

# COMBINATION OF MSWC AND COAL FIRED POWER PLANT

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## ABSTRACT

The paper describes a concept for the combination of a municipal solid waste combustion plant and a coal fired power plant in such a way that the dedusted and pre-cleaned offgas of the waste combustion serves as carrier gas for the pulverized coal. The coal combustion cares for the destruction of PCDD/F and the SO<sub>2</sub> from waste combustion is removed in the SO<sub>2</sub> scrubber of the power plant. A comparison to other co-combustion and combination scenarios and a theoretical consideration of the fate of waste originated pollutants indicates that this concept guarantees a minimum transfer of pollutants into the power plant and looks economically attractive.

## ECONOMICAL PROBLEMS OF WASTE COMBUSTION

About twenty years ago interest groups started to criticize waste combustion for partly real, partly assumed unacceptable environmental impacts, first of all emissions of the 'ultimate poison' polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/F). In some Central European countries, e.g. in Germany, these debates resulted in a strong opposition of wide parts of the public against this technology. It must be admitted that in the early eighties the environmental standards of waste combustion were far away from what we are used to accepting today and there was reason to decrease the limits on air emissions as well as to increase the requirements on the residue quality.

The tightened legislative regulations caused the implementation of high sophisticated technical measures for upgrading old and optimizing new plants. Especially in Germany the ecological quality had a high priority and economical constraints were not considered. Multi-stage gas cleaning systems with all kinds of recycling options for special residue fractions pushed the investment as well as the processing cost to astronomical levels.

The financial burden caused customers to look for other and cheaper disposal options and a substantial share of waste from commerce and industry was diverted from the local public waste management system to other, cheaper and often obscure places. This development reduced the throughput of the waste combustion plant and consequently the tipping fee had to be increased again.

Hence today the economical aspect of thermal waste treatment is gaining interest again. The challenge is the development of simple strategies in order to minimize the investment and operational costs without changing its environmental standards.

## OPTIONS TO IMPROVE THE ECONOMY

A first approach in that direction has been made with the concept of head-end techniques in waste combustion [Vogg & Vehlow 1993, Vehlow 1996]: primary measures like an optimized combustion control are simple and efficient measures to reduce the formation of pollutants in the raw gas, e.g. PCDD/F, to reduce the efforts for abatement of such species and to improve the bottom ash quality and make it fit for utilization.

Two perspectives to minimize the expenses for waste combustion can be taken into consideration:

- the combustion or co-combustion of waste or waste fractions in other thermal processes like coal fired power plants or cement kilns or
- the combination of waste combustion and other combustion units in order to use some units like the boiler or the air pollution control system for both processes.

In the following only coal fired power plants will be considered as alternative thermal processes for co-combustion or combination.

The discussion of advantages and problems of the various scenarios will follow the logic of increasing utilization of the installations of the power plant and will hence start with combination options and end with co-combustion. A short description of the processes will be followed by a more detailed discussion of the fate of pollutants. The pollutants to be dealt with will be limited to chlorine, sulfur, a number of volatile heavy metals, and to PCDD/F.

## Combination of Waste Combustion and Power Plant

The combination of a waste combustion facility and a coal fired power plant can be performed in different ways. Following the above mentioned ranking of increasing integration four options can be considered which are schematically depicted in Fig. 1:

- a) transfer of the steam from the waste boiler to the boiler of the power plant,  
 b) option a) plus transfer of the dedusted or dedusted and partially scrubbed offgas to the gas cleaning system of the power plant,

- c) option a) and transfer of the dedusted and partially scrubbed offgas to the primary air of the power plant,  
 d) transfer of the hot raw gas directly into the furnace of the power plant.  
 For the time being only option a) has been realized in full scale.

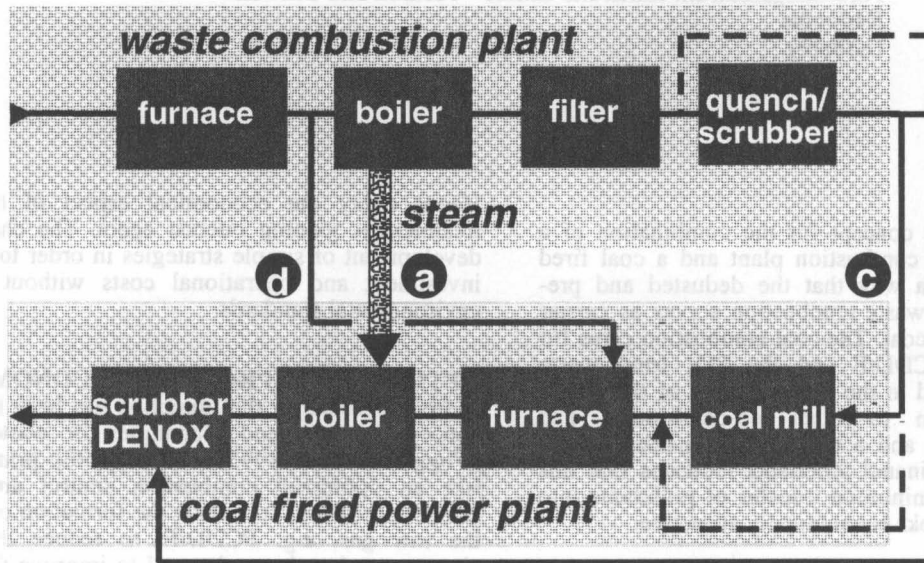


Fig. 1: Four options for the combination of municipal solid waste combustion and coal fired power plant

**Combination of Steam Circuits:** The option a), the utilization of the steam from the waste boiler in that of the power station saves the turbine in the waste combustion plant. This simple strategy is applied at some locations in Germany where a waste combustion plant has been built close to a power plant. The combination of both steam circuits can be performed in different ways. The waste boiler can be used for preheating the steam of the power plant's boiler. In this case the boiler parameters can be kept low with maximum steam temperatures of 250 °C. If the waste boiler, however, is operated at the higher temperature of the power plant's boiler the risk of boiler corrosion increases significantly. This risk can be reduced if the superheater in the waste boiler is separated and heated by natural gas [Albert 1997].

