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TNO-report

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Case Study RCP Bremerhaven Facility

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Note

TNO-MEP, the Netherlands, performed this study for the IEA Bioenergy Task 36 Working group ‘Energy from Integrated Solid Waste Management Systems’.

The study was executed with use of public information and knowledge available to TNO-MEP, partly supplied by VonRoll Inova.
Results are based on the typical local situation in the Bremerhaven 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 in question and financial aspects of waste treatment than a similar study elsewhere might.

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1. Background

This study was performed by TNO-MEP, the Netherlands, for the IEA Bioenergy Task 36 Working group “Energy from Integrated Solid Waste Management Systems". The Dutch authorities through NOVEM and the Dutch Waste Management Association (VVAV) sponsored the activities.

The study is based on public information and knowledge available to TNO-MEP and the information contributed by Von Roll Inova during a plant visit.

The goal of the project is to produce a document on advanced technologies to help decision-makers in the choice of future systems.
Important considerations are:
– Risks and organizational structure;
– Reliability of technology (Proven Technology);
– Environmental impact;
– Financial aspects.

The selection of the Bremerhaven RCP facility is a part of a wider project comprising several case studies conducted by the IEA working group. Other facilities [1] selected for case studies were:
– Robbins in Chicago, Illinois, USA [2]
– Tirmadrid in Madrid, Spain [3]
– LDHP in Lidköping, Sweden
– DER in Dundee, Great Britain
– Toshima incineration facility in Tokyo, Japan
– ThermoSelect in Karlsruhe, Germany [4]
– Valene, Mantes la Jolie, France [5]

1.1 The monitoring programme

After receiving permission from the plant management of Von Roll Inova and Bremerhaven RCP facility and signing a proprietary agreement, a visit to the plant was arranged.
During the visit (June 2000), the operation of the plant was observed, data were gathered and discussions with the plant managers took place. Also the control room was visited, providing insight in online data. Print-outs of the process are presented in Annex C. The compiled reports and information were evaluated. In January 2002 information on operational experiences was studied.

The waste recycling facility of Bremerhaven was subjected to the following monitoring activities:
– Checking of process operation;

- Study of process technology;
- Study of process data in the control room;
- Gathering and evaluation of process information;
- Discussions about the gathered information with:
  - Dr. Sc. Marc Stammbach; RCP marketing, Von Roll Inova
  - Dipl.Masch.Ing.ETH Erwin Wachter; R+D, Von Roll Inova
  - B.Sc. Hans Wüthrich, plant manager RCP, Von Roll Inova
  - Control room employees
  - Ing. Kaletka, plant manager BEG

These activities resulted in:
- General information on the Bremerhaven plant: Organizational structure, history, general plant characteristics, and a specification of typical waste composition.
- Impression of the process technology: Material recovery / production of clean products and steam.
- Insight into the environmental impact of such a process: stack emissions, leaching analyses of molten bottom-ash and filter ash.
- Some insight into the financial aspects of operating such a plant.

Finally, the information was classified, evaluated, and reported.

1.2 Organizational structure of Bremerhaven RCP facility

In September 1995, the Bremerhaven Entsorgungsgesellshaft (BEG = Bremerhaven Waste Disposal Company) and VonRoll Environmental Technology Ltd signed a contract for the construction of an RCP plant.
This plant, designed with a capacity of 6 Mg per hour, was integrated into the existing municipal waste incinerator plant (3 lines, 15Mg/h per line) of BEG.

The complete waste recovery facility will be owned by BEG and is situated in Bremerhaven. VonRoll Inova ran the facility during a test period from 1996 till June 2001.

1.3 History and operational experience

In September 1995 the contract was signed.
In March 1996 the foundation was laid and the construction of the facility was started.
In March 1997 the first phase of signal testing and cold start-up began.
In August 1997 hot slag flowed for the first time and the first RCP melt pellets were produced.

Up to June 2001, the waste throughput of the first RCP system was smaller than originally expected. Various problems prevented the quick assumption of normal industrial operation. In particular, the delays were caused by:
- Installing a stronger auxiliary burner and retrofitting the throats to the CFB (1997-1998);
- Optimisation of the waste heat boiler (1999);
- Smelting furnace: Retrofit for a larger cooling efficiency (1998) and for a water-film cooling system (beginning 2000);
- Smelting furnace: Installation of a special interior cooling system at exposed system junctions (December 2000).

1.4 Design Characteristics

The RCP process is an advanced thermal waste treatment process, which should maximize the production of reusable products. The RCP process was developed in Bremerhaven to demonstrate the technology for other future markets and countries, where melting of bottom-ash is legally obliged (Japan).
In Bremerhaven the plant has been integrated into an existing MSWI plant. The plant was designed as a commercial operating plant, but is still in an experimental phase to demonstrate the technology. After a 90-day demonstration period, which ended in June 2001, the operational activities with the RCP process were stopped. The plant is now being adapted for commercial operation to BEG. For further information, please see 5.4.

In short, the BEG Bremerhaven RCP facility takes its MSW through the following steps:
- Pyrolysis chamber with grate
- Smelting furnace / Reduction furnace
- Circulating fluidised bed boiler (CFB)
- Air Pollution Control (APC)

In Table 1.1, the design characteristics of the Bremerhaven RCP facility are presented.

Table 1.1 Bremerhaven RCP design characteristics

	Demonstrated*)	Design
Total MSW throughput [Mg/h]	5.5	6.0
Flue gases to APC [Nm^3w/h]	15,900	12,600
Steam production [Mg/h]	16.3	20.1

*) Highest daily throughput averaged 120 Mg/day= 5 Mg/h

1.5 Typical MSW Composition

During the demonstration period, typical Bremerhaven MSW was treated in this plant. During several test periods, 400 tonnes of car shredder dust were tested as well. Figure 1.5 shows the range of lower heating values (LHV) for the typical Bremerhaven MSW. No further analyses of the Bremerhaven waste were available.

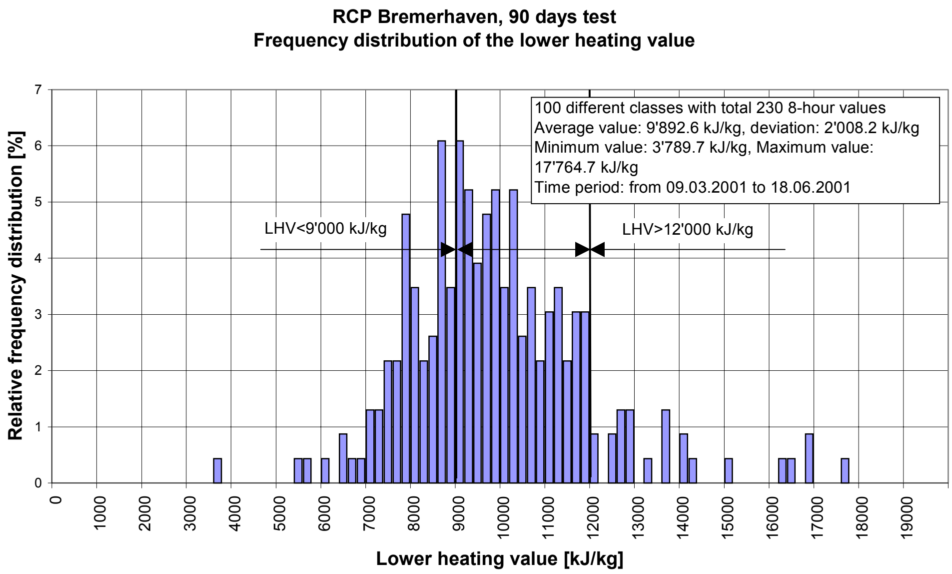

Figure 1.5 Distribution of LHV's during the 90-day test period

2. Process Technology

2.1 General

The Von Roll RCP process is a new thermal process for waste treatment, consisting basically of four steps:

1. Pyrolysis of waste
2. Smelting furnace / reduction furnace
3. Incineration with heat recovery in a CFB
4. Air pollution control

A diagram of the process is presented in Figure 2.1.

