MATERIAL FLOWS AND INVESTMENT COSTS OF FLUE GAS CLEANING SYSTEMS OF MUNICIPAL SOLID WASTE INCINERATORS (MSWI)

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ABSTRACT

The aim of this study is a comparison of four different flue gas cleaning systems of municipal solid waste incinerators (MSWI). The main topic of the investigation is the relationship between type of flue gas cleaning system and investment costs. This comparison will be done with the aid of material flow analysis. The elements chlorine, sulfur and mercury are considered. In addition, the amounts of residues will be taken into consideration. As a result of this work, a flue gas cleaning concept with a wet flue gas cleaning system equipped with fabric filter followed by a two-stage scrubber system seem to be very interesting for the construction of new plants.

INTRODUCTION

The incineration of municipal solid waste makes a contribution to waste disposal in Germany irrespective of a discussion about waste management. Up to now, 57 municipal solid waste incinerators (MSWI) equipped with grate furnaces are in operation in Germany with a total capacity of 13.5 Mio t waste per year. Additionally no less than 7 new incinerators are planned. Other technologies for thermal waste treatment like pyrolysis or gasification were applied in 4 plants. (1)

In future, older plants have to be replaced and new incinerators have to be built to meet the requirements of the TA Siedlungsabfall (Technical Directive for Recycling, Treatment and Other Management of Residential Wastes). In connection with these aspects, a question arises about the selection of adequate flue gas cleaning technologies. The partially expensive flue gas cleaning systems installed in operating municipal solid waste incinerators are the result of the several times upgraded emission standards during the last 15 years and often - on top of that - of demands to stay even far below those stringent limits. An other reason was the demand to remain far below the existing emission limits.

There is a lack of detailed comparison between different flue gas purification systems including the examination of the distribution of pollutants, the need for auxiliary chemicals, the amounts of residue and finally additional consideration of the investment costs.

MSWI-TECHNOLOGY AND FLUE GAS CLEANING

Grate firing systems shown in Fig. 1 are mainly used for thermal waste treatment in Germany.

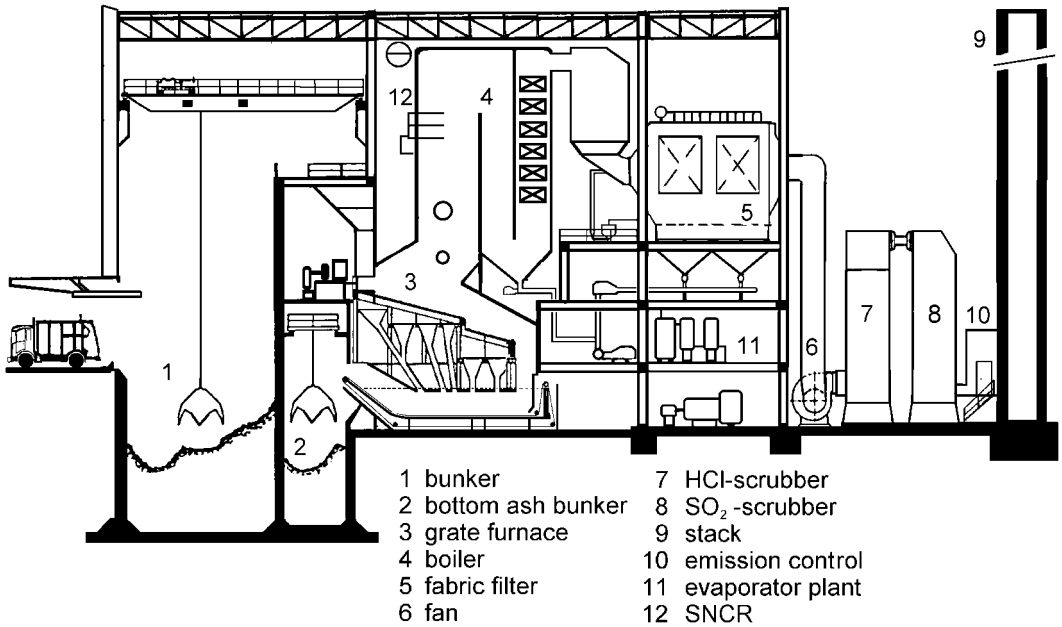

Fig. 1. Scheme of a Municipal solid waste incinerator with flue gas cleaning.

The waste delivered is stored in the bunker (1). A charging system fed by a crane is used to load the incineration chamber (furnace) (3) where the waste is incinerated on a grate. The air necessary for combustion is fed through the grate (primary air) or directly into the combustion chamber (secondary air). The incineration residue named as bottom ash falls into a bottom ash discharger and is transported by a conveyer to the bottom ash bunker.

The heat energy of the hot flue gas is used to generate steam in the boiler (4) above the furnace. The flue gas temperature decreases from up to 1000°C down to the range of 200°C. The pollutants contained in the raw gas have to be separated in the flue gas cleaning installed downstream the boiler. The flue gas cleaning system shown in Fig. 1 is a simple wet one chosen from a large variety being developed to meet the emission limits. The first device is a fabric filter (5), followed by a HCl-scrubber (7) and a SO_2-scrubber (8). The pressure drop in the plant has to be compensated by the fan (6).

The first flue gas cleaning step is a dedusting device performed as a fabric filter (5). The addition of pulverised coke to the flue gas upstream the fabric filter makes the separation of PCDD, PCDF and mercury in this cleaning step possible, too.

