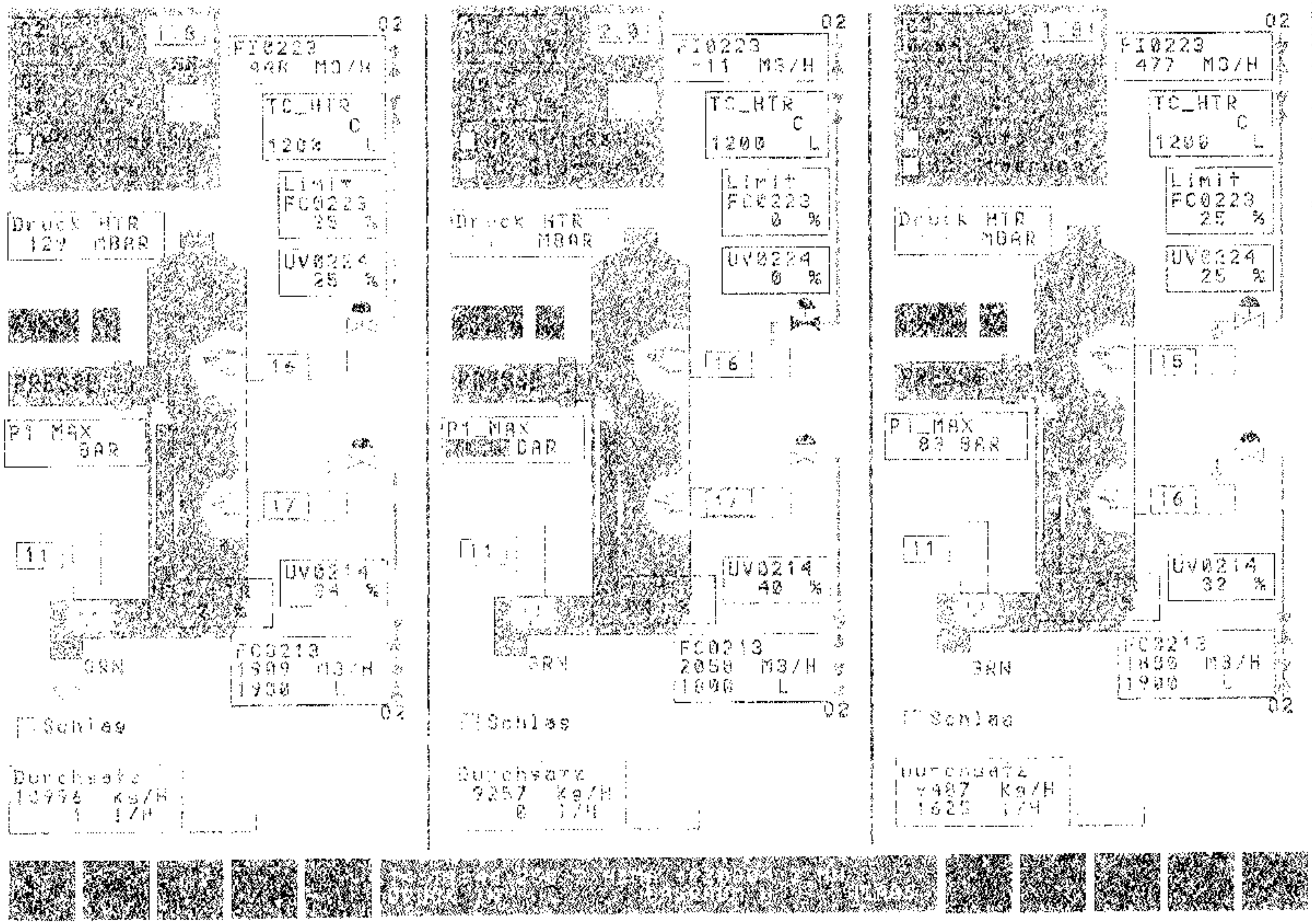

[/usr/GRF/S7/HTR_MAIN]
17:17 25-1-02
Sys
MAIN_M
HTR_M
PKR_M
4
FI0223
486 M3/H
02
TC_HTR
1091 C
1150 L
QUENCH
Limit
UV0224
30 %
Druck HTR
102 MBAR
UV0224
30 %
16
Max.P
70 BAR
16
11
UV0214
25 %
R
FC0213
877 M3/H
867 R
GRN
Schlae
02
Durchsatz
7878 KG/H
4
FI0223
228 M3/H
02
TC_HTR
1039 C
1150 L
QUENCH
Limit
UV0224
29 %
Druck HTR
110 MBAR
UV0224
29 %
16
Max.P
82 BAR
16
11
UV0214
26 %
R
FC0213
1038 M3/H
1200 L
GRN
Schlae
02
Durchsatz
5373 KG/H
4
FI0223
611 M3/H
02
TC_HTR
1103 C
1150 L
QUENCH
Limit
UV0224
30 %
Druck HTR
107 MBAR
UV0224
30 %
16
Max.P
65 BAR
15
11
UV0214
25 %
R
FC0213
1086 M3/H
1098 R
GRN
Schlae
02
Durchsatz
9153 KG/H


