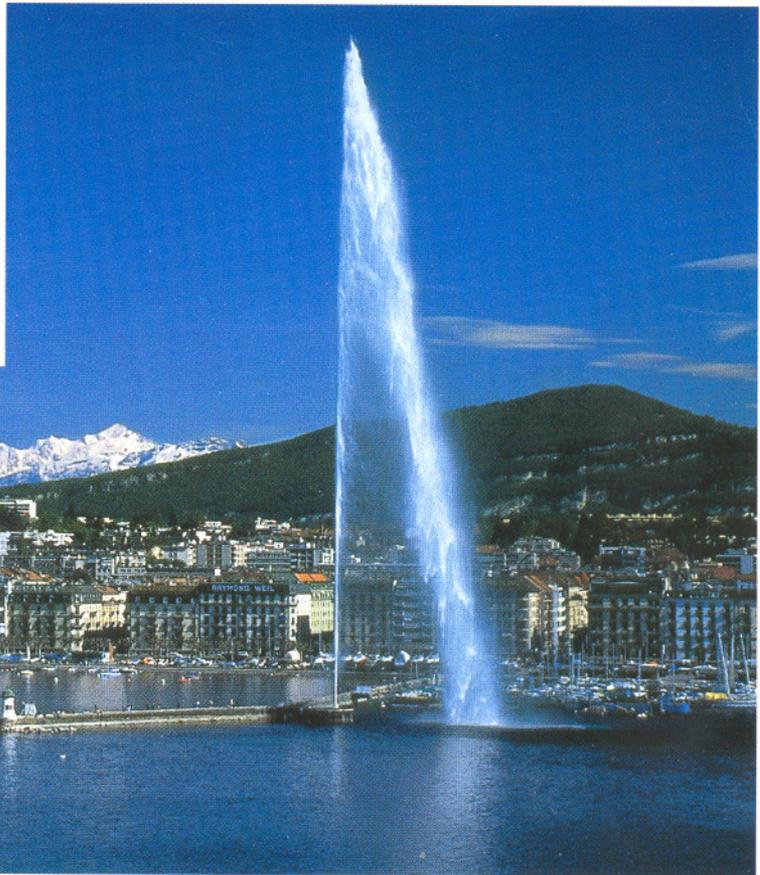


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Report on the operating trial with automotive shredder residue (ASR)

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Over the past decade, an innovative waste recycling technology – the THERMOSELECT process – has been developed, proven in a large scale demonstration facility and commercialised. Solid wastes, including municipal solid waste (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 are in operation in Karlsruhe, Germany, in Tokyo-Chiba, Japan and in Mutsu, Japan. The Karlsruhe plant has a waste treatment capacity of 720 t/d, the Chiba plant of 300 t/d, and the Mutsu plant of 140 t/d. Currently, 4 further plants are under construction in Japan.

Automotive shredder residues, ASR, receive today special attention. Currently, ASR is mainly landfilled, but according to the European end-of-life directive for vehicles, the recycling rates must increase in future. In Germany, when the new TASI legislation comes into effect in 2005, landfill disposal of the ASR will no longer be permitted.

Due to the large diversity of substances in this waste stream, and the ever increasing utilisation of complex composite materials, the demand for comprehensive, sustainable and environmentally friendly treatment methods becomes therefore increasingly higher. In this context, the rather high contents of heavy metals and chlorine in ASR require appropriate equipment.

In response to this demand, the THERMOSELECT high temperature recycling process has successfully demonstrated its capability to deal also with this type of input. During an extended trial operation in the waste treatment facility in Karlsruhe, approx. 400 tons of ASR have been processed during 3 days. The results of this trial operation are reported in this paper.

PROCESS DESCRIPTION

Waste Feed System

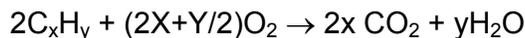
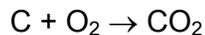
In the first process step the untreated as received waste is discharged directly into a storage bunker. The bunker has about 5 days storage capacity and is used to dampen out fluctuations in waste receipt cycles. A grapple crane is used to transfer the waste to the feed chute of the baling press. The 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.

Gasification of waste

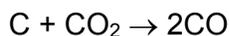
The press is directly connected to the degassing channel. The channels cross sectional area increases slightly as the gasification reactor is approached, which eases the movement of the waste plugs and the transportation of the gases (evaporation of water, pyrolysis and synthesis gases) from the waste 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. 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 transformed into a synthesis gas with a composition that reflects the thermodynamic equilibrium at the top of the reactor (approximately 1200°C, 1.2 bars).

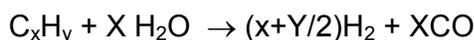
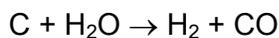
The high temperature, oxygen free environment and long residence time beyond 2 seconds in the upper part of the reactor ensures that only small molecular species such as H₂, CO, CO₂ and H₂O leave the reactor as prime constituents of the synthesis gas. The main prevailing exothermic reactions occurring in the upper part of the reactor are:



with a simultaneous endothermic Boudouard reaction, e.g.