**Combination of the Gas Cleaning Systems:** A further integration can be reached by applying option b) which uses the gas cleaning systems of the power plant for the cleaning of the waste combustion offgases. The critical components in the raw gas of waste combustion are heavy metals in the fly ashes, PCDD/F, hydrohalogens and mercury. Sulfur and nitrogen oxides are common in both facilities. Hence it can be considered to remove the particle bound heavy metals from the waste combustion offgas and to transfer the dedusted gases to the desulfurization and DENOX facilities of the power plant. In order to remove mercury and PCDD/F, too, activated charcoal should be injected into the raw gas and a fabric filter should be used for dedusting.

The hydrohalogens still present in the offgas might cause complications and require a washing of the gypsum produced in the gas scrubber of the power plant. An alternative concept would be to install an acid scrubber downstream of the filter which removes more than 99 % of the hydrohalogens.

Such combination results in two hazardous residues typically not generated in power plants: the heavy metals and PCDD/F containing filter ashes and the mercury and halogenides containing scrubbing solutions from the pre-cleaning of the waste combustion offgases. The filter ashes can be inertized by means of the 3R Process [Vehlow & al. 1990] which recovers mobile heavy metals, especially mercury. An alternative disposal route is the final storage in an underground disposal site. Since this process only influences the scrubbing unit of the power plant it will not be discussed in detail in the following.

**Waste Combustion Offgas as Coal Carrier Gas:** A more far-reaching integration can be accomplished by the concept which has been developed in the Forschungszentrum Karlsruhe. According to option c) in Fig. 1 the waste combustion flue gas is dedusted - preferentially by means of a fabric filter - and partly cleaned in a simple acid wet-scrubbing stage. As mentioned above this procedure guarantees the almost total removal of particle bound heavy metals, mercury, and hydrohalogens.

The partially cleaned gas contains still gaseous PCDD/F, SO<sub>2</sub> and NO<sub>x</sub> and is used as part of the primary air and carrier gas of the pulverized coal in a coal fired power plant. The PCDD/F adsorbs on the coal surfaces and is totally destroyed inside the combustion chamber. NO<sub>x</sub> is converted in the reburn zone and SO<sub>2</sub> is removed in the respective abatement system of the power station.

The high thermal destruction capability of waste combustion has been demonstrated already at the Karlsruhe test facility for waste combustion TAMARA as well as in full scale [Vehlow & al. 1990, Rittmeyer & al. 1994, Vehlow & al. 1997]. To demonstrate the practicability of the proposed process, specific tests are planned in a coal fired dry bed boiler test facility feeding an artificial PCDD/F, SO<sub>2</sub> and NO<sub>x</sub> containing waste combustion offgas. The major impetus is to investigate the operation of the burner using oxygen poor gases as primary air. Another aspect is the substitution of the offgas by flue gas recycling in case of failure in the waste combustion system.

**The Satellite Combustion Concept:** Finally the hot waste combustion flue gas can - without energy recovery or any cleaning - be directly fed into the combustion chamber of a power plant [Hölter 1997]. This 'Satellite Combustion' called process which is marked as option d) in Fig. 1 transfers all volatilized heavy metals out of the waste combustion chamber into the coal fired power plant.

### Co-combustion

The co-combustion of waste in power plants or cement kilns is practiced in some European countries. Problems associated with co-combustion are additional air emissions and operating problems like boiler corrosion caused by waste ingredients, especially the high chlorine inventory in the waste. Hence in most cases pretreated waste or special waste fractions only are used. The required fuel conditioning has to be paid for and reduces the economical benefit. On the other hand, however, fuel from waste is subsidized by the public waste management system and hence economically attractive.

Various national legislative regulations set limits for the replacement of regular fuel by waste (25 % in Germany) as well as for the air emission in case waste is co-combusted. E.g. in Germany for the calculation of actual emission standards the share of a pollutant in the offgas theoretically generated by the waste input has to meet the standards for air emission from waste combustion whereas the residual share of the same pollutant has to be handled according to the - in all cases less stringent - regulations for the respective thermal process.

In fact co-combustion makes use of the differences in emission standards for different processes and can be looked upon as a kind of dilution of waste combustion flue gas in the offgas of the respective process. For the time being the environmental compatibility of co-combustion of waste is the subject of controversial debates.

Another often neglected aspect is the disposal of the residual waste stream if high calorific waste fractions only are co-combusted. These materials are characterized by lower heating values in combination with higher levels of pollutants and may require additional fuel in order to maintain the high temperatures required in the waste combustor. Such strategies would mean that the public subsidizes the fuel from waste and spends money again to compensate the lack of heating value in the waste combustion plant by regular fuel.