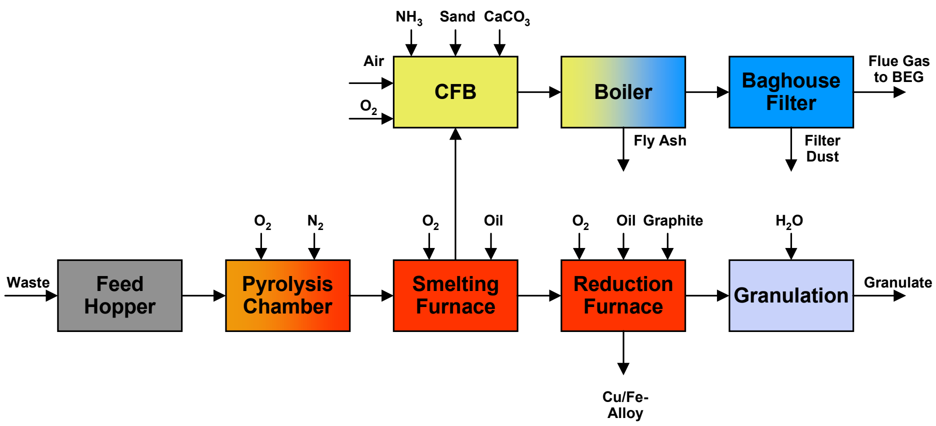

Figure 2.1 Diagram of the RCP process Bremerhaven

The plant has been integrated into the existing BEG incinerator plant (3 lines, 15Mg/h per line). See Figure 2.2.

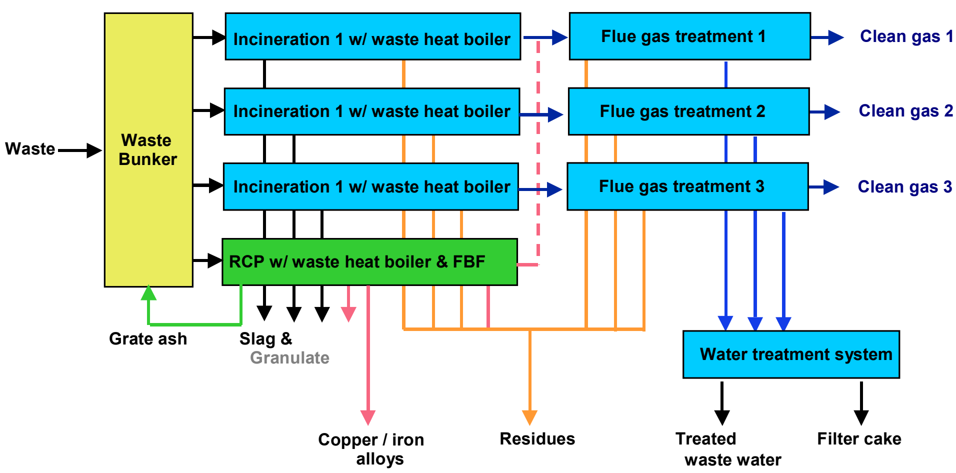

Figure 2.2 Integration of the RCP plant into the existing MSWI of REB

The integration with the flue gas treatment and the steam system of the existing MSW plant, influences the process conditions to be controlled. This means that the process conditions of the RCP are sometimes restricted depending on the process conditions of the existing waste incinerators.

The technology is described in Annex A.

2.2 RCP Process

A diagram of the RCP process is presented in Figure 2.3.

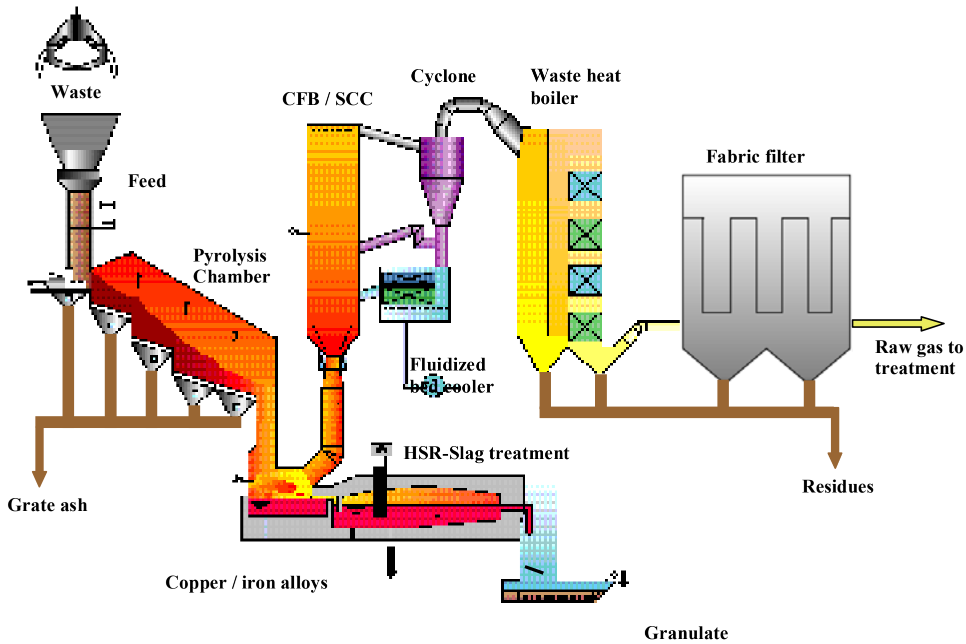

Figure 2.3 RCP process in Bremerhaven, Germany

2.2.1 Pyrolysis chamber

Pre-treatment of the waste is not required before feeding the waste into the pyrolysis chamber. The heat in the chamber dries the waste and then transforms it into pyrolysis gases and coke. The radiant energy needed for this process is released by the partial incineration of the pyrolysis gases with oxygen.

2.2.2 Smelting furnace

In the smelting furnace, the pyrolysis gases are further oxidized and the mineral and metallic components of the waste are melted together with the pyrolysis coke using oxygen.
The tangential injection of the oxygen gives an angular momentum to the slag bath, thus setting the bath into rotation. The resulting turbulence causes the combustible materials and oxygen to be evenly distributed and mixed so that all carbons are completely incinerated. Co-currently, the inert portion of the pyrolysis coke is smelted. Local temperatures are above 1400°C. Even inert particles with very high melting points are bound and smelted in this heterogeneous bottom-ash system.

2.2.3 Reduction furnace

Heavy metals are separated from the liquid slag in the integrated slag treatment system. Highly volatile heavy metals (zinc, cadmium, lead) convert to their gaseous phase. Copper and iron are separated from the slag bath to be used in the metal industry. The stripped slag is granulated and can be used as aggregate by the cement industry.

2.2.4 Circulating fluidized bed / Secondary combustion chamber / Waste heat boiler

The hot flue gases exit the smelting furnace and enter the circulating fluidized bed. Here they come into contact with a large amount of cooled sand, by which they are shock-cooled to below 1000°C. Oxygen is added in the upper part of the secondary combustion chamber so that the flue gases burn out completely. The flue gases then flow through a cyclone to the steam boiler.

The sand that is carried along with the flue gases serves as a heat transfer medium and is removed again in the cyclone. The heat transfer to the steam boiler takes place in the fluidized bed cooler (FBC). Thus, the sand serves as an intermediate heat transfer medium and facilitates the separation of the steam generation surfaces (boiler pipes) and the corrosive flue gases. The heat transfer characteristics of the gas/sand mixture are better than those of conventional systems. This can result in higher boiler efficiency, if superior steam conditions are reached (> 400 °C, > 40 Bar), and in a compact design.

2.2.5 Fabric bag filter

The flue gases exit the boiler at approximately 200°C. The fly-ash is filtered out in the fabric filter. From there, the fly-ash is transported to the existing residues treatment system of BEG and afterwards disposed of in a special landfill.

2.3 Material Recovery

Because of the experimental nature of the Bremerhaven facility, material recovery has not taken place. The molten bottom-ash (granulate) is mixed together with the bottom-ash of the other three existing MSWIs and recovered after treatment in road constructions. The same happens with residues like fly-ash and filter cake because the flue gases are mixed with the flue gases of the other three existing MSWIs.

The residues of the flue gas treatment system are disposed of in the usual way, depending on local directives.