and the endothermic water shift reaction



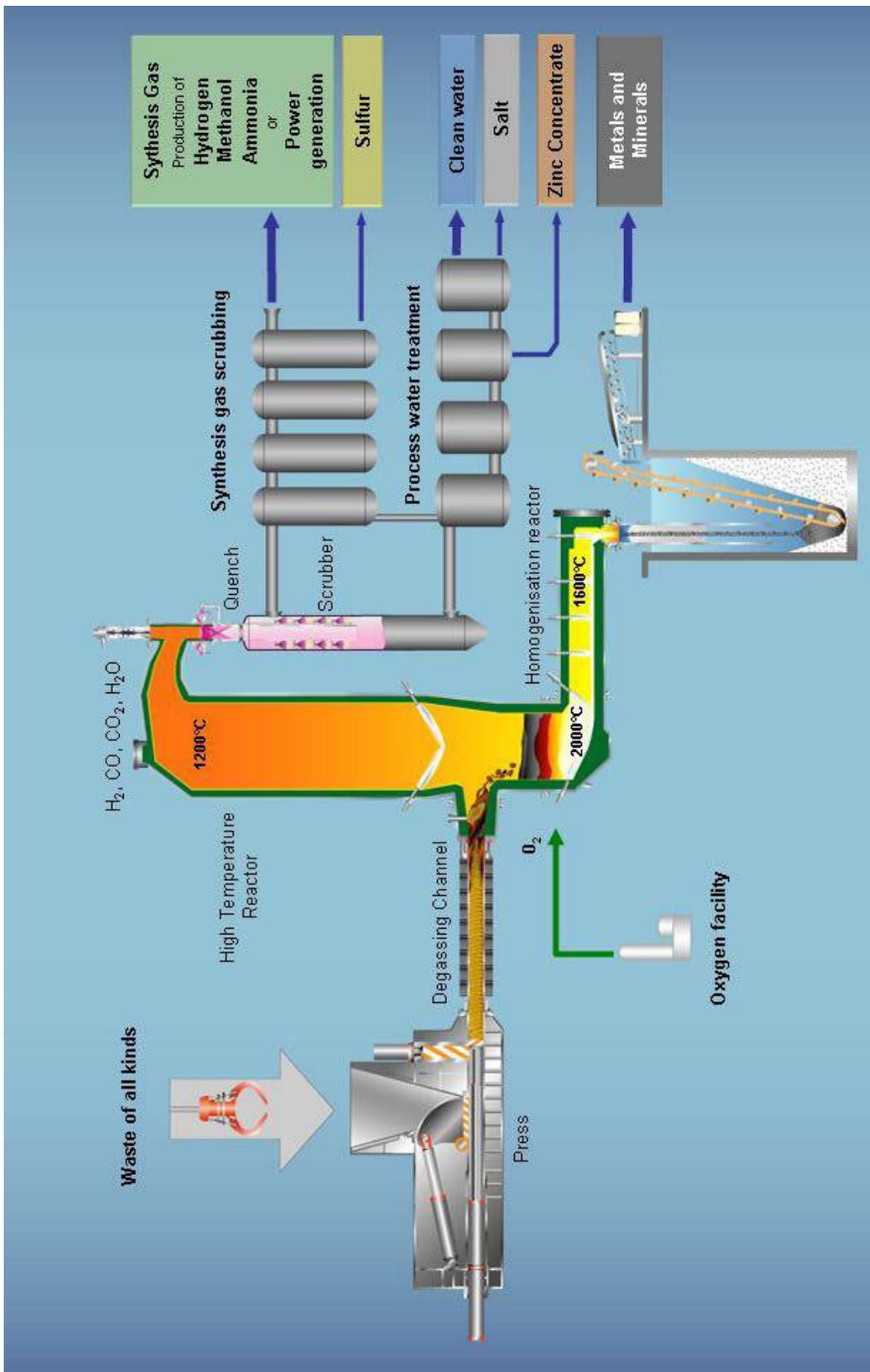


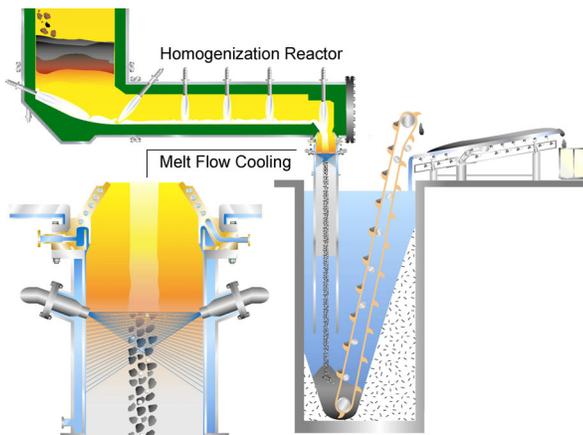
Figure 1 THERMOSELECT Resource Recovery Process

After gasification at a gas exit temperature of 1150-1200°C, a synthesis gas is obtained being typically composed of 25-42 Vol-% H₂, 25-42 Vol-% CO, 10-25 Vol-% CO₂ and nitrogen.

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 partially 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. 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 density (3 and 7 respectively). Any residual carbon in the melt is synthesized to syngas.

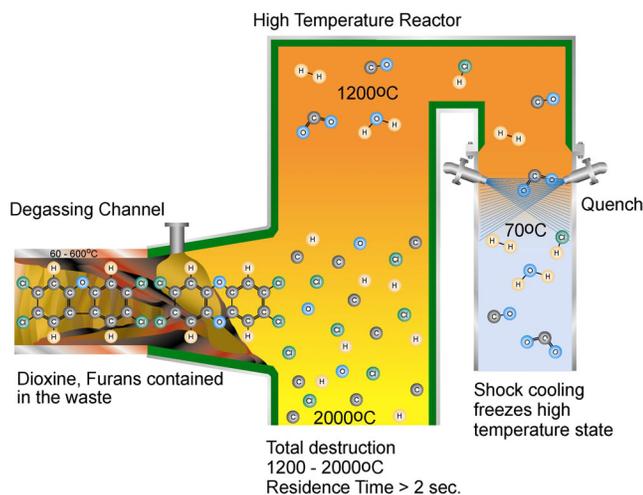


The molten substances are then granulated by water quenching and extracted from the quench basin using a bucket elevator. The difference in thermal conductivity between mineral and metal melt results in two products with different physical properties – metal and mineral granulate. The metal granules are then separated from the mineral granules by magnetic separators.

Synthesis gas cleaning

The synthesis gas passes through a water quench, acidic scrubber, alkaline scrubber, desulphurization 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 denovo synthesis back reactions. 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.