In wet flue gas cleaning plants like the example shown in Fig. 1 aqueous liquids are applied to separate HCl, SO_2 and other pollutants from the flue gas. In the first scrubber, an acid solution with pH 1 absorbs HCl. A neutral absorption solution must be applied in the second scrubber for SO_2 removal. The effluents of the scrubber system are vaporised with an evaporator plant (11) with the result of a solid residue. A Selective Non Catalytic Reduction (SNCR) System installed in the boiler reduces the nitrogen oxide emissions.

Other municipal solid waste incinerators in Germany with wet flue gas cleaning are equipped with additional flue gas cleaning steps. An entrained flow reactor or a carbon adsorber are built downstream the scrubber system to reduce the emissions of PCDD, PCDF and mercury and instead of a SNCR-System a Selective Catalytic Reduction (SCR) System is installed in some cases.

Additional variations of wet flue gas cleaning result from the demand for a waste water free plant operation. To achieve this, a spray dryer partial in combination with a further dedusting device is employed.

In Germany not only wet flue gas cleaning systems are in use for cleaning the flue gases generated by MSWI. Semi-wet and semi-dry systems are in existence, too. In a semi-wet cleaning process, a slurry of a calcium compound, general calcium hydroxide, is used for separation of HCl, SO_2 and other pollutants. In a semi-dry process, a pulverized calcium compound is injected after cooling the gas by injecting water. In both cases, a solid product is formed, which have to be separated from the flue gas by using a fabric filter or electrostatic precipitator.

APPROACH AND SYSTEM BOUNDARY

The material flow calculation can be carried out with data and information from technical scale MSWI, but earlier work (2, 3) had shown differing material flows for identical flue gas cleaning due to different plant operation. For that reason the material flows calculated in this work are based on a model plant with typical fuel and furnace parameters of technical scale plants in Germany. Additional information about each flue gas cleaning step is taken from the literature or is obtained from plant manufactures and operators.

The system boundary selected for balances comprises the entire flue gas cleaning plant. The area of coverage begins downstream the boiler and ends with the stack. The flue gas, the auxiliary chemicals required and the resulting residues were taken into consideration. The results described are limited to SO_2, HCl and mercury. The values given are related to 1 ton (t_W) of waste burned and calculated for the chemical elements. This was necessary to take into account the different chemical compounds of pollutants generated due to the chemical reactions in the in the flue gas cleaning plant.

BALANCES OF THE FLUE GAS CLEANING SYSTEMS

This section contains a short description and the corresponding balances of 4 flue gas cleaning systems considered in this study. For the separation of the pollutants in the model plants A and B a wet flue gas treatment process is applied. In the case of plant A relatively simple construction is considered. In contrast plant B is more complex with a spray dryer and a fine cleaning stage upstream the stack. Plant C is considered to operate with a semi-wet system whereas plant D is equipped with a semi-dry flue gas cleaning system**.**

Plant A

The flue gas cleaning system of plant A corresponds to the flue gas cleaning system presented in Fig. 1. It consists of a fabric filter and a two stage scrubber system. For the balances it is assumed that the SNCR process has no influence on the material flows. Figure 2 shows the balance of chlorine.

According to the model calculations the dusty raw gas downstream the boiler transports 5890 g/t_W chlorine in all plants considered in this study.

The fabric filter removes 720 g/t_A chloride bound in the filter ash. The main amount of chlorine (4587 g/t_W) is absorbed in the first scrubber. The second scrubber removes only small quantities (569 g/t_W) of chlorine from the flue gas. The waste water treatment of the scrubber liquids occurs outside the system boundary. The clean gas which leaves the stack contains 14.1 g/t_W of chlorine.

The sankey diagram in Fig. 3 shows a different distribution of sulfur in the flue gas cleaning. The balance starts with 1265 g/t_W sulfur in the dusty raw gas downstream the boiler.

Only small amounts of sulfur (70 g/t_W) are removed in the first scrubber, whereas large amounts of sulfur (621 g/t_W) are absorbed from the flue gas in the second scrubber which uses a NaOH solution. The waste water from the scrubber system is externally treated as mentioned above. According to the calculations 14.1 g/t_W of sulfur pass the stack to the atmosphere.

The Fig. 4 shows the expected distribution for mercury arisen from the properties of mercury. The calculations indicate that the dusty raw gas contains 1.65 g/t_W of mercury. In the incineration process most of the mercury is passed to the flue gas as $HgCl_2$ and is taken up to 90 % (1,485 g/t_W) by coke injected into the gas upstream the fabric filter. The absorber liquid in the first scrubber removes 0.138 g/t_W of mercury from the flue gas. Only very small amounts (0,0081 g/t_W) of mercury are absorbed in the second scrubber. As mentioned, the waste water treatment