[/usr/GRF/S7/HTR_MAIN]
11:20 3-7-02
2.9
FI0223 240 M3/H
O2
TC_HTR 1119 C 1180 L
QUENCH
Limit UV0224 30 %
Druck HTR 146 MBAR
UV0224 30 %
16
P1_MAX 76 BAR
17
11
UV0214 35 %
FC0213 1562 M3/H 1693 R
GRN
Schlss
Durchsatz 9400 KG/H
2.8
FI0223 23 M3/H
O2
TC_HTR 1164 C 1180 L
QUENCH
Limit UV0224 30 %
Druck HTR 166 MBAR
UV0224 13 %
16
P1_MAX 61 BAR
17
11
UV0214 33 %
FC0213 1540 M3/H 1560 R
GRN
Schlss
Durchsatz 6710 KG/H
10
FI0223 98 M3/H
O2
TC_HTR 1177 C 1180 L
QUENCH
Limit UV0224 30 %
Druck HTR 173 MBAR
UV0224 15 %
16
P1_MAX 64 BAR
17
11
UV0214 20 %
FC0213 1602 M3/H 1600 L
GRN
Schlss
Durchsatz 5259 KG/H


[/usr/GRF/S5/1/CCT_2BOILERS]
17:12 25-1-02
Sys
Alarm
MAIN_M
HTR_M
PWR_M
KESSEL UEBERSICHT
FT1076_AB 6529 NM3/H
UV1074 37 %
SYNGAS
FIC1079A 0 NM3/H 500 TR
UV1089 20 % 19 %
FT1033_AB 19.0 T/H
PT1100 BAR
BR01
PI1048 -40 MMWS
KESSEL 1
BR02
QT112002 6.0 %
SPEISEWASSER
LIC1017 72 MM 80 L
EINSPRITZ-WASSER
UV1040 58 %
TIC1039 437 C 440 L
PT1001 89 BAR
UV1037 76 %
FIC1017 4 T/H 3 R
Syngasdruck
PIC0073A 38 MBAR 40 R
FT2076_AB 6754 NM3/H
UV2074 42 %
SYNGAS
FIC2079A 0 NM3/H 500 TR
UV2089 20 % 20 %
FT2033_AB 17.1 T/H
PT2100 BAR
BR01
PI2048 -28 MMWS
KESSEL 2
BR02
QT212002 6.1 %
SPEISEWASSER
LIC2017 60 MM 80 L
EINSPRITZ-WASSER
UV2040 29 %
TIC2039 433 C 440 L
PT1001 89 BAR
UV2037 70 %
FIC2017 9 T/H 9 R

[/opt/fsck/grf/s2/HTR_MAIN]