Following the quench the synthesis gas flows through

- an acidic scrubber where further HCl and HF acids as well as heavy metals are removed
- an alkaline scrubber to knock out any residual acid liquid droplets
- a desulfurization scrubber
- a gas dryer

Process water treatment

The process water originates mainly from the condensed water vapor inherent in the processed waste and from the reaction products of the gasification process. Iron and aluminum as well as heavy metal hydroxides are removed in appropriate precipitation stages and salt is removed in a final evaporator stage. The purified water is reused internally for cooling purposes.

Ancillary units

An air separation unit supplies oxygen, nitrogen and compressed air. Oxygen is required as the gasification medium. Nitrogen is used for inertisation during maintenance and compressed air is required for control equipment and the regeneration of the desulphurization agent.

There are multiple applications for the purified synthesis gas:

- Hydrocarbon production e.g. methanol
- Hydrogen (and Carbon monoxide in SOFC) e.g. Fuel cells
- 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 and possibilities to use existing power generation equipment, e.g. co-firing in large scale gas turbine power plants.

Suitability of the THERMOSELECT process for ASR recycling

When old cars are recycled, they are first pre-treated (removal of operating fluids, tyres dismantled, battery and spare parts removed) and then shredded. After shredding, the metallic fractions are separated from the non-metallic fractions. While the ferrous materials are passed on to steel works and the non-ferrous metals are passed on to metal reprocessing companies, the non-metallic fractions, which are called automotive shredder residue (ASR), cause disposal problems. These arise because the automotive shredder residue is an extremely heterogeneous mix of various composite materials made up of plastics, elastomers, textiles, glass, ceramics, wood, ferrous and non-ferrous metals, and to date it is not possible to be economically separate and/or reuse this kind of material. For this reason, the ASR is currently mainly land filled. However, when the TASI comes into effect in 2005 in Germany, landfill disposal of the ASR will no longer be permitted. Individual solutions, such as using the high calorific fraction as a substitute for fossil fuels, e.g. in blast furnaces or cement rotary kilns, is limited to amounts of 5-10% of the input due to the composition of ASR (e.g. chlorine content). Conversion of existing facilities (use of corrosion resistant materials, extension of the gas scrubbing trains) is economically not viable.

The THERMOSELECT process on the other hand enables environmentally friendly treatment of the automotive shredder residue without any additional processing. In order to verify this, a trial operation was carried out in the period from November 26th to November 29th, 2002 using a MSW/ASR mix (up to approx. 45 % weight ASR) in the THERMOSELECT plant in Karlsruhe.

This trial operation was carried out on the basis of an approval granted by the Karlsruhe regional council¹. As higher calorific values as compared to normal MSW operation were expected, the throughput per line was limited to 7 tons/h to prevent excessive thermal loads.

The aim of the operating trial was to show that it is possible to treat ASR in a THERMOSELECT plant with a proportion of approx. 45% weight and to comply with all the limiting emission values and retain the properties of the mixed granulate (e.g. leachability resistance) under large scale industrial operating conditions. Therefore the results were also compared with the data from MSW treatment (annual values, Karlsruhe 2002).

¹ on October 15th, 2002, file reference 55-8823.12/8.1

Implementation of the trial operation

Automotive shredder residue (ASR) from SWH Shredderwerk Herbertingen GmbH was used in the trial. When old cars are processed, individual parts such as batteries are removed first and engine oils and fuel drained off before the car wrecks are crushed in a shredder. This crushed fraction is separated into metallic and non-metallic fractions using ferrous/non-ferrous metal separators and air separation. The residual non-metallic materials resulting from the air separation are called the automotive shredder residue. The automotive shredder residue essentially consists of

- Plastics (e.g. polyvinyl chloride (PVC), polyurethane (PU), polystyrene, polyethylene (PE), etc.),
- Elastomers (rubber),
- Textiles,
- Wood,
- Glass,
- Mineral fractions (sand, dirt)
- Ferrous materials and non-ferrous metals.

Due to the large number of car models and the various outfits, the composition of ASR varies. For the operating trial a mixture of approx. 45% weight ASR and approx. 55% weight of MSW was produced. In total, 1020 tons of this mixture was put through the system. In Table 1 the composition of the ASR used in the operating trial is compared with literature values. The zinc concentration was approx. 5 times above the expected value for ASR and MSW. The concentrations for fluorine, tin and cadmium were below the values to be expected for ASR according to the literature.

The ASR introduced to the bunker via a separate delivery pit was mixed with MSW using the main crane within a bunker area kept free for this purpose. During the trial phase, two thermal lines were operated with comparable throughput quantities.

Right at the beginning of the operating period it became obvious that the increase in synthesis gas volumetric flow remained below the expectations at the planned throughput of approx. 7 tons/h per line. This was due to a lower as expected heating value of the waste mixture, the reason why the throughput was subsequently increased to 8 tons/h. A further increase was not possible due to the limits imposed by the regional council permit for the trial.