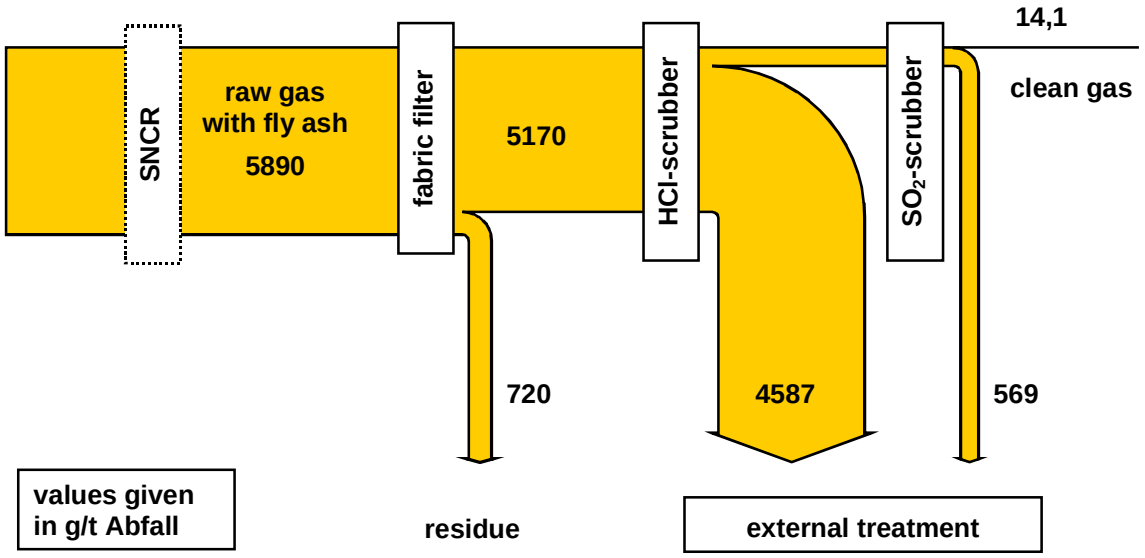

Fig. 2. Chlorine balance of plant A.

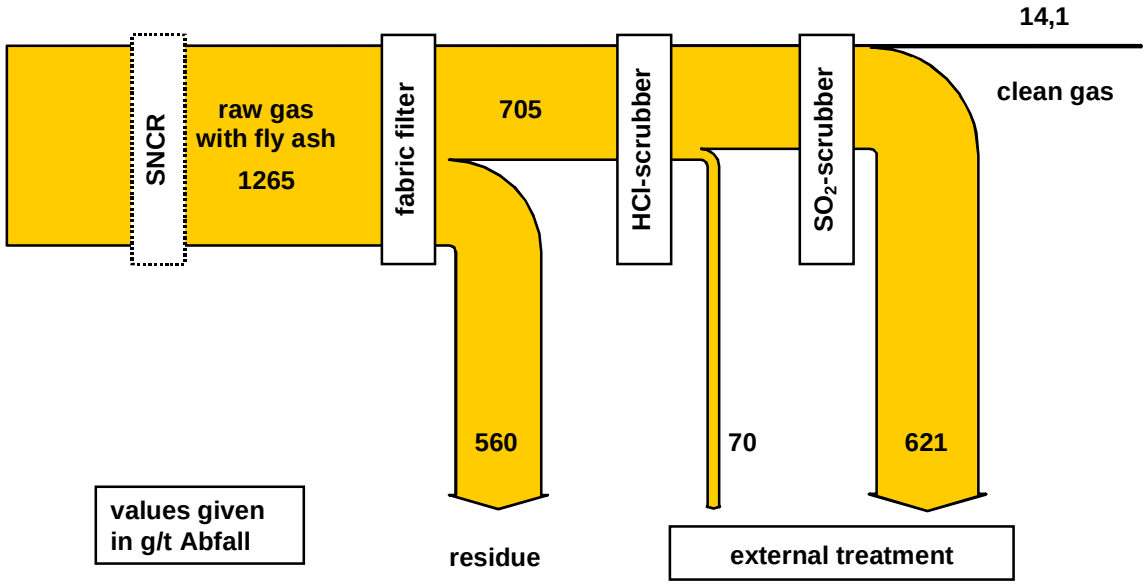

Fig. 3. Sulfur balance of plant A.

and the evaporation of the scrubber effluents is made externally. Only very low amounts of mercury remain in the clean gas.

Plant B

Plant B is equipped with a more complex wet flue gas cleaning system shown in Fig. 5. For cleaning the flue gases an electrostatic precipitator, a spray dryer, a second electrostatic precipitator, an two-stage scrubber system and a carbon adsorber are used. The first electrostatic precipitator separates the dust from the raw gas. The heat content of the raw gas is used to evaporate the neutralized effluents generated by the scrubber system. The resulting salt residues are precipitated in the second electrostatic precipitator. The gaseous acid pollutants are then absorbed in the two-stage scrubber system. The effluents are fed back to the spray dryer. After a SCR process the flue gas passes a carbon adsorber as fine cleaning stage.

The Fig. 6 shows the balance of chlorine in plant B. For chlorine, the mass flow of the dusty raw gas is again calculated to 5890 g/t_W. The first electrostatic precipitator separates 720 g/t_W chloride, bound in the fly ash.

For the removal efficiency it is assumed that the electrostatic precipitator has the same efficiency as a fabric filter, since the slightly higher efficiency of the fabric filter has no significant effect on the material flows. The path of the flue gas through the spray dryer has no influence on the chlorine flow. In total 5156 g/t_A chlorine are removed in the two-stage scrubber system. Due to the evaporation of the scrubber liquids in the spray dryer the same amount of chlorine is precipitated as residue in the second electrostatic precipitator. The SCR process downstream the scrubber system has no influence on the chlorine flow. The carbon adsorber removes approximately half of the chlorine flow. Finally, the clean gas contains only 7 g/t_W of chlorine.