2.4 Energy Generation

The Bremerhaven RCP process delivers steam (400°C, 40 Bar) to the existing steam system of BEG.

3. Process and Environmental Performance

The process performance is characterized by input and output materials per Mg or % of MSW input. The environmental performance is expressed in quantity and quality of recovered products, stack emissions and process residues.
The data presented in this chapter are mainly based on data processed during a 90-day test in 2001, which was set up to demonstrate the performance to Hitachi Zosen.

3.1 Typical Quantities of the Bremerhaven RCP Process

In Table 3.1, the RCP process is characterized on the basis of 4 Mg/h of capacity. The figures are an update of those drawn from the 90-day test and are representative for a medium LHV of waste (Annex C).

Table 3.1 Characteristics of RCP Bremerhaven

Parameter	Input [Mg/h]	Output [Mg/h]	[%] of MSW
MSW	4.000		100
Oxygen	4.274		107
Nitrogen	1.010		25
Combustion air	9.864		
Lime	0.080		2
Sand	0.080		2
Fuel	0.285		7
Electrodes (graphite)	0.025		0.6
Cu/Fe alloy		0.060	1.5
Bottom-ash (granulate)		1.200	30
Fly-ash		0.190	4.8
Flue-gas (wet)		18.168	nd

3.2 Typical Quality of the Bremerhaven RCP Process Streams

The quality of input materials such as nitrogen, oxygen, lime, sands and fuel are specified in Table 3.2.

Table 3.2 Quality of input materials

Parameter	
MSW	see Figure 1.5
Oxygen (liquid)	99 %
Nitrogen (liquid)	95 %
Lime	$CaCO_3$
Sand	∅ 250 µm
Fuel oil	Light Oil

Table 3.3 shows the emission levels measured after the RCP bag house filter during MSW periods.

Table 3.3 Emission levels flue gas downstream of RCP bag house filter

Parameter	Unit	Average Value	Minimum Value	Maximum Value
NO_x	mg/m^3 i.N. dry	256	65	460
SO_2	mg/m^3 i.N. dry	12.1	2.4	24.3
CO (Bypass)	mg/m^3 i.N. dry	<30		
HCl	mg/m^3 i.N. dry	526	101	1252
Dust	mg/m^3 i.N. dry	2.3	0.4	4.6
HF	mg/m^3 i.N. dry	1.9	1.0	3.1
Hg	$\mu g/m^3$ i.N. dry	111	19	202
TOC, organics	mg/m^3 i.N. dry	1.5	0.3	4.1
PCDF/PCDD [TE]	ng/m^3 i.N. dry	1.27	0.12	10.60

The figures of Table 3.3 are based on the measurements taken during the 90-day test period.
The emissions levels at the stack of the BEG-MSW plant are frequently measured by independent laboratories and checked by the government. The limits comply with the limits set in the 17^{th} BimSchV.

The composition of the granulate and fly-ash are presented in Table 3.4.

Table 3.4 Analyses of granulate and fly-ash of MSW

Parameter	Unit	Granulate (1)	Fly-ash (1)
SiO_2	% (w/w, TS)	53.9	45.2
CaO	% (w/w, TS)	14.0	22.9
Al_2O_3	% (w/w, TS)	9.9	0.65
Cl	% (w/w, TS)	0.08	5.5
Fe_2O_3	% (w/w, TS)	13.6	0.73
MgO	% (w/w, TS)	<4	0.49
Zn	% (w/w, TS)	0.14	1.76
P_2O_5	% (w/w, TS)	0.86	<0.01
K_2O	% (w/w, TS)	<1.5	0.97
Na_2O	% (w/w, TS)	<4	1.9
Pb	% (w/w, TS)	0.061	0.79
Cr	% (w/w, TS)	0.27	0.075
Cu	% (w/w, TS)	0.18	0.297
Ni	% (w/w, TS)	0.019	<0.005
TiO_2	% (w/w, TS)	0.78	0.14
Cd	% (w/w, TS)	<0.001	0.018
Hg	% (w/w, TS)	n.m.	<0.0014

(1) analysed during 90-day test

In Table 3.5 the results of the Swiss leaching tests are shown for the granulate out of the reduction furnace.

Table 3.5 Results of Swiss leaching tests of granulate(after HSR)

Parameter	Unit	Limit Value TVA	MSW Periods		
			Average Value	Minimum Value	Maximum Value
Al	mg/L	1	0.18	0.08	0.44
As	mg/L	0.01	< 0.005	< 0.005	< 0.005
Ba	mg/L	0.5	0.011	0.005	0.017
Cd	mg/L	0.01	< 0.001	< 0.001	< 0.001
Co	mg/L	0.05	< 0.002	< 0.002	< 0.002
Cr	mg/L	0.05	< 0.001	< 0.001	0.002
Cr(VI)	mg/L	0.01	< 0.002	< 0.002	< 0.002
Cu	mg/L	0.2	< 0.05	0.03	0.08
Cyanides	mg/L	0.01	< 0.002	< 0.002	< 0.002
Fluorides	mg/L	1	0.16	0.04	0.34
Hg	mg/L	0.005	< 0.005	< 0.005	< 0.005
Conductivity TVA 1	µS/cm (25°C)		40	34	48
Conductivity TVA 2	µS/cm (25°C)		10	2	33
NH_4	mg/L	0.5	< 0.04	< 0.04	< 0.04
Ni	mg/L	0.2	< 0.1	< 0.1	< 0.1
Nitrit	mg/L	0.1	< 0.02	< 0.02	<0.03
Pb	mg/L	0.1	0.029	0.018	0.038
pH		6-12	7.4	6.3	9.9
Phosphates	mg/L	1	< 0.22	0.06	0.47
Sn	mg/L	0.2	< 0.002	< 0.002	< 0.002
Sulphides	mg/L	0.01	< 0.01	< 0.01	< 0.01
Sulphites	mg/L	0.1	< 0.2	< 0.1	0.39
TOC	mg/L	20	< 2	1.5	< 2
Zn	mg/L	1	< 0.18	< 0.05	0.30

These results comply with the limits set by the Swiss Government for “Inertstoffe”.

In Table 3.6, the main components of the Cu/Fe alloy are specified.

Table 3.6 Specification of Cu/Fe alloy

Parameter	Unit	Average value
Cu	% (w/w)	10.1
Fe	% (w/w)	86.8
P	% (w/w)	2.74
Ni	% (w/w)	0.85

4. Evaluation

4.1 Mass and Energy Balances

VonRoll Inova presented a mass and energy balance, based on the optimised condition (during one day) in the 90-day test in 2001, as shown in Table 4.1.

Table 4.1. Mass and Energy Balance for Bremerhaven RCP facility

Parameter	Flow Mg/h	Heat content MW
In		
Waste (heat content)	5.512	13.334
Liquid oxygen	4.994	0
Liquid nitrogen	1.048	0
Air wet	10.271	0
Bed sand	0.080	0
Fuel	0.278	3.293
Boiler feed water	16.358	2.720
Total	*38.541*	*19.347*
Out		
Fluegas	20.533	1.458
Granulate +Cu/Fe alloy	1.350	0.574
Radiation	-	0.375
Fly-ash	0.300	0.020
Steam	16.358	14.375
Cooling systems	-	2.545
Total	*38.541*	*19.347*

Table 4.2 shows the results of calculations made on the basis of the data in the mass and energy balance in Table 4.1 (fuel oil input included).

Table 4.2 Thermal specifications of Bremerhaven RCP facility.

Thermal capacity	MW	16.627
Useful heat generated	MW	14.200
Net calorific value of MSW	MJ/kg	8.708
Thermal efficiency with cooling system	%	85
Boiler efficiency	%	70

4.2 Environmental Aspects

It is proven that the emission level to the air of the RCP process can be kept within the legal limits. This is mainly a matter of selecting the right flue gas treatment technology.

In commercially-operating RCP–plants, Von Roll Inova expects the bottom-ash can be reused: Copper/iron alloy can be separated from the molten bottom-ash to be used in the metal industry. The stripped molten bottom-ash is granulated and can be used as aggregate in the cement industry (Cement additive as a substitute for clinker). It is not certain whether the cement industry is really interested in processing these materials.