### **ENVIRONMENTAL ASPECTS**

All process strategies reviewed above need to be checked in view of their environmental compatibility. Municipal solid waste is characterized by lower heating value, substantially higher ash content and humidity in combination with higher loads of heavy metals and halogens than hard coal. Furthermore specific products of incomplete combustion, especially PCDD/F may be present in the residues from waste combustion. The occurrence and fate of these waste originated contaminants in the different processes will be discussed briefly.

Coal fired power plants as well as waste combustion plants have to meet specific standards concerning air emissions and the quality of the various solid residues. In most countries the air emission limits for waste combustion are more stringent than those for power plants. The definition of so-called 'regular fuel' for power plants, however, prevents waste from being burnt in these facilities. Exceptions like in cases of co-combustion have been regulated in some countries.

For the time being in coal fired power plants the bottom ashes, the coarse ashes discharged from the the combustion chamber, and the fly ashes discharged in the dust precipitation system are almost totally utilized as aggregates in the building sector. The regulations concerning their elution stability are easily met. For concrete application especially the inventory of chlorides and hexavalent chromium are critical parameters. The effluents from the scrubber comprise mainly sulfur with low chlorine contamination. They are often converted to gypsum which is easily disposed of or even marketed.

Residues from waste combustion are typically higher in pollutant concentration and have to be looked upon more critically. The bottom ashes have - after ferrous removal, screening and aging - a high potential to be utilized as secondary building material whereas the fly ashes carry high loads of - soluble - heavy metal species and low volatile organic compounds such as polyaromatic hydrocarbons and PCDD/F [International Ash Working Group 1997]. These materials are in most regulations classified as hazardous waste and need special disposal sites or have to be inertized prior to disposal. The same is true for the residues of the scrubbing system.

Pollutants of concern which are discussed in more detail in the context of combination and co-combustion strategies are chlorine, sulfur, some heavy metals and PCDD/F.

**Table 1:** Averaged concentration ranges and transfer factors of selected elements in municipal solid waste (MSW) [International Ash working Group 1997] and in hard coal burnt in a dry bed boiler [Maier & al. 1992, Gerhard & al. 1996, Martel & Rentz 1998, Rentz & al. 1998]

	el	concentration in mg/kg			transfer factor (to residue)				
		av.	low	high	bottom ash	boiler ash	fly ash	scrub. res.	emiss.
MSW	S	4000	1000	6000	0.35	0.02	0.25	0.35	0.03
	Cl	7000	3000	9000	0.1	0.003	0.1	0.8	0.005
	As	7	2	20	0.6	0.015	0.37	0.01	0.005
	Cd	10	3	20	0.12	0.03	0.8	0.03	0.025
	Hg	3	0.5	10	0.02	0.003	0.1	0.8	0.07
coal	Pb	700	400	1500	0.67	0.01	0.3	0.01	0.01
	S	7000	4000	15000	0.05		0.05	0.6	0.3
	Cl	1000	100	3000	0.05		0.05	0.7	0.2
	As	20	1	60	0.05		0.85	0.08	0.02
	Cd	1	<0.1	2.5	0.05		0.9	0.02	0.02
	Hg	0.12	0.1	0.6	0.02		0.25	0.48	0.25
	Pb	20	10	60	0.07		0.82	0.09	0.02

## INORGANIC POLLUTANTS

### Fate of Elements in Waste and Coal Combustion

The fate of elements in a combustion process depends on their speciation and on the volatility of their species. For the comparison of the processes in question chlorine, sulfur and four heavy metals are selected which are thermally mobile and are regulated due to their toxicity. Averaged inventories of these selected elements in municipal solid waste and in hard coal are taken from literature and are compiled in Table 1.

It is evident that with the exception of sulfur and arsenic the load of pollutants in waste exceeds that in hard coal substantially. The speciation of the elements in the matrices, however, is widely unknown and so is the species transformation during combustion. Some theoretical considerations can be made on the basis of general properties of the elements in question.

The most stable oxidation state of chlorine under the conditions of combustion is -1. This means that the major chlorine products are chlorides with HCl as the most prominent compound. Hence in either combustion process chlorine will mainly be found in the offgas.

A slightly lower volatilization is to be expected for sulfur. The combustion products are sulfur oxides with the preference to sulfur dioxide and sulfates. The thermal stability of sulfates depends strongly on the temperature and hence sulfur undergoes a higher transfer into the raw gas at the higher combustion temperature in a coal fired power plant than it does in a waste combustion unit.

Heavy metals are known for the high volatility of their chlorides. Since there is a comparably high chlorine concentration in municipal solid waste these compounds

form easily and are the major volatile species of heavy metals in waste combustion. At higher temperature metals and oxides may contribute to the volatility, too. The vapor pressure curves for the elements, oxides and chlorides of As, Cd and Pb are depicted in Fig. 2. Mercury is not included in the graph since all mercury species stay in the gas phase at temperatures exceeding 300 °C.

The typical temperature ranges of waste combustion on the grate and of coal combustion in dry or wet bed boilers are marked in the graph. The areas indicate that in the case of waste combustion mainly heavy metal chlorides will be evaporated whereas in dry bed boilers and more so in wet bed boilers the oxides contribute substantially to the volatilization. Hence the volatilization of the depicted heavy metals should be much higher in coal combustion than it is in waste combustion.