Figure 7 shows the material flow of sulfur in plant B. According to calculations of all model plants the raw gas downstream the boiler contains 1265 g/t_W of sulfur. In the first scrubber only 70 g/t_W of sulfur is absorbed. The second scrubber takes

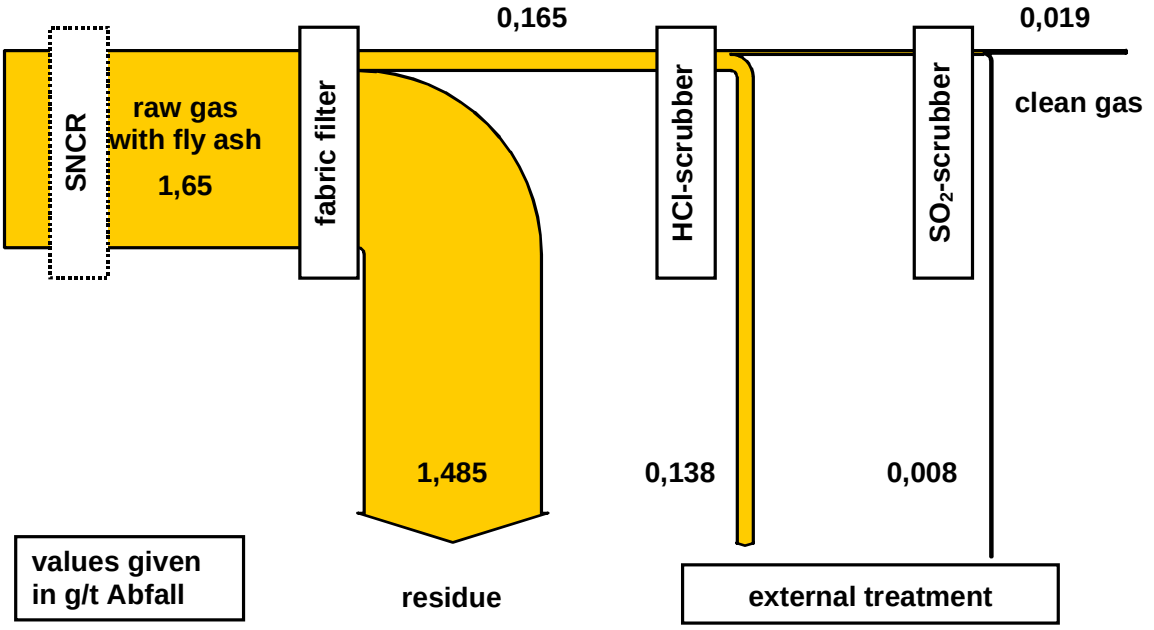

Fig. 4. Mercury balance of plant A.

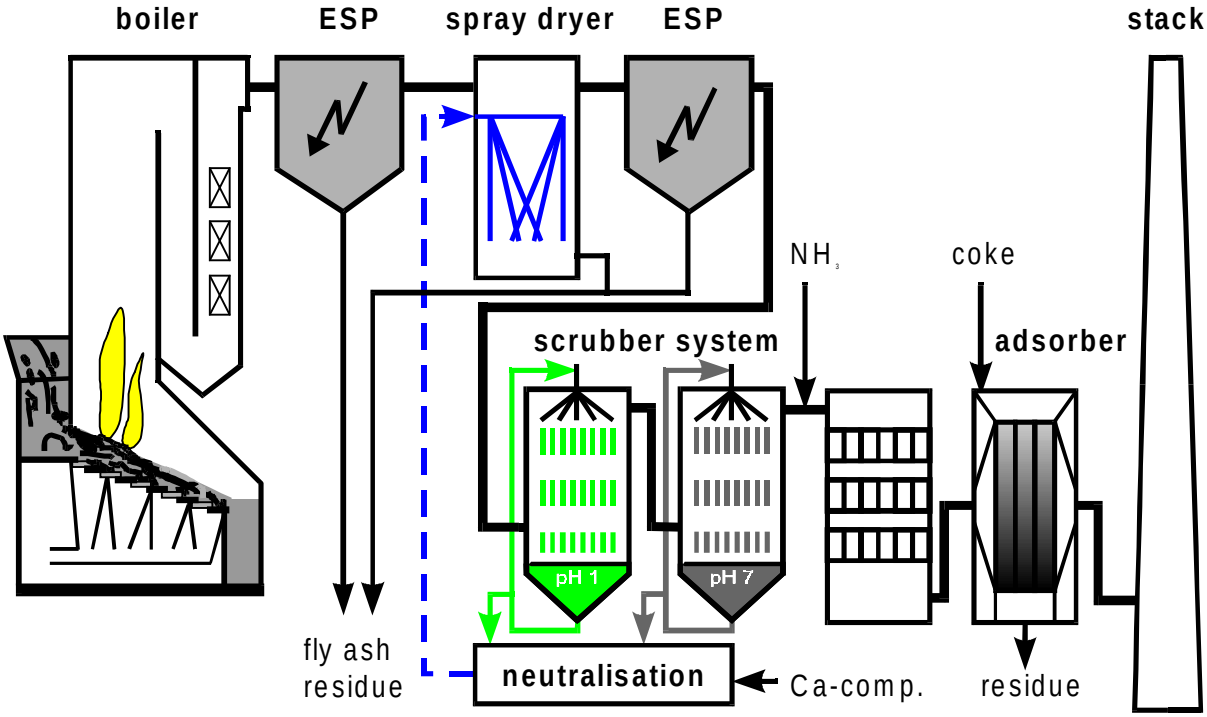

Fig. 5. Flue gas cleaning system of plant B.

up 621 g/t_W of sulfur. In total 691 g/t_W sulfur arises as residue after the evaporation of the effluents. The sulfur flow is not influenced by the SCR stage. According to the model calculation the carbon adsorber removes approximately 9 g/t_W sulfur from the flue gas. As a result the clean gas contains approximately 5 g/t_W of sulfur.