In annex D, a VonRoll Inova presentation of leaching behaviour of bottom-ash from RCP and conventional grate fired MSWIs is compared to the Swiss procedures. Because of differences in tests of leaching behaviour it is possible that different tests in different countries can lead to different results. It is expected, however, that the conclusions will be the same.

4.3 Financial Aspects and Market

The Bremerhaven demonstration project is not considered financially representative. However, Von Roll calculated costs of elements in the process on the basis of significant experience with MSW incinerators.
The average operational costs based on a throughput of 5.5 Mg of waste per hour and an LHV of 10,500 kJ/kg were between 135 and 150 US$ per Mg.

The investment costs and operating costs of the plant are considered too high for the European market at the moment. Almost no income can be expected from the recycled products.
The Japanese market is more attractive due to heavy pressure on the use of molten bottom-ash. Von Roll granted a license for the RCP process including the RCP Derivatives to Hitachi Zosen. The appropriate concept will be labelled RCP-2000 (see also Annex B, RCP Derivatives)

4.4 Operational Aspects

Von Roll Inova demonstrated the technology especially for the Japanese market during a 90-day test. The test showed that the different RCP modules (pyrolysis, smelting furnace, reduction furnace, CFB boiler) can be seen as promising technologies. The conventional part of the boiler (vertical 3-pass) turned out to be the bottle neck, reducing the availability of the plant. The CFB boiler part did not fulfill all expectations in terms of flexibility and avoiding super-heater corrosion. It is not superior to a conventional boiler design. Von Roll will use CFB technology only if fuel or special waste fractions need to be burned in a CFB.
On the basis of the proven RCP modules and taking into account the market development, Von Roll now offers three RCP products, so-called RCP Derivatives (see Annex B).

In Figure 4.1, the waste throughput of the plant is presented per year demonstrating an increase in plant availability.

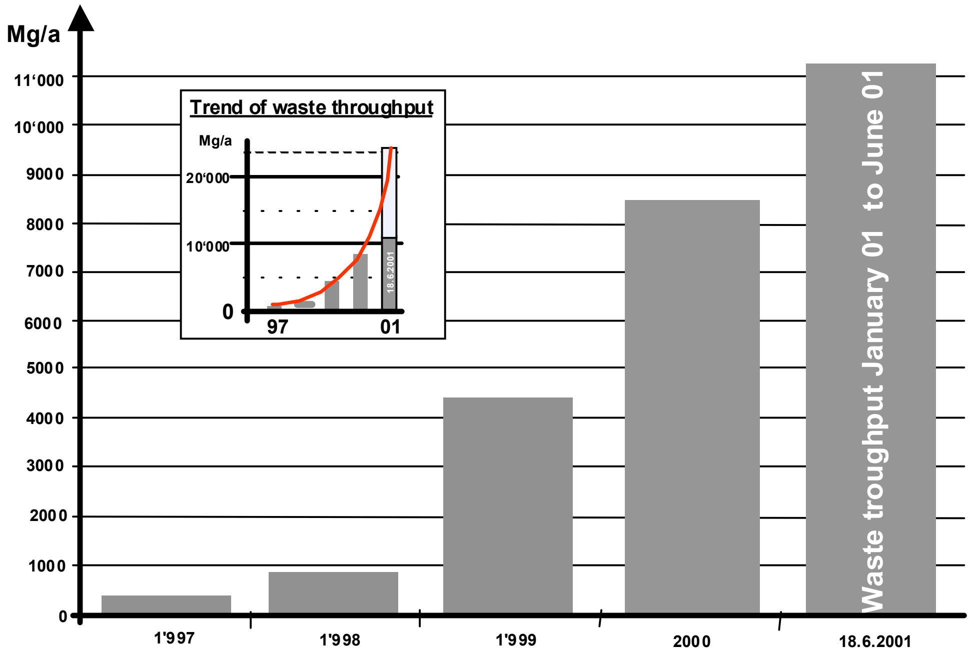

Figure 4.1 Waste throughput of the RCP line from 1997 until 18.06.2001

In 2001, the industrial operation of the RCP process was put through a 90-day test period for the Japanese market. The RCP plant was tested with two different types of waste: municipal solid waste (MSW) and car shredder dust (CSD). The range of the lower heating values of the waste treated during the test period was between 5,500 kJ/kg and 13,200 kJ/kg. The plant was capable to demonstrating a total waste throughput over 8,100 Mg was reached within 101 days: 90 days of continuous throughput and 11 days of boiler cleaning with the smelting part operating at high temperature.
Unfortunately, the original boiler design of the RCP plant in Bremerhaven did not include leak and additional air needed for the fluidised bed. As a result, larger flue gas flow rates and a fast fouling of the vertical economizer section prevented continuous boiler operation. This is the weakest part of the plant. Consequently, the boiler had to be cleaned four times during the test period. This can easily be established in connection with Figure 1.2, where the daily throughput is shown. Each day without any waste flow represents a purging sequence. Obviously, the short selective cleaning process did not disturb the subsequent operation. On the contrary, the last period – beginning 23rd May 2001 – demonstrates a smooth constant running of the RCP plant. Figure 4.2 shows the availability of the plant during the 90-day test

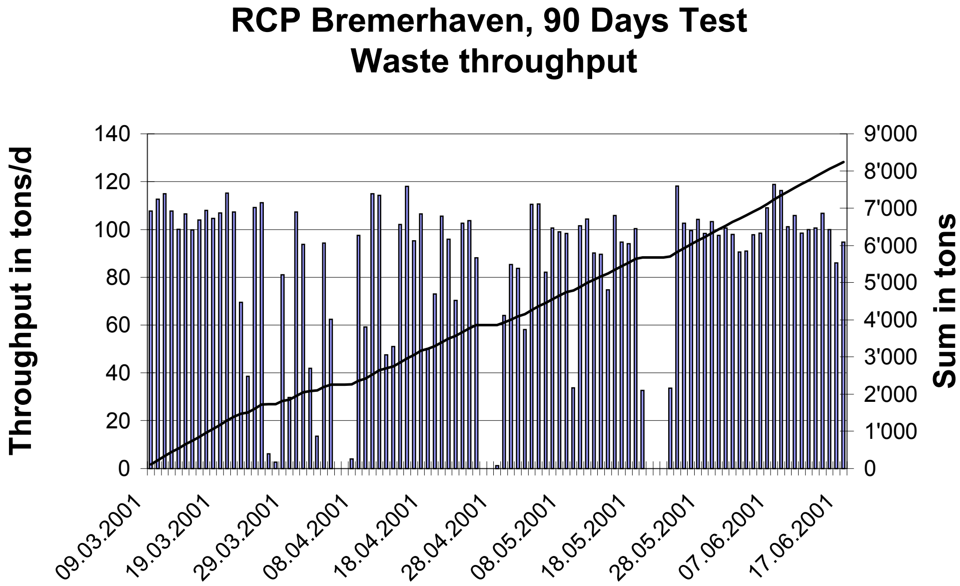

Figure 4.2 Waste throughput during 90-day test of RCP-Bremerhaven

5. General Comments and Conclusions

Technology
The technology is considered to be advanced and is applicable in special local conditions where environmental aspects are emphasized by the authorities (Japan). Especially the processing of molten granulate plays an important role. Unfortunately, this step costs energy and thus reduces the energy efficiency of the process,

Operational aspects
The general impression is that the RCP process could be exploited on a commercial scale, but it has not been fully demonstrated on a commercial scale.

Environmental aspects
The RCP facility in Bremerhaven can be operated in compliance with environmental legislation. The marketability of granulate and fly-ash has not been demonstrated. It is generally expected that recovery of products in the metal and cement industries will be possible in the future; however, the markets for recycled products tend not to be reliable. The facility's energy recovery has not been demonstrated but is expected to be poor.

Financial and commercial aspects
The investment costs and operating costs of the plant are considered to be too high for the European market at the moment. Almost no income can be expected from the recycled products.
The Japanese market is more attractive due to heavy pressure there on the use of molten bottom-ash. As far as is known, no contracts for RCP processes have been signed.