These theoretical considerations are verified by published results of element balances in test plants and in full scale [International Ash working Group 1997, Maier & al. 1992, Gerhard & al. 1996, Martel & Rentz 1998, Rentz & al. 1998]. Transfer coefficients for waste and coal combustion extracted from these references are included in Table 1. For coal combustion only the today prevailing dry bed boiler is considered. A visualization of the different partitioning is given in Fig. 3.

The partitioning of cadmium and lead found in both combustion scenarios is well in line with the behavior predicted from the vapor pressure curves. The peculiar partitioning of arsenic in waste combustion has to be attributed to the fact that a substantial amount of arsenates are either present in the waste or - more likely - formed in the combustion process [Vehlow, Birnbaum & Köppel 197].

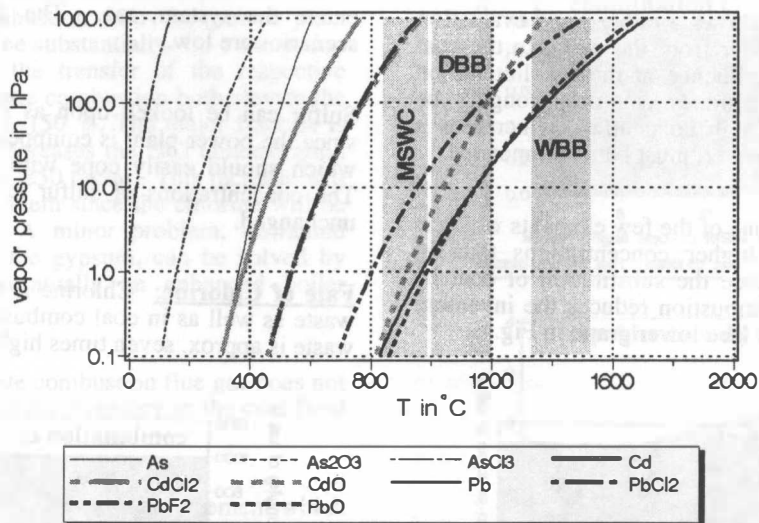


Fig. 2: Vapor pressure curves of selected elements and compounds with temperature ranges of municipal solid waste combustion (MSWC) and coal combustion (DBB: dry bottom boiler, WBB: wet bottom boiler)

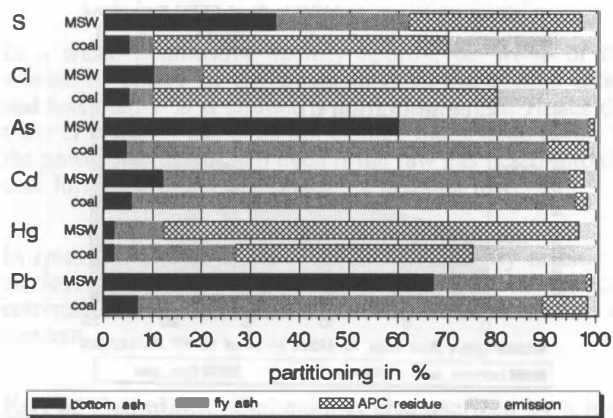


Fig. 3: Partitioning of selected elements in a municipal solid waste combustion plant (MSW) and a coal fired dry bed boiler

In the following the transfer numbers will be used to evaluate the total amount of the transfer of the mentioned elements from the waste combustion process to the coal fired power plant and the partitioning in the power plant. The specific offgas volumes and the amounts of solid residues used for the respective calculations are taken from literature, too, and are compiled in Table 2.

Since the co-combustion in power plants is limited to 25 wt-% this will be the upper limit of waste addition in either scenario. The limit is close to the practical limitation in the concept b) where the pre-cleaned flue gas is used as carrier gas for the pulverized coal. The carrier gas is about 10 % of the entire air supply and the specific air supply of coal is about twice that of municipal solid waste.

Table 2: Specific flue gas volume  $v$  in  $m^3/kg$  and residue streams in  $kg/kg$  of fuel for municipal solid waste combustion (MSW) and coal fired dry bed boiler (DBB) [International Ash Working Group 1997, Günther 1994, Gerhardt & al. 1996]

	$v$	bottom ash	boiler ash	fly ash
MSW	5	0.25	0.003	0.015
DBB	9.6	0.0035		0.046

The evaluation will distinguish between the final inventory of an element in the bottom and filter ashes and in the raw gas of the power plant. For these calculations the transfer numbers of elements in coal combustion are kept constant for all scenarios. This is of course a rough estimate for co-combustion since the transfer numbers have been obtained from experiments in dry bed boilers and co-combustion will more likely be performed in grate or fluidized bed systems. In case of co-combustion changes in the mass balance of the power plant have to be expected, too, but for the time being there are no valid data for such changes to be found in the literature. Furthermore, since only the transfer in a single residue compartment is considered the actual masses are not needed.

The influence of changed pollutant levels in a solid residue on the elution quality will also not be discussed since there are no experimental data to back up any evaluation. A separation between emission and gas cleaning residues makes no sense either since the emission standards have - regardless of the efforts - to be met anyway.