The mercury balance of plant B is shown in Fig. 8. According to the model calculation the mercury flow in the dusty raw gas is 1.65 g/t_W.

With the electrostatic precipitator 0.06 g/t_A mercury bound in the fly ash are removed from the gas. The spray dryer does not change the mercury flow. The main amount of mercury is absorbed in the HCl-scrubber, in which 1.33 g/t_W of mercury is absorbed. The second scrubber takes up only small amounts (0.08 g/t_W) of mercury. The effluents produced in the scrubbers are neutralized and treated with a precipitating agent before being piped to the spray dryer. The carbon adsorber reduces the mercury load down to 0.019 g/t_W.

Plant C

Plant C is equipped with the semi-wet process which differs in construction and in use of auxiliary chemicals from the wet flue gas cleaning systems discussed above. As shown in Fig. 9

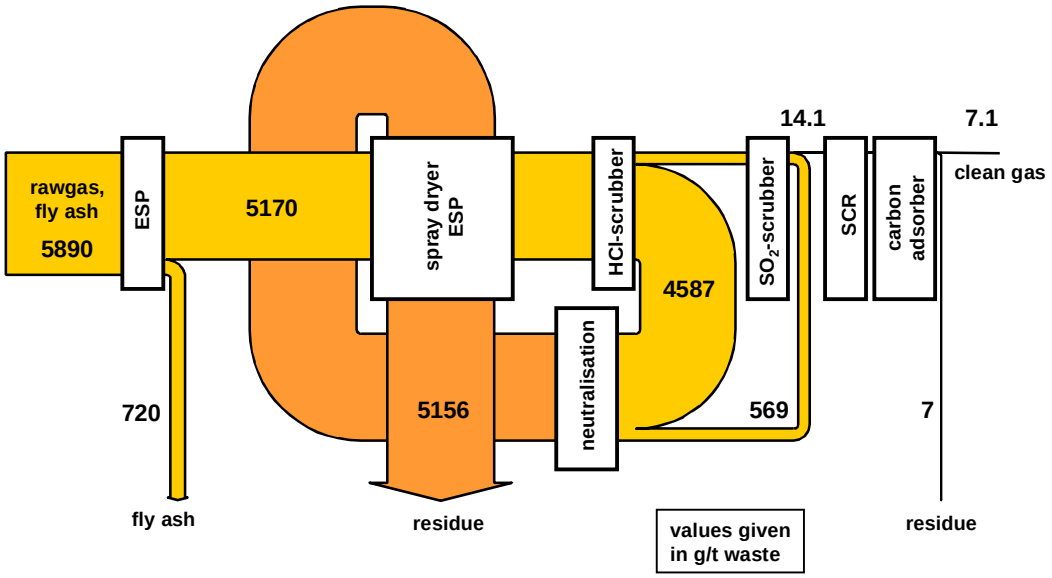

Fig. 6. Chlorine balance of plant B.

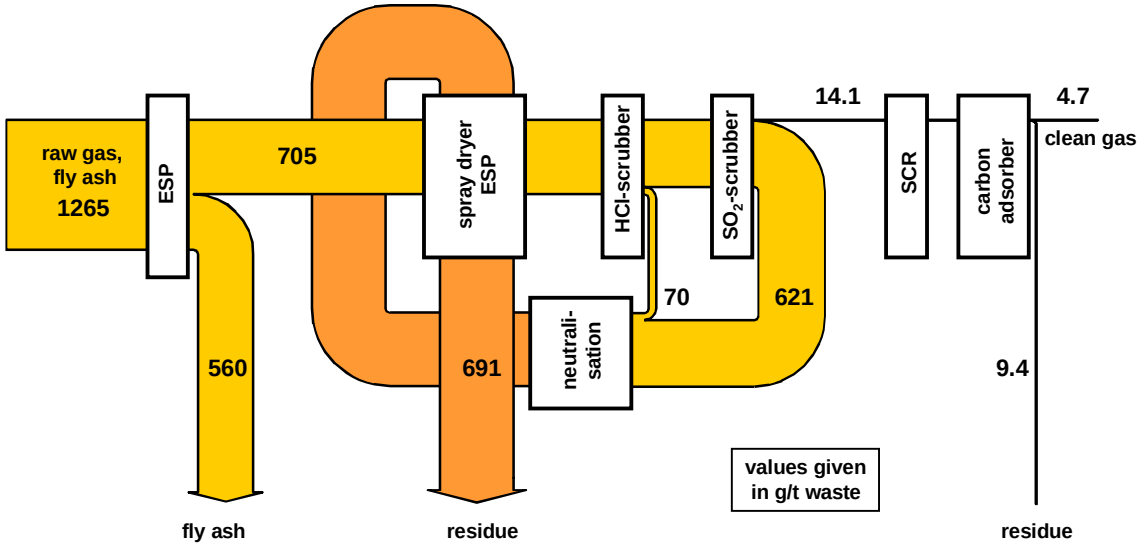

Fig. 7. Sulfur balance of plant B.

the flue gas cleaning of plant C consists of a SNCR process and a spray absorber followed by a fabric filter.