Parameter		Domestic waste - Literature	ASR- Literature	ASR-Herbertingen Declaration Analyses Operating Trial 12/2002						
				Sample 1	Sample 2	Sample 3	Sample 4	min	Mean	max
Calorific value LCV	kJ/kg	7000-10000	14000-20000	16940	10280	11350	14920	10280	13373	16940
Residue 550°C	wt.-%	20 - 35	30 - 75	79.3	79.6	79.6	78.8	78.8	79.3	79.6
Water	wt.-%	25 - 35	1 - 15	11.8	20.5	23.9	16.4	11.8	18.2	23.9
Hydrocarbons (CH)	mg/kg TS	-	-	10,500						
Iron	Gew.-% DS	2 - 5	7 - 15	12.0	10.7	26.6	13.36	10.7	15.7	26.6
Chlorine	Gew.-% DS	0,1 - 1	0,5 - 3	1.8	1.72	3.18	3.52	1.7	2.6	3.5
Fluorine	Gew.-% DS	0.01 - 0.02	0.03 - 0.1	0.01	0.02	0.01	0.01	0.01	0.015	0.017
Sulphur	Gew.-% DS	0.05 - 0.5	0.1 - 2	0.2	0.3	0.2	0.2	0.2	0.2	0.3
Copper	g/kg DS	0.1 - 2	3 - 20	8.4	3.6	25.6	5.3	3.6	10.7	25.6
Zinc	g/kg DS	0.4 - 4	0.1 - 2	14.0	9.9	13.5	15.0	9.9	13.1	15.0
Chrome total	g/kg DS	0.2 - 2	0.5 - 3	0.6	0.3	0.5	0.4	0.3	0.4	0.6
Tin	g/kg DS	0.05 - 0.5	0.15 - 0.4	0.03	0.003	0.01	0.05	0.003	0.021	0.045
Barium	g/kg DS	0.1 - 1	1 - 8	0.31	0.202	0.42	0.56	0.20	0.37	0.56
Lead	g/kg DS	0.2 - 2	0.5 - 20	4.4	2.7	2.4	4.7	2.4	3.6	4.7
Antimony	mg/kg DS	o.A.**	2 - 226	94	72	226	512	72	226	512
Arsenic	mg/kg DS	1 - 8	20 - 35	11.6	10.0	16.5	13.1	10.0	12.8	16.5
Cadmium	mg/kg DS	3 - 30	30 - 120	21.8	25.1	31.3	37.3	21.8	28.9	37.3
Mercury	mg/kg DS	0.3 - 10	1 - 10	2.1	4.1	2.6	1.6	1.6	2.6	4.1
PCB	mg/kg DS	0.2	5 - 14	4.6	6.6	1.5	7.6	1.5	5.1	7.6

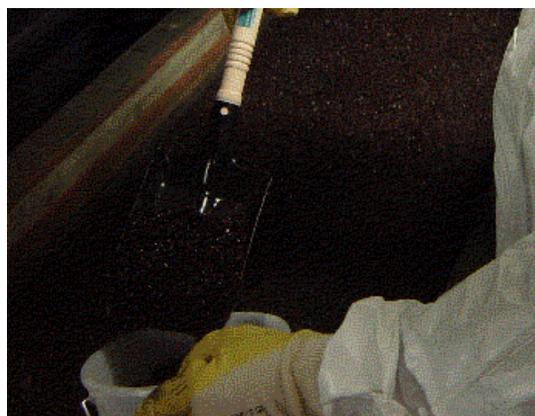
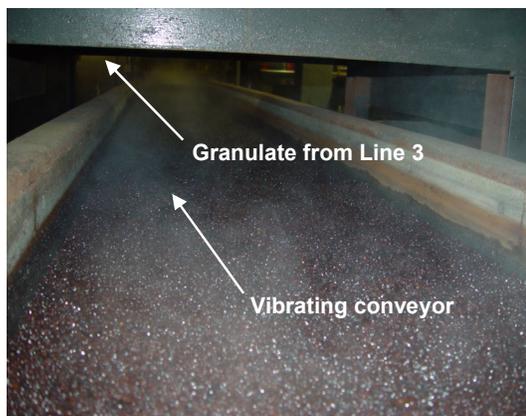
* The calculation was carried out taking into account the water content of the sample and the estimated hydrogen content (5.5%) of the dried sample
** The literature does not give any values for antimony contents in domestic waste. Sewage sludge contains approx. 2 - 10 mg/kg.

Table 1 Comparison of the composition of automotive shredder residue (ASR) with MSW [2 - 6]

A large quantity of samples was taken during the trial to track the quality of the by-products. The analysis of those demonstrated that property changes, which would impair recycling, did not occur. The samples were taken from the on-going by-product flow as close as possible to the sources. The following photos document the sampling points for the individual by-products.

Mixed granulate:

The mixed granulate is transported by a bucket elevator from the granulate basin onto a vibrating conveyor. This vibrating conveyor transports the mixed granulate into the granulate bunker. The samples of mixed granulate were taken directly from the vibrating conveyor.



Zinc concentrate:

Following the hydroxide precipitation, the zinc concentrate is separated out using a decanter centrifuge and ejected into a small container. The samples were taken at the ejection point at the entrance to the container.



Mixed salt:

After the evaporator facility the mixed salt is separated out using a centrifuge. The samples were taken from the discharge of the centrifuge.



Dry sorption residue:

The dry sorption filter, which is operated with a mixture of sodium bicarbonate and charcoal, is used to purify the flue gases downstream of the boiler. The residue samples were taken after the ejector at the entrance to the big bag.



Sulphur:

The sulphur produced is separated out using a decanter centrifuge and ejected into an ASP container. The samples were taken at the ejection point at the entrance to the container.



Results

No problems occurred during the trial operation, neither while handling ASR alone in the bunker nor while handling the ASR/MSW mix. The main bunker crane as well as the line feeding cranes were able to pick up the ASR/MSW mix without any problems and to convey it without transport losses.

		Pre-period	Trial
		26.11.02/ 12:00h – 21:00h	26.11.02/ 21:00h – 29.11.02/ 15:30h
Lines in operation	-	3	2
Waste type	-	MSW	MSW / ASR
Ratio of waste types	%	100%	62-55% / 38-45%
Waste throughput, total	kg/h	25'921	15'706
Waste throughput, per line	kg/h	8'640	7'853
Total syngas flow	Nm ³ /h	22'862	14'467
Syngas flow, per line	Nm ³ /h	7'621	7'234
Volumetric flow syngas, spec.	M ³ /kg waste	0.88	0.92
Calorific value synthetic gas	MJ/m ³	6.84	6.91
Waste calorific value (calculated)	kJ/kg	approx. 8100	approx. 8800

Table 2 Evaluation of the average synthesis gas quantity per kg waste or ASR mix (Evaluation on the basis of the archived minute values)

Also, no relevant changes occurred in the gasifiers. As expected, the synthesis gas temperature at the gasifier exit, the pressure and even the synthesis gas flow variations remained unchanged during the trial as compared to operation with pure MSW. Furthermore, also no significant changes occurred in the remaining process stages such as synthesis gas scrubbing, synthesis gas combustion in the boilers and process water treatment. The main operation data is given in Table 2.