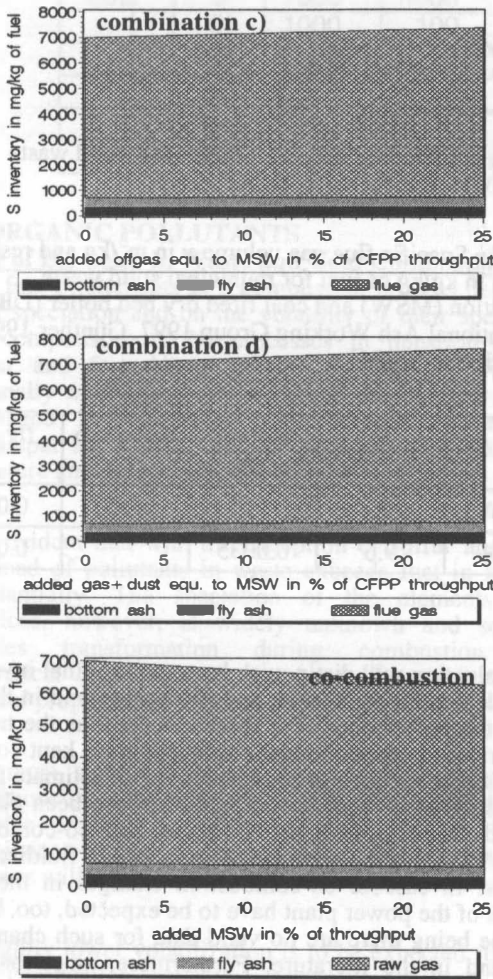
The available information allows a rather good evaluation of the total pollutants transfer from the waste to the coal combustion process. The influence of these pollutants on the quality of the solid residues can only roughly be estimated. In the case of high concentration increases a thorough investigation, however, must be recommended.

**Fate of Sulfur:** Sulfur is one of the few elements which is present in hard coal in higher concentrations than in municipal solid waste. Hence the substitution of coal by waste in the case of co-combustion reduces the inventory of sulfur in the power plant (see lower graph in Fig. 4).

enters the system, too. The differences between both scenarios are low.

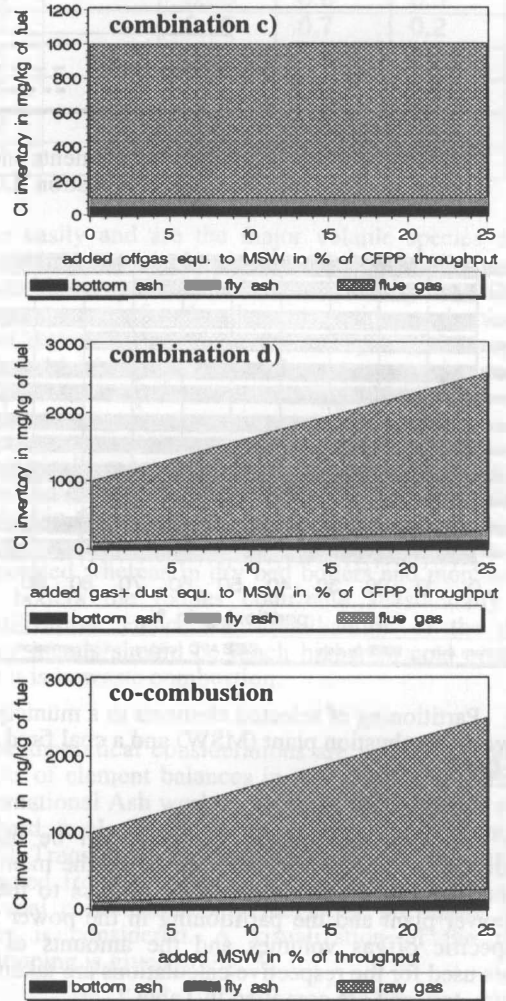
Sulfur can be looked upon as an element of no concern since the power plant is equipped with a scrubbing system which should easily cope with the changes in question. The concentrations of sulfur in the residues stay almost unchanged.

**Fate of Chlorine:** Chlorine is a high volatile element in waste as well as in coal combustion. The concentration in waste is approx. seven times higher than that in hard coal.



**Fig. 4:** Partitioning of sulfur in a coal fired power plant for the combination concepts and co-combustion (MSW: municipal solid waste, CFPP: coal fired power plant)

The transfer of waste combustion offgas, however, increases the inventory in each case (compare the upper graphs in Fig. 4). Combination scenario c) has a slight advantage since in the case of scenario d) the sulfur which would be discharged along with the boiler and filter ashes



**Fig. 5:** Partitioning of chlorine in a coal fired power plant for the two combination concepts and for co-combustion (MSW: municipal solid waste, CFPP: coal fired power plant)

Fig. 5 comprises three graphs which illustrate the fate of chlorine in the co-combustion and in both of the compared combination scenarios.

The co-combustion as well as the transfer of the uncleaned raw gas from waste combustion into the power plant increase the input of chlorine substantially. Co-combustion of 25 wt-% of waste or the transfer of the respective volume of raw gas from waste combustion both elevate the level of chlorine by approx. 150 %. The major fraction is found in the raw gas and increases the HCl concentration from approx. 100 to approx. 250 mg/m<sup>3</sup>. This increase will not cause any emission problem since the chlorine will be removed in the scrubber. A minor problem, unwanted chloride concentrations in the gypsum, can be solved by washing that material. Eventually an enhanced boiler corrosion can be envisaged.

The transfer of cleaned waste combustion flue gas does not significantly add to the chlorine inventory in the coal fired power plant.