Pollutants are separated from the raw gas in a spray absorber in which a slurry of calciumhydroxide is injected. The slurry water evaporates and the calciumhydroxide reacts with the acid pollutants. For the removal of particularly heavy metals and PCDD/F coke has to be injected upstream the fabric filter. The resulting salts, the loaded coke and the fly ash are separated in the fabric filter. For the reduction of NO_x in the flue gas a SNCR process is applied. The SNCR process has no effect on the material flows of the elements considered.

As in all model plants, the chlorine balance which is shown in Fig. 10 starts with 5890 g/t_W of chlorine in the raw gas. After the injection of the calciumhydroxide slurry, chlorine is removed from the flue gas as calciumchloride and as part of the fly ash respectively. In total 5867 g/t_W of chlorine are obtained in the residue. In the clean gas remains 23.5 g/t_W of chlorine.

The distribution of sulfur is shown in Fig. 11. The injection of the calciumhydroxide slurry causes the precipitation of 1242 g/t_W sulfur and 23.5 g/t_W of sulfur are emitted into the atmosphere.

The Fig. 12 shows the material flows of mercury in plant C which starts with 1.65 g/t_W of mainly gaseous mercury in the dusty raw gas. In the spray absorber the injection of calciumhydroxide causes no significant separation of mercury. The addition of coke allows the separation 1.63 g/t_W of mercury from the flue gas. This results in a mercury load of 0.019 g/t_W in the clean gas.

Plant D

Plant D uses a semi-dry process for the removal of pollutants in the flue gas. The construction of this system is similar to the semi-wet flue gas cleaning described above. It consists of a SNCR process, a cooler and a fabric filter.

For the reduction of NOx a SNCR process is used. In the cooler the flue gas is cooled by water injection to generate optimal conditions for pollutant separation. In a next step, a calcium compound and coke are injected in form of dry powder into the conditioned raw gas. The pollutants react with the calcium com-

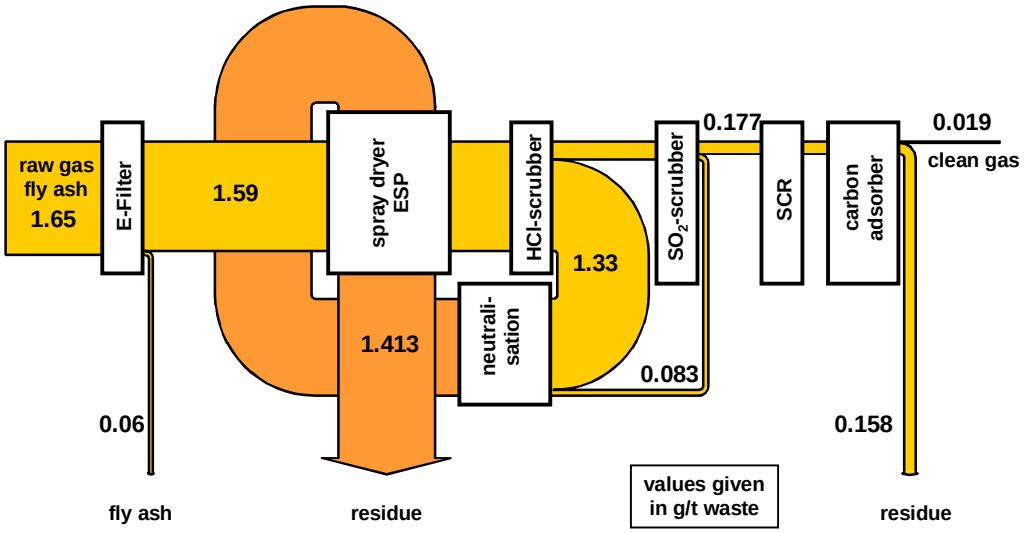

Fig: 8. Mercury balance of plant B.