The calorific value of the waste given in Table 2 was calculated on the basis of an overall thermodynamic and elementary balance. All input streams and internally recycled flows (e.g. C-sludge return) were taken into consideration.

Emissions

In order to demonstrate that all emissions value limits are securely complied with even when ASR is processed, the concentrations for the total heavy metals and dioxins in the flue gas were determined after 30h and 58h during the trial in addition to the continuously measured emission values. As Figure 2 shows, the emissions did not change when ASR was used as compared to the 2002 annual average values. Thus, during the trial operation, all emission limits were safely complied with.

The emission measurement results confirm that the THERMOSELECT process is a “robust system” suitable to process also waste streams with significantly increased heavy metal content as compared to MSW.

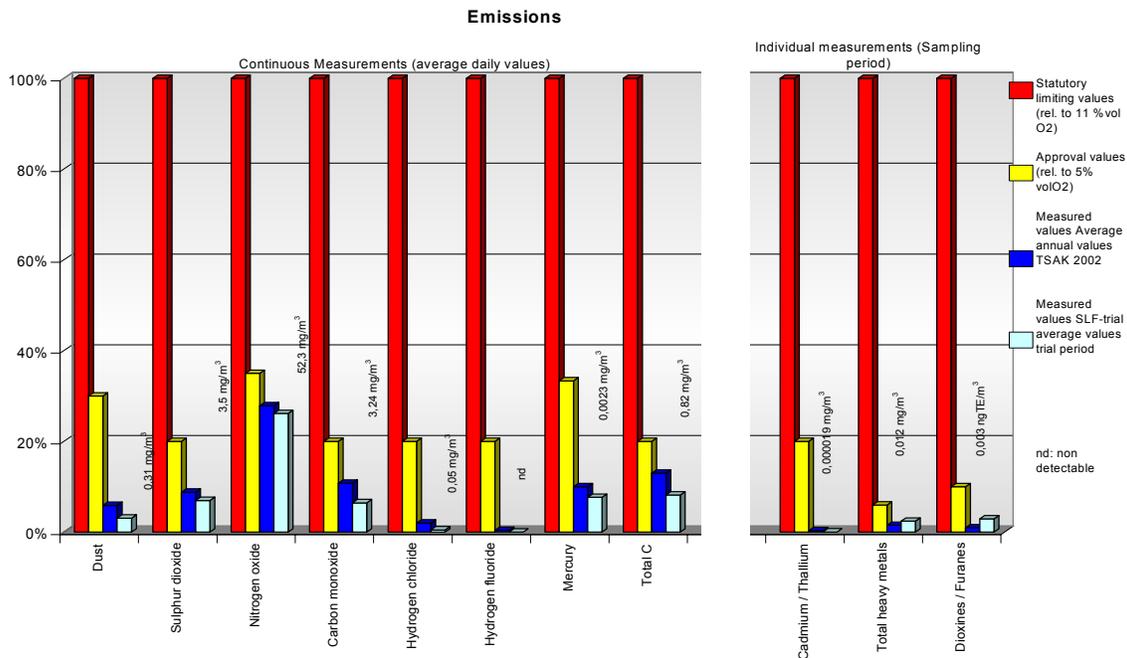


Figure 2 Comparison of the emissions during the ASR trial with the approved emissions and the average values from 2002

Properties of the mixed granulate

The expectation that during the trial more granulate would be generated per ton of input – due to the increased inert fraction – was confirmed. The annual average quantity of granulate produced per ton of waste [2] in the THERMOSELECT plant in Karlsruhe in 2002 was 224 kg. By comparison, during the trial operation with the ASR and MSW mix, 258 kg/ton mixed granulate were produced. The quantity increased by approx. 15% compared to the annual average. Approx. 9.44 t of metal were separated out from the total quantity using a metal separator (= approx. 3 % wt.)

From the mixed granulate samples taken – before the start of the trial, after 36h and at the end of the trial – sieve analyses were carried out in addition to chemical investigations. The main fraction with approx. 70% had a grain size of 1-5 mm in all three samples. The fraction of mixed granulate with a grain size of 0.5-1 mm was between 7.5 and 17.8% depending on the sample. Grains with a diameter of > 5 mm were contained in the mixed granulate from 7.7 to 21.4% depending on the sample. In fact, the use of ASR did not have any significant influence on the grain size distribution.