14:17 22-11-02



Annex E Karlsruhe TS Plant Emission Data

Latest emission data:
www.thermoselect-karlsruhe.de

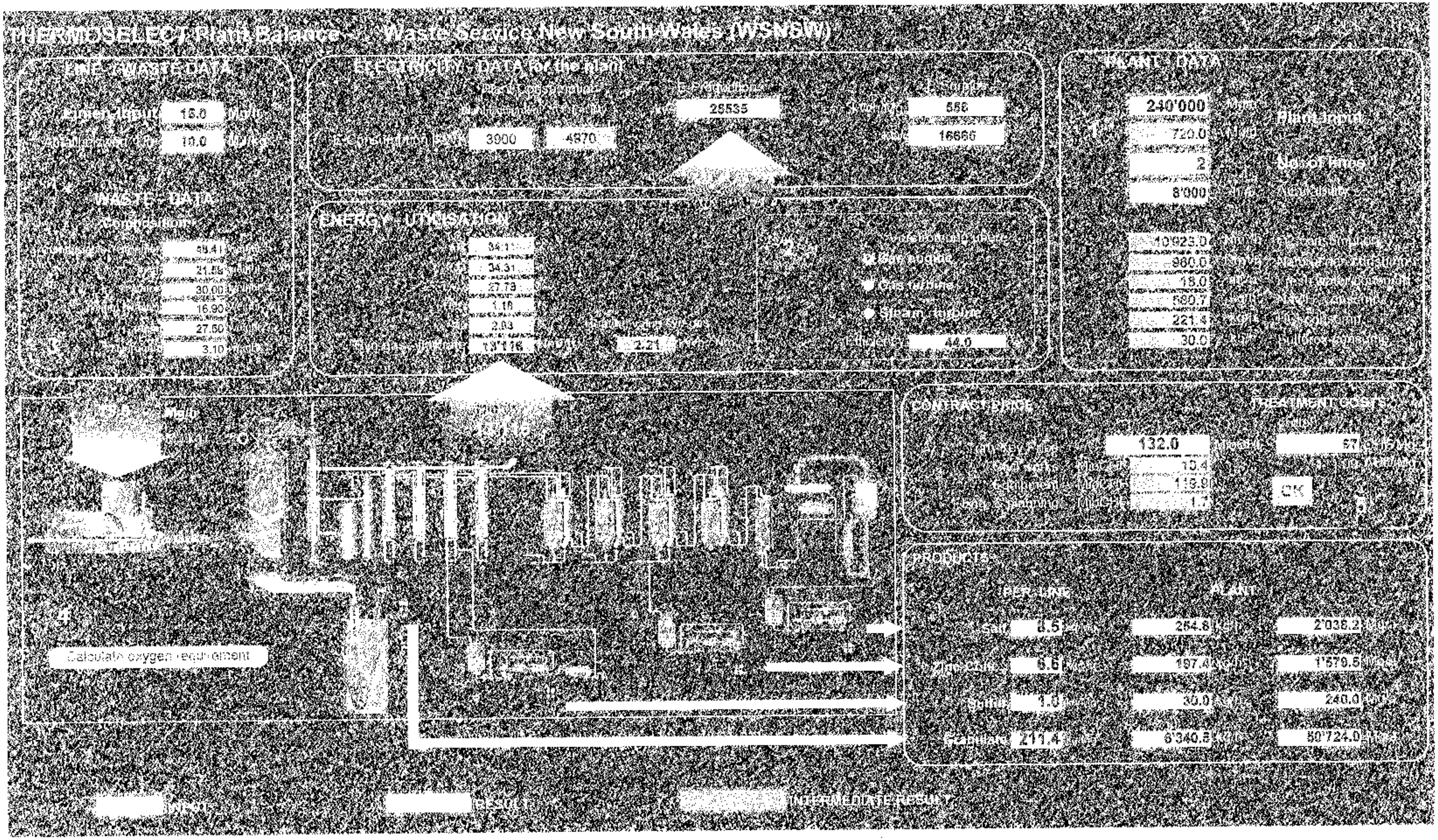
	Normalbetrieb, 99,4 % der Jahresbetriebszeit (Tagesmittelwerte der kont. Überwachung)			[illegible]				
	17. BImSchV	genehmigt 1996		genehmigt 1996 für max. 50 h/a	genehmigt 2001 für max. 46 h/Jahr TeilG		genehmigt 2001 unbegrenzt ReinG	
Emissionsquelle	Normalbetriebskamin	Normalbetriebskamin mit 50 m Höhe		Fackel mit 23 m Höhe, einmalige Messungen	Brennkammer mit Abgasreinigung über Normalbetriebskamin mit 50 m Höhe			
Schadstoff	Konzentration in mg/m³							
Staub	10	**3**	0,6	**10**	**10**	1,1	**10**	1
Schwefeldioxid	50	**10**	0,91	**50**	**50**	< 0,2	**50**	2,3
Stickoxide	200	**70**	52,2	**400**	**400**	46,5	**150**	58,8
Kohlenmonoxid	50	**10**	3,8	**200**	**200**	23,5	**100**	33
Chlorwasserstoff	10	**2**	0,2	**10**	**10**	< 0,4	**10**	< 0,4
Fluorwasserstoff	1	**0,2**	0,003	**1**	**1**	< 0,1	**1**	< 0,1
Quecksilber	0,03	**0,01**	0,007	**0,05**	**0,05**	0,02	**0,05**	0,018
Org. Stoffe	10	**2**	0,68	**10**	**10**	3,1	**10**	6,6
Cadmium/Thallium	0,05	**0,01**	0,0005	**0,05**	**0,05**	0,004	**0,01**	0,003
Schwermetalle	0,5	**0,03**	0,013	**0,05**	**0,05**	0,037	**0,03**	0,005
Dioxine/Furane	0,1 ng/m³	**0,01 ng/m³**	0,0025 ng/m³	**0,1 ng/m³**	**0,1 ng/m³**	0,008 ng/m³	**0,01 ng/m³**	0,005 ng/m³

Messwerte Messwerte

TSAK
Thermoselect Südwest

Genehmigte und gemessene Emissionswerte der Thermoselect-Anlage Karlsruhe

Annex F Calculation of Future ThermoSelect Plant


THERMOSELECT Plant Balance - Waste Service New South Wales (WSNSW)
LINE - WASTE DATA
18.0
10.0
WASTE - DATA
Composition
55.41
21.55
30.00
16.90
27.60
3.10
ELECTRICITY - DATA for the plant
3900
4970
25535
556
16666
ENERGY - UTILISATION
34.11
34.31
27.73
1.18
2.03
13'116
2.21
Gas engine
Gas turbine
Steam engine
44.0
PLANT - DATA
240'000
720.0
2
8'000
Plant input
No. of lines
10'923.0
960.0
18.0
580.7
221.3
30.0
CONTRACT PRICE
TREATMENT COSTS
132.0
13.4
118.90
1.7
57
OK
PRODUCTS
PER LINE
PLANT
Salt
8.5
254.8
2'038.2
Zinc Conc.
6.6
197.4
1'579.5
Sulfur
1.0
30.0
240.0
Granulate
211.4
6'340.5
50'724.0
Calculate oxygen requirement
INPUT
RESULT
INTERMEDIATE RESULT