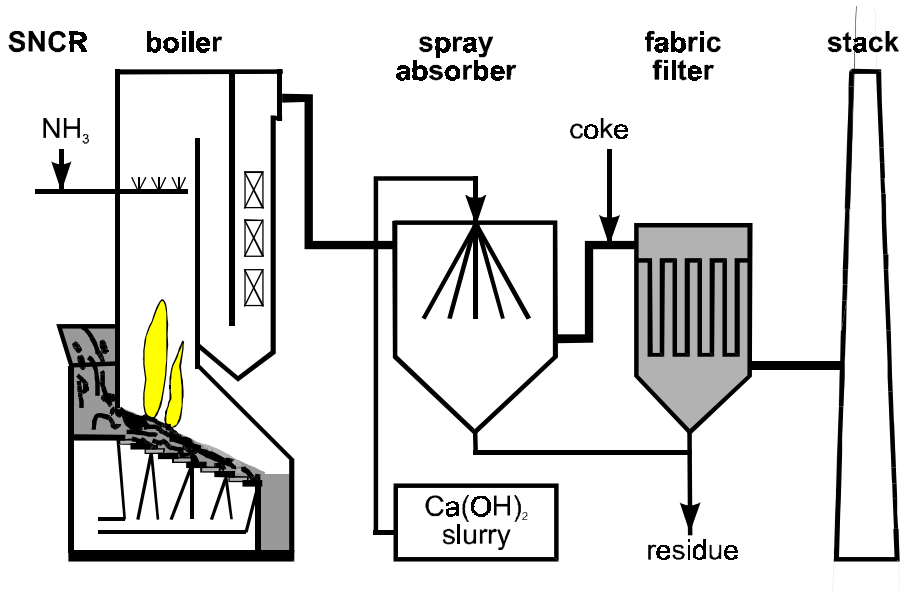

Fig. 9. Flue gas cleaning system of plant C.

pound or are adsorbed by the coke. The solid residues are separated in the fabric filter.

The model calculations have been performed in such a manner, that the material flows of chlorine, sulfur and mercury in the semi-wet process and the semi dry process are the same. But it is important, that a higher amount of neutralisation agents is required in the semi dry process to achieve this aim.

As a result, there is no difference in material flows of the elements considered in plant C and plant D. Therefore the distribution of the elements can be seen in the sankey-diagrams of plant C, too.

AMOUNTS OF RESIDUE - COMPARISON OF THE PLANTS

The amount of residues in the flue gas cleaning is controlled by the consumption of auxiliary agents for the neutralisation of acid pollutants and the fly ashes. In this study NaOH and $Ca(OH)_2$ are used in the wet process and only $Ca(OH)_2$ in the semi-wet and conditioned semi-dry process. The model calculations in this study assume an amount of fly ashes of 16 kg/t_W. The use of coke in the fabric filter and carbon adsorber as well as the precipitation agent for the removal of heavy metals in the scrubber effluents are taken into account.

The consumption of neutralisation agents depends on the process used for the separation of the acid pollutants. Semi-wet and semi-dry processes have a need for different stoichiometric ratios to remove the pollutants. The stoichiometric ratio is the quotient of chemical equivalent of neutralisation agents to chemical equivalent of acid pollutants. If the stoichiometric ratio increases, an excess of neutralisation agents is indicated and this results in an increase of the residues. The Table I compiles the stoichiometric ratios used in this study and the values listed in the literature.

The higher emissions calculated for plants C and D can be avoided by a higher stoichiometric ratio as shown in Table I.

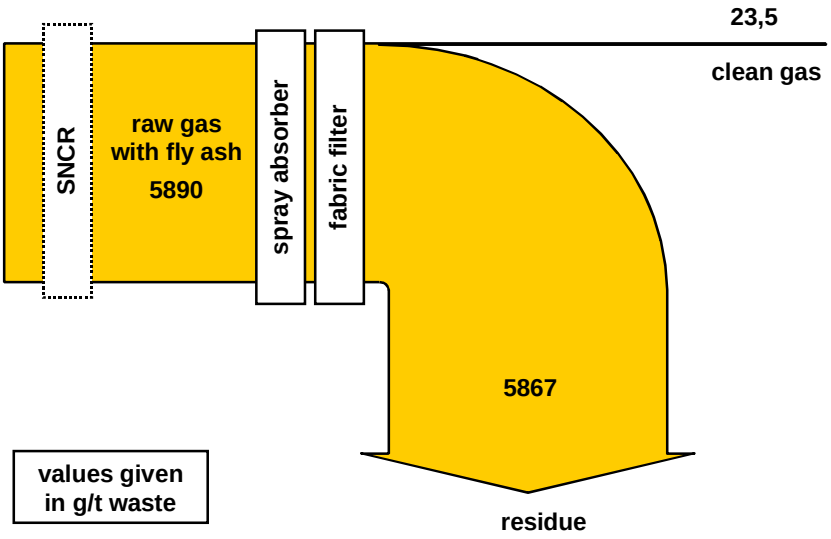

Fig. 10. Chlorine balance of plant C.

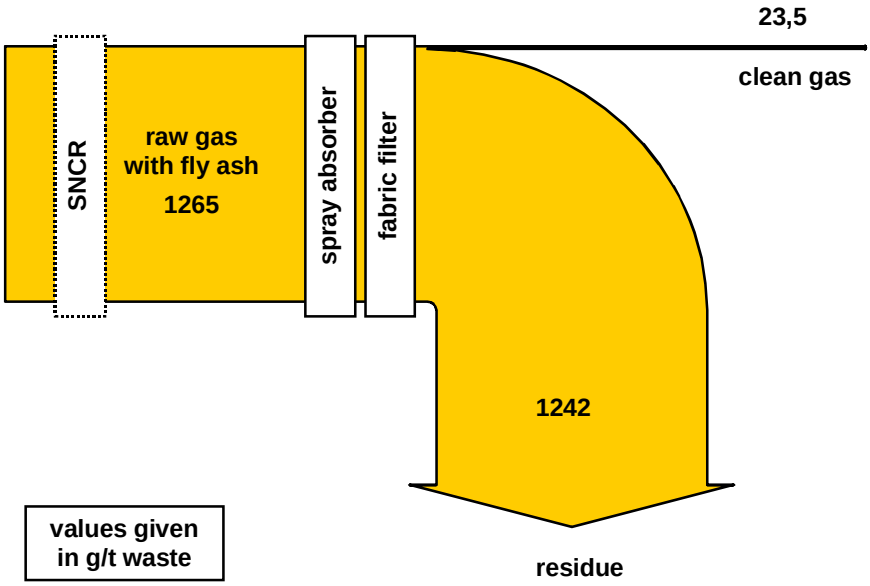

Fig. 11. Sulfur balance of plant C.