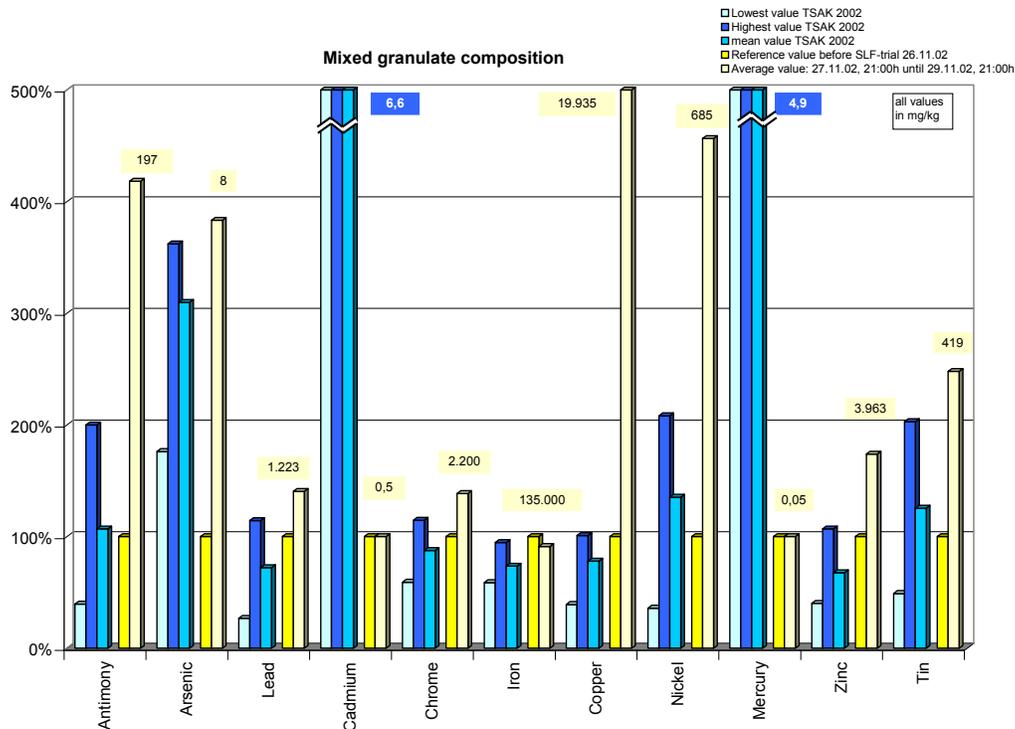


Figure 3 Mixed granulate composition

Figure 3 shows the granulate composition during the trial compared to the composition at the start of the trial and the values from the year 2002 during normal operation of the plant (measurements THERMOSELECT plant Karlsruhe – TSAK – 2002). In the chart, the respective average value of a component measured during the trial is normalised to the value at the start of the trial (100%)

value). In addition the absolute values in mg/kg are indicated for the average values during the trial.

The composition ranges shown in a detailed collection of results [2] match very well with the results obtained when ASR/MSW mixtures are fed through.

Figure 3 shows that the concentrations of all components except iron have increased compared to the start of the trial. The iron fraction (135 g/kg) remains essentially constant and leads to an increase of the granulate quantity. The uptake of larger iron fractions in the mineral system with a greater oxidation potential was observed on several occasions previously [2].

The clearest increase results for copper (approx. five-fold) and antimony, arsenic and nickel (approx. 3 - 4-fold).

Generally, the comparison between the annual values (min, max, average value 2002) and the trial values in Figure 3 clearly shows that the granulate composition fluctuates significantly even when the plant is operated with MSW only, without influencing the properties (leachability, low residual carbon).

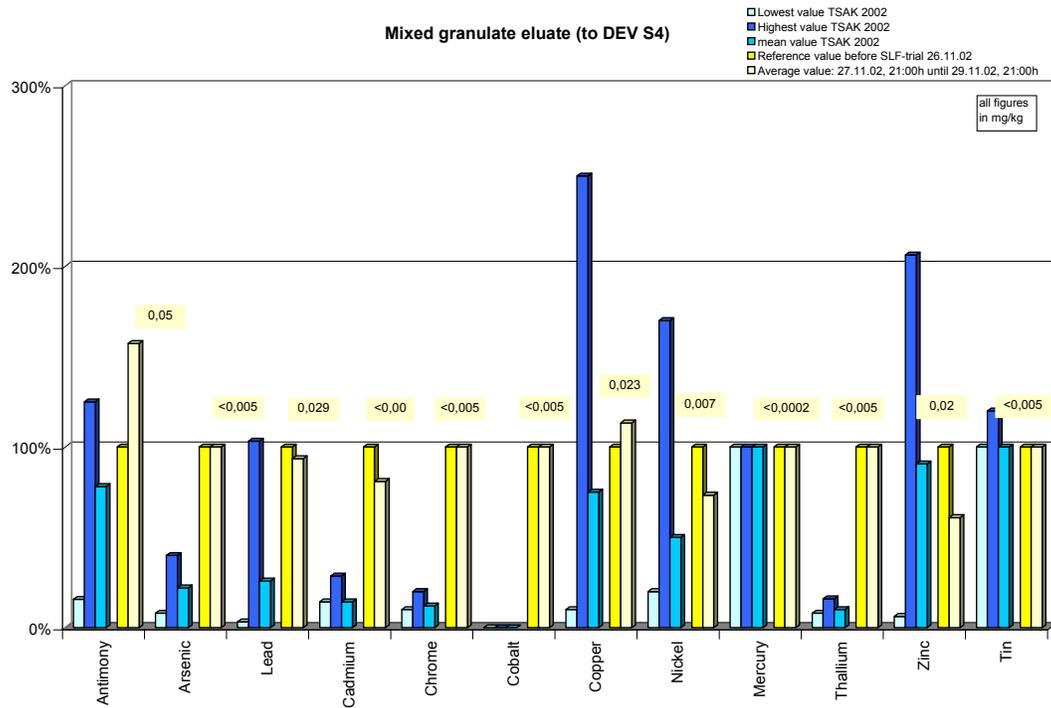


Figure 4 Mixed granulate – leachability concentrations to DEVS4

The leachability behaviour is important for the utilisation of the granulate. Figure 4 shows a comparison of the average leachability concentrations of the various components measured in accordance with the German DEV S4 regulation [3]. It can be seen that, with the exception of antimony and copper, the concentrations did not increase during the trial compared to the values at the start of the trial. Although the copper content in the mixed granulate increased fivefold during the trial, the leachability value is only slightly higher than the initial value before the trial. The average copper leachability concentration of 0.023 mg/l lies clearly

below the permissible limiting value of 0-3 mg/l for the use of slags according to German regulations (LAGA). This example clearly shows that the increased concentrations in the ASR and thus in part in the granulate, too, do not lead to proportionally increased leachability concentrations. This proves that the heavy metals are securely bonded in the glass-like minerals.