6. References

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[4] Hesseling, W.F.M., "Case Study: ThermoSelect Facility Karlsruhe", IEA Task 36 Report, April 2002.

[5] Hesseling, W.F.M., "Case Study: Valene, Waste Recovery Facility in Mantes la Jolie", France 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

Names and establishments to which part of the research was put out to contract:

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

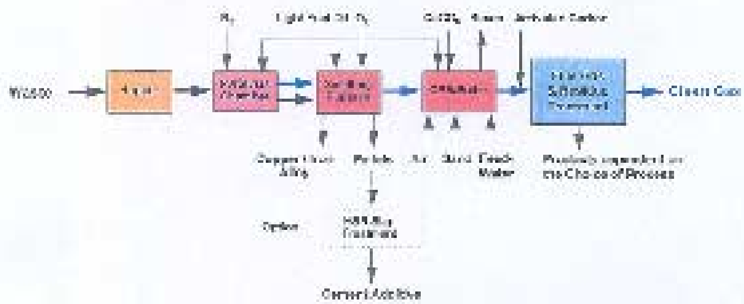
Signature:	Approved by:
Ing. W.F.M. Hesseling Project Leader	Ing. S. van Loo Head of Department

Annex A Specification of Bremerhaven RCP Process

RCP

vonRoll INOVA

Von Roll RCP Process with HSR optional



January 1999

1. Von Roll RCP Converts Waste to Reusable Products

RCP (Recycled, Clean Products) converts waste into directly reusable products. This revolutionary process is the result of extensive research and long proven industrial experience in "thermal waste treatment".

The Von Roll RCP process complies fully with current environmental and recycling regulations. The products of the process can be directly utilised thereby being reintroduced into a new life cycle.

The major product of the RCP process, which effectively has the largest mass, is a vitrified slag and can be used directly as construction material.

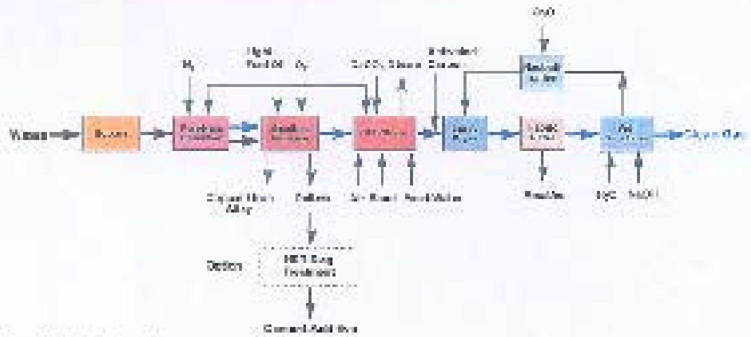
As an option, a further slag treatment process can be integrated which reduces the concentrations of the heavy metals in the slag glass. Thus pellets are produced which can be used as as an additive in cement production.

After extensive research and the successful pilot operations of the critical process steps, the first production scale RCP Plant is now under construction in Bremerhaven, Germany. The plant which has a capacity of 6 tons waste per hour and features an integrated slag treatment, went in operation in 1997.

RCP - The Major Advantages

- A genuine sustainable process, which combines proven and newest technologies.
- Complete know how is supplied by one source.
- No landfilling of the slag is required, therefore no disposal costs are necessary.
- Modern fluidization technology yields a high energy output.
- The steam generator is highly resistant to corrosion since the superheater is located outside the flue gas flow.
- Flue gas cleaning is significantly simplified: the formation of new hazardous materials during the thermal treatment is suppressed and the SO_x removal is located in the circulating fluidized bed instead of the wet scrubber.
- The plant is space-saving and compact.
- Flue gas volume is minimised since pure oxygen is used instead of air.
- Stack gas volume and total mass emission are therefore minimised.

2. Von Roll RCP Process Description



Pyrolysis Chamber
In principal the waste can be fed untreated into the pyrolysis chamber. Under the influence of heat the waste is converted to pyrolyzed gas and coke. The required radiation energy for this process is released by partial incineration of the pyrolysis gas with oxygen.

Smelting Furnace
The pyrolysis coke oxidises and is melted in the smelting furnace. By tangential introduction of oxygen, a rotation impulse on the slag bath is transmitted which produces rotation. The resulting turbulence causes dispersion and a thorough mixing of the burnable materials and oxygen, leading to complete incineration of the carbon. Simultaneously the inert fraction of the pyrolysis coke is melted down. The prevailing temperature is over 1400 °C. Additionally the inert fraction which is usually only melted at higher temperatures, reacts with this heterogeneous slag system. Copper and iron are separated as an alloy beneath the fluid slag, for further use in the metal industry.

Option: Heavy Metal Reduction with HSR Slag Treatment
In the integrated HSR slag treatment the heavy metals are extracted from the fluid slag. Volatile heavy metals (such as zinc, cadmium, lead) are evaporated to the gas phase. The slag which is free of heavy metals is pelletised for later use as a cement additive. The pellets fully comply with the stringent regulations of the Swiss TVA (Technischen Verordnung Abfall - Swiss Directive for wastes).

Circulating Fluidized Bed/Post Combustion Chamber / Waste Heat Boiler
The hot flue gases from the smelting furnace are led into the circulating fluidized bed and mixed with large amounts of cooled sand, thereby being rapidly cooled to temperatures below 1000 °C. By adding oxygen the flue gases are burnt out completely in the upper part of the post combustion chamber, and are then led over a cyclone into a steam boiler.

The sand carried along with the flue gas flow carries the heat. Flue gas and sand are separated in the cyclone. In the fluidized bed cooler, the heat transfer from the sand to the steam process takes place. Thus, sand serves as an intermediate carrier for the heat, and separates the steam surfaces from the corrosive flue gases. The heat transfer properties of the gas/sand mix are significantly better than other comparable conventional systems. As a result, maximum boiler efficiency and a more compact construction of the heat recuperation system are achieved.

Pollutant Reduction in the Circulation Fluidized Bed / Post Combustion Chamber

The addition of lime (calcium carbonate, $CaCO_3$) in the post combustion chamber enables the separation of sulfur dioxide. Thus the SO_2-content in the flue gas stream is largely reduced. Hence the flue gas treatment is facilitated. Surplus lime also separates HCl to a smaller proportion in the fabric filter.

Flue Gas and Residue Treatment of the RCP Standard Plant Concept

The standard plant concept is based on an effluent-free flue gas treatment composed of a fabric filter, wet scrubber, neutralisation and spray dryer.

Different concepts allow the recycling of filter residues (please refer to publication "VonRoll RCP Process, Standard Offer").

Wet Scrubber

The flue gases still contain a high proportion of HCl which is separated in the wet scrubber. The scrubber is a three stage construction, consisting of a quench stage, an acidic packed bed stage and a neutralised packed bed stage. In the third stage the residual SO_2 is removed with caustic soda.

Neutralisation / Spray Dryer

The effluent from the wet scrubber is neutralised with lime slurry and later atomised in the spray dryer. The water is evaporated after contact with the hot flue gases. The residual dried solids comprise of salts, dust and heavy metals.

Fabric Filter

The dried solids are separated in the fabric filter and without further processing, can be used as a filler material in underground mining. The residue is made up of all heavy metals, gypsum, salts and dusts.

3. RCP Products: Without HSR-Slag Treatment

The main products of the Von Roll RCP process are recycled into a new life cycle. The development of the marketable products is done in close cooperation with industry. Such an opportunity results not only in an economic advantage for waste recycling, it also saves our natural resources.

Main products and their utilization:

- Pellets (vitrified slag) — For use as construction materia
- Copper iron alloy — Application in copper industry

Quality of Pellets: Comparison of Elutrition Values

Several physical construction properties as well as the elutrition behavior of the pellets determine its use as an construction material.

During the melting of the slag the easily vaporized heavy metals (mercury, cadmium, arsen) are practically all removed as well as the quantities of zinc and lead. The residual parts and the other heavy metals such as copper, nickel and chrome are fixed in the matrice of the glassy slag.

The table below explains this fact: The elutrition values of the pellets are compared to those of untreated raw slag from conventional municipal waste incineration plants as well as today's requirements.