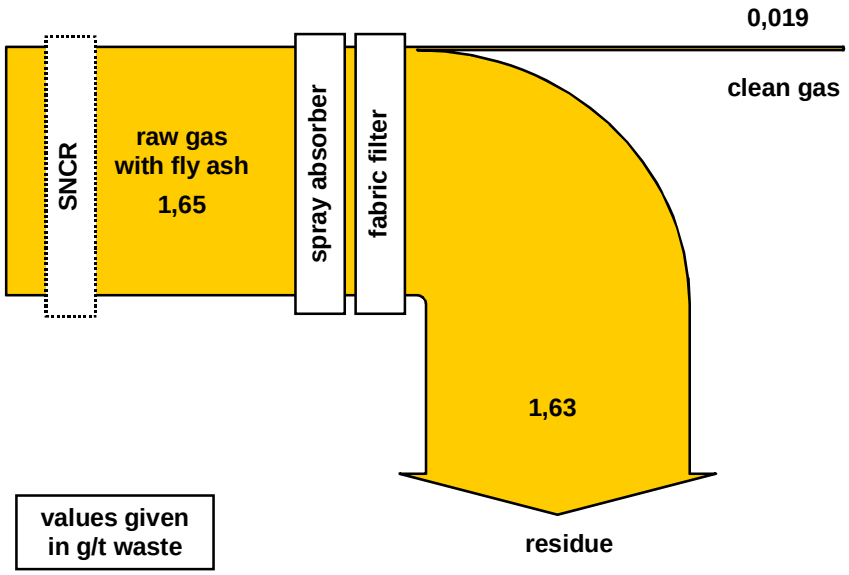

Fig. 12. Mercury balance of plant C.

TABLE I
Stoichiometric Ratios

process	stoichiometric ratio used in this study	ranges in literature
wet	1.1	1.1 bis 1.4
semi-wet	2.5	2.2 bis 3.0
semi-dry	2.8	2.4 bis >3

TABLE II
Total Amounts of Residues in all Model Plants

plant	residue from neutralisation [kg/t_W]	fly ash [kg/t_W]	lime/coke or coke [kg/t_W]	TMT-15 kg/t_W]	residue from external evaporation [kg/t_W]	in total [kg/t_W]
A	external	16	1		12.6	29.7
B	12.6	16	1	0.019		29.7
C	22.4	16	1.5	-	-	39.9
D	24.5	16	2.2	-	-	42.7

TMT-15™ : 15% solution of trimercaptotriazine

The use of calcium compounds which have an improved activity are not considered in this study due to relatively high costs.

The effluent evaporation actually lies outside the system boundary. For comparison, it is assumed that the residues of the external evaporation are approximately equal to the amount of the residues of the spray dryer. The Table II compares the total amounts of residues in all model plants.

INVESTMENT COSTS

The cost analysis was extensive and difficult. The calculation of the specific disposal costs of the model plants does not make sense, since in real MSWI local waste management and other conditions generate complex effects on costs.

For this reason only the investment costs of flue gas cleaning stages are taken into consideration without instrumentation and control and additional costs respectively. For the calculations a plant with two boilers, each one equipped with a flue gas cleaning system, and a total annual capacity of 200,000 t of waste is taken into account as example.

In the last few years an investment cost decay of design and manufacture of apparatus occurred. The investment costs of an individual flue gas cleaning stage are in the range of $0.25 - $3.5 million related to our example plant. The investment costs of complete flue gas cleaning plants are calculated by addition of individual stages. The resulting costs for the flue gas cleaning plants are in the range of $7 - $15 million.

CONCLUSIONS

The balances calculated for chlorine and sulfur are different for the considered flue gas cleaning systems. The wet flue gas cleaning systems with fine purification upstream the stack show the lowest emissions. In this study, higher emissions were calculated in the case of semi-wet and semi-dry flue gas cleaning plants. The higher emissions are due to stoichiometric ratios and other model parameters defined in this study. By use of a higher stoichiometric ratio the higher emissions can be avoided. Nevertheless, the emission limits of legal regulations are not exceeded in all cases.

In contrast, no such dependence on the type of flue gas cleaning system can be seen for mercury. This fact is objectively based on the uncertainty about the removal efficiencies of the flue gas cleaning steps, in particular the fine purification stages.

The amount of residues depends on the stoichiometric ratio used for separation of the acid pollutants. Other auxiliary agents do no significantly influence the residue amount. Therefore, the wet flue gas cleaning systems are distinguished by the lowest amounts.

The semi-wet and semi-dry systems have the lowest investment costs. Only slight differences in the investment costs exist between these plants. A wider range of the investment costs is calculated for wet flue gas cleaning systems. A wet system constructed in a relatively simple manner is only slightly more expensive than a semi-wet sorption system.

As a result of our study, a wet flue gas cleaning system, consisting of a fabric filter and a two-stage scrubber-system is an interesting alternative. This plant generates small amounts of residues in connection with relatively low investment costs.

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