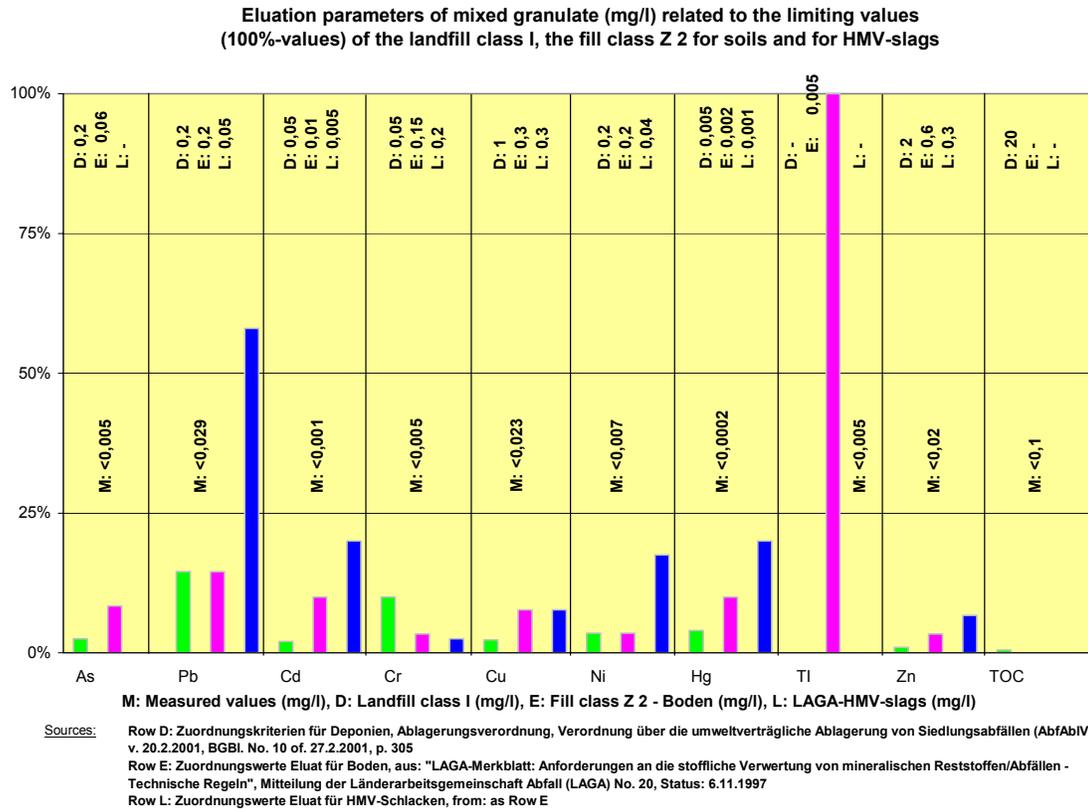


Figure 5 Comparison of the average leachability concentration and limiting values for recycling mineral substances

Figure 5 shows the average leachability concentrations of the individual components from the trial compared to the relevant limiting values for recycling the mineral granulate². One may state that the following are complied with:

- limiting values of German landfill class 1, row D (storage in inert material landfill sites)
- the German regulation classification values Z2 for soils, row E (material reuse of soils)
- the classification values for MSW incineration slags (HMV slags), row L (material reuse of HMV slags).

² The percentage figures result as follows: $X\%_{\text{Components}} = \left(\frac{\text{Measured value}_{\text{components}}}{\text{Limiting value}_{\text{Components}}} \right) \times 100$

Further results of the trial operation

Wearing of Refractory

After completing the trial operation the thermal lines were shut down and an internal inspection was carried out. At the time of the trial 7'300 to 9'000 tons of waste had been fed through each line since the last inspection (mid October). The inspection of the gasifiers revealed no increased refractory wearing. As expected the cooling elements were covered with a slag coating. An external expert (accredited according to Art. 29a BImSchG³) assessed the condition of the gasifier refractory; "Report on the internal inspection of the HTR" dated March 23rd, 2003. He came to the following summarising result:

"Based on the type and extent of wear, there is no reason to doubt the original track time of the refractory of 12 months".

Composition analysis

In Table 3 the composition of ASR is compared to the composition of MSW together with generally accessible information from the literature, cf. e.g. [4] and [6]. The "Evaluation" column shows the changes which resulted from the treatment of ASR during the trial.

Parameter/ Components	Units	Average value ASR trial	Comparison factor	Evaluation / Effect of the changed composition
Calorific value (LCV)	kJ/kg	13'375	approx. 1.5 Related to the calculated calorific value of domestic waste (without bulky waste) in Karlsruhe of 7,000	The calculation of the calorific value for the domestic value used in Karlsruhe at the time of the trial gives a value of approx. 7'000 kJ/kg. The average calorific value of the ASR was 13'373 kJ/kg. The reverse calculation based on the thermodynamic balances shows however that the calorific value lay in the range of the minimum analysed value for automotive shredder residues of 10'280 kJ/kg. According to the reverse calculation the calorific value of the ASR / domestic waste mix was approx. 8'800 MJ/kg:
Combustion residue 550 °C	% wt.	79.3	approx. 2-fold	The combustion residue of the ASR was around twice as high as to be expected for MSW according to literature. As expected, the increased fraction increased the quantity of mixed granulate per ton of waste.