	Hg (mg/l)	Cd (mg/l)	Pb (mg/l)	Zn (mg/l)	Cu (mg/l)	Ni (mg/l)	Cr (mg/l)
Untreated raw slag [1]	0,0020	< 0,010	1,380	1,50	0,99	0.01	< 0,05
RCP pellets experimental values [2]	< 0,0002	< 0,001	< 0,008	< 0.01	< 0,01	< 0.01	< 0,01
LAGA [3]	0,0010	0,005	0,050	0,30	0,30	0.04	0,20

1) Test according to DEV S4 raw slag [illegible], Rassfeld, 1995.
2) Test according to DEV S4, ZEUT, Wiener, 1996.
3) German Directive [illegible] Länderarbeitsgemeinschaft Abfall (LAGA), 1994.

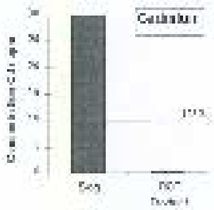
The RCP pellets fulfill all requirements for further utilization without additional treatment or intermediate storage.

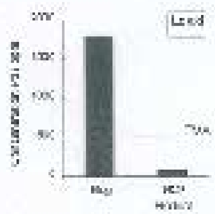
Optional HSR Slag Treatment: Production of a Cement Additive

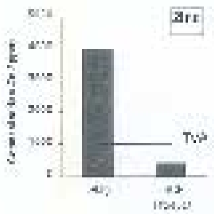
The smelting furnace can be combined with an integrated HSR slag treatment. In this case the slag glaze is largely freed of heavy metals prior to pelletizing. Consequently the pellets can be safely used as a cement additive.

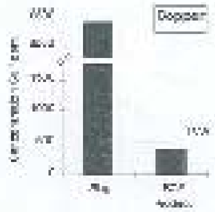
Cement Additive: Contents

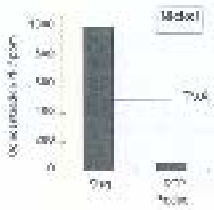
The slag treatment (HSR process) was tested successfully during several months with a scale of 500 kg/h. The concentrations of the heavy metals were lowered far below the standard requirements.







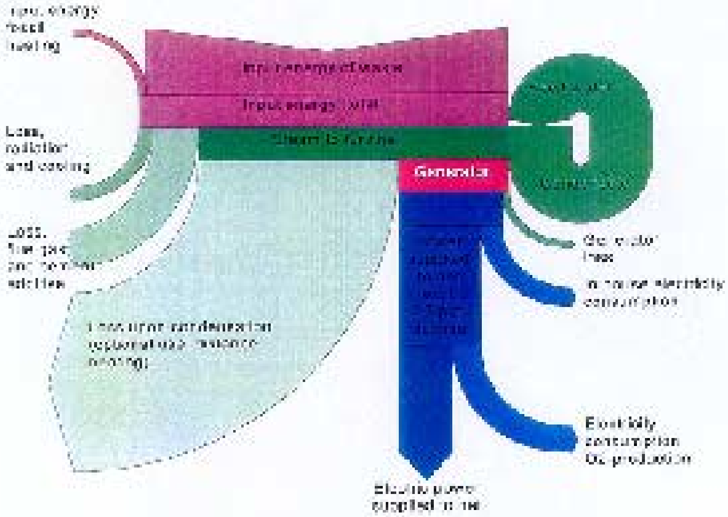




TVA
Technische Verordnung für Abfälle (CH)
Swiss Directive for wastes
Requirements for [illegible] makers

1. Energy Balance (Standard Plant Concept with HSR as Option)

Data excluding internal circuits	Power	
	MW	%
Input energy of waste (mass=18 t/h, calorific value=10 MJ/kg)	52,5	99,4
Input energy, fossil heating	0,3	0,6
Input energy, total	52,8	100
Loss, radiation and cooling	3,4	6,4
Loss, flue gas and additives	4,8	9,1
Steam from turbine (400 °C, 40 bar)	44,6	84,5
Condensed waste heat (condensation circuit considered)	29,0	54,9
Generator loss	0,8	1,5
Produced electric energy	14,8	28,1
In-house electricity consumption	3,1	5,9
Supply of current to the grid; excluding O_2 production	11,7	22,2
Electricity consumption O_2 production	4,1	7,7
Supply of current to the grid; inclusive O_2 production	7,6	14,5



6. Recommended Prices for RCP

Supply Basis: The supply basis excludes spare parts, exterior work, connections costs and real estate prices (supply in Germany)

Price Matrix: (Price basis March 1996, excluding value added tax). The prices are based on common terms of payment in the waste treatment business.

	Standard Plant Concept inclusive HSR-Slag Treatment	Standard Plant Concept with HSR as Option
Annual capacity	135 000 t	
Number of Lines	2 Lines with each 9 t/h throughput	
Flue gas treatment	effluent free with spray dryer	
Investment cost	163 Mill. DM	149 Mill. DM
Estimated costs for waste treatment with RCP process [3]		
Indicated in	DM/t Waste	DM/t Waste
Operational Costs	183	150
Chemicals Maintenance Personnel Residues General costs	54 52 35 12 30	52 41 32 10 24
Capital service [1]	146	133
Energy income [2]	30	38
Waste treatment costs [3]	299	245

1) Capital service over 15 years, 7.5 % interest, capital costs over 24 months construction time included. Excluded are preliminary costs (conceptualisation, permit application, customer project management, customer specific costs during construction/commissioning).
2) Minus in-house requirements
3) Construction price and operational costs in countries other than Germany may vary. Please contact our sales representatives for country specific information.

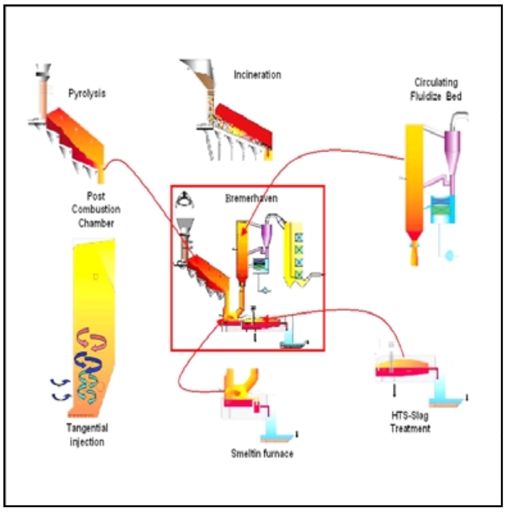
Annex B Descriptions of RCP Derivates

RCP - Derivatives

The innovative system for today breaks ground for the future and balances economy, ecology and sustainability.

Article by B. Andreoli, RCP-Derivatives, Von Roll Inova

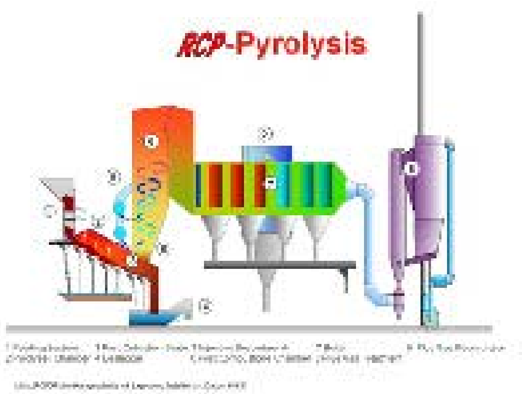
The RCP-Family and its derivatives



Today's policies of avoidance and separation have altered the end quality of waste. In addition to the classic municipal and industrial waste sectors, a large number of special fractions have entered the market. These special fractions exhibit very different quality characteristics regarding calorific value, bulk consistency and in particular, contaminate content.