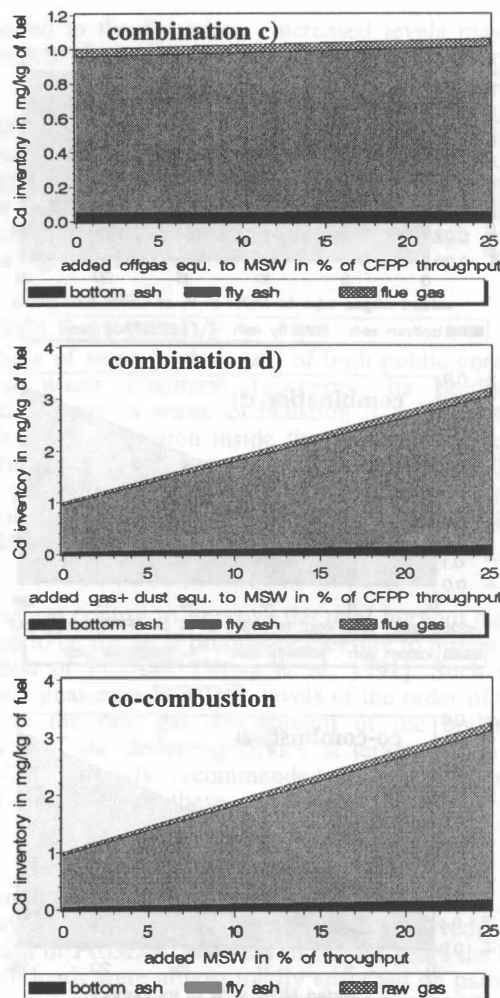
**Fate of Arsenic:** Arsenic is like sulfur an element which is abundant in coal at a much higher level (approx. 20 mg/kg) than it is in municipal solid waste (approx. 7 mg/kg). Hence in the case of co-combustion of 25 wt-% of waste the inventory of arsenic in the power plant is reduced by approx. 20 %.

In a waste combustion facility approx. 60 wt-% of the arsenic inventory of the waste stays in the bottom ashes and less than 1 % is emitted with the clean gas. Hence the transfer of clean gas does not change the arsenic levels in the power plant at all and even if the raw gas is fed into the coal furnace the increase in arsenic is rather low.

In spite of its toxicity and its thermal mobility arsenic is obviously neither in coal combustion nor in the co-combustion or combination scenarios an element of concern.

**Fate of Cadmium:** Cadmium is characterized by a high volatility in waste combustion where it is evaporated as chloride. According to the higher combustion temperatures in coal combustion the oxide contributes mainly to the volatilization.

The concentration of cadmium in waste (approx. 10 mg/kg) is typically by a factor of 10 higher than it is in hard coal. Hence both scenarios, the co-combustion of 25 wt-% of waste and the transfer of the respective volume of raw gas from waste combustion elevates the level of cadmium in a power plant by approx. 200 % (compare Fig. 6). The cadmium is preferentially routed to the fly ashes and hence the quality of this residue stream may be altered in an unwanted way. Co-combustion and transfer of raw gas to the power plant require a thorough quality control of the fly ashes if a utilization is intended.

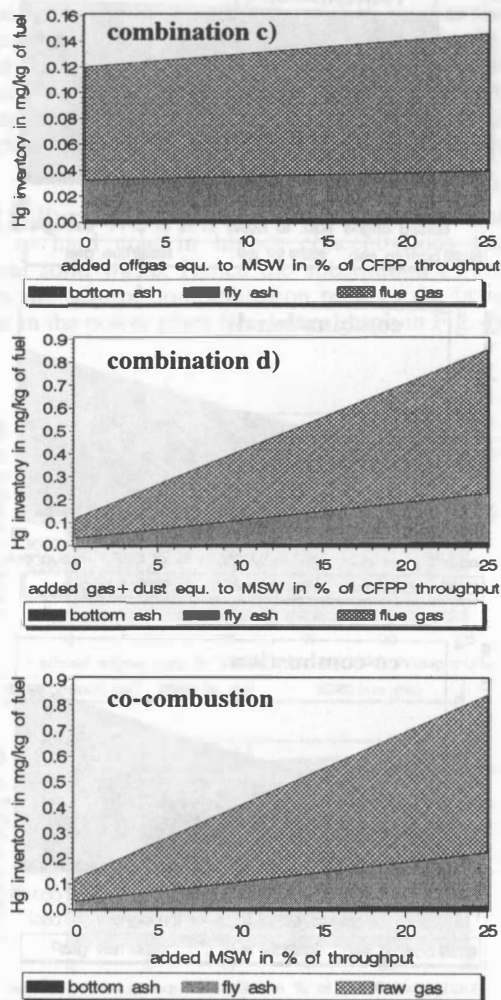


**Fig. 6:** Partitioning of cadmium in a coal fired power plant for the two combination concepts and for co-combustion (MSW: municipal solid waste, CFPP: coal fired power plant)

Since cadmium is mainly removed from the waste combustion raw gas along with the fly ashes the addition of cleaned raw gas to a coal furnace has almost no unwanted effect on its level in the power plant. This is documented in the upper graph of Fig. 6.

**Fate of Mercury:** Mercury has the highest volatility of all of the heavy metals. Furthermore, its concentration in municipal solid waste (approx. 3 mg/kg) is by a factor of 20 to 30 higher than it is in hard coal.

Fig. 7 makes evident that the mercury level in the power plant is substantially influenced by co-combustion of waste or by feeding of raw gas from the waste combustion plant. The middle and lower graph indicate an increase in mercury inventory in the power plant from approx. 0.1 to more than 0.8 mg/kg of fuel if 25 wt-% of waste or the respective volume of waste combustion raw gas are fed in.