³ German Federal Emissions Control Act

Parameter/ Compo- nents	Units	Average value ASR trial	Comparison factor	Evaluation / Effect of the changed composition
Iron	% wt. DS	15.7	approx. 3-fold	The metal fraction in the granulate did not increase due to the conditions in the HTR. The iron fraction was mostly oxidised and absorbed by the mineral substance. The leachability resistance of the mixed granulate was retained.
Chlorine	% wt. DS	2.6	approx. 3-fold	As a result of the large buffer volume in the process water cleaning, only a lengthy period of throughput leads to a significant increase in the quantity of mixed salt per ton of waste.
Sulphur	% wt. DS	0.2	Comparable	No significant changes occurred as a result of the comparable sulphur contents and relatively large buffer volumes.
Copper	g/kg DS	10.7	approx. 5-fold	The sink for the copper is in the mixed granulate. Due to the increased inorganic fractions, the quantity of mixed granulate increased. The copper content in the granulate rose by a factor of 5 compared to the sample at the start of the trial.
Zinc	g/kg DS	13.1	approx. 5-fold	The essential sink for the zinc is the zinc concentrate. In addition the mineral granulate contains part of the zinc fed in. The increase in zinc content led to a larger quantity of zinc concentrate. The zinc content in the granulate almost doubled compared to the sample at the start of the trial.
Chrome	g/kg DS	0.4	Comparable	No significant effect was expected in the chrome contents analysed in the ASR. The sink for chrome is in the mineral granulate. The chrome content in the granulate increased by around 40% compared to the sample at the start of the trial. The values from the trials, however, only lay slightly above (approx. 15 %) the maximum chrome value measured in the mixed value in 2002.
Tin	g/kg TS	0.02	Lower	The sinks for tin are essentially the zinc concentrate and partly the mineral granulate. As a result of the low tin contents of approx. 21 mg/kg in ASR the changes in the concentration in the zinc concentrate can be attributed to the usual scatter.

Parameter/ Components	Units	Average value ASR trial	Comparison factor	Evaluation / Effect of the changed composition
Lead	g/kg DS	3.6	approx. 4 - fold	The important sink for lead is the zinc concentrate, the sulphur and partially the mineral granulate. The lead content in the mixed granulate increased by approx. 40% compared to the sample at the start of the trial. The values from the trial however, are only slightly above (approx. 15 %) the maximum lead content measured in the granulate in 2002. The lead concentrate in the zinc concentrate doubled compared to the sample at the start of the trial. However, it must also be taken into consideration that even the maximum lead concentration measured during the trial was still less than the average lead values measured in 2002. The lead content in sulphur increases by approx 40% compared to the start of the trial. However, it must also be taken into consideration that even the maximum lead concentration measured during the trial was still less than the average lead values measured in 2002.
Arsenic	mg/kg	12.8	approx. 3-fold	The important sinks for arsenic are the sulphur, the zinc concentrate and partially the mixed granulate. The arsenic content in the mixed granulate roughly tripled compared to the sample at the start of the trial. The values from the trial lies in the same order of size as the maximum arsenic contents measured in the mixed granulate in 2002. The arsenic concentration in the zinc concentrate or sulphur does not display any significant trend, obviously as a result of the low input quantities.
Cadmium	mg/kg	28.9	Comparable	No significant effect was to be expected in the cadmium contents analysed in the ASR. The essential sink for cadmium is the zinc concentrate and partially the sulphur. There is no change in the low cadmium concentration in the mixed granulate during the trial. The cadmium concentration in the zinc concentrate does not show any significant trend. The concentration tends to fall during the trial. The cadmium content in the sulphur almost doubles compared to the start of the trial. However, it should be taken into account that even the maximum cadmium concentration measured during the trail is in the range of the maximum cadmium concentration measured in 2002.

Parameter/ Compo- nents	Units	Average value ASR trial	Comparison factor	Evaluation / Effect of the changed composition
Mercury	mg/kg	2.6	Comparable	No significant effect was to be expected in the mercury contents analysed in the ASR. The essential sinks for mercury are the zinc concentrate and the sulphur sludge and partially the mineral granulate. The mercury content of the sulphur fell slightly or rather remained constant during the trial compared to the start of the trial.
PCB	mg/kg	5.1	approx. 25 fold	As expected, the clearly increased PCB concentrations in the automotive shredder residue were unproblematic, as on the one hand the high temperatures in the reactor ensures that the PCB is destroyed and on the other hand a "denovo" synthesis is generally precluded by shock cooling.

Table 3 Comparison of the composition of domestic and commercial waste and automotive shredder residue (ASR) and evaluation of the effects in the trial (*TS (Units)=Dry Residue*) (Changes in the mixture have been related to the information given in the literature for domestic waste).

Summary

The trial operation in the THERMOSELECT plant in Karlsruhe using a mixture of automotive shredder residue (ASR) and MSW confirmed that the THERMOSELECT technology is suitable to process in an environmentally friendly manner ASR without prior treatment. It was possible to treat high ASR fractions (approx. 45 %) jointly with domestic waste without impairing the normal disposal operations.

No problems occurred, neither when handling the pure ASR in the bunker nor when handling the ASR / MSW mixture. The main bunker crane and the feeding cranes were able to pick up the ASR/domestic waste mix without problems and to transport it without losses.

The gasification of the organic fraction and the direct melting of the inerts, as well as synthesis gas scrubbing and process water treatment took place without significant changes to the operating points.

It was demonstrated that when ASR was processed the emissions remained at very low values – significantly below the approved limits. The results were comparable with those obtained when MSW is treated.

The increased fraction of inorganic substances in the ASR led to an increase in the quantity of granulate of approx. 15 % compared to the quantity when processing MSW. As expected the increased heavy metal input from the ASR led to an increase in the heavy metal concentrations in the granulate. The quality of the mineral granulate is nevertheless comparable with those from MSW operation, as the heavy metals are securely bonded in the glass-like minerals. Despite the increased heavy metal concentrations the leachability resistance of the minerals was proven. The leachability concentrations of the minerals determined according to the DEV S4 regulation were comparable to those when processing MSW only. The relevant limiting concentrations for the recycling of granulate, e.g. the German allocation value Z2 for soils or the limiting values for MSW incineration slags were not exceeded.

The by-products products serving as contaminant sinks (zinc concentrate, mixed salt and sulphur) as well as the dry sorption residue show increased concentrations for several heavy metals. Relevant changes to the quantities could not be observed except for the zinc concentrate. The properties of these fractions did not change when the ASR / MSW mixtures were used, despite the high ASR fractions (approx. 45%).

An internal examination of the gasifier carried out after the trial operation had been completed, did not show any noticeable additional refractory wear.

The results of the trial operation suggest that the THERMOSELECT process may also treat higher ASR fractions without any technical alteration. Thus, previous forecasts have been confirmed [4, 5].

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