Against this backdrop, Von Roll Inova has developed the innovative *R*ecycled *C*lean *P*roducts treatment concept and and the RCP family of derivatives.
A large spectrum of applications can utilize this treatment process at low investment and operational costs. The process consists of standarized process segments which can be combined according to requirements

RCP - Pyrolysis



Process segments:

- **Feed hopper**
- **Pyrolysis chamber**
- **Aquaroll system**
- **Burn-out grate**
- **Oxygen injection**
- **Tangential injection**
- **Secondary combustion**
- **Steam generator**
- **Flue gas treatment**
- **Pellet discharge**

Wastes:

- **Municipal waste**
- **Rubber tires**
- **Synthetic/plastic wastes**
- **Pasteous wastes**
- **Biomass**
- **Solid industrial wastes**
- **Treated-wood wastes**
- **etc.**

Application:

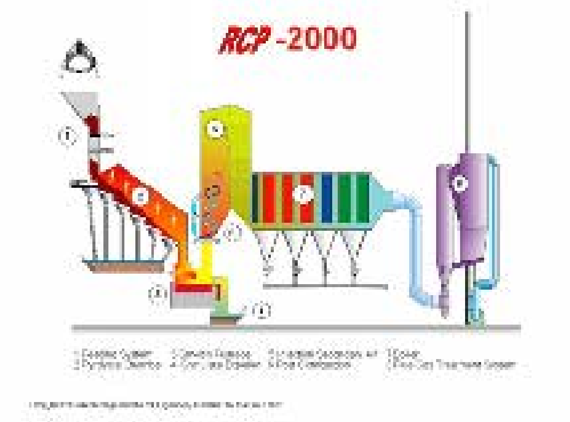
- **Total flexibility (calorific value and wastes)**
- **Broad spectrum of calorific values**
- **Control over the treatment process, even for high calorific fuels**
- **Replacement for incineration lanes with existing and/or retrofitted flue gas treatment systems**
- **Improve output performance with retrofit; injected oxygen reduces flue gas volume**

Technical Data:

- **Range of calorific value: 6000 to 34000 kJ/kg**
- **Waste throughput: 6000 to 30000 Mg/h**
- **Mech. load capacity: 100% to 38%**
- **Therm. output: 21 MW to 85 MW**
- **Therm. load capacity: 100% to 60%**

RCP – 2000

Types: 16 MW and 26 MW



Process segments::
- Feed hopper
- Pyrolysis chamber
- Aquaroll system
- Oxygen injection
- Burn-out grate
- Smelting furnace
- Metal tapping system
- Tangential injection
- Secondary combustion
- Steam generator
- Flue gas treatment
- Pellet discharge

Wastes:

- Municipal waste
- Rubber tires
- Synthetic/plastic wastes
- Pasteous wastes
- Liquid wastes
- Electronic scrap
- Auto-Resh
- Meat and bone meal
- Treated-wood wastes
- etc.

Application:

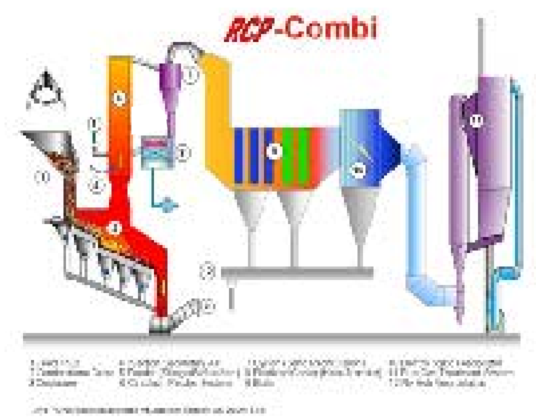
- Total flexibility (Calorific value and wastes)
- For high requirements for the residues
- Production of base products for the construction industry
- Vitrification of slag
- Vitrification of flyash
- Recycling of metals

Technical Data:

- Range of calorific value:	6000 kJ/kg to 34000 kJ/kg	
- Waste throughput:	a)	6000 Mg/h
	b)	9000 Mg/h
- Mech. load capacity:		100% to 38%
- Therm. output:	a)	16 MW
	b)	26 MW
- Therm. load capacity:		100% to 60%

RCP – Combi-plant

Types: 16MW and 26 MW



Process segments:

- Feed hopper
- Aquaroll system
- Circulating Fluidized Bed
- Heat transfer with Fluidized Bed Cooler
- Steam generator
- Flue Gas Treatment
- Ash return
- Pellet discharge

Wastes:

- Municipal waste
- Liquid wastes (CFB)
- Sludges (CFB))
- Biomass
- Wood chips (CFB)
- Granulates (CFB)
- Dusts (CFB)

Application:

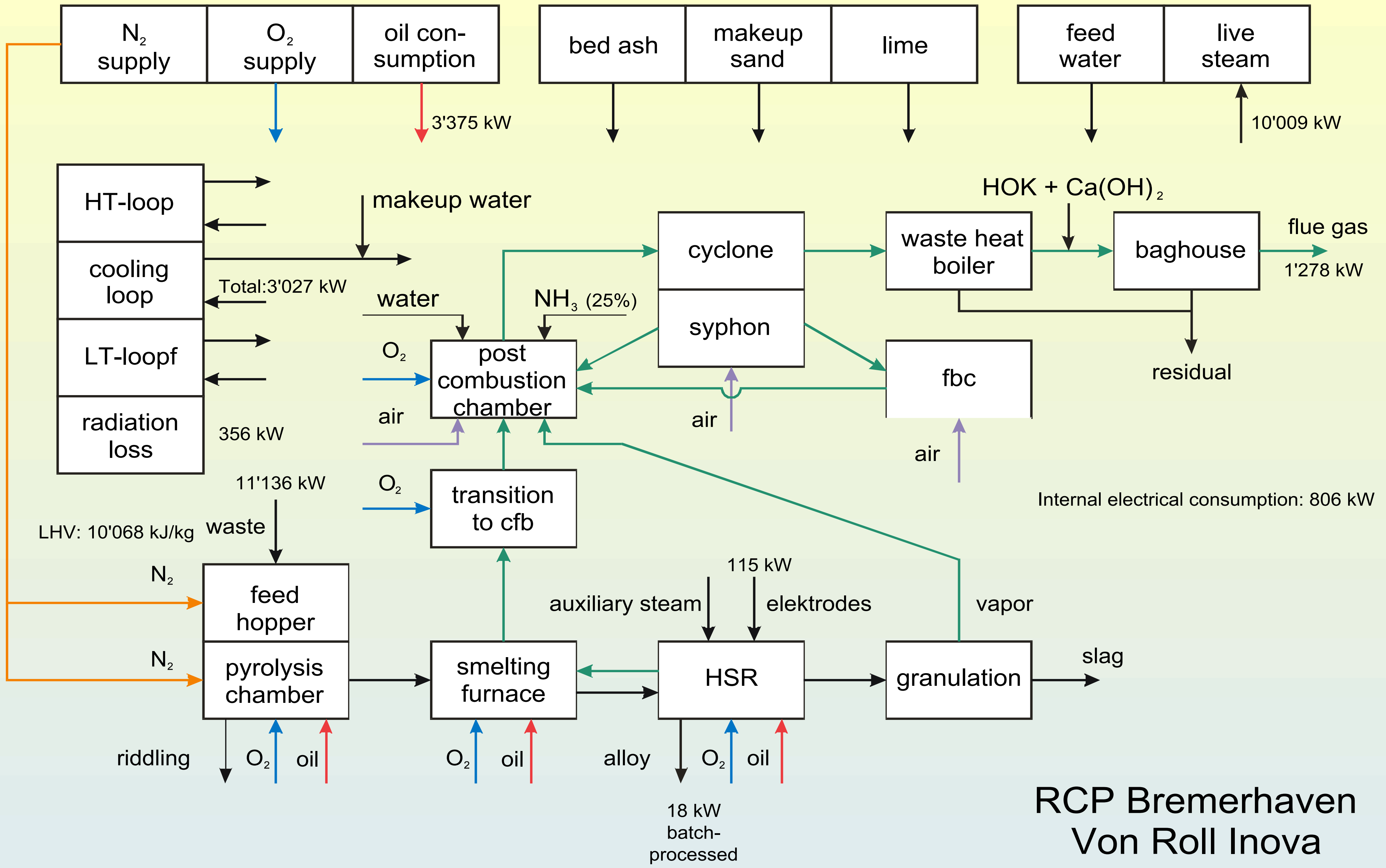
For concurrent thermal treatment of non-pretreated municipal waste and large portions of fuels that are suitable for treatment in a circulating fluidized bed, such as sludges, liquids, granulates, biomass, etc.