**Fig. 7:** Partitioning of mercury in a coal fired power plant for the two combination concepts and for co-combustion (MSW: municipal solid waste, CFPP: coal fired power plant)

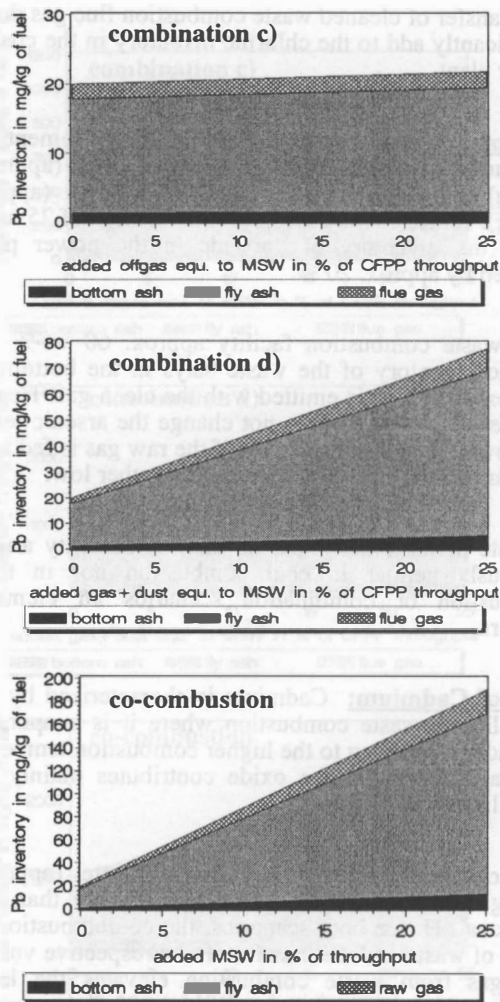
The mercury enters mainly the gas phase. The mercury level in the raw gas of a coal combustion plant is on the order of 10 mg/m<sup>3</sup>. The addition of 25 wt-% municipal solid waste would push this number to about 60 mg/m<sup>3</sup>, a level which calls for special abatement measures. With respect to the high concentration of SO<sub>2</sub> in the raw gas of the power plant it has to be expected that a substantial fraction of mercury is present in the metallic state. If no charcoal filter is installed the compliance with the emission standards is endangered.

Another problem in co-combustion and in the feeding of uncleaned waste combustion flue gas might be seen in an unwanted high mercury level of the gypsum produced in the scrubber of the power plant.

The effects of mercury on the quality of fly ashes, too, should carefully be observed.

Again as experienced for cadmium already, the lowest impact of mercury on the power plant is to be expected if the cleaned offgas of waste combustion is fed into the power plant. As documented in the upper graph of Fig. 7 the mercury level is only elevated by some 15 %, a quantity which should cause no problems in the system.

**Fate of Lead:** Lead is a common heavy metal found in coal at about the same level as arsenic (approx. 20 mg/kg). The typical concentration in municipal solid waste varies between 400 - 1500 mg/kg.



**Fig. 8:** Partitioning of lead in a coal fired power plant for the two combination concepts and for co-combustion (MSW: municipal solid waste, CFPP: coal fired power plant)

The metal is moderately volatile in municipal solid waste combustion due to the preferred formation of lead chloride. In coal combustion the volatility of PbO contributes mainly to the volatility. In principle the thermal behavior in both combustion processes resembles that of arsenic.

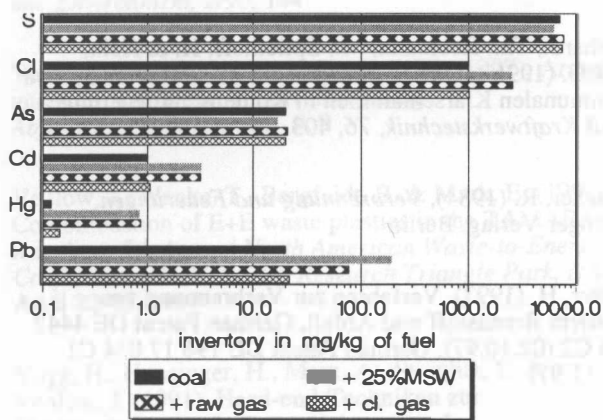


Due to its high enrichment in waste compared to coal, co-combustion and the feeding of raw gas from waste combustion into the coal fired power plant have a significant effect. The lower graph in Fig. 8 demonstrates that co-combustion of 25 wt-% of municipal solid waste increases the lead inventory in the power plant to an almost tenfold level. The increase is lower (from 20 to approx. 80 mg/kg fuel) in the scenario where untreated raw gas is added (see middle graph).

If the flue gas of the waste combustion plant, however, is pre-cleaned, its addition does not alter the lead levels in the power plant significantly as is documented in the upper graph.

### Comparison of Concepts

The different levels of selected elements in the fuels hard coal and municipal solid waste result in varying impacts on the inventories of these elements in a coal fired power plant depending on the co-combustion or combination scenario in question. Fig. 9 summarizes the levels of the discussed elements for coal combustion and the regarded three waste related options.



**Fig. 9:** Inventory of selected elements in a dry bed boiler fired with hard coal, with the addition of 25 wt-% of municipal solid waste (MSW) or with the addition of raw respectively cleaned flue gas from the combustion of the same amount of waste.

It is evident that high volatile elements like chlorine, mercury or cadmium which are enriched in the waste cause serious increases of the level in the power plant. The minimum influence of waste on the situation in the power plant is always found if pre-cleaned flue gas is fed into the coal furnace. Even for mercury the increase is in an order of magnitude (some 10 - 20 %) which is not expected to cause any environmentally significant effects.

The increase caused by the additional input of other volatile metals like lead is more moderate. A similar behavior is to be expected for zinc, tin or antimony. Since these metals are in coal fired power plants mainly

transferred to the fly ashes, increased levels may cause problems in view of the quality of these ashes.

The co-combustion as well as the combination using uncleaned raw gas from a waste combustion plant results in significant increases of the inventory of thermally mobile heavy metals. Especially mercury and cadmium, both characterized by high volatility and high toxicity, show a high enrichment.

### THE ROLE OF PCDD/F

This class of compounds is still of high public concern in thermal waste treatment processes. Its predominant formation route in waste combustion is a heterogeneous oxychlorination reaction inside the heat recovery system. The critical temperature range of the reaction is 200 - 500 °C. In grate systems the flue gas at high temperatures - at the exit of the combustion chamber - is always low in PCDD/F.

Combustion control to improve the total burnout has been revealed to be the most promising measure to minimize the formation of PCDD/F [Vogg & al. 1991]. Such simple measures guarantee PCDD/F levels of the order of 0.1 - 1 ng/m<sup>3</sup> in the raw gas downstream of the boiler. The operation of the dedusting device at temperatures below 200 °C is strongly recommended in order to prevent further formation of these compounds [Hunsinger & al. 1996].

An improved burnout reduces the amount of TOC, especially of particulate carbon as well as it reduces the formation of PCDD/F. Whereas in former years the higher PCDD/F loads were almost totally adsorbed on particulate carbon, in today's waste combustion plants a substantial fraction of the PCDD/F stays in the gas phase.

Various simple strategies to remove residual PCDD/F from the flue gas have been developed and implemented in full scale plants during the last years. Hence PCDD/F do not cause real problems in modern and well operated waste combustion plants any longer.

The formation of PCDD/F in coal combustion can typically be neglected. The oxygen concentration in the flue gas is very low (3 - 5 vol-%) compared to that in waste combustion (7 - 10 vol-%). Furthermore, the amount of available chlorine is much lower and the high SO<sub>2</sub> concentrations in the offgas reduce the efficiency of the oxychlorination reaction.

This situation may change if the chlorine level in a power plant is increased by direct addition of waste or by the addition of uncleaned waste combustion flue gas. A theoretical consideration is difficult and experimental data are required to reveal real effects.

The introduction of PCDD/F into a coal fired power plant can be looked upon as generating no problems. Such

PCDD/F may be present in the municipal solid waste or in the pre-cleaned flue gas. As can be deduced from their thermal properties and as has been experimentally confirmed the conditions inside a combustion chamber cause an almost total thermal destruction of even rather stable organic compounds [Vehlow & al. 1990 and 1997, Rittmeyer & al. 1994].

This fact is of major importance for the combination option using pre-cleaned flue gas which still contains the gaseous PCDD/F built in the combustion plant. Before implementing the process an experimental verification in a test plant is needed.

Today's knowledge allows no final decision about the importance of PCDD/F in the scenarios discussed in this paper. Co-combustion and the utilization of raw gas may promote a formation due to the increased chlorine level. The effect, however, should not be of fundamental importance. If feeding pre-cleaned flue gas a total destruction of eventually present PCDD/F is expected. In all cases an experimental investigation of the role of PCDD/F is recommended.

### CONCLUSIONS AND OUTLOOK

In order to minimize the cost of thermal waste treatment a combination of this process with other thermal processes has been proposed. In the context of this paper the options

- co-combustion in a coal fired dry bed boiler,
- the transfer of hot untreated flue gas from a waste combustion plant into and
- the utilization of partially cleaned flue gas from waste combustion as carrier gas for pulverized hard coal in a coal fired power plant

have been compared.

Regarding inorganic species in waste a significant increase of chlorine and volatile heavy metals, especially of mercury and cadmium is expected for the co-combustion and for the untreated gas transfer scenario. The increase in mercury inventory may cause emission problems and eventually a contamination of the gypsum typically produced from the residues of the gas scrubber in the power plant. Increased intakes of other volatile metals like cadmium or lead endanger the quality of the solid residues, first of all that of the fly ashes.

More or less no effect on inorganic constituent levels in the coal fired plant are expected if pre-cleaned gas from waste combustion is used as carrier medium for the pulverized coal.

Volatile organic compounds in the waste or in the waste combustion flue gas should be destroyed during the coal combustion process. An increased chlorine level should not have serious consequences on a potential formation of PCDD/F in the power plant. Our knowledge of the role of PCDD/F in all of these processes, however, is limited and experimental work in this field is strongly recommended before any method is implemented in full scale.

From an environmental perspective the proposed utilization of partially cleaned flue gas as coal carrier medium looks much more promising than the utilization of raw gas or simple co-combustion. The economical advantage of the latter options does not - at least in the eyes of the authors - compensate for their environmental deficits.

The new process needs a number of open technical questions to be solved before it can be used in full scale:

- The stability of coal combustion by replacing part of the primary air by oxygen poor flue gas,
- measures in case the waste combustion plant has to be shut down and finally
- the role of PCDD/F have to be investigated.

Respective experiments have been planned in the Karlsruhe test facility for waste combustion TAMARA and in a dry bed boiler test facility at the Stuttgart University.

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