Technical Data:

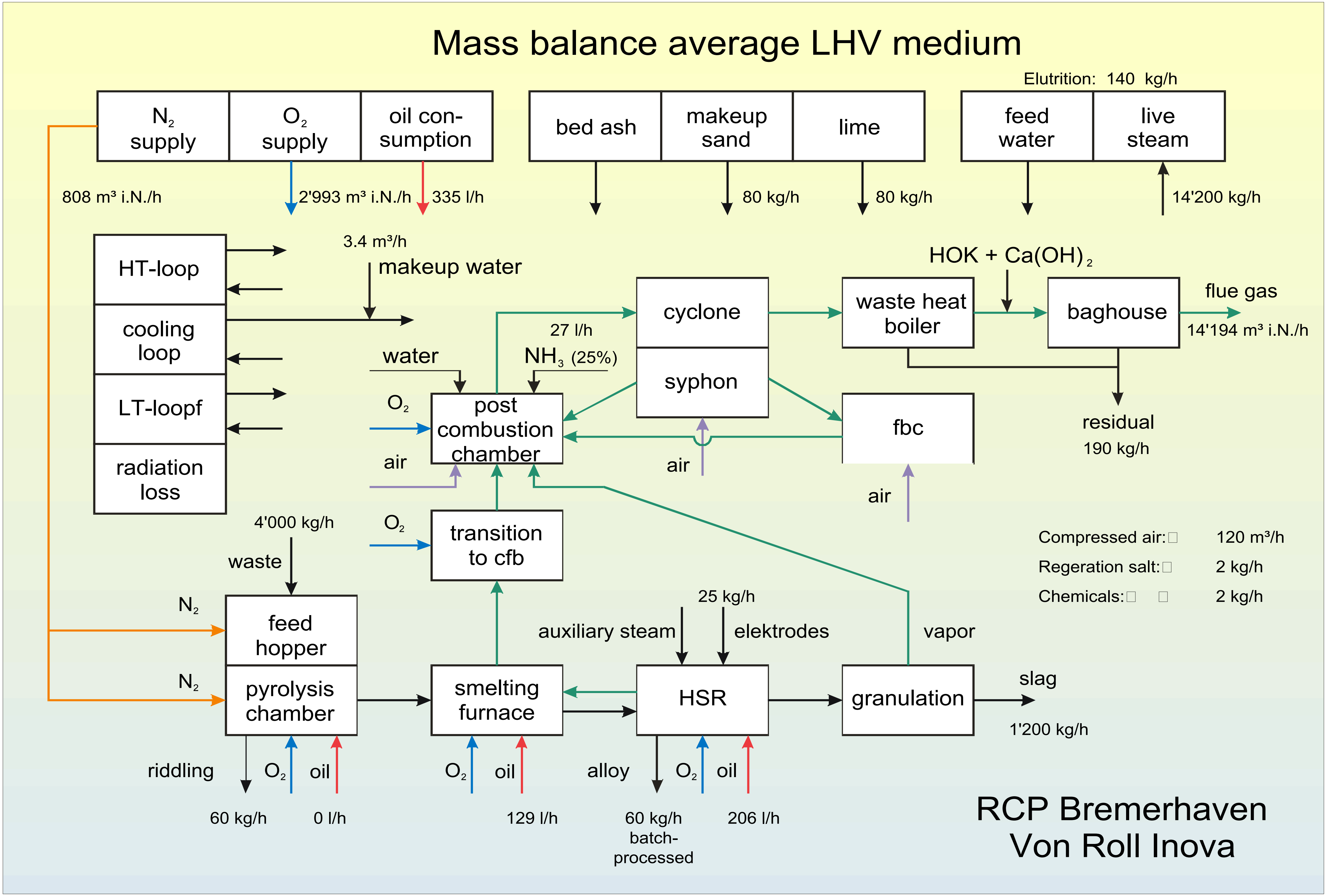
- Range of calorific value:		6000 to 16000 kJ/kg
- Waste throughput:	a)	6000 Mg/h solid waste
		2300 Mg/h in CFB
Grate + CFB:		5260 + 2300 Mg/h
	b)	9000 Mg/h sold waste
		3500 Mg/h in CFB
Grate + CFB:		7900 + 3900 Mg/h
- Mech. load capacity:		100% to 50%
- Therm. output:	a)	16MW
	b)	26 MW
- Therm. load capacity:		100% to 60%

Annex C Mass and Energy Balances

Energy balance average LHV medium

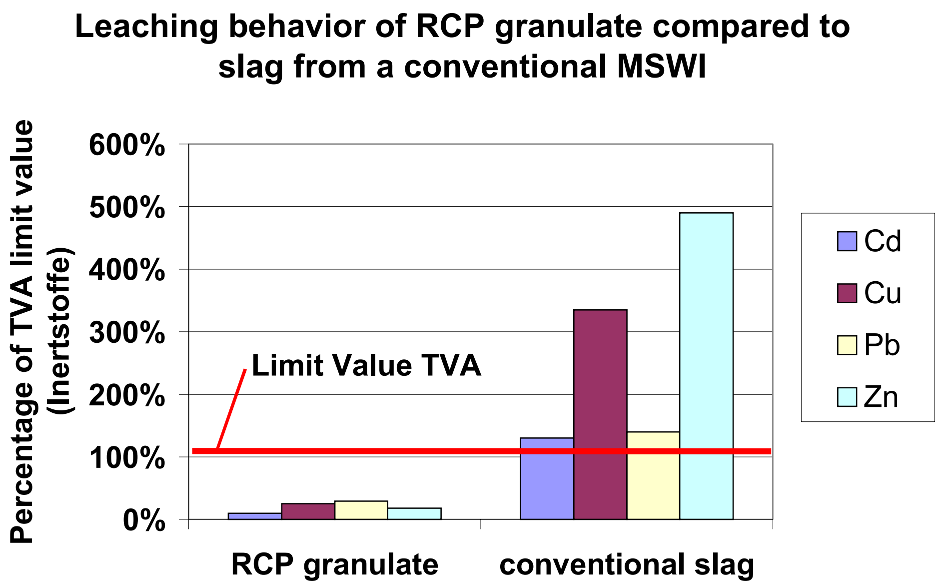


RCP Bremerhaven
Von Roll Inova


Mass balance average LHV medium
Elutrition: 140 kg/h
N2 supply
O2 supply
oil con-sumption
bed ash
makeup sand
lime
feed water
live steam
808 m³ i.N./h
2'993 m³ i.N./h
335 l/h
80 kg/h
80 kg/h
14'200 kg/h
HT-loop
cooling loop
LT-loopf
radiation loss
3.4 m³/h
makeup water
HOK + Ca(OH)2
cyclone
syphon
waste heat boiler
baghouse
flue gas
14'194 m³ i.N./h
27 l/h
water
NH3 (25%)
O2
post combustion chamber
air
air
fbc
residual
190 kg/h
air
4'000 kg/h
waste
O2
transition to cfb
Compressed air: 120 m³/h
Regeration salt: 2 kg/h
Chemicals: 2 kg/h
N2
feed hopper
N2
pyrolysis chamber
25 kg/h
auxiliary steam
elektrodes
vapor
smelting furnace
HSR
granulation
slag
1'200 kg/h
riddling
O2
oil
O2
oil
alloy
O2
oil
60 kg/h
0 l/h
129 l/h
60 kg/h batch-processed
206 l/h
RCP Bremerhaven
Von Roll Inova

Annex D Bottom-Ash From RCP Compared to Conventional MSWI (Leaching Behaviour)

The leaching behaviour of the granulate is in compliance with the strict regulations of the Swiss Test for "Inertstoffe". This is an improvement in slag quality compared to conventional combustion systems.
The design of the RCP process aims at good product quality (recycling idea). The energy efficiency therefore is of secondary importance.
The improvement in product quality achieved by the RCP process becomes obvious when comparing the leaching behaviour of the granulate to that of the slag from a conventional MSWI. The leachate values of lead are five times lower in the RCP granulate than in the conventional slag, those of cadmium and copper more than ten times, and those of zinc more than twenty times lower, see Figure below.



Annex E Control Room Print-Outs